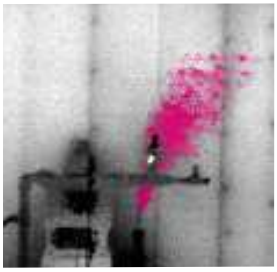
OTD

Operations
Technology
Development

RESEARCH PROJECT SUMMARIES 2019



Operations Technology Development, NFP

RESEARCH PROJECT SUMMARIES

2019

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Chairman / President's Letter

The vast natural gas infrastructure provides the vital link in delivering energy to millions of homes, businesses, and industrial customers 24 hours a day, 7 days a week. Operations Technology Development (OTD) – a not-for-profit collaborative representing 26 member companies who serve over 60 million customers in the U.S. and Canada – is improving the safety, efficiency, and reliability of this infrastructure through industry-funded R&D.

OTD's members drive the vision, guidance, and support for a program focusing on the most critical needs of the gas operations sector. The program is larger and more impactful than ever, and continues to deliver greater benefits to the energy industry and energy consumers each and every day.

This report summarizes more than 100 projects in the 2019 OTD portfolio, and it highlights some of OTD's most meaningful past achievements. As in previous years, DOT/PHMSA has awarded several significant projects directly to OTD. In other instances, members benefit from co-funding our contractors have received, which offers increased leverage and further enables the impact OTD can make.

Projects include the development of a myriad of exciting new tools to prevent third-party damage, methodologies to identify and mitigate methane emissions, and technologies to understand and validate risks to pipeline integrity. All of these initiatives are core to the industry's success in delivering safe, resilient, affordable, and environmentally conscious energy.

A virtual reality training system that puts natural gas field personnel into highly realistic immersive and interactive 3D scenarios was commercialized in 2019, and a new suite of modules is helping prepare them for other critical missions. Additional virtual training programs under development will provide a wide range of options for "hands-on" distance learning that enables individuals to train while social distancing.

All the while, OTD strives to make the industry smarter and safer by developing and adapting robust technologies for data management, risk management, system inspections, cybersecurity, material tracking, and other important areas.

The key to OTD's success is the involvement and support of its members – subject-matter experts from North America's leading energy providers – who identify, select, fund, and oversee research efforts aimed at their specific company and consumer needs.

We appreciate your interest and support, and we look forward to a future of even better things to come!

OTD Members

- > Ameren Illinois
- > APGA Research Foundation
- > Atmos Energy Corporation
- > Avista Utilities
- > Black Hills Energy
- > Consolidated Edison Co. of NY, Inc./ Orange & Rockland Utilities, Inc.
- > Dominion Energy
- > Duke Energy Corporation / Piedmont Natural Gas Company, Inc.
- > Enbridge Gas Distribution Inc.
- > Intermountain Gas Company
- > Liberty Utilities
- > Louisiana RDC
  - - Atmos Energy Corporation
  - - CenterPoint Energy, Inc.
  - - Entergy Corporation
- > National Fuel Gas Distribution Corporation
- > National Grid
- > New York State Electric & Gas Corp. / Rochester Gas and Electric
- > Nicor Gas
- > NiSource Inc.
- > NW Natural
- > Oklahoma Natural Gas
- > Pacific Gas and Electric Company
- > Peoples Gas
- > Southern California Gas Co., a Sempra Energy Utility
- > Southwest Gas Corporation
- > Spire (Alabama)
- > TECO Peoples Gas
- > Washington Gas

Jon G. Huddleston
Chairman of the Board

Ronald Snedic
President

Results in Use

Since 2003, the OTD program has provided utilities, pipeline companies, service providers, and others in the natural-gas-delivery business with innovative tools, enhanced processes, and advanced equipment for improving gas system operations.

These products represent the results of OTD efforts to build a stronger industry infrastructure, enhance system integrity, and improve the efficiency of a wide range of operations activities.

Selected OTD-Developed Products in the Marketplace

Virtual Reality Training
Pixo VR

OTD partnered with PIXO VR to create a proof-of-concept Virtual Reality Training module designed to make emergency-response training more efficient and effective for a new generation of field technicians. The team created a new suite of highly relevant and fully immersive training simulations with valuable features such as interactive 3D environments for superior trainee immersion. This groundbreaking new training delivers more meaningful experiences, reinforcing critical, multi-step, inspection and safety protocols.

Contact: Sean Hurwitz
248-996-8298
sean.hurwitz@pixovr.com

UtilAlert Excavation Notification System
Hydromax USA

A GPS monitoring system for excavation equipment was developed to periodically transmit active excavation-equipment-location information to a portal. The system monitors the behavior of excavators and other equipment entering a utility right of way to characterize its behavior as safe or threatening. The proper alerts are generated to notify the excavator operator and the utility to take the necessary actions.

Contact: Andy Scott
281-684-7673
www.utilialert.com

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Jameson Directional Entry Tool and Live Tracer
Jameson, a Spartaco Company

This directional tool enables vertical insertion of tracer rods and cameras into live gas mains, facililtating the difficult first bend of the entry. It operates on live mains with no blow by and is compatible with keyhole procedures (fits 24-inch minimum keyhole). The tool can be used on mains as small as two inches in diameter; rotates 360 to insert in either direction; and fits most camera heads.

Contact: Brad Kokoski
803-222-8454
www.jamesonllc.com

Large-Diameter, Medium-Pressure Inflatable Stoppers
Mainline Control Systems

The Kleiss MCS Flow Stopping System is used to stop the flow of gas in polyethylene, steel, cast-iron, and PVC pipes at diameters up to 18 inches and pressures up to 60 psig. The system, which is manufactured in Europe, was investigated through OTD to validate its operation and potential savings in the U.S. gas industry.

Contact: Wade Farr
812-459-3936 wfarr@mainlinecs.com
www.mailinecontrolsystems.com

Portable Methane Detector (PMD)
SENSIT Technologies

This handheld SENSIT® PM uses optical detection to provide sensitivity and cost advantages over conventional techniques employing flame ionization detectors. The PMD provides the efficiency of leak surveys, is less costly to maintain than other technologies, and can detect leaks from low ppm to 100% gas.

Contact: Scott Kleppe
219-465-2700
jScottK@gasleaksensors.com
info@gasleaksensors.com

IRED Infrared Portable Ethane Detector
SENSIT Technologies

This easy-to-use handheld detector was developed for use in the field to discriminate natural gas leaks from other sources of methane (e.g., swamp gas, landfill gas, and engine exhaust) and detect trace levels of ethane. The detection of ethane can be used as a fingerprint for natural gas in situations where the origin of a methane leak signal is questioned.

Contact: Scott Kleppe
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info@gasleaksensors.com

Acoustic Pipe Locator (APL)
SENSIT Technologies

SENSIT's ULTRA-TRAC® APL acoustic-based pipe locator provides the ability to locate plastic pipes before excavations and construction. Now commercially available, in tests the system was shown to be capable of detecting multiple buried plastic pipes at depths up to five feet.

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info@gasleaksensors.com

LocusIQ for Intelligent Inspections
LocusView

A software platform developed through OTD is now part of the LocusView mobile product suite to allow users to collect new installation data directly within a GIS environment. Applications to integrate real-time, sub-foot accurate GPS and barcode scanning are included.

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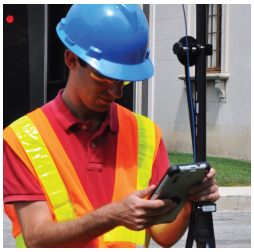

LocusMap Mobile GIS Solution
LocusView

This system maps new installations with comprehensive tracking and traceability data, creating GIS features in a format that allows field-collected data to be directly integrated into the enterprise GIS. Barcode scanning and high-accuracy GPS automate the system and help create high-accuracy maps.

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LocusSurvey for Tracking Leak-Survey Routes
LocusView

LocusSurvey uses tablet computers and GPS to track leak-survey routes. The GPS breadcrumb trail is overlaid in a GIS to track pipe segments that are surveyed to provide real-time reporting and monitoring. LocusSurvey eliminates paper maps and records, automating the process of documenting surveys and leak locations.

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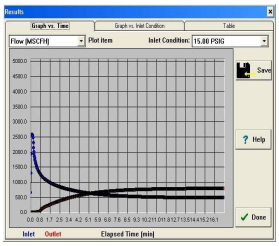
www.locusview.com



Pipeline Purging Program Update
Bradley Bean

The Pipeline Purging Program calculates the purge time, purge pressure, gas flow rate, and the required inert gas volume for the user's specific pipe geometry. The updated program uses a modern web-based platform will allow utilities to utilize the program for planning pipeline purging operations.

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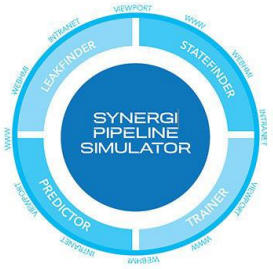


Synergi Pipeline Simulator
DNV GL

DNV GL's pipeline integrity software, Synergi Pipeline, is a scalable company-wide risk- and integrity-management system. It enables safe and efficient pipeline operations, documents risk, and provides users, including upper management, with a clear overview of the integrity of distribution networks and offshore and onshore pipelines.

Contact: Michael Moore
717-724-1900
michael.moore@gl-group.com
www.dnvgl.com

Lift Assists for Pavement Breakers and Rock Drills
Integrated Tool Solutions, LLC

These devices assist workers in lifting pavement breaker and rock drills after the bits break through surface pavements and rocks and need to be repositioned for the next penetration. By eliminating the need to manually lift and re-position the heavy tools, the lift assists make breaking easier and less physically demanding.

Contact: Ryan Purczynski
951-929-4808
rpurczynski@integratedtoolsolutions.com
www.integratedtoolsolutions.com

Keyhole Pipeline Inspection Camera System
ULC Robotics

The PRX250K keyhole camera is an internal inspection system designed for visual assessment of live mains through conventional pits or small keyholes. The system is easily maneuverable through tight bends, allowing utilities to examine pipe segments without the need to drill additional access holes.

Contact: Greg Penza
631-667-9200
gpenza@ulcrobotics.com
www.ulcrobotics.com

Metallic Joint Locator (MJL)
SENSIT Technologies

The SENSIT Ultra-Trac® MJL accurately locates bell joints, repair clamps, and service connections on metallic piping systems, significantly reducing excavation areas and pavement restoration costs. In field tests, the MJL was also able to detect bell and spigot joints for an eight-inch-diameter water main buried at a depth of six feet.

Contact: Scott Kleppe
219-465-2700
jScottK@gasleaksensors.com
info@gasleaksensors.com

Information on additional available products can be found at the OTD website: **www.otd-co.org**

Informational Products

Selected OTD-Developed Technical Reports

In addition to the development of new tools, processes, and products, OTD supports research that results in useful information on various aspects related to gas delivery and operations. Listed here are some of the key reports developed under OTD sponsorship.

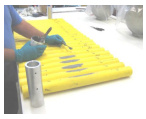
PIPE & LEAK LOCATION

RFID Marker Technology Implementation Guidelines
A set of guidelines was developed for the implementation and application of integrated Global Positioning Systems (GPS), Geographic Information Systems (GIS), and "Smart Tag" technologies to streamline public-improvement project planning and prevent damage caused by excavations.

Cross Bores Best Practices Guide & Video
Significant research was conducted to investigate gas line/sewer line cross bores. The Guide and "how-to" videos (available through the OTD website) provide recommendations and procedures for preventing and detecting cross bores. (OTD-12/0003)

Residential Methane Gas Detector Program
This report provides results of a project initiated to determine whether commercially available combustible gas detectors are susceptible to giving false positive responses to an assortment of typical household chemicals, including ammonia, ethanol, acetone, toluene, isobutane, ethyl acetate, isopropanol, heptane, and hydrogen. (OTD-13/0003)

PIPE MATERIALS, REPAIR & REHABILITATION



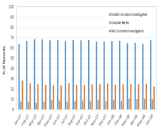
Repair Wrap for Polyethylene (PE) Systems
Researchers evaluated a new composite pipe wrap system for the repair of mechanically damaged polyethylene gas pipe. The repair system has the potential to lower repair costs, reduce repair times, and minimize disruptions. (OTD-17/0001)

Liners/Composites for the Rehabilitation of Distribution and Transmission Lines
A report titled *Transmission Infrastructure Roadmap* was prepared to address the implementation of composite piping materials in the rehabilitation of gas transmission systems. This report includes information on composite pipes, trenchless repairs, and cured-in-place structural liners.

Evaluation of Structural Liners for the Rehabilitation of Liquid and Natural Gas Piping Systems
This report details the results of testing conducted to evaluate the long-term performance of liners and composites used in trenchless operations for the rehabilitation of aging gas distribution and transmission lines.

Polyurea Coating Testing and Assessment for Gas-Industry Use
A Final Report is available on research into field-applied polyurea coatings for gas industry use. Through a new initiative, long-term field trials will be conducted to evaluate these additional coatings and determine a cost-effective coating-application method and process. *(Project Summary, p. 15)*

Electrofusion Coupling Evaluation and Best Practices
Researchers investigated techniques used to perform electrofusion joining of plastic gas pipe in an effort to develop guidelines for the use and operation of electrofusion coupling. With a detailed set of guidelines, the gas industry can enhance the performance and safety of its plastic piping systems.



Risk-Based Atmospheric Corrosion / Leak Survey Considerations

To address new regulations, researchers reviewed historical and current data on indoor gas service piping. In addition, thousands of recent inspections on outdoor and indoor services were collected and statistically analyzed to determine the trends and drivers behind corrosion rates. A White Paper is available (OTD-15/0004).

EXCAVATION & SITE RESTORATION

Evaluation of Lightweight Jackhammers

A research team evaluated the performance of currently available lightweight pneumatic and hydraulic jackhammers with respect to their effectiveness in breaking asphalt and concrete pavement, while considering other operational factors such as noise, vibrations, operator impact, and performance.

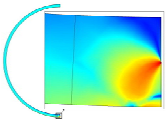
Cold-Patch Products Performance Results

This report provides the results of a testing program that evaluated nine commercially available cold-patch products, including two products introduced in the market as “green” patches. Cold- and warm-weather tests were performed and repeated moving loads were applied with a wheel-loading machine that conducted 50,000 wheel passes.

Evaluation of Flowable Fill Around Buried Pipes

Flowable fill is required by some agencies for use as backfill material for pipe repairs, rehabilitations, and other operations. Presented in this report are the results of performance tests of flowable fill, including the effects of flowable fill on pipeline corrosion and on the detection of gas flow and leaks through the backfill. (OTD-07/0004)

PIPELINE INTEGRITY MANAGEMENT & AUTOMATION

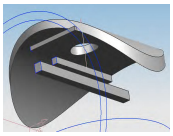


Correlating Pipeline Operations to Potential Crack Initiation, Growth, and Arrest

To help to reduce risks associated with vintage transmission pipeline materials, researchers developed and validated a model for pipeline operations that correlates pressurization to pipe crack-growth rates, crack initiation, and crack arrest. A Final Report was issued in 2016 that includes a training manual on the use of a Critical Crack Propagation Pressure Calculator that provides a convenient and simple way to calculate the critical pressure at which an axial crack will propagate.

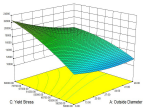
Hydro-Testing Alternative Program

Researchers developed and deployed a Critical Flaw and Critical Wall Loss Calculator that allows pipeline operators to determine if an inspection technology could detect a crack-like flaw and/or wall loss that would fail a pressure/hydro-test at a particular pressure. A Phase 3 Final Report was issued in 2016.



Establishment of Yield Strength Using Sub-Size Samples Without Gas-Line Shutdown

This report presents the results of a multi-phase project is to develop, validate, and obtain regulatory acceptance for a method to establish pipeline yield strength that allows for a less expensive sampling procedure that does not require the line to be taken out of service. (OTD-13/0005).



Leak-Rupture Boundary Report and Calculator

This report and associated software allows operators to determine the leak-rupture boundary for a pipe segment based on properties such as the diameter, toughness, and yield strength. Operators can use the calculator for risk modeling and consequence analysis. (OTD-13/0002 and OTD 13/0004)

Field-Applied Pipeline Coatings: Short- and Long-Term Performance

This report presents the culmination of a 10-year research program to assess more than 80 different commercially available field-applied pipeline-coating products. The goal was to establish an unbiased, third-party basis for operators to select the most appropriate coating system for particular applications.

Evaluation of Guided Wave Technology as a Hydrotest Equivalent

This report details an evaluation conducted to demonstrate and validate the use of Guided Wave Ultrasonic Testing as an equivalent to a hydrotest. A standard was developed and incorporated by the National Association of Corrosion Engineers (NACE) into the NACE TG410 committee standard. (OTD-11/0001)

Black Powder Contamination in the Gas Industry: Survey and Best Practice Manual

Black powder – a substance composed mainly of iron sulfides and iron oxides – can cause corrosion and create wear on pipelines. This report provides information on issues, cleanup techniques, and management methods related to black powder contaminants. Results were compiled into a "best practices" industry manual. (OTD-07/0002)

Literature Review for Elemental Sulfur Deposits in Natural Gas Transmission Pipelines

Deposits of elemental sulfur – which can block natural gas pipes and equipment – are becoming an increasing concern in the natural gas industry. This report summarizes a literature review to develop a better understanding of the sources, causes, and mitigation possibilities for sulfur deposits found in gas pipelines. (OTD-09/0001)

Flaw Acceptance Criteria and Repair Options for Low-Stress Natural Gas Pipelines

Researchers partnered with pipeline companies and industry organizations to develop modified assessment criteria for low-stress pipelines. The goal was to develop criteria for discriminating flaws that truly affect pipeline integrity from flaws that have no significant impact.

In-Field Corrosion Rate Measurement/Determination for Integrity Reassessment Intervals and Risk Prioritization

Research was conducted to develop a systematic and simple method to calculate realistic corrosion growth rates for determining pipeline-reassessment intervals.

CONSTRUCTION/INFRASTRUCTURE TECHNIQUES

Evaluation of Meter Set Placement and Clearances

This report presents the results of a testing program to evaluate the distribution of natural gas concentrations around leaks in outdoor meters and regulators. The report summarizes the risk of gas accumulation, gas ignition, and/or gas migration into a building for the various situations tested. (OTD-17/0002)

Assessment of Frost Impact on Cast-Iron Pipes

This study of winter leak-breakage records correlated pipe breakage due to freeze conditions with local site conditions, such as soil properties, weather patterns, and pipe attributes (e.g., depth, diameter, and age). Statistical analysis established relationships between various parameters to enhance winter leak-surveillance procedures. (OTD-15/0001)

Evaluation of Static Suppressors on Existing Polyethylene Piping Systems

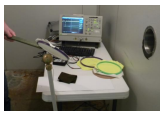
Researchers evaluated selected commercially available static suppressors for suitability for use on polyethylene piping systems to eliminate static charge and assess their effects on heat-fusion-joint performance and pipe materials.

Evaluation of Commercial/Light-Industrial-Sized Excess Flow Valves (EFVs)

This reports presents the results of an evaluation of the performance of high-volume EFVs for commercial, multi-residential, and light-industrial applications in response to regulations requiring an expanded use of EFVs.

Natural Gas & Indoor Air Quality Website

A website of vital information on indoor air quality and safety issues was developed for OTD members through the OTD website *(otd-co.org)*. The site provides a center of expertise and a single-point access to scientific data, performance information, and natural-gas-related issues.



UV Degradation and Static Buildup Testing of Personal Protection Equipment Fabrics

Researchers tested various utility-vest materials to determine if degradation is caused by ultraviolet light and to evaluate the potential for static buildup to become hazardous. The results of safety vest testing are available in technical reports.

Ignition Testing of Electronic Devices

In this project, handheld electronic devices were tested to determine if ignition occurs in the presence of a flammable methane/ air mixture. Laboratory tests demonstrated a large margin of safety under the scenarios investigated. (OTD-12/0001)

Intelligent Utility Installation Process

This report provides a methodology, field process, and a data model for capturing data during new utility installations. The process is used to capture information regarding the location, materials, installation process, environmental considerations, and other factors. (OTD-12/0002)

Tracer Wire for HDD Applications

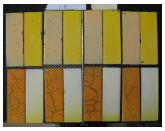
Extensive research and testing culminated in the release of a report that provides valuable information on the properties and performance of various tracer-wire products for use in horizontal directional drilling (HDD) operations. (OTD-13/0001)

Enterprise Decision Support System

This report presents the results of efforts to create a technology roadmap for the development of an Enterprise Decision Support System to integrate gas-system data and knowledge from various sources into a single information source to support decision making.

Assessment of Vehicle-Barrier Design for Aboveground Facility Protection

Investigators compiled the latest information on the design, regulations, and installation practices of structural vehicle barriers used to protect aboveground utility facilities from vehicular damages. The Final Report also includes a review of various state and federal safety guidelines.



Study of Low-Impact Markings

A variety of paints, materials, and techniques were tested and characterized in an effort to identify products and methods that can be used for temporary utility marking. Information developed in this study allows users to identify the most appropriate marker type for a given environment to achieve the desired marking duration. (OTD-11/0002)

Solar-Powered Remote Monitoring

In this study, solar-powered devices were investigated as power sources for the remote monitoring of various gas utility facilities to more cost-effectively obtain rectifier data, pipe-to-soil measurement, pipe-to-casing readings, and other information.

Integrating GPS into Routine Operations

This report provides a set of recommendations and GPS implementation strategies developed through pilot programs, literature searches, and reviews of existing applications. Operations that were considered included meter reading, leak surveying, new installations, corrosion monitoring, and valve inspections.

DVDs for Training First Responders

DVD training products help gas companies better educate first-responding personnel about natural gas emergencies. Learning modules with realistic scenarios cover a variety of issues to enhance public and worker safety. The product also serves to improve emergency-response effectiveness and coordination.

METHANE EMISSIONS/DETECTION & GAS QUALITY

Siloxane Concentrations in Biomethane

Biomethane from various waste products could provide consumers with a significant source of "green" renewable energy. In efforts to help develop this green resource, a study was conducted into siloxane – one of the potential constituents in biomethane – to assess its influence on health, the environment, and gas-fired appliances.

Field Measurement Program to Improve Uncertainties for Key Greenhouse Gas Emission Factors for Distribution Sources

This report summarizes the results of field surveys conducted at six natural gas utilities. With the support of the American Gas Association, research updated emissions factors for metering stations, regulating stations, and customer meters. (OTD-10/0002)

Improving Methane Emission Estimates for Natural Gas Distribution Companies

This report details Phase 2 of a four-phase field-testing program to evaluate gas leak rates from belowground pipelines, provide a simplified procedure that can be used to monitor pipeline leaks from surface measurements, and update the methane emission estimates for the main lines in a distribution system.

Pipeline-Quality Methane: North American Guidance Document for Introduction of Dairy-Waste-Derived Biomethane into Existing Natural Gas Networks

The guidance document provides reference and recommendations for the consideration of biomethane from dairy-waste digestion for introduction into gas pipeline networks. The report details results of a biogas/biomethane Gas Technology Institute research program.

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OTD RESEARCH PROJECT SUMMARIES 2019

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CONSTRUCTION/INFRASTRUCTURE TECHNIQUES *(cont.)*

METHANE EMISSIONS/DETECTION & GAS QUALITY

PIPE & LEAK LOCATION

Advances in technologies for pipe and leak location enhance the safety and maintenance of natural gas delivery systems.

Developments in this area include improvements in leak detection and plastic-pipe location and investigations into residential methane detectors.

Multiple approaches are being investigated, including the use of GPS-enabled equipment to reduce third-party damage (the primary cause of gas system leaks and incidents), increase productivity, and improve system integrity.

Significant efforts include projects to address, detect, and prevent utility line cross bores.

GPS-Based Excavation Encroachment Notification

In a project aimed at reducing excavation damage, researchers investigated the potential to use GPS technology to monitor excavation activity. A product was developed to provide the ability to alert excavators and utility owners when digging is encroaching upon pipelines and other facilities.

Project Description

The Global Positioning System (GPS) Excavation Encroachment Notification (EEN) project focused on the development and implementation of technology to enhance situational awareness of excavators and to significantly reduce the risk of excavation damage to a utility's infrastructure.

A GPS unit, in conjunction with communications and motion sensors, was assembled in one device and installed on excavators to provide utility operators with real-time accurate locations and operational status of excavating equipment.

The specific objectives of the project were to:

- Deploy the EEN units on excavators and agricultural equipment and provide the system architecture to support it. Utility communication protocols were developed to accommodate various levels of enterprise scaling and sustainability.
- Configure and deploy an operations dashboard. The dashboard displays the excavator's location, state of operation, the right-of-way boundaries of pipeline infrastructure, and provides alerts in real time in relation to the pipeline assets.
- Utilize the system architecture to enhance emergency response situational awareness by providing a platform for accurate incident location, targeted alerts, communications, and near real-time access to asset maps.

Several prototypes of the hardware were developed and demonstrated at utility sites. The EEN components were successfully developed into a near-commercial product requiring focus on maintaining system performance, enhancing the software platform, and building robust access to the historical data.

In the current third phase of the project, the objective is to support the continual development of necessary system performance aspects of the EEN system and the commercialization activities.

Deliverables

Deliverables for this project include:

- Developed EEN units installed on utility excavators
- A web-based portal to collect and display data
- A pilot project demonstrating the implementation of the technology, and
- A Final Report detailing pilot project results.

Benefits

It is reported that about 40% of damage in the utility industry is the result of excavators failing to notify one-call centers or not digging cautiously near underground assets. The application of this technology provides a real-time interface to the utility operator, thus allowing for monitoring the excavation equipment in their territory while making informed decisions on prioritizing the monitoring and response activities.

Technical Concept & Approach

The key aspect of this effort was to integrate GPS monitoring into excavation activities so equipment operators can be automatically alerted to potentially hazardous situations. The GPS coordinates of the excavation activity are cross referenced with the location from pipeline data. This information is collected in a portal that performs the analysis, detects violations and encroachments, and sends warnings and notifications to the stakeholders. Specific tasks included software development, demonstrations, and pilot projects.

Results

A GPS monitoring system for excavation equipment was developed to periodically transmit active excavation equipment location information to a portal. The system monitors the behavior of excavators and other equipment entering a utility right of way to characterize its behavior as safe or threatening. The proper alerts are generated by the system to notify the excavator operator and the utility to take the necessary actions.

Multiple prototypes were installed on excavators and construction equipment in Toronto and California. Services and devices were monitored multiple times per day to ensure that the system was functional. The devices were successful in sending data every five seconds as designed. The backend server environment archived the data records with sufficient capacity to handle their large size.

As a result of the project, researchers were able to develop the structure for a commercially viable product that at a minimum is able to report the location of construction equipment in real-time, process its location, compare the location with GIS data of the gas system (pipe, fittings, etc.), characterize movements of the construction equipment, and identify or alert users of potential behaviors that pose risk to the gas system. The activity-recognition routine allowed for continuously recording sensor data from hardware devices and passing them to a learning algorithm in real time to predict the equipment activities.

The project included the deployment of 150 of the devices monitoring the excavator activities in a program cofunded by the California Energy Commission (CEC). Monitoring activities led to an evaluation of sensor performance and areas of the EEN architecture that are stable or need improvement.

In 2019, the project team executed agreements with with Hydromax USA to support commercialization activities. In addition, project representatives continued to support industry awareness of the EEN product by attending the Common Ground Alliance Safety Conference. Researchers supported Pacific Gas & Electric Company and Hydromax USA during the demonstration for the 811-day activity. This demonstration was aired on the local Sacramento news. The project team also supported Hydromax USA through discussion and development of a pilot project proposals aimed at exercising the EEN platform currently in development

Status

This project supports the technology transfer. Commercialization activities are under way. OTD will support Hydromax USA in implementing pilot programs in 2020. The product is being marketed as UtilAlert.

A Final Report is being developed.

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Field Measurement of Leak Flow Rate

The goal of this project was to develop an inexpensive and repeatable device that can provide a measurement of the gas-leakage rates in the field from Class 2 and 3 non-hazardous pipe leaks. The technology will improve the ability of pipeline operators to prioritize activities and manage resources.

Project Description

Larger utilities, with older infrastructures, may have as many as 10,000 non-hazardous leaks (Class 2 and 3) on record at a given time. The goal of this project is to develop a device that is inexpensive, simple to use, and can be used to prioritize leak repairs. The training required to use the device is expected to be on the order of that needed for a combustible gas indicator. Accuracy within 10%-15% is acceptable as long as repeatability and cost constraints can be met.

In Phase 1 of the project, the research team developed a device that can provide a *coarse* measurement of the gas-leakage rate in the field while investigating leaks on distribution piping.

In Phase 2, efforts were made to further develop the technology to *accurately* quantify the leak rate of non-hazardous leaks. This involved improvements on the alpha prototype and upgrading the technology.

Deliverables

Phase 1 deliverables included a functioning prototype of a field methane-flow-measurement device.

Phase 2 deliverables include:

- An experimental test protocol
- A field-ready prototype, and
- A testing methodology report, design documents for the prototype, and a validation testing report.

Benefits

Class 1 leaks, which pose the highest risks to people and property, are always addressed first and tend to be straightforward to prioritize. For non-hazardous Class 2 and Class 3 leaks, a device to estimate the flow rate would assist in prioritization efforts.

Knowing which part of the leak backlog should be addressed first will optimize methane reduction with the same workforce.

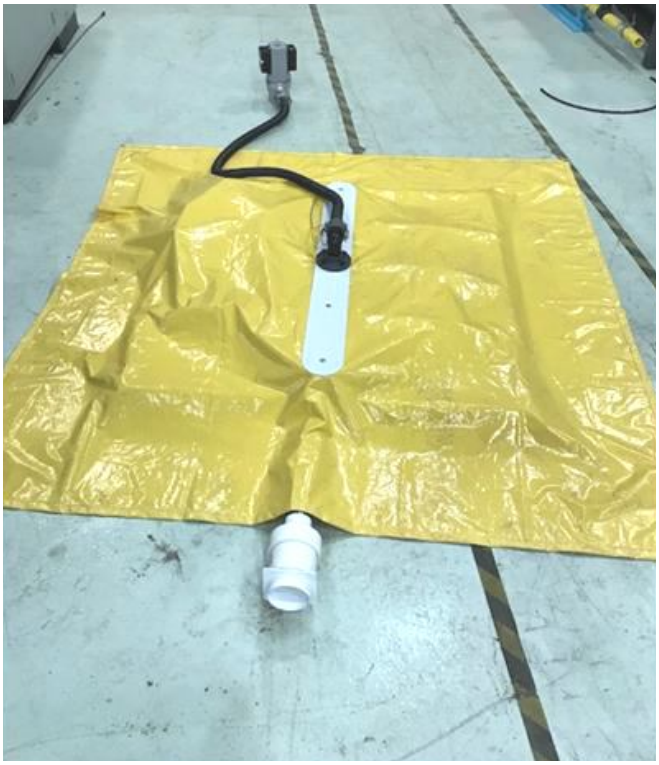
Technical Concept & Approach

In the first phase of the project, an alpha prototype was developed and demonstrated that can provide a coarse measure of the flow rate of methane from an area where a leak is suspected. The focus was on using existing methane sensors in conjunction with air-flow measurement devices.

Results

For this project, a prototype was built that includes sensors for methane, flow, temperature, and humidity, and a small fan to draw a sample through the system. These are coupled with a processor to collect the data and to provide wireless connectivity to a user interface device. The sensor package tracks the methane concentration and the total volume flow through the orifice. The methane flow is calculated from this data.

The initial package design was targeted to fit in the opening at the top of a standard traffic cone to allow



Wide sampling scoop.

collection over a known ground footprint. Other collectors that can be folded when not in use are being considered.

The entire package was subjected to testing in varying concentrations of methane in air. The sensor was demonstrated to be appropriate for the range of use.

An enhanced prototype was subjected to varying levels of methane at constant temperature and humidity in a test chamber. Further consideration of the physical hardware indicated that it may be improved by changing the current flow sensor for one with a greater volume rate. Additional efforts were made regarding the calibration of the methane sensor used in the prototype.

Phase 2 focused on improving the calibration and accuracy of the methane flow measurement device as well as the range of concentrations to be measured. Modifications to the Phase 1 prototype were made. Upgrades were also made to the software and the battery-charging system.

Field demonstrations of the flow-measurement device were carried out at participating utilities in 2017-2018. The testing was well received and valuable feedback was captured from the utility personnel.

Based on comments received from utility personnel, several improvements were made to the software. These modifications were subsequently tested on controlled leaks at a pipe farm.

In-house validation testing of the methane sensor and flow sensor accuracy was carried out. Testing of the methane sensor itself was also performed under varying relative humidity conditions. As with several other methane sensing projects, the user interface is provided as a webpage served by the methane flow rate device hardware. This eliminates the need for device-specific applications for different models of phone or tablet.

Performance comparison testing was conducted to compare the Methane Flow Rate Device (MFRD) with the Hi Flow Sampler™ instrument. The testing included a few days of measurements examining different-sized simulated aboveground natural gas leaks. Overall, the leak flow values from the prototype agrees well with that from the HiFlow sampler. Overall, the prototype readings were found to be within 3% of the HiFlow sampler measurements, indicating the good agreement. The accuracy of the prototype was found out to be about (+/-) 14%, while that of HiFlow sampler, from manufacturer's specification, is (+/-) 10%.

The project team built an adapter to use with the existing tent enclosure used for quantification of underground pipeline leaks. Researchers also explored the development of a collapsible umbrella-type unit for ease of use and to alternatively use instead of the traffic cone.

The prototype response, at lower sampling rate (< 100 SCFH), was noted to be affected greatly by the prevailing wind condition. However, at higher sampling rate (>150 SCFH), the effect of crosswinds on the measurement was found to be minimal. This may be attributed to higher suction pressure induced by the venture vacuum pump when compared to the draft created by the prevailing crosswinds.

In addition, a better sealing between the ground and the sampling scoop would greatly reduce the crosswind effects. This can be easily done by using a rubber seal underneath the cone.

After a review of the results, it was decided to do one more round of testing at leak rate below 0.05 SCFM (3 SCFH).

Testing on lava rocks proved to be more difficult for the tool to pick up methane because of the large free air spaces within the ground. The methane would disperse before it was able to reach the sensor in the tool. Testing on a manhole cover and street grates was conducted, detecting 1 SCFH of methane when the valves were completely open.

In 2019, the project team compiled feedback on the report from sponsors to finalize the project.

Status

This project is complete. A Final Report was issued in January 2020.

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Residential Methane Detectors Program

The objective of this project was to create a comprehensive program for achieving full customer adoption of cost-effective, reliable, accurate, and readily available residential methane detectors.

Project Description

In this program, several discrete initiatives were conducted, with initial activities focused on 1) a consumer behavior study to better understand how customers react to potential leaks and 2) the development of a "Fit-for-Purpose" standard for residential methane detectors.

This project also included a pilot program to evaluate commercially available detectors that performed well during laboratory evaluations. The pilot program investigated the performance of the detectors in actual home settings, consumer responses to alarms, and where to place the detectors within the household.

Deliverables

The deliverables for this program include: 1) A fit-for-purpose detection-level determination; 2) a revised standard; 3) a consumer behavior study; and 4) pilot study and implementation plan.

Benefits

The results of this research will allow utility companies to add to their environmental and safety public-awareness programs by offering technically validated information regarding the reliability and enhanced safety that in-home methane detectors can provide.

Technical Concept & Approach

Specific tasks include:

- **Consumer Behavior Study**

  Although residential methane detectors are currently available, there is not widespread adoption and a general lack of awareness of these safety devices exists. This type of study complements existing market research on low customer adoption of gas detectors and customer responses in regards to leaks. The study looks at issues such as limitations in consumer knowledge, consumer motiva-

Methane detectors undergoing testing in an environmental test chamber.

tion, and decision making. These insights will help utilities develop appropriate strategies to increase the effectiveness of both natural gas odorant and residential methane detectors.

Results from this study will be leveraged to develop a marketing and implementation strategy to improve customer adoption of residential methane detectors and to influence behavior so that customers take action (report a leak) when a hazard is recognized.

- **Development of Appropriate Detection Level and "Fit-for-Purpose" Standard**

  Commercially available residential methane detectors currently alarm at 25% LEL, which is also the detection threshold that is specified in Underwriters Laboratories (UL) standard 1484. However the Code of Federal Regulations 49 CFR 192 specifies a gas detection level of 20% LEL in confined spaces, while some states such as New York are even lower at 10% LEL. There is a need to determine the appropriate detection level specific for residential methane detectors and to develop a new

- **Pilot Study**

  A pilot program investigated the performance of detectors in actual home settings, consumer responses to alarms, and where to place the detectors within the household. These factors influence how detectors are used and perceived.

Results

The first phase of this program determined whether commercially available residential methane gas detectors were susceptible to giving false-positive responses to an assortment of typical household chemicals. Research found that the two most commonly sold devices were the best performers.

In Phase 2, the project team conducted a more comprehensive testing program on commercially available residential methane detectors, expanding the testing program to international products. Laboratory testing was conducted to identify both strengths and deficiencies in these detectors.

Phase 3 was initiated in 2015 with a consumer behavior study. A survey of approximately 1,000 people was completed. Preliminary data states awareness of natural/ methane gas alarms or detectors is about 49%, which is the lowest among other safety products such as home security systems, fire alarms, etc. The study also suggested that improvement is needed in regards to natural gas safety education and awareness.

In 2016, the pilot program was initiated and a test plan developed. Three manufacturers were selected based on market share and performance in previous test phases. Approximately 1,000 detectors were installed in residential homes for up to a one-year period. Each participating utility was responsible for installation according to manufacturers' instructions. At the end of the test period, each detector will again be tested to verify performance over the pilot period.

In 2018, the project team completed the "Fit for Purpose" recommended standard revisions to UL and completed testing the next tier of detectors.

Phase 4 of the program involved the development of a rationale for recommendations on where to place commercially available residential methane detectors. The implication from literature sources is that placement of an detector should be close to the leak source. For many residences, the largest potential leak source is a furnace, followed by a water heater, gas-fired dryer, and kitchen appliances. According to the NFPA, two out of five (39%) home structure fires starting with ignition of a flammable gas began in the kitchen. Cooking and heating equipment are the biggest source of fires. This encourages placement in basements, garages, and kitchens, which is counter to many manufacturer recommendations.

Phase 5 involved an evaluation of utility gas safety literature using the lessons learned in the consumer behavior survey. The goal is to make technical recommendations on how to incorporate the use of residential methane detectors into gas safety messaging.

A total of 66 detectors failed the post-pilot testing.

Status

This project is complete. A Final Report was issued in February 2020.

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Cross Bores – Sewer System Cleanout Safeguard Device

The focus of this project is on the development and deployment of a safety device that allows sewer system clearing operations to occur with the ability to seal various sized sewer cleanout openings. In the event a natural gas line (inadvertently installed in a sewer) is damaged, the safeguard device will minimize or eliminate blowing gas into the house through the sewer clean out.

Project Description

The cross boring of a sewer main or lateral during the trenchless installation of a natural gas line can result in serious consequences. Most utilities are addressing cross bores and how to safely handle past trenchless installed gas facilities (potential legacy cross bores), and new procedures and methods to mitigate this risk are being developed.

Safety issues arise when a clearing activity damages a gas line that had inadvertently been installed through the sewer lateral. A natural gas line damaged during sewer line clearing activity can result in gas blowing back into the house through the sewer cleanout. Depending on pressure and the nature of the cross bore, the uncontrolled flow rate of natural gas into the building can be substantial.

To address the issue, industry representatives identified the need for a device that could be used to stop the flow of natural gas back through the cleanout if a natural gas line is damaged as a result of clearing operations. In this project, research is aimed at developing and deploying a safety device that has the ability to seal various sized sewer cleanout openings, thus minimizing or eliminating blowing gas into the house.

In Phase 1 of this project, the research team developed a device designed for a four-inch-diameter PVC sanitary cleanout that has good, intact threads. This size was targeted as it is the typical installation for most newer homes. Several different prototypes were examined, resulting in a split-cap design that attaches around the cleanout rod and threads into the cleanout opening. However, older homes may have various sizes of cleanouts, and may contain stripped threads. It may not be feasible or practical for a plumber to carry multiple-sized split-cap devices. Additionally, the condition of the threads on the cleanout may not be useable if they have been damaged.

The current Phase 2 is focused on developing a prototype that is capable of addressing the various sized openings (other than four-inch) and openings with damaged threads.

Deliverables

The deliverables for this project will be a summary report and a sewer system cleanout safeguard device prototype.

Benefits

A sewer system cleanout safeguard device would provide plumbers and home/business owners with a safety device that can reduce the risk of blowing gas into a facility.

Technical Concept & Approach

The research team examined various conceptual designs. Several prototype options and design features were considered based on the recommendations of the sponsors, plumbers, and others.

Development and evaluations of design concepts and prototypes were conducted on the typical cleanout and pipe size ranges and materials likely to be encountered during sewer system clearing activity. The evaluation looked at:

- Ease of installation, operation, and removal
- Durability with repeated use, and
- Effectiveness of preventing the flow of natural gas past the safeguard device when deployed at various pressures and with various types and configurations of clearing tools and sewer systems.

A deployment and commercialization strategy will be developed and implemented based on the success of initial project phases. Upon the successful completion of prototype testing and product refinement, a trial deployment effort will be initiated with a test group of plumbers who have a long-standing relationship with one or more of the sponsors. Following a two-month pilot, recommendations for product improvement will be solicited from the plumber test group and a final product developed for commercialization.

Results

In Phase 1, the project team finalized the prototype cap design by instituting a slight modification of the inner cable seal. The team performed a final evaluation of this split-cap prototype that included performing installations of the under various conditions, including with 60 psig air pressure with and without water and other debris in the lateral. The water and debris in the sewer lateral was used to test the installation of the split cap under more realistic field conditions. A video of the tests was prepared for the secure project website. Subsequently, 35 split caps were manufactured, installation procedures prepared, and materials shipped to all sponsors for feedback. Insights from sponsors and plumbers indicated that while the cap design will work on newer installations, many of the homes (especially older homes) have smaller or different size cleanouts. Also, sometimes the threads are damaged and a threaded cap can't be installed.

In response, Phase 2 of this project involves the development of a plug-type cap that may work on a variety of sizes and conditions of cleanout openings. In 2017, the project team developed a prototype for a combination split cap that can be used on 3-to-4-inch-diameter cleanouts sealing around 0.5-inch, 0.625-inch, and 0.75-inch-diameter cables. In addition, researchers created a conceptual design for smaller individual split caps that utilize the same engagement tool as the combination split cap. Several iterations of prototypes were made, including modifications to the body to make it easier to install the spring pins.

Early in 2018, the project team received a quote from a mold manufacturer to create the mold for injection the Split Cap Safety Plug. Pending the approval of the project sponsors, the project will move forward with the mold creation. Additionally, researchers will develop a proposal to present to all OTD members to commit money for an initial purchase order of the Split Cap Safety Plugs.

Status

A proposal was put before the sponsors for an initial purchase of the Split Cap Safety Plugs. If there is enough interest, an order will be placed with the manufacturer.

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Pipeline Defense with Combined Vibration, Earth Movement, and Current Monitoring

The objective of this project is to demonstrate the feasibility of a pipeline right-of-way (ROW) monitoring and defense system based on stationary sensors mounted on, or adjacent to, the pipeline.

Project Description

While significant efforts have been devoted to the continuous, real-time monitoring of pipelines and right-of-ways (ROWs), there has been very little commercial penetration of products for this market. The objective of this project is to demonstrate the feasibility of a pipeline ROW monitoring and defense system.

The concept involves the wireless transfer of sensor data from multiple locations along the pipe to a central location for further analysis. Analytics will correlate the data from multiple sensors to alert operators to events of interest occurring in the ROW.

This project is a collaborative effort cofunded by the U.S. Department of Transportation's Pipeline and Hazardous Materials Safety Administration, Operations Technology Development, and the California Energy Commission.

Deliverable

The primary deliverable will be the deployment of a Pipeline ROW Monitoring and Defense System prototype.

Benefits

A pipeline/ROW monitoring system that can provide early warning of an incident developing has a high value both in safety and in costs. There is also the general need to capture operational data that could be served by the same system.

Technical Concept & Approach

The minimum installation package consists of a housing, wireless link, a datalogging system, vibration sensors on the pipeline, earth-movement sensors, and sensors for cathodic protection (CP) monitoring. Additional sensors for soil movement, soil moisture, and temperature were incorporated into the system.

A complete reference system, identical to those being deployed to the utility test site, will be constructed and connected to pipes already in place at Gas Technology Institute facilities. This process will allow for debugging of the sensors and instrumentation in a realistic setting prior to field deployment. The test data collected using the reference system will provide a performance baseline.

Left: Sensors during epoxy cure; right: RPMA radio.

Appropriate housings, instrumentation, and sensor packages will be installed at the utility test site. After installation, there will be a period of observation prior to long-term testing. The sensitivities and alarm thresholds for the various sensors will be set. The integrity of the wireless connections will be verified.

Field testing will refine the calibration of various sensor alarm thresholds and will include one or more "staged" events that involve contact with the pipeline.

Results

A large number of sensor types and models were examined, including:

- Vibration sensors on the pipe for impact and proximity sensing
- Strain sensors mounted on the pipe to determine tensile stress
- Pipe current sensor to determine AC and DC currents on the pipe
- Soil-moisture and soil-temperature sensors alongside the pipe, and
- Seismic soil-motion sensors alongside the pipe to measure background vibration noise.

The digested vibration data will be transferred to a datalogger over a serial link. The other pipe and soil sensors will be connected directly to the datalogger. The overall aggregate data for a single location is then transferred out through a RPMA (random phase multiple access) radio system. From the base station it is transferred to the Internet via a cellular or landline connection.

The project team is currently testing adhesive bonded strain gauges to replace the welded types.

Test installations of vibration sensors and strain gauges were performed at utility laboratories to allow personnel to become familiar with the process. A shielding method was also been developed to protect the pipe sensors during backfill.

The soil moisture, soil movement, and current monitor sensors were installed at a site in California. The hydrotesting of the California line at took place in early July 2018. In-situ testing of the vibration sensors took place in mid-September. While the entire system has not been tested yet, these individual tests did provide calibration data for several components. After the hydro-test was complete, the instrumentation was removed to a safe storage area in the construction yard until the permanent enclosures could be completed. The sensor cables were pulled through conduits and brought above ground. Footings were poured at two locations to support the pole for the instrumentation cabinet. The remainder of the soil backfill was put in place on top of the slurry fill covering the pipe. The poles were put in place and the permanent enclosures with their solar power system installed in early September. The dataloggers and associated sensors were installed and wired.

A series of tests were carried out to verify the response of the system to vibrations and impacts. For this series of tests, the signal processing equipment was installed in the enclosure and connected to the sensors. The purpose of the compactor testing was to put repeatable vibrations into the ground at known locations.

At this time, the sensors are being applied only to new or out-of-service pipes. The consensus with the utilities is that if the sensor system is successful, procedures for applying it to in service pipes will be developed going forward.

The *State of the Art Technology Review Report* was completed. A section on the technology requirements for attaching sensors to operational pipelines was included.

The RPMA radio equipment was installed on the test site. Two of the three sensor stations provided data over the radio link throughout December 2018.

Status

Ongoing activities include:

- Development of a database ontology, semantics, and structure for capturing pipeline data
- Testing of the monitoring equipment in the field, and
- Development of analytics that can digest sensor data and identify events of interest in the presence of background noise.

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PIPE MATERIALS, REPAIR & REHABILITATION

In this area, researchers focus on various aspects related to the evaluation and development of materials and processes used to maintain, repair, and rehabilitate gas piping systems.

Current efforts include projects to evaluate pipe coatings, composite repair wrap, pipe squeeze off, and semi-automated plastic pipe fusion.

R&D results from this area – developed in state-of-the-art testing facilities and demonstrated in the field – contribute to improvements in system safety, deliverability, and integrity.

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In-Service Field Evaluation of Polyurea Coating Systems

Research into field-applied polyurea coatings for gas industry use is being conducted through long-term field trials designed to evaluate coatings and determine a cost-effective coating-application method and process.

Project Description

In recent years, gas utilities have expressed increased interest in using plural-component "polyurea" coatings for service applications such as vaults, pipe on bridge crossings, pipe for horizontal drilling applications, above-ground meter sets and distribution equipment, and vehicle truck beds/underbodies.

In general, polyurea coatings have exceptional high elongation and toughness. Polyureas also offer rapid application rates, fast curing (< 1 minute), and a quick return of components to service. In addition, they can have strong abrasion resistance and excellent encapsulation characteristics. Some systems are available in high-pigment UV-inhibited formulations, making above-ground applications acceptable.

The most problematic application of polyurea coatings is related to potential coating damage from cathodically protecting the pipe. Polyureas are generally known to perform relatively poorly compared to fusion-bonded epoxies (FBE) in ASTM cathodic-disbondment (CD) testing. However, due to their exceptional impact resistance, many fewer holidays should be expected to form.

In Phase 1 of this project, a comprehensive evaluation of polyurea pipe coatings was conducted.

Tests were conducted to determine:

- Cathodic disbondment
- Impact resistance
- Abrasion resistance
- UV resistance, and
- Corrosion resistance.

Two types of polyurea coatings from Nukote Coating Systems (HAR and HTD) performed well in laboratory testing and appeared promising for use in the natural gas industry. Their impact and corrosion resistance out-performed the benchmark liquid epoxy coating. In addition, the formulation of Nukote HAR and HTD coatings significantly improved their CD resistance in comparison with other types of polyurea coatings.

In the current Phase 2 initiative, coatings are being further tested through long-term field trials in several applications.

Comparison of polyurea coating between April 2017 (left) and November 2018 (right).

Deliverables

Deliverables will include a report on the application of the coatings at various field sites. The report will also provide guidance for the polyurea applications method and process.

Benefits

This research will provide utilities with the comparative, sound engineering data necessary to make decisions regarding the use of polyurea coatings.

Technical Concept & Approach

- Identification of Field Test Sites and Coating Applicators
- Establishment of a Field Testing Matrix
- Evaluation of Field-Coating Applications
- Coating Evaluation, and
- Guidance for Polyurea Applications.

Results

The overall performance of polyurea coating was evaluated and compared with a benchmark liquid epoxy coating.

In 2015, an installation was made in New York. The research team documented the conditions of the pipe before, during, and after the installation. Surface profile measurements were taken after pipe blasting and before the coating was applied three times and in five different locations in order to obtain a representative sample size of measurements. Once the pipes were sandblasted, the surface was coated with a polyurea sprayed onto the pipe and allowed to cure. Thickness measurements were taken at different locations along each of the pipes. The target minimum coating thickness was 40 mils and the actual measured average coating thickness was 48.20 mils and 52.25 mils for the north and south pipes, respectively. After the minimum target coating thickness had been achieved, the pipes were spray coated with a 3-4 mil topcoat of yellow Nukote paint for visibility and safety.

In 2017, the coated pipe segment in New York was inspected (about 18 months after its initial coating of polyurea). Researchers reported that the coating appears to be holding up well.

At the site, coating-thickness measurements were taken at 12 locations along pipe sections in sets of four places around the diameter of the pipe at each location, for a total of 48 measurements.

Another component of the inspection focused on rust formation. At first glance, very small pinpoint-style rusting seems to have formed in areas along the pipe. A possible explanation for this formation is overspray, which is a common issue with the application of polyureas due to its fast curing time. If it is only deposited on top of the coating, overspray should not be detrimental. If overspray occurs on the pipe surface prior to the application of the coating, however, delamination could result. The pattern will not be classified as rust at this time, but dark, dotted areas will be monitored and their growth patterns will be noted.

Very small paint blistering was observed in a few locations along the length of the aboveground pipe. These blisters are very small and few in concentration. The blisters are most likely osmotic blistering due to temperature variations of the effluent and ambient temperatures. They are hard, firm blisters and if they are cut open, we can assume that one will find moisture but no corrosion below. The liner keeps the moisture from contacting the pipe surface and since no oxygen is present, there is no corrosion.

In 2018, researchers went to a site of a pipe to inspect the polyurea coating. The coating was installed three years prior to the time of inspection. No major sizes of corrosion were found during the inspection and the coating thickness, surface salt concentration, rust pattern development, and paint blistering was measured at multiple locations on the pipe surface.

The most noticeable difference observed occurred in the coatings color. The coating is a slightly paler yellow than it had been at the one-year inspection. Some spots of rust are also visible at the flange locations on the valves.

Status

The project team completed an inspection of the coating in November of 2018, the three-year mark. The coating appears to be holding up very well. Another inspection is scheduled at the five-year mark in 2020.

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Composite Repair Wrap for Polyethylene Systems

Researchers are evaluating a composite pipe wrap system for the repair of mechanically damaged polyethylene gas pipe. The repair system has the potential to lower repair costs, reduce repair times, and minimize service disruptions.

Project Description

With existing polyethylene (PE) pipe repair methods, typically a short section of the distribution system is shut down and bypassed while the damaged pipe section is cut out and replaced. This approach is time consuming, expensive, and requires multiple excavations and complicated procedures.

In this project, researchers are investigating a pipe wrap system for the repair of PE pipe components that shows promise of being a fast, easy-to-use, durable, and cost-effective method for PE pipe repair. This method provides direct bonding of composite materials to the PE pipe surface with minimal surface preparation. The composite material may be either resin pre-impregnated fiberglass cloth or field-impregnated fiberglass that adheres to PVC, fiberglass, concrete, and all metal pipes. According to the manufacturer, the PE pipe repair method and materials will also provide abrasion and impact resistance to the PE pipe. A single system can be used to repair pipes and/or fittings of various diameters, sizes, and shapes.

Although composites have been used for more than 20 years to remediate steel piping, the ability to repair PE pipe was limited due to the inability of composites to bond to the PE material. The patent-pending pipe wrap technology overcomes this limitation.

A research team is conducting a thorough evaluation of the pipe-wrap system to develop information on the permanency and life expectancy of the repairs.

Deliverables

The deliverables for this project include testing reports detailing the performance of repairs made with the pipe-wrap system.

Benefits

PE pipe systems experience two common types of damages. The first type is third-party mechanical damage that results in pipe wall loss that requires immediate remediation where the only available option is to remove and replace the damaged section. The second type is longer-term damage which manifests from either crimp-type fittings or the crimping operation required to conduct a cut-and-replace operation, which introduces micro-cracks into the pipe wall. These micro-cracks can become problematic and can be considered as deferred remediation projects. Both types of damage, if left in their natural state, will result in leaks and/or other hazards.

In some situations, the currently used repair systems were never designed for outdoor atmospheric exposure, and when used under these environments may prematurely degrade, leading to the reoccurrence of a leak. In addition, some of these repair systems are complex to install properly and their inherent designs produce a large degree of variability in the installation and, therefore, performance quality.

A practical PE permanent repair system will save time and money while minimizing service disruptions.

Technical Concept & Approach

The investigation of the pipe-wrap PE pipe-repair system focuses on applying the repair technique to different gas system components to evaluate effectiveness. Simulated defects are machined in each pipe specimen. The mechanical properties of pipe wrap will be

Squeezed and wrapped pipe samples.

evaluated by determining lap shear strength in accordance with ASTM testing procedures.

Prepared samples undergo the following:

- Short-term hydrostatic burst testing.
- Rate Process Method (RPM) analysis by performing long-term hydrostatic pressure testing at elevated temperatures. Then, failure data obtained at all temperatures will be used to predict the performance of the repaired pipe samples at end-use temperature and pressure conditions.
- Impact testing in general accordance with ASTM D2444 *Standard Test Method for Determination of the Impact Resistance of Thermoplastic Pipe and Fittings by Means of a Tup* (falling weight).

Results

In this project, various pipe specimens were prepared with simulated defects and subjected to testing. Based on specimens subjected to hydrostatic burst testing, it appears that the repaired two-inch-diameter pipe samples, irrespective of the pipe sample being heated or not during the repair process, are performing well.

Specimens were notched during preparation with generally four-inch-long longitudinal notches milled in the center of the pipe specimen to a depth of 80% of the measured minimum wall thickness of the specimen. Repair-system applications were conducted while the pipe was both heated and unheated. Plaques of high-density PE measuring 12 inches x 12 inches x ¼ inch were prepared and underwent lap shear testing.

Notched (gouged) pipe specimens were sent to the manufacturer, who designed and built a prototype heat-gun field tool used to apply the repair technology. This device is designed to clamp onto a pipe at either end of the repair area. The device has a variable temperature heating device and a custom-built nozzle that applies a constant temperature heat circumferentially around the pipe. The heater is attached to linear motion bearings allowing the nozzle to be moved over the repair area.

In 2017, the project team initiated RPM testing and performed tensile pull testing on butt-fusion specimens. Test results were compared with those of a control pipe (i.e., straight pipe) and an actual butt-fused pipe. It was shown that the adhesive is required to make an adequate bond to the pipe and the wrap. It was also shown that the butt-joint has a higher peak load than those of the control and butt-fused samples. For all the eight butt-joint specimens tested, the ultimate failure occurred by yielding of the pipe material outside the repair area.

Pipe samples squeezed-off under pressure.

In 2018, dynamic thermo-mechanical analysis and squeeze-off evaluations were completed. Pipe specimens were squeezed-off in accordance with ASTM F1041 and D2513 under 60 psig internal pressure at room temperature. Technicians prepared and wrapped two-inch-diameter medium-density PE pipe samples for burst and long-term hydrostatic strength testing at various temperatures. Dynamic mechanical thermal analysis of the wrap material was also completed.

In 2019, burst testing was completed on wrapped samples at 140°F, 176°F, and 194°F.

For cyclic pressure testing, a trapezoid pressure waveform will be set up so that the highest pressure corresponds to 670 psi hoop stress where the specimens will be subjected to this stress for approximately 40% of the total cycle time. Specimens will be periodically inspected to see if there has been any delamination of the wrap material from the pipe.

Status

Researchers are testing squeezed and wrapped samples at 176°F (80°C).

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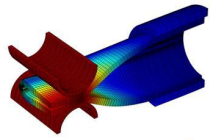
Assessment of Squeeze-Off Location for Small-Diameter Polyethylene (PE) Pipe and Tubing



Through this project, researchers developed a model for predicting the effects of squeeze-off on small-diameter PE pipe. Study findings may result in changes to current standards that could facilitate natural gas operations and provide efficiency and economic benefits.

Project Description

This project involves an examination of the potential for reducing current minimum PE pipe squeeze-off distances from fittings in order to facilitate routine operations and maintenance (O&M) tasks.

In Phase 1 of the project, the applicability of minimum squeeze-off distances from fittings and other appurtenances for the case of small-diameter (two inches or less) PE pipe and tubing was addressed. Through this study, researchers developed and experimentally validated a model for predicting the effects of squeeze-off incurred as a function of pipe diameter, temperature, and pinch-point location in relation to the proximity of fittings and other appurtenances. In addition, this study presented an opportunity to investigate modern bimodal (medium-density and high-density) materials which had not previously been formally evaluated for squeeze-off applications.The current Phase 2 focuses on the investigation of modern PE materials that were not previously evaluated for squeeze-off in Phase 1 of the project.

Deliverables

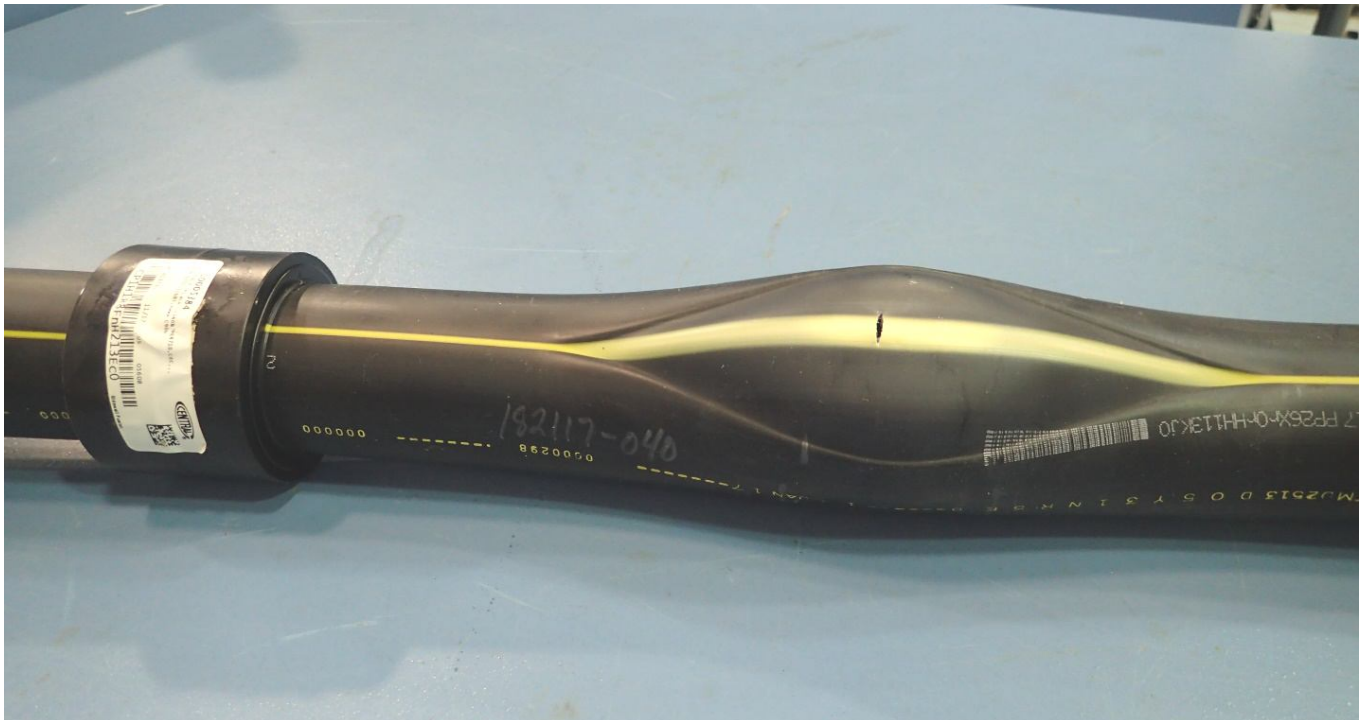
The deliverables for the project include a project report that details findings from the modeling and experimental efforts, along with a recommendation for minimum squeeze-off locations relative to pipe joints in smaller-diameter pipes for each material included in the study.

Benefits

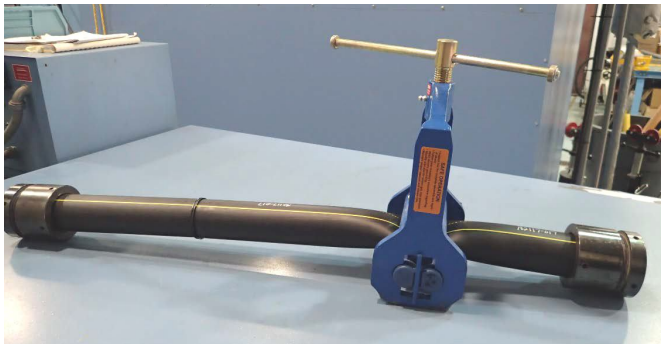
The ability to perform squeeze-offs within one foot of pipe joints and couplings may significantly reduce required excavation sizes. Study findings may result in recommended changes to current squeeze-off procedures with potential efficiency and economic benefits for O&M activities.

Technical Concept & Approach

Finite Element Analysis (FEA) and accelerated testing were performed to provide a solid standing for any



Ductile failure at squeeze-off point.



proposed changes to the best practices outlined in ASTM F1041-02 (2008).

The project team used FEA model predictions of pipe squeeze-off in close proximity to two common fitting types: a straight coupling and a service tee. In addition, proximity to a prior squeeze-off location were simulated. Parametric sweeps of pipe diameter, ambient temperature, and pinch-point proximity were run to assess the impact of moving the pinch point to various locations within 12 inches of the fittings/appurtenances.

Accelerated hydrostatic sustained pressure testing was conducted at three temperatures, each with three replicates.

The goal was to determine critical proximity for which detrimental effect is equally likely to be sustained in the pipe at the squeeze location or at the fitting, and then back-off the squeeze location such that a 10% stress reduction is observed at the fitting. Researchers experimentally validated crossover location predicted by the FEA model for a single temperature (e.g. 80ºC) for a coupling scenario.

Microscopic assessments were conducted of pipe damage imparted by squeeze-off performed at a range of distances from the nearest fitting.

Results

Simulation of medium-density (MD) PE pipe squeeze-off required development of an advanced constitutive model for MDPE. Mechanical testing was tailored specifically for the squeeze-off model in order to capture the application's conditions, including: large deformations in tension and compression, variable strain rates, temperature variations, and stress relaxation.

The results from the squeeze-off FEA model indicate that a squeeze-off can be performed at a distance three pipe diameters from a fitting with any size pipe. The constitutive model developed for simulating PE calibrated well to various test data. The FEA model also showed that it is able to capture the effects of squeeze-off loading and unloading rates.

Strain at a coupling edge was probed to assess the impact of distance of the squeeze-off bar from the coupling edge. Results show that the coupling strain levels for a ½-inch IPS DR 11 and a four-inch IPS DR 11 pipe are similar, when the squeeze-off is offset from the coupling by three times the respective outer diameter. This suggests that smaller-diameter pipe does not need to be limited by the 12-inch minimum squeeze-off distance and can use the same outer-diameter multiplier as used for four-inch IPS sizing and above.

A technical review of previous research was conducted to investigate: 1) conditions that induce damage during squeezing; 2) methods that can be used to identify materials susceptible to squeeze-off-induced damage; and 3) squeeze-off procedures and tools to avoid or with the potential to minimize damage.

In 2018, project work continued with long-term hydrostatic pressure testing, material testing, and calibration. Additional squeeze-off simulations were conducted using HDPE material calibrations obtained from the material testing. The additional simulations showed the same trends as the preliminary simulations.

In 2019, the project team completed the long-term hydrostatic pressure testing, material properties testing, and finite element simulation of various squeeze-off scenarios.

All the simulations and empirical test results thus far indicate that squeezing at a distance of 3xOD from a fitting or butt-fusion joint is not detrimental to the fitting/joint, as no failures occurred at the joints.

In the first half of 2020, researchers will address outstanding concerns raised by project sponsors and other industry stakeholders related to acceptance of a 3xOD minimum distance instead of the current 12-inch minimum for small-diameter pipes and tubing. Outstanding concerns include squeeze-off near "cold" butt-fusions, squeeze-off of vintage pipe materials, and pipe loading during squeeze-off.

Status

Researchers are addressing outstanding sponsor and industry stakeholder concerns with acceptance of a 3xOD minimum squeeze-off distance for small-diameter pipes and tubing and

A Final Report is being drafted.

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Semi-Automated Fusion Equipment Steering Committee

An industry steering committee was formed in order to capture and analyze technical issues, market requirements, and manufacturing concerns related to semi-automated fusion equipment for common PE fusion operations.

Project Description

Polyethylene (PE) fusion operations have been used since PE pipe was first installed for natural gas distribution. For the most part, this process is a manual one, with operator-to-operator variances.

Interviews with experts revealed that the possibility of human error in fused PE joints is a legitimate concern and that technology that could significantly reduce the likelihood of human error in the fusion process would be of great value. There is also a need for technology that can capture fusion data in the field to allow for timely quality-control reviews of fusions installed on a daily basis. The current manual machines do not allow for the automated collection of fusion data.

The initial phase of this project focused on the development of a steering committee in order to capture and analyze the technical issues, market requirements, and manufacturing concerns related to semi-automated fusion equipment for common PE fusion operations (butt and sidewall fusions). This steering committee will bring fusion-equipment manufacturers and customers together to generate ideas, develop concepts, and perform business analysis.

Deliverables

Deliverables from this project include:

- A fusion-equipment requirements report
- A list of essential variables for the fusion process, and
- Webinars and stakeholder meetings as needed.

Benefits

Improperly constructed PE fusion joints can present a significant threat to pipe system integrity. The ability to automate the process of performing plastic pipe and fitting fusions will reduce the risk by minimizing operator-to-operator variances. This will provide for a more consistent and controlled end product.

In addition, automation of the fusion process may allow for data-collection capabilities that do not exist today and provide a convenient, traceable, and complete record of fusion operations.

Technical Concept & Approach

The scope of this initial phase of the project included the creation and management of an industry steering committee to identify the needs, create ideas, and perform business analysis related to the creation of semi-automated fusion equipment and fusion data-collection capabilities.

The project team will engage the project sponsors and fusion manufacturers to jointly develop fusion-equipment requirements.

Activities will include periodic conference calls, webinars, and face-to-face steering committee meetings. Input will allow fusion manufacturers to better understand their customers' requirements when designing and developing products.

Results

The project was initiated in 2015. Since then, a steering committee was established and meetings were held with various manufacturers in order to review the OTD effort and gain manufacturer support and cooperation.

One of the potential issues identified was related to manufacturer competition. While two major manufacturers expressed interest, they also expressed their reluctance to share information with other manufacturers. Individual meetings may need to be arranged to overcome this issue.

The project team solicited input in the development of a list of "must-have" and "like-to-have" features for a semi-automated fusion machine. The lists to date include:

"Must-Have" Features

- Compact size
- Light weight
- GPS location
- Minimum controls or supporting equipment
- Audible timers
- Alarm for process time parameters
- Program fusion card
- Easily adaptable to various procedures
- Set pressure for each step semi-automated for next step
- Be able to abort semi-automated feature
- Function for manual completion
- Barcode reading and fitting selection, and
- Traceability.

"Like-to-Have" Features

- Retrofit to existing equipment
- Simple steps for the fusion process
- Automated pressure application and hold time
- Ability to record time, pressure, and operator data
- Fitting identification
- Pipe/iron temperature capture, and
- Multiple levels of coaching.

In 2017, the project team executed a non-disclosure agreement with a fusion-machine manufacturer in order to gain information on the company's developing fusion platform. Company representatives met with project sponsors to solicit feedback and present some of the company's development efforts. The manufacturer is moving forward with the development of a new machine and originally designed for the polypropylene market. The machine is not "automated" in control, but when paired with the new data logger provides full tracking and traceability for the two-inch– to four-inch-diameter pipe segment.

According to the manufacturer, the project resides in varying levels of the development stage and its engineering group has initiated testing on two prototype concepts.

Status

Sponsors continue to share their needs for various fusion applications (butt fusion, sidewall fusion, etc.)

The project team will continue to hold interactions with fusion-equipment manufacturers.

Due to the lack of further advancement, the project team is in the process of creating the Final Report for this project.

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INSPECTION & VERIFICATION

Projects in this area focus on the development of tools and techniques to assist companies in enhancing safety and meeting integrity requirements in a cost-effective manner.

To meet the challenges of pipeline integrity management, researchers are developing pipe-inspection systems and other technologies for gas delivery systems.

Through R&D in this area, pipeline and distribution system integrity can be maintained and improved based on sound, scientific developments related to inspection, testing, and other activities.

Initiatives include efforts to develop a butt-fusion inspection device for use in the field, an EMAT sensor for the internal detection of cracks in smaller metallic pipes, and a tool to detect coating disbondment and metal loss.

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Tool for Detection of Cathodic Disbondment and Metal Loss

This project is focused on the development of a practical tool for detecting cathodic disbondment and metal loss. The technology would enhance the safety of steel gas piping systems by providing the ability to locate potential pipe-corrosion sites before leaks or serious metal loss occurs.

Project Description

A significant amount of the steel pipe used in gas distribution systems is more than 50 years old. To ensure system safety, these older pipes are regularly assessed for corrosion, which generally requires exposing the pipe for inspection and often requires the removal of a coating.

Of specific concern is that corrosion can be severe under a coating disbondment when the fusion-bonded epoxy, coal-tar enamel, or field-applied tapes separate from the steel. Since exposing the entire pipe is prohibitively expensive, inspections are conducted that assume that a statistical sampling of an area is representative of the pipe condition.

The objective of this project is to develop, test, and demonstrate a platform for detecting coating disbondment and external corrosion by measuring magnetic fields from above ground. The technology incorporates sensors to detect magnetic fields, sensors to determine the orientation of the pipe, and computational means to extract coating disbondment and corrosion locations from this data.

In Phase 1 of this project, researchers evaluated a system capable of assessing features in coated steel pipe. Based on limited field testing, the results indicated the tool has strong potential for locating breaks in coatings and attached appurtenances from above ground. The objective of Phase 2 is to execute additional field tests to build a robust sample size from which to evaluate the tool's effectiveness.

Deliverables

Deliverables include a field-tested beta prototype, results of field tests, and reports summarizing the findings of field tests and containing recommendations for commercialization steps.

Benefits

The ability to locate potential coating disbondment and corrosion sites before serious metal loss or leaks occur will improve public safety.

Technical Concept & Approach

The operating principle for the technology studied is to inject or induce a current on the pipe being surveyed that, in turn, generates an exterior electromagnetic (EM) field around the pipe. The next step is to carefully map the EM field around the pipe in three dimensions. The properties and curvature of the exterior field will be influenced by the path of signal current through the pipe metal, coating, and surrounding soil. Unlike standard pipe locators that infer the pipe location from the field magnitude only, the system being developed also captures the phase angle of the signal.

In order to accomplish the detection of flaws, a suite of sensors is moved along the pipeline route with stops at specific intervals to take readings. A pre-defined current excitation signal is placed on the metallic pipe in order to generate an external EM field that some of the sensors are tailored to receive. Measurements of this field allow the inference of the pipe location and orientation relative to the sensors.

Other components of the sensor suite capture the geospatial location of the sensor package. Taken together, these data enable the absolute location of the pipe to be captured with a high degree of accuracy. The data is automatically captured, then stored for post-processing to locate pipe and coating features. An end goal is for visualizations of the data to be available in the field.

In addition to multiple magnetometers to locate the pipe, the system integrates GPS location and timekeeping. Multiple systems can be linked wirelessly when longer baselines are needed to triangulate deeper pipes.

Results

The project team initially identified several upgrades for the prototype instrument for Phase 1 testing. The primary improvements were the inclusion of GPS data with the cathodic disbondment survey data, the ability to vary the frequency of the signal injected into the pipe to suit field conditions, and the ability to store greater amounts of survey data.

The testing was useful in determining the operating characteristics of the sensors over a live piping system. Two significant improvements were made to the system: 1) custom firmware was created to provide the data in a format specific to the requirements of this project and 2) the implementation of real-time kinetic correction for the GPS.

Three utility companies provided active survey sites during the first phase of the project. Detailed reports of the survey process and data collected were prepared.

Research found that the primary requirement for conducting a successful survey is to inject an adequate signal onto the facility being surveyed. Although the a priori knowledge of pipe location is less problematic than other methods, there is still a need to consider probable locations of other facilities when interpreting the data. Large masses of metal in the survey area, such as cars parked over the facility, were seen to cause interference.

Phase 1 of this project was completed in 2016. Testing indicated that the survey technology can find breaks in the pipeline coating through the analysis of the pipe current data. It has also been shown that the phase data can indicate changes in “shape” of the pipeline caused by appurtenances or metallic interferences.

In 2017 Phase 2 activities, the project team executed a field demonstration with a project sponsor, processed the collected field data, and identified additional potential sites for technology demonstrations. The results of the dig correlate well with electromagnetic signatures from the prototype system.

Onsite surveys were completed in 2018. A total of seven test sites were visited over the course of two days. This data will allow correlation between the system data and actual physical features on the pipeline.

In 2019, post-survey excavation results were obtained for one of the 2018 sites.

The project team and a sponsor focused on identifying sites and defining the timing to be available for a field survey.

Some modifications to the application used to produce graphics from the survey files were required. The newer version of the application displays larger dots on the map image when the accuracy is lower and small dots when the accuracy is high. This gives a quick visual of the location accuracy and possible interferences.

Status

Researchers will visit and survey the new set of test sites in California.

The project team is seeking test sites from the sponsors. The desired conditions are metallic pipe with a test station or other point available for signal injection. It is also required that a dig is scheduled to verify the data.

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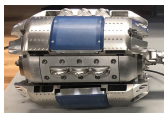
EMAT Sensor for Small-Diameter and Unpiggable Pipe



This project focused on the development, testing, and demonstration of Electromagnetic Acoustic Transducer (EMAT) sensors for the inspection of smaller-diameter distribution and transmission pipelines.

Project Description

Many natural gas distribution companies operate segments of pipe that are classified as transmission lines, and, therefore, fall under specific integrity-management regulations. However, these pipe segments cannot always be inspected with traditional in-line tools designed for high-pressure transmission lines.

In Phase 1 research, EMAT (Electromagnetic Acoustic Transducer) technology was identified as a promising technology, with the ability to detect and characterize corrosion, stress-corrosion cracking, cracks (including longitudinal fatigue, toe, and long seam-weld cracks), and mechanical damage. EMAT is a dry-coupled sensor (can be used in live natural gas pipelines without a liquid slug) that uses alternating current in a wire to induce an eddy current that can identify and characterize many defects that traditional magnetic flux leakage technology cannot. The collapsible tool was designed to traverse multiple back-to-back bends and navigate through features such as port valves and unbarred tees.

Phase 2 focused on constructing and testing a prototype on eight-inch-diameter field samples with various crack sizes, based on the benchscale sensor.

Phase 3 produced a fully-integrated and field-ready prototype tool capable of detecting and quantifying cracks in small-diameter, unpiggable and difficult-to-inspect pipes.

Deliverables

The deliverables for this project include the development of a prototype, performing testing, and conducting demonstrations.

Benefits

The goal of this project is to enable natural gas pipeline operators to identify traditionally difficult-to-find-and-assess defects and, therefore, improve system integrity and public safety.

Technical Concept & Approach

In Phase 2, a Design of Experiments (DoE) procedure was used to identify the operational parameters and ranges of pipe defects and flaws to be included in controlled laboratory testing. Pipe samples for testing had machined defects and cracks to cover the range of the defects identified in the field. The defects were fully characterized using manual and 3D scanning to establish the baseline parameters before installation at the test site.

Phase 3 included further development and modifications.

6' Flaw-Free Sample	20' Flaw-Free Sample	9x3' Crack Samples	20' Wall Loss Sample 1	20' Wall Loss Sample 2	20' Flaw-Free Sample

Test section with various machined flaws.

Major funding for this project was provided by the U.S. Department of Transportation's Pipeline Hazardous Materials and Safety Administration (PHMSA) with shared funds from OTD.

Results

In Phase 1 of the project, the research team developed a prototype EMAT sensor and tested the sensor on precision-machined defects and naturally cracked pipe. The prototype was successful in detecting cracks on both pipe and flat plate and demonstrated superior wear resistance.

Phase 2 included calculations and simulations to determine the pulse characteristics necessary to generate significant broadband energy over the operation frequency range. To speed the inspection process, the project team redesigned the tool and driving mechanism used to move the tool through the pipe. Modifications were also made to increase the magnet strength in the tool, resulting in a significant improvement in signal strength.

A pull-test fixture was designed that uses a winch to pull the module though the series of pipe sections and allows for multiple pipe sections to be measured at the same time.

In 2019, Phase 3 modifications were made to the sensor module. Researchers verified the recommended design changes, wiring corrections, tool power up, and preliminary navigation inside of a horizontal eight-inch-diameter steel pipe.

New ceramic wear pads performed well during tool cruising and exhibit increased survivability. The tool was able to navigate different types of bends and diameter changes. In parallel, the tool was capable to gather data and inspect the pipes for cracks. All measurements were stored on the on-board memory. The data was downloaded and analyzed on a laptop. It was found that the tool was able to find not only cracks but also wall-loss flaws.

In parallel to the mechanical testing of the system, the sensor and battery modules were further integrated and tested.

The testing setup included six pipe segments with a total length and two winches to pull the tool on both directions. By counting the defects, researcher found that there were at least 50 flaws, including both crack and wall loss.

The data acquisition speed at the time of the field test was 35 Hz. This provides data every eight mm at approximately one foot per second. Subsequent changes to the firmware have increased that to 50 Hz (providing data every eight mm at 17 inches per second)

Status

The field test completed the development of the EMAT tool. A commercialization partner has joined the program to bring the product to market.

A Final Report is being prepared.

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Correlation of Surface to Through-Wall Properties of Pipe

Efforts are under way to develop a technique that allows pipeline operators to determine the material properties of in-service pipe with minimal disruption to system operations. In this project, specific activities are focused on the development of correlation factors to relate surface properties to actual material properties to allow surface-indentation techniques to be used for material characterization.

Project Description

Current regulations require pipeline operators to either assume a pipe yield strength value of 24 ksi or perform testing in accordance with American Petroleum Institute guidelines, with a sampling rate of approximately 10% for undocumented pipe. For operational reasons, some operators may choose to assume 24 ksi instead of performing testing; however, this may result in pipe segments being classified as transmission lines because they are being operated above 20% SMYS (Specified Minimum Yield Strength). Operators, therefore, must perform specific integrity-management activities on pipe segments that may actually operate at lower stress levels.

Integrity Verification Process (IVP) regulations may require operators to perform material testing for all transmission pipe that does not have validated and traceable material-property records. Compliance with this regulation using currently allowed techniques could be extremely expensive.

This project addresses the need for a technique that allows operators to determine the material properties of in-service pipe with minimal disruption to system operations.

Past research proved the ability of surface indentation techniques such as stress-strain microprobes and hardness testing to accurately determine material properties of pipes within a localized area, but variations in material properties through the wall are problematic for local interrogation techniques. This project focuses on the development of correlation factors to relate surface properties to through-wall material properties to allow surface techniques to be used for material property validation for pipelines.

Deliverables

The deliverables for this project include a database of through-wall properties by vintage for typical pipelines in service in the natural gas industry. The probability distributions of these properties can be used to correlate existing and future surface-based measurement techniques to an aggregate through-wall property to comply with IVP and pipeline safety and integrity requirements.

Benefits

The ability to characterize material properties – particularly yield strength – of in-service pipelines without taking the line out of service or removing samples will significantly reduce the cost of complying with existing and pending federal regulations. Backfiling records with material-property information also improves integrity management through system knowledge that allows for enhanced modeling and analysis.

Technical Concept & Approach

The scope of this project includes the development of factors to correlate surface properties with through-wall material properties based on vintage.

Testing included full-size tensile, probe, Charpy V-notch toughness, metallography and microstructure, hardness, and other metallurgical and mechanical tests as warranted.

The approach taken to validate the surface-interrogation methods was to assemble a comprehensive database of material properties of pipeline steels, including surface and bulk chemistry; surface and bulk mechanical properties; and surface and bulk metallurgical grain size.

The project team:

- Analyzed the variance of the difference between surface and bulk measurements
- Developed a simple in-field procedure to remove a minimal outer layer from the pipe surface to reduce the variance between surface and bulk properties to an acceptable level
- Determined the robustness of recognized chemical mechanical models for predicting the mechanical properties of the steels and selected the most appropriate models, and
- Adjusted and validated the model.

To address the issue of non-uniformity, a technique was developed to remove a full-wall thickness, sub-sized samples from a standard six-inch hot tap coupon to allow yield strength testing to be performed. An extensive testing program validated the equivalence of the sub-sized samples to the full-size samples.

Results

In this project, researchers investigated the use of a chemistry-based approach vs. a mechanical-property approach for bounding bulk properties. Early in the project, it was decided that the primary methodology would be to use *in-situ* chemistry and micro-structure to identify material properties of interest rather than through mechanical testing alone. Researchers tested the chemical models on 18 pipe steels, showing more promising results than with the indentation technique.

Modeling scripts for mechanical properties were developed along with normal distribution plots of surface vs. bulk chemistry properties for key element variables needed for derived mechanical properties.

In 2018, the project team executed an agreement with the U.S. Department of Transportation's Pipeline and Hazardous Materials Safety Administration for Phase 2 of the project. In Phase 2, researchers are reviewing pipe samples and existing data for gaps in the baseline data (e.g., yield and tensile strength, toughness, grain size, and chemistry).

New data was introduced into the pipe sample library – including bulk nitrogen chemical composition and grain size for select samples – and data was reorganized and simplified. Sample pipes from utilities were received.

In 2019, researchers enhanced the laboratory with a high-weight capacity worktable, pipe stands, and a plasma cutter for efficient and safe pipe handling, cutting, and testing.

Researchers established the testing regime/matrix for: yield and tensile strength; toughness; chemistry; microstructure and grain size; and hardness. Testing was completed on 35 of 70 pipeline samples for yield strength, ultimate tensile strength, and toughness for: base metal, weld zone, and both heat affected zones.

A detailed Bayesian Model Averaging (BMA) analysis was conducted to determine the efficacy and use of this approach to improve modeling results. It was shown that the BMA can provide better/similar performance with a surface-only indentation technique and linear regression with complete data.

The project team developed an enhanced full-wall tensile testing process using state-of-the-art video extensometer and performed quality-control testing of the process with satisfactory results and commenced full-wall tensile testing.

Research focused on the effect of adding quadratic (non-linear) terms to this linear model and the comparison between the linear and quadratic models. The previously developed BMA method for multimodality information fusion for strength estimation was utilized. The full calibration dataset was used for model comparison according to posterior model probabilities. The validations were made by splitting the data 100 times to evaluate the models according to predictive performance. Results showed that the linear model behaves as well as the top quadratic models. The linear model also shows robustness for prediction.

Status

Baseline laboratory testing continues to complete the second half of the 70 pipeline samples. Modeling has moved into Gaussian Process methods and these will be compared to the linear, non-linear, and Bayesian models next.

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Ensure Consistency and Quality of Field Measurements of Wall Loss and Dents

The goal for this project is to develop a quality-control process for field measurements of pipeline wall loss and dents that ensures correct and consistent results. Researchers will evaluate the accuracy and efficacy of existing and close-to-market tools.

Project Description

Proper measurements of pipeline anomalies such as corrosion and dents are critical to being able to calculate remaining life and making informed decisions on pipeline repair or replacement. However, there is considerable variability in measurement results due to experience, training, and the tools being used.

Manual tools, such as pit gauges and bridge bars, are primarily used for these measurements. Utilities are also investigating structured light and 3D laser-scanning tools for more accurate measurements; however, these tools can be expensive. Regardless of the tool, utilities have a need for a consistent, repeatable, and accurate method for analyzing pipeline anomalies.

The goal for this project is to develop a quality-control process for field measurements of pipeline wall loss and dents that ensures correct and consistent results. The project team will evaluate the accuracy and efficacy of existing and close-to-market tools and devices, including structured light and 3D laser-scanning technologies.

Deliverables

The deliverable for this project will be a quality-control procedure for field measurements of wall loss and dents. A report detailing the test results and tool evaluation will be developed.

Benefits

Utilities currently use several types of pit gages and bridge bars in the field for metal loss and dent measurements of their pipelines. Typically, utilities have multiple personnel performing the measurements, resulting in a variation of the results. With the lack of consistency, utilities often utilize overly conservative values in subsequent calculations. A consistent quality-control procedure for taking measurements and performing the evaluation, as well as statistically evaluating the variation of staff results, will allow utilities to establish statistical confidence intervals and carry through proper values in calculations.

Technical Concept & Approach

Specific tasks involve:

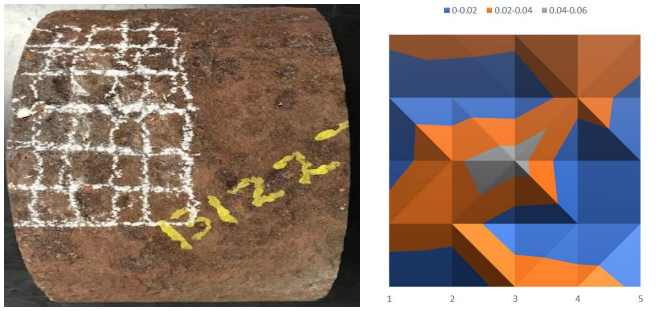
- **Development of Statistical Method**

  A statistically sound and consistently repeatable model will be developed. The model will be packaged with a graphical user interface into an executable file that can be used by utilities to test the methodology.

- **Laboratory-Scale Specimen Acquisition**

  The project team plans to use the samples available with its pipe library that are deemed fit for this project. Apart from that, specimen with certain features (e.g., slots and dents) will be fabricated and baseline precise measurement of the geometry will be taken.

Measurements taken using a 3D microscope.



Left: Corroded pipe sample; right: contour map of the measured depths.

- **Model Testing**

  An initial set of measurements will be taken on the available samples for the purpose of quality control method development.

- **Field Testing and Analysis**

  Researchers plan to send baseline samples to utilities along with a custom application for testing.

- **High-Accuracy Measurements**

  The purpose will be to provide a qualitative and quantitative sense to the measurements by comparing them with the output from the developed statistical procedure.

Results

This project was initiated in 2016 with a sponsor survey to determine how each utility performs field measurements and gathers data. In 2017, the project team developed a procedure for testing the accuracy of different types of gauges and styles to measure wall loss.

Searches were made to find a manufacture to systematically damage a pipe with accurate measurements in order to use this as a baseline for the project's testing procedure.

Statistical methods for quality control were developed and summarized in a project execution plan. Laboratory-scale samples wereused for measurements and to test the developed quality-control method.

The quality-control procedure allows utilities to evaluate the uncertainty associated with their field measurements.

The procedure has the following features:

- The procedure can be used to compare a group of novice operators against a group of experienced operators, a group of measurements taken using different instruments, and a group of measurements done using different procedures
- The procedure will allow for the evaluation of field-measurement personnel, different measurement techniques, and different measurement procedures, and
- Assuming the field conditions are similar, the realized uncertainty values can be used to determine conservative wall loss/dent value.

In 2018, the project team focused on further development of the statistical methods and testing them for developing the quality-control procedure. This included developing a data-gathering procedure, preprocessing, and refining the statistical procedure. The laboratory-scale samples (with features such as axial slots, radial slots, stepped depths, holes, and corroded pits) are being used for collection data. High-accuracy measurements were taken using a 3D microscope. Researchers also initiated data collection to test the quality-control procedure.

About 160 measurement points were captured. About 40 individuals participated in the measurement study.

A graphical user interface was developed to package the statistical procedure.

The procedure is developed in a way to do a comparative analysis and individual measurement analysis. The individual analysis provides the 95 % confidence limits about the mean value. The comparative analysis is used to compare between measurement tools, different measurement procedures, and different skill levels of operators.

In 2019, researchers completed the statistical analysis of the collected dataset. The project team also reached out to project sponsors to provide pipe samples to collect additional data points.

Status

Ongoing activities include:

- Complete data analysis of the newly collected data, and
- Complete the draft final report.

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Development of a Long-Term Enhancement of Direct Assessment

In light of pending pipeline regulations, the objective of this project is to provide a technically justifiable, augmented method to retain direct assessment as an acceptable integrity-assessment process for pipeline segments.

Project Description

Pending pipeline rulemaking restricts use of direct assessment (DA) – an approved, structured process for determining pipeline conditions – as the *sole* inspection method if any one of five other inspection methods are "capable" of being used, namely: in-line inspection (ILI), pressure testing, hydrostatic spike testing, excavation and direct examination, and guided-wave testing. However, pipeline operators have a significant number of covered transmission assets that are not conducive to ILI and/or pressure or spike testing. Full pipe excavation and direct examination is often not possible or practical, and guided-wave inspection has limited range and restrictions on use.

Based on the pending rule, there is interest in a process improvement or enhancement to the current practice that would allow DA's continued, justified use for specific categories of transmission lines. This enhancement might include supplementation with other data or inspection technologies and increased preventative and mitigative (P&M) measures and surveys, but not require the same operational actions of ILI or pressure/spike testing. Advanced probabilistic/statistical analysis is also desired to define the uncertainty and provide quantitative confidence limits in DA's assessment of pipeline integrity.

This project builds upon two previous projects:

1. A hands-on, demonstration, testing, and analysis project titled *Demonstration of ECDA Applicability and Reliability for Demanding Situations*, and
2. A study titled *Improving the Performance of the External Corrosion Direct Assessment (ECDA) Methodology.*

The overall objective for this project is to develop a technically justifiable, augmented method to retain DA as an acceptable integrity-assessment process for pipeline segments.

Deliverables

This project provides the following:

- A prioritized list of DA applications from an operator's perspective
- Identification of the strengths, weaknesses, opportunities, and threats for DA use in the highest-priority cases for ECDA
- A set of process enhancements for the selected use cases for ECDA, including augmented inspections and P&M measures, and
- A statistical analysis process for ECDA that will establish confidence, uncertainty, and prediction limits for ECDA assessments.

Benefits

An enhanced DA technique, with technical justification and eventual standard support, would allow operators to comply with regulations for challenging assets such as: vintage pipe that could be damaged by pressure or ILI testing, short tap/tee sections, cased pipe, non-full-bore sections, and other pipeline assets.

Technical Concept & Approach

Specific tasks in this project include:

- **The Development of a Prioritized List of DA Applications**

  This task includes determining the system configurations where use of DA is most critical and where the loss of this option would be of the most detriment. The list will be prioritized by both the type

Congested meter regulator station DA site with crossing situations.

of DA being used (i.e., external corrosion, internal corrosion, and stress corrosion cracking) and also by the physical and operational category of the asset (i.e., station piping and systems, non-full-bore systems, tees, single feeds, vintage pipe, etc.).

- **The Identification of the Strengths, Weaknesses, and Gaps for DA in High-Priority Applications**

  Based on the findings, researchers may select some applications for enhancement development.

- **The Development of Process Augmentations**

  The project team will develop the augmentations to specific ECDA processes. This task will focus on bolstering the current DA practice for the selected applications with additional preliminary data requirements, indirect inspection tool technology and use, changes to current practices such as close interval survey spacing requirements and post-assessment efforts

  Researchers will leverage the lessons learned and statistical and probabilistic methods developed for two projects:

  - Horsehead's Third-Party Damage Determination (completed), and

  - Atmospheric Corrosion and Leak Survey Requirements for Indoor Piping in NY State (ongoing).

  These projects successfully developed a statistical and probabilistic method to determine the likely damage, corrosion, and leak conditions of assets. The method uses Bayesian statistics and probability theory to provide these predictions based on historical and operator data and allowed the setting of a mutually accepted confidence level (between the operators and the regulators) to determine the best- and worst-case scenario for damage, corrosion, and leak conditions. This task will adapt these statistical techniques to be used with ECDA data and would allow the operators to apply the results and associate a confidence level and prediction limits to the DA predictions.

Results

In 2018, the project team completed a review of PRCI documents and merged results with a NACE document. Researchers completed a full draft of the SWOT (Strengths, Weaknesses, Opportunities, and Threats) Gap Analysis for ECDA.

In 2019, the project took a temporary turn with an opportunity to join another project developing enhanced statistical and probabilistic analysis techniques that could be fully leveraged for the DA project.

Congested meter-regulator station DA site with tees, stubs, and tap lines.

A report was released that contained the ECDA literature review. The review includes 53 summaries of standards and peer review papers related to direct assessment, primarily to external corrosion direct assessment.

The report also includes information on the ECDA strength/weakness analysis and a key section on opportunities to enhance the ECDA process and data analysis. This section lists 48 opportunities, which are a combination of those expressed in the publications reviewed in the literature search, coupled with those from a sponsor survey.

The opportunities were divided into seven categories:

1. Data and Pre-Assessment
2. Inspection Tools
3. Training
4. Casings, Facilities/Stations, and Pavement
5. Failure Analysis; Corrosion Rates; and Tracking, Trending, and Effectiveness
6. Risk-Based and Probabilistic Analysis, and
7. Accelerate and Simplify.

Status

The next step will be to hold a web-based meeting with the sponsors for a high-level summary of the project and the prioritization survey results.

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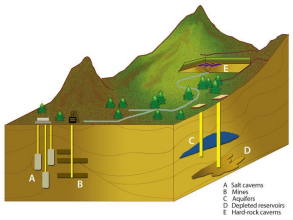
Underground Natural Gas Storage Corrosion Risk – MIC/Gas Quality

The overall purpose of this research is to ultimately create a preliminary guidance document for assessing MIC risk and an early-warning gas-management marker for MIC in underground natural gas storage facilities. The Phase 1 project objective was to gather gas and liquid samples across underground storage facilities to provide background knowledge of corrosion risk associated with MIC and sour gas.



Project Description

Natural gas storage is an important component to the supply, delivery, and reliability of natural gas during high demand. The desire to introduce new sources such as shale, renewable natural gas, and hydrogen into natural gas storage fields creates many unknowns about contamination, gas quality, and potential risks of well souring and corrosion. Additionally, the naturally occurring microbial environment or water from natural events such as rain runoff into these storage caverns can add another potential source of contaminants. These factors affect known risks to the gas delivery infrastructure and its components.

The U.S. Department of Energy's Pipeline and Hazardous Materials Administration (DOT PHMSA) advisory bulletin ADB-2016-02 called on owners/operators of underground natural gas storage facilities to ensure the integrity of their assets are in proper working order. On February 12, 2020, the final rule was issued with considerations that API 1170 and API 1171 will be the basis of enforcement and formalizing the need for integrity management programs for natural gas storage facilities. Potential risks to storage facilities include corrosion and integrity loss as well as the risk of gas souring, which in some cases, years of mitigation have proven unsuccessful in addressing.

There have been a few hypothesized mechanisms in regards to the souring and decrease in production of gas wells. These include physical accumulation of microorganisms, plugging due to growth of microorganisms from either the formation or the gas/water source, and plugging due to the metabolic by-products of microorganisms. However, determining the source in previous studies was difficult due to the available technology.

During the life of this project, the results of the root-cause failure analysis of the October 23, 2015, gas leak at the SS-25 wellbore in the Aliso Canyon storage facility was released by Blade Energy Partners. The root cause of the gas leak was integrity loss due to microorganisms known to cause corrosion, specifically methanogens.

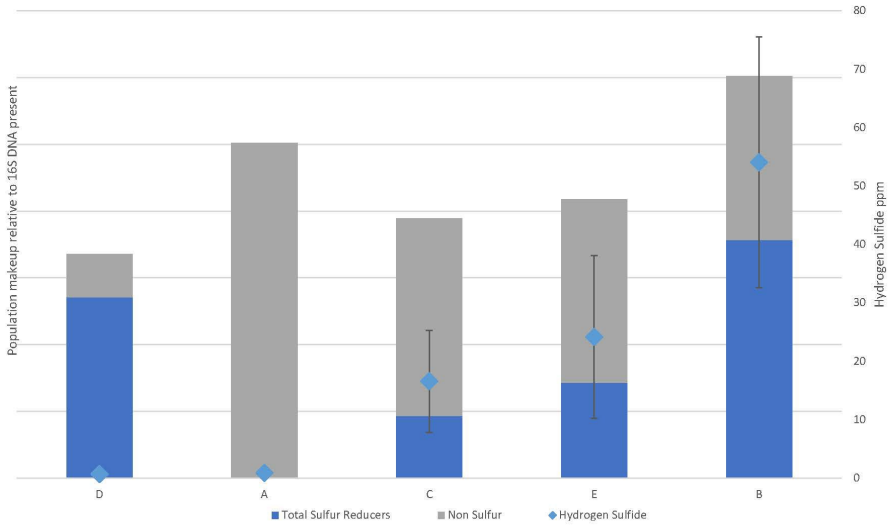


Figure: Percent Sulfur Microorganisms Relative to the Total DNA Present Compared to H_2S

Gas sampling point at underground natural gas torage wellhead.

Microbiologically influenced corrosion (MIC) is the result of specific interactions between microbes/biofilms, the material surfaces to which they attach, and electron transfer mechanisms that result from the interaction. Microbiologically influenced souring (MIS) is the souring of gas due to current hydrogen sulfide production by microbes.

Deliverables

Deliverables for Phase 1 include:

- Gathering gas and liquid samples across underground storage facilities, and
- A background knowledge Final Report with analysis.

Benefits

The guidance document for natural gas storage owners/operators and downstream local distribution companies is being designed to maintain optimal production of gas storage wells. Conclusions made using the guidance document will create an early-warning gas-management marker for MIC. These items will influence prevention/mitigation strategies to address gas quality and corrosion issues in natural gas storage fields.

Technical Concept & Approach

The driver in Phase 1 is to provide background knowledge of the corrosion risk associated with underground natural gas storage facilities resulting from MIC organisms.

The project team initially focused on collecting relevant background information and input from the DOT PHMSA, the American Petroleum Institute, and owners/operators of underground natural gas storage facilities.

Gas samples (injection and withdrawal) and water samples were collected from underground natural gas storage facilities. The collected samples were analyzed for microbes implicated in MIC. Additional testing included chemistry methods for water quality (pH, conductivity, alkalinity, ion chromatography, metals, and dissolved solids). Some limited gas-component analysis was performed for components and sulfur compounds.

Between August 2017 and April 2019, samples were collected from underground natural gas storage facilities during injection and withdrawal operations. Approximately five wellheads at six different storage facilities were visited to collect gas and liquid samples from depleted natural gas and aquifer formations used for underground natural gas storage. Priority of sample locations were wells with higher than 4 ppmv of hydrogen sulfide and, thus, considered sour gas. The samples were collected directly from the wellhead before it was cleaned and processed.

Results

Results from the gas and liquid samples show different gas and liquid chemistries and microorganism populations not just from different storage facilities but also amongst different wells within each storage facility.

The conclusion from the data analysis from each storage facility indicates that hydrogen sulfide concentrations either alter the environmental biology or the biology alters hydrogen sulfide concentrations. More data is needed to determine which mechanism dominates and if this claim is valid.

Gas components and the majority of MIC analysis was completed on the injection samples. Next-generation sequencing of gas and liquid samples was conducted by Argonne National Laboratory.

Status

A Phase 1 Final Report was issued in March 2020.

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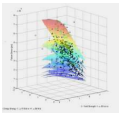
MAOP and Materials Verification



This project leverages four significant OTD-sponsored efforts that each address a part of the MAOP and materials verification requirements, but currently operate with different software platforms and are not interconnected.

Project Description

The objective for this project is to provide a comprehensive and easy-to-use web-based software solution to assist operators in complying with pending maximum allowable operating pressure (MAOP) and materials verification requirements for the integrity verification process (IVP) used by gas companies to help maintain safety and reliability.

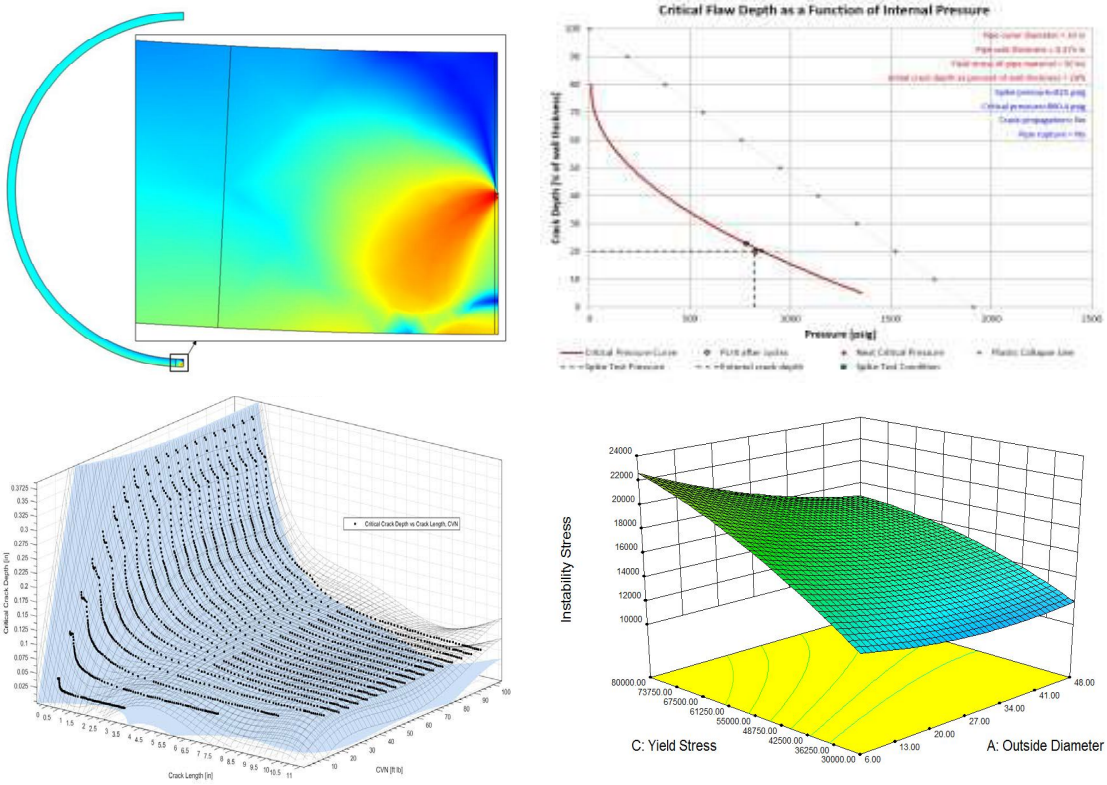
New regulations allow for the use of Engineering Critical Assessments (ECA) in lieu of a hydro-test, de-rating, or pipe replacement. This will also support the use of structured pipe-surface-based non-destructive measurements in lieu of cut-outs and minimize the number of destructive tests when those are absolutely necessary.

This project leverages four significant OTD-sponsored efforts that each address a part of the MAOP and materials verification requirements, but currently operate with different software platforms and are not interconnected:

1. ***4.12.b - Correlating Pipeline Operations to Potential Crack Initiation, Growth, and Arrest*** - This project successfully developed and validated the material models necessary to properly model crack initiation in pipeline steels. A detailed calculator using the response surfaces was developed.

2. ***4.13.d - Hydro-Testing Alternative Program*** - This project successfully developed a convenient way to calculate the critical crack axial-flaw sizes and/or non-crack wall loss (e.g., corrosion pitting) that will result in predicted failure at the given pressure.

3. ***4.9.a Leak-Rupture Boundary Determination*** - A study was conducted using incident and laboratory testing data with advanced modeling techniques to calculate the boundary between failure by leak and failure by rupture as a function of the pipe's Specified Minimum Yield Strength.



Information from four key OTD projects is being combined into one easy-to-use format.

4. ***4.14.c Surface Indentation for Material Characterization: Correlation of Surface Properties Based on Vintage*** - The objective of this ongoing project is to develop correlation factors to relate surface properties to bulk material properties for material property validation for pipelines. This will include a surface-chemistry-based model to predict yield ultimate tensile strength with an established confidence, a database of through-wall properties by steel type/vintage for typical pipelines, and probability distributions of the difference between surface and bulk chemical properties.

Deliverables

The major deliverable for Phase 1 of this project is a vetted software framework that will integrate multiple OTD project models into a single system to assist operators perform MAOP and materials verifications. A Subject-Matter Expert (SME) Group will be established related to IVP and ECA and this group's needs.

Benefits

An integrated solution will provide the benefits from the four foundational OTD projects, but in an easier-to-use, single platform that is also mapped to the most recent, pending code requirements.

This approach leverages research that is already completed and focuses the solutions on the newest code-compliance requirements.

Technical Concept & Approach

Specific tasks for this project include**:**

- **Establishing an SME Group for MAOP and Materials Verifications**

  In this task, researchers and sponsors will establish an expert group focused on the use of MAOP and materials verification processes and procedures. The goal is to develop use cases that the sponsor companies will consider to comply with the IVP/ECA process for verifications.

- **Correlating Verification Requirements to the OTD Body of Work and Models**

  In this task, the project team will document the detailed requirements for material verification sampling requirements, including allowed accuracy and margin of errors. Researchers will map the requirements for ECA, materials sampling, fracture mechanics, and metallurgical considerations, toughness assumptions to the existing OTD bodies of work and current model solutions.

- **Developing an Integrated Software Framework**

  The research team will establish requirements and functionality to meet the use cases. Researchers will also establish the output requirements of the software platform to be able to provide a technically justifiable report to support MAOP and materials verification requirements.

Results

Researchers identified and laid the foundation for a potentially very beneficial case study to conduct one or more IVP and ECA efforts on actual transmission pipelines using in-line inspection (ILI) and in-the-ditch technology. This would facilitate the development of a technically rigorous IVP/ECA process and the framework for the project deliverable.

In 2018, the project shifted directions by incorporating two actual transmission pipeline field studies with full IVP/ECA implementations. Physical inspection and analysis of the two transmission lines were made with the pilot study operator and service provider. The pilot project ran multiple ILI tools and in-the-ditch nondestructive evaluation (NDE) testing to develop the IVP/ECA process and the framework for the associated engineering analysis software. A number of indentation were cut out of the pipe and sent for laboratory analysis.

In 2019, excellent progress was made. Both of the pilot transmission lines have completed four ILI runs. ILI analysis is under way with multiple, detailed components planned.

Utility excavations and nondestructive and destructive testing has started, but the vast majority still needs to be completed.

Status

The project is now ramping up since the ILI runs were successfully repeated.

Destructive coupon testing is partially complete. More coupons are planned to be tested once the ILI analysis reports are provided. The largest defects will be dug up, cut out, and validated.

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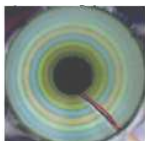
Structured Light Scanning Tool for Distribution Pipeline Inspection



The objective of this project is to advance the development of a structured light scanning tool for internal inspection of plastic and metallic pipes. The project team will establish a roadmap with involvement of the technology developer and a potential commercial partner.

Project Description

The internal assessment of pipe surfaces has been investigated with various nondestructive evaluation techniques – such as direct visual and optical methods using cameras, ultrasonic testing, liquid-coupled acoustic measurements, and laser-based surface inspection approaches including light detection and ranging, and laser topography. In contrast, internal light scanning tools are smaller and can be mounted and inserted into small-diameter pipes.

Non-contact measurement technologies such as light scanning provide reliable and repeatable assessment of anomalies and offer significant potential to streamline largely automated data and reports.

In this project, researchers are investigating a structured light sensor that can reconstruct the profiles of the internal pipe surface and detect the existence of deformations and defects. The sensor consists of a light module that projects a highly textured pattern and a camera that captures the deformations in the projected pattern.

The objective of this project is to advance the development of the structured light scanning tool for internal inspection of plastic and metallic pipes for inspection of vintage plastic pipes.

Deliverables

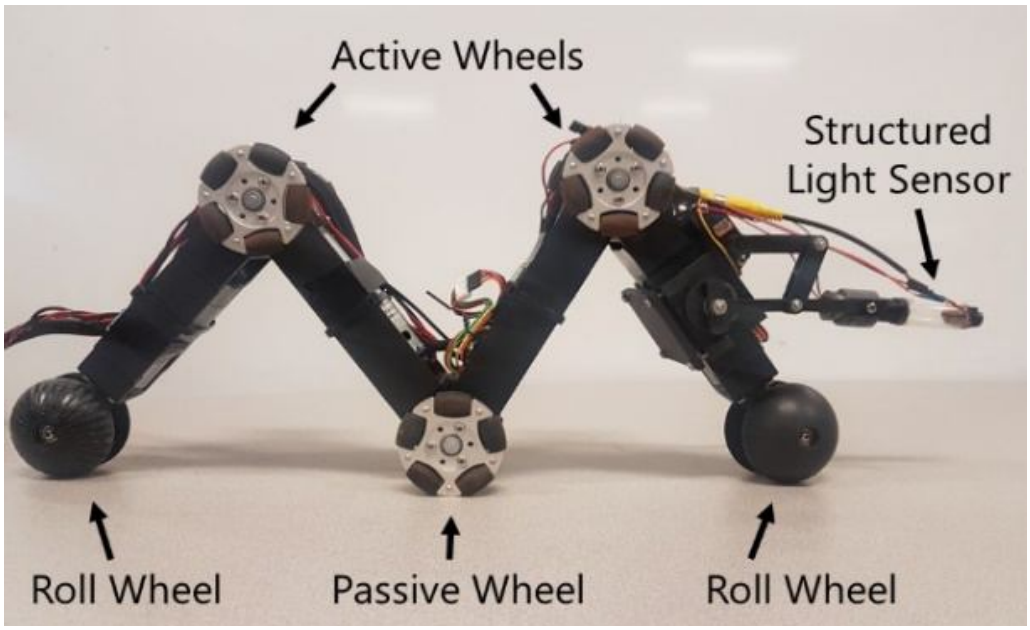
The project deliverables will include a Final Report with a roadmap for research and a closeout webinar.

The overall effort will require follow-on phases for the development, testing, and commercialization of the tool.

Benefits

The internal inspection of pipe (steel and plastic) geometry and surface conditions of distribution mains will provide the operators with knowledge of joints, laterals, internal corrosion, roundness, dents, and cracks which are difficult to detect by current technologies in steel distribution pipe systems and are the primary sources of stress intensifications that cause damage to propagate through the pipe wall.

Additionally, inspection of the plastic pipe-surface condition would be important to monitor the cross-sectional deformations resulting from pipe squeeze-off, which have been shown to be the main causes of slow crack growth in plastic pipes.



Technical Concept & Approach

The focus of this project is on the continuation of the tool development by establishing a roadmap and a testing plan to advance the tool from its current laboratory prototype to a commercial product.

The current prototype provides a high-quality and fast surface profile in a controlled laboratory environment. Further work is still needed to increase its spatial resolution and improve the hardware design. Further tests are also required for system calibration and for a more efficient reconstruction algorithm of the anticipated damage types. The performance requirements will provide the acceptance criteria for the device operation, such as for controlling the tool path inside the pipe, device orientation and positioning, effect of mechanical vibrations during the platform insertion, and evaluation of bends and complex geometries.

The project team will identify the development needs of the data structure and algorithm to adapt various damage types and sizes under different light conditions. Establishing the requirements for the improvement of data reduction and reconstruction will lead to faster and more accurate damage detection. The algorithm's development plan will also identify a path for automatic damage recognition while multiple failure modes are considered.

Results

In 2019, researchers developed a light scanning in-line inspection robot prototype. Two active wheels and two roll wheels, are used to propel the robot and rotate the robot, respectively. To adapt to complex pipeline systems, torsional springs are placed in the joints to bend them and provide the contact forces between the pipeline and the wheels when the robot operates inside the pipeline.

A sensor adjustment mechanism is introduced for the robot-sensor integration and the control of the sensor's position. It can be centralized by the angle adjustment via the mechanism to achieve the optimal 3D reconstruction outcome. The adjustment mechanism can also prevent the collision between the sensor and obstacles inside the pipeline.

Current digital light projectors in the market are not good candidates for small distribution gas pipelines due to their large size and the difficulty of customizing them to be embedded in the sensor. In this project, researchers are developing a new small slide-projector light module. The system is based on a static pattern projection with movement. These types of projectors can be scaled down to four millimeters in diameter and can also provide high flexibility in changing the optical properties of the projector.

"This technology combines novel optical nondestructive evaluation sensing, smart micro-systems, robotics, and data analytics to enable more accurate and efficient pipeline inspection and integrity management. It is expected the unique high-resolution, miniaturized structured light scanning will adapt to complex pipeline field inspection environment in the near future."

- Yiming Deng, Ph.D.
Associate Professor
Principal Investigator, Nondestructive Evaluation Laboratory
Department of Electrical and Computer Engineering
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The projector consists of a white light source that illuminates a photo slide. A collimation lens is used to collimate the light beam and focus it on the photo slide. The photo slide is a printed transparency film that can be customized to project different types of scanning light patterns. A spherical mirror provides a larger field of view, but this comes with a slightly higher distortion as we go toward the mirror edge. The mirror camera also offers reduced distance between the camera and the projector, which is crucial for small-diameter pipe sensor design.

The performance of the device was evaluated by scanning a six-inch-diameter PVC pipe with a length of 50 cm. An artificial defect was introduced to the pipe surface to simulate a dent of the side of the pipe. The results show that the defect caused deformation in the projected ring which leads to the successful reconstruction of the defect shape.

Status

Researchers are establishing the performance requirements for a prototype and demonstration unit for use in a PE gas pipe.

The snake-shaped robot was modified to operate wirelessly rather than having it tethered. Testing is in progress to calibrate the sensors in PE pipes.

The development of a structured light prototype is performed by Michigan State with cofunding from the U.S. Department of Energy's Pipeline and Hazardous Materials Administration (PHMSA). The PHMSA project will be completed on March 2020. A report at the end of the project will identify further development activities and requirements for field testing.

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Coating Collaborative

Researchers are establishing a collaborative program for natural gas system operators that tests and evaluates new coatings or existing coatings with reformulations. Ongoing deliverables include a recurring process of coating selection, testing, and reporting in following phases.

Project Description

This project involves the establishment of a collaborative program for natural gas system operators that tests and evaluates new coatings or existing coatings with reformulations.

The AGA Corrosion Control Committee supports this effort and has agreed to act as a technical sounding board for the collaborative program.

The goal of the collaborative is to independently and objectively evaluate coatings for the natural gas industry – specifically, for buried and aboveground pipeline and distribution systems.

Deliverables

The main deliverable for the first year of the collaborative is an agreed upon set of laboratory and field testing protocols and an associated testing roadmap/plan.

After the first year, the ongoing deliverables for this program will be a recurring process of coating selection, testing, and reporting in following phases.

Benefits

The goals of the coatings collaborative is to:

- **Reduce Risks**

  This program provides third-party, independent testing of coating performance for specification development, avoiding the specification of a coating system that may result in system failures and costly replacements, repairs, or incidents.

- **Implementable Results**

  Efforts will be made to ensure that the coating testing will be timely and meaningful; with results organized so end users can apply and implement them efficiently.

- **Collaborative Efficiency**

  Individual sponsors can submit requests for particular coating systems that would then be put into the program cycle for testing.

Technical Concept & Approach

The focus of this project is placed on existing, new, and improved coatings, such as:

- Two-part liquid epoxies for buried and aboveground assets
- Fusion-bonded epoxy coatings
- Quick-curing fiberglass fabric wraps
- Bore and horizontal directional drilling coatings, abrasion-resistant overlays, and polymer concretes
- Wax and petrolatum tapes
- Mastic-based and modern visco-elastic polyolefin coatings soil-to-air transition coatings, e.g. at risers
- Vault application coatings
- Keyhole maintenance and installation coatings
- Composite-based coatings and tape wraps, and
- Other coatings submitted by the collaborative membership.

Coating systems will be applied to full-size gas pipe with girth welds vs. coupon testing alone.

Testing will include the key performance metrics important to the industry, such as testing for:

- Adhesion
- Impact resistance
- Abrasion resistance
- Cathodic-disbondment resistance
- Cyclical corrosion (salt-fog)
- UV resistance (aboveground applications)
- Other, application-specific measures.

These shorter, laboratory-based tests will be supplemented with burial testing to correlate short- to long-term testing results.

The project team will draft a laboratory- and field-testing plan. Investigators will estimate how many coatings will be tested each year and at what cost. Each year, a set of coatings will be selected and tested, and performance results will be provided.

Results

In 2019, the project team began a review of related projects completed over the last 10 years. A product matrix was created and is being populated with the prior testing results.

The team also created a first draft of the typical and extended/specialized coating test methods, will continue to add to this list, and then prioritize and categorize the tests in groups applicable for specific generic coating classes.

The team also reviewed coating tests and is researching the required sample numbers and sizes, durations, and approximate costs per test.

Status

The project team is finalizing the coating test result matrix. These tests will be ranked by priority as a function of use case as well.

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In-Field Compliance Validation

Researchers are performing an automated validation of field-collected data gathered during construction to ensure that all data required for regulatory compliance is captured. This validation is being performed in real-time to identify any gaps while in the field to allow issues to be addressed immediately before the asset is put into service.

Project Description

Pending regulations will require gas pipeline operators to increase the quantity and quality of data collected when new assets are installed in the system. New rules will likely require operators to capture material traceability information, including material, manufacturer, lot code, and joiner information. Regulations will also likely require enhanced quality and traceability of material records, pressure test records, weld records, and other data.

While operators have processes to collect the required data, most of these processes are manual and performed weeks or months after the asset has been installed and put into service. This type of workflow increases the risk of records having incorrect or incomplete data that requires follow-up activities that are time consuming and expensive.

The objective for this project is to perform automated validation of field-collected data during construction to ensure that all data required for regulatory compliance is captured. This validation will b performed in real time to identify any gaps while in the field to allow issues to be addressed immediately before the asset is put into service and the project is closed-out.

The proposed solution would use compliance algorithms to perform, for example, the following validations for a transmission line:

- Every pipe joint has a Material Test Report (MTR) record that verifies the material type, seam type, diameter, wall thickness, and pipe grade (yield strength) specified in the engineering design for Maximum Allowable Operating Pressure (MAOP).
- Every fitting has a Certificate of Compliance (COC) with the supporting MTRs.
- Every fitting has a COC that supports the pressure rating specified in the engineering design.
- Every pipe segment has a weld record containing the operator qualification verification of each welder, visual inspection report, and non-destructive testing (NDT) record.
- Every pipe joint has a pressure test record.
- Every fitting has a pressure test record.
- Every pressure test record was performed at a pressure and duration in compliance with the engineering design specifications for the MAOP and class location.

The following are example notifications that would be provided to the inspector in the field on a mobile application:

- *"This valve does not have a Certificate of Compliance record from the manufacturer."*
- *"Three welds are missing NDT inspection records."*
- *"The pressure test was performed at an incorrect pressure for the specified MAOP provided in the engineering design."*
- *"No electronic flow valve was installed at 123 Main Street."*
- *"One segment of pipe is missing the lot code attribute."*
- *"Two service lines have no pressure test record."*

Deliverables

Deliverables include:

- A set of compliance validation algorithms
- Field test report, and
- Final reports

Benefits

The goals of the project is to:

- Address new regulations
- Validate regulatory compliance prior to putting the asset into service
- Provide real-time analysis to identify issue/gaps before the asset is buried
- Identify issues that might pass a human review, and
- Provide real-time contractor oversight.

Technical Concept & Approach

Specific project tasks include:

- **Compliance Validation Algorithm**

  Activities in this task will develop the compliance validation algorithms. Separate algorithms will be developed for logical asset classes potentially including transmission steel pipe, distribution steel pipe, and distribution plastic pipe. The algorithms will be developed independent of any software solution to allow companies to implement the algorithms with existing or future tools.

- **Testing**

  The algorithms will be tested with simulated and real-world data sets.

- **Implementation**

  The algorithms will be implemented into a software platform to support real-world testing.

- **Pilot Project**

  A pilot project will be conducted with one operator on a real-world job site to further test and validate the models.

Results / Status

This project was initiated in June 2019. A pilot project is expected to begin in 2020, with a demonstration to be conducted in the third quarter.

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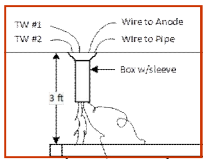
Remote Monitoring of Pipe-to-Soil Readings, Equipment Identification, and Evaluation



Researchers are identifying and evaluating easy-to-deploy remote options that are available for measuring galvanic cathodic protection (CP) in the natural gas industry. Manufacturers of corrosion-protection equipment are being engaged in identification and development efforts to review equipment, materials, and software to obtain pipe-to-soil readings accurately and remotely.

Project Description

Obtaining pipe-to-soil readings is a federal requirement that ensures the safety of the gas distribution system by measuring the cathodic protection (CP) applied to steel pipelines to determine if corrective action is required to prevent corrosion.

The ability to remotely monitor the cathodic protection of a gas distribution system offers a variety of advantages to a gas system operator. In this project, a research team will identify and evaluate easy-to-deploy remote monitoring devices for measuring levels of galvanic CP in gas distribution systems. The evaluation will include the CP devices, associated equipment and materials (i.e., reference cells), and the software platform for remote monitoring of the pipe-to-soil potential readings.

Researchers are identifying and evaluating remote pipe-to-soil options that are available within the natural gas industry that could be easily installed on a gas service pipe. Two vendors have agreed to supply equipment. These two vendors provide a turnkey system of components that are completely installed below grade and can be used on service pipes. The testing for these two vendors will be performed at a pipe field and will be using a cellular-based communications network to confirm the remote pipe-to-soil readings.

Deliverables

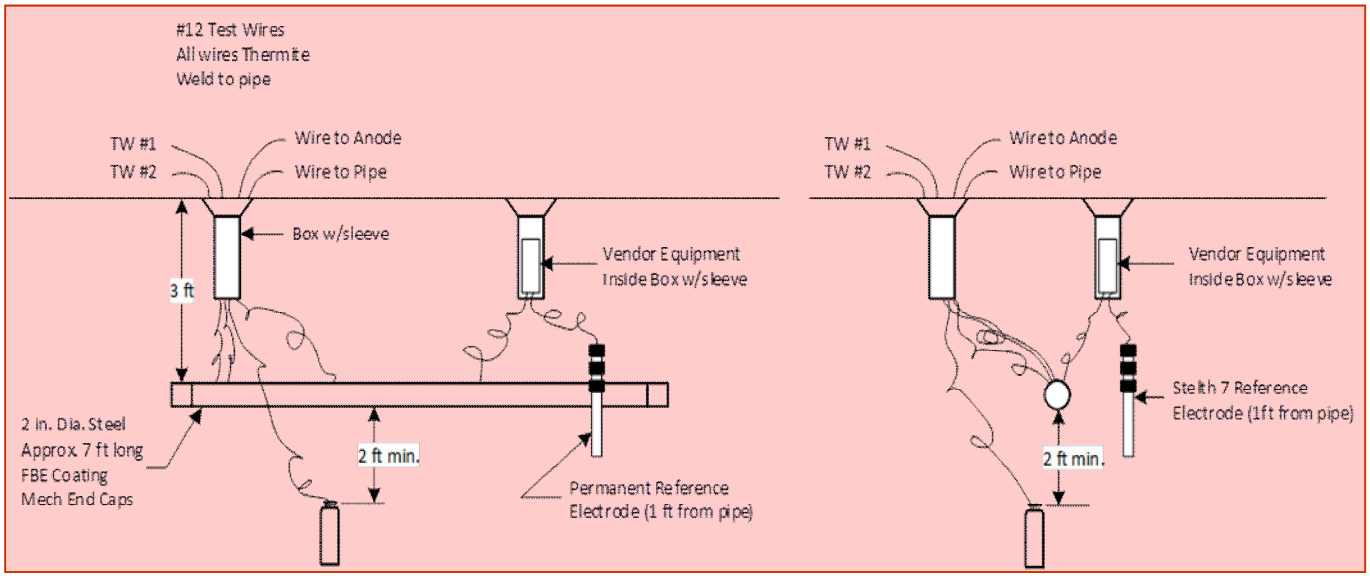
The deliverables for this project will include:

- A test plan and field study of the vendors equipment, including software and communications over a cellular network, and
- A Final Report detailing the technical specifications and the field testing for each of the devices that were tested.

Benefits

Obtaining routine pipe-to-soil readings on steel distribution systems throughout an entire service territory is a time-consuming and costly expense for utilities. Also, the number of personnel specializing in performing this type of work effectively and efficiently is decreasing across the industry.

Monitoring widespread pipe-to-soil measurements on a more frequent basis would be the best first-line of defense in identifying areas of a pipeline system with weak or inadequate corrosion mitigation. Frequent data to allow for trending analysis is a powerful tool for CP specialists to use in identifying changes in protection levels throughout a system.



The ability to remotely monitor the CP of a gas distribution system offers the following advantages to a gas system operator:

- Improves safety by reducing human error related to improper pipe-to-soil readings by employees
- Improves compliance by alerting and providing needed information in a timely manner
- Provides the ability to have readings more frequently and readily available to allow for trending analysis for future estimating and planning, and
- Will reduce or potentially eliminate the total number of labor hours required to perform pipe-to-soil readings and to determine corrosion-related corrective action workloads

Technical Concept & Approach

Specific tasks include:

- **Identification of Existing Easy-to-Use Turnkey Remote Pipe-to-Soil Vendors**

  This task includes project kick-off activities, identification of CP telemetry needs, sponsor interactions, needs analysis, tasks preparation, and other related activities.

- **Identification and Evaluation of Available CP Devices**

  In this task, researchers will identify and evaluate current CP telemetry devices available in the market. The evaluation will include the CP device operating features, associated equipment and materials needed, and the software requirements for transmitting and receiving the remote readings.

- **Field Testing of CP Devices and Software Applications**

  This task will include installing the selected CP devices on different-sized steel piping, with different types of coatings, levels of anode protection, and types of soils. The project team will record regular readings remotely and manually for comparison.

Results

Activities for this project included identification of the project team, conducting a project kick-off call with sponsors, performing a search of existing products, and speaking with industry subject-matter experts on available products. Two vendors were chosen and their equipment has been installed at the Gas Technology Institute pipe field in Des Plaines, IL.

Status

- Equipment from both vendors has been installed at the pipe field
- Implementation of the test plan to the end of the project (potential testing of an AMI network) is ongoing
- Continuous field verification of remote data is being obtained
- Preparation of the Final report with test results is under way.

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CONSTRUCTION/ INFRASTRUCTURE TECHNIQUES

Addressing issues often beyond the traditional areas, this research involves the development of tools and techniques for metering, gas shutoff, remote monitoring, cathodic protection, data collection, and other applications.

Developed technologies are subjected to a regimen of laboratory and field evaluations to ensure their safety and efficiency.

Efforts include projects to enhance and broaden the knowledge base for plastic pipe materials, development of technology for remote service abandonment without excavation, cybersecurity, and re-development of underground piercing tools and stoppers.

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Development of an Intelligent Shut-Off Device for Commercial and Industrial Customers

Efforts are under way to develop an intelligent gas shut-off device with the ability to detect third-party damage to facilities and, in response, limit the flow of natural gas to minimize the potential hazard from the incident.

Project Description

Gas industry distribution integrity management program standards are expanding the requirements of excess flow valve (EFV) installations from solely single-family residential locations to multifamily, commercial, and industrial gas customers. Consequently, the large-scale implementation of EFVs in the commercial and industrial market requires long-term planning to be effective.

The application to commercial and industrial customers presents several issues:

- From a safety standpoint, multi-family, commercial and industrial customers expect a highly reliable gas supply. An inadvertent shutoff of commercial or industrial facilities (e.g., such as hospitals, manufacturing, or chemical plants) could create a greater hazard than the gas leak it was intended to address.
- The challenge of load variability is inherent to commercial and industrial locations as customers who occupy these spaces frequently change based on rental agreements (such as from a small retail clothing store to a restaurant), which can significantly change the required loads. Due to this variability, life-cycle loads (50-100 years) often differ considerably compared to that at the time of service installation. As a result, pre-installed EFVs with a set flow rate tend to be sized either too small (creating false trips) or too large (rendering the EFVs ineffective at times).
- As the cost to replace an incorrectly sized EFV may vary from $5,000 to $50,000 (if the municipality allows the street to be cut), replacing improperly sized EFVs can become a costly endeavor.

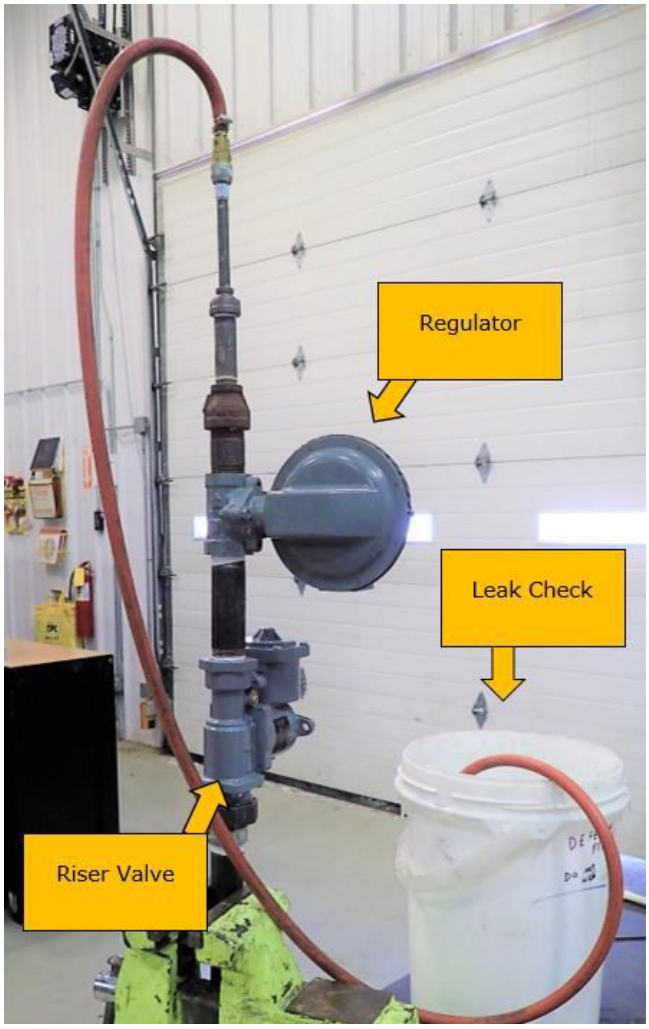
In response to these issues, this project is focused on the development of an intelligent shut-off device (ISOD) to address regulations and risks associated with service and meter set assembly (MSA) damage and associated leaks. The device will be designed to have the ability to detect third-party damage to the service or MSA and, in response, limit the flow of natural gas, thereby reducing the hazard from the incident.

Deliverables

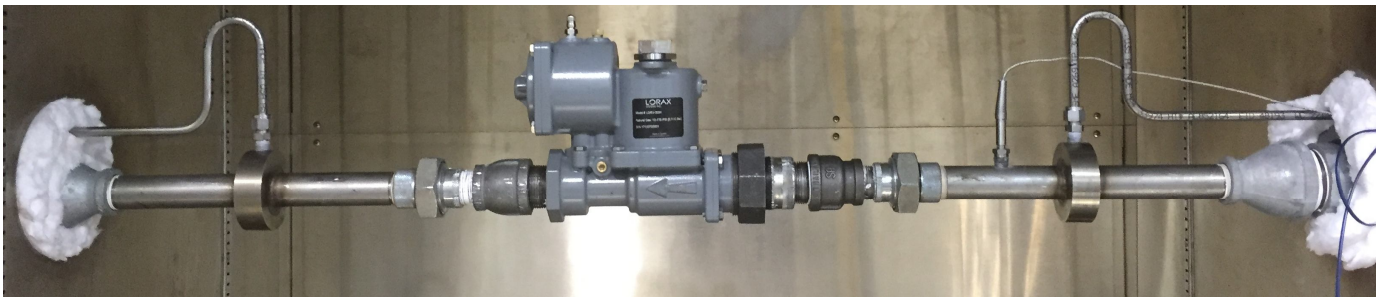
Deliverables include a prototype ISOD and supporting documents providing details on the development of the system.

Benefits

Third-party damage is the number one threat to natural gas distribution systems. Service lines and MSAs are particularly vulnerable to damage from third-party excavators and vehicular traffic. The goal of this project is to develop technology to minimize this risk by limiting the volume of gas released from such incidents.



Operational cycle test setup.



System prototype on laboratory test rig.

Technical Concept & Approach

- **A Market Review and Development of Design Parameters**

  This task included a review of historical data to help to determine the influential design constraints of the ISOD.

- **Development of Evaluation Methods**

  This task involved the development of a testing strategy for the prototype ISOD systems.

- **Development & Evaluation of Prototype System**

  This task focuses on the development of a prototype system based on the set of design constraints.

Results

In 2014, researchers evaluated a remote shut-off system concept to determine if it is able to meet the needs of the natural gas industry and to identify areas for enhancements and modifications. Subsequently, in 2015 a subcontract was made with Lorax Systems Inc. for development of the shut-off valve as part of this project.

In 2016, Lorax successfully designed, manufactured, and tested an alpha prototype of the ISOD. Testing was conducted at very low leak rates to verify that the valve would keep operating even though a very small leak was detected.

In 2017, the Phase 2 prototype was refined. A 3D print version of the prototype was created for testing prior to sending units to be machined. Lorax produced two riser valves for evaluation and functional testing. The project team created a test matrix to sufficiently test the current iteration of Lorax's valve design and non-destructive testing was initiated.

In 2018, Lorax completed the mechanical design for the service line valve. The service line valves are being tested both above and below ground to ensure operational characteristics are maintained.

Researchers successfully completed the outdoor test of the riser valve. The valve endured eight months of exposure to the outdoors and was still able to open and close while providing a bubble-tight seal.

In 2019, the research team received a set of three meter valves from Lorax. These were the cast versions of the valves, as opposed to the machined prototype version that was previously tested. Researchers also received another service line valve assembly for flow testing. The service line valve assembly was installed onto an existing testing rig and flow testing of the valve initiated.

The meter valves are were subjected to a 30-day pressure test to evaluate their ability to remain bubble-tight when pressurized to both 10-psig and 60-psig and set to a closed position.

Demonstrations of both the meter valve and the service line valve were conducted as a part of the OTD meeting in November 2019.

One of the two service line valves received from Lorax was buried in an outdoor pipe farm. The aim of this test is to evaluate the valve's ability to operate in differing weather conditions. The outdoor weather will be monitored using a weather station, and a thermocouple was also buried with the valve assembly to monitor underground soil temperature.

One of the three Lorax meter valves was placed onto a mobile cart and is currently outdoors to test the valve's operation in different weather conditions. The valve will be operated periodically, and the results of these operations will be observed and recorded along with outdoor weather conditions.

Status

Service-line and meter valve testing continues.

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Large-Diameter Inflatable Stoppers

For this project, researchers evaluated existing high-pressure (60 psig) inflatable stoppers as an alternative to currently employed stopping equipment for use on large-diameter U.S. natural gas distribution systems.

Project Description

Line-stopping equipment used in the natural gas industry is usually heavy, takes multiple people or mechanical assists to maneuver, is costly to maintain, and is very time consuming when installing and tapping necessary fittings.

In response, researchers investigated new line-stopping equipment that has the potential to reduce these problematic issues while providing the same assurance of safety and performance.

In this project, a research team partnered with a European equipment manufacturer to evaluate and test the company's inflatable stopper technology. The existing system is capable of stopping off line pressures of 60 psig in steel, cast-iron, ductile-iron, and polyethylene (PE) pipe at diameters of 10 inches to 18 inches.

Research addressed several industry needs:

- One application is for use on larger-diameter (10-inch to 18-inch) steel, cast-iron, ductile-iron, and PE pipe that operate at pressures greater than five psig and have limited options to control gas flow. Currently, bag-stopping equipment can only be used up to five psig. Therefore, when systems that are operating at medium pressures (greater than five psig), the options for shutdown are either valves or costly line stoppers.
- Another application is related to the natural gas industry's increasing use of larger-diameter PE pipe. Hydraulic squeeze tools are manufactured to squeeze the PE pipe to stop the flow of gas, but an alternative is needed.
- New bag-stopping equipment may have the potential to be used in combination with traditional line-stopping equipment to provide additional safety. The bag can act as a secondary stop with a vent (bleed) between the primary stop (traditional equipment) and the bag. This application can potentially be used on higher-pressure systems (greater than 60 psig). The bag system could be used to completely stop off the gas flow while the "blow by" from the traditional stopper is vented to atmosphere.

16-inch steel cold-weather test.

In Phase 1 of this project, researchers evaluated the flow-stopping system for use on gas pipe diameters up to 18 inches and pressures up to 60 psig.

The Phase 2, a research team provided supplemental testing, evaluation, and enhancements for the large-diameter (10-inch through 18-inch) applications for steel, cast-iron, ductile-iron, and PE pipe .

Deliverables

This project resulted in a laboratory- and field-tested large-diameter stop-off system and some validation of smaller-diameter systems.

Benefits

New bag-stopping technologies currently used overseas have the potential to provide the U.S. natural gas industry significant savings in day-to-day operations while increasing operational efficiencies and safety.

Technical Concept & Approach

This project will assist with the technology transfer and evaluation of currently manufactured flow-stopping equipment in Europe for the U.S. natural gas industry.

"This system has given us cost savings by performing more stopping in-house due to the multiple main sizes and materials it works on that we have typically contracted out. It's great because stopping, purging, and pressure monitoring all happen in the same tower, which would have otherwise required separate fittings for each function."

- Karl Frisk, PE
Engineering Supervisor
Peoples Gas

Upon completion of the project, based on the results of the evaluations and recommended enhancements, a commercialized alternative line-stopping system will be available for larger-diameter, higher-pressure piping systems.

Results

In this project, enhancements were made to improve the overall safety of the equipment and user performance.

A demonstration of all the equipment, including the new large-diameter PE equipment, was conducted using the new equipment to stop off the flow on an 18-inch pipe at 25 psig. In addition, another demonstration was performed on a six-inch steel pipe operating at 60 psig.

Activities for 2018-2019 included the development of a laboratory evaluation test matrix, preparation of all material required for the laboratory evaluation, and execution of specific tests for the large-diameter, high-pressure system.

Status

MCS has introduced the product into the market and it has been successfully used by numerous companies. The company also began demonstrating the large-diameter, high-pressure system to utilities.

A Final Report on the project was issued in May 2019.

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GPS-Based GIS Conflation System

Activities in this project focus on increasing the awareness of a GPS-based conflation system designed to enhance the accuracy of a GIS using GPS data collected as part of routine operations.

Project Description

Many natural gas system operators improved the accuracy of their geographic information systems (GIS) through conflation – a process that typically uses a commercial land base to shift the position of assets in the GIS to more accurate real-world coordinates. Use of a commercial land base allows the GIS to be blended with (or, conflated) to an existing data set with an accuracy of one to 10 meters.

Research suggests that GPS can potentially be used as an alternative data source for performing GIS conflation to provide a higher level of GIS accuracy. Conflation to GPS coordinates of features within the GIS will not only result in a higher level of spatial accuracy in relation to real-world features, but it will also potentially improve the underlying accuracy of the data because it will allow inaccurate "as-built" data to be corrected. Collecting the GPS coordinates of features when exposed or located would allow features to be conflated to a truly accurate position. Furthermore, conflation to centerline data is very difficult in rural areas where landmarks are not present and conflating to GPS may be the only feasible option for improving the accuracy of the GIS.

The results of research indicated that conflating to GPS coordinates can provide superior accuracy compared to a commercial land base and, in some situations, may be the only feasible option for GIS conflation. Through the OTD-sponsored *Intelligent Utility Program,* a system was developed that can efficiently collect field data using mobile technology such as smartphones and tablet devices. High-accuracy GPS receivers were incorporated to provide survey-grade data without the need for post processing. Building on these technologies, it is now possible to develop tools that can cost-effectively collect high-quality GPS data and perform GIS conflation.

This project builds on the development and demonstration a GPS-based GIS conflation system developed in Phases 1 and 2. The current Phase 3 focuses on increasing awareness of the now-available system.

Deliverables

The deliverables for Phase 3 of this project will include a Final Report, sponsor webinar, and pilot project conflated data.

GIS conflation is a process to "move" the GIS data using a more accurate data source. Typically, the conflation process is accomplished using a base layer such as street centerlines that are readily available and accurate. However, this project used the actual real-world location of the gas facility to conflate to the GIS-based gas system.

"With damage prevention such a high priority, it is critical that the conflation of gas facilities is done with the highest degree of accuracy achievable. This new technology enables us to do just that."

- Wendy Politano
Sr. Analyst - Gas Engineering
Con Edison

Benefits

Higher-accuracy maps could be extremely beneficial in emergency situations where valves, meter sets, and other assets need to be located quickly.

Some of the benefits of a high accuracy GIS include:

- **Reduced Buffer for One-Call Tickets and High-Consequence Areas**

  Higher-accuracy maps allow buffer zones around assets to be decreased. A reduced buffer would eliminate one-call tickets that would normally be issued but that are not near any facilities.

- **Ability to Relocate Facilities**

  Better maps will reduce the occurrence of the wrong facility being located and will provide information that will help the overall locate process. Additionally, having the GPS coordinates of assets will potentially allow GPS to be used to assist in the locate process.

- **Design and Engineering Analysis**

  A reliable and high-accuracy GIS could decrease design time by reducing the number of field visits required to collect field measurements.

Technical Concept & Approach

In the current Phase 3 of this project, the research team will review previous conflation processes and determine appropriate modifications that need to be made to meet requirements from the pilot project utility.

The Esri ArcGIS Collector can be configured to support high-accuracy GPS devices to provide up to centimeter level GPS data. This application is constantly updated and requires configuration to ensure that it collects data at the level of accuracy that is expected.

A conflation pilot project will be conducted in cooperation with a sponsoring utility.

The project team will create a commercialization plan to introduce the GPS-based conflation technology and process into the market.

Results

Phase 1 project took the concept of using high-accuracy GPS for data collection to the field evaluation phase. The results of the effort increased the speed of data collection, accuracy of the final conflation product, and improved the process of associating actual gas features with the data that was conflated.

Phase 2 further developed tools used to process RK-based GPS data capable of providing centimeter-level results. In addition, researchers performed a pilot project with to conflate a three-square mile area.

The current Phase 3 of the project involves additional pilot project opportunities with other OTD sponsors. In addition, researchers have been working with a new version of ArcGIS Collector to ensure that the latest technologies are being used.

In 2019, a pilot location was selected to perform data-collection activities. Researchers also contracted for conflation data-processing services and to develop a commercially available offering for utility companies.

Data-collection methods were tested locally using high accuracy GNSS receivers, a RTK base station, and Esri's Collector for ArcGIS application. Researchers spent four days in the pilot area attempting to locate and edit the locations of 17 compliance valves and 77 non-compliance valves.

Working with an additional sponsor, researchers obtained data in preparation for data collection in October 2019. The project team helped to identify the area that would provide the best opportunity to collect above-ground features and locations.

Status

The following activities are scheduled for execution:

- Data collection from the current pilot project
- Review conflation results for the earlier pilot project, and
- Address commercial options for the GPS-based conflation process.

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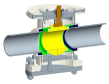
Transmission Cut-In Valve



In this project, researchers investigated a concept for a commercially available valve used in the water industry to allow for its use on natural gas transmission lines.

Project Description

This project focused on the development of a valve-system concept similar to the commercially available EZ™ Valve System, but designed for higher-pressure distribution and transmission pipes.

The current EZ Valve System is used in the water industry and bolts to the pipe to allow for the installation of an in-line valve without shutting off the flow. Advanced Valve Technologies, Inc., developed the EZ2™ Valve System that can be installed under pressure in one excavation, eliminating expensive multiple excavations.

This project involved R&D aimed at developing the EZ Valve fitting to be permanently welded to a steel pipe after installation. Researchers developed a concept for a transmission EZ Valve for sizes up to 12 inches in diameter with working pressures up to 300 psig.

Deliverables

Deliverables included a conceptual design for the EZ valve and a Final Report.

Benefits

The concept showed promise to provide a variety of benefits, including:

- Faster installation times, especially in urban environments
- No need for flow control and/or by-pass
- Only single excavations needed since there is no need to stop off the flow in the pipe and no need to install a by-pass
- Enhanced safety, and
- Lower cost of installation.

Field use of water industry cut-in valve.

Technical Concept & Approach

Specific key tasks for Phase 1 of this project included an evaluation of the existing EZ Valve System and other current valve designs. Conceptual valve designs were created.

Phase 2 activities were focused were suspended.

Results

Phase 1 of this project introduced the design concept of a transmission cut-in valve as well as the manufacturing processes that would be used to supply it. The base system was modeled after similar valve installation systems in the water industry. The design parameters of the valve were established as a six-inch-diameter pipe for the initial prototype and up to 12 inches in diameter for production models.

The goal of the second phase was to have the components of the valve constructed and the prototype built for a proof-of-concept demonstration for project sponsors and contractors. Another goal of this phase was to identify a possible commercializing partner of the cut-in valve and to support the prototype demonstration with cutting equipment.

Delays in securing epoxy specimens and a lack of feedback on a market survey led to the cancellation of an agreement with a manufacturer. Subsequently, the project to be put on hold without the necessary support for the prototype demonstration.

In 2018, efforts were made to secure a partner to commercialize the Cut-in Valve after prototype demonstration. One manufacturer requested market analysis and information on the potential use of the valve in the industry.

Status

Sponsors decided to terminate this project in 2018. A Final Report was issued in May 2019.

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Testing Program for Itron-100T-GGRD Valve with Water Sensor for Storm Hardening

Research is being conducted to validate the performance of an integrated gas safety system, develop "fit for purpose" utility utilization guidelines and system specifications, and perform laboratory evaluations and field testing.

Project Description

The objective for this project is to integrate a methane sensor, in addition to a storm-hardening water/flood sensor, with a remote shutoff valve (the Itron-100T-GGRD) to enhance overall gas system safety.

Phase 1 included performance validation of the ability of the valves to isolate gas service to a building upon remote activation. The evaluation also considered general safety and operation of the valve.

The current Phase 2 includes several parallel-path evaluations of sensor performance and integrated operation of the valve/sensor system.

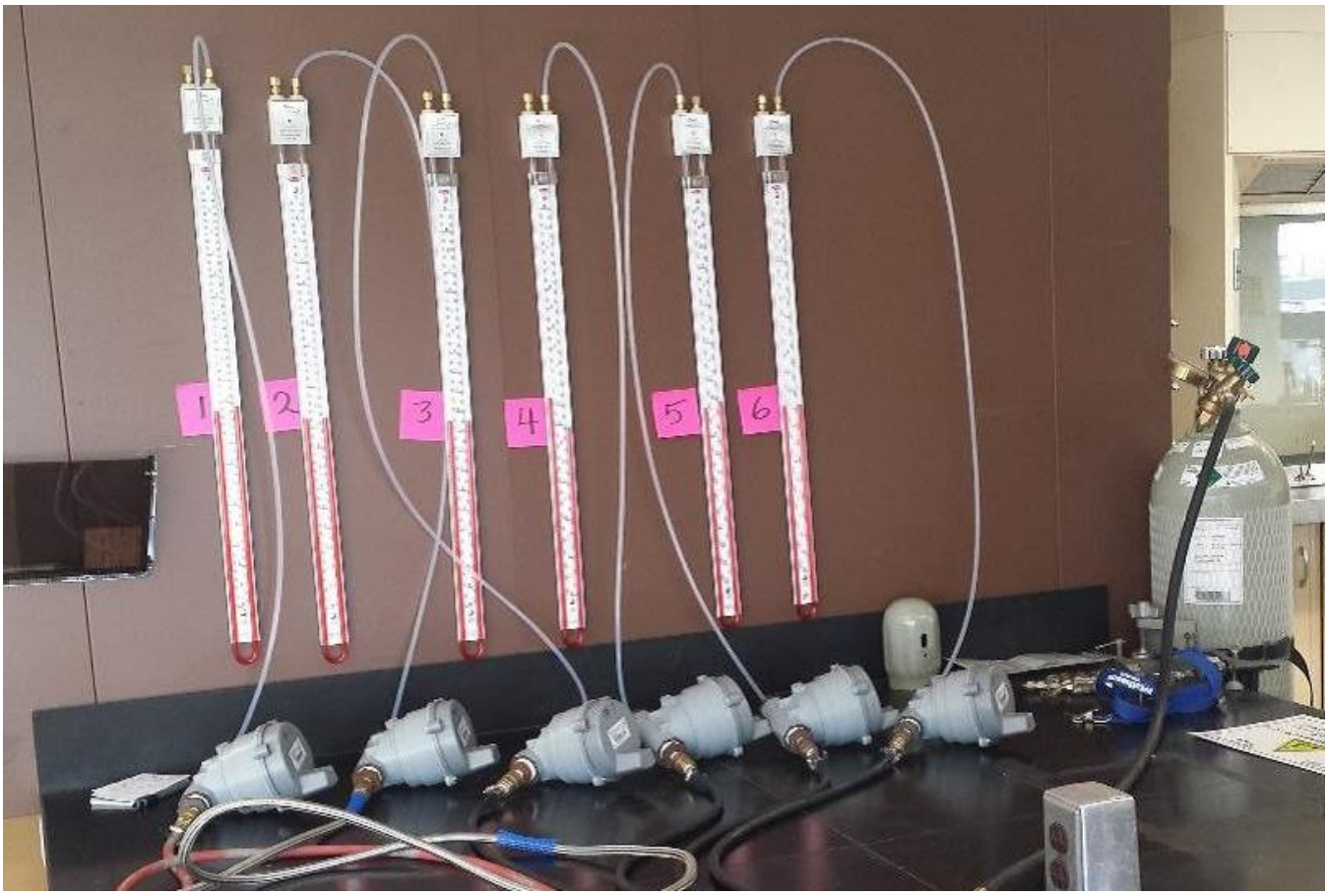
Approximately 12 combination units will be configured and exposed to three threshold concentration gases. Phase 2 is also a field-testing program.

Deliverables

The project team will develop a Technology Utilization Roadmap and Guidance Document and an associated device specification matrix. The team will also create a report detailing the findings of the methane sensor testing, integrated valve/sensor testing, and field test results.

Benefits

Integration of a methane sensor, in addition to the storm-hardening water/flood sensor, with the Itron remote shutoff valve would enhance overall gas system safety by providing gas operators with advanced indication of an abnormal operating condition resulting in a gas release inside a building. If methane is detected in a building, the service may be isolated in advance of



Phase 1 laboratory testing.

first responders. For leaks in the street resulting from a damaged distribution main and migration into buildings, the sensor would allow for advanced monitoring of a potential broader system problem.

Technical Concept & Approach

Phase 2 tasks include:

- **Development of "Fit for Purpose" Utility Utilization Guidelines and System Specifications**

  This task includes facilitating a utility technical workshop to provide the opportunity for technology providers to obtain a better understand how to further enhance device specifications and options and optimize designs to meet the needs of operators in a fit-for-purpose manner. Ultimately, the output from this task will include a Technology Utilization Roadmap and Guidance Document and an associated device specification matrix.

- **Laboratory Performance Evaluation of Methane Sensor**

  This phase of work includes performance evaluation of a methane sensor. This task will require a minimum of 12 sensor devices to facilitate performance testing.

- **Evaluation of Integrated Gas Gate Shutoff Valve/Methane Sensor/Moisture Sensor Communication Performance**

  This task includes benchscale testing of the integrated valve/sensor device, including communication protocols. Combination units will be configured and exposed to three threshold concentration (low-medium-high) gases (methane/air mixtures) to confirm integrated performance of the sensor/valve technology. This evaluation will also include simulated remote communication back to a central monitoring source and the ability to remotely isolate service via valve operation.

Results

In Phase 1 of the project, a series of laboratory testing was conducted to fully evaluate the remote shutoff valve. The research team was supplied 10 valves along with a handheld remote-control device to actuate the valve.

A series of pressure tests were conducted to determine the valves ability to shut off the flow of gas and sustain shutoff. Since the valves could be installed indoors or outdoors, pressure testing was also conducted at various temperatures. Finally, the valves were open and closed repeatedly (100 times) and checked for leaks, battery life, and overall mechanical performance (wear and tear).

An experimental set-up was used to investigate the effect that debris has on the valve's ability to close to a bubble-tight seal.

The valve's inlet and outlet was sealed and units were submerged under various depths of water to examine the effect of water intrusion on the valve's ability to remotely open and close. The valve was left submerged at each depth for a period of 48 hours, then an attempt was made to remotely open and close the valve while it was submerged, and then again outside of water. If the attempt to open and close the valve was successful while it was underwater, then the water level was increased and the test was repeated.

The valve was placed into a salt fog chamber in order to test its performance in a corrosive environment.

Two Itron remote shutoff valves were placed outside to test the valves' performance in an outdoor environment.

Phase 2 focuses on various evaluations, including the methane sensor performance and then the integrated operation of the valve/methane sensor system.

Prior to the start of the project, some initial evaluation of the sensor was conducted, along with developing "fitness for purpose" guidelines for the system. The manufacturer is currently making some enhancements to its sensor for additional testing.

Itron announced in 2018 that the company is now working with a Japanese-based safety device manufacturer to integrate their ML-310 hot wire semiconductor type gas sensor with MEMS technology and Itron's Milli 5 network communication module.

Status

Ongoing activities include the continued development of draft specifications and additional testing of the enhanced methane sensor.

The project team discussed the current status of the Itron shutoff device and various methane sensors in preparation for the next steps of the project.

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Cybersecurity Collaborative

This project involves the development of a multi-year collaborative program between natural gas distribution companies and the U.S. Department of Homeland Security (DHS) to address natural gas industry high-priority cybersecurity issues.

Project Description

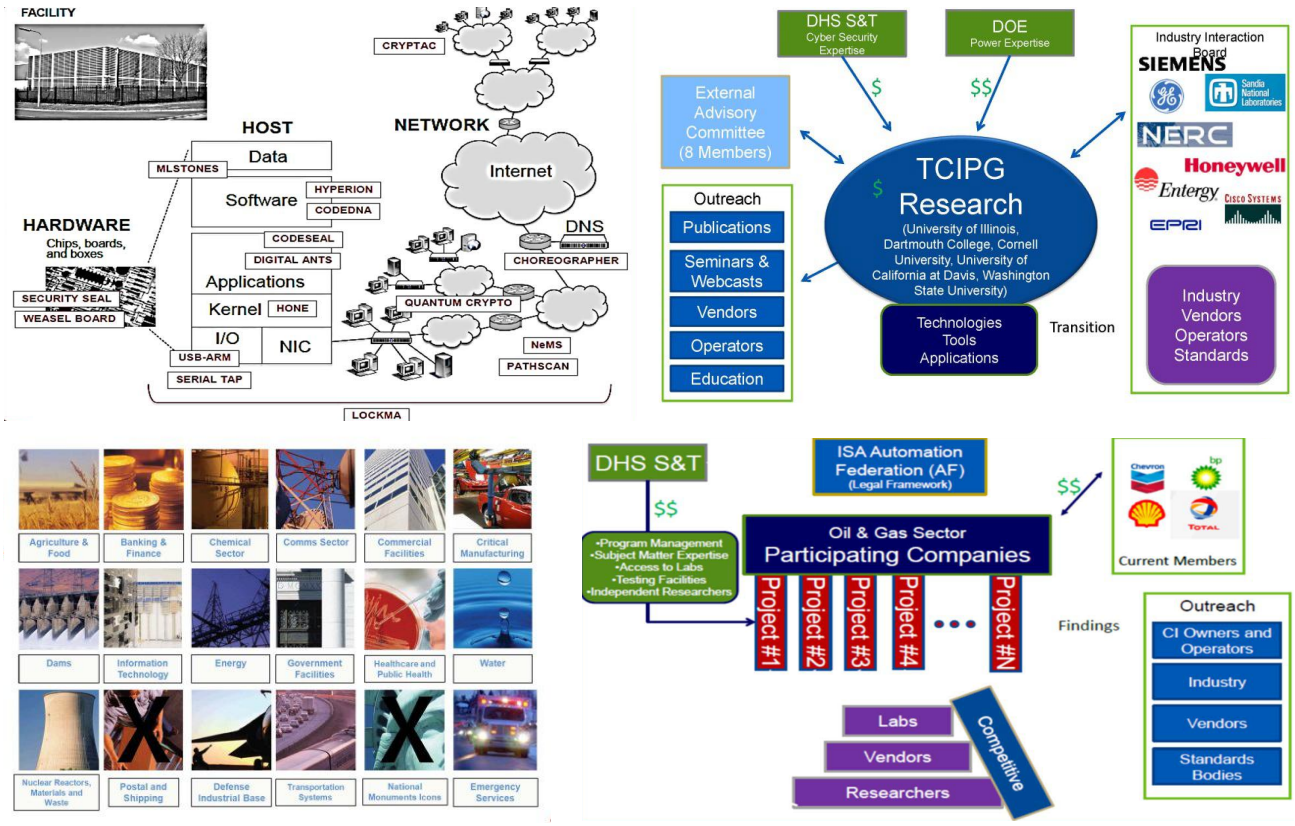
The Cybersecurity Collaborative focuses on broad industry cybersecurity advocacy and related strategy.

This multi-year collaborative program between natural gas distribution companies and the U.S. Department of Homeland Security (DHS) addresses the high-priority cybersecurity issues through an outreach and education process and a technology evaluation and transfer initiative. This combined emphasis is intended to reduce risk and diminish cyber-attack threat exposure, intellectual property theft, and system operations disruption or damage.

Program results may be used by operators to educate internal and contracted personnel about cybersecurity, as well as evaluate and, where appropriate, implement state-of-the-art technologies focused on the prevention, detection, and mitigation of cyber threats.

Prominent activities and initiatives undertaken to date to mitigate cyber-attacks include:

- Promoting collaboration among cybersecurity-focused organizations, such as National Association of Regulatory Utility Commissioners, Cyber Resilient Energy Delivery Consortium, American Gas Association's Cybersecurity Strategy Task Force, and California Energy Systems for the 21st Century
- Curating a team cybersecurity reference site which – when combined with quarterly meetings, educational field visits, and tabletop exercises – provides a forum to identify needs, share concerns, and discuss technology gaps, and
- Assessing cybersecurity technology effectiveness, evaluating methodologies to protect field-based technology, and identifying best practices.



A needs-identification workshop provided attendees with a variety of critical information for improving the safety of gas distribution systems.

Deliverables

The deliverables are expected to include:

- An outreach and education program
- A vetted, prioritized, brief list of technologies and supporting material for transfer to utility operations
- One or more technologies identified and vetted by DHS transitioned to practice
- A cybersecurity technology improvement "roadmap"
- One or more projects addressed within each the areas of Asset Management, Detection, and "Technology to Manage Technology"
- A test bed for modeling control systems, SCADA monitoring, detection/correlation, and failure scenarios, and
- The development of Best Practices.

Benefits

This combined emphasis is designed to provide a reduction in the risk and exposure to the threat of cyber-attacks and malicious activity directed at the theft of intellectual property or disruption/damage to system operations.

Technical Concept & Approach

A strategy was developed for a program to address the remaining areas with the highest priorities: 1) asset management of devices and systems capable of providing a pathway for cyber-attack and malicious activity and 2) detection of a cyber-attack and/or malicious activity.

Results

The Collaborative holds webinars and face-to-face meetings on an alternating basis approximately every quarter. The project's secure team website is updated on a regular basis with a variety of reports, documents, and links to relevant sites.

In 2018, Pacific Northwest National Laboratory was contracted to support the Cybersecurity Collaborative through consultative subject matter expertise, execute technology tests for development of best practices, secure operation of natural gas distribution, and provide access to and manage testbed and other test resources to enable collaborative test execution.

Additionally, the Collaborative executed a Tabletop Exercise, including two scenarios derived from real-world situations. The first scenario required participants to identify the operations procedures necessary to troubleshoot compressor station alarms from a cybersecurity perspective. Similarly, the second scenario occurred at a city gate, where operators noticed loss of flow-controller communications and pressure decreases system-wide.

The team developed a vetted, prioritized, brief list of technologies and supporting material for transfer to utility operations and is creating a cybersecurity technology improvement "roadmap." The ability to transfer one or more asset management and detection technologies identified by DHS as ready to transition to practice is among the highest-priority initiatives.

In 2019, the project team conducted a face-to-face meeting of the Collaborative at the Duke Energy facilities in Charlotte, NC. Updates on several initiatives were provided, including access control, failure scenarios, and the cyber-analytics dashboard for operations technology. Additionally, DHS provided an organizational update and the Collaborative was updated on the cybersecurity efforts presently under way.

Also, on September 11, 2019, the Collaborative participated in the first-ever Joint Consortium Meeting for Critical Infrastructure sponsored by the DHS in Arlington, VA. The invitation-only meeting's purpose was to connect government and partners from various industries to discuss common threats, challenges, and successes while learning about the mission and strategy of government agencies to help secure critical infrastructure.

Status

Researchers are providing are variety of program administration duties.

The project team continues to develop various access control taxonomies and determine the key operational technology metrics required to provide comprehensive situational awareness.

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Development of a Tee Antenna for Fitting Protection

In Phase 1 of this project, a tee antenna prototype was developed to enhance damage prevention during construction excavation. Phase 2 focused on making modifications to the original design and on an evaluation of a commercially available antenna.

Project Description

In gas operations, tapping tees are used for various reasons, including providing service to customers, accessing mains for pressure readings, conducting flow-control procedures, and establishing by-pass setups during maintenance operations.

The use of these tees results in their subsequent abandonment, leaving the tee's tower behind, which protrudes from the gas pipe. Often, these fittings are not mapped and, as such, pose a risk for damage by third-party excavators.

During Phase 1 of this project, the project team designed a prototype for a tee antenna warning device. The antenna is designed to be strapped onto a main line adjacent to a service tee and protrude approximately 24 inches above the tee/pipe. When an excavator starts digging above an unidentified service tee, it will hit the antenna first, which will warn the operator that there is a gas fitting/pipe below.

In Phase 2, the project team refined the prototype design. Three different designs were created. Two of the designs use a ½-inch pipe for the antenna, similar to the Phase 1 testing. However, the third design uses a one-inch pipe for the antenna to see if a larger antenna will perform better during backfilling and excavations.

The project team also evaluated an additional tee antenna product that is already commercially available.

Deliverables

The deliverables from this project include a commercial-ready design of the tee antenna and a working prototype.

Benefits

The protection of service tees and/or other types of fitting stubs and gas pipe will help prevent gas companies, their contractors, and/or third-party excavators from accidentally damaging gas systems. This will improve operator and overall public safety and reduce emergency responses required due to excavation damage.

Technical Concept & Approach

Phase 2 of the project involved modifications to the prototype design to make the fitting easier to install and more resilient. In addition, the modifications allowed for a prototype to be produced. In addition, a commercially available product was tested.

Results

The Phase 1 tee design that was ultimately developed consisted two components that are connected by a snap fitting, with the bottom component strapped to the main line on either side of the service tee and a long section of one-half-inch-diameter tubing attached to the top component. When an excavator impacted the vertical tubing, the top component would disconnect prototypes from the bottom component in order to prevent the load being transferred to the main line. Four prototypes of this design with varying snap-fitting designs were created and tested in both sand and clay soil in order to determine the best snap-fitting design.

Phase 2 was initiated in 2017 with the development of a survey regarding the intended use of the tee antenna and contacting various manufacturers regarding potential commercial partnerships. Most manufacturers did not want to pursue this project. However, one manufacturer gave the project team the suggestion of making the device a single piece since that would be less expensive and easier to produce.

"This project is a perfect example of how OTD develops innovative solutions from the highly technical to simple marking devices to address the needs of operators."

- Rick Trieste
Dept. Manager R&D
Consolidated Edison Company of New York

"Cumberland Products is pleased to have participated in this project concerning efforts to provide a critical solution in preventing damage in gas systems. It is through the commitment of OTD and project sponsors that we continue to innovate products, enhance operator safety,

- Scott Gleisner
President
Cumberland Products

In 2018, researchers developed a single-part design that would attach directly to the pipe. The single-part design was created to make it easier to install the antenna onto the prototype as well as making it easier to injection mold.

Researchers tested different size hose barbs to ease the attachment of the tee antenna to the rest of the prototype. Additionally, the different size hose barbs were tested in order to find the ideal size to prevent the barb from snapping during the backfilling process but snapping easily during the excavation process to prevent the load from the excavator bucket from transferring to the pipe.

The project team obtained four versions of the one-piece, through-strap design to evaluate which diameter connection would provide the ideal breaking force for the antenna to snap. All four prototype sizes were tested where a 12-inch-long ½-inch plastic pipe was attached to the barb fitting and pushed over until it snapped. The 5/16-inch-diameter connection between the barb fitting and the base had a good combination of most of the ductile failure going into the base part, but wasn't too difficult to snap. Therefore, for the design of having the barb fitting snap off, the ideal diameter connection is 5/16 inch.

The project team tested two ½-inch antenna prototypes (one with a 5/16-inch-diameter connection and one with a 3/8-inch-diameter connection), and a separate one-inch antenna prototype by burying four of each type in clay soil and excavating with a 30-inch grooming bucket with a flat leading edge. It was found that both ½-inch antenna designs snapped during the backfill process. During the excavations it was found that the antennas were pulled off of the fitting before snapping, suggesting that a stronger connection to the base could be used and still have the design be successful without transferring force to the pipe.

In 2019, the single-piece design was refined upon to have thicker walls to prevent the snapping which occurred in the previous testing. This design was to have a one-inch antenna since those performed well in the previous testing. The project team acquired eight prototypes of the one-inch antenna redesign to proceed with testing.

Before this testing was to commence, it came to the project team's attention that Cumberland Products was selling a tool similar to this single-piece design. This device was simpler to produce, easier to attach, and most importantly, was already on the market. Additionally, this device had a high-powered magnet at the end of the antenna which allows it to be located easily with a metal detector above the surface when this device is buried.

The Cumberland Tee'd Up Marker was tested, along with the refined single-piece design. It was found that during a worst-case scenario backfilling the Cumberland Tee'd Up Marker did not perform well. However, if one were to use the suggested safety protocols while installing the Tee'd Up Marker, it should survive the installation process. It was found that the Cumberland Tee'd Up Marker performed exceptionally well during the excavation process and was a good passive marker for where tee fittings exist underground.

Since the Tee'd Up Markers are currently commercially available and are less expensive than any price estimates for distributed single-piece products, while additionally providing an magnetic locator, they are the best option for the project sponsors for a tee antenna. Therefore, it is suggested that this project be closed and the project sponsors are directed to Cumberland Products to purchase the solution to this project.

Status

Testing of the single-piece design and the Cumberland Tee'd Up Marker was concluded, finding that the Cumberland Tee'd Up Marker is a commercially available and viable option. Therefore, no further testing or development will be done on this project as there is an inexpensive solution available on the market.

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Remote Service Abandonment Without Excavation

For this project, research and demonstrations were conducted to develop a technology/process that creates a permanent plug for service-line abandonments. The concept is based on an existing prototype design that allows a stopper device to be inserted through the service head and eliminate the need for an excavation.

Project Description

Gas utilities routinely terminate gas services. When the main and service tee is located under pavement (road, sidewalk, or driveway), the time and cost to properly abandon the service at the main can increase substantially. Also, the need to excavate can increase the risk of damaging underground facilities.

In response, this project focused on developing the means to permanently abandon a service line without excavation. The concept involves abandoning a service from the service head. This concept may also be used to terminate the service from behind the curb without excavation in the street.

In Phase 1 of this project, a system was developed to quickly and safely abandon a low-pressure (5 psig or less) service line by accessing the service piping near the meter set, therefore not requiring the field crew to excavate. A working field prototype of this system was completed and tested at several utility worksites with success. The system is currently available from Seal-Werks.

Phase 2 involved the development of prototypes to be able to terminate both higher-pressure steel and plastic service lines (up to 60 psig) without having to excavate.

Deliverables

Deliverables include two prototype remote abandonment systems (one for high-pressure steel services and the other for high-pressure plastic services) and supporting documentation.

Benefits

The development of this remote abandonment system and process will reduce the cost and time involved to abandon gas services by eliminating the need to excavate in the roadway above the main and service tee.

The use of a remote abandonment system will also enhance safety by reducing the risk of third-party damage by eliminating partial, behind-the-curb service terminations.

Technical Concept & Approach

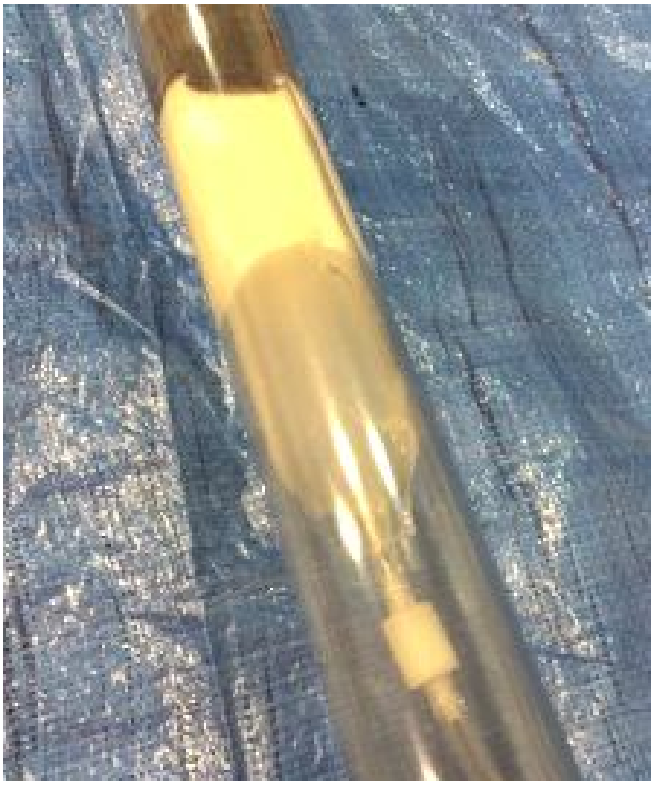
High-Pressure Steel System

During Phase 1, a foam-dam device was developed which consisted of a solid foam piece which was inserted into a steel pipe followed by expandable epoxy piece creating a dam behind the expandable foam. While the foam-dam device was able to be installed in a 3/4-inch steel pipe, it was unable to make it around a 3/4-inch steel elbow.

During Phase 2, the goal was to develop a system to get this foam-dam device around the 3/4-inch steel elbow so that it can be deployed through a service riser from the meter set.

High-Pressure Plastic System

A new system had to be designed which can block off the plastic piping while locking in place due to the high pressures (60psig) involved in the service line.



Foam-dam device in high-pressure plastic pipe.

Modified electronic flow valve shell expanded inside pipe.

Results

Phase 1 of this project successfully developed a system that could enter a low-pressure service line from accessing it through the basement, and deploy two bags which are inflated and then locked in place by deploying an expandable rubber plug. A prototype was created for stopping off a high-pressure steel service line; however, the components of the prototype were unable to navigate a 3/4-inch-diameter elbow, preventing it from being deployed in the proper position. Details for the prototype for the low-pressure system and the high-pressure steel service line are found were presented in a report to sponsors.

Phase 2 consisted of two different tasks towards the termination of a high-pressure service line: 1) determine way to navigate the elbow at the bottom of the riser on a 3/4-inch steel service line, and 2) develop an entirely new system to terminate a plastic service line going through a pre-bent riser.

A prototype was successful at terminating a plastic service line pressurized at 58 psig. However, it was unable to seal the 58 psig overnight due to the requirements of an electronic flow valve (EFV) not requiring a full seal of the service lines. To move this product to market it is recommended to first develop a new membrane or coating to place on the outside of the prototype to have it create a full seal, then to work with the manufacturer to make these modifications so that they can distribute a high-pressure plastic termination system. It is then recommended to test this commercial product at pressures up to 90 psig.

Additionally, this product was tasked with developing a system which would terminate high-pressure steel service lines. While researchers were able to navigate the tubing required to deploy the expandable epoxy around a 1-1/4-inch-diameter elbow using a spring double-down, the project team was unable to develop a method to navigate that same tubing around the desired 3/4-inch elbow. Without being able to get around this elbow, the expandable foam cannot get past the service riser and cannot be deployed at the proper location close to the main on the desired 3/4-inch service line.

In 2018, researchers developed a new design which utilizes a modified insertable excess flow valve shell which is expanded into the wall of the plastic pipe using a commercially available hydraulic pump expansion device. This expansion both locks the device in place and creates a seal on the inner wall of the polyethylene pipe.

Status

A Phase 2 Final Report was issued in June 2019.

The next step for this project is to test various membranes or coatings on the outside of the EFV shell to have it create a better seal when it expands into the wall of the plastic service line. Once a solution has been found, it is suggested to undergo a long-term pressure test. If it passes this pressure test, it is proposed to seek commercialization of this product.

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Evaluation of Meter Set Placement and Clearances

This project will provide utilities and their customers with additional knowledge and more options regarding the placement of gas meter sets. Phase 1 developed a method to measure natural gas leaks around meter sets in relation to house openings such as windows, vents, and doors. Phase 2 includes tests on specific leaks and meter settings.

Project Description

Utilities are frequently challenged to find suitable locations to place natural gas meter set assemblies (MSAs) that satisfy the various codes and operation requirements. Additionally, meter-replacement services are on the rise due to the increase in main and service replacement efforts and increased customer loads.

In response, this project involves a testing program to evaluate the distribution of natural gas concentrations around leaks in outdoor meters and regulators. Phase 1 of the project developed a method to measure natural gas leaks around meter sets to provide clearance distances. The current Phase 2 involves additional tests with more arrays of sensors to address specific regulators' leaks and meter settings that utilities encounter at their service areas, including:

- Inlet air vents with negative air pressures directly above and below leaking gas meters
- Accumulation of gas inside of electric meters/ boxes located above the gas leak source
- Vented eaves or overhangs, and the gas concentration around "limited-release" regulators as compared to typical "full-release" IRV regulators.

Deliverables

The deliverables from this project include a Final Report summarizing the risk of gas accumulation, gas ignition and/or gas migration into a building for the various situations tested.

Benefits

This project provides utilities and their customers with additional knowledge and more options regarding the placement of meter sets. Utilities are provided data to support meter set placement options and potentially support changes to applicable codes. Additionally, information developed through this project can be used to better manage risks through a company's distribution integrity management program.

Technical Concept & Approach

Specific tasks in this project included:

- **Codes and Standards Review**

  Researchers performed a review of the various utility codes to determine the restrictions currently in place. The project team also reviewed the history in regards to how the current "clearance zones" were determined and if any prior research in this area exist.

- **Meter Set Leak Evaluation**

  The project team performed an evaluation of MSA placement in relation to the sources of the leak. Concentrations of methane were measured at various distances away from commonly used regulator

vents to identify how far one could safely install the vent from source of ignition. An array of gas sensors were used to monitor gas concentrations from 0% to 100% gas at 15-inch intervals and at various locations around the leak source.

Results

A testing program was performed to evaluate the distribution of natural gas concentrations around leaks in outdoor meters and regulators. The test results help in determining if current clearance zones are appropriate with measured levels of safety.

Phase 1 testing program results can be summarized as follows:

Tests at Low Flow Rates

Tests were performed at low pressures of 0.25 psig and small 1/16-inch-diameter pinhole leaks. The flow rate in these tests was about 3 SCFH. This rate represented typical leaks detected in soap bubble tests of joints at the meter set. The results of these tests show gas readings at low leak rates in pinholes dissipated quickly at still-wind to 5% gas at about one foot from the leak and were at 2% gas within two feet from the leak source.

Tests at Medium Flow Rate

Tests were performed at a pressure of 0.25 psig and 1/8-inch-diameter pinholes, resulting in leak rates of about 11 SCFH. These leaks could be detected by sound and smell several feet away from the source. Tests were performed to evaluate the gas plume in various site conditions and at higher and more conservative flow rate.

Tests with Air-Intake Vents

Tests were performed at leak rates of about 11 SCFH and with various distances between the air-intake port and the leak source. An airflow rate through the vacuum fan was applied at 200 SCFM (ft^3/min) and gas concentration readings in the vent were negligible (at 0% to 0.1% gas) when the vents were at three feet horizontal distance from the leak source.

Tests at High Flow Rate

Tests were performed with leaks in the upstream line at 55 psig pressure. These high-flow leaks commonly result in line shutoff and immediate repair. These tests were performed to identify clearance distance of the 5% gas readings in worst-case scenarios.

Some Findings:

- **Clearances to Windows and Building Vents**

  For meters leaking at low flow rates (below 3 SCFH), gas readings at one foot from the source were less than the 5% gas ignition limit. For meters leaking at medium rates (3 to 11 SCFH), readings less than 5% gas were at minimum clearances of three feet horizontal and five feet vertical. Larger leak rates would result in 5% gas at more than six feet above the leak.

- **Air Intake Vents**

  At an airflow rate through the vent of 200 SCFM and the medium gas readings (less than 11 SCFH), gas reading inside the vent was negligible (around 0.1% gas).

Controllable variables such as wind shields, leaks in the regulator, and locations of openings and vents with respect to the meter set were evaluated mainly at medium flow rate conditions. The unpredictability of wind speed and direction had a large impact on the shape of the leak plume. The leak plume would dissipate quickly in the presence of high winds. Accordingly, tests were performed at still-wind speeds of 0-2 mph and at relatively medium speeds of 5-7 mph.

In 2018, the methane sensors for the measurements of natural gas concentrations were calibrated. These sensors are dual-range infrared sensors that can accurately measure methane concentrations within the ranges of 0-5% gas and 0-100% gas.

Researchers performed gas leak imaging tests using a camera that uses infrared spectroscopy to visualize and measure natural gas leaks.

Status

Regulator testing for Phase 2 is complete. The Final Report is in preparation.

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Alternative Caps for PE Service Tees

The objective of this project is to design an alternative cap for polyethylene service tees that will reduce the possibility of nuisance leaks from cross-threading, over-tightening, and improper O-ring installation.

Project Description

Polyethylene (PE) service tees that act as the connection point to a utility's main line require a cap because a portion of the main is bored open after the service tee is fused to it. In operation, a boring tool enters the fitting through the top of the tee. After the hole is drilled through the main, the tee is covered by a threaded cap and an O-ring is compressed to form a leak-tight seal.

In this project, researchers are investigating alternative caps and fusing methods.

The research team is exploring options with sponsors and service-tee manufacturers, culminating with the development of a requirements document along with alternative conceptual designs.

The overall objective is to design an alternative cap for PE service tees that will reduce the possibility of nuisance leaks from cross-threading, over-tightening, and improper O-ring installation.

Deliverables

The deliverables for this project include conceptual designs for an alternative service tee cap and fitting specifications based on the requirements of North American gas distribution companies.

Benefits

PE service-tee nuisance leaks are a major concern for gas utilities because they usually require excavation and can be expensive to fix.

A major cause of service-tee leaks is a faulty cap, which can be accidentally cross-threaded or over-tightened during installation or have an O-ring installed in the wrong position, which eventually leads to the cap losing its leak-tight seal.

Creating an alternative cap that is more reliable than the current threaded caps, such as a fusible-type cap, could save money and time because of the reduced amount of nuisance leaks.

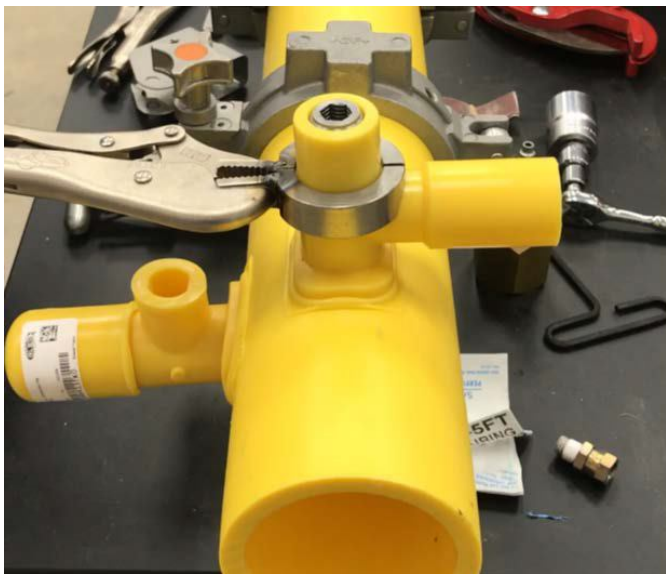
Technical Concept & Approach

Initial tasks in this project included a sponsor survey to identify the needs and applications for a fusible cap device. A summary of sponsor requirements was compiled. Based on the needs and requirements, the project team developed conceptual alternative cap designs.

Project representatives contacted various tapping tee manufacturers to determine interest in developing alternative caps for their tapping tees. A method of connection with a "fusible cap" for tapping tees was investigated. A cap with more robust threads to prevent cross-threading was also studied.

After developing a comprehensive set of sponsor requirements and conceptual designs, there could be follow-on efforts with interested fitting manufacturers in the development and testing of tapping tees with fused caps.

Twelve service-tee assemblies were built and tested.



Fused service tee with custom cold ring clamp and special threaded punch.

Results

Design activities on a threaded cap began in 2017. A generic parametric model of an alternative tapping tee cap (for new fittings) was completed.

In 2018 the scope of the project was narrowed to consider only caps for new installations and not retrofits. There are three possible options for alternative PE caps: improved mechanical cap, socket fusion cap, and electrofusion cap. An improved mechanical cap would address the issues with current mechanical caps. For operators that prefer a fusible cap, either socket fusion or electrofusion caps are possible, the former being simpler to design and manufacture. In both fusible cases, the tower of the respective tapping-tee may need modification or machining/scraping tools may need to be developed. Additionally, both fusible-cap types would require a method to stop blow-by around the cutter.

Discussions with one manufacturer showed promise. The manufacture would like an estimate of product volume to justify development costs. A survey was re-sent to ascertain the sponsors' preference regarding a fusible tapping-tee cap type. The manufacturer is developing two types of caps (an electrofusion cap and a socket fusion cap), but is much further along on the socket-fusion solution. The company has made some aluminum cavities to remove the tower threads on the service tee and should have some molded samples soon to test the theory.

The first round of cap fusion tests at 100 psig pressure were completed, followed by 1,000-hour hydrostatic pressure testing. The company is also developing coil designs for the electrofusion cap and evaluating the changes required for the tee body.

In 2019, the manufacturer molded additional fittings. and refined the procedure for installing socket-fused caps following the tapping operation (into a live main).

An additional company was contacted about its tapping tee electrofusion cap. This is currently designed for its own tapping tees; however, the company noted that it could be designed for anyone's tapping tee with a few mold changes.

A custom mold cavity was built to produce a service tee fitting without the tower threads for a standard threaded cap.

The manufacturer's opinion is that in order to safely and consistently perform the cap fusion process, a new sidewall tool needs to be developed that combines both the sidewall fusion and the socket fusion to keep everything in alignment.

Status

Researchers are gathering information from sponsors regarding the expected number of retrofits and interest in fusible caps for new installations. The project team continue to follow-up with developmental activities being performed by the product manufacturer.

Cap being installed on service tee.

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Piercing Tool Redevelopment – Enhancement to Remove "Mole" from Small Excavations

The focus of this project is on the design and development of a concept for a piercing tool that will enable the installation of gas services and removal of the piercing tool through small keyhole excavations.

Project Description

In recent years, the use of keyhole technologies has increased significantly due to the ability to reduce pavement-restoration and landscaping costs by avoiding trenching. Recent tool development now allows utilities and their contractors to install and replace gas services through a 24-inch keyhole excavation.

One remaining item needing to be addressed is the process of installing the service line from the house to the keyhole. Piercing tools can be used today to trenchlessly install a new service from the house to a small excavation; however, extracting the tool ("mole") from a small keyhole excavation cannot be accomplished as the tool is too long to be removed. The crews must back up the piercing tool to the entrance pit; taking more time and effort.

This project is focused on making enhancements to currently used piercing tools to allow them to be removed through small excavations (24 inches in diameter).

Deliverables

The deliverables for this project will include a summary of the sponsors' requirements and conceptual designs for the piercing tool.

Benefits

Keyhole and trenchless technologies have provided several utilities with considerable advantages over standard excavation and restoration techniques. However, most utilities state that additional equipment/tool development needs to be conducted to fully realize the benefits of these practices.

This project addresses one of the final processes of renewing and/or installing gas services through small holes by working with existing trenchless equipment manufacturers to develop piercing tool concepts that can be used in conjunction with keyholes. This will reduce the cost of serving customers, especially in urban environments that have mains under pavement.

Right-of-way excavations have become expensive, cumbersome, and require traffic control that may cause congestion. Municipal mandates and fees are also being applied, which can substantially increase the cost of reinstating pavement.

Both keyhole and trenchless construction practices provide opportunities to address today's complex underground infrastructure issues economically, safely, and with a minimum of inconvenience to the public and impact to the environment.

Technical Concept & Approach

An initial survey was conducted to better identify the needs and piercing equipment used by the project sponsors and their construction partners. A summary of the sponsor requirements for installing/replacing services using trenchless methods will be compiled.

Based on identified needs and requirements, the project team will develop conceptual piercing-tool designs aimed at developing a tool to be used more efficiently with small excavations. This may include various designs to allow the piercing tool to either be started in the small excavation or removed from the excavation (no need to reverse the tool all the way back to the entry pit).

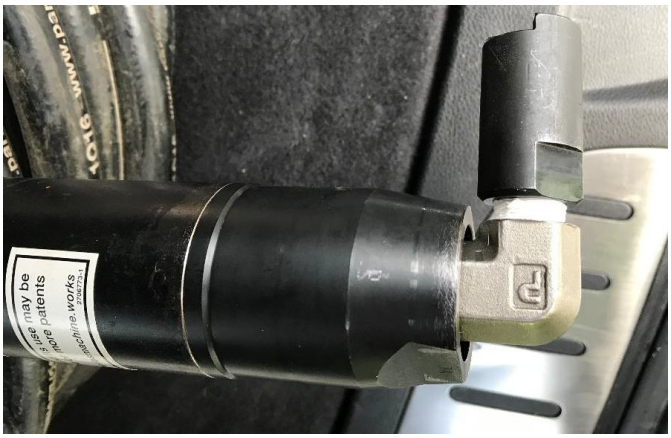
The project team will meet with various piercing tool (trenchless technology) manufacturers to determine interest in developing an enhanced piercing tool.

Results

The project team, along with the project sponsors, identified several concepts and designs for a mole so it can be removed from a 24-inch keyhole. Subsequently, project representatives contacted trenchless-equipment manufacturers to discuss a potential partnership to design a mole based on the various concepts. One company presented a concept it developed for launching a mole from the keyhole to the house.

The project team reviewed various practices that are currently being performed by utilities and reviewed the designs from manufacturers. It was discovered that one manufacturer offers a piercing tool that is approximately 30 inches long for a two-inch-diameter bore. The company has agreed to investigate its current mole design to see if the tool, with slight modifications, can be used in a 24-inch-diameter keyhole. The project team visited the manufacturer to discuss design specifics for a mole that can be used while utilizing keyhole excavations. They are hesitant in creating a new mole design without first testing its series of moles (new shorter designs) in order to insert a service through a keyhole.

In 2018, preparations were made for the testing at the manufacturer's facility to determine if the company's existing pneumatic moles can be removed or inserted through a 24-inch keyhole. However, tests were cancelled due to lack of sponsor involvement. The manufacturer was seeking direct sponsor input prior to making decisions about modifying their current shorter mole design. This field trial of the shorter tool will help determine the need for possible modifications (i.e., shortening the length, making pneumatic hose articulating, etc.) to use it in keyholes.



90-degree adapter on rear of piercing system.

In 2019, one of the project sponsors stated interest in testing the 30-inch piercing tool on one of their construction sites with the minor changes the manufacturer suggested. The company's system was subsequently demonstrated in the field and launched from a 24-inch keyhole with a custom 90-degree adapter. The system was able to successfully enter into the vacuum excavation wall of the keyhole using the custom adapter. The adapter was then removed so that the flexible pneumatic hosewhip could be installed for the rest of the piercing tool operation. With both of these operations, the system was successful at reaching a trench on the far side of a residential street. However, there were concerns with how the adapter would be removed and the flexible hosewhip would be installed at the bottom of the 24-inch-diameter keyhole. Therefore there were discussions regarding the development of a permanent adapter which could change angles.

The company will develop other adapter designs, such as a swivel or pivot that would allow the adapter to remain on the system for the entire trenchless piercing operation. The project team will support this design process.

Status

Project is running behind schedule due to lack of interest from manufacturers to make changes to existing piercing tools. In order to overcome this pushback, the project team is engaging manufacturers to try and develop a simplified guide system to be used with existing piercing tools in keyholes.

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Remote Emergency Main Shutoff – Stopping Off Low-Pressure Mains with No Excavation

In this project, the objective is to develop an effective Remote Emergency Main Shutoff (REMS) system that will isolate large-diameter, low-pressure main lines without the need to excavate. This will greatly reduce utility response time in emergency situations.

Project Description

During an emergency situation (e.g., a major gas leak or main break), isolation of certain sections of gas mains are required to safely shut off the flow of gas. Depending on the location of the leak, the nearest valve(s) to stop the leak could be blocks away, leading to a large number of customer outages. Also, in order to currently stop off the flow of gas, traditional stoppers must be installed on the pipe, requiring excavations to be made, which often takes significant time, especially when pipe is under pavement.

In previous efforts, researchers developed a Service Applied Main Stopper (SAMS) system. The concept involves a snaking device that is inserted through service lines equal to or greater than 1.5 inches in diameter. Once the device reaches the main line, an inflatable bag is filled to stop off the flow of gas. While there were some successful prototype tests of the SAMS system, results were inconsistent.

In this project, the goal is to develop an effective Remote Emergency Main Shutoff (REMS) system based on the SAMS system that will isolate large-diameter, low-pressure main lines without the need to excavate.

Deliverables

The deliverables from this project will include:

- The design and development of a prototype of REMS system, and
- A Final Report detailing all aspects of the program.

Benefits

Having a system to quickly isolate sections of gas pipe without the need for excavation would enable utilities to more efficiently stop off the release of gas during abnormal events. After the emergency has passed, the line can then be excavated to repair the pipe and remove the REMS system. Such a system can minimize potential damage resulting from a major gas leak along with improving safety to the general public, first responders, and employees.

Technical Concept & Approach

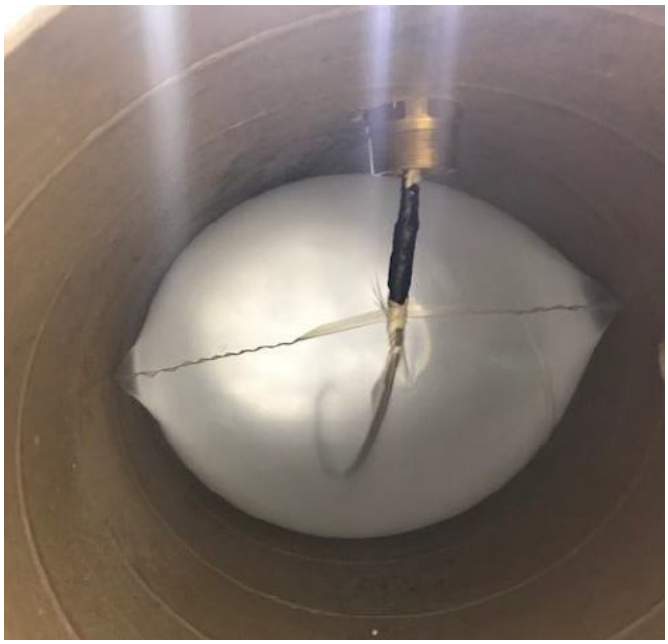
Specific tasks in this project include:

- Prototype Development
- Prototype/System Evaluation, and
- Prototype Modifications and Reevaluation.

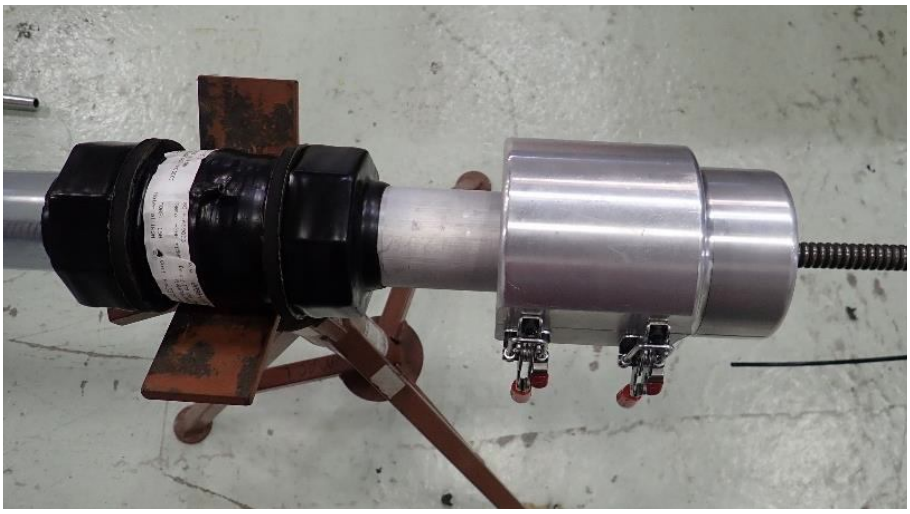
Results

In prototype testing in 2017, the project team was able to successfully navigate a six-inch bag down a 1.25-inch steel service line and into a six-inch main line and, using a redesigned air-inflation setup, was able to fill the six-inch bag in 20 seconds to fully expand to block a six-inch-diameter plastic pipe.

The REMS expandable bag system was designed to fill two different sized mains: six- and 20- inch-diameter mains. This was done because 40% of the industry service responses said that they would like to use this system on six-inch mains and smaller and the largest size they would expect would be 20-inch mains. The bags are made out of a polyurethane material that is designed to expand to the size of the main while being



20-inch bag in 20-inch-diameter pipe.



Left:Hinged stuffing box closed onto a two-inch pipe and cable behind a 20-inch bag. Right: Bag navigation and inflation testing.

resistant to tears and punctures. The system also uses two different style tips in order to navigate around different style fittings.

The design for six-inch systems was able to go through a 1-1/4-inch elbow fitting and street tee and was able to inflate to fill the main.

In March 2018, the Final Report for Phase 1 of this project was released. Phase 2 of this project involves the development of new concepts navigating the lip inside the steel elbow fitting. In addition, team members are working with the bag manufacturer to develop a new generation of bag to address the issues encountered in Phase 1 of this project.

Based on sponsor feedback, the testing was re-focused in include curb valves in addition to the elbow fittings. In tests, technicians were able to successfully navigate the 20-inch REMS device through a curb valve, elbow fitting, and street tee. After being manipulated by the operator, the bag was able to fully inflate and lock onto the walls of the pipe.

The project team developed a new cable connector which allowed researchers to increase the cable going through the 20-inch bag from 0.25-inch diameter to 0.375-inch diameter. This increase in cable size allowed for more force to be transmitted to the bag to get around the elbow and to prevent kinking with the air line.

A new 20-inch bag has a felt-like material inside designed to not compress during the vacuum process to help take more air out of the bag before deployment. Researchers also added a silicone spray to the outside of the bag to help it navigate around the elbow and street tee.

In 2019, researchers tested the 20-inch REMS device in an elbow and street tee. Researchers developed a new cable connector prototype to allow for the bag to inflate quicker and a stuffing box concept which can allow for the bag to be inserted into the pipe and close onto the cable behind it. A device was developed which slides up and down the cable and then can be locked on to the cable to provide a grip which allows the operator to be able to spin the cable manually.

The project team tested a prototype version of the turning device and cable connector and were able to successfully navigate the pipe and fitting configuration with the 20-inch bag and inflate the bag much quicker with the new cable connector feeding the air.

Status

Prototype testing continues. Researchers will conclude the laboratory testing of the 20-inch REMS device on a PE pipe and fitting configuration with one elbow and the full port ball valve.

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Improved Safe Excavation Productivity for Locating Buried Utilities

The goal of this project is to improve the effectiveness of vacuum excavation with compressed air to equal the productivity of hydro-excavation. The objective is to develop a new tool or system of tools with increased volumetric excavation rates over existing air-digging tools.

Project Description

Soft digging via pressurized water is becoming a common method for utility excavation. However, water can, when improperly applied, result in over-saturation of the soil. Also, if water is used at too high a pressure, it can damage coatings or plastic pipe, old steel and cast-iron gas lines, or other buried utilities.

In recent years, several organizations have conducted research into hydro-excavation:

- Enbridge, Inc., and the University of Waterloo conducted research and published recommendations on maximum nozzle water pressure when digging around buried utilities. The results were used to create the hydro-excavation guidelines required by the Technical Standards and Safety Authority. Enbridge also conducted research related to improved productivity and safety of orbiting/spinning water nozzles.
- The Waterjet Technology Association conducted research on nozzle designs and the efficacy of pulse-jet waterjets.
- Gas Technology Institute (GTI) conducted various studies on the effects of high-pressure water on various types of gas pipes. GTI's keyhole program also developed a Vacuum Excavation Guideline document to support proper excavation when using vacuum technology.

The objective for this project is to improve the effectiveness of vacuum excavation with compressed air to equal the productivity of hydro-excavation. The aim is to develop a new tool or system of tools with increased volumetric excavation rates over existing air-digging tools.

Additional goals are to reduce the water used during hydro-excavation. This will reduce the cost of disposal due to the need to haul off the wet spoil (wet spoil is often treated as hazardous and requires special disposal fees and sites) and reduce the risk of damage to underground utilities.

Deliverables

Deliverables include:

- A Final Report on testing and research.
- A field-tested prototype tool or system of tools that provides a volumetric excavation rate that is equivalent to excavating with water. This tool or system of tools may utilize compressed air only, a combination of compressed air and water, or compressed air and other medium.
- Recommended best practice for excavating around buried gas utility lines and other buried utilities.

Benefits

Digging with compressed air is a growing alternative to digging with water and is estimated to account for approximately 20% of the soft-dig market today. The primary advantage of vacuum excavation is safety by greatly minimizing the chance of damaging the underground infrastructure.

Technical Concept & Approach

This project is being conducted in three phases:

- **Phase 1 - Testing**

  Testing and benchmarking will be conducted to understand the volumetric excavation rate (various soils excavated in cubic feet per minute) of the commercially available vacuum-excavation tools. This phase includes testing the average excavation productivity when using water or compressed air. The project team will also test and define how changing compressed airflow and pressure affects excavation rates; test the compressed-air impact to various gas pipe materials to determine the maximum threshold of safety for air pressure; and test and define what pressure and airflow is required to equal the average excavation rate of hydro-excavation. If the research finds that compressed air is unable to achieve comparable excavation rates with water, the project will be terminated.

- **Phase 2 - Research and Design**

  Research will be conducted on the manipulation of compressed air in other industries, such as jet propulsion. This research would require fluid mechanics expertise and would include investigation and validation of what, if any, value adding water or another gas to compressed air has on digging efficacy.

- **Phase 3 - Prototyping**

  The project team will develop a new air-excavation nozzle, air lance, air tool, or system of tools that provides an excavation rate equal to that of using water in difficult soil conditions.

Results

Testing was conducted on existing air lances and water nozzles in silty and clay soils. It was found that in both soils some of the existing air lances performed excavations at rates faster than the existing water nozzles. It was determined that further testing would be needed with the existing air lances and water nozzles on harder clay soil samples that better resemble “difficult to excavate” field conditions.

Puncture testing with the low-flow air lances and water nozzles on polyethylene (PE) pipes was found that the low-flow air lances and spinning water nozzles did not puncture the outer wall of the PE pipe even at distances as close as one inch above the surface of the pipe. However, the straight-jet water nozzle did puncture the outer wall of the medium-density PE pipe and punctured the outer wall and pierced the inner wall of the Aldyl-A pipe at distances as far as 11 inches away.

While evaluating eight different air lances and four different water nozzles in three different types of soil (silt, clay soil, and naturally compacted silty clay soil in Texas), it was found that on every type of soil the high-pressure and high-flow combination air lances had faster excavation rates than the water nozzles. In addition, they were safer to use around various types of pipes than the single-jet water nozzles as the air lances did not damage the pipe while being held one inch above the pipe, while the single-jet water nozzles punctured the pipe at distances as far away as 11 inches in 12 seconds or less. However, the rotating water nozzles were also very safe around the pipe where they also did not damage the pipe while being held one inch above the pipe in place for five minutes.

In 2019, efforts were initiated to develop a new nozzle design. However, based on results from Phase 1 and discussions with the project sponsors, it has been determined that due to the success of the combination high-pressure, high-flow nozzles, that remaining funds should be used to test these nozzles on other pipe materials instead of developing a new nozzle.

Status

A Phase 1 Final Report is being finalized.

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Enhancement of the Dynamic Cone Penetrometer Compaction Device

For this project, researchers enhanced the Dynamic Cone Penetrometer device for use in soil-compaction measurements of backfills. Significant improvements were made to the system's data control unit and functionality.

Project Description

The Dynamic Cone Penetrometer (DCP) is a simple handheld device used in field conditions to ensure proper soil compaction. With the DCP, an operator drops a five-pound weight onto a cone for a distance of 3.25 inches in the soil. The number of drops correlates to percent compaction of the soil based on the calibration of the device in similar soils with known percent compaction.

The focus of this project was to enhance the device by updating its data-transfer and management system and improve its use and data-recording capabilities.

Deliverables

The deliverables for this project included an enhanced commercial version of the DCP and a Final Report summarizing the development task and the operation manual.

Benefits

Some utilities use a Nuclear Density Gauge (NDG) to determine soil compaction. However, the use of the DCP in place of the NDG provides a safer alternative and significant savings from the current practice of using contractors for compaction-control measurements.

The modifications to the DCP provided through this project improved the device's functionality, data control, and management of the compaction results by the operators. This enabled the operators and supervisors to have permanent records of the compaction operations.

The updated device will also facilitate its acceptance by state highway departments and municipalities as a state-of-the-art device, and gain their confidence that street cuts are being backfilled properly to avoid patch failures and callbacks.

Technical Concept & Approach

The scope of this project included:

- Development and production of a new DCP device
- Evaluation of the enhanced functionality of the new device in controlled tests, and
- Demonstration of the device in a field test and comparison of the enhanced DCP with the NDG device at a selected utility site.

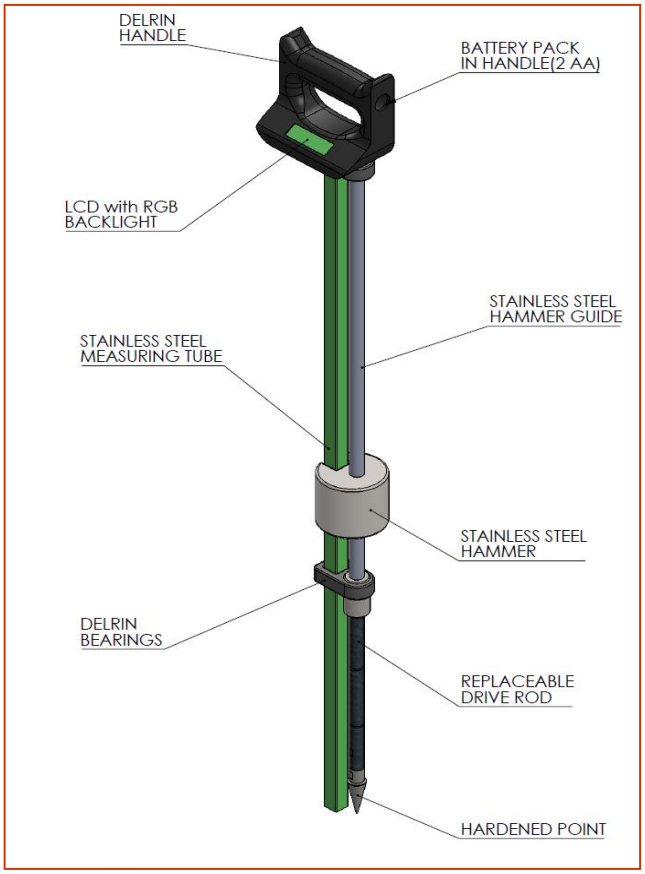
The enhancement needs of the device were previously identified during demonstrations for utilities and regulators.

The device was first evaluated for the enhanced functionality in controlled tests. The calibration of the device with the NDG will not be required unless the backfill is different from the ones used in the original calibrations.

Results

The project team enhanced the DCP by updating its data-storage functionality and by providing the following modifications:

- **Added a data communication keypad:** The team installed a built-in Bluetooth connection and interface. The device now communicates with a standard Android cellular phone/tablet for data entry, collection, and display.
- **Enhanced data entry at the site:** Data entry included automatic counting and recording of the number of drops and cone-penetration distance in soil. It also records the GPS coordinates from the phone/tablet device to identify and record site location.
- **Ensured full lift of the drop-weight:** A control was added to the algorithm to ensure that the operator lifted the drop-weight to its full-height, as required in the testing procedure. When the drop-weight is not fully lifted, the drop will not be counted as complete.
- **Data output:** Formatted the data input and output to provide a full on-site testing report in the mobile device, with capability to e-mail the report to the office.
- **Improved the DCP design:** Material and manufacturing were enhanced, and hardened cone-tips provided for resiliency.



Five DCP units were built for testing and evaluation by the utilities and to provide feedback for its use and acceptance in the compaction measurements of backfills in place of the NDG.

Bluetooth communication provides the primary method for controlling and reading data between the DCP device and the tablet/phone application. The whole Bluetooth pairing and exchanging of information process was investigated.

Status

This project is complete. A Final Report was issued in March 2019.

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Evaluation of the ORFEUS Look-Ahead Technology for Horizontal Directional Drilling

Research is being conducted to improve the ORFEUS obstacle-detection technology by: making improvements to the bore head radar; software enhancements to improve the user interface; improvements in the communications to the drill head; performing system validations and market launch preparations; and conducting operational field tests.

Project Description

Cross bores have become an industry concern because of incidents involving natural gas mains and services that were installed using trenchless technology that inadvertently transected a sewer line or private septic system.

The objective is to produce a field-proven, market-ready, obstacle-location technology for use in horizontal directional drilling (HDD) applications. ORFEUS (Optimized Radar to Find Every Utility in the Street) is an effort aimed at developing a safe, cost-effective "look-ahead" system. The ORFEUS effort is conducted by a collaborative organization of multiple companies to develop a prototype that has been field tested, both in Europe and the U.S. This project seeks to further develop the technology to bring forward a commercially viable product for identifying obstacles in and around the path of a HDD drill rig, therefore, reducing third-party damage to underground utilities.

This project seeks to improve the ORFEUS obstacle-detection technology by: making improvements to the bore head radar; software enhancements to improve the user interface; improvements in the communications to the drill head, enabling the lengthening of the total drill length; performing system validations and market launch preparations; and conducting operational field tests.

Deliverables

The deliverables for this project include field demonstrations, reporting of demonstration results, and a Final Report.

Benefits

HDD offers significant benefits for urban environments by minimizing the disruption caused by the installation of underground utility infrastructure such as natural gas pipelines. The continual growth of using HDD operations has raised the need to reduce the threat of damage to other underground infrastructure, especially unknown sewer mains and laterals.

Operating within the drill head of HDD systems, ORFEUS provides real-time obstacle detection needed to increase the safety margins of HDD operations to allow its use in the widest possible range of conditions.

This technology has the potential to markedly increase safety for homeowners, utility companies, and contractors from cross bore incidents. This technology can also enhance the installations of distribution gas lines in difficult areas where other utilities may intersect.

Performing live field demonstrations in the U.S. provides a deeper understanding of how this system operates, its benefits, and its limitations.

Technical Concept & Approach

The ORFEUS system consists of:

- Equipment at the surface
- A modem to connect the operator's computer to the drill string transmission line
- A power supply to deliver power to the drill string transmission line
- A slip-ring system to interface the stationary surface system to the rotating drill string
- A communications module at the drill head

- A modem to connect the radar system to the drill string transmission line, and
- A unit to receive power transmitted along the drill string and convert it into the various voltages required by the modem and radar system,

The technology has a look-ahead range of up to about 20 inches, which includes both straight ahead of the drill tip and to the sides of the drill tip.

Through this project, the system was demonstrated at a field site in California in 2017. The robustness of the system was proven, as well as the ability to fulfill the requirement of locating and recognizing obstacles within the drilling envelope. Most of the engineering challenges have been overcome, and the task ahead is to refine the technology to produce a marketable system.

Results

A field trial of the ORFEUS system was conducted in April of 2017 in California. The equipment was tested on a purposely built testing area including several targets (utilities and boulders). Results from the trial confirmed the performance of the ORFEUS system and the suitability of the technology for preventing the striking of utilities and other objects when drilling through the ground.

Specifically, a selection of non-conductive and metallic pipes with different diameters and layout with respect to the expected drilling path were used for the trial. The ground in the testing area consisted of moderately wet clay mixed with gravel/crushed rocks.

Superficially, the development in this project appears to be a straight-forward extension of ground-probing radar, a technology that has been in existence for many decades. There are, however, some significant differences, including:

- A very demanding spatial restriction, both in terms of volume and geometry, which is not a serious design constraint in conventional GPR systems. The principal consequence of this is a limitation in antenna size, which prevents the propagation of low-frequency radar signals, required for the penetration of the ground.
- The detection and recognition of targets requires the integration of many radar signals, assembled as a coherent set, from a well-defined and well-understood strategy of scanning the ground as a rectangular grid. This is not possible with a drill string radar, where the scanning produces data in a cylindrical format.
- Processing and reducing the volume of data produced by the radar requires the application of significant computing resources with associated high-power requirements. In addition, the transmission of even a reduced set of data to the surface by a wireless method, with the present available technology, is not possible. It is, therefore, necessary to transmit large volumes of radar data to the surface, and power from the surface, along the drill string.
- A high shock, vibration, and temperature environment within the drill head need a careful engineering approach to the protection of the electronic systems to ensure robustness and reliability.
- Producing a workable, integrated technical solution to the issues has required close cooperation between engineering organizations.

This project resulted in the evaluation of a practical drill string radar system that has now undergone a series of demanding operational field trials in Europe and a successful demonstration on a prepared test site in the U.S.

In 2019, the project team reached a new path forward with the addition of a main subcontractor with other subcontractors. Terms of the agreements are being finalized.

Status

Once the contracts are finalized, the subcontractors will begin initial steps for the following tasks:

- **HDD Bore head Radar**

  Initiate the HDD radar hardware development incorporating system hardware architecture, radar antennas and electronics, angular position sensor, and mechanical redesign and ruggedization.

- **Communications Link**

  Initiate communications link development, incorporating drill tip communications and power supply, in-cab modem and power supply, and in-cab wiring systems.

- **System Software**

  Initiate tasks for system software requirements.

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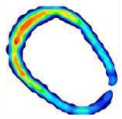
Interfacial Contact Verification System for Saddle Fittings

Research is being conducted in an effort to develop a pressure-mapping system that would improve infrastructure safety by being able to confirm if a plastic pipe is properly prepared in terms of its fusion-zone geometry.



Project Description

In natural gas plastic piping systems, variability in component and field conditions (e.g., pipe ovality, uneven scraping, flat spots on the pipe, weather, trench conditions, and pipe-preparation tools) can lead to inconsistency in pipe preparation and, ultimately, fusions.

One situation operators encounter is where pipe preparation resulted in an uneven surface, which may present an excessive gap between the pipe and a saddle fitting. Excessive gaps can lead to improper fusion or shorting of the electrofusion coil from excessive movement of the wires.

The objective for this project is to develop a system that can confirm if a pipe is properly prepared in terms of its fusion-zone geometry.

Pressure sensor used for pipe ovality check.

Currently, saddle tee fittings use a mechanical under-clamp or top-mount clamp that compresses the fitting to the outside of the pipe using levers, springs, and/or bolts. However, there is no measurement from this device as to how much force is being applied between the fitting and the pipe. In addition, there is currently no method to ensure that the entire fusion zone is in contact with the pipe, which is important for attaining a quality fusion.

For this project, researchers are evaluating a mature technology that is capable of directly mapping the interfacial force between a pipe and a clamped saddle fitting. Such a system can directly confirm if gaps exist between a saddle fitting and the pipe, as well as digitally save force readings.

Deliverables

The deliverables for this project include:

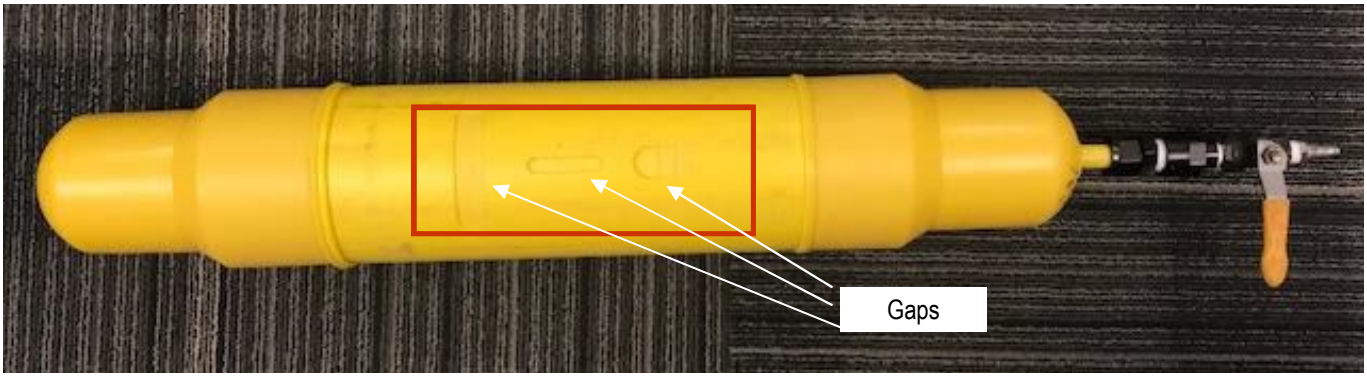
- A feasibility study report on adaptation of the mapping technology to a saddle interfacial contact verification system
- A dataset of measurements that shows whether the system can identify interfacial contact gaps, and
- A correlation of interfacial force measurements to fusion-integrity measurements.

If a field deployable system is proved viable, a Phase 2 of this project may be proposed to develop a wireless sensor system that is suitable for field use.

Benefits

Verification of fusion interface contact could increase saddle-fusion quality and avoid costly rework by allowing field crews to:

- Avoid fusing fittings where excessive gaps are present
- Correct inadequate pipe preparation before fusing, and



Pipe sample with gaps and arrangements to allow pressurization.

- Obtain quantitative and qualitative field data for use in documenting fusion processes from a quality-assurance standpoint.

Some utilities have seen instances, where upon excavation, a service tee that was fused to a pipe completely pops off with minimal to no force applied. Ensuring proper contact pressure between the tee and the pipe could help prevent this from happening in the future.

Technical Concept & Approach

The project team is conducting a feasibility study of potential modifications to mapping system and/or technology to make an affordable, field-deployable system that is suitable for saddle fittings.

Researchers are evaluating the system with a number of saddle fittings covering a representative pipe-size range.

The evaluation includes the following steps:

- Measurements on pipe with known gap size and ovality will be performed to check if force readings identify the interfacial contact gaps, and
- The testing of saddle fusions to correlate interfacial force readings with fusion peel/de-cohesion test results.

At the conclusion of this project, a Final Report will be issued with an overview of the results of the testing.

Results

This project began in 2016 with the development of a survey to review customer needs and a testing approach.

In 2017, project researchers completed the design work on calibration plates and initiated the fabrication in 2018.

The project team modified the test fixture design for better controllability (by use of a pneumatic actuator). Attention was given to the test fixture's geometry to ensure that it correctly applies pressure to the sensors, as in the field application (saddle clamping). A test method for evaluating the pressure-mapping system was developed to quantify measurement hysteresis and repeatability.

Pressure sensors were tested on a four-inch-diameter plastic pipe. An aluminum tube with reasonable circularity and smooth surface finish was fabricated for reference purposes. However, due to sensitiveness of the sensor, a high-tolerance reference sample may be required, which is expensive. Alternative approaches of using air-filled bladders are being explored.

The pressure senor was evaluated for its repeatability, hysteresis, and ability to determine pipe ovality. The response of the pressure sensor indicated good repeatability. The hysteresis test indicated that the pressure sensor response drifts over successive measurements and thus requires frequent calibration. The calibration frequency depends on the operator/application tolerance level for the drift. The sensor is currently being tested to verify the interfacial contact on a pipe with 5% ovality. De-cohesion tests will be performed to correlate fusion ductility with the response of the interfacial pressure sensor.

Testing of the interfacial pressure sensor was completed during the first quarter of 2019.

Status

The project team is completing the Final Report.

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Evaluation of Excess Flow Valves at Environmental Conditions That Can Cause False Closures

In this project, researchers evaluated the performance of excess flow valves (EFVs) at environmental conditions that can cause false closures. Evaluations are being conducted at various temperatures and pressures.

Project Description

False closures of EFVs have been of concern for utilities, especially false closures during cold-temperature conditions. These cold conditions – in combination with EFVs in close proximity to farm-tap regulators with their large pressure drops – have caused issues that are suspected to be related to freeze-up. While there is little information on the performance of EFVs at these extreme environmental conditions, at least one utility has reported false closures on EFVs manufactured by all three major EFV manufacturers.

Currently, ASTM F1802 *Standard Test Method for Performance Testing of Excess Flow Valves* requires that all EFV tests are to be performed at 67°F +/- 10°F. However, the standard allows, but does not require, alternative test temperatures of 0°F and 100°F +/- 10°F.

In this project, researchers evaluated the performance of EFVs at environmental conditions that can cause false closures – specifically, evaluations of EFVs under cold and humid conditions.

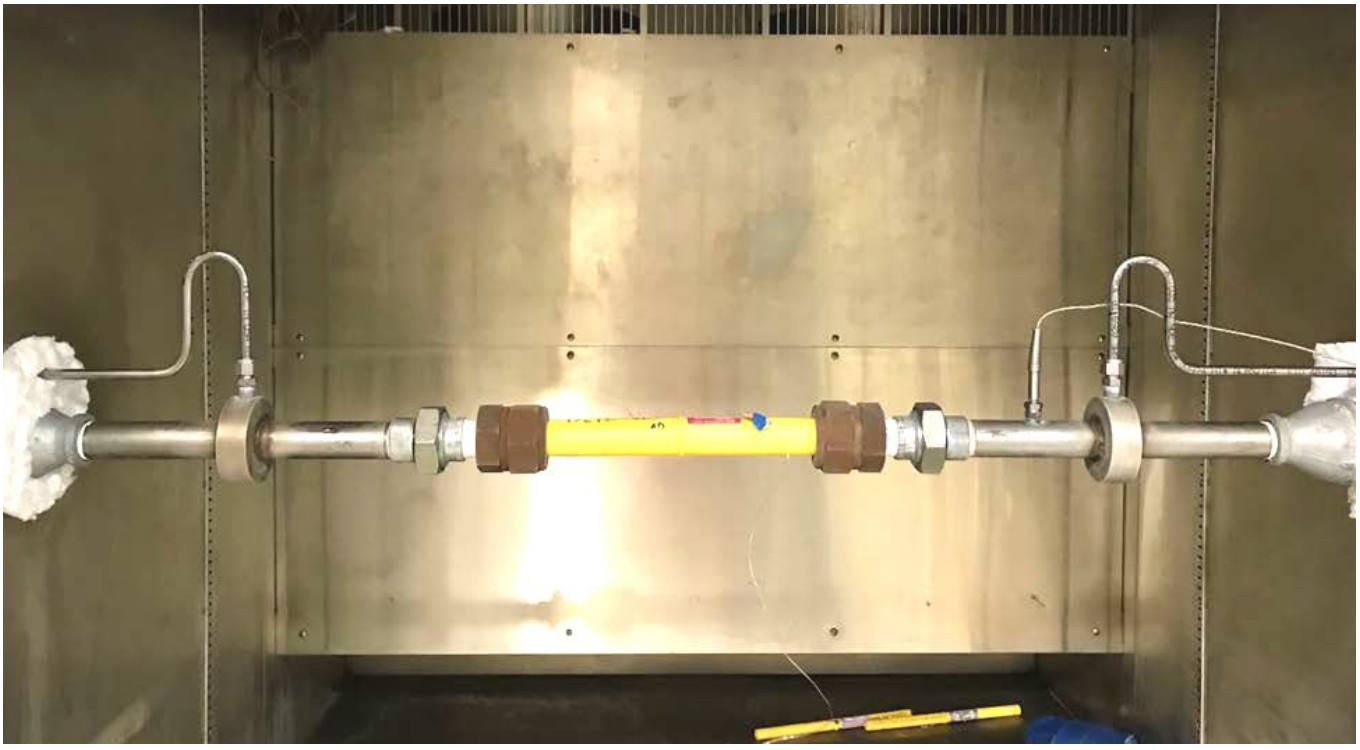
Deliverables

Deliverables for this project include an identification of environmental conditions that would cause icing and blocking of EFVs.

Benefits

Current requirements call for the installation of EFVs on all new services for single-family residences. There are also proposed plans to incorporate multi-family, commercial, and light-industrial customers into the requirements as well. Consequently, there is a need to better understand the performance of these EFVs at various environmental conditions.

While some information on EFV performance is available through manufacturer data, there is little to no information related to EFV performance in extreme environmental conditions.



EFV setup inside environmental chamber for low temperature testing.

"Enbridge was experiencing false closures in excess flow valves due to cold winter temperatures and water present in the gas supply. The evaluation work that was completed by OTD enabled us to confirm the conditions at which the false closures would occur. This, in turn, allowed us to alert the excess flow valve supplier about this issue and source a new valve for future installations."

- David Furdas
Senior Engineer, Innovation & Technology
Innovation & Technology
Enbridge Gas Inc.

This project will assist utilities by providing a better understanding of the capabilities of EFVs at various operating conditions. This project may also support future modification to the ASTM testing standard.

Technical Concept & Approach

Initial tasks included the development of an industry survey to address the issues/concerns with EFVs, occurrence of accidental or unwanted closures, service length range, environmental conditions, and other EFV experiences and concerns.

The performance evaluation for EFVs is being conducted similarly to that of the previous residential and commercial EFV evaluation projects but include the minimum and maximum environmental conditions.

Research is addressing: 1) performance differences between manufacturers at low and high temperatures, low and high pressures, etc., 2) false closures, and 3) the effect of moisture in the line at various temperatures and loads.

Results

The original objective for this project was to evaluate the performance of EFVs at environmental conditions that can cause false closures – specifically, evaluations of EFVs at low and high temperatures and pressures. The project team solicited feedback from sponsors regarding the false closure of EFV through a survey and conference calls. Based on the feedback, it was agreed to pursue the testing under cold and humid (wet gas) conditions.

Technicians upgraded an existing EFV testing apparatus to test the EFVs at the determined environmental conditions and to ensure the accuracy and repeatability of the test data. The upgraded test apparatus includes datalogging of all sensors and automation of the critical test control parameters (pressure and flow rate), which are essential for quantifying the dynamic behavior of EFVs and achieving good test control.

Three EFV models were tested at low temperature (-4°F/-18°C) and with humid air streams flowing through them.

Based on the test observations:

1. Blockage of the EFV can occur under a condition of temperature below water's freezing point and sufficient humidity in a pipeline system. Low temperatures can be due to inherent ground conditions during cold seasons, and/or, due to the Joule-Thomson effect at the outlet of pressure regulators with a large pressure drop (e.g., farm taps).

2. EFVs are expected to be a formation site for ice (under icing conditions) since they are inherently a flow bottleneck in a service line.

3. EFVs do not trip due to excess flow under icing conditions; instead, ice buildup gradually constrains flow until complete blockage.

4. EFV performance is not affected by high humidity at 72°F/23°C ambient temperature.

It would be prudent to consider any EFVs exposed to freezing temperatures to be at risk of getting blocked by ice buildup. The degree of risk could be explored by further testing at various humidity levels, at temperatures at or below freezing.

Due to multiple factors (e.g., soil temperature, humidity, and presence of contaminants), the determination of exact conditions that causes ice formation is challenging. Investing in monitoring of temperature and humidity levels of a gas stream may be difficult to justify considering the sporadic nature of the phenomenon. Ensuring dryness of the gas stream will help in mitigating the icing issue to a large extent.

Status

The project is complete. A Final Report was issued in March 2019.Future work may include a more comprehensive exploration of the temperature and humidity limits that result in ice formation on EFVs. Such an exploration can inform operators as to the maximum allowable humidity level or minimum allowable temperature for parts of their system that may be susceptible to sub-freezing temperatures.

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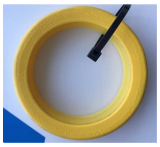
Polyethylene Systems Joint Industry Program (JIP) – A Total Quality Approach



The Polyethylene Systems JIP was established in 2016 to provide funding, guidance, and input into the process and priorities of specific R&D initiatives. One of the main goals of the program is to provide clear guidance that incorporate newly developed knowledge into currently accepted best practices.

Project Description

For natural gas distribution systems, the advantages of using modern polyethylene (PE) pipe over steel are universally accepted to the point that today PE pipe is used in the majority of all new and replacement gas pipe installations. However, the increased use of plastic materials has led to an increased level of scrutiny of PE piping systems and fusion practices. Regulators and utilities alike are looking to enhance the fusion process and implement quality controls to ensure the integrity of PE fusions and other aspects of PE pipe maintenance and repair.

In response, OTD established an industry-sponsored collaborative research program to provide funding, guidance, and input into the process and priorities of specific initiatives. The PE Systems Joint Industry Program (JIP) is focused on addressing the plastic systems R&D gaps and the standards development needed to enhance the design, installation, and operation of PE gas distribution systems.

Initial activities involve the development of a *Total Quality Approach to PE Fusion,* in which critical fusion-process parameters – inclusive of pipe, fittings, surface preparation, fusion equipment, controls and tolerances – would be clearly understood, defined, and validated for use and adoption throughout the industry.

Elements of this *Total Quality Approach* include:

- Review and definition of best practices in surface-preparation procedures
- Definition of essential variables that impact the integrity of PE fusions, along with testing to understand the limits of essential variables
- Development and qualification of new fusion procedures (as needed)
- Incorporation of the above into applicable industry standards
- Development of *in-situ* quality and process control metrics along with automated or standardized methods to ensure variables are within limits
- Implementation of appropriate tracking and traceability of PE fusions, and
- Development of field-deployable fusion non-destructive evaluation methods

The *Total Quality Approach to PE Fusion* is modeled after the American Society of Mechanical Engineers and American Petroleum Institute standards for the welding of steel pipe.

Deliverables

The deliverables for this project include:

- Establishment of a Program Advisory Team and Technical Steering Committee to prioritize and guide the efforts of this and future projects
- A well-defined set of projects and reports designed to fill in identified knowledge gaps pertaining to fusion procedures
- Clear guidance documents that incorporate the newly developed knowledge into currently accepted best practices, and
- Focused and consensus-driven efforts to improve existing standards and develop new standards where gaps exist.

Benefits

The PE Systems JIP is designed to establish a roadmap and prioritize tasks by identifying the most pressing industry needs and defining the scope of projects to address the identified needs. The JIP helps to secure and coordinate funding sources; coordinate and facilitate interaction and communication among various stakeholders; and communicate results.

Technical Concept & Approach

A Program Advisory Team oversees the entire program and a Technical Steering Committee was established to provide guidance to the program. The Technical Steering Committee guides the development of the research projects and scopes of work that will be performed.

Results

The PE systems JIP was established in 2016.

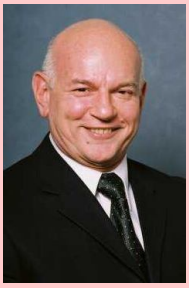
Program members include:

- OTD members
- Associations
- Various other utilities
- Manufacturers, and
- Contractors.

The major focus of the JIP participants is to identify and discuss industry needs, achieve consensus on prioritization of issues for project research, and participate in the direction and review of the various project efforts.

Recent industry discussions identified agroup of needs to help enhance the overall quality of plastic piping systems. The identified needs include:

- Fusion joining preparation best practice development
- Creation of ovality and out-of-round standards, including re-rounding guidelines
- A more thorough understanding of the durability of elastomers used in mechanical fittings
- Development of design guidelines for fittings, including the interaction of multiple materials with elastomeric seals
- Understanding the impact of heavy hydrocarbon permeation in PE pipe on mechanical joints.



"As a member of the JIP Steering Committee, I fully support the effort to improve the quality of polyethylene fusion joints. A chain is as strong as its weakest link, and a plastic pipeline is as strong as its weakest joint. Although polyethylene components are easily joined by the heat-fusion method, there continues to be an industry need to improve the overall quality of the joining method used in the field by incorporating the latest technology into our best practices."

- Dr. Gene Palermo
President
Palermo Plastics Pipe Consulting

- Best practices for evaluating new appurtenances
- Best practices for evaluating fusion procedures, and
- Evaluation of repair methods for plastic piping systems.

In 2018, pipe-fusion preparation guidelines were developed. The effort focused on cleaning and pipe preparation – how to properly clean pipe based on different field conditions (e.g., wind, moisture, and water in a ditch); using the "one-and-done" approach by using an approved single-use towel once and discarding the used towel after each cleaning step; peeling or scraping the pipe correctly, ensuring that if any remaining contamination is present, it is fully removed; and installing and fusing the fitting promptly after scraping to minimize any future contamination.

In 2019, a series of fusion joining preparation projects were completed. Various scrapers were tested with respect to scrape depth, scrape uniformity, and contamination (bentonite powder) removal, at different temperatures. Three solvents were tested with respect to contamination removal (talc, bentonite powder, and silicone grease), with three different cleaning tools (polyester fiber wipe, paper towel, and cotton rag).

Status

The project team developed industry best practices, scraping guidelines, and pipe-fusion preparation guidelines to enhance the overall integrity of plastic piping systems.

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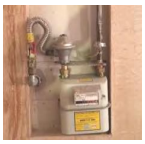
Guidelines for Indoor Meters, Regulators, and Piping



In this project, researchers are developing information to allow utilities to better categorize risks associated with inside meter set locations. The project team is also exploring alternative retrofit options incorporating state-of-the-art construction and design concepts.

Project Description

Decisions regarding meter replacement need to take into account various factors, including company policy, customer interest, and various codes and regulations. When utilities are inspecting existing indoor meter sets and/or moving out gas meters they must follow all codes along with their own company specifications in order to supply natural gas in a safe and compliant manner.

Clearance distance from various sources of ignition, house openings, and venting requirements have been in place for many years. However, many indoor meter sets still create challenges for utilities. Operators are seeking a better understanding of the risks regarding the various configurations of inside meter sets.

The objective of this project is to provide utilities with a standardized process for assessing risk associated with indoor meter set relocation outdoors or to other suitable locations. By utilizing the structured approach developed in this project, gas-system operators will be better able to categorize the risk associated with inside meter sets and examine these issues in greater detail.

As part of the project, researchers will investigate alternative retrofit and other options incorporating state-of-the-art construction and design concepts.

There are obvious concerns with relocating meters to outside the building in congested urban environments where there is little or no space for meter-set assemblies, as well as increased risk from vehicular damage.

Deliverables

Deliverables of this project include a practical strategy guide to identify and reduce the risks of inside meter sets and/or their relocation.

Benefits

Utilities are frequently challenged to find suitable locations to place meter-set assemblies that will reduce risk and satisfy the requirements of the various codes, the local commissions, and customer requests. This project will provide utilities with additional knowledge and retrofit options to validate meter-set placement and/or relocation decisions.

Technical Concept & Approach

The approach for this project is to perform a study which would categorize meter location and relocation

Gas meters installed indoors can present significant challenges for gas utilities.

challenges (based upon pre-defined installation situations) and identify risk prioritizations for the various installation categories. The study will also include the investigation of new concepts.

The project team will develop criteria for categorizing installation configurations and challenges. Once complete, a sampling plan will be developed for site assessment and characterization of utility baseline situations.

Researchers and utilities will coordinate random field surveys to better define and quantify the developed categories. Depending on the field survey results, categories and criteria may be refined. Results from the field surveys will be analyzed, categorized, and reviewed with each participating utility.

The results will be translated into technology-implementation plans geared to mitigate risk for specific categories of installation configurations. This may include products, best practices, and new technologies to mitigate the risk of the existing and/or relocated meter sets.

Results

Initially, project sponsors received an itemized list of procedures and operations-related information requests to serve as input into a risk-categorization model. The project team developed an online questionnaire/survey of operations and meter-relocation metrics information to serve as input into the model. Additionally, sponsor survey results and supplied documentation were integrated into a risk-categorization model.

The project team developed a strawman diagram that provides a framework for risk considerations related to the relocation of indoor meter sets. The model was converted into a paper form that was used in field settings to validate the model effectiveness in assessing indoor meter set relocation risk.

The risk-assessment form uses the following variables to assess the meter set's current indoor installation location:

- Building type
- Accessibility of meter set and piping
- Number of meters installed in area
- Volume of space where meter is installed
- Length of piping
- Ability to shut off gas flow
- Proximity to ignition sources, and
- Regulator vent configuration.

Researchers leveraged Esri's Survey 123 application to convert the paper form into an electronic format, capable of being accessed and completed via a field device.

The project team initiated a six-week field-pilot period in which project sponsors were encouraged to download the electronic indoor meter risk assessment form and test the system functionality in their real-world settings. Additionally, the project team finalized the initial set of risk-mitigation strategies for all risk categories and incorporated them into the form to display as potential next action steps.

In 2019, the project team identified a project sponsor interested in piloting the risk-assessment form and initiated communications to plan, schedule, and coordinate the logistics associated with executing a field trial. Additionally, the team conducted knowledge transfer with the organization to build their familiarity with the solution prior to hands-on application via a field pilot. A two-day field trial was conducted in early 2019 to assess the form's completeness and usability in a real-world setting. The pilot test went very well, and the form is field-ready. By the end of the second day, the field resource was able to complete the form in under five minutes

The project team completed the integration of the Indoor Meter Relocation Risk Assessment form into the Survey123 Connect Library. The form is now available to utilities for download as an additional tool in their field operations to consistently classify high-risk indoor meter locations and identify potential mitigation actions.

It is intended that the wide adoption of the form across the industry will lead to continued refinement and improvement over time. The form may be downloaded by navigating to the community tab of Survey123 Connect. Once downloaded, the form is ready to be used as is, or may be customized to meet the specific needs of your utility.

Status

Researchers are drafting a Final Report that incorporates field-pilot results and lessons learned. A webinar will be held with project sponsors to review and receive feedback on the report.

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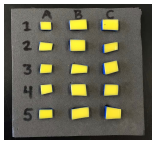
Assessment of PE Fittings Shelf Life



For this project, researchers quantified the aging process of PE fittings with respect to UV exposure and oxidation from air (at elevated temperatures). The aging process was quantified in terms of rate and extent (depth of aged material) to establish a proper understanding of PE fitting shelf life with and without fitting packaging.

Project Description

There is a need for consistent information regarding shelf life of polyethylene (PE) fittings. Currently, manufacturer specifications can range from a few years to many years, which leads to ambiguity when needing to decide whether or not to use stored components. It is also unclear as to under what exposure conditions these shelf lives are applicable. In addition, many fittings lack information regarding their manufactured date. Unlike PE pipe, which is required to include the manufactured date in the print line, fittings often do not include this critical piece of information. The data may be included in the 16-digit unique traceability identifier; however, this information cannot be easily deciphered.

The underlying physical processes of PE aging are well understood; however, a model for shelf-life prediction or residual shelf-life estimation, akin to the rate process method (RPM) model used for operational lifetime prediction, has not been developed. As with the creep process in PE, an RPM model is applicable to chemical processes such as oxidation of PE. The approach to quantifying PE aging processes will utilize an RPM model with accelerated testing to capture the time-temperature dependencies of aging.

In this project, researchers quantified the aging process of PE fittings with respect to UV exposure and oxidation from air (at elevated temperatures).

The aging process was quantified in terms of rate and extent (depth of aged material) in order to establish a proper understanding of PE fitting shelf life with and without fitting packaging (UV blocking).

Deliverable

Researchers developed an RPM model (equation) that can be used to predict the shelf life of PE components exposed to UV and/or air.

The details of the RPM model, including its statistical confidence bounds, is provided in a Final Report.

While this project focused on UV degradation and oxidation from exposure to air – the aging mechanisms in the most common storage environments – the model should be applicable to other chemical exposures and follow-on work could explore additional environments.

Conventional black-bag (not manufacturer packaging) before and after 350 hours of UV exposure.

Benefits

A quantification of the PE aging process under common exposure conditions can reduce shelf-life ambiguities and provide a better understanding as to the ability to prolong the life of PE fittings.

Prior R&D on the degradation of pipes established shelf life for pipes; however, there is little to no guideline for fittings. An understanding of PE fitting aging (UV exposure and/or elevated temperatures) will help establish consistent and reliable guidelines as to when stored components can be used as per normal procedures, can be used with special procedures (e.g., scraping), or must be discarded.

With such guidelines, utilities can manage their inventories to avoid exceeding component shelf life and the associated financial losses and logistical overhead. Additionally, by evaluating the efficacy of UV blocking packaging, a potentially universal solution could be developed for minimizing shelf-life concerns.

Technical Concept & Approach

The scope of this project encompassed an evaluation of fittings under two exposure conditions – UV light and elevated temperatures – designed to induce aging by UV degradation and oxidation, respectively.

Samples were taken out of each exposure test at different times and subjected to evaluations to determine oxidation depth and anti-oxidant depletion. A test matrix was comprised of four materials: two uni-modal medium-density PE resins, and two bimodal high-density PE resins. Injection molded fittings were evaluated per material to determine if the manufacturing process significantly affects aging.

Three replicates (exposed fitting, bagged fitting, and a fitting in a UV blocking bag) were used for each material and condition.

The general UV test is conducted on cubes taken from medium-density two-inch-diameter PE couplings to determine the rate and depth of oxidation due to UV exposure. Additional UV testing of black electrofusion tapping tees and comparative testing of plastic bags were conducted after the general test.

The general oxidation test was conducted on full fittings at elevated temperatures.

Testing results were used to calibrate an RPM model that can be used to predict shelf life of new PE components and estimate the residual shelf life of stored components.

Results

In this project, two aspects of material aging related to PE fittings were evaluated: 1) surface oxidation from UV radiation exposure and 2) depletion of anti-oxidants from natural oxidation (aging).

With respect to UV exposure of fittings, the salient conclusion reached from the tests performed is that fittings should not be exposed to UV light (sun light) during storage. The UV exposure tests showed that:

1. Modern medium-density polyethylene (MDPE) degrades at a similar, although slightly lesser rate than vintage MDPE
2. The original fitting packaging offered some degree of UV protection, but it cannot be relied upon as a long-term UV blocker, and
3. The carbon black in high-density polyethylene (HDPE) was alone not sufficient to protect high-density HDPE from surface oxidation in a 1,000-hour UV exposure test.

With respect to the natural oxidation of PE fittings, the conclusion is that the fittings that were tested had sufficient stabilizers in the bulk of their material to have a shelf-life of at least 10 years at 86°F (30°C); however, the practical consideration should be with respect to surface oxidation, since the fusion surfaces of coupling and saddle fittings are not scraped.

Based on the limited surface oxidation data from this project, it is estimated that it would take MDPE 1.5±0.5 years at 86°F (30°C) to reach the minimum required value of 20 minutes, and HDPE would take 1.9±0.3 years at 86°F (30°C) to reach the same value. These prediction tolerances are based on a 95% prediction bounds of the fitted models.

Additional R&D is required to determine a more reliable prediction of shelf life based on surface oxidation. Predictions would have to be determined per fitting, as the manufacturing process affects the amount and distribution of stabilizers in the polymer.

Status

This project is complete. A Final Report was issued in July 2019.

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Harvesting Power at the Gas Meter

Researchers conducted a study of energy-harvesting technologies that could extend the mission life of remote devices used for advanced metering. The study includes a thorough analysis of the economics and reliability of primary batteries.

Project Description

In this project, researchers reviewed of the current state of energy harvesting and energy-storage technologies that could extend the mission life of remote devices used for advanced metering infrastructure (AMI).

The resulting study includes a thorough analysis of the economics and reliability of the dominant competition to energy harvesting: primary (non-rechargeable) batteries as power sources for meter reading, remote shut-off, and various sensor devices.

Deliverables

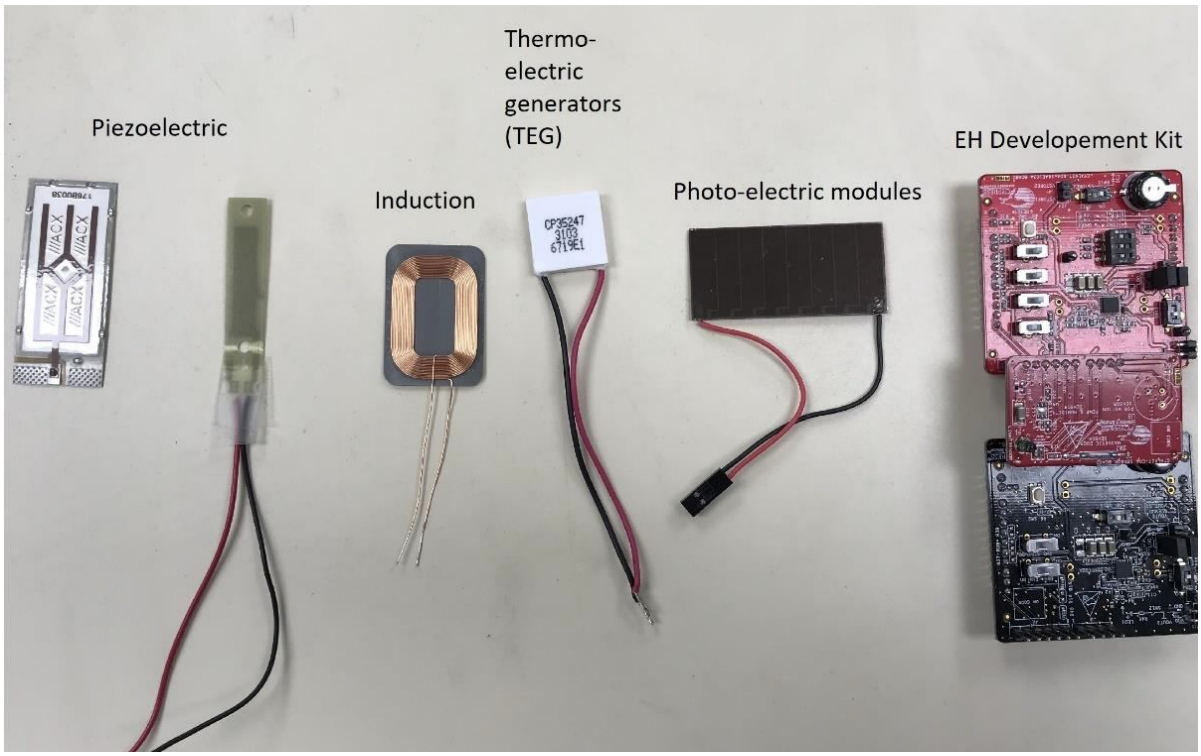
Deliverables from this project include:

- An analysis of the current state of primary battery technology that includes reliability and economics metrics and addresses end-of-life disposal issues
- An updated reference of energy-harvesting technologies
- A similar study of rechargeable batteries and/or capacitors to store harvested energy
- Several gas industry use cases where energy harvesting and storage are a good engineering/ economic fit, and
- A White Paper describing a reference design for one energy-harvesting use case with estimates of cost and reliability.

Benefits

The need for timely operational data from gas utility systems has led to the adoption of wireless, battery-powered technology.

As more AMI devices are developed and deployed, extended battery/service life becomes critical. A system that could trickle charge a storage cell would serve this need.



Various energy-harvesting products and development kits.

Technical Concept & Approach

This scope of this project addressed more than just battery life and includes investigation into multiple AMI components with their own lifetimes within the total system design. In addition, associated radios, sensors, and other electronics have become more efficient with time. Alternatives to rechargeables, such as super capacitors, have also improved and may be a viable alternative.

Another aspect of this review was to analyze the use cases in terms of energy available. The most efficient harvesting and storage method must have sufficient energy on the front end to be viable.

Results

In this project, the latest innovations in energy-harvesting technologies were reviewed. Recent advances in battery technologies, both primary and rechargeable, were also reviewed. Super-capacitors were investigated for short-term storage of electrical energy.

Overall, energy harvesting is not as mature a technology as primary batteries. Energy harvesting can extend the life of some applications but must be integrated with storage.

The project team also evaluated the performance of a commercially available thermoelectric generator (TEG).

Key conclusions from the project:

Energy Harvesting

- The order of different energy harvesting technologies by maturity of technology and availability of commercial product is:
    1. Solar/Photovoltaic (PV) energy harvesting – PV-cell-powered applications
    2. Electromagnetic (EM) or radio wave energy harvesting
    3. Thermal energy harvesting – Thermoelectric generators
    4. Flow energy harvesting – miniature vertical wind turbines, and
    5. Piezoelectric energy harvesting
- Energy harvesting systems are subjected to variations of available ambient energy with time and location.
- Energy harvesting needs to be supplemented by an energy storage system like a battery or super-capacitor to ensure continuous power supply for the application.

Energy Storage

- Super-capacitors are best suited for applications requiring high power ratings, long cycle and calendar life, and reliability.
- A manufacturer's study claims life of more than 20 years for primary batteries in automatic meter reading applications.
- R&D efforts in Lithium ion and other rechargeable batteries is likely to result in battery products that are safer, longer lasting, and light weight.

Gas-industry applications identified include pressure sensing near regulators, power for methane sensors, atmospheric corrosion measurement, and other uses.

The typical application of super capacitor storage is to complement batteries to enhance the operational efficiency. The combination of a battery and super capacitor provides the ability to provide large pulses of power for short durations. In principle, a super capacitor can be charged and discharged an infinite number of times.

After extensive battery testing, it was reported that the original battery life estimated at 15 years was conservative and average life in excess of 25 years can be expected when operated in a wake-up mode. The testing took into account the product type, battery type, location, and climate.

The TEG unit was paired with a heat sink and fan for better heat convection. Then, the TEG unit was evaluated, periodically increasing the temperature and acquiring the voltage drop data across pre-determined loads.

A theoretical evaluation of a small wind turbine was carried out for use with long-term, remote methane sensors.

Status

The Final Report was issued in January 2019. Energy harvesting will be more beneficial for frequent monitoring applications than for long-term usage when a device is operated in hybrid mode. Algorithms that can control duty cycle based on the energy available will help in optimizing the power management.

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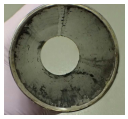
Best Practices to Address Odor Fade in High-Rise, Low-Occupancy Buildings



Research is under way in a effort to determine the best way to address odor fade in gas pipes in high-rise, low-occupancy buildings. Researchers are developing a consistent approach for conducting odor fade risk assessments.

Project Description

Natural gas utilities are seeing an increase in new customers in urban areas in the form of high-rise buildings. These customers provide various challenges for gas utilities, including the need to address low odor readings in high-rise and low-occupancy buildings. This phenomenon – known as odor fade – is defined as the loss of odorant by physical or chemical processes occurring inside the pipeline.

In a OTD-sponsored project, it was shown that the odorant compound most impacted by fading in a steel pipe was t-butyl mercaptan (TBM). Concentrations in the gas phase were quickly lost in the presence of rust on the pipe surface.

To overcome odor fade, operators generally add extra odorant to supplement existing concentrations. In conjunction with this, natural gas flow rates can be increased to purge more gas. Unfortunately, the option of increasing flow rates cannot be used in low-occupancy buildings, where the flow is often very low to nonexistent, especially in summer months.

The objective of this project is to identify the scenarios in which odor fade may occur within complex interior jurisdictional and non-jurisdictional piping systems and determine best practices to address the phenomenon in high-rise or other low-occupancy buildings. Additionally, goals are to develop a consistent approach for conducting odor fade risk assessments within these environments, including identification of mitigation options prior to servicing a customer.

Deliverables

Deliverables from this project include:

- Survey information of the current practices to pickle steel pipe
- A laboratory assessment of selected best practices
- An odor fade mitigation guide, and
- A Final Report with summaries and recommendations.

Benefits

Loss of odorant effectiveness in natural gas is not a new phenomenon. However, it has become a high-profile issue for the natural gas industry due to recent incidents and increased litigation due to perceived odor fade.

Results from this project will help to increase the safety of natural gas delivery systems and enhance the integrity of the infrastructure.

Laboratory testing.

Technical Concept & Approach

The project has two parallel paths: one involves a survey of industry best practices and combining it with knowledge to date. The second path involves laboratory testing of a selected mitigation pathway.

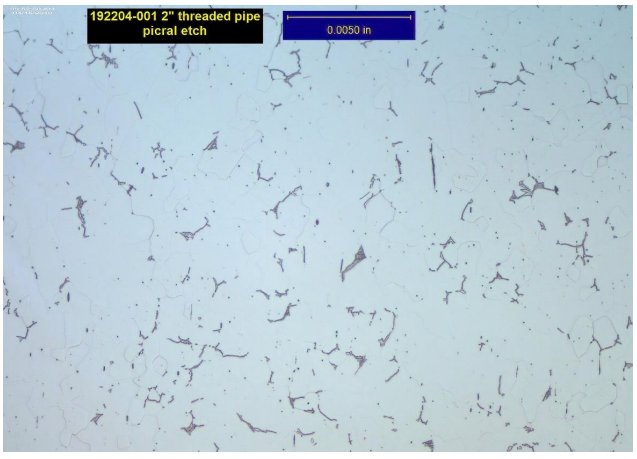
Project sponsors and others will be surveyed for their typical practices in low-flow or locked-in situations. Information gleaned from odor-fade projects will be added. The American Gas Association also publishes information that will be included. This information will be summarized, chemically evaluated, and presented to project sponsors.

Selected techniques will be evaluated under laboratory conditions. The gas will initially be odorized with tetrahydothiophene and/or TBM, using house gas or synthetic odorized gas.

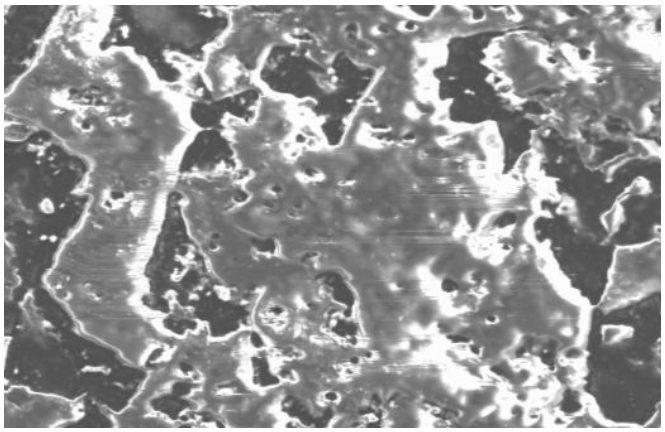
Results

During 2018, researchers constructed a testing matrix, itemizing the pipe materials to be included in the testing. Pipe sizes, lengths, and material compositions were finalized by the team based on sponsor requirements and gaps in past tested materials. Multiple average Btu usage scenarios were computed to assist in the burner and other requirements specifications. Other design topics included the incorporation of venting and flaring of gas, gas on/off switches, flow valves, and sensors. The plastic pipe sticks were purchased and butt fused with fittings. Electronic controls and sensors were purchased and assembled.

The test rig was constructed, and safety and sensor-related devices were installed and tested. The first test was initiated with gas containing TBM at a trickle flow. Preliminary results indicated the coated steel pipe successfully prevented odorant fade. A weld joint present in a second pipe had no effect. The plastic pipe experienced a slight amount of odorant loss. The uncoated steel pipe experienced significant odorant loss.



Microstructure of transverse section.



Scanning electron microscope image of residue on pipe interior wall.

For the tests, a series of ball valves was used to control the flow of the gas and ensure limited interaction with non-inerted surfaces. By comparing the difference in concentration between the inlet and outlet sample points, the amount of odorant loss can be quantified.

In 2019, a new task was performed for a project sponsor investigating a pipe implicated in odorant fade in an apartment building. An oily residue and pipe dope was found on the interior surface. Visual examination of the pipe interior found a white/gray colored surface contamination on the pipe interior that was oily to the touch. This material was isolated and identified as the same pipe dope used to connect the pipe to the tees. The oily residue is surmised to be from cutting fluid used to make the pipe threads. This oil appears to have softened the pipe dope, allowing it to spread beyond the joints where it was applied, possibly in excess.

Additionally, the research team completed test execution and results reporting of all activities performed under the laboratory evaluation portion of the project scope. Sponsors indicated they have a strong need to understand the time to saturation/time to odor fade for uncoated steel pipe, which was not part of the original testing. The team produced an initial time to saturation analysis to outline the methodology a utility could use to develop a "rule of thumb" estimate the risk of odor fade for a given scenario.

Status

Researchers are finalizing the methodology and scope and budget estimates for conducting the time to saturation testing requested by project sponsors.

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Non-Traditional Natural Gas Regulators – Slam-Shut and Vent-Limiting Regulators

In this project, researchers investigated the operations, applications, standards, and limitations of slam-shut and vent-limiting regulators for potential broader use to enhance efficiencies and safety in the natural gas industry.

Project Description

In multifamily housing and residential units in crowded urban environments, it is common to have difficulty finding a suitable location for the placement of gas meter sets – and venting of the meter-set regulator can be difficult as well. In multifamily buildings, meter rooms and configurations can vary widely. Some companies place regulators outside of the building, while others may place facilities inside of the building.

Venting of these regulators can be challenging, particularly if there are meter rooms on multiple floors of a building. Vent limiters are designed for use indoors and in spaces where limiting the amount of gas escapement due to diaphragm failure is critical. However, vent limiters should not be used outdoors if they are exposed to the environment. Regulators with a built-in slam-shut valve are designed to shut off the flow of gas under specific conditions, such as excess pressure or, optionally, if there is a fall in downstream pressure.

This project focused on documenting the limitations of each available type of regulator to help operators to reduce risk to customers, the atmosphere, and the utility. Specifically, researchers examined the operations, applications, standards, and limitations of slam-shut and vent-limiting regulators for potential broader use in the industry.

Deliverables

- Documentation of the various vent-limiting and slam-shut regulators on the market
- Information on applications in which slam-shut and vent-limiting regulators could be used, and
- A Final Report detailing project findings.

Benefits

Inside and outside of many homes and buildings, particularly older ones, it can be difficult to find a safe location to install the regulator and/or to run vent piping to safe locations. Slam-shut regulators enable the reduction in pressure without the need to vent gas to the atmosphere. Vent-limiting regulators limit the amount of gas that is released to safe levels should the regulator vent for any reason.

Utilizing a slam-shut or vent-limiting device may enable placement of meters and regulators at safe locations that would not traditionally be able to be used (i.e., near a window, ignition source, etc.). Additionally, eliminating unnecessary venting of gas to the atmosphere will help in the management of overall methane emissions.

Technical Concept & Approach

Sponsors were surveyed to determine the slam-shut or vent-limiting regulators currently being used and any issues that may have been encountered. Researchers also identified and documented other technologies that are available for use and identified applications, benefits, and any limitations in performance. Areas investigated included, but are not limited to, maximum operating pressure, flow rates, and reset methods. A review of standards was performed as well.

Slam-Shut Regulators

Results

A technical White Paper report for this project examines the applications, operations, standards, and limitations of non-traditional service pressure regulators (SPR) and line pressure regulators (LPR), specifically slam-shut and vent limiter style. These style regulators may offer improved performance and operational efficiencies as compared to the use of standard SPRs and LPRs depending on the installation application. Examples of improved performance include increased safety due to the reduction and/or elimination of natural gas venting to atmosphere during normal operation or in a failure state, which could create a hazardous accumulation of gas and may lead to injury and/or property damage. Also, the reduction or elimination of natural gas venting to the atmosphere reduces methane emissions into the environment.

The product offerings of various manufacturers were examined as part of this research. The following activities and resources contributed to the details contained within the White Paper:

- Interviews with project sponsors
- Interviews with gas distribution operator representatives on the installation of non-traditional gas regulators
- Interviews with manufacturer representatives of non-traditional gas regulators.
- Factory visit of a non-traditional regulator manufacturer to witness the assembly and QA/QC process for non-traditional gas regulators, slam shut, and governor style
- Interviews with non-traditional gas regulator distributors
- Review of technical bulletins and data sheets for the different types of non-traditional gas regulators.
- Review of the codes and standards governing service- and line-pressure gas regulators
- Participation at industry conferences and seminar sessions related to gas pressure regulators, including the *ANSI B109.4 Self-Operated Diaphragm-Type Natural Gas Service Regulators* task group committee meetings, and
- Internal subject-matter expert interviews.

Researchers found that there have been technical advances in regulator design that offer improved customer and system safety, improved regulator performance, reduced methane emissions, and reduced operations and maintenance costs associated with gas pressure regulator placement, indoors, and outdoors.

"Service regulators incorporating slam-shut safety features and vent-limiting designs are becoming important tools for utilities providing service in crowded urban environments. OTD has effectively captured the state of technology development for these regulators and advances a common understanding of expected benefits."

- Kevin Murphy, P.E.
Director - Energy Acquisition
Washington Gas

Based on research findings, the technical advances in slam-shut-style regulators seem to address most of the current outdoor placement challenges and restrictions for high-pressure gas service regulators. There are a few utility operators that have started installing slam-shut-style regulators system-wide or as a pilot program. Unfortunately, at this time, current U.S. governing codes and standards are not up to date with the technical advances of the slam-shut-style design. This delay in updating the governing standards may require this advanced design to be installed the same as traditional-style regulators unless a waiver is granted by the state public utility commission.

Status

This project is complete. The Final Report (White Paper) was issued in January 2019. Researchers recommend that the next steps for utility operators, regulator manufacturers, codes and standards committees, and governing agencies should include the following action items:

- Continue to educate utility operations personnel on the enhanced performance of slam shut and vent-limiter-style regulators
- Identify potential installation applications within each gas distribution delivery system
- Educate state public utility commission personnel on the enhanced performance and benefits of installing slam-shut- and vent-limiter-style regulators
- Update current codes and standards governing slam-shut- and vent-limiter-style regulators and maintain these standards concurrently with technical advancements in regulator design, and
- Perform independent third-party evaluations on the different advanced regulator technologies.

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Material-Supplier Quality-Assurance Program

Through the development of a material-supplier quality-assurance program, efforts are being conducted to create a standardized approach to key processes affecting the quality of materials used by gas utilities.

Project Description

Natural gas utilities are required to implement integrity programs that focus on system risk assessment that includes purchased materials. However, while utilities are responsible for the quality of the materials, the manufacturers producing materials for the industry are not under the same level of scrutiny. Due to a lack of clear industry guidance, utilities often create their own sets of requirements (test conditions, traceability, packaging, etc.), with a main focus on technical characteristics and less attention on process-related activities. The diverse range of requirements from utilities diminishes product quality due to variations infused into material operation processes. This requires manufacturers to allocate additional resources to control these variations, which leads to increased cost.

The objective for this project is three-fold:

1. To assist gas utilities in creating best-practice guidelines to develop and manage a material-supplier quality-assurance program
2. To create a standardized approach to key processes affecting the quality of materials used by the gas utilities, and
3. To identify comprehensive regulatory and technical requirements specific to products utilized in natural gas transmission and distribution systems.

Deliverables

Deliverables from this project will include two manuals: 1) *Material Technical and Quality Requirements Manual* and 2) *Material Quality Assurance Manual*. In addition, a comprehensive set of guidelines/best practices for utilities to utilize when managing material quality will be provided.

Benefits

The success of any business is directly impacted by the ability of suppliers to consistently deliver materials that meet required specifications. A standardized, collaborative approach to develop a material-supplier quality process will:

- Improve material quality processes by formalizing quality-assurance activities that are focused on: planning, risk assessment, and suppliers performance monitoring and evaluation.
- Reduce variability by standardizing requirements.
- Reduce costs associated with:
  - Materials through standardization
  - Rejects, dig-ups, and delayed projects through material quality, and
  - Developing the program through the use of collaborative pooled resources.
- Improve the understanding of applicable industry standards requirements.
- Improve communication, collaboration, and information sharing with suppliers and make more informed decisions based on data derived from supplier quality-assurance activities.
- Raise the bar of overall material quality and system integrity by collaborating as a group and creating an industry standard approach to material quality-assurance processes.
- Identify possible gaps in current standards and regulatory requirements.

Technical Concept & Approach

This is a collaborative program that includes a steering committee comprised of representatives from each participating sponsor along with subject-matter experts (SMEs). The steering committee is responsible for providing relevant information, communicating expectations as to the direction of the program, participating and providing feedback in the development of the manuals, and identifying priorities as to the project deliverables.

This program will define a manual/handbook with comprehensive material requirements and best practices of material-supplier quality-assurance processes (methods, policies, and procedures) that will help utilities to control and improve material quality and, therefore, overall system integrity.

Specific tasks include:

- **Project Scoping and Gathering of Information**

  The work in this task includes contracting and subcontracting the industry SMEs to assist in creating the program, and gathering material information utilized by the sponsors and steering committee interactions.

- **Gap Analysis of Product and Process Requirements**

  A review of the product types selected by the sponsors will be performed to determine their technical specifications and quality requirements.

- **Gap Analysis of Utilities' Internal Material-Supplier Quality Processes**

  In this task, a review will be conducted of utilities internal material-quality practices to identify best practices in material-supplier quality-assurance activities by benchmarking gas utilities and other industries that have successfully implemented programs.

- **Development of Material Technical and Quality Requirements Manual for Material Suppliers**

  This task includes the development of a manual that incorporates material technical specifications and quality requirements (e.g., certification, documentation, inspection and testing, management of change, traceability and identification, delivery, packaging, recall plan, contingency plan, and right of access).

- **Development of Material Quality-Assurance Manual for Utilities**

  This task includes the development of a manual that incorporates best-practices material-quality-assurance processes.

"Many times, manufacturers have to comply with many different specifications from different utilities, which makes it difficult for everyone involved. The long-term effect of this project would allow manufacturers to make material to the same specifications for multiple customers, which will improve material consistency, lead times, and availability."

- Eddie Lynch
Sr. Gas Specialist
Ameren Illinois

Results

In 2018, the project team initiated the gap analysis of customer specifications and the standards for service regulators, rotary meters, diaphragm meters, excess flow valves, and PE mechanical fittings. In 2019, the project team received material specifications and performed gap analyses against regulatory standards for the following product categories:

- PE Mechanical Fittings
- Excess Flow Valves
- Meter Risers
- PE Ball Valves
- Transition Fittings
- FBE Coating for Line Pipe and Fittings, and
- API 6D Valves.

Status

Researchers will perform a gap analysis against regulatory standards for the following product categories:

- Service Regulators
- Forged Steel Threaded Fittings
- Incoming Inspection
- Qualification of Suppliers
- Suppliers' Performance Monitoring
- Control of Documents and Records
- Control of Nonconforming Material, and
- Calibration.

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Investigation of Drilling Mud Permeation in PE Pipe

In this project, researchers investigated the effects of the constituents in drilling mud (used during the trenchless installation of PE pipe) and how they may affect the quality of PE fusion joints.

Project Description

It is well known that silicates – the primary constituent of soils and drilling muds – will disrupt the fusion process of PE; however, experts suggest that such contaminants should not penetrate PE material and should be able to be removed with adequate cleaning and scraping.

It is possible that other constituents of drilling muds, such as hydrocarbon additives that may be detrimental to PE fusion, are permeating the pipe to depths greater than the scraping depth, and thus are not removed by the operator's pipe-preparation process (cleaning and/or scraping).

The objective of this project was to investigate the effects of the constituents of drilling mud and how they may affect the quality of PE fusion joints. In addition, an investigation was conducted on the ability of drilling mud constituents to permeate into the PE.

Deliverables

The main deliverable from this project is a Final Report containing information obtained from various tests. This research advises operators on the risk, if any, posed by the exposure of PE pipe to drilling muds, or specific constituents thereof. If a risk exists, test data will provide recommended mitigating steps, such as increased scraping depth, go/no-go decisions for fusion, and pressure de-rating of permeated pipe.

Benefits

Knowledge of drilling-mud constituents that may permeate and harm PE pipe and/or fusion quality will help to develop mitigating strategies or lead to alternative drilling mud formulations that would not adversely affect PE fusions and material strength. Eliminating the fusion-quality issues will reduce rework and system-integrity risks.

Technical Concept & Approach

The initial tasks in this project included a survey of drilling muds used by the sponsors and/or their contractors and the development of a testing approach.

Testing activities included:

- **De-Formulation of Drilling Mud(s)**

  Various drilling muds were analyzed to ascertain their chemical composition and to identify constituents that may permeate PE.

Scraped pipe samples on the left and non-scraped samples on the right.

- **Permeation Testing**

  Pipe samples were saturated in drilling mud(s) or specific constituents thereof and extracted at three different exposure times to determine the permeated constituents, their penetration depth, and their rate of diffusion.

- **Fusion Testing**

  If the depth of permeated drilling-mud constituents exceeds the minimum scraping depth for removing oxidized material, electrofusion saddle tests were conducted with saturated PE pipe samples, and destructively examined to determine if fusion joint strength is affected by saturation in drilling mud.

- **Mechanical Testing** (optional):

  If more than 10% of the wall thickness is permeated by drilling mud constituents, dynamic thermo-mechanical analysis and tensile tests were performed to measure the activation energies and toughness of the material, respectively.

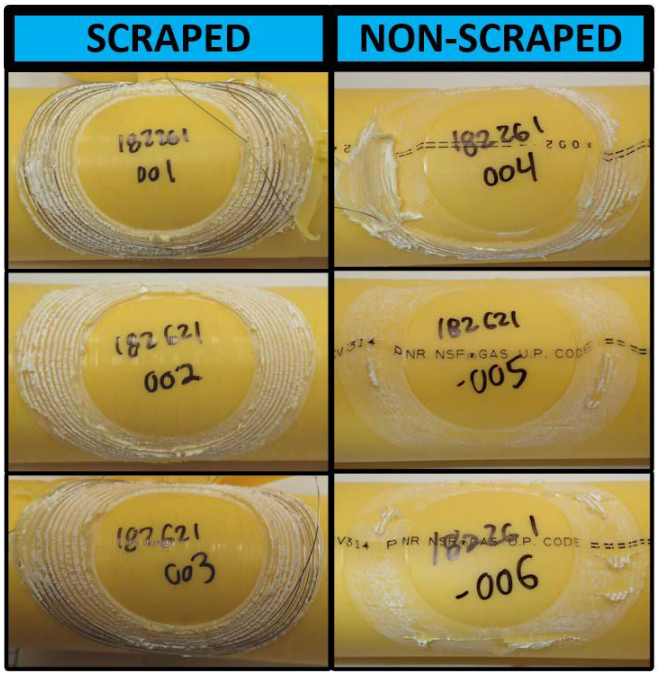
Results

This project was conducted to determine if the constituents of drilling fluid (drilling mud) used in horizontal directional drilling (HDD) permeate PE pipe and, thus, become detrimental to fusion joining.

The primary ingredient in HDD drilling fluids, bentonite clay, was deemed to not be a permeation risk to PE due to its molecular structure. Consequently, this project focused on identifying other ingredients that are commonly used in drilling mud and test their ability to permeate into polyethylene and whether they affect fusion quality. With the guidance of the HDD industry and PE industry experts, two commonly used drilling mud constituents – a surfactant and a polymer stabilizer – were identified as potential permeates.

Coupon samples of both medium-density polyethylene (MDPE) and high-density polyethylene (HDPE) were submerged in these drilling mud constituents at an elevated temperature and extracted at various times to measure the PE samples' gain in mass. An estimated depth of permeation into the polyethylene samples was then calculated. For both the surfactant and polymer stabilizer, the estimated depth of permeation was less than 10 microns, which is well below than the minimum required scrape depth of 178 microns (0.007 inch).

Fusion testing using electrofusion tapping tees fused to MDPE and HDPE pipes that were submerged in surfactant for over 1,000 hours at 80°C (176°F) have shown that scraping to a depth of approximately 0.007 inch is sufficient to remove the surfactant-affected material. Without scraping, full joint ductility was not achieved due to surfactant traces on the fusion surface.



De-cohesion test results of MDPE pipe.

It is important to note that PE pipe that has been in contact with drilling fluid will have traces of bentonite on its outer surface as well as bentonite near the joint area (e.g., in the ditch). Bentonite is very detrimental to PE fusion joint and its dust may settle on a scraped pipe if the fitting is not promptly assembled and fused on a properly scraped pipe. Also, if the pipe is not thoroughly cleaned prior to scraping, then bentonite traces may get transferred onto the scraped pipe during the scraping process. It is recommended that operators apply best practices for PE fusions to prevent surface contamination of the fusion zone.

The conclusions of this project are that the surfactant and polymer stabilizer tested in this project do not present a permeation risk and will not affect fusion quality if and only if the pipe is thoroughly cleaned to remove any loose contaminants in the joint area and then properly scraped promptly before performing the fusion joint.

Status

All tests have been completed. A Final Report was issued in April 2019.

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Protecting Tracer Wires from Corrosion – Best Practices and New Methods

In this project, researchers are developing methods and reviewing best practices for protecting buried tracer wires from corrosion. The focus is on a cost-effective means that does not impair the ability of the wire to carry the tracing signal.

Project Description

To help locate buried plastic pipe, the natural gas industry has a large base of tracer wire installed alongside its plastic pipe, and continually adds to it. Tracer wire is typically solid copper or a copper layer on a steel core. High-quality tracer wire will have polyethylene insulation at least 30 mils thick.

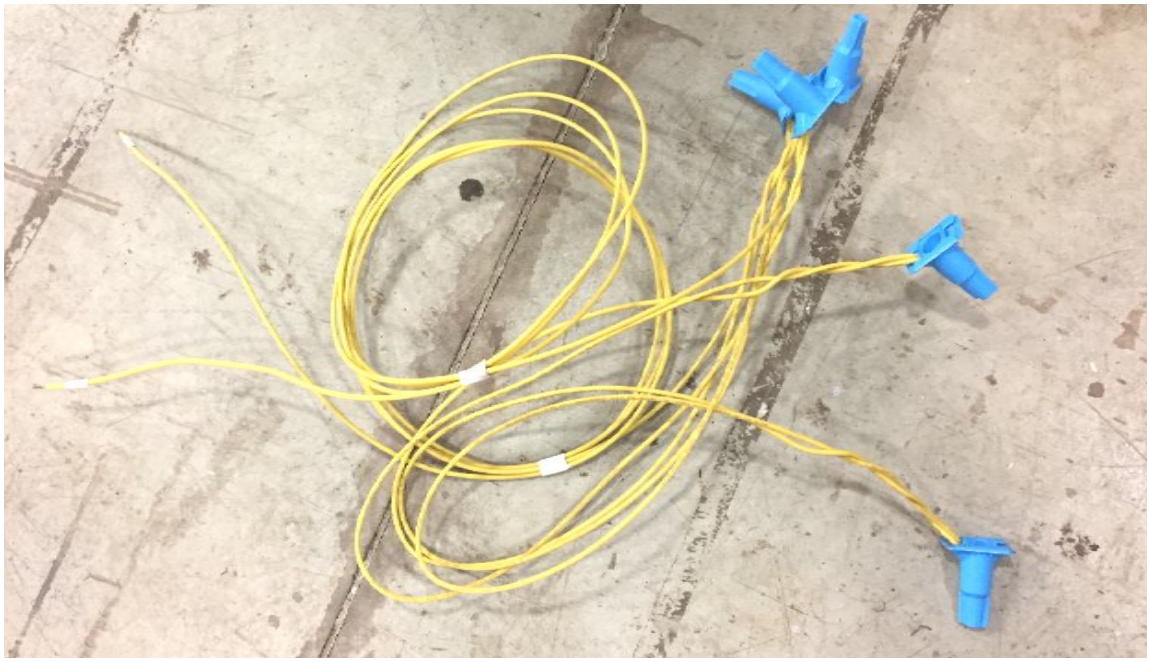
OTD-developed *Guidelines for Use of Copper-Clad Steel Tracer Wire* (OTD project 5.7.c) covers the installation practices for such wire. However, even appropriate insulation can be damaged during horizontal directional drilling and other operations. Once tracer wire is installed, it needs some form of corrosion protection to ensure that it has a long working life. This protection must be implemented in a way that does not compromise the tracing function of the wire.

Cathodic protection can significantly extend tracer-wire life. Magnesium or zinc sacrificial anodes can provide sufficient negative potential on the copper to retard corrosion of the exposed or wet surfaces. The tracer-wire surface area is small compared to that of pipe, so modestly-sized anodes will suffice. However, using anodes to protect tracer wire can drain the tracing signal-to-ground. If the tracing signal is injected into a free end of the wire, this signal can be followed only as far as the first anode on the tracer wire or the first break in the tracer wire. Either will stop the signal from travelling further. The locator personnel tracing the wire cannot distinguish between a break or a "hidden" anode without making an excavation. The limitations of tracing-signal interaction with anodes has prevented widespread adoption of this protection method.

The accurate documenting and marking of anodes used to protect tracer wire is also a critical aspect of effective tracing operations. Locator personnel require the ability to disconnect anodes in the work area. Alternatively, the anode may be connected in a manner that passes the DC protective current and blocks the AC tracing signal. This removes the necessity to disconnect the anodes, simplifying the operation.

Gas Technology Institute (GTI) and the American Water Works Research Foundation (AWWRF) jointly developed a technology termed "tracer wire coupler" that manages the signal injection and attachment of the anode for tracer wire. A limited set of field trials was performed with good results.

The objective of this project is to develop methods and review best practices to protect buried tracer wires from corrosion.



Deliverables

The following deliverables are expected:

- A review of hardware technology
- A compilation of best practices for tracer wire
- A description of a cathodic protection method appropriate for tracer wire, and
- A demonstration of the identified method involving a manufacturer.

Benefits

Results from this project will provide gas system operators with information on the optimal methods for maintaining installed tracer wire and enhance the safety and efficient operation of plastic piping gas distribution systems.

Technical Concept & Approach

Project personnel reviewed multiple aspects of tracer wire technology, including:

- The variety and physical attributes of wire
- The standard and best practices for installation of tracer wire
- Connectors and appurtenances used in tracer wire installations
- Signal generators and receivers for tracer wire, and
- New technologies related to tracer wire.

Plans are to have the project team and a manufacturer facilitate a field trial of the previously developed tracer wire coupler or suitable new technology. This task would consist of procuring or fabricating test samples, distributing them to the sponsors, and providing training in their use.

Findings from all the tasks will be compiled into a report detailing the technologies and practices currently applied to tracer wire.

Results

The project team reviewed multiple aspects of tracer wire technology, including variety and physical attributes of wire currently in use and best practices for wire installation.

The tracer wire technology review was completed in 2018, culminating in the creation of a draft version of the Tracer Wire Recommended Practices document. As a result of feedback from the Recommended Practices document and subsequent project discussions, sponsors decided to move forward with the optional field trial with a manufacturer.

The project team is focusing on the following:

- Additional tracer wire instruction, including where to place anodes and the appropriate distance between anodes
- Best practices for installation, how to best utilize connection/test boxes, and bringing the anode's three wires up to the connection/test box, and
- Connectors corrosion analysis, including simulating corrosions cycles to better understand why corrosion at connectors occurs and how to best install connectors to prevent corrosion.

In 2019, the project team reviewed the sponsor survey results and identified prominently utilized tracer wire connectors. A mix of connector types, including insulation displacement, screw compression, and twisting were acquired as these represent the primary methods of mechanically joining wire in the field. Researchers defined the methodology to simulate corrosion and planned the series of tests to be executed and completed the tracer wire connector test equipment setup.

Researchers monitored the instrumentation to assess the chamber air flow and temperature to achieve equilibrium during the drying out process. Dashboard display data was analyzed and air flow and temperature changes were made as warranted. A data backlog was extracted from the data archiving server and researchers processed the information to graph connector resistance over time.

Status

Researchers continue to monitor the buried connector conditions in an environmental chamber and make adjustments as necessary. The project team will monitor all project instrumentation to make certain data capture is occurring as expected at the pre-defined timeframes.

The findings from all the tasks will be compiled into a report that details the technologies and practices currently applied to tracer wire.

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Pipeline Purging Program Update

The focus of this project was on updating the 1997 GRI Pipeline Purging Program in order for it to be supported by modern operating system platforms.

Project Description

Through this project, the American Gas Association (AGA) Purging Principles and Practice Manual was updated for the first time in 15 years. As a companion to the revised manual, the industry requested that the GRI Pipeline Purging Program be referenced and updated as well.

The 1997 GRI Pipeline Purging Program calculates the purge time, purge pressure, gas flow rate, and the required inert gas volume for the user's specific pipe geometry. The program currently only runs on Windows 3.1/95/98/2000/XP/Vista (32-bit) platforms and is not compatible with modern operating systems.

The focus of this project was on updating the 1997 GRI Pipeline Purging Program in order for it to be supported by modern operating system platforms.

Deliverables

The deliverables for this project is an updated purging program, a user's manual, and a detailed Final Report.

In addition, project team outreach efforts will help to make the software available to the industry.

Benefits

The Pipeline Purging Program was developed between 1994 and 1997 in a software environment that has subsequently become obsolete and unusable.

Updating the program to a modern web-based platform will allow utilities to once again utilize the program for planning pipeline purging operations.

Pipeline Purging

There are a number of factors that can complicate pipeline purges and a variety of safety hazards must be considered when performing purge calculations. For safety reasons, inert gas purge segments, or slugs, are introduced to separate air and natural gas from mixing in a pipeline as shown in Figure 1.

However, simply introducing an inert gas is not enough to separate air and natural gas safely. If gases are introduced below a critical velocity, called the stratification velocity, differences in gaseous densities will cause "layering" through the cross section of a pipeline as shown in Figure 2.

If flow velocity during a purge segment exceeds the turbulent flow regime too greatly, the gaseous interface will become mixed in the pipeline as shown in Figure 3.

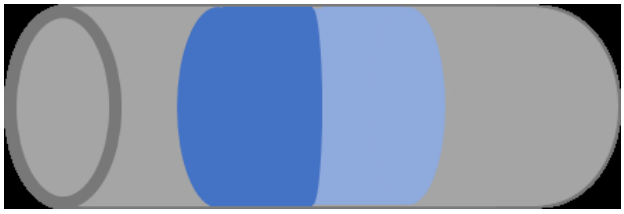

Figure 1. Ideal separation between purge gas and process gas.

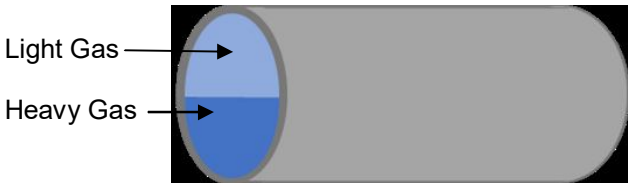

Figure 2. Example of flow stratification.

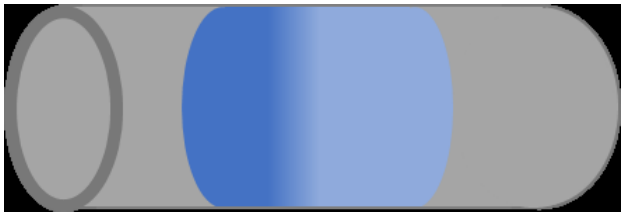

Figure 3. Example of mixing from excessive turbulent flow

Technical Concept & Approach

Specific tasks in this project included:

- Development of an in-depth review of client needs and potential approaches to the project
- Development of new basic calculation algorithms based on a review of the documentation contained in the AGA revision and GRI Final Report
- A definition of the required software functionality based on review of the original software and user's guide and client needs
- Review and finalization of functionality and development scope
- Development of the User Interface (UI)
- In-house testing of the UI and calculation results
- Development of installation and setup software
- Development of server-based access and security features and license management software
- Preliminary testing, review, and comment
- Development of user and software documentation, and
- Software support and bug fixes.

Results

The project team developed a Final Report that outlines the next-generation pipeline purge calculator and user guide to replace the legacy purge program which was developed by GRI in 1997.

This modernized purge program is vital to the natural gas industry because of the frequency and complexity of pipeline purges. Pipelines are commonly purged to remove the gas content or to replace the content with another gas. When properly controlled, the purge operation causes the injected gas to displace the current pipeline contents with minimum gas dispersion at the interface of the two gases. It is especially important to minimize this gas mixing when flammable mixtures are formed near the interface between the purge gas and the pipeline gas. Less mixing or dilution generally means more efficient purging. Inadequate purge techniques can lead to wasted process gases, inefficient purge times, or hazardous conditions. Preventing these undesirables can reduce pipeline downtime while increasing project safety.

"It was an honor to work on the project. I think that the flexibility of GASPurge being a web-based product, its easy to use data entry wizard, and its fast calculation speed will prove it to be a useful and effective tool for the natural gas industry for years to come."

- Brad Bean
Partner
Bradley B Bean PE

It is worth noting that the effort to update the original GRI Purge Program was spurred by the American Gas Association's (AGA) effort to update its Pipeline Purge Manual in 2018. This project received cofunding from AGA.

To maintain the effectiveness of the legacy pipeline purge calculator, the need for an updated program was desired by most of the local distribution companies. Thus, the legacy purge program was upgraded to ensure compatibility with modern operating systems and mobile applications.

Status

The updated pipeline purging program is available at *www.b3pe.com.*

A Final Report on the project was issued in October 2019.

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Survey of Plastic Pipe Locating Technology and Locating Practices

For this project, a research team reviewed the current state of the art of plastic pipe locating technology. In addition, efforts were made to identify new or improved locating methods and practices.

Project Description

Currently, no method exists for locating plastic pipe under *all* field conditions. Rather, there is a toolbox of multiple devices and methods employed depending on site conditions. However, the user interfaces for the various locating devices are often complex and difficult to interpret.

In this project, researchers reviewed the state of the art of plastic pipe locating technology and made efforts to identify new or improved locating methods and practices.

Deliverables

The primary deliverable from this project will be a White Paper/Final Report that consists of the following:

- A synopsis of the current sponsor plastic pipe locator usage and issues with existing methods
- A set of goals and attributes that describe the plastic pipe locator desired by the sponsor
- The current plastic pipe locator technology state and best practices of locating, and
- A list of technologies that warrant further investigation.

Benefits

The quick and accurate location of plastic pipe is critical to the execution of field operations. Missed or inaccurate locates can add expense to excavations and repairs and can create excavation hazards for construction crews and the public.

Technical Concept & Approach

For this project, researchers reviewed the current state of plastic pipe locator technology, including technologies still in their infancy.

Utilizing prior research sponsored by OTD, a White Paper was produced summarizing advancements in plastic pipe locating technology and operational best practices, including the reporting of research findings.

Initially, the project team surveyed project sponsors to determine the plastic pipe location methods currently used and their level of satisfaction. The goal was to develop an understanding of the negative and positive aspects of current practices.

Researchers revisited the technology covered in earlier studies to determine what, if any, advances have occurred. Efforts were also devoted to reviewing user interface technology. Physical attributes, such as daylight readability and ruggedness, were reviewed. Display interpretation was considered in light of recent advances in machine learning and image processing.

Project personnel also contacted locating contractors identified by the sponsors. These contractors were sur-

veyed to ascertain the latest locator best practices and may be retained to demonstrate or present the current locating techniques for plastic pipe.

Field best practices were summarized. In addition, the White Paper identified the most promising technologies worthy of further testing or development.

Results

Current methods for locating plastic pipe fall into the following categories:

- Electromagnetic reflection
- Acoustic
- Electromagnetic (with tracer wire), and
- Radio Frequency Identification (RFID) tags.

The most extensively used electromagnetic (EM) reflection method is ground-penetrating radar (GPR). GPR works well in dry and sandy soils but is seriously impaired by wet and mineralized soils. This restriction applies to approximately 60% of the soils in the continental U.S. The typical display for commercial GPR units can also require significant experience to interpret.

There is at least one microwave-based "edge detection" device sold commercially. Testing results have been ambiguous, as ground clutter, such as buried stones or metal debris, has set the device off. The same soil conditions that can impede GPR can also impede this device.

Acoustic techniques tend to work well in wet, well-compacted soils, precisely the conditions that block GPR. There are commercial offerings in this area that operate in the right field conditions. Acoustics struggle when soil is loose, dry, or has a high level of inclusions. A trench boundary, where the type of backfill or compaction differs from the native soil, can also cause false positives.

The most common method for locating plastic pipe is electromagnetic (EM) using a tracer wire. EM tracing requires a transmitter and a detector that measures the EM field created by current flowing on the tracer wire. However, for plastic pipe, the tracer wire must be installed with the pipe and properly maintained. Tracer wire may corrode or be broken by subsequent excavation activity. Injecting the tracing signal requires both a free end of the wire and a good ground. These systems work reasonably well where the tracer wire has been properly installed and maintained.

Radio Frequency (RF) marker or ID tags are applied at the time of pipe installation or retroactively during repair and other pipe-exposing operations. A handheld device is required to locate these devices. The located RF marker may also contain a serial number (RFID). If the RF marker is properly installed, the location provides one point on the line. A challenge with the RF marker technology is the distance between markers along the line. Utilities are often forced to balance the trade-off between the cost of procuring and installing the RF markers and the number of location points that are available.

Both tracer wire and RF markers share a common attribute: they provide the location of a secondary device, not the primary location of the pipe. Both of these systems require well-defined installation practices to assure that the wire or RFID is placed properly.

In addition to understanding the variety of locating tools in the toolbox and identifying which one to use, locators also need to consider other factors that create challenges to locating buried piping, including soil conditions, nearby utilities, signal bleed-off, correct locator settings, and various others.

In 2018, the project team created and distributed a 10-question survey to project sponsors regarding locating practices and technologies currently in practice. Results from complete surveys were analyzed and incorporated into the project analysis. Additionally, researchers reviewed past OTD projects to identify plastic-pipe-locating technologies that were studied and to assess if other, more effective solutions are currently available. Results from past studies were compared and contrasted against present-day locating industry research sources. Furthermore, the project team interviewed a locating subject matter expert from Staking University to validate the present state of locating trends and technologies.

The project team reached out to locating-industry subject-matter experts to validate industry trends and technology adoption directions and incorporate feedback.

In 2019, revisions to the draft Final Report were made.

Status

Completion of the Final Report will take place in 2020.

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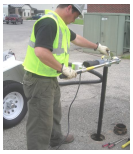
Tool to Limit and/or Display Torque When Operating Belowground Valves



Researchers are conducting a technology search for different torque wrenches that are capable of exercising gas valves. The results will provide a baseline understanding of the products on the market so that operators can make informed decisions about tooling acquisitions.

Project Description

The maintenance of valves is essential for operating a safe and reliable pipeline system. Critical valves need to be operated and inspected on an annual basis and when a situation calls for gas to be shut off.

Over time, valves can become difficult to operate. Applying too much torque can damage the valve stem. Being able to capture the data on how much torque is being applied, throughout the life of the valve, can help operators make predictions or understand when additional valve maintenance and/or valve replacement may be required.

Currently, there are a variety of different truck-mounted and handheld torque wrenches that are available on the market. There are commercially-available valve exercisers that are truck mounted and can be used to view the amount of torque being applied to a valve. These units tend to be more expensive and obviously take up a significant amount of space on a truck.

Handheld, hydraulically-operated valve exercisers are also available. These can apply a fixed amount of torque to a valve so that operators know they do not exceed a certain amount of torque.

In addition to the hydraulically-driven valve exercisers, there are also handheld wrenches with torque-limiting/display capabilities. These are less-expensive, smaller tools, with applications for smaller valves. Some of these tools are available with audible and visual displays of the torque, and they can be combined with data-collection devices to record the torque applied.

The objective of this project is to perform a technology search for different torque wrenches that are available on the market capable of exercising gas valves. The project will provide a baseline understanding of the products on the market and the operational needs and requirements of each so that operators can make informed decisions about tooling acquisitions. Tools examined will include wrenches that can limit the amount of torque applied, as well as tools to display the amount of torque applied in real time during the exercising of gas valves.

Deliverables

The deliverable for this project will be a document that outlines the available tools on the market for torque-limiting wrenches, as well as torque display and data-collection tools.

Benefits

Valves installed in the ground can become difficult to operate over time. Operators encounter several issues when a valve becomes difficult to turn, including situations where undue stress to the stem and the body of the valve can cause unnecessary fatigue or potential failure. This can occur when operators use excessive mechanical force, or use a backhoe to help "break free" the valve. Having a tool to display the torque being applied, or a tool that allows only a limited amount of torque to be applied, can assist in ensuring that undue stress is not applied to the valve. Additionally, when employees are straining to operate a valve, the potential for injury is heightened. New technologies could help to reduce this risk.

Technical Concept & Approach

This project will document the different torque-limiting/display tools that are available in the gas utility market and other markets to provide operators an understanding of the available options to assist with exercising valves.

Project tasks include a survey of sponsors to determine current practices regarding the use of torque wrenches. The information collected will include types of equipment used, as well as any documentation of data related to torque applied to valves.

A search of tools available in other markets will be performed and the information documented and provided to project sponsors. The search will include torque wrenches as well as tools to document/display the torque data as the wrench is in use.

Plans are to demonstrate the performance of up to two selected torque wrenches.

Results

This project began in November 2017 with an initial market search for products currently on the market. Information on a valve-maintenance-system company that designs and manufactures valve-exercising equipment. The company has a wide variety of equipment for different valve exercising scenarios and have integrated data collection into their existing systems. These data-collection systems allow utilities to synchronize the work that is being done in the field with their internal databases by collecting and storing critical data pertaining to valve operation (e.g., measured torque levels, torque control limits, and real-time GIS tracking).

In 2019, steps were taken to advance the project's progress and the project team conducted a live demonstration of torque-controlled valve equipment on a steam valve in New York City. The valves that are on the steam-distribution system are typical square-nut, multi-turn valves that are used on natural gas systems. The manufacturer successfully exercised a valve and generated a report that describes the amount of applied torque (as well as GPS data for storage and record-keeping purposes).

The valve-exercising equipment creates a torque curve that documents the required torque needed to turn the valve throughout the entire operation of the valve. Sometimes, a valve will have a rough spot where the required torque is increased to work through the turn operation. Hopefully, though, through exercising the valve a few cycles, the torque curve will flatten out and make the valve easier to operate for future exercises. Depending on whether the system is in a loop configuration, differential pressure can be a large concern. If the valve is closed and a large enough pressure differential is created on either side of the valve, then the valve will likely be much more difficult to open again.

Status

A Final Report is being prepared.

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Field Testing of Nano-Technology Coatings to Reduce Aboveground Corrosion

To address corrosion concerns with aboveground utility assets, field trials are being performed with unique and promising coatings for challenging utility corrosion-prevention applications. These coatings have the potential to substantially reduce wet/dry aboveground corrosion in various areas of application.

Project Description

Utilities have long expressed interest in the development of improved pipeline coatings for challenging environments. Of particular concern are applications for aboveground facilities.

The concept for this project came from needs expressed by a utility group wanting to explore super-hydrophobic nano-coatings to improve corrosion resistance in high-risk areas. Other utilities are interested in testing these novel coatings in snow/ice areas, as well as bridge crossings that have significant, industry-wide issues with caustic leafing corrosion from bird droppings.

For this project, field trials are being performed with relatively new, unique coating systems, including super-hydrophobic coatings and calcium sulfonate alkyd passivating coating.

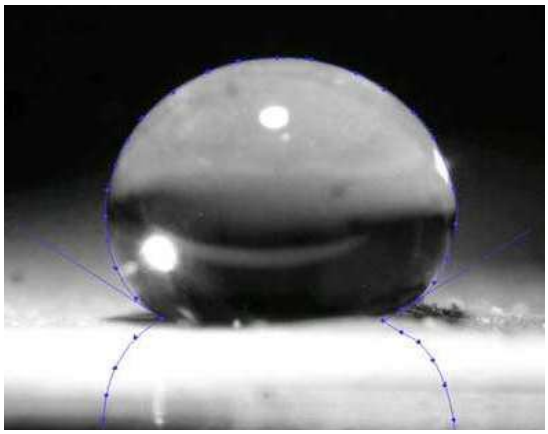
In the laboratory, coatings demonstrated an improvement in corrosion prevention that is four to six times better than the leading coated-steel surface. The comparison was made with top-of-the-line commercial polyurethane coatings used on bridges and infrastructure across the bridge and construction sector. The formulation is a super-hydrophobic system that repels water, mud, ice and other liquids. This new "nano" class of coatings cause water to form nearly perfect spheres which roll off the surface, keeping items dry and clean. Although this coating system seems to hold promise, it has not been tested on gas-industry-system components and the associated/typical service environments. There are questions related to UV resistance, coating toughness, longevity of the hydrophobic properties, and others issues that need to be investigated and tested to fully vet this technology for gas industry use.

The high-ratio co-polymerized calcium sulfonate proprietary formulation has the unique ability to: neutralize acidity (passivating); create a hydrophobic barrier that repels water; bond ionically; and thoroughly wet the surface profile, making it suited for the reclamation and long-term protection of bridges, steel structures, cable-suspension systems, industrial infrastructures, highway overpasses, utility towers, and potentially pipelines.

Deliverables

Specific deliverables from this project include:

- A set of applicable use cases in a gas utility for these coating systems
- Completion of set of field tests
- A coating-performance summary
- Recommendations for specific uses of the product, and
- A Final Report detailing all activities.



Water on the coating surface sits as an almost perfect sphere. Water beads "glide" over surfaces with almost no surface friction.

Benefits

Corrosion of aboveground facilities are of particular concern for gas-system operations. For aboveground assets, operators cannot rely on cathodic protection to backup coating protection; therefore, operators seek to specify and apply the most appropriate and best-performing coating system available. By providing long-lasting coating protection, operators can reduce the amount of rework needed on their aboveground systems.

Some aboveground piping locations are very difficult to access and require permitting, multiple crew members, and special equipment and vehicles to inspect and/or repair coatings. These include highway and bridge crossings, water crossings, and vaults. Operators that have outdoor meter sets and regulators also experience snow and ice damage of these assets. A coating that does not allow water, snow, or ice to accumulate on aboveground assets can prevent the associated damage.

Field testing these unique coatings in the natural gas utility environment will give operators data to support their use to reduce system damage and loss of integrity, thereby reducing the risk of system leaks or failures. By testing the coatings under varying climate and system configurations with different operators, researchers will obtain a more complete picture of product performance in a variety field sites.

Technical Concept & Approach

- Use Case and Field Site Selection
- Product Review and Selection
- Development of a Field Testing Protocol and Testing Matrix
- Conduct Field Trials
- Assess Performance, and
- Develop a Final Report.

Results

In 2018, the project team completed field site selection, product review, and testing matrix.

In 2019, the last of the field site companies submitted their sites and product selections for the field trials. The only item remaining is the field protocol, which will be finalized and sent out to the field trial companies as set of useful/supplementary guidelines for surface preparation and application.

The project team completed and distributed the:

- Concise Field Applied, Aboveground Coating Best Practices
- General Surface Preparation Guidelines
- Guidance on what type of scribe tool to use and how to purchase that option
- Manufacturer recommendation for application brush type for ZRC coatings, and
- Field site key lessons learned.

Field trials were successfully completed in August, September, and October of 2019.

All of the coatings have temperature/humidity/dew-point restrictions. This will most likely be a challenge on the low-pressure side of regulators.

Status

Additional field trials remain for the project.

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Leak Seal for Meter Set Joints

Research is focused on the evaluation and commercialization of a new method to seal thread leaks on meter set assemblies. The evaluation will be conducted to establish ease of use and permanency.

Project Description

Some utilities are now classifying and logging leaks on residential and commercial meter set assemblies (MSAs), and many have established that a significant number of the leaks occur at threaded joints between components. Currently, a common practice is to dismantle an MSA once a leak has been detected, reseal the leaking joint, and reassemble the MSA, which requires customer downtime, relights, and time involved in conducting the repair. However, many of the components (other than the thread area) are in good working condition and not requiring replacement.

For many years, pipe "dopes" (joint sealants) have been used as one method of ensuring proper sealing of threads. Solvents in the pipe dope provide stability during application and ensure a proper cure. When the solvent evaporates, the product dries to form a tough seal. Unfortunately, when dried, the bond can also become rigid and brittle in nature. Aging and temperature cycling can cause these rigid sealants to crack, creating small leak paths around the pipe on the unsealed threads. As the cycling continues, crack propagation continues and increases the severity of the leak.

Often, leaks are so minor that they can only be detected by application of a liquid leak detector. For these instances, the removal and resealing of the leaking component is especially time consuming and disruptive.

In this project, researchers investigated alternate solutions involving the application of a spray-on or a brush-on material to the leaking threaded joint to permanently stop the gas leak. Researchers identified various spray-on, brush-on, putty, or epoxy solutions, and developed a product in collaboration with a sealant resin manufacturer.

The objective of this project is to commercialize a permanent leak sealant for non-hazardous low-pressure gas leaks on MSAs.

Deliverables

The deliverable from this project include development of a fast-curing, easy-to-apply permanent leak sealant product for non-hazardous, low-pressure MSA thread leaks that has been laboratory tested and formulated specifically for the natural gas industry.

The project team will also execute a field pilot study for the product.

Benefits

Utilities could more effectively and efficiently address leaks on MSAs if an easy-to-apply system was identified and validated for use on low-pressure natural gas leaks. Addressing these very small "nuisance" leaks on MSAs will assist the industry in minimizing the effect of one source of methane emissions and reduce the time and cost associated with performing this maintenance operation.

Technical Concept & Approach

The initial task for this project included an in-depth review of the commercially available products that can be applied to metallic MSA components to stop leaks.

Other tasks included:

- **Resin Manufacturer Collaboration and Reformulation**

  The project team collaborated with an existing resin manufacturer who already markets a product that was tested in this program.

- **Short-Term and Long-Term Leak Repair Testing**

  Different formulations of the product will be laboratory tested to evaluate the short-term and long-term performances.

- **Field Pilot Study**

  Researchers will organize a field pilot study to evaluate performance when used in day-to-day utility repair work.

- **Commercialization of Reformulated Product**

  If the product proves to be useful and has satisfactory results, the project team will move to commercialize phase of the final product.

Results

In Phase 1, researchers evaluated more than 20 leak-sealant products. Through this evaluation, several putty-style leak-sealant products were identified that could potentially provide efficient and effective ways to permanently repair small non-hazardous low-pressure gas leaks.

Six repaired and painted pipe assemblies

In 2019, activities for this quarter included completing the short-term testing of the different leak-sealant products. This short-term testing consisted of applying the sealant product to one-inch threaded pipe joints. The short-term testing included evaluation of sealant reaction to leak soap and gray meter paint along with the overall cure time of the product. The products that successfully passed the short-term test protocol were then put through the long-term test protocol. The repaired specimens were evaluated by subjecting them to temperature cycling in an environmental chamber. The specimens were subjected to temperature cycling on a 24-hour cycle from -20°F to 140°F at 2 PSIG for 10 cycles (10 days).

Resin manufacturers with sealants that tested favorably during Phase 1 were contacted to gauge their interest in participating in the Phase 2 commercialization project.

Status

The project team is ensuring that agreements are in place with resin manufacturers.

The hand-applied product formulation and packaging needs to be customized for use by utilities (i.e., low level of VOCs, short cure time, paintable, etc.). The project team and the resin manufacturers of existing products will create and commercialize a product that is specifically designed to repair low-pressure leaks on MSAs.

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Insertable Excess Flow Valves for Existing PE Service Lines

Researchers conducted a review of insertable excess flow valves (EFVs) currently on the market that are suitable for existing PE natural gas service lines. A reference document was developed to address operational parameters, insertion techniques, and other considerations.

Project Description

Recent changes to regulations regarding excess flow valves (EFVs) allow customers to have the option of requesting an EFV on their service line. As a consequence, there is a renewed interest in EFV systems that can be directly inserted into service lines.

Insertable EFVs provide cost-effective installations on existing service lines, without the need for excavation. However, utilities need to better understand EFV's commercial availability and the feasibility of insertion into various types and sizes of polyethylene (PE) service lines.

Some of the concerns regarding these valves include:

- Ease of insertion into existing service lines
- The effects of EFV insertion on the performance of the PE pipes
- Sizes and specifications available, and
- Limitations of current insertable EFVs.

OTD has supported several projects related to the evaluation of EFVs. These studies resulted in the development of information on EFV performance, bypass flow, effect of service length, instantaneous load (demand surge), corrosion resistance, and the integrity of EFV materials of construction. However, the EFVs tested in these projects were not of the *insertable* type.

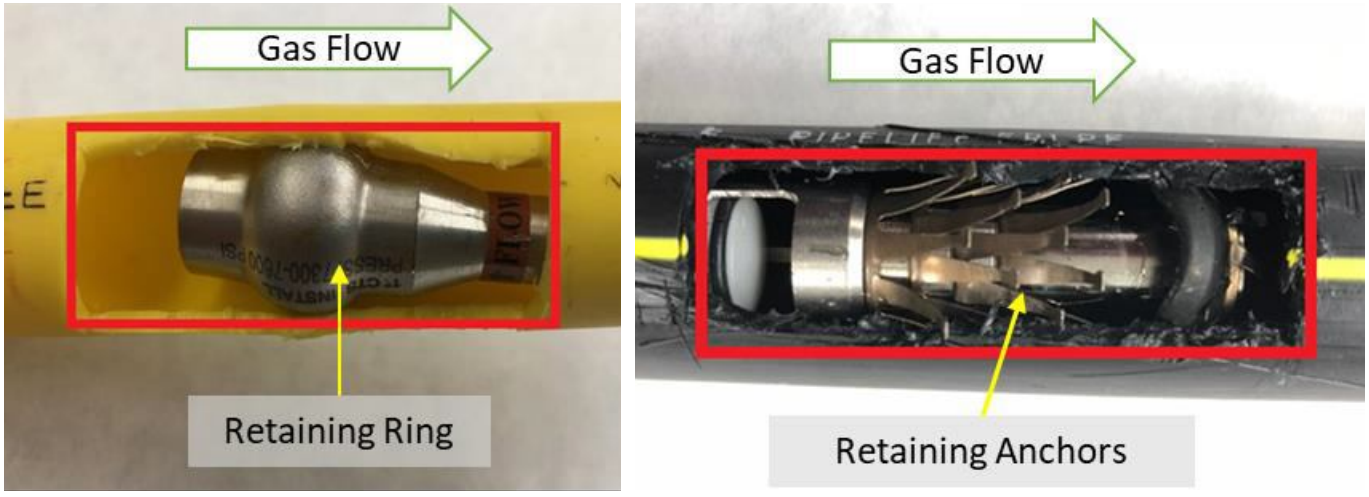
In this project, researchers conducted a review of insertable EFVs currently on the market that are suitable for existing PE natural gas service lines. A reference document was developed to address operational parameters, insertion techniques, and other considerations.

Deliverable

A White Paper was developed on insertable EFVs for existing PE service line. The document contains information on commercial availability, technical specifications, and insertion techniques. The study also identifies certain promising EFV systems and the feasibility (pros and cons) of using them on existing service lines.

Benefits

The Pipeline Transportation Safety Improvement Act (S.B. 275) addresses various safety issues, including the use of automatic shutoff valves and EFVs – expanding the requirements of EFVs to multifamily buildings and small commercial/ industrial facilities. With changes to the rules concerning EFV installations, utilities are now required to notify their customers about their right to request an EFV installation. This will result in an increase in the demand for EFV installations on existing PE service lines.This project offers a third-party reference on insertable-type EFVs.



Insertable Excess Flow Valves.

Technical Concept & Approach

Initial activities included a survey and conference call with sponsors to determine their requirements. The survey addressed:

- Service line pipe size(s) for EFV insertion
- Flow requirements for EFV sizing, and
- The identification of various insertable EFVs.

The project team identified commercially available insertable EFVs and reviewed their specifications, such as, but not limited to, standard sizes, trip flow ratings, operating pressures, time required for insertion, and cost of the system. A comparison between EFVs from different manufacturers (standard EFVs) was included in the review.

Results

This project provided a White Paper report on commercially available insertable excess flow valve (EFV) systems, the operational parameters of these devices, the insertion techniques, and other considerations for using this type of device.

As part of this research, two systems were identified and evaluated. Both manufacturers assemble the installation unit required to install these devices. The limitations of each system is detailed within this report.

There are some usage limitations with insertable EFVs. It is important that utility operators assess their system design to determine the feasibility of installing insertable EFVs within their system before investing in equipment and devices. Some design considerations include service line pipe size, types of fittings and connections on a service line, flow capacity, and length of service. There are utility operators within the U.S. that are installing insertable EFVs successfully within their system on a regular basis. One specific utility operator installs approximately 800 units devices annually without any issues.

Long-term hydrostatic testing was performed on test pipe samples with insertable EFV devices installed and subjected to squeeze off. No failure was observed after 1,700 hours of testing, which extrapolates to a service life of more than 100 years.

Some findings on limitations and tooling investment:

- Pipe Sizes: ½" IPS, ¾" IPS, 1" IPS, 1-1/4" IPS. The ½" IPS size cannot be installed through bent risers.
- Maximum Flow Capacity: 550 SCFH for all sizes.
- Maximum Insertion Length: 200 feet.
- Tooling Investment: Approximately $13,000 per unit.

The project team coordinated insertable EFV demonstrations. common service line fittings (i.e., service risers, mechanical couplings, etc.) were obtained to develop a pass/fail criterion for the installation of insertable style EFV's. Also, a 3D-printed reference gauge was developed for project sponsors to use and determine if an insertable EFV will fit through the different fittings installed within their distribution systems.

Long-term hydrostatic testing of PE piping with an insertable EFV installed was conducted.

Both systems have similar operational and equipment advantages and disadvantages. Also, both systems offer mostly the same benefits of improved system safety and reduced operations and maintenance expenses associated with the installation of these types of devices.

Status

This project is complete. A Final Report was issued is March 2019.

The next steps to increase usage applications of insertable EFV systems are to:

- Continue to work with manufacturers and product developers to improve their products by addressing the identified limitations and recommendations of each system
- Continue to educate utility operations personnel on the usage applications for insertable EFV systems.
- Identify potential field installations with a participating utility operator to prove the value of the system
- Conduct thorough product testing to understand the long-term impact of installing insertable EFVs, and
- Conduct long-term hydrostatic testing on vintage PE pipe to confirm there are no integrity concerns.

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Determining Minimum Recovery Time from PE Pipe Pullback

The objective for this project is to develop guidelines to help understand and predict the recovery time of PE pipe after pullback during trenchless installations such as horizontal directional drilling or split-and-pull activities.

Project Description

During horizontal directional drilling (HDD), split-and-pull processes, and other trenchless installations of polyethylene (PE) pipe, friction, soil loads, and pipe weight resist the pulling force on the pipe and can cause the pipe to elongate. Upon completion of the pull, the pipe will elastically recover some of this elongation over a certain amount of time. To avoid undue axial stress on the pipe, operators allow this recovery to complete before tying the newly installed pipe into the operational system.

Currently, there are no specific guidelines on calculating the pullback recovery time of pipe installed by trenchless methods. In response, this project is focused on establishing guidance for more accurately estimating the recovery time to both avoid excessive waiting time and ensure adequate recovery time.

Deliverables

The deliverables from this project will be a pullback recovery-time calculator, a guideline document, and a Final Report.

Benefits

Prediction of the pullback recovery time per installation case will assist operators in determining the minimum time they should allow for a pipe to relax, thereby minimizing the risk of premature tie-in while also avoiding unnecessary tie-in delay.

Development of an industry-accepted guideline for pullback recovery-time estimation, and an associated calculator, can increase confidence in the quality of trenchless installation procedures and enhance the overall integrity of the installed pipe.

Technical Concept & Approach

- **Material Testing**

  Material testing includes tensile testing of specimens (taken from pipes installed using an HDD process) and full pipe specimens. Testing is being conducted on two pipe materials: bimodal medium-density PE and bimodal high-density PE.

  The tensile tests mimic the pulling forces and pull durations of trenchless installations to quantify elongation and recovery times.

  Each test specimen goes through the following load steps, mimicking an HDD installation:

  1. Ramp to a pull stress
  2. Hold pull stress for a given amount of time (creep)
  3. Unload to zero stress
  4. Hold sample at zero stress for a given amount of time (recovery)

  These steps are repeated for a given number of cycles.

The pull stresses are based on the allowable 12-hour pull stress as defined in Plastics Pipe Institute (PPI) *Handbook of PE Pipe.* Tests are performed at four temperatures to cover the operating temperatures during HDD installations.

- **FEA and Calculator Development**

  Material models were calibrated to the data collected from material testing. A finite element analysis (FEA) model is being used to generate a calculator for operators that takes material, pipe diameter, pipe thickness, temperature, pulling force, and pull duration to determine the pullback length and recovery time. The model will be verified against full pipe tensile tests.

- **Guideline Development**

  Experts from Gas Technology Institute and PPI will partner in the development of an industry guideline. This task will include related industry outreach and discussions.

At the conclusion of this project, a Final Report will be issued with an overview of the results and guidelines regarding pullback length and time. A webinar will also be conducted to demonstrate the calculator and interpret results.

Results

Initial activities included the development of reference information on pipe loading during HDD installations, preparation of a survey for project sponsors, and development of a material-testing plan. The project team reviewed and analyzed HDD current practices gleaned from the survey responses.

The material test matrix includes specimen load steps that simulate HDD installation. Additionally, the variables and parameters were identified and defined for creep-recovery multi-step and single-step tests.

Test specimens were obtained and tested. The initial model for pipe pullback was created. Model verification will take place against the full pipe tensile tests accomplished during the materials testing task. The calculator is envisioned to take pipe diameter, material, and either elongation and recovery of weak link or force-time curve as inputs.

In 2018, the project team executed several shakedown runs leading to continuous refinement of the test setup and related protocol.

The highly nonlinear behavior of polyethylene is proving to be a challenge to calibrate to a single material model that comprehensively covers different creep stresses and number of loading cycles. PE material is known to exhibit variance in creep rate under given a stress, which needs to be considered. Currently, the project team is taking a phenomenological calibration approach to capture the creep behavior of the material and intends to develop multiple models for specific loading cases and cycles.

The constitutive modeling of the PE material numerically captures the behavior of the material when subjected to different loading conditions. Further, this model enables FEM simulations to accurately predict PE deformations under stress.

Creep-recovery test data was reviewed and a mathematical model is being developed to capture the recovery time in these tests.

Status

Material testing and material model calibration are ongoing.

Researchers are preparing for full-pipe tensile testing. The Finite Element model will be refined and validated based on calibrated material models and full-pipe tensile tests.

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In-Service Welding Qualification Test Rig Guidelines

In this project, researchers developed a test and construction guide for in-service welding that can be used to assist gas utilities in the qualification of welders according to the American Petroleum Institute (API) Standard 1104.

Project Description

The American Petroleum Institute's API Standard 1104 is the preeminent text on pipeline construction and repair. Numerous sections have been mandated by regulations since its introduction in 1953.

As typical of standards, API 1104 does not include supplemental materials detailing instructions or explaining the reasoning behind the requirements. There have been supplemental texts developed in recent years interpreting the guidelines set forth by this standard as well as updating technical information as pipeline construction has incorporated advanced materials and technology. However, practices for in-service welding have not received much attention in regards to welder qualification.

This project focused on the development of a testing rig and guidelines based on the technical information and requirements outlined in API 1104. This rig will serve as a uniform qualification tool for the gas industry.

Deliverables

Deliverables include:

1. A three-dimensional model of a prospective welding qualification rig
2. Construction guidelines for developing the rig, and
3. A Final Report and construction guide for the in-service welding test rig (detailing dimensions and capabilities of rig as well as improvements that may be added to standard requirements).

Benefits

An In-service Welder Testing Guide and Construction Manual is a first step toward providing the industry with a standard qualification testing apparatus. If adopted, this rig and guideline would ensure that all welders are qualified based on the procedures and technical qualifications outlined in the API standard.

Test assemblies where a piece of 12-inch pipe is clamped into place.

Performing uniform tests would allow utilities to have a cohesive knowledge of the standard as well as allowing them to analyze and determine deficiencies within the evaluations.

Technical Concept & Approach

Initial efforts involved determining requirements outlined in the API standard relating to qualification testing for welders – specifically in-service welding. A three-dimensional model developed from the technical dimensions served as a preliminary determination of the rig's operation and efficiency in qualification testing. From this, a construction guide was made to provide the necessary details of the rig for utilities.

A second phase may be introduced as a follow-on effort to develop the model into a working product that can be commercialized for the industry.

Results

The In-Service Welder Testing Guide and Construction Manual was created to support natural gas utilities by defining the recommendations of in-service welder qualification. Because of a high level of ambiguity in the API Standard 1104, *Standard for Welding Pipelines and Related Facilities*, including Annex B, *In-Service Welding*, many questions arise on what type of testing is required when qualifying a welder to perform in-service welding per Annex B. There has also been an increase of regulatory oversight in recent years with some operators reporting significant issues because of this ambiguity and differences in opinion about the true intent of some of the requirements in API 1104.

While Annex B of API 1104 covers *recommended* welding practices for making repairs to or installing appurtenances on pipelines and piping systems that are in service, this manual can still be used as a guide to qualify welders for in-service conditions.

The In-Service Welder Testing Guide and Construction Manual was created with the intent of not only providing guidance for in-service welding techniques and information for qualifying welders and creating in-service weld procedures, but also as to why it is important to apply these practices. The principal reason to follow these recommendations is to reduce the risks of Hydrogen Assisted Cracking (HAC). The guide includes general welding recommendations, choosing the type of and applying preheat, the proper welding sequence when welding on full-encirclement and other types of fittings, and finally the inspection and testing of in-service welds.

Status

This project is complete. The In-service Welding Guide and Construction Manual was issued in February 2019.

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Compact Gas Meters

Researchers are reviewing the current state of smaller, more compact gas meters rated for 250 standard cubic feet per hour or less. These smaller designs will allow for greater flexibility when installing meters in small spaces and areas where multiple meter sets are required.

Project Description

Space is always an issue when installing meter sets. The meter set's final location must conform to varying clearance distance guidelines regarding the meter's proximity to windows, air ducts, electric meters, and other types of installation obstacles. The challenge is even greater when installing multiple meters in a small amount of space.

Utilities could save a large amount of space and increase installation options if smaller-profile meters were available. These smaller-footprint meters would especially be of benefit for multifamily applications.

In 1995, a gas meter was developed that was 35% smaller than a standard meter. This compact meter was sufficient for normal residential needs and was capable of measuring flows up to 250 standard cubic feet per hour. A useful feature of this design was the ability to be installed in multiple configurations, offering utilities even further installation flexibility.

This new project is revisiting this compact meter design and research meters that are similarly configured, offering a more compact and modernized design alternative to current meter sets.

These smaller designs will allow for greater flexibility when installing meters in small spaces and areas where multiple meter sets are required (i.e., multifamily buildings).

While reviewing these smaller meters, the research team will evaluate the available products for their potential usefulness.

Deliverables

The deliverables for this project will be a Final Report (White Paper) summarizing the current market of compact gas meter designs as well as their use around the world. These compact meter sets will be evaluated for their potential usefulness according to important design factors such as meter accuracy, overall meter size while retaining flow capacity, etc.

If the current state of the market is deemed inappropriate for current utility needs, then researchers may propose a follow-on project where a compact meter set is designed in collaboration with a meter set manufacturer. If needed, another project will be proposed to create a final design that is smaller than meters that are in use today without sacrificing performance. The new design should also be relatively easy to produce with a production cost competitive with existing models.

Benefits

Size reduction is one of the primary design criteria for meter sets that are currently under development. Increased real estate and construction costs have high-

lighted the need to minimize that amount of space on each floor that developers need to dedicate to service areas. Compact meter sets can save space and maximize the area of space that is available to building tenants.

A compact meter set design will have the most noticeable positive effects when installing meter sets in areas with scarce available wall space. Urban apartment complexes, for example, would see a dramatic decrease in occupied wall space with the implementation of a more compact meter set design. As a result, indoor meter rooms would not have to be as large.

Technical Concept & Approach

The project team will reviewed the current state of the art of compact meters and evaluated commercially available meters and their use cases. Various compact meters and features were reviewed with the project sponsors to identify the most crucial design elements that a meter needs to have for actual integration and use. This group of compact meters includes both diaphragm and ultrasonic meters.

Factors to consider during the evaluation process:

- Understanding of accuracy compared to traditional diaphragm meters
- Decreasing overall meter size while retaining flow capacity
- Past and current designs that existing meter manufactures may have
- Available compact meter designs used in other parts of the world
- Input from current utility users of these compact meters
- Meter and battery life (if applicable), and
- Any additional features of the meters.

Results

In 2018, a survey was sent to sponsors for feedback on compact flow meter requirements. These results are incorporated into a market analysis and evaluation of commercially available compact flow meters.

A list of viable candidates that meet project specifications was compiled. Specifications were filled in for identified compact meters for suitability specifically on accuracy, dimensions (footprint, center to center), flow capacity, maximum allowable operating pressure, basic features (e.g., temperature compensation), and meter and battery life. This process produced a list of 23 meters from 16 companies. Features such as automatic shutoff, methane sensors, tamper notification, and high-flow shutoff are being addressed.

A White Paper was drafted that includes a specification table for 42 different compact meter types.

Status

The project team is developing a list of additional questions for determining the value of particular features to operating companies.

A Final Report is being drafted.

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Advanced Metering Infrastructure Communications Protocols

In this project, researchers are investigating recent developments in advanced metering infrastructure communications platforms. This study will help utilities identify vendor solutions that are truly interoperable and offer standard interfaces between disparate utility systems.

Project Description

Many gas utilities have already or are considering migrating from automatic meter-reading (AMR) systems to advanced metering infrastructure (AMI) platforms. These decisions can be influenced by AMI's ability to support devices that offer increased operations and environmental monitoring.

While some manufacturers claim that their systems support "open and interoperable" communications with field devices, closer inspection reveals that sometimes these communications occur over proprietary networks.

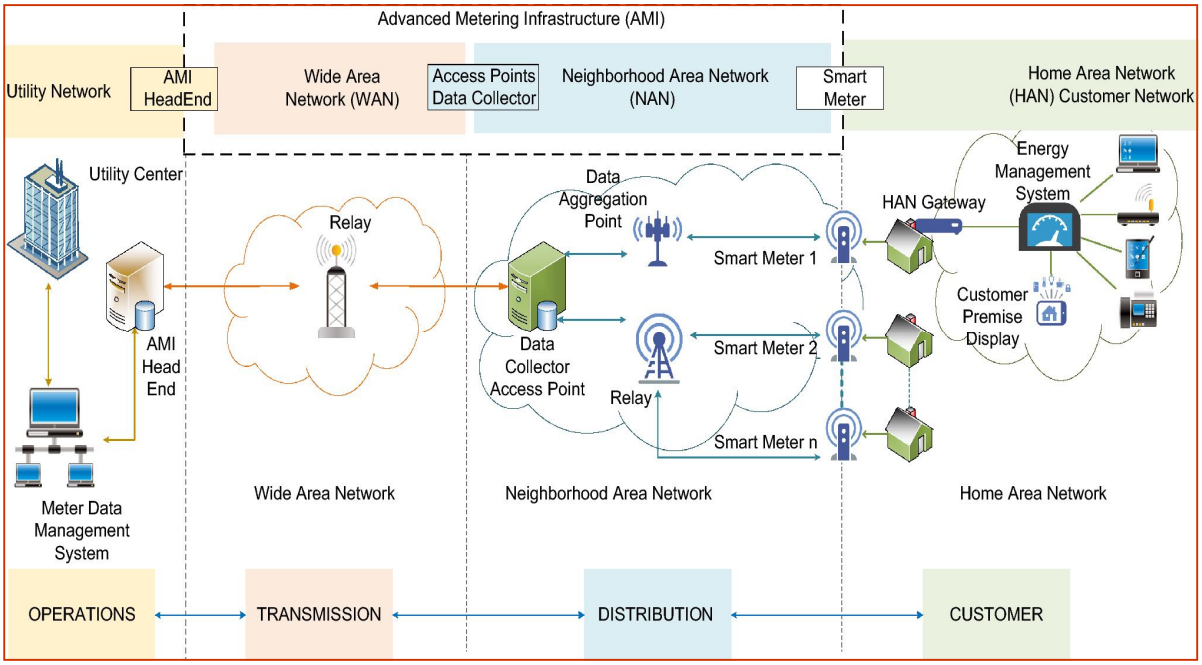
Research is this project is being conducted to help identify the characteristics of truly open communications protocols so gas system operators may make informed decisions when choosing an AMI system provider. The focus is on recent developments in AMI communications platforms. The intent is for utility operators to use the study's findings to identify vendor solutions that are truly interoperable and offer standard interfaces between disparate utility systems.

Open communication protocols are important because they allow operators to implement the various smart sensors and other devices (e.g., shut-off valves, methane sensors, etc.) that are now being developed and commercialized. Several major AMR/AMI vendors recently endorsed open communication protocols. An industry group, Wi-SUN (Wireless Smart Ubiquitous Network) Alliance, was formed to curate these standards.

Deliverables

The results of this research will be a White Paper (Final Report) on the state of the art of the AMI communications protocol industry. Specific contents for the White Paper include:

- A review of the mission, goals, charter, and scope of the Wi-SUN Alliance
- Participation in the Wi-SUN Alliance
- The methodology and challenges associated with validating that a device conforms to the Alliance standard
- A summary of what is on the horizon for AMI devices, and



- An outline of next steps for follow-on project phases.

Benefits

The primary benefit of utilizing systems that operate on open AMI standards is the ability to realize additional value from the infrastructure beyond customer meter reading. For example, companies that have invested in AMI would also gain the ability to add sensors and actuators to that infrastructure, including distributed methane sensors and gas shut-off valves. Interoperable AMI standards would eliminate the need to buy devices from a single vendor, keeping the market competitive.

An open AMI connection standard will also accelerate innovation of goods and services in this space. The challenge in the current AMI environment is being able to ascertain which vendor solutions are truly interoperable and which make interoperability claims but rely on proprietary network communications. This project will help overcome this hurdle by providing a methodology to sort through a vendor's claims and identify truly open AMI solutions.

Technical Concept & Approach

In this project, researchers are investigating the Wi-SUN Alliance activities to determine if any of the current Wi-SUN-certified devices are of value to gas distribution companies.

Specific activities include:

- **Wi-SUN Alliance Engagement**

  Researchers engage Wi-SUN and determine how well its activities and standards align with gas industry needs.

- **Apply Wi-SUN Standards to AMI Open Standard Devices**

  The project team will analyze the open and interoperable standard(s) endorsed by the Wi-SUN Alliance.

- **Define AMI Open Standard Device Use Cases**

  In this task, the project team will identify the AMI application devices that are of greatest interest to the project sponsors.

Results

The project team gained familiarity with the Wi-SUN Alliance organization through a review of website documentation, videos, and supporting materials A Contributor membership to the Wi-SUN Alliance was approved, which allows participation in and voting privileges for working groups and committees, among many other benefits.

The project team purchased hardware sensor devices and successfully executed a demonstration program in support of the standard endorsed by the Wi-SUN Alliance.

In 2018, the Wi-SUN Alliance launched a Field Area Network (FAN) certification program. The FAN certification process is intended to address two goals: 1) to verify that FAN devices from different manufacturers are interoperable and 2) to verify that certified devices provide a reasonable level of security for that device's purpose. This framework is intended to create an ecosystem of devices that can readily interoperate.

The Wi-SUN Alliance is promoting open standards for communication based on the IEEE 802.15.4g wireless standard. On top of this communication, Wi-SUN is also promoting IPv6 addressing and security protocols based on best practices.

The project team has been identifying various equipment, such as wireless sensors, that adhere to the communication standard. The purpose of this activity is to investigate the feasibility of adapting these existing components to the Wi-SUN framework.

The research team identified that the use case of highest interest to the gas industry at this time (excluding metering) is the monitoring of methane. This is being driven both by safety considerations and by increased scrutiny of greenhouse gas emissions. There is also interest in the use cases of cathodic-protection monitoring and pressure monitoring.

Several approved testing laboratoriess for Wi-SUN compliance are now operating. The first five products completed and passed Wi-SUN certification during the first quarter of 2019.

Status

Researchers continue to identify and investigate devices of interest to the gas industry that show promise of being Wi-SUN compliant going forward.

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Low-Cost Non-Corrosive Anodeless Risers

The objective for this project was to perform a gap analysis between anodeless service risers that are currently on the market and project sponsors' needs for an enhanced anodeless service riser.

Project Description

Anodeless risers are commonly used in gas-metering equipment; however, many natural gas utilities are experiencing potential safety issues with anodeless risers due to corrosion and general thinning of the gas-carrying pipe components.

Pipe wrenches, yard equipment (lawn mowers and trimmers), yard mulch, and concrete can cause corrosion to occur with current risers, shortening their lives. Current risers require the gas-carrying steel pipe nipple to be welded to the transition portion of the riser. The transition and lower portions of the riser are typically powder coated by the fitting manufacturers; however, the upper portion of the riser (steel nipple and weld area) cannot be powder coated and therefore must be coated with a less robust, hand-applied coating.

Various utilities are periodically replacing their risers due to corrosion on the metallic, non-buried, portion on the riser. Utilities and their customers would benefit with new risers that do not require the installation of an anode with the riser to address potential corrosion. Some utilities have suggested replacing the metallic portion of the riser with advanced composites to prevent corrosion while maintaining the structural integrity of the riser.

There are multiple anodeless risers currently on the market. For this project, investigators performed a gap analysis between anodeless service risers that are currently on the market and the project sponsors' needs for an enhanced anodeless service riser.

Deliverable

The deliverable from this project is a Final Report containing:

- A review of existing anodeless risers currently available on the market
- A gap analysis outlining key features and/or characteristics desired by the project sponsors that are not met in existing products, and
- Suggestions for possible modifications to existing anodeless risers.

Based on the findings of this project effort, the project team may be able to identify manufacturers that are interested in designing and developing low-cost non-corrosive anodeless risers that meet the project sponsors' needs. This may be in the form of follow-on development phases.

Anodeless service risers with pre-installed service valves cut to 18 inches.

Benefits

An enhanced low-cost non-corrosive anodeless riser will improve overall system integrity and reduce the operational expense required to to replace corroded anodeless risers.

Improved anodeless service riser performance will increase customer safety due to a reduction in premature service riser failures. Also, it will reduce operations and maintenance costs associated with maintaining corrosion protection coatings and/or having to replace service risers altogether as a result of a premature failure.

Technical Concept & Approach

The research team gathered technical data on commercially available anodeless risers from various manufacturers. These anodeless risers were analyzed based on technical specifications and manufacturer claims. The findings were compared to the sponsor survey information in order to determine if any of these anodeless risers satisfy the requirements of the project sponsors.

An evaluation (physical testing) of promising commercially available risers was conducted to validate the claims of the manufacturers.

Manufacturers will be contacted to determine their interest in developing/enhancing one of their existing anodeless risers.

Results

This project provides a gap analysis – based on market research and laboratory testing – for low-cost non-corrosive anodeless service risers commercially available in the market. Also, additional information on why non-corrosive composite (i.e., fiberglass) type anodeless service riser materials do not exist in the market today is provided. The findings from this gap analysis will help utility operators make material and purchasing decisions when selecting non-corrosive anodeless service risers to install within their distribution systems.

Based on the findings from this project, commercially available options do exist with each of the manufacturers that were evaluated. Besides considering improved coatings, the manufacturers recommend having service riser valves factory installed. It is estimated that 80% of premature service riser corrosion can be prevented with factory-installed valves. This is a result of causing damage to the factory-applied coatings when installing the service valves in the field and relying on field-applied corrosion protection coatings which do not perform as well as factory-applied coatings.

There were a total of four anodeless service riser manufacturers evaluated as part of this project. Between these four manufacturers, a total of 10 different anodeless service riser designs were evaluated. Each manufacturer offered at least one improved coating option for their anodeless service riser design, and as expected, each of these improved coatings outperformed the standard coating. Besides improved coatings, some of the manufactures offered an improved material (i.e., stainless steel) at the threaded portion of the service riser. In most cases, this offers additional protection against premature corrosion.

The estimated cost increase for an improved coating, improved material, improved coating and material, or a factory installed service shut-off valve is a fraction of the cost of what utility operators incur annually for labor and restoration expenses for replacing anodeless service risers that prematurely fail due to corrosion. Also, besides the replacement costs, utility operators should consider their current corrosion maintenance expenses and the potential non-compliance issues with public utility commissions that may result from corroded service risers that are not maintained timely.

The primary anodeless service riser performance gaps related to premature corrosion include installing service riser shut-off valves in the field, the performance between wet and fusion bonded epoxy, and the use of epoxy coatings above ground, and exposed to UV.

The accelerated corrosion testing performed as part of this project supports the fact that all standard coatings should not be considered equal. For example, a liquid applied epoxy coating does not perform as well as a fusion-bonded epoxy coating.

Some additional corrosion-protection options include the use of shrink tubing, mastic wraps, and tracer wire shields.

As for a composite materials for service risers, manufacturers state that their R&D efforts have not found a material that meets the heat resistant value required for encasing polyethylene piping.

Status

This project is complete. A Final Report was issued in March 2019.

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Improved Tools to Locate Buried Pipelines in a Congested Underground

The purpose of this project is to help mitigate third-party pipeline damage and cross bores through the development and commercialization of a geospatial probe to map existing buried utilities.

Project Description

Historically, identifying and recording the accurate location of pipes, cables, and other utility infrastructure facilities was neither formally required nor carried out in a consistent manner. As a result, many of the mapping records that exist are inaccurate or obsolete. Often, the mapping formats are incompatible between utilities, making the sharing of data or locating the position of pipes or cables relative to another's even more difficult.

While technology has improved in recent years to enable the accurate mapping of newly installed underground utilities, there remains millions of miles of older pipe and conduit buried with no precise mapping of where these utilities are located.

Two major concerns arising from the lack of utility mapping are excavation damage and cross bores between the utilities. Third-party excavation damage and the creation of cross bores – an intersection of an existing underground structure by a second utility – compromises the integrity and safety buried structures.

In this project, research is focused on adapting a commercially available pipeline-mapping system for use in live gas pipelines. Currently, the system has the ability to accurately determine the x, y, and z position of the centerline of a pipeline in non-pressurized pipelines from 1.5 inches in diameter and larger. However, the system has numerous limitations for use within the natural gas industry, including the inability to:

- Map pipelines with no access to the interior of the pipeline
- Gain entry and insert a probe to map pressurized pipelines
- Extract data and provide software to accurately determine the correct x, y, and z positioning of the pipeline, and
- Directly download positioning and video onto a conventional GIS platform.

In this project, researchers are addressing these limitations in order to create an accurate mapping system that can be used in live gas piping.

Deliverables

This project will deliver prototypes for testing at selected utilities.

A new access fitting will be designed to allow the system to enter live lines without any gas leakage.

Benefits

By modifying the existing technology in order to allow local utilities to map their existing piping infrastructures, the following benefits can be expected:

- A significant drop in the rate of third-party excavation damage
- A reduction in cross bores
- The ability for crews to work more efficiently with more readily available and accurate mapping information, and

Pipe access fitting.

- A reduction in delays and cost overruns on roadway construction projects due to the accurate knowledge of underground utilities and the ability to confirm conflicts with planned sewer, water, and other roadway structures.

Technical Concept & Approach

The concept involves a probe that is placed into the pipeline and attached to a pull-string or mule-tape. Using specialty winches, the probe is pulled through the pipeline and the changes of direction in the x, y, and z plane are recorded on the device. Software processes the data, creating highly accurate 3D digital maps and models of underground infrastructure.

Specific tasks include:

- **Project Scoping**

  Utilities were surveyed to determine the range of pipe sizes, pressures, and types of pipelines that are of higher risk. In addition, discussions will be held regarding GIS mapping of the location data.

- **Enhancement of Existing Technology**

  The system manufacturer will refine its current system design to address the current limitations.

- **Pipeline Access Development**

  Researchers will develop a method to gain access into live gas pipelines for mapping purposes.

- **Cloud-Based Data Collection and GIS Development**

  The project team will develop integration capabilities to have both the mapping and inspection data visible in near real time by coordinating software development and its integration to allow multiple users on multiple devices, including desktop systems, mobile tablets, and smart phones.

- **System Evaluation**

  After the initial design is complete, in-ground testing will be conducted in which several hundred feet of pipe will be buried and pressurized. The new mapping system will be inserted into the live piping system to ensure that the initial prototype is functioning as planned.

- **Utility Testing of Geospatial Technology**

  Based on system evaluation, a field-ready mapping system will be developed and deployed. Validation of mapping accuracy will be conducted by making test holes (excavations to expose and locate the pipe) along the pipe.

Laboratory testing.

Results

In 2018, a third-party industry/market survey was performed to capture key performance parameters and overall industry interest.

In 2019, the project team developed conceptual designs for the new tool and cloud-based data storage system. Research was expanded on the conceptual design for the alpha-prototype for the new upgraded probe. High-quality 3D-printed components were manufactured to test the new designs capability of passing through a 90-degree access fitting in order to enable mapping in both directions. Additionally, a launching-shoe design was reformed to enable a smooth transition into the pipe. The project team also created a flow diagram for the cloud-based data-collection system that is being developed in conjunction with the new probe.

With the prototype mapping tool and 90-degree launch shoe, a successful demonstration was performed. The alpha-protoype was launched into a pipe, completed the 90 degree bend, and was then pushed with a pneumatic duct rod pusher. The measuring reading provided by the pneumatic duct rod pusher validated the total distance of 300 feet.

Status

The evaluation of the performance of the mapping probe continues in preparation for field trials. Data-management options are being discussed to improve the transition of the mapping tool data to GIS software.

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Uniform Frequency Code

The goal for this project is to create an industry standard, guideline, or best-practice uniform frequency code for passive frequency tags/markers used to locate buried utilities. This code would establish a consistent frequency setting for markers based on their respective utility designation.

Project Description

In the past, as utilities buried their infrastructure, many locators relied on hand drawings or computer models based on estimated distances of buried pipe or cable. This created a difficult situation in identifying where to excavate for construction and repairs without running the risk damaging the buried utility.

In response, passive frequency markers have become a tool used in marking and identifying buried utilities. Passive frequency markers provide a low-cost, efficient option of placing the marker with the buried utility and locating the marker through use of locators tuned to the marker's specific frequency.

Passive frequency markers are devices that generate an electromagnetic radio wave frequency to signal the location of an underground facility. Electronic markers can locate and identify an underground utility in two ways:

1. The electronic marker can transmit a radio wave frequency that is a match to a predefined utility type and
2. The electronic marker radio wave can carry identifying data from the chipset in the marker associated with the underground utility.

Electronic marking products may incorporate one or both of these capabilities to identify an underground asset. In general, radio wave frequency match is the more traditional form while data transfer identification is expanding as radio frequency technology advances and costs decline. Advantages of frequency matching include: greater depth of read, no need to read data to identify a utility type, and tradition of use.

Electronic markers fall into two primary use case categories: point marking and path marking. Both device types generate an electromagnetic radio wave frequency to provide accurate location information. However, whereas point markers are installed along the vertical axis to identify the specific location of an underground facility feature or utility type, path markers are installed along the horizontal axis along a buried underground facility.

PE pipe with locatable tags attached.

As these markers have become more popular in the industry, different arrays of tools utilizing this technology were developed. However, as many utility sectors such as water, gas, and electric encompass the same buried areas, it became beneficial to assign a frequency signal to each respective utility. To distinguish between separate utilities, a range of frequencies was developed for each utility and a color applied to each marker. However, there is no official standard of frequencies used for markers with separate utility designations.

The objective for this project is to create an industry standard, guideline, or best-practice uniform frequency code for passive frequency tags/markers used to locate buried utilities. This code would establish a consistent frequency setting for markers based on their respective utility designation (gas, electric, water, etc.).

The project team would establish a set of frequencies based on the most popularly used settings in the industry today. The team will then seek to publish a uniform code in the appropriate standards.

Deliverables

- An assessment of the currently used, but unofficial, frequency range as a proposed standard uniform frequency code for locating buried utilities
- A proposal document to have the uniform frequency code adopted into a best-practices or standards format within the industry, and
- Obtaining a published uniform frequency code.

Benefits

Introducing a uniform frequency code for passive locating devices would make the product evaluation and use of the product a more efficient process, as all locating equipment would search for the single frequency related to each specific utility. Also, as a range of frequencies has already served as unofficial identifiers of each utility, it would be beneficial to make this the standard range to continue consistency and form a base for future products introduced.

Technical Concept & Approach

The research team is examining the most frequently used frequency range in the industry and will verify the frequencies used by passive tag manufacturers. This also includes assessing this range's use in locating products across the industry.

The goal is to substantiate the code's significance and impact to locating buried utilities.

Passive frequency markers.

The team will produce a guideline document in order to share the information gained from this project and achieve industry acceptance. This may also include review and discussions with various American Gas Association committees.

Results

In November 2018, the research team presented a Uniform Frequency Code proposal to the Common Ground Alliance (CGA) Best Practices Committee. The project team was subsequently granted permission to form a Task Committee comprised of a subset of CGA Best Practice Committee members to address two key issues: 1) that a practice might limit future technology growth and 2) require potential proprietary frequencies. Upon revising the original proposal to successfully address the two issues, the Task Committee agreed it was ready for re-submittal.

In November 2019, the CGA Best Practices Committee approved the formation of an official Best Practice Working Group team to develop the electronic markers best practice consensus language.

Status

The Electronic Markers Working Group team met multiple times in the first quarter of 2020 and is targeting the summer 2020 CGA Best Practice meeting for presentation of the consensus language best practice.

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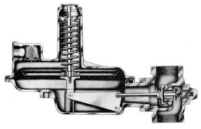
Performance, Durability, and Service Life of Residential Gas Regulators

The objective of this project is to determine the durability and expected service life of common residential natural gas service regulators. Utilities can include service-life predictions as a basis for their residential regulator replacement plan.



Project Description

As with other components in the gas delivery infrastructure, regulators are expected to be replaced in accordance with their service-lifetime predictions. Many parameters affect the life performance of regulators and manufacturers do not commonly provide the expected lifetime of their products. Utilities accordingly rely on short-term data, repair history, and experience with certain types of regulators to set the number of years for regulator replacements. These replacements are also commonly included along with gas meter replacement schedules.

Traditional internal relief valve (IRV) regulators have a cast-iron body and a die-cast aluminum case that houses the diaphragm. These materials are usually coated in order to prevent corrosion. Moisture intrusion into the main body cavity of the regulator can corrode the regulator's inner components, hinder its ability to accurately regulate gas pressure, and could potentially cause a leak.

The inner components of the regulator (e.g., the springs and elastometric diaphragms) also may slowly wear during temperature changes and normal operations over time and contaminate the gas stream. The long-term performance of regulators would vary for different manufacturers, regulator models, age, and various service and environmental conditions.

The objective of this project is to determine the durability and expected service life of common residential natural gas service regulators. Utilities can include service-life predictions as a basis for their residential regulator replacement plan.

Deliverables

The following deliverables are anticipated from this project:

- Identification and information gathering of regulator models regarding their long-term performance and durability
- Analysis findings of in-service regulators, and
- A Final Report.

Benefits

Utilities will be provided with results and technical support for a better understanding of the expected service life of regulators. They may build on the results to optimize their replacement programs by identifying the regulators that are past their recommended lifetime service and avoiding the replacement of good regulators that are not yet at the end of their service life.

This will result in savings to utilities and avoid costs associated with labor, material, and unnecessary customer service interruption.

Technical Concept & Approach

In this project, multiple models of IRV regulators will be investigated with the participating utilities to select the most common ones for the testing program. This task will include a comprehensive study of failure modes of regulators selected for this project. Input from manufacturers and gas utilities will be sought. In addition, it will include a study of previous research and testing requirements on regulator performance.

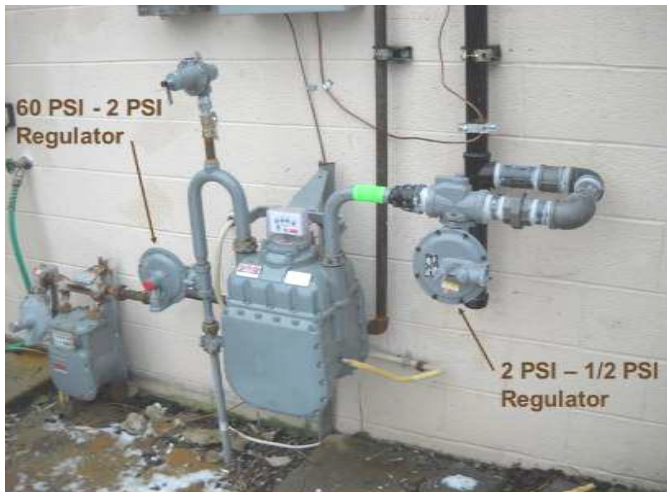
Researchers will gather and test a statistically significant set of residential regulators which were in use for a various number of years (failed and non-failed regulators). The set should represent various ages, manufacturers, types, service environments, and service conditions. These regulators will be subjected to failure analysis to identify their failure modes and/or state of performance.

The project team will develop test protocols that are valid for lifetime prediction/reliability testing of new and used regulators. The testing protocol is envisioned to be long-term cycling flow/lock-up and pressure relief capacity tests at various percentages of the outlet set pressure and at various environmental and gas quality conditions.

The requirements and budget of the test rig for multi-regulator units will be identified to monitor the tested regulator performance using full computer control. The test rig will be configured for long-term cyclic loading and will allow testing at various temperatures and other environmental conditions. The design of the system will allow for applying an air-pressurized system for mechanical failure in selected environmental-controlled tests.

In Phase 2, a test rig for multi-regulator units will be built. Construction of the test rig will collaborate with other projects to build a flow-controlled testing facility for evaluating valves at various upstream and downstream pressures and flows.

New regulators and selected units extracted from the field will be subjected to various cyclic pressures and environmental tests (temperature, water intrusion, etc.) to failure.



Results

Initial activities in 2018 included the development of a survey to gather regulator-failure data. From the responses, the project team was able to identify the residential regulator models of interest and understand common failure modes and failure root causes, if any.

Researchers received regulators from project sponsors and performed preliminary evaluations of the regulators.

A preliminary fault tree analysis for the regulators was conducted.

Status

The project team will conduct a survey debrief meeting with the sponsors, develop a reliability assessment plan, and obtain additional regulator samples from sponsors in accordance with the plan.

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Abandoned-Line Detector

Research is under way in an effort to create a nondestructive tool that when placed on the exterior of an exposed pipe would determine if the pipe is abandoned or in use. Designed for use on both metal and plastic pipes, multiple on-board sensors would identify if natural gas or live electrical lines are present within the pipe.

Project Description

Currently, the industry lacks a quick, external method for determining whether an unidentified pipe is abandoned or in use. For this project, a proven technology will be integrated into a new tool. The objective is to create a nondestructive tool that when placed on the exterior of an exposed pipe will determine if the pipe is abandoned or in use.

Related research in this area includes the completed OTD project 5.8.d *Tool for the External Classification of Pipe Contents - Field Demonstration,* which resulted in a tool to detect whether live electrical lines are present within a steel pipe.

Researchers expect that, with the aid of multiple on-board sensors, the tool will be able to identify if natural gas or live electrical lines are present within both metal and plastic pipes.

Deliverables

The deliverables for this project depend on the achievements accomplished during early tasks. If no reproducible method can be developed for nondestructively detecting natural gas (either flowing or stagnant) within a pipe, the tool will only include live electrical-line detection. Otherwise, a laboratory-tested prototype will be delivered with the ability to determine whether an unmarked, unidentified pipe is abandoned, contains power conductors, or is still in use.

Benefits

An abandoned-line detection tool has the potential to improve utility worker efficiency and safety by providing the ability to quickly and nondestructively determine whether a pipe is abandoned or in use.

Technical Concept & Approach

As natural gas flows through a pipe, it interacts with the interior pipe wall, producing subtle vibrations on the wall of the pipe that can be detected using sensitive equipment. In a very similar way to how the pipe-contents detector operates, these flow vibrations can be used to classify what is inside the pipe.

When natural gas within a pipe is pressurized but stagnant, it becomes difficult to distinguish as there are no vibrations to record as with gas flow or live electrical line conditions. As a result, new principles of detection, possibly based on the thermal conductivity or density of the fluid, are needed. These new detection methods are being explored in this project.

Specific activities include:

- Investigation of Flowing, Pressurized Pipe Methods
- Investigation of Zero-Flow, Pressurized Pipe Methods
- Integration and Design of a Sensing System, and
- Construction of a System Package.

Contact microphone.

Results

In 2018, the project team began investigating the current state of the art to develop a clear understanding of the pipe content identification capabilities that currently exist. Additional initial-stage tasks focused on clearly defining the set of frequency ranges for detecting gas in pipe.

Sensors were examined that are potentially less expensive alternatives to the accelerometer used in the original tool developed in OTD 5.8.d. Some of these upgraded sensors include:

- Contact microphones
- Micro-electro-mechanical (MEM) microphones, and
- Piezoelectric sensors.

In 2019, the project team continued its efforts to identify if a pipeline exposed in an excavation is active or abandoned by purely external methods. An acoustic transducer was identified and tested that shows good promise for being able to detect flow noise. A mechanism to apply the transducer to the pipe under field conditions was prototyped and tested. Several software libraries for signal processing and machine learning that can run on inexpensive microprocessors have been examined. These can be used to help make the determination less ambiguous under field conditions.

A high-sensitivity contact microphone was selected as the primary transducer for the system. When placed in contact with a pipe, it converts vibrations into electrical signals to be processed by the microcontroller. A microcontroller will analyze the signal from the contact microphone and deliver a result on whether the pipe is abandoned or not.

To test the contact microphone, the device was connected to the tool developed from OTD Project 5.8.d. After confirming basic functionality of the contact microphone, it will advance to further testing on flowing and zero-flow pressurized pipe conditions.

A mechanism for holding the contact microphone to the pipe was developed and 3D printed. The mechanism consists of a collection of magnets that hold the sensor to the pipe and a spring-loaded center column that securely presses the contact microphone rubber tip to the surface of the pipe.

A microcontroller was selected to process acoustic signals from the contact microphone on the exterior of the pipe. A printed circuit board containing a preamplifier circuit needed for the contact microphone was designed.

Technicians constructed a controlled environment to produce various levels of flowing gas through steel

pipe. Sensor readings were acquired using the contact microphone, preamplifier, and microcontroller on pipe in flowing gas and zero-flow states. Using the acquired data, a preliminary machine learning model was trained and proven to, with 88% accuracy, detect whether never-before-seen signal data contained 20 scfh or zero flow.

Status

Researchers are collecting large amounts of flow-noise data on a variety of pipe diameters and materials using the in-house testing apparatus as well as live field pipe. Data has been collected on live field pipe ranging in diameter from two-inch PE to 14-inch cast-iron distribution mains. This data is being used to train a machine learning model to accurately predict when flow-noise is present and alert the operator. The machine learning model will be deployed to run locally on the sensing hardware used in the field, eliminating the need for data to be sent to the cloud for processing.

The project team is also collecting impact response data from a solenoid hammer in an attempt to distinguish any differences in internal pressure. The sensing hardware will be designed in a way that will accommodate both small and large signal strengths and adjust automatically.

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Noncamera-Based Technology to Detect Cross Bores

Research is being conducted in an effort to develop a tool to detect legacy cross bores. The initial objective is to identify viable technologies and evaluate prototypes.

Project Description

Addressing the inadvertent crossing of utility line, such as a gas pipe installed through a sewer line (commonly known as a "cross bore") remains a top priority for the utility industry in general and gas utilities in particular.

A variety of research is under way to develop cost-effective methods to identify/inspect for cross bores after trenchless installation activities. In addition, efforts are being conducted to develop technologies to identify legacy cross bores currently in the system.

In the 2010, OTD conducted a workshop to develop an R&D roadmap for addressing cross bores. The result of the workshop was a matrix of industry needs, which included tools to prevent and detect cross bores, risk analysis, best practices, information, and processes. Subsequently, OTD funded projects to identify various cross-bore technologies for detecting potential trans-sections primarily during directional drilling; develop a tool to detect hits to sewer laterals during the horizontal directional installation of gas pipes; and identified camera/imaging tools that can detect cross bores during gas pipe installations.

The objective of this project is to develop a tool to detect legacy cross bores. To achieve this, research is focused on identifying viable technologies and evaluating prototypes that can lead to the development of reliable and cost-effective cross-bore-detection tool for legacy trans-sections.

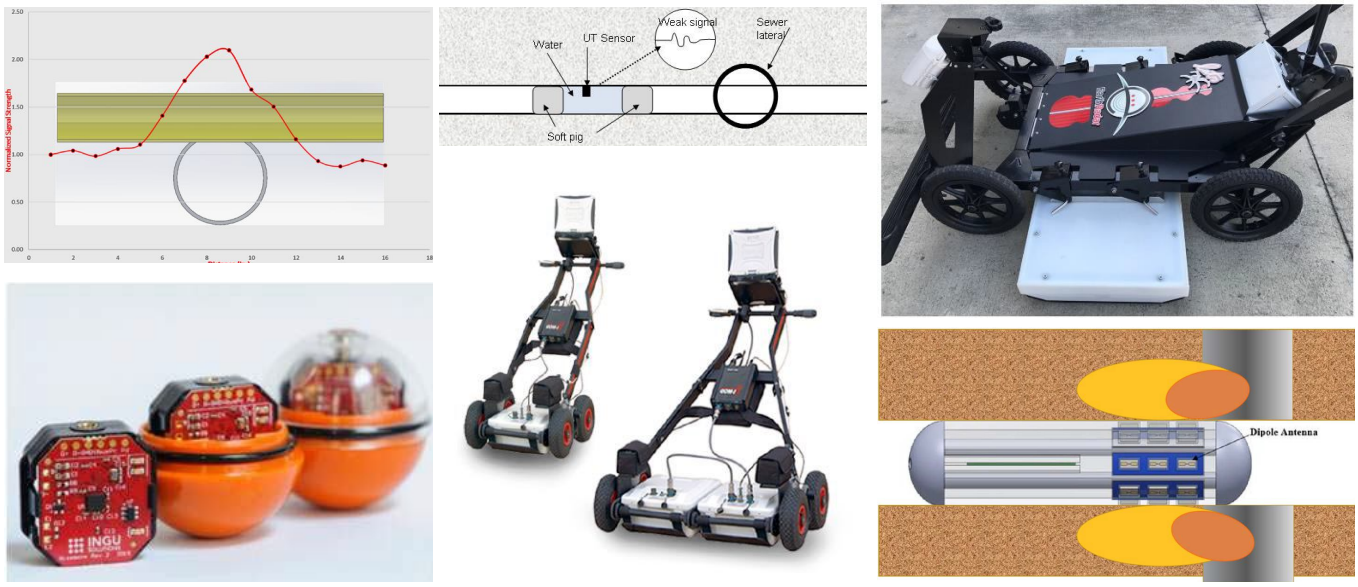
Deliverable

The deliverable for this project will be a summary report with the following content:

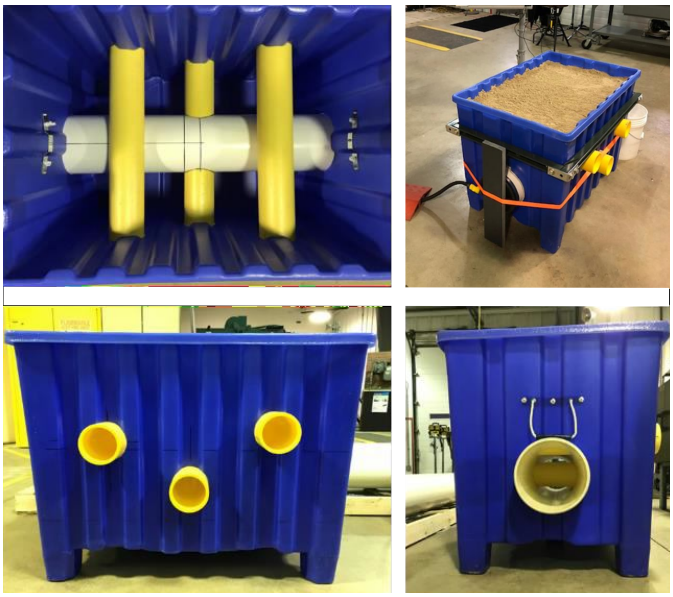
- An updated list of technologies for cross-bore detection
- Results of an evaluation of micro-impulse radar technology, and
- Prototype development details (if applicable).

Benefits

Cross bores pose a significant threat to the safety of the general public and utility workers. A reliable and cost-effective solution to this issue will help utilities to detect and eliminate cross bores and greatly reduce the associated risks and operating costs.



Researchers evaluated a variety of technologies to detect cross bores, including ground-penetrating radar, ultrasonic sensors, and acoustic-based technologies



A soil box experiment setup.

Technical Concept & Approach

Technologies used for cross-bore detection during pipe installation were reviewed and their feasibility for legacy cross-bore detection will be studied. Primary concentration was on noncamera-based technologies. In addition, suitable technologies from other industries, (e.g., mining, defense, and water) were reviewed and a feasibility analysis of adopting such a technology will be made.

Based on the results from the technology search and evaluation, researchers will proceed toward the development of a prototype system to detect legacy cross bores. Prototype development will include fabrication/ assembly of the prototype, development of an insertion technique (if needed), and laboratory-scale testing.

Activities such as prototype generation, field evaluations, and commercialization can conducted in subsequent phases.

Results

During the course of the project, the research team reviewed several technologies to detect legacy cross bores, reached out to the technology/product developers, and conducted testing to prove the concept on some of them. The technologies include ground-penetrating radar (GPR), electro-magnetic (micro-radar) sensing, capacitive sensing, and vibration-acoustics sensing, among others.

A soil box experiment setup to evaluate cross-bore technologies was designed and built and the project team developed a test matrix to evaluate near-field sensing technology.

In 2019, the project team focused on proving earlier identified concepts. Technologies such as near-field electro-magnetic sensing and capacitive sensing were able to detect cross-bore (pipe intersection) that was set up for testing purposes. GPR technology and acoustic-sensing technology were also reviewed.

Researchers completed the evaluation of the electro-magnetic wave sensor. The sensor was able to detect "void" around the pipe in the laboratory-scale setup.

In Phase 1, GPRs, along with an acoustic pipe locator (APL), were selected to assess their capabilities in locating pipes and laterals on sites in San Francisco. In Phase 2, these systems were evaluated at 12 sites.

Results show that:

- The APL could not reliably identify laterals or pipes at any parcel. The APL performed poorly in all locations and does not appear to offer a viable alternative.
- All laterals and pipes identified and marked on the last day of scanning were not post-processed, demonstrating back office post-processing is not necessary.
- Post-processing can help correctly decipher between sewer laterals, gas pipes, and water pipes. It can also help more accurately locate laterals and pipes.
- The push-camera failed to locate the way the GPR devices were able to locate. The push-camera failed to locate the main sewer lateral.

Status

Four promising technologies were identified for further advancement in terms of product development. The project team is evaluating the capability of electro-magnetic sensors to detect cross bores under different soil conditions.

The project team is looking to find more information on above-ground scanning technologies such as gradiometers by reaching out to service providers and experts.

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Clothing Performance Guidelines to Reduce Heat Stress for Natural Gas Workers

The objective for this project is to establish guidelines for selecting workwear ensembles that will provide reduced heat strain and worker comfort in operations conducted in hot conditions.

Project Description

Thermal comfort and heat stress are significant concerns for outdoor workers in the natural gas industry. There are currently no industry-wide requirements or standards to guide the selection of fire-resistant clothing worn by workers in oil and gas operations to reduce heat strain. Few technical studies have qualified deployment of additional layers of fire-resistant personal protection equipment (PPE), such as flash-fire suits or the time that workers can operate without incurring heat stress in hot working conditions.

The goal of this project is to demonstrate how modern methods of clothing comfort testing can be used to select more thermally comfortable fire-resistant clothing for natural gas workers. It will show how these methods can guide PPE options for use in hot service areas. It will also show how more technically informed clothing solutions can reduce heat strain of workers operating in hot environments or while wearing flash-fire suits.

The National Fire Protection Association 2112 Standard on Flame Resistant Garments for Protection of Industrial Personnel Against Flash Fires does not establish minimum performance requirements for the thermal comfort of flame resistant garments worn by industrial personnel. This is an important consideration, particularly for workers required to don flash-fire gear for added protection when working in environments with higher expected risk for accidental fires.

An objective for this project is to establish guidelines for selecting workwear ensembles that will provide reduced heat strain and worker comfort in operations conducted in hot conditions. Researchers will use modern laboratory tests (including advanced sweating manikins) and controlled-climate human physiological wear studies.

The project will provide a technical foundation for developing work/rest cycles for operations that require workers to wear flash-fire suits and other protective clothing in thermal-stressing conditions.

Deliverables

A Final Report will contain recommendations that can be used to select PPE that will reduce heat strain on gas workers in hot environments. It will provide technical performance guidelines for selecting optimum clothing configurations for climatic temperatures and solar load focused on the hot weather climates.

Other specific deliverables include:

- Scientifically qualified correlations between selected protective clothing and heat stress, and the impact of environmental and working conditions on clothing related heat strain
- A better understanding how additional PPE layers (flash-fire suits) impact worker heat stain and work tolerance, and
- A technical basis for next-generation test methods and performance requirements for protective gear that incorporates thermal-comfort specifications.

Benefits

By characterizing how specific choices in protective clothing impact thermal comfort and heat stress, this project will contribute to increased safety and health. This will enable the development of optimized work/rest cycles for workers wearing flash-fire suits. It will contribute to workplace efficiency and reduce the financial burden of operations conducted in hot environmental conditions.

Technical Concept & Approach

This project will quantify the role of key physiological human response variables occurring during wear of flame-resistant clothing by workers in the oil and gas industry. It will establish the relationships between the measured breathability of protective clothing materials and their comfort and heat stress using laboratory tests made on fabric swatches and protective clothing ensembles. Resultant data will be used to identify the most thermally comfortable clothing ensembles consistent with fire protection. The outcomes of this project will be used to develop work/rest cycles based on the work rate levels and temperatures encountered in wearing flash fire suits.

This project will use advanced sweating hot plates and sweating manikins to establish the relationship between the breathability of protective clothing materials and the ability of worker PPE to dissipate trapped body heat.

The correlation between PPE and worker comfort and heat stress will be validated in controlled wear trials conducted in temperature and humidity conditions and metabolic levels associated with specific work tasks.

The project team will leverage the world-class facilities of the Textile Protection and Comfort Center, the nation's leading laboratory devoted to measurement of fire-protection and clothing comfort.

Results

To help the research team understand the working environment, team members visited companies to see workers in action.

Researchers received garments and information about work uniforms and flash suits worn by workers for companies sponsoring the project. For the work uniform, researchers found major differences in the types of fabrics and garments worn. Some companies used coveralls while most used a pant and shirt combination. The fabrics used in those garments varied by fiber types, weights, blends, weave, and treatments. The information provided about flash suits indicated they all were coveralls, but the fabrics varied by similar properties identified in the work uniform.

Researchers are focusing on understanding the effects of heat strain and comfort as it relates to flash suits that all natural gas companies utilize.

In 2019, a literature review was conducted to better understand how we can assist the natural gas companies with making work rest cycles based on their PPE and the environment. From that literature search, more than 100 different indexes were located. However, most were either too simple to provide a reasonable result or too complex to be used in the field. After review of several promising methods from these indexes, researchers recommended two possible methods for the project. Both indexes consider the PPE properties as well as environmental conditions such as temperature, solar radiation, relative humidity, and wind speed.

Basic fabric properties effecting heat stress were measured using material from three of the flash suits received. Measurements included evaporative resistance, thermal resistance, total heat loss, and visible light reflectivity.

Results from fabric swatch tests indicates a large heat loss difference between the single-layered system and the three-layered system. However, this test was shown to overestimate the actual heat loss of a suit garment because it does not account for undergarments, air layers, added accessories, and fit of an actual suit.

In addition to these tests, technicians also measured the reflectance of the same three suit materials to the visible light spectrum. By measuring reflectance, an indication of how different fabrics might absorb heat from the sun is determined.

Status

The following tasks are planned for execution in 2020:

- The research team hopes to see workers use the flash suits in an actual event or in a training event to help the team understand what type of work is involved.
- Investigators will continue to test and evaluate more fabrics from different flash suits. We received notification that at least one more company is sending more suits/fabrics for evaluation.
- In addition, researchers want to evaluate air permeability at the fabric level. If possible, technicians will measure the material with the same fiber and fabric construction with various colors to see if heat loss values change with the use of a hot plate and a sun light simulator.

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Thermally Activated Gas Shut-Off Devices

In this project, researchers investigated commercially available thermally activated gas shut-off devices that prevent or reduce the escape of gas in the event of a fire at a customer's premise. Performance tests were conducted on selected products.

Project Description

Automatic thermally activated gas shut-off devices are passive safety devices that prevent the uncontrollable release of gas when some part of the natural gas delivery system has been damaged or fails.

Similar passive devices include excess flow valves (EFVs) that protect service-line break locations and service riser breakaway fittings that protect meter sets from impact.

An automatic thermally activated shut-off device can be an added layer of safety to accompany the EFV and breakaway fitting.

Although U.S. fire codes and certifications do not specifically address automatic thermally activated shut-off devices, this technology is approved for installation. Currently, there are no U.S. standards governing the design, operation, or installation requirements for this type of shut-off device.

In this project, researchers conducted a requirements review and performance tests of commercially available thermally activated gas shut-off devices for the industry. Three manufacturers were identified as having commercially available thermal shut-off devices for the natural gas industry within the U.S.

The main conclusion from the performance testing conducted on these different devices is that the flow rate passing through the thermal shutoff device at the time it is exposed to excessive heat will cause the activation temperature to increase above published temperatures by the manufacturer.

Deliverables

The deliverables for this project include:

- A guideline on the commercial availability, usage, operational parameters, and associated standards of thermally activated gas shut-off devices and
- Short- and long-term laboratory testing results of selected devices.

Benefits

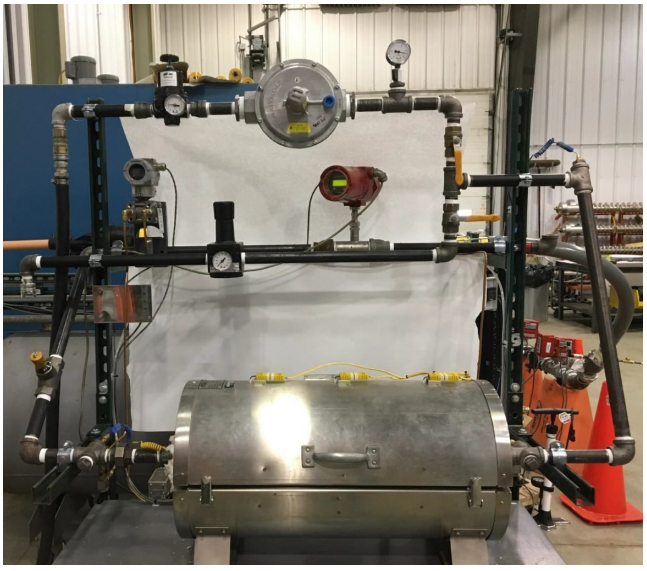
Thermally activated gas shut-off valves can significantly improve fire safety for premises supplied with natural gas. Significant safety is achieved without the need for expensive actuators, electrical power, or heat detectors.

Other benefits include:

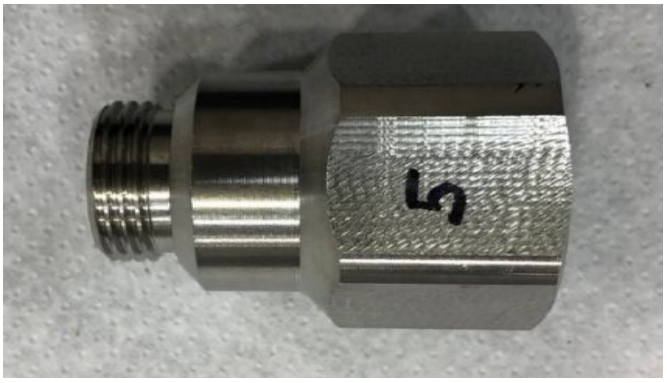
- Maintenance free operation
- Triggering only in a fire situation
- No regular inspections required, and
- No fire or heat detectors required to automatically intercept the gas flow.

Technical Concept & Approach

Performance testing was performed for each of the manufacturers on the different style fittings that they manufacture. The goal of this testing was to confirm published performance specifications and identify any potential variables that affect the functionality of these thermally activated shut-off safety devices. As the performance testing progressed, the test matrices designed evolved in response to the results of the preliminary tests performed.



Assembled test rig for device performance testing.



Valves tested.

A new test rig was designed and built. The rig consists of two different portions, a low-pressure section and a high-pressure portion. This design added flexibility to the possibilities of the assembly so that different devices falling within a wide range of pressures can be tested. The flow was controlled using a high-precision manual valve placed downstream of the sample to simulate an increase or decrease in the demand for natural gas.

Results

Only three manufacturers were identified as supplying thermally activated shutoff devices to the U.S. Each manufacturer has its own unique design and material for manufacturing this type of device. This contributed to the variance in performance test results among the manufacturers for outlet pressure drop across the internal shutoff mechanism, activation temperature of thermal shut-off, and integrity test results at elevated temperatures for a prolonged period.

The performance test results of this project were consistent with what was expected from the devices studied. However, one test result that stood out for each of the devices tested was that the thermal shut-off activation temperatures during project testing were more than 20% higher than shut-off activation temperatures published by the manufacturers. The main hypothesis for this difference is that the devices were tested with flow going through them, which would be closer to a real-case scenario. Follow-up discussions with the manufacturers confirmed that their published test results were achieved without flow conditions and that the temperature at which thermal shut-off devices trigger is dependent on the flow rate going through the device, which explains the difference in results. Depending on construction materials, a typical residence fire can be expected to reach temperatures of 1,100°F, this is well above the highest activation temperature of 472°F measured during this project.

Overall, the performance test results of this project support that thermally activated shut-off devices can be relied on, if installed per manufacturer's instructions, to secure the flow of natural gas when exposed to elevated temperatures from a structure fire.

Status

This project is completed. A Final Report was issued in September 2019.

Listed are potential future projects related to thermally activated shut-off devices to consider:

- Development efforts for creating a U.S. and Canadian standard(s) for governing the installation and operation of thermally-activated shutoff devices
- Conduct performance testing of high-pressure rated thermally activated shut-off devices at low delivery pressures to confirm satisfactory pressure drops
- Conduct performance testing at elevated flow rates to identify how high activation temperatures become at different flows, and
- Conduct research and development efforts to incorporate an EFV device into high-pressure rated thermally activated shut-off devices.

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Virtual Reality Training - Emergency Response Situation

Efforts are under way to introduce virtual reality (VR) as a training tool in the gas utility industry. This project will include a demonstration on the value that this VR training can bring to the natural gas industry.

Project Description

As the utility industry prepares for 40%-50% of its workforce retiring over the next five years, companies are reassessing their training programs to ensure that they will be able to meet the training needs of new employees. Company trainers are no longer entering the training department with 20+ years of experience, and field personnel are generally no longer given the opportunity to train side-by-side with other employees for five years or more before performing work independently themselves. Companies are finding a need to bridge this experience gap of trainers and expose trainees to more virtual experiences to make up for the lack of actual experience.

In this project, immersive virtual reality (VR) is being investigated as a means to enhance training. VR training is a tool to deliver impactful training consistently, on-demand, and cost effectively in a wide variety of industries, including healthcare, automotive, education, military, and law enforcement.

The goal is to develop a content library for utilities to assist with the training of their personnel on operations and maintenance (O&M) procedures including emergency response activities. These modules will include randomization of training scenarios and reporting capabilities on a user's performance and areas of improvement. The modules will allow for future customization with company specific O&M procedures to test for critical thinking skills and knowledge to fit each user's needs.

Deliverables

The deliverables for this project include up to four realistic, interactive, computer-generated, immersive VR training modules on industry O&M tasks that can be used within the natural gas industry. In addition, these modules will have multi-user, grading, and reporting capabilities. Modules will be built on familiar platforms and environments that allow for randomization and customization to be able to test critical thinking skills and knowledge of company-specific O&M procedures.

Benefits

VR provides consistency of training and higher trainee retention rates to help reduce the business risk for an organization. Also, cost savings can be achieved through reductions in training class set-up time, training delivery (initial and remedial), and training completion (onsite or remotely).

The use of VR modules allows training to be conducted on demand by operations; increases the number of real-life training scenarios available for trainees to experience; reduces the risk of injury to trainees, trainers, and the general public on risky activities; and reduces the cost of instructor labor and materials for preparing traditional classroom and laboratory training.

As modules are customizable, the user can train on many random scenarios to grow their experience and

critical thinking in a safe environment. Mistakes made in the modules will not be repeated on costly equipment and allow for continuous training without the need to set up and take down equipment or props.

Technical Concept & Approach

With sponsor input, the project team will develop a storyline and the VR environment in which the trainee will respond to a variety of scenarios. Project team members and sponsors will develop industry general approaches to responding to natural gas emergency situations.

Demonstrations will be conducted for sponsors and their training teams. Application development will include creating all visual assets, environments, and programming training scenarios.

Results

In 2018, researchers identified the learning objectives, described the physical environment features for the module, identified the tools and equipment that will be used within the module, and reviewed general emergency response procedures. The VR hardware equipment required to test and demonstrate the completed module was procured and set up.

For this project, there will be two different emergency response scenarios created with multiple randomizations for each different scenario. The first scenario will include widespread gas migration within the centerline sewers and into customer homes within the virtual neighborhood. The second scenario is third-party excavation damage which causes blowing gas from the mainline.

The VR developer released three stable beta versions of the training module that includes gas leaks located in different areas within the environment, the use of tools, teleporting, and multi-person capabilities.

Example of teleporting in the module.

Jake Wilken
Manager
Operator Qualification
Peoples Gas Delivery

"Virtual Reality gives us the ability to simulate numerous realistic examples that our employees are likely to encounter in the field. This allows us to train field technicians on these situations in an environment that is safe and is conducive to trainer/trainee interaction. The addition of VR technology enables us to provide alternate learning methodologies in a safe and controlled environment."

The VR developer is addressing identified enhancements within the training module. The user feedback received to date has been very positive and supportive of this technology.

In 2019, storyline and environment development was completed and a draft user feedback survey was created to assess user experience.

Demonstrations were performed with staff to test reaction and user-friendliness of the VR hardware. This was followed by demonstrations at various industry conferences. Subsequent, onsite training and demonstrations were conducted for six project sponsors.

The first five modules for development were identified: *Appliance Inspection, Inside Leak Investigation, Outside Leak Investigation and Classification, Facility Locating and Marking, and Pipeline Patrolling*.

Status

Current project activities include:

- Continued development and testing of five new training modules
- Identification of the next training modules to be developed, and
- Identification of project sponsor subject-matter experts to assist with the learning objectives and storylines for each of the new training modules developed.

The response to this new training technology has been so well received by project sponsors and the industry that all new customization, module development, and onsite training and demonstration has been postponed until 2020.

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Pipe-Thread Sealant Performance

In this project, researchers evaluated the performance of pipe-thread sealants used to lock and prevent gas leakage on metal piping and fittings. This evaluation included performance tests on the effects of vibration, pipe movement, different pressures, and changing temperatures.

Project Description

Utilities with an estimated one million customers/meter sets have at least one million jurisdictional threaded pipe and fitting joints in their distribution systems. Over time, these threaded joints can leak prematurely due to failure of the thread sealant.

Some factors that influence the failure of pipe-thread sealant may include the pipe/fitting size, operating pressure, different atmospheric conditions (i.e., extreme heat or cold), and the amount of movement impacted on the piping system. There is no "one-size-fits-all" sealant solution for all operational use cases.

In this project, researchers identified the best-performing pipe-thread sealants for the varying elements. A project team evaluated the performance of sealants used to lock and prevent gas leakage on metal piping and fittings. This evaluation included performance tests on the effects of vibration, pipe movement, different pressures, and changing temperatures.

Deliverable

The deliverable from this project is a Final Report that includes an analysis of the effectiveness of the evaluated thread sealants.

Benefits

Non-hazardous threaded-joint gas leaks can account for significant expense for utilities and their customers. In addition to the actual expense for repairing these leaks, the additional workload can lead to an increased potential for employee injuries and vehicle accidents; increased compliance tracking and reporting tasks; and delayed emergency response time to hazardous gas-leak emergency situations.

The results from this project will aid gas operators in choosing the optimal sealant for particular situations.

Technical Concept & Approach

Specific tasks for this project included:

- **Pipe-Thread Sealant Identification and Initial Evaluation**

  This project included with an in-depth review of commercially available pipe-thread sealants that can be applied to metallic piping and fittings (i.e., steel, stainless steel, brass, etc.). The review included evaluating thread-sealant characteristics and recommended applications. The research team provided a recommendation for which products to be tested and developed a testing matrix.

- **Performance Testing**

  In this task, the identified pipe-thread sealants were applied to metallic test samples ranging from ¼-inch to two inches in diameter. The test samples were subjected to vibration testing, movement (expansion/contraction and ground settling), temperature cycling, pressure cycling, etc. These tests measure the capability of the thread sealant to withstand the effects of movement, temperature changes, and pressure changes on different pipe and fitting sizes.

Results

In collaboration with project sponsors, a list of 17 pipe-thread sealant products was identified. These were categorized into three types – regular, polytetrafluoroethylene (PTFE), and anaerobic. The products were subjected to technical and market analysis followed by performance testing. Sealant behavioral trends under experimental field conditions were observed, and best-performing products were recognized.

Performance testing consisted of fabricating three schedule-40 black steel and three 304 stainless-steel test assemblies, with each pipe-thread sealant candidate. These test assemblies were exposed to a 10-20 day and 140°F temperature cycling protocol, pressurized up to 450 psig, and monitored for leaks. Supplemental high-performance testing was continued for the nine best-performing products, which consisted of additional high-pressure testing, impact testing, torque-removal testing, and viscosity temperature dependence.

In general, the anaerobic-type products marketed improved temperature and pressure ratings compared to the regular- and PTFE-type, but the cost of these products is much greater. A significant number of leaks among the regular- and PTFE-type products were observed during pressurized testing following the temperature cycling protocol. Additionally, more leaks were observed among the 304 stainless-steel assemblies than the schedule-40 black steel. Of the 17 products initially tested, nine best-performing products were identified for Phase 2 performance testing. During Phase 2, only two leaks were observed throughout high-pressure testing at pressures greater than 1,500 psig, and none were observed following impact testing. Torque-removal testing identified that many of the anaerobic products were unable to be disengaged. A total of three cost-effective options with leak prevention results equal to the anaerobic-type products were identified from the testing protocol and recommended for usage.

Typically, anaerobic-type products offered higher pressure ratings than regular and PTFE-type thread-sealant products. However, costs may prohibit widespread adoption of anaerobic-type products depending on the piping configuration. Market and product specification analysis suggested that anaerobic-type products should offer improved pipe thread sealant performance results over standard and PTFE-type sealants. Thus, performance testing has the potential to identify cost-effective options with capabilities compared to that of the anaerobic-type products.

Nine pipe-thread sealant products selected for supplemental testing.

Status

This project is completed. A Final Report was issued in June 2019.

Performance highlights included identification of three cost-effective products that maintained seals at pressures up to 1,700 psig, vibrational resistance, minimal temperature influence on viscosity, and costs between 1.05-1.12 $/oz.

As a result of the technical details provided by this project, the proposed next steps seek to investigate the threat imposed by improperly-sized pipe components.

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Polyethylene Squeeze Tool Gap Stop Evaluation

In this project, researchers are investigating requirements in an effort to develop a tool/ measuring device to verify that PE squeeze tools are within tolerance in relation to pipe and tubing when performing a squeeze operation.

Project Description

Squeeze tools used to stop the flow of natural gas in polyethylene (PE) pipelines are a very common piece of equipment used every day in field situations. Operations include emergency stoppage, planned extension and abandonment of PE pipelines, and training and operator-qualification purposes. By flattening the pipe between two parallel bars, this squeeze-off provides an easy and quick shut-off of the line. However, improper squeeze-off can cause damage to the pipe, create a safety hazard, or both.

When performing a squeeze, a gap in the pipe may appear. If too large of a gap, the operator will not be able to obtain proper flow control or make a complete stop. Too small of a gap could lead to over compression of the PE pipe. After the squeeze tool is removed, the pipe is forced back to near round shape by internal pressure or may be mechanically re-rounded. In either case, a permanent deformation results and a stress concentrator is created.

To provide over-squeeze protection, squeeze tools come with mechanical stops, which are based on pipe diameter and wall thickness. Typically, the tool stops are set for 30% or less wall compression based on maximum wall thickness.

Utility personnel currently do not have tools to quickly check the performance of the squeeze tools. The use of a stop gap device as a calibration tool and/or validation tool before performing a squeeze on a PE pipe can lessen the risks associated with performing a squeeze improperly.

In this project, researchers are investigating the gap requirements to develop a tool/measuring device to verify that PE squeeze tools are within tolerance in relation to the PE pipe and tubing when performing the squeeze operation.

The resulting tool could be used to check new and used squeezers to verify if they are within the required tolerances. It could also be used during field operations to make sure the mechanical stop on the squeeze tool is set at the correct position.

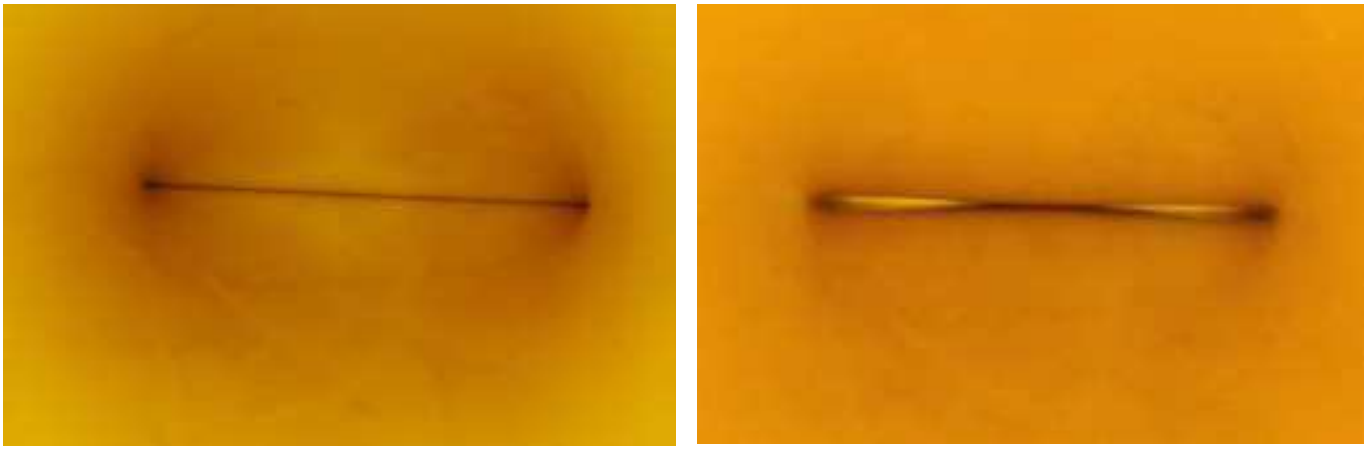
Deliverable

The deliverables of this project will include:

- A Final Report that includes research findings on the gap stop measurements on new and used squeeze-off tools
- The development of a series of validation/ inspection tools to measure the gap stop of PE squeezers for various pipe diameters, and
- Recommended procedures on measuring the gap stop to determine if tools are within the recommended tolerances to perform a squeeze.

Benefits

A gap tool could be used by field personnel and inspectors to avert both immediate and potential long-term damage to PE pipes from improper squeezing of the pipe. This can be accomplished by verifying the correct distance between squeeze bars with a gauging device before the squeezer is put into use. This tool could be used to validate the gap for both new and existing squeeze tools.



Examples of over-squeezed and under-squeezed PE pipe

Technical Concept & Approach

A project team is reviewing ASTM standards for PE squeeze-off tools and various squeeze-tool manufacturers' literature to determine if and what formal process is in place for determining and checking the gap stops.

Researchers will also investigate the gaps in various squeeze tools. This will include the inspection of currently used field tools at various utilities and the inspection of new tools direct from various manufacturers.

A measuring device (gap tool) will be designed, developed, and fabricated to meet the required gap allowance that the specification calls for various pipe sizes.

Researchers will validate the gap tool and its capability to accurately provide a go/no-go confirmation in both the laboratory and in the field. Investigators will also send the tool to sponsors – along with recommended procedures – for validation and feedback.

Results

The project team compiled information regarding PE sizes used by project sponsors. This included creating a questionnaire for the OTD members.

Researchers developed conceptual squeeze-tool gap validation devices and created various CAD drawings. Based on feedback, the team created 3D-printed squeeze gap stop tools.

It was decided to group similar sizes of pipe and tubing into multiple gap tools, particularly separating the tubing sizes from the pipe sizes. This information also helped the project team to elect to create specific gap tools for each utility based on individual needs.

Research found that when the distance between the squeeze tool bars is greater than twice the wall thickness, the pipe walls are not compressed, which yields a negative value for the wall compression percentage.

The project team developed the sizes (thickness) needed for each participating individual utility. These sizes are based on 30% or less wall compression based on maximum wall thickness (a distance that is 70% of twice maximum wall thickness when the squeeze tool is closed to the stops). By fabricating the gap stop tool to these tolerances, operators can verify that the squeezers are acceptable if fully closed to the stop.

It became apparent that there is little room to be able to insert the gap stop tool while the squeezer is in use. However, the gap stop tool still can be used as a quality check, such as for operator qualification, training, maintenance, and, if required, before actual use of the squeezer.

Status

The following activities are scheduled for execution:

- Confirm which stop gap tool type will be fabricated and determine pipe size and identification (e.g., the lettering engraved on the horizontal or the vertical).
- Perform testing on readily available squeezers for functionality in house
- Send prototypes of the gap stop tool to the project sponsors to test, and
- Modify the prototypes, if necessary, based on feedback.

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Purging Gas Pipes into Service without Venting Gas to the Atmosphere

Research is under way to evaluate, enhance, and develop an alternative method to purge gas pipes into service with no or minimal gas vented to the atmosphere. This project will include an investigation into the economic, environmental, and social impact of vacuum purging as an alternative practice.

Project Description

Gas purging – a process of displacing one gas by another gas – occurs on a routine basis in the natural gas industry when pipelines are put into and out of service.

Pipelines are purged to prevent the presence of a combustible mixture of gas and air. Failure to follow good purging guidelines and procedures may result in a serious incident and/or outages.

During the direct purge method for commissioning a new gas pipe, the air in the pipe is purged out of the pipe by introducing natural gas into one end of the system and venting the air, air/gas mixture, and finally natural gas from a open vent at the other end of the system. The venting will typically continue until gas readings at the open vent reach 95% natural gas or greater.

This method has proven to be very effective; however, it may result in the venting of large quantities of natural gas to the atmosphere and contribute to a utility's annual carbon footprint.

In this project, research is being conducted to find alternative methods of purging gas pipes into service to reduce overall methane emissions.

One alternative to venting the gas to the atmosphere is through the use of a vacuum pump. This process pumps the air out of the pipe to be placed into service. Once the proper vacuum level is reached inside the gas pipe, the vent is closed and the natural gas is introduced into the pipe without the need to vent.

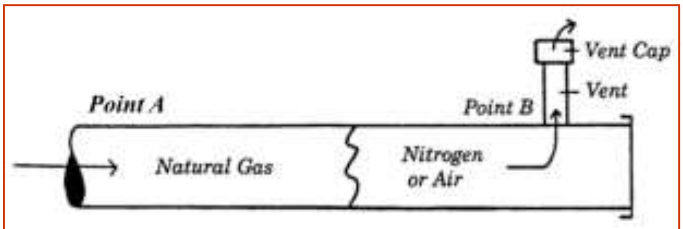
Naturgy (previously Gas Natural Fenosa) in Mexico assembled equipment and procedures for the vacuum-purging method to commission new pipelines. Naturgy's solution allows the company to significantly reduce these emissions during various operational activities. The vacuum-purging procedure eliminates trapped air without venting natural gas into the atmosphere during pipeline commissioning by using the correct vacuum-pump capacity. This also results in time improvement compared to traditional purging procedures.

This project includes an investigation into the economic, environmental, and social impact of this alternative practice. Vacuum-purging guidelines will be developed as part of this project effort.

High-priority issues to be addressed include:

- The concept and current practices of using vacuum pumps to purge gas pipes into service
- Market needs/drivers and the potential economic and environmental impacts
- An investigation of the vacuum-purging process to determine its effectiveness and identify enhancement opportunities, and
- The design/development an enhanced vacuum-purging system (future phase of work).

A utility crew purging in a section of pipe using vacuum instead of venting gas to the atmosphere.



Typical purging of a gas pipe into service.

Deliverable

This project will provide a comprehensive report that describes the current vacuum-purging practice being employed by Naturgy to minimize the venting of natural gas to the atmosphere. The report will include sections that cover:

- Market drivers and environmental impacts
- The current effects of venting blowdown gas to the atmosphere
- A cost analysis of implementation of alternative methods that includes environmental impacts of these methods, and
- Guidelines/equipment needed to implement the vacuum-purging system.

Benefits

Minimizing or eliminating the current practice of venting natural gas to the atmosphere during purging can help reduce methane emissions.

Some of the benefits identified by Naturgy include:

- Methane emissions greatly reduced
- Enhanced safety by minimizing exposure to explosive mixtures
- Reduced natural gas loss generated during the purge process (unaccountable gas losses)
- Eliminated use of nitrogen as inerting agent
- Improved company image by increasing confidence within communities by avoiding gas purges (no noise or gas odor), and
- The cost-effective system eliminates the need for a nitrogen slug, reduces gas losses, and saves time.

Technical Concept & Approach

For this project, researchers and utility sponsors will determine the key technical requirements and address purging processes that are currently used in the industry. Discussions will be held with Naturgy regarding the details and procedures of its vacuum-purging technology/method. Project sponsors will be surveyed for their current methods of dealing with of gas vented during purging operations. The analysis will include the market drivers, environmental, and social impacts.

In addition to evaluating the overall system and purging capability, system components will be evaluated to determine if there is any impact from the vacuum that will be created (mechanical coupling and other elastomeric seals, line valves, etc.). Areas of concern will be identified.

A possible follow-on phase may include the enhancement, field testing, and eventual commercialization of a vacuum-purging system for North American utility use. The current system implemented by Naturgy is assembled from various commercially available components. For broader acceptance and implementation, a vacuum-purging packaged unit is needed. This may include a vacuum-pump system with integrated methane-detection alarms and safety shutoff; incorporated flame arresters in the exhaust outlet; and appropriate hoses, connectors, purge stacks, etc.

Results / Status

Initial discussions were held with Naturgy regarding further evaluation of the vacuum-purging system. A non-disclosure agreement was drafted for Naturgy. Researchers are reviewing Naturgy's internal standard (Commissioning Distribution Networks with Vacuum Pump) to understand the vacuum system and identify areas in need of further testing. Efforts are under way to obtain the purging system components in order to conduct initial evaluations. Researchers also constructed a test loop with pressure-sampling capabilities to observe the effects of vacuum conditions on a distribution network and various operational parameters of the vacuum system. This will allow for a better understanding of the operation, performance, and areas for possible improvement of the current system that is being used by Naturgy.

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Design Day/Gas Modeling Workshop

For this project, researchers hosted a workshop to allow group discussions regarding design day and gas modeling best practices for gas purchasing and system planning/ design purposes.

Project Description

There are currently differences in the natural gas industry on how to use both planning models and engineering models to produce the most accurate results. Calculating accurate peak gas supply is critical to ensuring that the utilities are not over-purchasing gas supplies and have enough supply to survive peak demands.

Several utilities have been inquiring about how to accurately determine peak-day loading with less than ideal data. Some utilities still use one-time low-temperature data from more than 30 years ago and have never experienced a peak-day temperature in that range. This has most likely caused inaccuracy within the gas models and made many utilities purchase more gas supply than necessary.

To address the issue, this project involves holding a workshop/roundtable discussion with industry experts will help capture best practices to reduce industry confusion and gain knowledge.

Deliverable

The deliverable for this project will be a Final Report summarizing the results, findings, and next steps identified during the workshop.

The report will also identify a framework for potential follow-on activities.

Benefits

Utilities depend on peak-day planning software in order to ensure they have purchased enough gas for peak flow conditions and have properly designed their gas system, especially for the winter.

Eliminating uncertainty in degree-day calculations and how they integrate with engineering models and will save utilities money through the accurate purchase of gas supply. It will also reduce the risk of unplanned outages due to supply shortages.

"I found the workshop and roundtable to be very helpful in the planning of our natural gas system. It was great to network with peers in similar roles around the country and to gain insight on modeling techniques from subject-matter experts across the industry. We look forward to integrating these best practices into our processes."

- Dustin Brisset
Senior Engineer, System Planning
Natural Gas Business Unit
Duke Energy

Technical Concept & Approach

A project team coordinated and hosted a workshop to bring together project sponsors, their subject-matter experts, and other industry experts to participate in a roundtable discussion to identify any gaps in knowledge and needs of the industry, and uncover the best practices with calculating peak-day gas loads.

At the conclusion of the workshop, a Final Report will be issued with an overview of the results, findings, and next steps identified from the workshop.

- Investigating metering devices and their potential to provide useful data.
- Research forecasting with renewable natural gas sources. What is the best way to model reliability of renewable natural gas sources as they are introduced into the system?

Results

The workshop was held on October 3, 2019.

A list of follow-up actions was created during the workshop that included:

- Document best practices for integrating Top Down (Supply Forecasts) and Bottom Up (Hydraulic Modeling) approaches.
- Create best practice for calculating peak-hour loading and margin.
- Develop an industry standard for calculating what design day number to use.
- Including energy efficiency updates into forecasting models.
- Investigating metering devices and their potential to provide useful data.
- Research forecasting with renewable natural gas sources. What is the best way to model reliability of renewable natural gas sources as they are introduced into the system?

Status

A Final Report is being drafted.

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Single-Path Ultrasonic Meter Performance Testing

In this project, researchers will conduct necessary evaluations of recently introduced "single-path" ultrasonic residential meters for utility and state commission acceptance. This effort will prove the measurement performance and accessory meter technology to allow the use of this style of meter.

Project Description

Space is always an issue when installing gas meter sets. The meter's final location must conform to varying clearance distance guidelines regarding the meter's proximity to windows, air ducts, electric meters, and other types of installation obstacles. The challenge is even greater when installing multiple meters in a small amount of space. Utilities could save a large amount of space and increase installation options if smaller-profile meters were available.

In this project, researchers are evaluating the performance of "single-path" ultrasonic residential-sized meters from two manufacturers. A path is simply the path or track of the ultrasonic pulse as it travels across the pipe and back again. Many ultrasonic meters are single- or dual-path, meaning they send either one or two signals across a pipe and back.

These new meter sets are compact, but also have advanced features such as remote shutoff, pressure monitoring, and system diagnostics.

No formal third-party testing of these units has been performed and there are questions as to whether current regulatory guidelines will allow these units to be used without further testing. A review of current regulatory requirements is required to determine what is needed to allow use of these types of meters.

The objective of this project is to conduct necessary evaluations of recently introduced single-path ultrasonic residential meters for utility and state commission acceptance. This effort will prove the measurement performance and accessory meter technology to allow the

Deliverable

The deliverables of this project will include a Final Report summarizing the testing results of the residential ultrasonic meters.

Benefits

A compact meter set design will have the most noticeable positive effects when installing meter sets in areas with scarce available wall space. Urban apartment complexes, for example, would see a dramatic decrease in occupied wall space with the implementation of a more compact meter set design. As a result, indoor meter rooms would not have to be as large.

In addition to the unit size reduction, there are smart features, such as remote shutoff, pressure monitoring, system diagnostics, and theft detection.

Technical Concept & Approach

With input from the project sponsors, researchers will review all regulatory documents that have direct effect on the industry and project sponsors. Additionally, investigators will also examine key performance parameters to verify.

The project team will create a test plan that will address all testing to be performed during the project, and pass/fail criteria as required.

Testing of two single-path meters will be conducted using the testing matrix.

A testing report will be generated that will include any pass/fail criteria that was used to evaluate the meter sets. Additional ultrasonic meters from other manufac-

turers may be added if budget allows. In addition, evaluations will be conducted on other aspects of the meters, such as battery life, communication modules, pressure sensing, and remote shutoff.

Results

Activities included creating and distributing a project survey to better identify the performance test requirements of project sponsors. Interviews were conducted with the American Gas Association and state commission representatives, establishing meter manufacturer contacts, and evaluating sonic nozzle provers to be used for the accuracy testing of single-path ultrasonic meters. The industry reference documents and regulatory guidance, along with project sponsor input, will be used to create a performance test plan for this project.

The project team is working with each meter manufacturer to obtain meters for testing and the necessary equipment to test the capabilities of the accessory devices.

Researchers received sonic nozzle prover quotes from manufacturers.

The development of performance testing criteria was initiated. Regulatory requirements and project sponsor input is being used for development of this test criteria.

Status

The following activities are scheduled for execution:

- Analyze project sponsor survey results
- Finalize performance testing criteria and present to project sponsors for approval

- Complete regulatory requirement review
- Conduct survey debrief call with project sponsors and review proposed performance test criteria
- Obtain all meters and equipment from meter manufacturers required to complete performance testing, and
- Obtain and set up sonic nozzle prover required for performance testing of single-path ultrasonic meters.

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Evaluation and Demonstrations of the Utonomy Smart Regulator

In this project, researchers are conducting a technical review and evaluation of a smart regulator for medium- and low-pressure gas distribution systems. The system is designed to automatically control pressure-regulator output by remotely changing the pilot valve setting.

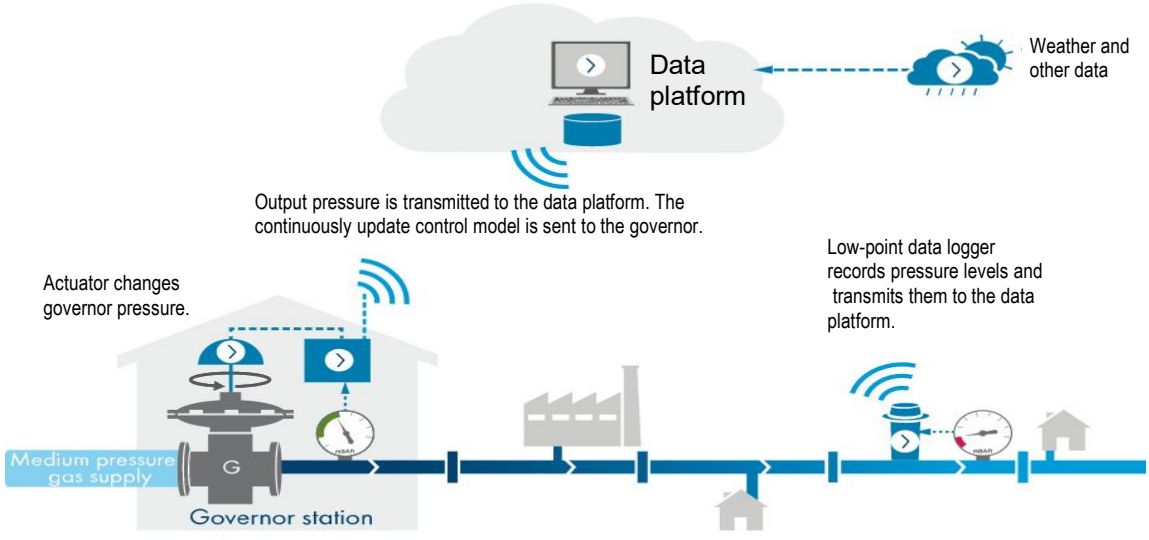
Project Description

District governors regulating the pressure in natural gas distribution systems are manually adjusted on a seasonal basis two to four times per year. They are set to the maximum pressure that is anticipated to be needed to satisfy the highest gas-delivery demand for the required period of time. The set-point pressure takes into account factors that will drive up gas usage, such as the time of day – typically, the early morning hours, a very cold peak heating day, etc.

Some systems have remotely monitored and controlled pressure regulation, but company personnel must operate these systems 24 hours a day. Low-pressure systems, where the pressure regulator can be a significant distance from the end of the distribution network, must also take into account the slower response time of the system to an increase in regulated pressure. Pressure adjustments may need to be made sooner and possibly at a higher set point to maintain the minimal operating pressure at the end of the system. This means that for the vast majority of the time, the set operating pressure is significantly higher than is needed. This leads to higher gas leakage and larger lost and unaccounted for gas than would be experienced if the pressure were autonomously adjusted remotely and automatically in real time as needed to meet changing gas demand, or by a system that could predict pressure requirements and make regulator adjustments before the need is detected.

There is also growing environmental concerns for the effects of greenhouse gases on the global environment. Gas companies are under growing pressure to decrease fugitive natural gas emissions through better control of the gas distribution system and the sources of natural gas leakage.

These issues could be addressed through the development and implementation of a system that would automatically regulate the pressure in gas distribution lines in real time. Increases in system pressure through automatic adjustment of a gas pressure regulator would only occur during times of increased gas demand,



PRESSURE MANAGEMENT WITH UTONOMY
Network and other data is used to continuously update and download control models to the governor controllers. Once downloaded, the models are used to adjust the governor set points to the optimum levels via motorised actuators.

while maintaining lower pressure during periods of low demand.

This project focuses on the Smart Regulator system, which was developed in the United Kingdom by Utonomy, Ltd., in 2015. The Smart Regulator is an innovative active gas utility pressure-management system that uses a combination of hardware- and software-based self-learning algorithms and remote-controlled actuators to control system pressure in real time. The system allows operators to regulate system pressure to the lowest possible pressure while meeting system-delivery requirements, thus reducing gas leakage and unaccounted levels.

The objective of this project is to conduct a technical evaluation and North American field demonstrations of the Smart Regulator for medium- and low-pressure gas distribution systems.

Deliverable

The deliverables of this project will include:

- A report comparing commercially available systems that remotely and autonomously control gas pressure regulator operations
- A report detailing the results of the Utonomy Smart Regulator laboratory testing in a simulated field environment
- A Case Study report detailing the results and experience with the Utonomy Smart Regulator
- A report describing the site visits, installations, implementation, and operation of the Smart Regulator in an operating field, and
- A report describing the results of the field demonstrations and an evaluation of the system and its operation.

Benefits

The Smart Regulator is designed to be retrofitted to existing gas distribution regulators and pressure control systems so that it can be applied to a range of current gas pressure regulation systems.

The use of the Utonomy Smart Regulator has the potential to significantly reduce gas leakage and lost and unaccounted gas.

Other potential benefits include:

- Demonstrated environmental awareness through a reduction in greenhouse gas emissions
- Reduced cost in not needing to manually adjust pressure regulators several times per year, and
- Reduced manpower over continuous remotely monitored and controlled regulators.

Technical Concept & Approach

This project includes a review of customer needs and development of a laboratory and field-testing approach.

Researchers will conduct a high-level study of similar technologies that may be available.

Fitness-For-Purpose testing will be conducted. This will include the design and construction of a small-scale gas distribution piping system that can be pressurized to different levels and flow rates. The Smart Regulator system will be installed on this laboratory piping system to evaluate its communication, analysis, and response to simulated changes in system gas delivery requirements. This will include establishing a cloud-based communications platform and data-logging capability. The project team will test the system's ability to retrieve instructions from the platform and return data and status information. An evaluation will be conducted from a cybersecurity aspect.

A site visit was conducted review the installation and use of the Utonomy Smart Regulator in operations.

The project team will coordinate field demonstrations of the Utonomy Smart Regulator. The field demonstrations will include the installation of the Smart Regulator system and components on a selected segment or segments of a gas company's gas distribution system. The field demonstration will be conducted over a period of 12 months to allow evaluation of its operation and response to seasonal load variations.

Results / Status

Meetings were held with Utonomy and SGN (the network operator in the UK currently pilot testing the Utonomy Smart Regulator system) to discuss an evaluation of the Utonomy system and next steps.

The development of case studies was initiated.

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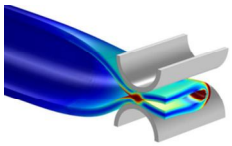
Best Practices for Squeeze-Off of Vintage Polyethylene Pipe



Specific guidelines and best practices are being developed for performing squeeze-offs on vintage polyethylene pipes. Research is being conducted on the ability of various repair clamps/fittings to reduce stresses on vintage PE pipes after squeeze-off operations.

Project Description

Gas utilities are aware of the potential damage that an improper pipe squeeze-off operation can impart on polyethylene (PE) pipe. In this project, research is being conducted to determine the probability of imparting damage in pipes and fittings in close proximity to a squeezed-off point and provide data, recommendations, and best practices (e.g., use of clamps for protecting the squeezed-off location) for performing a squeeze-off operation.

This method being developed is based on the results of OTD project 2.13.d, *Method for Developing an Initial Risk Profile for Aldyl-A Piping Systems*. A specific task under the project evaluated the expected residual lifetime of vintage Aldyl-A piping after squeeze-off with and without the use of a reinforcing clamp/fitting.

Several other projects were conducted also investigating the performance and life expectancy of vintage PE pipe, including an investigation to forecast the remaining useful life and pressure-carrying capacity of vintage Aldyl-A pipes, taking into account the effects of:

- Specific field temperatures and other conditions
- Rock impingement
- Soil loading and earth settlement
- Pipe bending, and
- Squeeze-off.

Deliverable

This project will provide information on the ability of various repair clamps/fittings to reduce stresses on vintage PE pipes after squeeze-off operations. Testing reports detailing the performance of the various clamps/sleeves will be provided in a Final Report.

Benefits

Squeeze-off is a technique used to stop or reduce the flow of gas in PE pipe by compressing the pipe between parallel bars until the inside surfaces of the pipe make contact. This operation has been shown to inherently induce damage at the squeeze-off. A method to protect gas pipes at the squeeze point by using specific repair clamps/fittings that are currently available in the market could potentially enhance and extend the lifetime of a squeezed pipe.

Technical Concept & Approach

The project team is building on research carried out in previous projects and further investigating and quantifying the stresses imparted on a PE pipe as a result of the squeeze-off procedure. In addition, researchers will evaluate the extent of imparted damage, and develop guidelines and best practices for maintaining the life of squeezed-off vintage PE pipes.

The approach is to employ Finite Element Method (FEM) analysis to determine the Stress Intensification Factors (SIFs) induced by the squeeze-off operation on various pipe sizes and materials. The SIFs will then be validated using 3D X-ray computed tomography (CT) scanning.

Various replacement clamps and fittings are being evaluated.

Specific tasks include:

- **Specimen Acquisition**

  Samples for testing include medium-density and high-density PE pipe samples and corresponding stainless-steel repair clamps, various electrofusion encirclement fittings, and butt-fusion repair sleeves.

- **Squeeze-off, CT Scanning, and FEM Analysis**

  Researchers will validate the kind of damage that is imparted in squeezed-off pipe. This will be accomplished by performing pipe squeeze-offs at 0°C, 23°C, and 40°C (32°F, 73°F, and104°F) in accordance with ASTM F1041 and D2513 under typical operating pressures. For each pipe size, multiple specimens will be prepared at each temperature. One sample from each temperature will be sent for 3D CT scanning before squeeze-off. On completion of the squeeze-offs, all of the specimens will be CT scanned. The acquired 3D scans will be used to generate CAD models. The generated CAD models will then be used to simulate pipe internal pressurization via FEM analysis to determine what the local SIFs are for various pipe sizes after they have been squeezed-off. This will generate absolute values of SIFs due to geometric deformation. The results will be compared to those of squeezed-off pipes in an historical database. This reference data will enable the team to provide lifetime prediction of squeezed-off pipe evaluated in this project.

  The CAD models from before squeeze-off will also be used in full squeeze-off simulation and the deformation results will be compared to the CT scanned deformation. This will help verify the simulation and provide insight about the damage induced by the squeeze-off process.

- **Material Properties Testing**

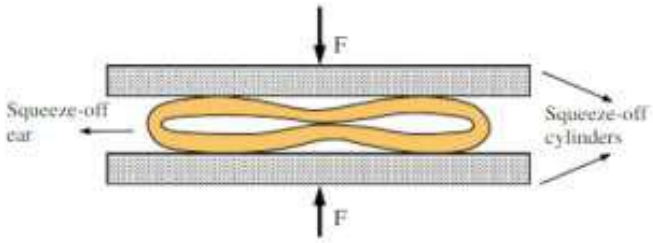
  To support the FEM analysis, material properties testing will be performed via tensile testing and Dynamic Thermo-Mechanical Analysis. For each pipe material, three replicate specimens will be tested at three temperatures. Two pipe materials will be tested.

- **Short-Term Validation Testing**

  In this task, the squeezed-off pipe samples that were 3D scanned will be prepared and tested. A total of 36 specimens for each pipe size/material combination will be tested. The squeezed-off and clamped pipe specimens will be subjected to elevated temperature sustained hydrostatic pressure testing to validate a desired lifetime at end-use operating conditions.

Results / Status

Project scoping is ongoing. No results to report.



Schematic of squeeze-off.

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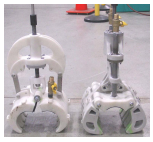
Emergency Leak Tool for Stopping Blowing Gas



The goal of this project is to provide a market-ready leak clamp tool that can be used to quickly, safely, and effectively stop off a gas leak from outside of the same excavation or opening. The current phase of the project involves collaboration with a manufacturer to bring the product to market.

Project Description

Third-party damage is a significant issue in the natural gas industry that is being addressed through research and development.

During Phase 1 of this project, two working prototypes were developed for emergency use in a third-party event – an External Pivot Clamp and an External Vertical Clamp. Both prototypes consist of an air pocket that surrounds a leak and contains it with a seal that is formed with a lead-screw-activated locking mechanism. The External Pivot Clamp consists of two halves that come together to grab onto the pipe and create a seal in the same motion. The External Vertical Clamp consists of a single part which is lowered onto the pipe and the seal is created when the prototype is locked in place.

Various seals were tested that were made of different materials, durometers, and thicknesses. With the best performing seals, both prototypes were tightened onto the pipe by turning the lead screw until it was handtight. In this scenario, both prototypes were able to hold 30 psi before they leaked, and a soap bubble started to form. To obtain the maximum holding pressure of the External Vertical Clamp, it was tightened and secured to the pipe with ratchet straps.

In an emergency today, typically additional openings are excavated away from the damaged leaking pipe to stop the flow of gas to the pipe section that needs repairs. In these additional openings, crews perform stopping operations, squeeze-off, or tapping and stopping to stop off the flow of gas to the leak. Upon successful completion of securing the gas, the damaged section of pipe is repaired or removed from service and a new segment installed. This repair process takes a significant amount of time and can result in a long duration of the uncontrollable release of gas and possibly service interruption to customers.

The goal of this project is to provide a market-ready leak clamp tool that can be used to quickly, safely, and effectively stop off a gas leak from outside of the same excavation or opening. In the current phase of project, efforts are being made to identify an industry manufacturer and distributor to enhance the design of the emergency leak clamp tool and ultimately bring it to market.

"The development of an emergency tool to stop blowing gas from a damage to our natural gas infrastructure is a perfect example of a project life cycle that begins as a member problem. The problem reaches conceptual maturity and then grows to full prototype development in OTD."

- Rick Trieste
Dept. Manager R&D
Consolidated Edison Company of New York

Deliverables

The deliverables for this project include:

- A field-tested product produced by a third-party manufacturer prepared to commercialize the tool
- Generation of a commercialization agreement with a third-party manufacturer and distributor, and
- A Final Report describing the improvements of the design and testing results of the final product.

Benefits

Having an emergency leak tool to stop blowing gas from outside of the trench will allow utilities to stop an active gas leak in a safe and more efficient manner.

This tool will improve employee and general public safety by reducing the amount of time required to secure the uncontrollable release of gas as a result of

third-party damage. Also, due to the reduced time of blowing gas, this will reduce the amount of methane emissions released into the atmosphere.

There are also potential labor, equipment, and restoration savings by eliminating the need to dig additional excavations to squeeze-off or stop-off the pipe away from the blowing gas location.

Technical Concept & Approach

Specific tasks include:

- **Design Refinement of the Tool**

  This task includes interactions with a manufacturer to refine the design of the external clamp prototypes such that it is stronger, more effective, and can be easily fabricated by the manufacturer. Currently, the leak clamp prototypes are designed to stop the flow of gas on polyethylene (PE) and steel pipe sizes of two inches in diameter through eight inches in diameter.

- **Fabrication of the Final Tool Design**

  This task will mostly be conducted by the manufacturer to fabricate the final external clamp tool with oversight by the project team to ensure tool requirements are met.

- **Laboratory and Field Testing of the Tool**

  This task includes laboratory testing and field testing the fabricated clamp tool by the manufacturer and testing it on damaged PE pipe and steel pipe. This testing will include multiple-size clamp tools and the different design enhancements made during the fabrication process.

- **Commercialization**

  This task includes the efforts required to bring this product to market, including, but not limited to, protecting intellectual property and seeking patents, obtaining a distributor, and efforts to secure licensing agreements.

Results / Status

Potential tool fabricators are in the process of being identified. The project team is actively involved with reviewing agreements in place with potential tool fabricators to confirm that OTD interests in this project are protected.

Researchers will review and refine the tool design from Phase 1 project with a potential tool fabricator.

Pipe samples for testing refined tool design will be prepared.

Research is under way to determine:

- Which pip size is an immediate need for utilities
- How would these units most like be deployed (i.e., with first responders, all-crew trucks, etc.), and
- Interest in making this a simple hydraulic device to achieve more compression force.

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Over-Pressure Protection Options for Low-Pressure Gas Distribution Customers

Researchers are identifying and evaluating over-pressure protection options available for the natural gas industry for low-pressure gas distribution customers. Gas pressure regulator manufacturers are being engaged in development efforts to enhance current designs to meet industry needs.

Project Description

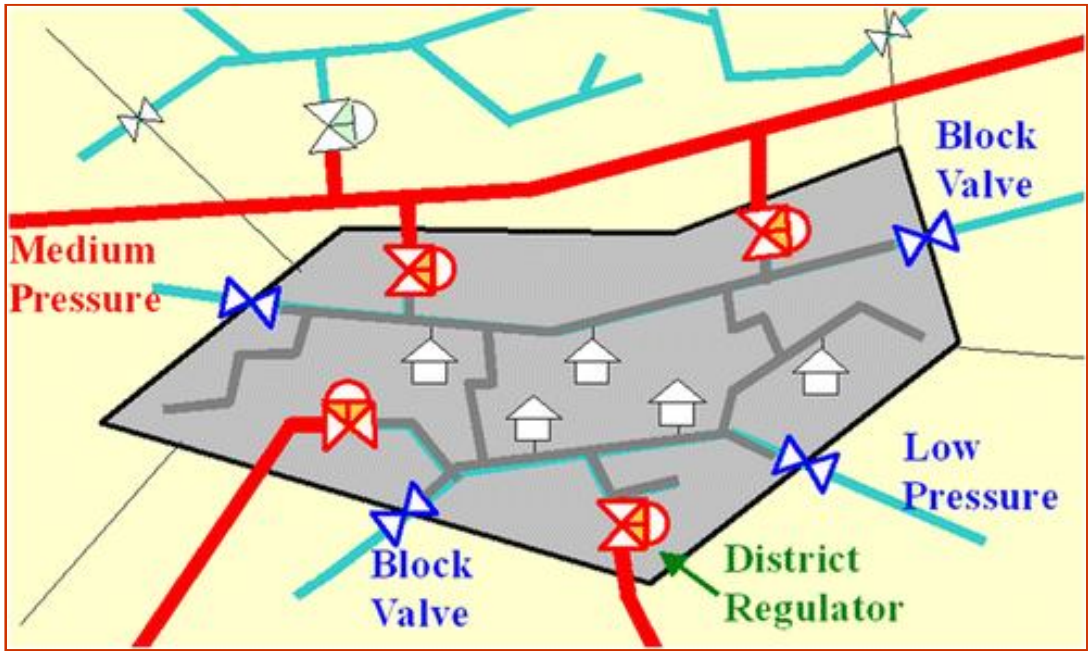
After experiencing an over-pressurization incident of a low-pressure gas distribution system, the natural gas industry has begun to reassess on how this type of incident can be prevented in the future.

Researchers find that low-pressure gas distribution systems are vulnerable to over-pressure situations for multiple reasons:

- Abnormal operation of regulator stations that may allow pressures to rise above set pressures
- The total number of regulator stations that may be controlling one area of a low-pressure system with dozens of pressure-sensing lines controlling system pressure
- The opportunity for errors in cross-connections with the large amount of new infrastructure being installed, connected, and disconnected from low-pressure systems
- Personnel that are unfamiliar with unique operating characteristics of low-pressure systems and may not be able to identify a potential failure before it occurs, and
- The decreasing knowledge and experience levels of personnel due to most of the new pipe installed over the last 30 years having been steel and polyethylene piping at higher operating pressure and pressure regulation at each user.

Low-pressure gas distribution systems will be in existence for the next 30-plus years based on the inventory of pipe remaining and the difficult-to-upgrade locations in which they are located. The safeguards put in place today will help to prevent future failures.

In this project, researchers are identifying and evaluating over-pressure protection options available within the natural gas industry for low-pressure gas distribution customers. This project will also engage gas pressure regulator manufacturers on possible research and development efforts to enhance current designs to meet industry needs (e.g., increasing flow capacity, having the ability to regulate minor over-pressure fluctuations, and minimizing the pressure differential through the device). In addition, a reference guide will be created for use when considering which type of over-pressure protection option to install on the end of low-pressure service lines to improve overall system integrity.



Deliverables

The deliverables for this project will include:

- A Final Report detailing the technical specifications for the different over-pressure protection options for low-pressure gas distribution service
- Coordination and facilitation of webinars with manufacturers (including potential new products), and
- A report that will include a reference guide comparing similar over-pressure protection options for each of the different manufacturers.

Benefits

Installing an over-pressure protection device (OPPD) on low-pressure gas lines to serve customers reduces risk in the event of an unintended system over-pressure situation that may be the result of a mechanical failure or human error.

Installation of OPPDs will prevent widespread catastrophic failures in the event of an over-pressurization of the system. If OPPDs are not installed and a system over-pressure event occurs, the cost of third-party claims related to emergency response, personal injury claims, property damage, temporary housing, and legal fees can exceed $1 billion.

Technical Concept & Approach

Specific tasks include:

- **Identification and Evaluation of Over-Pressure Protection Devices for Low-Pressure Service**

  This task includes the identification and evaluation of current over-pressure protection options for low-pressure gas distribution service to customers. The evaluation includes the technical specifications of each device. A reference guide will be prepared with this information comparing similar devices and options. In addition, regulator manufacturers will be interviewed on the level of research and development efforts for OPPDs currently under way or expected in the near future.

- **Regulator and Device Manufacturer Webinars**

  This task includes the coordination and facilitation of webinars for each of the regulator and device manufacturers to present on their over-pressure protection offerings for low-pressure gas distribution customers. One webinar will be conducted for each of the manufacturers. These webinars will be recorded for those unable to participate and the manufacturer presentations made available to project sponsors.

Results

The over-pressurization incidents investigated by the National Transportation Safety Board (NTSB) over the past 50 years demonstrate that low-pressure natural gas distribution systems that use only sensing lines and regulators as the means to detect and prevent over-pressurization are not optimal to prevent over-pressurization incidents. The NTSB recommended to "revise Title 49 Code of Federal Regulations Part 192 to require over-pressure protection for low-pressure natural gas distribution systems that cannot be defeated by a single operator error or equipment failure."

Activities for this project included identification of the project team, conducting a project kick-off call with sponsors, performing a search of existing products, and speaking with industry subject matter experts on available products.

Status

Current, ongoing activities include:

- A review of OPPD requirements with regulator and device manufacturers
- Identification of potential OPPD solutions with industry manufacturers and inventors
- The development of an OPPD reference guide, and

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Identify and Validate Best Practices for Applying Heat to Steel Near PE Materials

For this project, a research team is developing a best-practices guideline for operations that apply heat to steel components near polyethylene (PE) pipe, with respect to preventing overheating of the nearby PE system components.

Project Description

Currently, there is no industry guidance addressing the application of heat to steel pipes and components (that are upstream of PE pipe and components) to minimize the risk of potentially overheating the PE pipe and fittings.

The objective for this project is to develop a best-practices guideline for applying heat to steel pipelines near PE materials.

The phenomenon of heat transfer needs to be studied in the context of operations on steel pipe where heat is applied (e.g. welding). Such applications include heat transfer by conduction through the pipe and fittings, and heat transfer via convection from internal air/gas flow. The heat transfer via these mechanisms is generally dependent on the duration of the heating, internal air/gas temperature and flow rate, temperature of the pipe, ambient temperature, and wind speed.

Heat transfer to pipe and components downstream of the location of heat application will also depend on the specific geometry of the piping system, including internal pipe diameter, wall thickness, bends, and any flow-stagnation points.

Deliverable

The deliverable for this project will be a best-practices guideline for applying heat to steel components near PE pipe, based on the scope of the investigation.

Benefits

Establishing best practices for applying heat to steel components near PE pipe could help reduce operational risks associated with excessive heating of PE pipe/components (which can lead to short-term creep rupture).

It is anticipated that these best practices can be applied to welding operations in the vicinity of PE piping systems (welding transition fittings, stopper nipples, gauge tees, etc.).

Technical Concept & Approach

Specific objectives for this project are to:

- Identify realistic field conditions to maximize the efficiency of the project
- Determine the materials of interest and if material testing is needed, and
- Discuss execution of validation testing.

If existing material data is deemed insufficient, the materials of interest (steel and PE) will be tested for their heat-transfer properties – thermal conductivity and heat capacity – to ensure accurate simulations. Simulations will determine how long it would take for PE components to become overheated under various conditions.

One or more of the worst-case scenarioswill be physically reproduced and evaluated to validate the simulations. If appropriate, validation testing may be performed at one of the project sponsor's facility.

Results / Status

A kickoff meeting was held in March 2020. Testing will begin in the second quarter of 2020.

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Workshop on NDE Capabilities for Polyethylene Systems

For this project, a 1-½ day workshop is being organized to present the results of research from Michigan State University and GRTgaz on non-destructive evaluation (NDE) methods for polyethylene piping systems.

Project Description

While there are several platforms for introducing developments related to non-destructive evaluation (NDE) of polyethylene (PE) pipe joints, industry does not have a set of consensus guidelines on how to interpret the results of the NDE evaluations. There is also no clear understanding as to the difference between volumetric defects that are easily detectable and weak-fusion interfaces, that are difficult to detect.

Field failures mostly are due to the weak-fusion interfaces, not the volumetric defects. The industry needs clear statements as to the failure risk associated with each kind of defect, together with probability-of-detection information.

The importance of proper pipe-preparation methods was comprehensively addressed in OTD project (5.16.r) *Joint Industry PE Program*. However, no research has been done on the efficacy of NDE methods as a quality control for surface cleanliness in assembled joints.

Gas Technology Institute (GTI) performed an extensive project on the impacts of heavy hydrocarbon contamination on the quality of butt-fusion joints in PE pipe. This project included an extensive evaluation of non-contaminated butt-fusion joints to develop baseline joint-quality data for reference. Follow-on projects included two efforts that focused on developing ultrasonic methods for measuring contamination.

A project with Michigan State University (MSU) developed a reliable method for producing butt-fusion joints with known levels of interface strength based on quantitative destructive testing. Joints of known quality were sent to MSU in a blind study of the effectiveness of NDE methods in detecting weak-fusion interfaces.

The methods evaluated by MSU included:

- Micro-Computerized Tomography
- Microwave Frequency Scanning
- Co-axial Cable Probe
- Split-Ring Resonator
- Open-Ended Waveguide
- Capacitive Sensors, and
- Optical Transmission Scanning.

All test specimens evaluated by MSU were destructively tested.

GRTGaz has extensive knowledge of NDE evaluations performed in Europe and has spent considerable time and effort in developing methods for evaluating electrofusion joints. The GRTGaz efforts include long-term hydrostatic testing of joints evaluated and categorization of the failures due to volumetric joints and weak interfaces, together with their probability of detection by the GRTGaz method.

For this project, a research team will organize a 1-½-day workshop to present the results of R&D performed by GTI, MSU and GRTgaz on NDE methods for PE piping systems.

Deliverables

Deliverables include:

- The Workshop
- Workshop proceedings

GRTgaz

MICHIGAN STATE UNIVERSITY

gti GAS TECHNOLOGY INSTITUTE

- Summary of consensus of implications of information presented, and
- A roadmap for next steps in evaluating commercially available NDE technologies.

Benefits

A clear, science-based understanding of the capabilities of existing NDE methods in detecting heat-fusion joint anomalies will be very useful in helping utilities develop approaches to mitigating historic joint-quality issues. The information provided will give utilities the necessary reference points for evaluating alternative approaches to assessing joint quality and ensuring joint quality in future operations.

Technical Concept & Approach

Workshop topics include:

- Overview of North American and European field failures in PE heat-fusion joints
- The state of the art in NDE methods for PE piping systems
- Discussion of what defects each evaluation method can detect and how these defects relate to field failures
- Demonstration of GRTgaz experience with Phased Array Ultrasonic Testing (PAUT) of electrofusion joints
- Discussions on how to approach evaluation of existing NDE technologies
- Discussion of process-management approaches to ensuring joint integrity and where NDE approaches are relevant
- Discussion of how to process the information provided and develop a unified strategy for addressing quality and integrity of historic joints and new joints.

Results / Status

The workshop is being planned to take place in the third quarter of 2020.

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Quality Audit Program for Natural Gas Utility Suppliers

This program provides gas utility operators with a mechanism to collaboratively audit suppliers' quality-management systems. Experts conduct independent and unbiased assessments on behalf of participating operators to provide a reliable and standardized approach for monitoring suppliers.

Project Description

Distribution integrity management regulations encourage utility companies to place a new focus on supplier and supply chain quality. Identifying threats and mitigating risks starts with the manufacturing process.

Reducing supply-chain risk requires a comprehensive and well-coordinated supplier audit program to ensure that the integrity of the supply chain is controlled and that the supplier is following policies and procedures required by customers and regulators. Supplier audits identify non-conformances in manufacturing, shipping, engineering, and quality processes. Post audit, the supplier and auditors identify corrective actions which must be implemented by the supplier within an agreed-upon timeframe. Future audits ensure that these corrective actions have been successfully implemented.

While the need for enhanced quality audits and monitoring programs is increasing, the availability of resources to conduct these programs is decreasing due to a focus on operations and efficiencies.

This program was created to provide natural gas utility operators with a mechanism to collaboratively audit suppliers' quality-management systems. The program conducts independent and unbiased assessments on behalf of participating operators to provide a reliable and standardized approach for monitoring suppliers.

Deliverables

The deliverables for the program will be reports for each audit and annual summary reports. Only program members are eligible to receive the audit findings reports.

Researchers will also track the performance of suppliers against metrics and will follow-up on identified deficiencies and corrective actions.

An annual workshop is conducted to summarize audit findings and prepare a preliminary list of potential candidates for the following year's audits.

Benefits

Participation in a collaborative audit program provides value in the following ways:

- Creates efficiencies and cost savings by consolidating audits into one program
- Increases the number of audits performed
- Creates leverage and increases influence with suppliers
- Utilizes certified auditors with extensive experience
- Provides high-quality audits due to consistency and standardization of the audit methodology, and
- Allows internal resources to focus on the core business rather than auditing.

Technical Concept & Approach

The audits performed are based on the process approach methodology of the ISO 9001:2015 *Quality Management Systems* per the requirements and inquiries from sponsors. Since 2015, the criteria/scope of the audits changed to focus more on industry standards and utility requirements.

"At Southwest Gas, safety and quality are at the heart of our core values. That's why we appreciate the OTD Quality Audit Program and the additional assurances it provides. With OTD, we know that critical gas carrying component manufacturers have controls in place to ensure the quality of the products we purchase. By ensuring that manufacturers' quality programs are robust and controlled, and that products are only purchased from top-notch suppliers, Southwest Gas can continue to provide safe and reliable natural gas service to the communities we serve."

- Cynthia Davis
Operational Quality Assurance Manager
Southwest Gas Co.

In average, up to 17 processes were covered at each supplier site. These included:

1. Management Review
2. Training
3. Analysis and Improvement
4. Customer processes
5. Equipment/Preventive Maintenance
6. Documentation Control
7. Purchasing
8. Engineering Change Control
9. Internal Audit
10. Corrective Action
11. Production
12. In-process and Final Inspection
13. Verification of Incoming Materials
14. Identification and Traceability
15. Shipping and Inventory Control
16. Non-Conformance Process, and
17. Measurement Tools Calibration.

Each audit may take between two to three days based on the size of a site. Audits are performed by one auditor who may be accompanied by a subject-matter expert.

Metrics for both auditors and suppliers will be developed and monitored throughout the program. Examples of metrics include audit report turnaround time, number of corrective actions created, time for corrective action closure, number of overdue corrective actions, etc.

Results

Multiple opportunities for improvement were found at each supplier's site and documented in reports.

A new ranking system was created in 2015 to quantitatively assess suppliers' quality systems and to show the strength and the weaknesses of the organization. These scores can be used as a reference in determining whether the company is making improvements going forward.

In 2019, researchers completed 13 audits.

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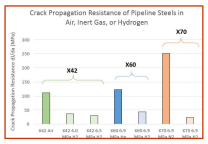
Initial Assessment of Effects of Hydrogen Blending in Natural Gas



Testing is being conducted to assess the impacts of 5% hydrogen-blended fuel on materials in the natural gas pipeline system. A project team will also develop engineering tools to allow an integrity assessment and a safety margin determination of hydrogen-blended gas use.

Project Description

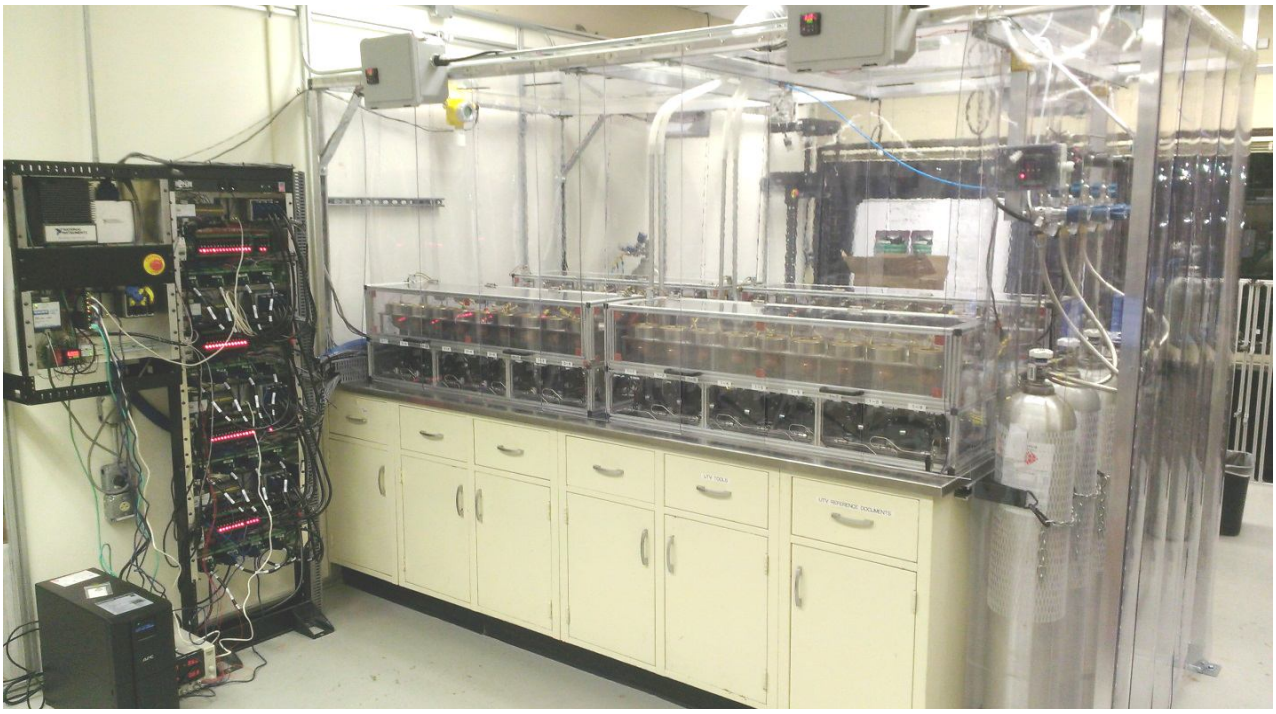
In Phase 1 – conducted in 2014 – researchers assessed the material integrity and operational compatibility of a bounded natural gas pipeline system and its components with a 5% hydrogen-blended fuel to help determine if any system upgrades might be necessary to reduce risk and support gas interchangeability with a 5% hydrogen blend. It also identified future research needs when considering gas interchangeability with blends that contain >5% hydrogen.

Overall, the 5% hydrogen-blended gas did not appear to have a significant impact of the integrity of nonmetallic materials.

A literature search also revealed that the addition of hydrogen to the natural gas stream is likely to have a significant effect on pipe steels. The data shows that hydrogen gas reduces the fracture toughness, crack propagation resistance, and ductility, and increases the fatigue crack growth rates for pipeline steels and their welds. This is also true for hydrogen/natural gas blends, and even when hydrogen partial pressures are very low, especially for crack propagation resistance. Material and service environment specific testing is necessary to determine specific threats and margins of safety for hydrogen-blended natural gas use.

With the introduction of hydrogen, however, comes the need for extensive study, testing, and possible modifications to existing pipeline monitoring and maintenance practices. Safety factors for hydrogen gas systems need to be established based on materials tests performed under relevant and site-specific mechanical, environmental, and material conditions without significant extrapolation. Operators should have applicable test data on these properties for the specific alloys/grades (many of them vintage or older materials) and hydrogen-natural gas blends that are intended for operational use.

In the current Phase 2, researchers are conducting physical testing to assess the impacts of 5% hydrogen-blended fuel on metallic materials in the natural gas pipeline system. A project team is also developing engineering tools to allow an integrity assessment and a safety margin determination for hydrogen-blended gas use.



Rig for testing with flammable gases.

Deliverables

- Sponsor-approved hydrogen-blend use case to bound testing and engineering modeling requirements
- Set of vintage and new material testing samples
- Physical testing and design plans
- Final Report and webinar, and
- Detailed plan for Phase 3 to execute testing, modeling, and development of reliability and engineering tools.

Benefits

As the natural gas industry moves towards reducing environmental impacts, exploring opportunities for renewable projects and de-carbonizing the pipeline are becoming more important. Companies are now evaluating renewable power-to-gas projects, including blending hydrogen into natural gas pipelines, which not only reduces greenhouse emissions, but also takes advantage of an existing infrastructure for effective means of delivery to customers. This also presents new business opportunities for increased distribution revenues if pipelines are transporting new incremental supplies of renewable fuel and storage revenues for electricity energy storage using hydrogen.

A study will provide the objective information necessary to:

- Support the pipeline industry's transition to a future requiring increased flexibility for transportation and distribution of a diversified blend of gaseous energy supplies.
- Assess the material integrity and operational compatibility of a bounded natural gas pipeline system with 5% hydrogen blended fuel.
- Help to determine what, if any, system upgrades might be necessary to reduce risks and support gas interchangeability with a 5% hydrogen blend, and
- Identify future research needs to consider gas interchangeability with >5% hydrogen blends .

Technical Concept & Approach

The Phase 2 project scope includes obtaining system-specific data and materials, formulating a Design of Experiment (DoE) approach, calculating parameters needed to make engineering decisions, and ultimately creating engineering tools to characterize the effect of hydrogen blending on a specific system.

Based on the literature review conducted in the Phase 1 effort, to avoid pipeline failure/rupture due to hydrogen-blended gas effects, there is an essential set of information needed for a specific steel pipeline system:

- Engineering tools - calculations/plots
- Measure material and physical parameters needed to make engineering decisions
- A DoE approach to develop and ensure that the testing matrix covered all the right combinations and minimized the uncertainty and error, and
- Calculated parameters/values needed to make engineering decisions.

In Phase 2, the investigators will establish the hydrogen-blend service and environmental conditions desired. Researchers will obtain vintage metallic pipeline materials and new materials for physical testing.

The project team will develop a set of laboratory testing requirements. This will include a detailed review of the available standards and test methods in the literature.

Results

Preliminary test results were promising in that they do not indicate any degradation of the material properties with regard to the ductile failure mode.

In 2019, nearly 100 related hydrogen documents, reports, and references were collected for review, with the next step to establish the hydrogen-blend use cases with the sponsors.

A use-case survey was distributed to the sponsors. The team also collected, organized, and presented the project use cases. A web-based meeting was held in November 2019 to summarize the use cases submitted by the sponsors.

Status

The team continues to collect and summarize related hydrogen documents. Researchers are reviewing responses to a sponsor survey to determine the system parameters for the most likely use cases of hydrogen blending industry gas systems.

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Adsorbed Natural Gas Storage Options for Operations Applications

An assessment is being conducted to compare adsorbed natural gas (ANG) vs. pure gas compression for storage and release rates and the quantity of gas stored at various pressures. The goal is to evaluate ANG materials performance with pipeline-quality natural gas for bulk gas storage uses.

Project Description

Bulk storage combined with a gas compressor, gas conditioning, and pressure-regulating station could provide an economically viable alternative to the installation of new pipe to 1) meet the peak gas demands of a system, 2) provide emergency backup for increased resiliency, and 3) offer a means for eliminating the venting of gas when taking gas mains out of service for replacements or repairs.

Activated carbon has a high capacity to reversibly adsorb methane due to its extremely high porosity, which in turn gives it a very high specific surface area. Its surface area can easily amount to several full-sized tennis courts per gram of material. This phenomena is different than absorption, where molecules are drawn into the structure of a solid and therefore are more difficult to be released. The storage advantage of using an adsorbent is most pronounced at lower pressures (below 1,000 psig in most cases) and the rate of pressure rise is different compared to pure compressed natural gas (this reduces the energy required to compress).

In this project, an assessment of adsorbent manufacturers' claims for natural gas storage is being conducted. The goal is to evaluate adsorbed natural gas (ANG) materials performance with pipeline quality natural gas for bulk gas storage uses.

Deliverable

The deliverables of this project will include:. performance charts based on laboratory test results comparison tables, and Quarterly and Final Reports.

Benefits

Natural gas distribution systems can occasionally be subject to supply shortages when there is new load growth in an area or when weather-related events cause short-term demand peaks. Construction challenges, inadequate return on investment, public pressures, or other barriers can cause new gas main and/or other system capacity improvements to be prohibitive. The strains placed on the system may cause end-user equipment malfunctions and periodic outages.

A technique recently investigated by OTD is the use of bulk compressed natural gas (CNG) storage systems used to supplement the gas distribution system during peak periods. The cost reductions of pure CNG storage containers in recent years instigated the investigation in search of a cost-effective solution.

Activated carbon products are ideally suited for sustainable working capacity performance to store and release mixed hydrocarbon vapors such as gasoline and natural gas. By tailoring an activated carbon ad-

sorbent from renewable raw materials, one company claims its product will hold up to three times the amount of methane as compressed gas at 230 psig.

The use of adsorbents particularly enhances the gas storage performance at lower pressures, which could improve the overall economics surrounding bulk gas storage investment and operating costs. As a result, significant cost savings potential exists from using much smaller tanks for the same volume of stored natural gas. Other potential applications for ANG include on-site emergency backup storage, low-pressure recovery, and reuse of flare gas, as well as low energy demand virtual pipeline.

Technical Concept & Approach

The scope of this project is to assess the claims of an adsorbent material manufacturer and validate the performance of adsorbents through laboratory testing and empirical data generation. The assessment includes basic laboratory testing to compare adsorbed natural gas (ANG) vs. pure gas compression for storage and release rates and the quantity of gas stored at various pressures.

Specific tasks include:

- **Literature Search and Materials Specifications Gathering**

  The specifications of the material will be gathered to assess potential concerns with the ability to be impacted by odorants, higher hydrocarbons, moisture, and/or other factors.

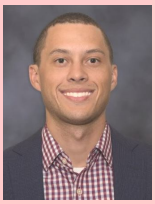
- **Develop Test Plan and Prepare Laboratory and Data Acquisition**

  A specific test plan will be developed to guide researchers in obtaining the needed data to validate the claims by the manufacturer. In addition, the proper measurement and data-collection requirements will be identified.

- **Laboratory Testing and Data Analysis**

  This task involves testing bulk-granular material to produce meaningful results at a scale adequate to model performance at larger gas utility application sizes. Data collection will take place at a variety of pressures and temperatures while varying the input and discharge flow rates.

There are several critical questions to be answered in order to fully assess the value of ANG for the scale, duty cycle, and applications. Namely, the cycle life degradation of the material when used with pipeline-quality natural gas is not fully understood. To date, most testing of ANG substrates has been conducted with pure methane in which the data shows an attractive less than 5% loss over the life of the adsorbent; but the impact of heavier hydrocarbons being present is not known. Additionally, the effects of other constituents in natural gas such as odorants, moisture, and natural gas liquids will need to be explored.



""Ingevity has leveraged our 100 years of activated carbon expertise to enable adsorbed natural gas (ANG) vehicle technology for light-duty trucks. This technology is already being utilized on bi-fuel Ford F-150 trucks with utility providers across the U.S. We are currently focusing additional resources on ways ANG can be applied to other applications."

- Kevin Moen
Business Development Manager
Ingevity

Results

In 2019, a research team conducted a project kick-off meeting to address project sponsors' specific interests and use cases. In addition, results from previously conducted research on bulk storage solutions were reviewed to ascertain additional use cases and define system supply requirements.

Attributes studied included required storage capacity, typical peak period durations, desired storage system recovery times, and desired discharge flow rates. A small sample of the activated carbon material was obtained to better understand the physical consistency of the material.

The research team surveyed sponsors to better understand needs, desired use cases, and system characteristics to ensure that the project approach will be based on real-world requirements. Survey results were analyzed to define and sequence additional project activities.

Status

The following activities are scheduled for execution:

- Researchers are developing a test plan to serve as a guide for collecting the information needed to assess the adsorbent material performance.
- Researchers are identifying the necessary measurement and data-collection requirements to support test-equipment preparation activities.

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METHANE EMISSIONS/ DETECTION & GAS QUALITY

Significant initiatives in this area are addressing greenhouse-gas issues, methods for estimating pipeline leak emissions, and remote gas sensing and monitoring. Research teams are also investigating gas-imaging techniques, biomethane monitoring, robots, drones, and various sensors and methane-detection devices.

Results from these efforts help companies to reduce operations costs, minimize environmental impacts, and more cost effectively comply with regulations.

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Gas Quality Resource Center

A web-based Gas Quality Resource Center is being updated and maintained to provide information and expertise on issues surrounding gas quality, interchangeability, and potential implications from the introduction of new supply sources into gas transmission and distribution systems.

Project Description

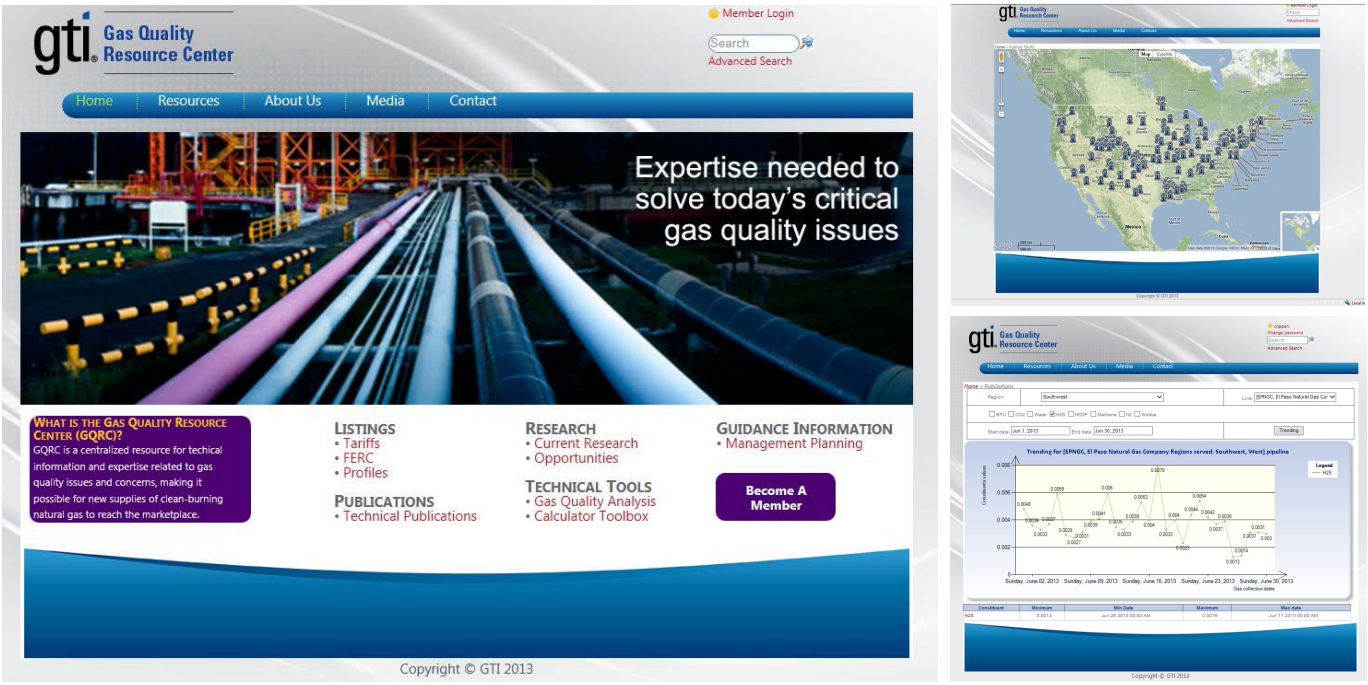
Natural gas transmission pipeline and distribution companies are increasingly being asked to evaluate opportunities and accept new supply sources into their systems. This situation has created a marked shift from traditional gas-supply flow patterns – a trend that is expected to continue as these new supply sources (e.g., shale gas production and the introduction of renewable gas) are brought to market.

Along with this change in supply comes a change in the gas composition. Traditional supplies and gas compositions that have been relatively stable and consistent for decades are now beginning to change, and stakeholders are looking to ensure that these compositional changes will not have an adverse effect on their gas-delivery infrastructure or their customers' end-use applications.

Foundational knowledge in gas quality and interchangeability is readily available. A study was conducted through an industry collaborative effort that resulted in the 2005 White Paper on Natural Gas Interchangeability and Non-Combustion End Use by the NGC+ Interchangeability Working Group. This document contains Interim Guidelines for Gas Interchangeability that have been widely used; however, the White Paper also recognized that there are significant informational or data gaps that require further research. Additionally, the NGC+ report does not address renewable gas at all.

Since the NGC+ report was published, the natural gas industry has generally taken a localized approach in understanding end-use performance and infrastructure issues through the initiation of isolated research efforts to address these increasingly global, systemic issues. Information generated from these research and development efforts is very useful and of great value, but generally fragmented and potentially proprietary.

For this project, a research team developed a Gas Quality Resource Center (GQRC) to provide access to recent and historical information resources and provide expertise and guidance in this technically complex area. The Center serves as a centralized clearinghouse for information related to gas quality, analysis of current flowing gas supplies in North America, identifica-



A web-based resource center is under development to provide for information on gas quality and unconventional/renewable sources of gas.

tion of constituent trends across identified regions, analysis of current technical regulatory trends associated with pipeline tariff negotiations, and identification of research needed to help fill information gaps.

Deliverable

The initial deliverable for this project was the creation of a dedicated Gas Quality Resource Center website and significant content.

Benefits

The Gas Quality Resource Center helps to allow for the safe introduction of new supply sources. The goal is to establish a common understanding and provide a sound technical basis upon which gas industry stakeholders can make informed decisions regarding new supply options. The GQRC helps to ensure continued system integrity and reliability, allow for an expanded use of clean-burning natural gas in growth sectors such as power generation and transportation, and help to reduce greenhouse gases through the addition/substitution of renewable gas.

Technical Concept & Approach

For this project, a research team and an industry advisory committee comprised of subject-matter experts developed a subscription-based Gas Quality Resource Center.

Researchers developed an on-line database on gas-quality-related information derived from publically published data as well as proprietary information garnered from various stakeholder groups.

Information focuses on renewable and unconventional gas. Within the renewable gas domain, the resource center contains information on resource assessments, conversion options, clean-up systems, gas-quality expectations, and studies on potential concerns, implications. and mitigating measures. Within the unconventional gas domain, the resource center contains information on historical and expected compositions from North American resource basins, gas-processing technology, gas-processing facilities and capabilities, blending capabilities, regional historic supply profiles, publicly available tariff requirements, and studies on known/potential implications to infrastructure and end uses as well as mitigating measures.

Phase 1 of the effort focused on providing information and technical support.

In Phase 2 of the project, various GQRC research projects are expected to be initiated.

Results

With the major building blocks and the underlying database architecture completed (e.g., the design and implementation of basic functions and database schema), activities mainly involve populating various categories in the on-line data base.

The overall interface was updated for functionality and ease of use.

The project team:

- Populated the Technical Publications module with more than 500 documents and articles pertaining to odorization, gas-quality measurement, and analysis
- Created packages for importing the gas constituent values for 68 pipelines
- Re-factored the data access layer and the search mechanism for Tariffs, FERC, Profiles, Current Research, Technical Publications, Management Planning, Gas Quality Analysis, and Advanced Search in order to improve the user experience
- Added the Password change and Password retrieve functionality
- Configured the production environment

Status

The first phase of the project is complete, with a working web-based prototype database established at: *gqrc.gastechnology.org*.

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Real-Time Gas Quality Sensor

The objective for this project is to demonstrate a practical, reliable, and real-time gas-quality sensor that can detect changes in gas quality (heating value and concentrations of methane, ethane, propane, butane, and carbon dioxide concentrations) and can provide this data to the operators of an liquefied natural gas plant.

Project Description

The introduction of shale gas and upgraded bio-gas into the gas transmission network is increasing the importance of accurate and regular monitoring of the natural gas heating value and composition. Currently, gas chromatographs (GCs) are used for measurements; however, GCs can be expensive and slow.

In a previous project, researchers developed and validated a Gas Quality Sensor (GQS) that can provide real-time heating value and composition monitoring at lower cost. The GQS uses the near-infrared light-absorption properties of hydrocarbon gases to measure the Btu content and composition of a natural gas mixture at response times less than one second.

The objective of the project is to demonstrate the GQS to determine its ability to detect changes in gas quality (heating value and concentrations of methane, ethane, propane, butane and carbon dioxide) in real time and can provide this data to the operators of a liquefied natural gas (LNG) plant.

Deliverables

The project deliverables include:

- GQS installed at an LNG plant
- Three-month-long testing, and
- A Final Report detailing the project results.

Benefits

A real-time GQS can improve the ability to provide accurate monitoring of gas of different consistencies. Currently available technologies such as gas chromatographs and calorimeters are not capable of providing needed information quickly enough, have a relatively high first cost, and require regular calibration.

The GQS being developed in this project is targeted to be significantly lower in price than other sampling methods and require only initial calibration.

Specific advantages:

- The GQS needs to be calibrated just once for the application. User calibration isn't required.
- Simple to use; no special training is needed.
- Measurements can be taken at high gas pressures.
- Measurements can be taken continuously, allowing trending and controls operation.
- In-line configuration is possible.

Technical Concept & Approach

It has been shown that the GQS technology can be used to measure the air/fuel ratio in air/hydrocarbon gas mixtures delivered to combustion equipment. The accuracy of heating-value measurements made by this instrument closely matches those of a GC, but at a much lower cost. A laboratory evaluation demonstrated that the GQS is capable of continuously monitoring natural

gas heating value and composition with an accuracy of 0.5% and a response time of one second.

Specific tasks include:

- **Sensor Schematic and Procurement**

  During this task, researchers collaborate with utility representatives to develop a schematic of the GQS installation at the selected LNG plant or other facility. One possible location for the GQS was identified at an LNG plant.

- **Sensor Preparation and Calibration**

  During this task, the project team conduct the GQS modifications necessary to optimize the sensor for the natural gas operation. The sensor was originally configured for bio-gas. This modification includes a replacement of the spectrometer and a software upgrade. The sensor will be calibrated for the natural gas composition range typical for the gas supplied by the utility.

- **Sensor Installation and Testing**

  During this task, the project team will install the GQS at a selected location and set necessary software to enable remote control and monitoring of the GQS over the internet. The sensor capabilities of real-time monitoring of methane, propone, butane, and carbon dioxide concentrations in the natural gas as well the gas heating value will be demonstrated by conducting a three-month monitoring of the natural gas received by the LNG plant. The GQS testing will be conducted concurrently with gas chromatograph sampling at the same location.

Results

This project began in 2015, with activity initially focused on a design for the climate-controlled sensor enclosure. In 2016, the software was updated to enable collection of carbon dioxide data that is more accurate.

In 2017, the enclosure for the GQS installation was designed and fabrication of the full sensor inside the enclosure was initiated. The project team will use a mobile hot spot to collect and transmit data to during the demonstration period. Software integration was completed. A new spectrometer can read high wavelength data and, therefore, collect carbon dioxide data directly. Software was modified to collect and process this data.

The project team decided to add a duplicate sensor to the enclosure for the demonstration test. This provides the team with two sets of sensor data from a single demonstration project. The sensors are both inside the enclosure and connected in series. Acquiring a dual set of data would be an significant advantage toward having the GQS reach the commercial market quickly.

The project team completed sensor assembly and calibration in 2018. The second sensor, this one based on an interferometer detector, was installed in parallel. Details of the dimensions, utility requirements, and other aspects of the box (inlet and outlet ports, temperature range, etc.) to hold the GQS for demonstration testing were laid out. The heating and cooling unit is attached to the sensor enclosure. Data will be collected on a laptop computer in a separate enclosure and sent via phone link for collection and processing.

Testing began in 2018, but had to be halted due to the interruption of operations at the plant. Plans were to move the sensor to another facility in North Carolina in to complete testing.

Status

A Final Report is being prepared.

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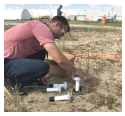
Remote Gas Sensing and Monitoring



Research is being conducted in an effort to develop a device to remotely monitor the level of gases during emergency situations and provide critical information to first responders and gas company personnel.

Project Description

During natural gas emergency situations, first responders need to quickly and efficiently assess the atmosphere within a building or confined space. In this project, researchers are investigating the use of wireless sensors that can be strategically placed to inform first responders of methane concentration. The device would provide critical information, allowing personnel to determine the concentration of methane inside buildings, sewers, and other structures from a safe distance.

This project is a continuation of a project supported by Gas Technology Institute's Sustaining Membership Program, which demonstrated the feasibility of using the Bluetooth Low Energy technology to relay data from multiple methane sensors to a central Windows device. However, there is some concern that the range may not be sufficient for all field conditions. Part of this follow-on work is to examine methods to extend the range and/or investigate wireless alternatives.

In Phase 1 of this project, researchers developed a local area network of methane sensors to assist leak investigators. The network employs off-the-shelf methane sensors, wireless technologies, and low-cost computing platforms. The communications is short range: from sensor node to sensor node and to investigators' handheld devices.

In Phase 2, hardware was modified to provide unattended methane monitoring. This monitor is placed in the vicinity of a suspected (or recently repaired) leak to provide up to five days of unattended monitoring. Placement of the device would be at the discretion of the investigator, determined by the hazards at a particular site.

The objective of Phase 3 was to develop a system to allow a leak investigator to remotely monitor methane levels at multiple points within a site under investigation. The investigator uses a tablet or phone to see the gas values in real time. Phase 3 involved field tests of the prototype system.

The current Phase 4 focuses on the development of a pre-commercial-ready units that can be tested by sponsors at actual leak sites.

Deliverables

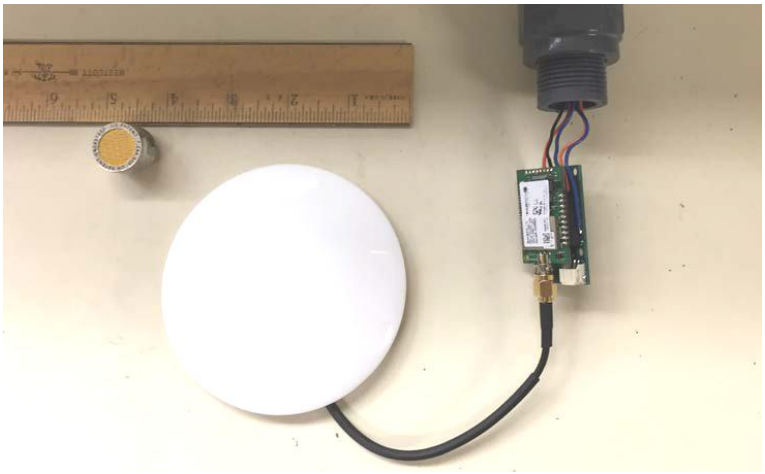
Deliverables include the development of wireless sensor nodes that can detect methane. The project team also developed mesh networking for seven sensor nodes with 100m node-to-node spacing indoors with obstructions. Each sensor node serves a webpage via WiFi that contains the data from all of the sensor nodes. Any mobile device adjacent to any sensor node can see the data.

Deliverables from Phase 3 include demonstrations of the prototype system and a report that captures the field-demonstration data, user feedback, and needed modifications.

Benefits

The safety of workers, first responders, and the general public will be increased by being able to monitor methane concentrations remotely. In addition, continuous remote monitoring of various gas levels during known gas leak situations will allow for better and quicker analysis of the situation. The remote sensors can be placed and/or operated in the area of the known gas leak.

Networked methane sensors.



Antenna used in testing.

Technical Concept & Approach

To improve the functionality of the device, researchers are developing a custom hardware/software solution comprised of a multiple-sensor system and a mobile monitoring device to improve the range and data connectivity of the wireless sensors.

The tangible objective is to produce a prototype of a system to be used by leak investigators and first responders. It will consist of multiple wireless sensor nodes that can be distributed over a site under investigation. The wireless connectivity will be such that the investigator will be able to simultaneously see the data from all nodes using a smartphone or tablet as the interface device.

Demonstrations of the system were performed at test sites to determine if it is a good fit for normal leak-investigation practice. The initial goal of the demonstrations was to allow utility operators to use the equipment under direction of project personnel.

A manufacturer of leak-survey equipment has expressed interest in the meshed network system. The project team will determine a path to commercialization for the networked methane detector for first responders.

Results

During Phase 1, the project team developed a set of wireless methane sensors that communicate with one another via a wireless mesh network. Researchers demonstrated the system at several OTD meetings. Subsequently, separate field tests were conducted in 2017.

The prototype system is able to measure methane concentration, temperature, and humidity at multiple points within an area and provide this data to the investigator through a phone or tablet.

The unattended methane-monitoring system consists of multiple sensor nodes that communicate wirelessly with a base station. The sensor nodes were mechanically configured to be inserted into a barhole with minimal exposure above ground. The base station can capture data from nearby sensor nodes, store it, and forward it wirelessly to a server. The data from the sensor nodes is exposed as a web page that can be viewed by any device with internet access. This allows one to check on the methane levels on a site remotely.

For the Phase 1 prototype, each node had access to data from the other active nodes in the mesh network. The mesh allows 100-meter maximum spacing between nodes and supports message relaying to maximize the area that can be monitored. For the Phase 2 prototype, a long-range radio system was adopted that does not require personnel to be present for reading, allowing unattended operation.

Three test sites were offered by the sponsors for field demonstrations in 2018. In all cases, the prototypes were demonstrated in a training facility. This allowed the test conditions to be well controlled. It also allowed the greatest number of utility personnel to participate in the demonstrations and provide feedback on the prototypes.

Status

Devices are being tested and deployed at an actual utility construction job site where new transmission lines are being installed. The data from this test will provide information on the performance of the devices for a longer-term deployment use case as well as provide important user feedback for the commercializer.

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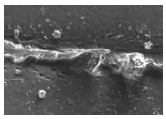
Evaluating Leaks from Slow Crack Growth and the Impact on Pipeline Emissions



This project involves an evaluation of how a leak evolves over time due to slow crack growth (SCG). The objective is to gain a better understanding of how SCG contributes to methane emissions from distribution pipelines.

Project Description

One of the main sources of leaks in vintage plastic pipe is from slow crack growth (SCG). However, it is not known if leaks that develop in vintage plastic pipes remain stable, or if the leak rate increases or decreases over time. This new project will provide information regarding the axial growth of a through-wall crack over time, thus helping to complete a model for crack evolution over time.

The current Phase 1 effort focuses on a first-level understanding of how a crack grows in a specific material given different stress conditions and seasonal changes in ambient temperature.

Future phases will focus on developing a more detailed understanding of multiple factors on the evolution of the leaks over time. These additional factors include: gas constituents, soil type, soil condition, burial depth, soil compaction, pipe size, fitting configurations, and temperature.

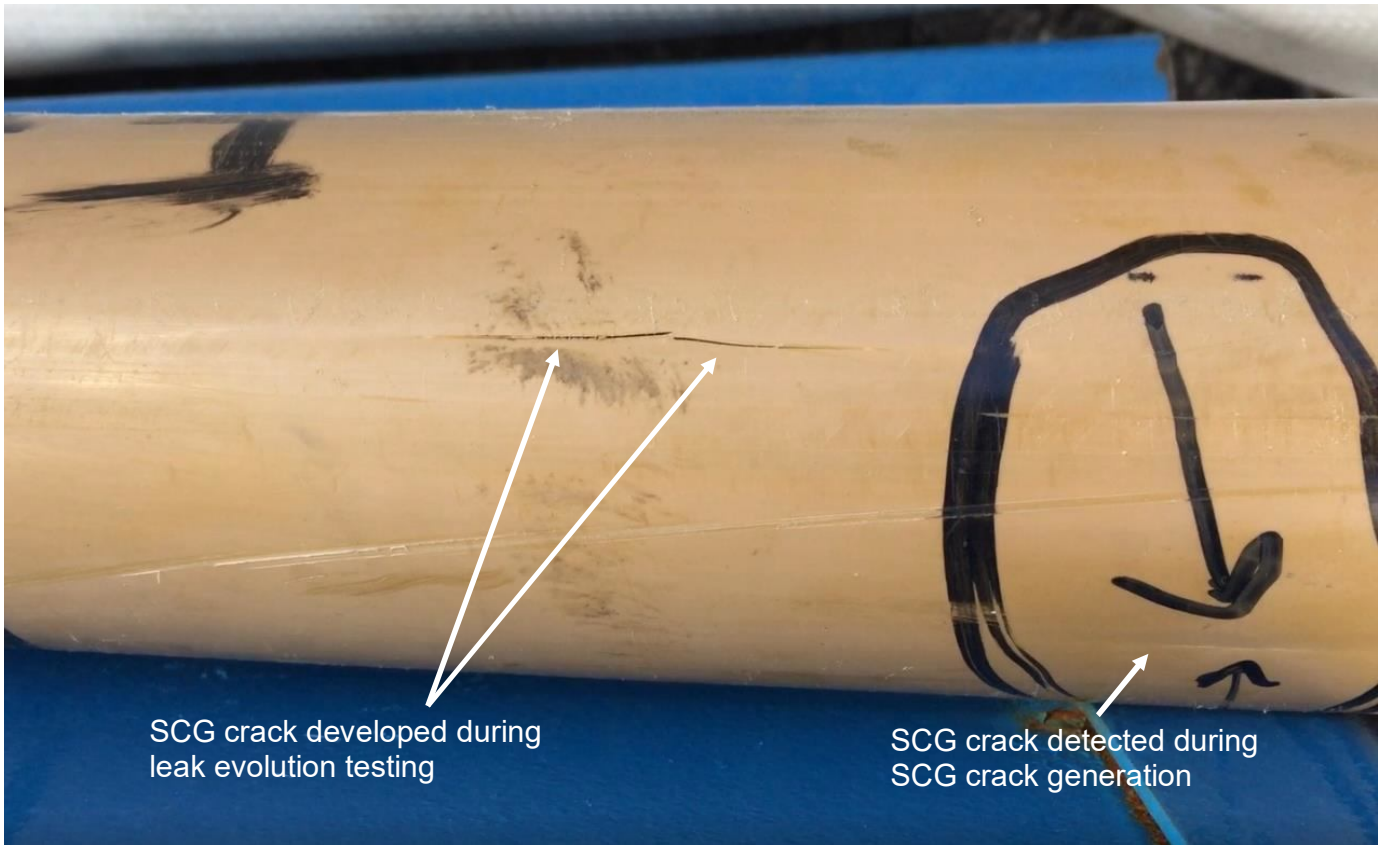
Deliverables

Deliverables include reports detailing testing results and findings, specifically the rate of crack growth as a function of time and seasonal temperature variation.

Benefits

A proper understanding of how leaks tend to develop over time will assist in determining how leak rates change and contribute to overall methane emissions from distribution pipelines. A well-formulated investigation of the various interactions between installation conditions, system pressures, pipe/fitting assemblies, and environmental conditions will be invaluable in developing a framework for more accurately estimating emissions.

Data from this study will provide information that utilities can use to improve leak-repair practices and procedures; therefore, reducing overall emissions.



Technical Concept & Approach

Pipes up to four inches in diameter and two different types of fittings (couplings and saddle tees) will be exposed to hydrostatic pressure testing. Testing will be performed at an elevated temperature (80°C or 90°C) and stress combination to ensure that slit failures are induced. A total of 18 specimens with SCG will be prepared. As soon as the specimens exhibit through-wall cracks, they will be removed from test.

A specially developed leak-flow-rate test rig is enclosed in an outdoor facility. The facility includes equipment and hardware to supply the continuous flow of air and to allow for continuous monitoring and acquisition of data. A by-pass system to allow for the flow of methane is incorporated for the periodic measurement of methane leak rates. Conducting the experiment in this manner eliminates the need for a complex compressor system and the associated safety measures needed for the continuous circulation of methane.

Two stainless-steel chambers were built, each one large enough to house up to nine four-inch pipe/fitting assemblies. Each chamber is arranged for the continuous flow of air through nine individual specimens. The specimens will be placed at the bottom of each chamber built and buried in two feet of soil. Air will continuously flow thorough the specimens at three different set pressures. The leak rate through each specimen will be continuously monitored and recorded by means of an instrumented data-acquisition system for 10,000 hours. Leak rates through the soil will be determined by switching the source gas from air to compressed natural gas, applying pressure to an individual specimen, and then using a Hi-Flow Sampler to measure the leak rate.

Potential follow-on phases could include efforts to:

- Expand the experimental data set to additional soil types and conditions
- Conduct experiments at controlled temperature and pressure conditions to substantiate the time/ temperature superposition principles needed to map experimental results to field conditions, and
- Develop a probabilistic model to allow operators to infer the expected leak evolution rate for a leak location given current measurements and additional system knowledge related to the likely pipe, fittings, and burial conditions at the location.

Results

The project team initially designed a leak-evolution test rig and software for the rig. The rig is used to generate pipe samples with small SCG leaks.

Specimen tub.

The generation of pipe samples with SCG leaks began in 2017. In 2018, three samples were put on test at 60 psig with no soil around the samples. One of the samples immediately developed a large leak (>10 SCFH) and was taken off test. The other two samples remain on test. Upon inspection of the sample, it was found that it developed a large SCG axial crack that did not breach during the SCG leak-generation phase, but manifested as soon as the leak-evolution testing began.

It was found from ongoing tests that the average leak rate of samples can vary between pressurization cycles, therefore, the project team develop data post-processing methods for extracting the leak rate of a sample over time and verification of the flow meter readings.

A proposal for Phase 2 of this project was presented to OTD to continue testing pipe samples generated in Phase 1.

Status

Current activities are focused on:

- Completion of the fabrication of specimen tubs
- The performance of flow meter reading verification
- Continued testing with samples already on test
- Leak-evolution testing on all stations, as per test the planned matrix, and
- Complete evaluation of rings taken from all the pipe specimens.

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Leak Repair Prioritization

Researchers are developing a method of prioritizing nonhazardous leaks, allowing utilities to schedule the repair of leaks based on scientifically sound practices addressing the most critical leaks first.

Project Description

In the natural gas industry, there is considerable regulatory pressure for utilities to prioritize the repair of leaks in order to minimize methane emissions to the atmosphere. However, current methods of measuring leak rates in the field are cumbersome and improved methods are still under development.

The Hi-Flow Sampler™ is commonly used to measure emissions. With this system, measurements can take from 30 to 45 minutes per leak to accomplish. Gas-imaging cameras have the potential to be used to quantify emissions; however the cameras currently on the market are expensive ($75,000-$100,000). Additional field leak-rate-measurement tools are under development, but are not immediately available in the market.

In the absence of available quantification tools, a method to prioritize leaks in a way that provides a relative ranking of emissions (low, medium, high, etc.) is needed. Such a method would enable utilities to repair the most significant leaks, thus allowing operators to systematically reduce their overall emissions profiles.

The goal of this project is to develop a method of prioritizing nonhazardous leaks – using tools that utilities already commonly own – so that once all safety factors are considered, utilities are able to schedule the repair of leaks that are emitting the most methane to the atmosphere.

Enclosure used to determine the leak rate to validate the new methodology.

In Phase 1, a significant correlation was observed between surface concentrations and emission rates in both sandy and clay soils. The current Phase 2 focuses on testing additional surface types. An emission rate conversion chart will be refined to include the calibration of low, medium and high, leak rates.

Deliverables

Deliverables include:

- An expanded technique for leak repair prioritization over expanded soil matrices
- A technique for leak repair quantification over cracks in pavement and bar holes
- A revised emission rate conversion chart or charts depending on findings for soil type and bar hole/ pavement testing, and
- A Final Report

Benefits

Developing a method that utilities and leak-survey crews can easily employ to provide a relative ranking of methane emissions will allow utilities to prioritize leak repairs based on not only safety but also environmental impacts.

Repairing the largest leaks will increase the reduction in methane emissions and improve the utility's overall carbon footprint.

Studies reported that less than 2% of distribution pipeline leaks measured in the studies accounted for 50% of total emissions measured. Being able to identify these and prioritize these leaks for repair can result in meaningful reductions in methane emissions.

Technical Concept & Approach

The intention of the prioritization method is to utilize tools that companies already have or can easily acquire. For this project, researchers are developing a method

for a field survey crew member to use to quickly analyze a leak site and gather a couple of data points (concentration, wind speed, area, etc.) to make a coarse determination of leak rate. This leak flow rate will be a rough estimate with the sole objective of categorizing or ranking the leaks. Once a conceptual method is developed, researchers will validate the method through backyard testing. A leak site will be developed and the method will be tested with a variety of leak rates and environmental conditions. The leak flow rate utilizing the conceptual method will be compared to the leak rate measured using the Hi-Flow Sampler.

In Phase 2, soil testing at utilities will be obtained using the methodology created in Phase 1. The effectiveness of the method will be validated against traditional quantification methods. Bar hole and pavement testing will also be conducted.

Results

Researchers investigated concentration readings and estimated leak area and compared that to the leak flow rates measured by the Hi-Flow Sampler. While little correlation was initially found on measurements taken using the Sampler pool enclosure, there was a stronger correlation on measurements taken using the cone enclosure when capturing the leak surface area. This could be due to less variability between the actual leak area and the covering device (i.e., the pool may have been a much larger area than the actual surface presentation of the leak). The project team will examine this during testing by matching the covered area more precisely to the leak area.

Given the initial findings, researchers determined that a careful characterization of both the concentrations around the leak and the leak area itself could potentially be used to crudely characterize or estimate leak rates in the field. Subsequently, the project team initiated an analytical setup of areas where researchers can generate below-ground leaks in plastic pipe buried in sand and silt soil types to test the potential method.

The field test site includes a way to control the size of an underground leak in sand and clay via fine control of the natural gas feed pressure. Engineers also designed and built a movable grid that will be used to assist in the collection of concentrations across the leak spread area. This will help to establish if there is any correlation between concentration and emission rate.

Researchers established the ability to create and control a belowground leak in sand. The test setup allows for the measurement of the leak with the laminar flow element to know how much gas is flowing from the leak. This is used only as a reference. Researchers use the Hi-Flow Sampler to measure the flow rate of the surface expression of the leak.

In 2018 testing, a significant correlation between leak rate and mean concentration emerged from the data collected. Controlled leaks were set within a range of rates from 0.002 to 0.14 cfm of methane. The gas was released from a pipe buried in sand and all the readings were taken in the area just above the leak where the highest concentrations of methane presented at the surface. A total of 35 individual data points (different leak tests) were recorded. Thirteen surface concentration readings were recorded across the leak-measurement area.

The leak survey wand was used to mitigate the effects of wind. The part of the tool in contact with the ground was flexible and allowed for a seal at the point where the concentration was taken. The tool was kept at each point for 40 seconds and the measurement was taken once the concentration reading stabilized. After concentrations were measured, a fan was placed inside the surface delimited by the squared structure and the area was covered with a plastic tarp. The volume between the tarp and the surface was sealed with a chain around the structure.

Leak testing was completed in sandy soil. The linear correlation value indicates that there is strong correlation between the leak rate and the concentration of gas at the surface of the leak. For environmental testing, this relationship is remarkably high and gives the project team confidence that at least in sand the method can be used to qualitatively say that one leak is larger or smaller than another leak.

Further evaluation of leaks in other soil types, as well as under pavement sections are being incorporated in Phase 2.

Status

Testing for Phase 1 was completed and a Final Report is being prepared. Phase 2 is under way.

Soil, bar hole, and pavement testing at utilities is being coordinated.

Researchers are developing a sampling plan for unpaved, unpaved/barhole, paved, and paved/barhole situations.

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Evaluation of Gas-Imaging Technologies for Utility Applications

In this project, researchers are evaluating the use of gas-imaging technologies for various applications in the gas industry, including the use of these tools for methane emissions quantification and as a tool for first responders during leak investigation and grading.

Project Description

With increased pressure to reduce methane emissions from the natural gas industry, measuring leak rates and quantifying emissions have become increasingly important to utilities. Various regulations at the federal and state level are requiring the reporting of greenhouse-gas emissions, and better tools are needed for measurement. While there have been several past OTD projects focused on developing and evaluating methane detection tools for leak-detection and leak-surveying applications, there has been limited focus on tools for the measurement and quantification of emissions.

Gas-imaging cameras will allow for the quantification of leaks that may not be as easily accessible (i.e., in the roadway or places that may otherwise require traffic control). These cameras also allow potentially dangerous leaks to be monitored from several meters away, which may be beneficial for safety reasons depending on the leak site.

One of the most commonly used gas-imaging cameras in the industry today is the forward-looking infrared (FLIR) camera. The infrared camera can rapidly scan large areas and identify leaks in real time. It is ideal for monitoring plants that are difficult to reach with contact measurement tools. Another gas-imaging technology involves a video camera that monitors, quantifies, and displays explosive/harmful gas leaks in real time. The imaging technology uses spectral data for automatic detection and quantification of methane leaks. The company has plans to miniaturize its system to provide a lightweight, battery-powered, automated, lower-cost version.

The objective of this project is to evaluate these and other gas-imaging technologies for various applications in the natural gas industry. Specific applications will include the use of these tools for methane emissions quantification (e.g., measuring leak rate) and as a tool for first responders during leak investigation and grading.

Deliverables

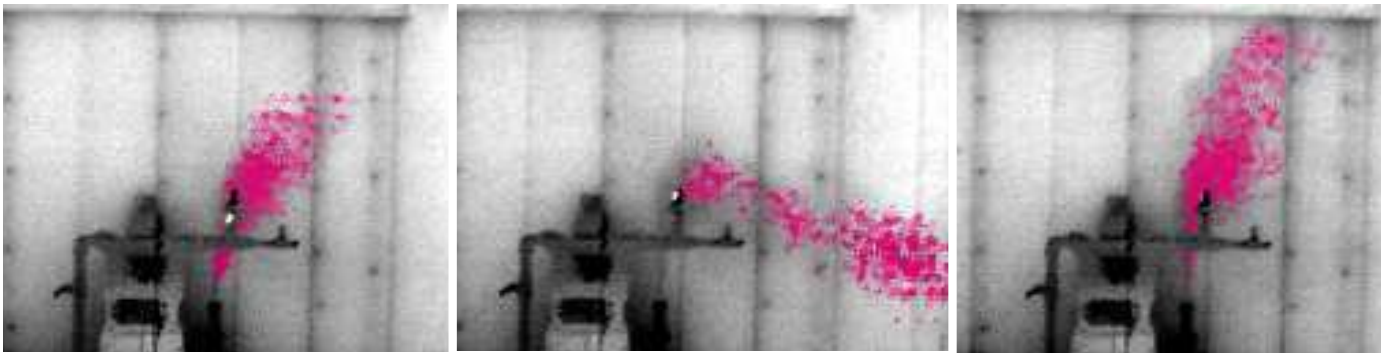
The following deliverables are anticipated from this project:

- Quantitative measurements of methane leak rates using selected gas-imaging technologies.
- A Final Report summarizing the data from the technology evaluation and field demonstrations. This report will enable operators to determine if the use of gas-imaging cameras is a viable option for identifying gas leaks and quantifying methane emissions.
- Recommendations for the manufacturers.

Benefits

Gas-imaging technologies can have the ability to provide for the detection and identification of leaks, as well as enable the quantification of leak flow rate. This

Testing at the GTI pipe farm.



Laboratory testing images.

results in increased safety for customers and utility employees along with added environmental benefits associated with leak repair and/or pipe replacement programs.

Gas-imaging cameras can reduce the time required to obtain a flow rate, enabling utility companies to collect emission rate data from every leak if so desired. Gas-imaging cameras can also help in the leak-investigation process as methane plumes can be visualized and used as an aid in investigating difficult-to-pinpoint leaks. The leak flow-rate information could then be used as a secondary factor (primary factor being safety) to develop leak-repair prioritization plans. As a result, emissions can be optimally reduced while maintaining a safe infrastructure.

Technical Concept & Approach

In this project, controlled tests are performed comparing the performance of the gas-imaging cameras to traditional leak-rate-measurement tools.

A testing matrix was developed to determine the parameters and evaluation conditions for the gas-imaging cameras. These include: distance from the leak, leak rate, leak area, leak source (e.g., pipeline leak, meters), temperature, and other environmental conditions.

Controlled testing is performed in an outdoor setting at Gas Technology Institute's pipe farm. The measurements from the gas-imaging cameras are validated using the Hi-Flow Sampler™ as the reference technique.

Pending the results of testing, two field demonstrations will be conducted with utilities on actual utility leaks. Demonstrations will help to determine the utility applications appropriate for using gas-imaging tools. Technologies will be tested on various types of leaks and leak sources.

Follow-on research could include evaluations of less expensive and more "field-ready" devices that manufacturers are currently developing.

Results

Testing focused on understanding the limits of gas-imaging technologies with regards to quantifying leaks under the following conditions: diffuse leaks in sand (i.e., spread over a large area), point-source leaks, diffuse leaks in clay soil, and diffuse leaks in silty soil.

Leaks were created and the performance of each unit compared/validated with other tools that have similar detection limitations.

In 2019, researchers provided a complete analysis and summary of two new cameras. Technologies were tested with a spoke test modified from the techniques used in the OTD laser point-and-shoot project and from scans of compressed natural gas fueling stations and natural gas customer meters.

One camera is used extensively in upstream leak detection and repair programs as it can be used as an alternative work practice specific to optical gas imaging for regulatory scans of equipment. The camera is robust and provides locating and visualization of larger leaks.

The other technology is is a methane-specific uncooled camera. The uncooled nature means the camera starts up instantly; however, the uncooled detector is approximately five times less sensitive.

Researchers found that both cameras performed well under specific use cases (which were larger pinhole leaks on above ground assets).

Status

Researchers continue to monitor for possible equipment to test.

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Implications of Odorant Dispersion in a Natural Gas Pipeline

In this project, research is focused on addressing several issues associated with odorant dispersion, including odorant permeation, odorant injection, and samplings points.

Project Description

In 2015, The Plastics Pipe Institute (PPI) published a revised technical note (TN-4/2015 *Odorants in Plastic Fuel Gas Distribution Systems*), recommending that odorant never be introduced into a plastic pipe system in a concentrated liquid state. The concern is that it will act in the same manner as liquid hydrocarbon (HC), with permeation resulting in weaker and softer material relative to non-permeated material.

Currently, no guidance exists to inform operators where to place an odorant injection point in relationship to a transition to plastic pipe or elastomers (valves, couplings, etc.). In general, the location must be far enough downstream to properly mix the odorant with the gas so that no liquid remains downstream of the injection point. In addition, the concept of odorant permeation into plastic pipe is disputed by some operators.

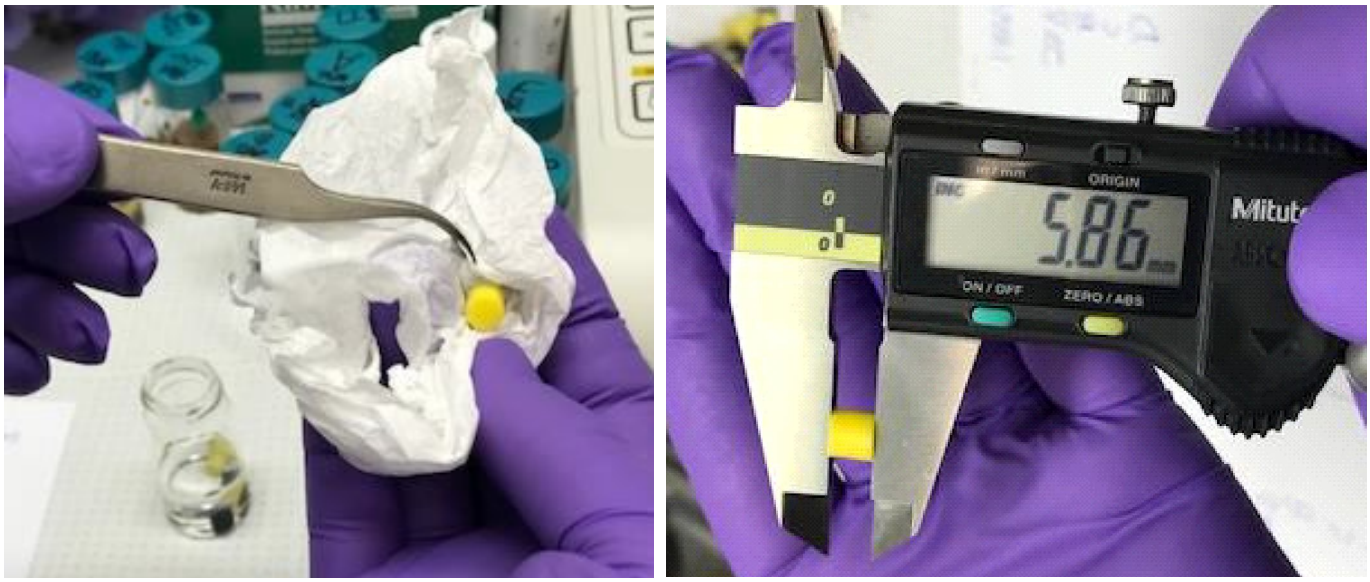
In December 2015, a three-year project invesetigating the effect of heavy HC permeation on plastic pipe fusibility and strength concluded that HC-permeated materials are up to 55% weaker at low strains relative to non-permeated material. This project was sponsored by the U.S. Department of Transportation's Pipeline and Hazardous Materials Administration (DOT/PHMSA). The scientific data supports the anecdotal information that formed the basis of PPI's technical note regarding liquid odorant exposure.

The two most common types of odorizers used in the natural gas industry are based on liquid injection and absorption/vaporization. In a liquid-injection odorizer, the odorant is directly introduced into a gas stream with a liquid drip or injection device. Vaporization odorizers direct a stream of gas across a pool of odorant that acts to volatilize the odorant into the gas. This stream of gas can be a bypass or slipstream. Both of these types of devices are in use today, depending on the needs of the operator. But the question that has not been answered – especially for the odorizers based on liquid injection – is where to optimally place plastic pipe and polymers downstream from the injection point.

The PPI technical note states that: *"Odorants should never be introduced into a plastic pipe system in a concentrated liquid state."* Neither the 2000 AGA Odorization Manual nor the 2016 update mention plastic pipe or polymer locations, although the 2016 update does reference the PPI technical note.

The technical objectives in this project are to determine:

- How far downstream of an odorant injection point any transitions to polyethylene (PE) pipe or polymer materials should be located
- The proper location for a sampling point for odorant concentration and odor monitoring, and



Samples are dried (left) before dimensioning (right).

- If and to what extent an odorant absorbs into a polymer matrix.

Deliverables

Deliverables include: A table with recommended sampling points for various pipe diameters and flows; absorption and desorption data to support the impact of odorant on the polymer materials; and a Final Report with summaries and recommendations.

Benefits

Knowledge of where polymeric materials may be properly located in a gas pipeline system and not be subject to liquid odorant permeation will improve the integrity and safety of the PE pipeline infrastructure. Integrating this information with sampling-point recommendations and knowledge of odorant-permeation rates would provide operators with data to make informed decisions regarding odorization-dispersion issues in specific systems.

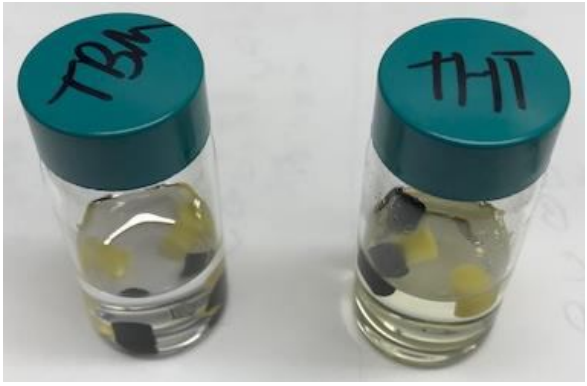
Technical Concept & Approach

Initial tasks included a gap analysis to ensure the appropriate direction and focus for modeling and testing efforts.

The project team is modeling vapor and mist dispersal within the pipeline using ANSYS® Fluent®, a fluid-flow simulation software package. This software contains the broad physical modeling capabilities needed to model flow, turbulence, heat transfer, and reactions for a variety of industrial applications.

A typical injector odorizer will be simulated to model what happens to the vapor or mist as it is dispersed into the pipeline. Six distinct pipe diameters (two-inch to 24-inch), three standard flows, and two sampling points (center and edge) will be used, totaling 36 conditions for a given odorizer and odorant combination. Both t-butyl mercaptan (TBM) and tetrahydrothiophene (THT) will be considered. A two-phase model setup will provide insight into the dispersion of the vapor within the natural gas stream.

To address the odorant-permeation issue, researchers will test the rates of absorption and desorption into and out of selected materials used in pipelines under ambient conditions. The materials will be saturated and micro-tomed into four slices, which will each be used to detect odorant concentrations from a gas chromatography headspace analysis. A curve will be generated to demonstrate absorption and desorption trends in the materials over time.



Material samples soak in TBM (left) and THT (right).

Headspace gas chromatography was selected as the technique to detect odorant concentration. A sample is sealed in a closed container and heated to evolve the hydrocarbons present. The air volume in the container is pressurized to a known pressure and sampled through a heated transfer line to a gas chromatograph (GC).

Results

All odorant absorption and desorption experiments are complete. Absorption testing for water for was completed with no absorption noted. The amount of water absorption into the rubber specimens is considerably less (3-4 orders of magnitude) than what was observed for the odorant absorption. The time frame for absorption of water is much longer than for the odorant.

The data continue to consistently show a bigger impact from THT over TBM in weight gain and GC headspace concentration. The THT desorption data appears to be on the same time scale as the absorption process.

The modeling effort was initiated using a surrogate compound to verify that the model scheme is correct.

The complete set of odorant properties required for the simulation were not found using literature sources, even after a comprehensive search. The project team ultimately calculated them from ASPEN Properties.

Status

Modeling efforts are on-going. Geometry creation and meshing of the different pipe sizes for simulation is in progress to determine the mixing length for the two odorants.

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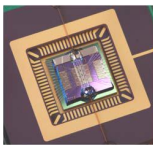
On-Line Biomethane Gas Quality Monitoring



For this project, research was conducted to determine if on-line monitoring systems can be used to ascertain key parameters in biomethane being blended into the gas distribution system. The focus was on those constituents that are not routinely monitored by on-line instruments but are critical to gas quality.

Project Description

The introduction of fuel gases from a variety of different sources is becoming more prevalent as states become more aggressive towards incorporating renewable energy into their energy portfolios. Projects focusing on renewable energy also represent important steps to addressing increasing climate challenges. For example, the California Air Resources Board is recommending methane emission mitigation strategies that include the conversion of agricultural and landfill waste into biogas or renewable natural gas. Food waste is also being proposed as a next-generation anaerobic digestion matrix.

Many of these gas sources have different trace chemical constituents from those found in natural gas. The need to understand the composition of these gases is increasing as the frequency of their introduction into the pipeline system grows.

The focus of this project is on those constituents that are not routinely monitored by on-line instruments but are critical to gas quality. The emphasis is on systems with lower cost and shorter analysis times than current techniques.

Deliverables

Deliverables include:

- A Task Summary Report to provide guidance on how to monitor the concentration of critical trace constituents in a renewable natural gas stream that are not already being routinely monitored, and
- A Final Report that includes recommendations for any follow-on activities, including a cost estimate, schedule, technology development team, and parameters for the design of an alternative analytical package if none are found available.

Benefits

Monitoring the concentration of critical constituents in the gas stream provides the industry with the capability of protecting valuable underground assets, delivering gas that meets end-usage requirements, and protecting human health.

Setup to spike siloxane in methane gas.

On-line instrument packages are a benefit to both the gas company and the supplier. Results are instantly available instead of having to wait days or weeks for an off-site laboratory analysis. With on-line capabilities, response to conditions could be immediate.

Technical Concept & Approach

In this project, researchers conducted a technology assessment of currently available and emerging technologies for their ability to determine the constituents of interest. These included micro-gas chromatographs, optical spectrometers, and mass spectrometers, but also included technologies that are currently being developed by private companies and universities. The focus was on low cost and quick data turnaround.

Technologies were assessed for their analytical characteristics (what components they could analyze and detection limits), their sampling characteristics (sampling pressure limits, scan time, and emissions), and their operational characteristics (availability, cost, consumables, maintenance, and packaging).

Results

This project developed a survey to determine the biomethane constituents with the highest risk and greatest need for on-line analysis. Five constituents were chosen based on survey feedback and expert knowledge:

- BTEX (Benzene, Toluene, Ethylbenzene, and Xylenes)
- n-Nitroso-di-n-propylamine (and other amines)
- Siloxanes
- Organic arsenic, and
- Halogenated hydrocarbons (e.g., vinyl chloride).

All of these constituents have been found in raw biogas samples from previous projects and the literature, and their presence should be avoided in biomethane.

A market survey and literature review was conducted to cover both commercialized and un-commercialized sensors for this application, looking at market-available analyzers and emerging sensors. Each technology's potential was assessed by direct correspondence. The review identified technologies are available with features such as on-line and automated sampling, low errors, and robustness to a natural gas medium are possible.

The conventional sensors include mass spectrometers, Fourier transfer infrared spectrometers (FTIR), near-infrared spectrometers, gas chromatographs, micro-gas chromatographs (μGC), photo-ionization detectors, flame ionization detectors, thermal conductivity detectors, chemical resistance, and colorimetry. New, disruptive innovations have entered the market and show great promise. Some companies deliberately designed their sensors for biogas analyses to enter the biomethane-sensing industry. Recent technologies include a nano-metric resonating sensor coupled with a μGC, a proton transfer reaction mass spectrometer, an ion mobility spectrometer, a vacuum uv-vis spectrometer, a quantum cascade laser infrared spectrometer, external quantum cascade laser cavity ring-down spectrometers, and an FTIR photo-acoustic detector.

Phase 2 of the project began in 2018. Researchers selected the compositions of the four artificial standards for investigation. The standards gases contain 10 of the 13 components in the baseline standard, 10 of the 25 for the low standard, 16 of the 25 for the medium standard, and 17 of the 25 for the high standard. The remaining gaseous components will be spiked by gas blending using a gas blender or headspace injection.

The project team finalized protocols to prepare the standards by partial dilution and completed prepared the facility for trimethylarsine (TMA) gas analysis.

The research team completed investigating the effects of the sampling cylinder temperature on siloxane stability and completed experimenting with valve outlet pressures, which support a higher correlation.

In 2019, researchers validated the identity and concentrations of all components listed on the Certificate of Analysis. The project team secured a portable sensor to safely handle high levels of TMA in the laboratory. The team also received a customized sampling cylinder regulator and started re-trialing the siloxane stability study.

Status

The following activities are planned:

- Conduct stability study at high levels
- Complete re-trial of siloxane stability study
- Complete method development for TMA gas analysis
- Complete sample containment study of TMA, and initiate comprehensive stability test with all components.

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Investigation of State-of-the-Art Methane Sensors

In this project, researchers investigated the current state of the art in "point" methane sensors and how they are used in the utility industry. A gap analysis was performed and sensors may be selected for further investigation.

Project Description

With the increased awareness and scrutiny of methane emissions, there has been a corresponding increase in methane sensing and alert technologies.

Sensing technologies investigated with OTD support have included laser-based sensors, optical imaging techniques, and MEMS (Micro-Electro-Mechanical Systems)-based methods.

The objective of this project was to investigate the current state of the art in "point" methane sensors and how they are used in the utility industry. A gap analysis was performed and sensors may be selected for further investigation.

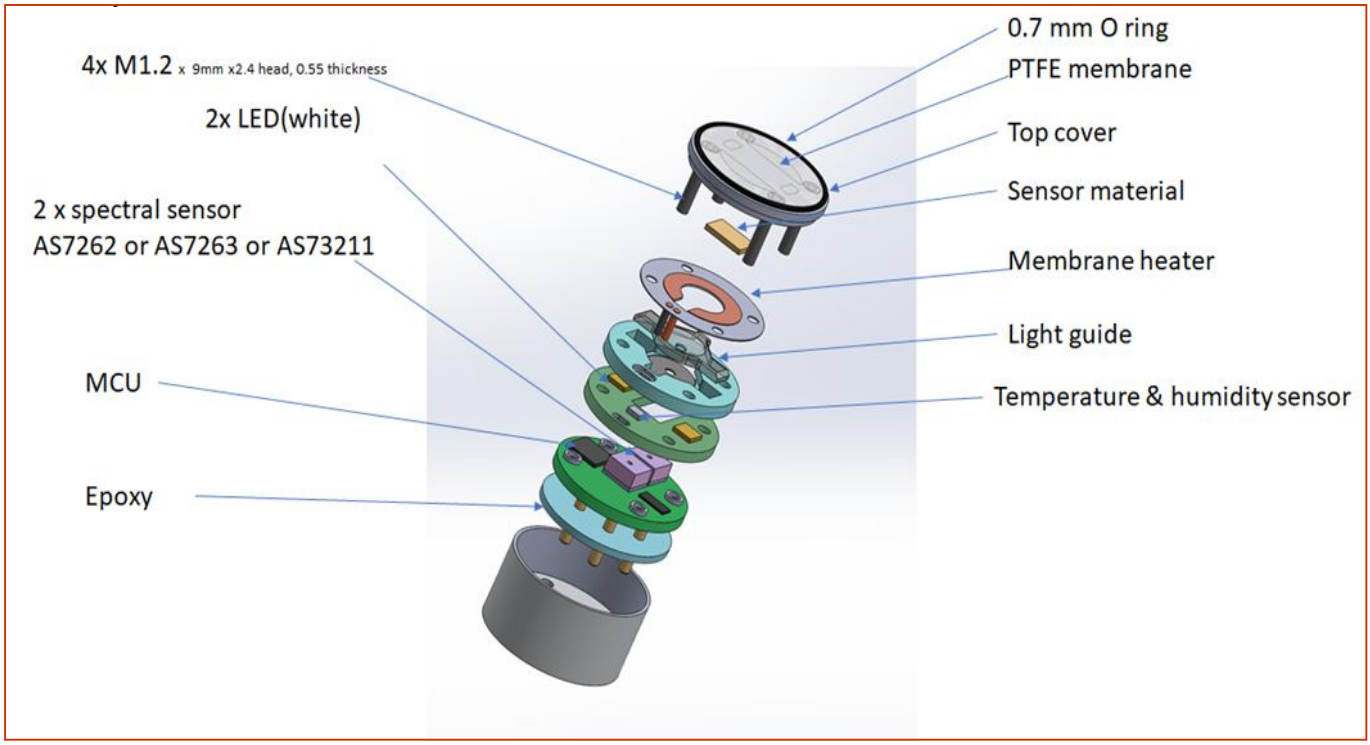
Deliverables

A detailed set of use cases for methane sensors relative to leak investigations and other utility activities was developed. These include the business objectives and regulatory drivers for the activities. The technical requirements for the methane sensors needed to carry out these activities were developed. The current equipment used, its costs, and the levels of sponsor satisfaction were also captured.

An analysis of the use cases and requirements was performed to determine if there are technology gaps that need to be addressed. The intent is to identify gaps in sensor technology, but others may be found. The project team will develop sample sensors, which will undergo independent verification testing.

Benefits

The value of this research effort will be derived by correlating the current (and possible future) uses for methane sensing in the sensing in the utility industry with the various technology solutions and their associated costs. This will provide a roadmap to determine if there are applications where new or disruptive sensing technologies can provide greater value than current practices.



Technical Concept & Approach

Specific project tasks included:

- **Requirements Analysis and System Design**

  An analysis of the requirements of use cases and documentation for business rules, system features, use cases, specifications, activity models, and domain topics. The project team also developed a set of models and documents which express the sensing and data requirements for the utility use cases. As a part of this task, the current study of the state of the art in methane sensing, as applied to the utility use cases, was carried out.

- **Optional Evaluation of Sensor Technology**

  The project team evaluated a methane-sensing technology that was brought to OTD for consideration. The decision to evaluate the technology will be based on how well it aligns with the use cases and/or technology gaps.

Results

In 2017, the project team issued a preliminary analysis document that includes a review of current methods of methane detection/measurement, sensor technology, early-stage methane-detection technologies being developed under the U.S. Department of Energy (DOE), technology gaps, sponsor input on areas of interest, and applications for new sensors/technologies.

There currently are numerous ways to measure methane concentrations in ambient air. However, important gaps in sensitivity and cost still exist and the development of an inexpensive methane sensor has a number of barriers. First, in order for a sensor manufacturer to realize a profit from wholesale production of a cheap sensor (less than a few dollars), there must be a significant number of the sensor sold. Second, results from the sensor must be reproducible, otherwise the cost of making the sensor precise and accurate (e.g., through extensive calibrations) must be factored into the cost of the sensor. Production of an inexpensive sensor for which each individual unit produced must undergo significant calibration and testing may negate the potential cost benefits. Third, production of the sensor is a very small piece of the puzzle and the required cost of obtaining and interpreting the data (i.e., through complex detectors, cameras, and software) produced by the sensor should be built into the overall cost of the sensor.

Research found several new types of sensors currently under development, including nanotechnology-based chemical sensors (which are claimed to be able to offer high-sensitivity, low-power and low-cost capabilities); phage/colorimetric materials that react to a particular chemical species by changing color; and polymer absorption sensors. The DOE's Advanced Research Projects Agency – Energy (ARPA-E) created a program called the Methane Observation Networks with Innovative Technology to Obtain Reductions (MONITOR) to develop new technologies. The ARPA-E MONITOR program recently funded a suite of projects to develop new sensors. The technologies are largely focused on the upstream on well-pad operations; however, it is possible that these technologies may be useful downstream to distribution companies.

One manufacturer is still fine tuning the hardware as well as firmware. They have sent out the latest iteration of their design to the manufacturing supplier. The company will follow up with the timelines for two different units (integrated detector vs. sensor module) with timelines for testing.

In 2019, researchers updated the original 2016 report to include new sensors, systems, and solutions that have been developed.

Status

This project has been put on hold and is being reevaluated. A Final Report is being prepared and will be completed in 2020.

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Distribution System Characterization

Research is being conducted in an effort to improve the characterization of emissions from the natural gas distribution system, specifically emissions from industrial meters, plastic pipelines, and plastic-lined steel/cast-iron pipes.

Project Description

The objective for this project is to develop the most current and complete information on methane emissions from industrial meters, vintage pipe, and plastic-lined steel/cast-iron pipe. The goal is to move toward a more accurate quantification of all U.S. methane emissions and an efficient reduction of emissions from the U.S. natural gas industry.

There have been several national and state studies that developed emission factors for various sources within the distribution system, with some studies focused on underground pipelines with emission factors developed based on material type. In order to improve the characterization of emissions from the distribution system, additional field data is needed for several sources, including industrial meters and vintage plastic pipelines (vs. new plastic). Having a more defined breakdown of emissions will allow for a more detailed quantification and reduce uncertainty in the Greenhouse Gas Inventory (GHGI) of the Environmental Protection Agency (EPA).

A key aspect of this project is to develop an understanding of the frequency of large emissions from these sources so that they can be accurately accounted for in the GHGI. Previous studies demonstrated that a few large leaks can account for as much as 40% of emissions.

The specific area of interest in this project involves efforts to improve the characterization of emissions from industrial meters in the natural gas distribution system. These meters are not currently calculated as a distinct source in the GHGI and are instead lumped together with commercial meters. Limited data available on industrial meters indicate that emissions from this source may be very high. Additional measurements of industrial meter emissions would allow for the calculation of these emissions in the GHGI.

Deliverables

The deliverables for this project will include:

- Estimated leak frequencies for large leaks from facilities
- A database of emissions results and the associated parameters that characterize them

Measurements being made with the Hi-Flow™ sampler.

- An analysis of existing GHGI emission estimates compared to measured emissions, and
- Recommendations on use in a national estimate to make it more likely that EPA will use the results in the GHGI.

Benefits

The research conducted during the course of this project will have a significant impact on the national estimates of methane emissions from the natural gas industry. It is intended that the improved emission factors and activity data will be incorporated into EPA's annual GHGI and be considered for EPA's GHG reporting program. The project will also identify specific metrics to be tracked at a company level so operators can prioritize the repair of their non-hazardous leaks to maximize the reduction of methane emissions.

It could then be made into practice in the field and possibly support the creation of a different classification for this type of pipeline to promote the use of these liners as a method of reducing emissions.

Technical Concept & Approach

Specific project tasks include:

- Sample Design and Initial Testing
- Evaluation of Existing Leak Data
- Development of a Field Testing Plan
- A Field Measurement Campaign, and
- Data Management and Statistical Analysis of Emissions Measurements.

The project team is seeking partners to provide access to distribution facilities for measurement activities.

Industry partners will provide:

- Participation in the Technical Committee, providing guidance on the scope and progress of the project
- Assistance in characterizing industrial meter types and locations and leaks on vintage plastic pipe and cast-iron and unprotected steel pipes with liners
- Data about facilities for pre-planning of the field campaign
- Access to facilities (if needed) for measurement
- Data about operations during measurements, and
- A review of results and input on use of data.

Results

In 2017, the project team developed a new method (standard operating procedure) for data collection for underground pipelines and meters. Researchers discovered an important discrepancy between the definitions of commercial and industrial meters used by the Energy Information Association (EIA), which is subsequently used by the EPA, and the industry. The industry does not separate according to the EIA definitions. Typically, meters are installed based on usage and not a specific industrial/commercial classification. This difference in classification has made identification of sites more difficult and raises the question about whether the EIA classifications/definitions or the industry definitions are more appropriate for determining methane emissions.

Other primary efforts were focused in two areas: standard operating procedures and sample site selection. The standard operating procedures for sampling industrial meters and pipelines (i.e., new vs. vintage plastic, lined steel and cast iron) were finalized and shared with study partners for evaluation.

In 2018, the project team completed evaluation of new vs. vintage plastic pipe and industrial meter samplings. For the project, researchers surveyed 18,934 components at 420 different meter sets, identifying 1,170 leaks with indications above 100 ppm and quantifying 351 individual leaks at 174 different meter sets. All 10 weeks of original measurements for industrial meters and two of the three campaigns for revisits of previous sites were completed.

Status

From this research, investigators concluded that:

- The initial blueprint provides for quantification of fugitive emissions in the commercial sector.
- Small-scale field measurement lays the groundwork for validation of the methodology
- Similar field collection and analytical methods can be applied to commercial sectors, and
- Results from small-scale field measurements indicate that fugitive emissions from commercial buildings are higher than characterized in current inventories.

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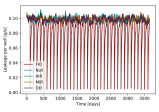
Leak Detection and Repair Modeling for Distribution Systems



Researchers are performing a preliminary evaluation of the feasibility of using the open-source Fugitive Emissions Abatement Simulation Toolkit (FEAST) model to evaluate distribution leak detection and repair programs.

Project Description

Instrumentation used to detect leaks can vary greatly in capital investment. For example, handheld units can cost $5,000+, vehicle-mounted units $20,000+, infrared camera units $100,000+, and high-sensitivity complete mobile survey systems $250,000+.

Trial runs of technologies can be expensive; therefore, a modeling approach to initially evaluate the systems may be faster and less expensive. With a fully implemented model, leak detection and repair (LDAR) programs that may have a high initial capital cost, are expensive to execute, or that have been newly developed could be evaluated on a case-by-case basis to determine the potential benefits of implementing new or different LDAR programs.

In this project, researchers are performing a preliminary evaluation of the feasibility of using the Fugitive Emissions Abatement Simulation Toolkit (FEAST) model to evaluate distribution LDAR programs. The FEAST model is available as a full, open-source set of code/modules that are run in Python with full documentation. Since the model is open source, it can be readily modified and adapted.

The model is driven by a module that simulates leaks from a virtual natural gas field with user-defined parameters – well spacing, leak area around well and number of components per well – driving the calculation. From this input, individual or multiple sources can be turned on and off and atmospheric transport simulated.

The current Phase 2 of the project focuses on further optimizing the FEAST model for walking surveys, expanding the use case scenarios, and exploring web-based deployment of the model.

Deliverables

The main deliverable from this project will be edited open-source FEAST model modules, including all Python code that is adapted during the evaluation for the distribution-use case.

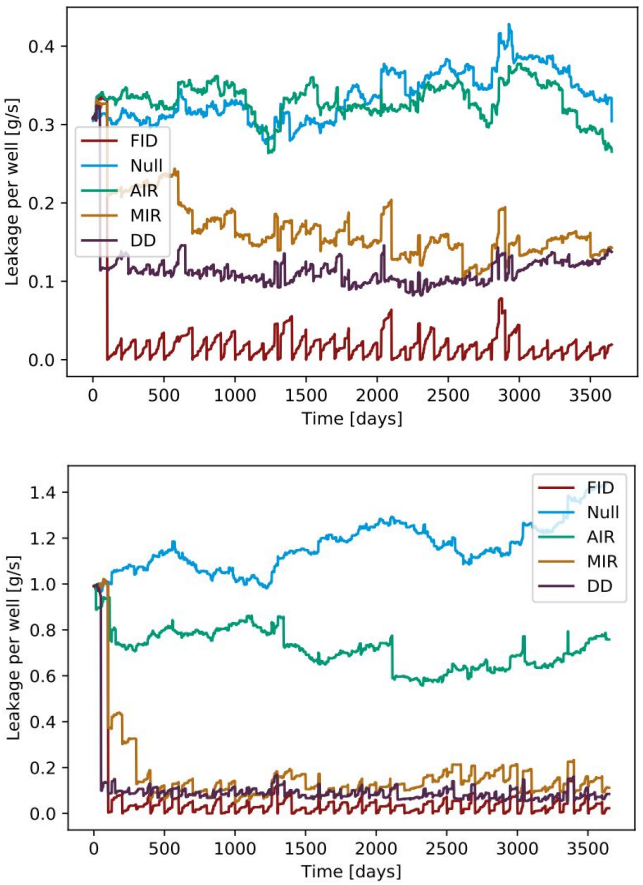
In addition, the project team will modify existing documentation to accompany the changed Python code so that the model can be used by anyone to study the impacts of different LDAR programs.

A detailed evaluation of the applicability of the FEAST model to distribution will be provided.

A Final Report will summarize the project.

Benefits

The ability to evaluate the net value of LDAR programs that includes but are not limited to capital costs of instrumentation, labor costs of use, costs of repairing leaks, and the value of the gas lost/not lost before implementation has the potential to save companies significant time and money with regards to choosing new leak-detection methods and technologies.



A variety of distribution-system leak scenarios were simulated.

Technical Concept & Approach

Three major tasks are planned:

1. To collaborate with project sponsors to gather data on current LDAR programs
2. To use the existing FEAST model to evaluate the potential for adaptation to distribution systems and the amount of effort needed for that adaptation, and
3. To attempt a test run of the preliminary distribution system FEAST model using existing economic modules with two distribution LDAR program scenarios.

The information gathered on the leak field will be used to inform the numerical modeling of the leak-field scenarios. Any new data on leaks will be combined with existing leak data to be implemented in the model.

The feasibility of incorporating a number of scenarios/ parameters for simulating leaks and atmospheric transport will be examined. These might include representing net value based on per mile of a particular type of pipe basis, a number of residences (i.e., number of meters), or the number of industrial facilities per square mile.

The form of the FEAST model that is currently available for download incorporates a particular model (i.e., set of equations) to simulate atmospheric transport away from a leak. Researchers expect that initially this model can be used to accurately simulate *above ground* leaks in distribution. However, for *below ground* (more diffuse) leaks, the project team will conduct a preliminary investigation into the feasibility of using a more advanced atmospheric transport model that may more precisely represent such leaks.

The performance of a modified FEAST model will be evaluated by attempting to run the model with existing distribution leak data anonymously provided by sponsors, from the literature, and from existing data.

Phase 2 focuses on further optimizing the model and developing it for other use-case scenarios, such as mobile surveys. Extensive model-sensitivity tests will be conducted to determine the influence of different parameters on model output and evaluate model performance.

Results

During Phase 1, the project team significantly modified modules to simulate a distribution pipeline network. Researchers adapted the model to represent a distribution network grid with leaks detected via a walking survey using a handheld tool. This established a base case for modeling the distribution of leaks generated, detected, and carried over from year to year.

Researchers created a different version of the model that attempts to simulate a gas distribution network on an areal basis (square kilometers or miles). The project team was able to successfully generate new leaks in random locations while simulating different survey intervals, with varying ability to locate leaks via walking surveys. Researchers also added an "accounting" of the leaks to track when they are generated and when they are found within a model run in order to track emissions.

Significant efforts were made to complete the model in 2018, and it is currently in a place where it can be used to examine questions about different survey variables. The 2-D grid matrix layout was changed to a 1-D array layout, which means that the system can be represented by total miles of pipe instead of square area. This greatly enhanced the performance and ability of the model to represent a wider number of systems. The model was automated to a run all survey frequencies and produce graphics for quick analysis and comparison of different model run scenarios. In addition, an initial vehicle-based survey module was developed to begin exploring this methodology.

The project team explored different ways of calculating the total cost of the entire leak survey program and studied the advantages to conducting all surveys by mobile/vehicle methods.

Status

Phase 2 activities are under way.

Plans call for finalization of a contract with Harrisburg University and initiation of a literature review on modeling gas distribution systems

Researchers will solicit sponsors for distribution pipeline leak-size data in order to develop realistic models of leak-size distribution.

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Methodology to Estimate Flow Rate of Aboveground Leaks Using a Soap Test

Researchers are evaluating a methodology using a soap test to characterize and estimate the flow rate of a leak on aboveground assets at 60 psig or less. This information will be used to help operators better estimate emissions from their assets.

Project Description

One of the largest contributors to emissions for a distribution company is from meter set assemblies (MSAs). Typically, these leaks are small, nuisance-type leaks that are located at threaded joints of meter-set components.

Currently, a common industry practice to characterize aboveground leaks as hazardous or nonhazardous is to utilize a soap test. If the leak is within close proximity to a building (within three feet) and the leak is strong enough to blow the soap off, as opposed to forming bubbles, then the leak is classified as hazardous. If the leak forms bubbles, then the leak is classified as nonhazardous.

The goal of this project is to evaluate a methodology using a soap test to characterize/estimate the flow rate of a leak on aboveground assets at 60 psig or less. The original scope of this project was to determine the point at which the flow rate is to large for bubbles to form when sprayed with a leak solution. After initial tests, this scope was changed to study bubble formation at flow rates between 0.1 and 5 scfh.

Additional testing was requested in a laboratory setting. There is a desire to understand the transition of foam to bubbles when a soap solution is sprayed on a leak on a threaded fitting. Concentration measurements of the leaks were also requested for characteristic comparisons of flow rates to emission concentrations.

Deliverables

The deliverables for this project will include a detailed testing report that documents the flow rate at which various soaps are blown off from a leak, enabling an easy field characterization of emissions.

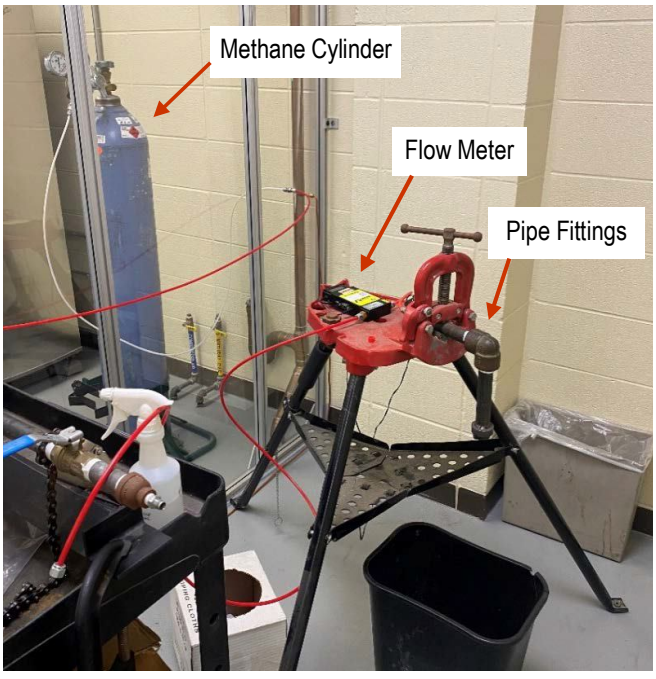
Benefits

Currently, emission estimates for aboveground distribution assets (e.g., MSAs) are estimated and reported using an emission factor that was developed by OTD in a study completed in 2009. The emission factors provide an average annual emission rate for the entire MSA facility.

This method allows for easy calculation of total estimated annual emissions from MSAs by multiplying the emission factor times the total number of assets. However, using this methodology, efforts taken by companies to reduce emissions through faster repairs of leaks, improved maintenance procedures, etc., cannot be recognized without developing new emission factors, which can be a costly and somewhat lengthy endeavor. Because of this, there is a drive to move towards a leak-based emission factor, where reporting of emissions is based on actual leaks discovered and repaired, and not the number of assets. This projects seeks to evaluate a methodology to efficiently estimate the leak rate on an aboveground distribution asset by using a soap test. This will allow operators to estimate emissions from meters in the field without the need for additional equipment.

Technical Concept & Approach

This project attempts to identify the flow rate at which a leak on an aboveground asset will not form a bubble, but be blown off. This information will be used to help operators better estimate emissions from their aboveground assets.



Laboratory test rig.

Specific tasks in this project include:

- **Soap Solution Identification/Procedure Review**

  Soap that utility companies use to identify leaks can vary widely. Moreover, the concentration and mixing in the field by crews can vary as well. A survey of project sponsors for commonly used soaps, and procedures for mixing, was performed. Three soaps and concentrations will be included in the analysis.

- **Laboratory Testing of Leak Rates and Soap Bubbles**

  Researchers developed a test matrix to conduct leak testing on the various soaps selected. The matrix includes pressure variations and temperature variations (of the soap and atmosphere). A test rig was constructed so that flow testing of a variety of different leak configurations can be simulated. These leaks were primarily on threaded connections as that is the most common location for a leak in the field. The average leak rate will be determined from the testing performed.

- **Field Validation**

  Researchers will validate leak flow rates in the field in comparison to those observed in the laboratory. Validation measurements can be made using a laminar flow element device (or similar instrument) as used in previous emissions studies.

Results

In 2018, the test matrix was completed. The test setup produces a gas supply of 55 psig to the regulator, which can be reduced to less than 0.25 psig during testing. The leaks are generated from a threaded fitting.

A change of scope was made to this project at the end of 2018. A request was made to observe leaking flow rates in the range of 0.1 to 5 scfh. A mass flow controller was ordered to better evaluate and control the flow rates in this range.

Tests were conducted and reported throughout the first and second quarters of 2019. Following the reporting of these findings, subsequent testing was requested to study flows more closely related to leaks found in residential meter sets (0.003 scfh to 0.1 scfh flow rates).

A test was designed to further evaluate the relationship between leak rates and bubble formation when soap solution is applied to pipe thread leaks. The most important considerations for this test included the low flow rates where bubbles begin to form and the corresponding concentration measurements. The setup and procedure were similar to previous experiments for this project, but performed in a laboratory setting to prevent influence from external variables such as wind, temperature, etc.

Tests were performed in a methane enclosure room for the purpose of testing methane detection devices in a controllable and safe environment. A ¼-inch tubing port is installed in the wall to allow gas to be injected into the room and controlled in a safer manner outside the room. A hood is installed in the room to vent gas. The pipe fittings were positioned in a tripod vise with the pipe fitting and cap pointed downward. This position was chosen so that gravity did not impact the direction of leak solution flow.

The pressure used on all flow rates was 1.5 psi. Five flow rates were chosen for observation: 0.7 ml/min, 1.5 ml/min, 3 ml/min, 5 ml/min, and the lowest flow possible where foam/and or bubbles are not formed. The flow rate was controlled by tightening or loosening the cap on the pipe nipple until the flow rate was consistent. Once the desired flow rate was reached, concentration measurements would begin. Concentration measurements were taken at five distances form the leak origin (up to six inches). Photos and video were taken for analysis.

Tests up to 1.53 ml/min contained primarily foam with some small bubbles forming periodically. At 3.08 ml/min, small bubbles formed much more consistently with foam interspersed between and under. At 5.08 ml/min, clear larger bubbles were developing. Some foam was formed on the opposite side of the pipe cap, but none was seen formed under or between the bubbles.

An additional low flow rate was attempted with this testing to determine if there was a flow low enough where foam nor bubbles are formed. The current flow meter used had a range of 0-10 ml/min. The flow was limited incrementally down to the lowest recordable flow of the meter, 0.01 ml/min but foam was still present when applied to the threaded fitting. This occurred under ideal laboratory conditions and may not be indicative of field observations, but it does demonstrate that a very small thread leak can produce a reaction when soap solution is applied.

Status

Additional analysis will be completed for the final laboratory report.

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Evaluation of Methane-Detection Devices for Utility Operations

This project focuses on the evaluation of new and advanced methane-detection devices for potential use in walking leak surveys, leak investigation, and stationary remote monitoring.

Project Description

With the advancement of technologies – coupled with an industry focus on reducing methane emissions from natural gas operations – there has been an increase over the past several years in the number of products entering the market for detecting methane. Consequently, there is a need to validate the technical specifications of these products and to evaluate the performance of these technologies for suitable applications for utility operations relative to tools currently used by the industry.

The challenge is in evaluating a diverse pool of detection tools that differ not only in their fundamental technology but also in their intended use and target applications.

In this project, a testing program is under way to evaluate these tools. The program is tailored for specific-use case scenarios, including walking leak surveys, leak investigation, and stationary remote monitoring.

Investigators are reviewing a large body of research in the area of methane sensing. Sensing technologies include laser-based sensors, optical imaging techniques, biosensors, and other methods.

Deliverables

The deliverables for this project will include a Final Report that summarizes the findings. The report will include recommendations on the best applications/use-case scenario for each tool evaluated.

Benefits

The adoption of new advanced methane-detection technologies can improve the ability to identify and locate leaks, resulting in a more efficient leak detection and repair process. These technologies also have the potential for remote monitoring of target assets that may require frequent, longer-term detection of methane.

Broadening the toolbox of methane-detection devices will allow for more tailored leak-detection methods, resulting in increased safety environmental benefits.

Technical Concept & Approach

This project focuses on evaluating technologies that are or near commercially available that can be used for walking leak surveys, leak investigation, and stationary remote monitoring.

Advancements in gas-sensor technologies have led to more sensitive devices that can detect methane at concentrations at the parts per billion level, far below the atmospheric concentration of methane, which is approximately two parts per million. These technologies, while extremely sensitive, typically have high capital costs, and often users have concerns with regard to false positives or identifying hits of methane that would not otherwise correspond to what a utility would define as a natural gas leak. On the other hand, these advanced technologies may allow for faster surveys and earlier detection of leaks, therefore preventing larger events from occurring.

Advancements have also been made that allow for the production of low-cost, lower-power methane sensors that can be deployed as a network of methane sensors to remotely monitor areas of interest.

The scope of the project includes a technical evaluation of these technologies. Information gathered on capital

Environmental test chamber.

or operating and maintenance costs will be included in the report, but will not be a part of the evaluation. The evaluation includes validation testing in the laboratory as well as controlled field evaluations of the technologies in simulations of target applications, such as a pipeline leak survey.

A candidate list of technologies was identified for evaluation in this project. The technologies range from laser-based systems requiring active sampling to micro-electromechanical systems requiring passive sampling.

A testing matrix was developed to validate the technical specifications of each technology. This includes detection level, sensitivity, accuracy, precision, false positives, repeatability, and reproducibility of results. Smaller devices that can fit into an environmental chamber will be tested in a constant-volume-controlled atmosphere. Backpack-carried devices that use a sampling wand will be tested using a smaller chamber where flowing gas can be introduced and sampled. A port will allow the sampling wand to withdraw a sample and divert it directly to the analyzer.

Controlled field testing is being conducted to determine the performance of technologies against leak/methane-detection tools currently used by utilities. A simulated leak site was created for the field testing. Independent sensors were placed around a leak area to monitor the methane concentrations and to create a methane map profile. They will also serve as referee sensors for the point sensors to be evaluated for the target application of stationary remote monitoring. Measurements using the technology under investigation as well as the referee tool will be conducted in parallel to ensure consistent environmental and operating conditions.

Results

In 2018, several test scenarios were prepared for field evaluations. It was decided to divide the types of instruments to be tested into two groups: Group 1 – Systems that actively sample via a pump and Group 2 – Passive systems (do not use a pump). A variety of instruments were tested in the laboratory and at a pipe farm to determine how they might be used in the field to conduct a leak survey. Units tested in the pipe farm were also pared with a high-accuracy GPS in order to determine how well they can be used to map a leak.

In testing, the lower detection limit was reduced to 4% LEL (the lowest possible setting) so that the detection limit could be assessed. The detectors were placed in an environmental chamber and tested at 25%, 10%, and 5% LEL of methane in air. The detectors all audibly responded to 25% and 10% LEL methane in air in air. At 5% LEL, the response was mixed with one detector responding intermittently and the other two detectors responding completely.

After each test cycle, the chamber was opened, and room air was circulated through the test chamber by an external fan to ensure that the chamber was thoroughly purged of its previous contents.

Following methane testing, units were exposed to a myriad of household chemicals to test for possible interferences. Where possible, researchers defined possible LELs for the test chemicals based on their composition. Non-gaseous chemicals were tested at a normal household-use level. For a first approximation, quantities which would be dispensed in a 10-second spraying into an 810-square-foot room. Using the volume of the chamber, appropriate amounts of each chemical were introduced to the chamber.

Purely gaseous materials were dispensed with a gas-tight syringe. Liquid samples were weighed into an evaporating dish which was placed into the chamber adjacent to the intake side of the air-circulating fan to ensure rapid dispersal of any volatile components throughout the chamber. Aerosols and/or spray bottles of other volatile chemicals were introduced in the chamber without weighing so as to ensure introduction of the volatile compound to the chamber. Mist contamination of the test devices was prevented turning off the fan as the material was sprayed.

Following each chamber purging during the household chemical and products testing, a 10% LEL volume of methane was introduced, serving both as a quality check and a determination if the previous chemical caused any contamination or loss of sensitivity.

Propane was injected to determine how the detector responds to other gases. Units responded to all three levels of 25%, 10%, and 5% LEL in air. Ethanol produced a response in the detectors at both 25% and 10% LEL in air. Acetone produced a response at 25% LEL in air.

Outside samples were used to verify the accuracy and to subject a device to any possible interferences occurring in various sample sources.

Status

Full results interpretation of field and laboratory testing is ongoing.

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Best Practice for Venting a Building

Researchers are investigating natural gas leak and hazardous-situation venting best practices, examining procedures that are currently in use by both utilities and emergency responders, and identifying additional means of evacuating gas from buildings.

Project Description

Mitigating natural gas leaks is very time sensitive, and actions to more effectively vent the building may prove extremely useful in preventing an impending hazardous event. This project intends to examine existing practices, identify gaps, and provide a recommendation for a best practice for utilities to follow.

Current procedures typically state that natural ventilation, such as opening windows and doors, should be used to evacuate natural gas from buildings. However, there may be other means to aid in ventilation, such as using industrial fans which can increase the flow of air through the leak site.

The objective of this project is to investigate natural gas leak and hazardous-situation venting best practices, examine procedures that are currently in use by both utilities and emergency responders, and identify additional means of evacuating gas from buildings.

Deliverable

The main deliverable for this project will be a Final Report containing the recommended practices for utilities responding to a natural gas leak that has accumulated inside of a structure.

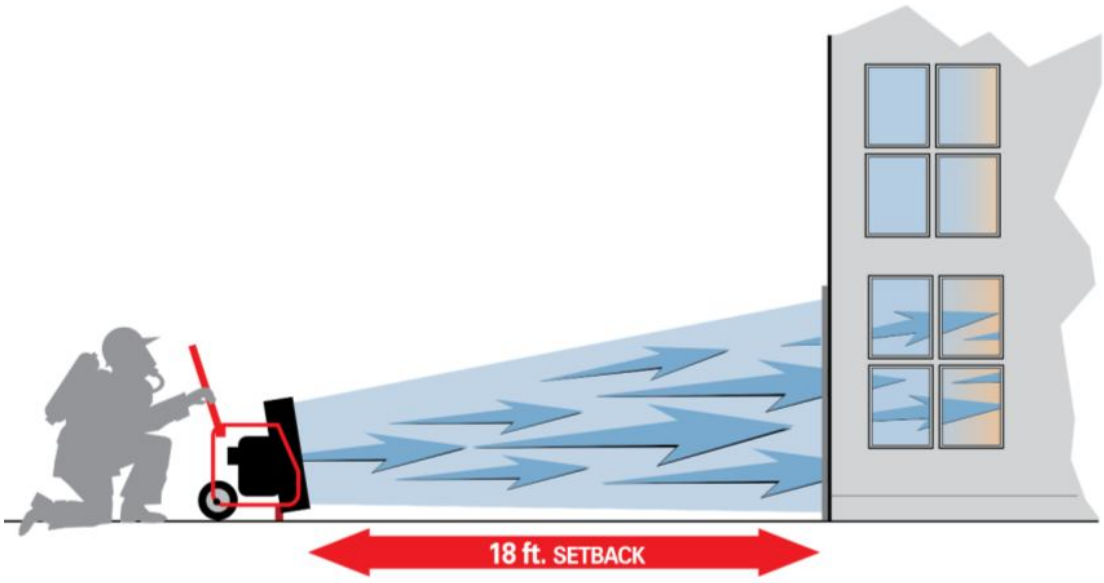
Benefits

It is imperative that companies use the most effective procedures possible to ensure that a structure has been completely evacuated of leaking natural gas and is no longer a hazardous environment. Effective procedures help to mitigate risks associated with lingering leaks or elevating concentrations of methane within a building or confined space while also ensuring that re-entry into the building is safe.

Technical Concept & Approach

Activities in this project include a review of fire codes and existing utility procedures, and summarizing their practices in regards to responding to a gas-filled structure and evacuating the gas. Other mechanical options for evacuating gas from buildings will also be explored, such as the use of explosion-proof industrial fans. Utilities can then use this information to make informed decisions pertaining to their own best practices.

A discussion between the utility sponsors and the project team was held to determine that the key technical requirements and needs are captured.



Positive-pressure exterior venting example.

Recommendations may include using mechanical means for ventilation or the use of devices that allow for continuous remote monitoring of methane concentrations to ensure individuals are returning to a safe environment.

Results

In 2018, the project team developed a natural gas venting survey for utility operators and first-responder agencies. This survey revealed that natural-venting techniques (opening doors and windows) is the primary method to vent natural gas from structures followed by positive-pressure techniques (explosion proof mechanical fans/blowers). The survey also revealed that the fire department, for most utility operators, assumes the responsibility of performing natural gas ventilation activities from structures (i.e., attics, crawl spaces, and living spaces).

The project team interviewed the Chicago Fire Department on their natural-gas-leak investigation and venting practices. Investigators also facilitated a venting best-practices roundtable for fire department first responders, finalized industry standards and best-practices research, finalized interviews with first-responder agencies, and completed the review of incident reports related to venting natural gas from structures.

Findings include:

- Natural ventilation is the most common venting method of among gas utilities and other first responders for structures with simple designs and lower concentrations of natural gas.
- For structures with complex designs, multiple floors, and dead areas, fire department agencies in urban areas will use positive-pressure ventilation (e.g., mechanical fans) to assist with the ventilation of low and high concentrations of natural gas. Most LDCs continue to use the natural ventilation method for these scenarios.

Positive-pressure mobile vehicle.

Examples of portable and mobile-type positive-pressure venting equipment used within the industry.

- Fire-department agencies mostly initiate and perform venting activities in urban areas when higher concentrations of gas are present. Whereas, the local utility first responder mostly initiates and performs venting activities in rural areas. Some contributing factors for this practice are the location of the fire department supporting the entire community, the response time of volunteer fire department staff, and the level of natural gas training utility first responders receive versus rural volunteer fire department staff members.
- Only one utility reported owning intrinsically safe mechanical fans to assist with venting of natural gas. Most fire-department agencies reported owning mechanical fans to assist with venting activities, but none were reported as intrinsically safe.
- Most utilities and fire-department agencies reported initiating ventilation of gas concentrations from within a structure regardless of all sources of ignition being eliminated (e.g., electric service disconnected or terminated).

In 2019, the project team continued discussions with utilities and industry first responders on venting best practices and lessons learned, began drafting the Final Report, and initiated the development of a venting best-practices procedure for first responders to use as a guide to enhance their own procedures.

Status

Research on industry best practices continues, along with identifying potential venting equipment that gas utility companies could use. Communications with additional first-responder agencies continues.

Researchers are developing a venting best-practices training presentation based on project research.

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Biomethane Justification Study for Improved/Accepted Gas Quality Standard

A project team is developing a study on the quality, analysis, risk, and compositional variability of final end-use-grade biomethane to demonstrate the viability and safety of biomethane use in natural gas distribution and transmission systems.

Project Description

Researchers are addressing a variety of issues related to biomethane injection in natural gas distribution and transmission pipelines. These include considerations regarding safety, reliability, interchangeability, continuity, and the requirements to keep gas flowing and avoid service interruption.

In this project, a research team is developing a study on the quality, analysis, risk, and compositional variability of final end-use-grade biomethane.

The goal is to provide biomethane project developers, producers, and distributors with sound science and clear facts that can be used to reduce uncertainty about technical issues related to biomethane utilization.

Deliverables

The deliverables for the overall project will include:

- The most recent tabulation of gas quality data
- A risk assessment of the constituents in biomethane
- A simple risk calculator for pipeline component integrity, and
- A biomethane acceptance justification document.

Benefits

Demand for natural gas is increasing as utilities change electricity production from coal to natural gas, and trucking fleets convert to compressed natural gas (CNG). Biomethane derived from landfills, wastewater treatment plants, dairy farms, food waste processors, and other sources is poised to become an increasing part of the natural gas equation.

Biomethane qualifies as an advanced biofuel under the Renewable Fuel Standard, and as a cellulosic biofuel (since 2014) when used for CNG production. These qualifications are leading to wider acceptance and specification by regulators and customers. States and other entities are becoming more aggressive in wanting to incorporate diverse sources of renewable energy into their energy portfolio.

Universally established gas quality acceptance standards for biomethane will provide answers to interconnect project skeptics and detractors.

Biomethane is being introduced into natural gas pipelines from a variety of sources, including landfills, wastewater treatment plant, and livestock operations.

Technical Concept & Approach

- **Data Collection and Mining**

  Data from previous gas quality analyses will be thoroughly vetted and tabulated for use in subsequent tasks. Data will include information from laboratory independent gas analyses that would be blinded as to actual source but would be grouped by region and type. Additional data from the literature will be added to form a comprehensive catalog of information on biomethane quality.

- **Evaluation of Risk**

  Researchers will update existing risk assessments. Metallic pipe will be added to the material matrix. Wherever possible, standard metal pipe corrosion data will be used. Data from existing literature studies and laboratory experimentations will be included.

- **Development of a Risk Calculator**

  A simple risk calculator for pipeline component integrity will be developed.

- **Development of Justification Document**

  The framework of previous guidance documents and reports will be used to develop a biomethane justification document that will apply across the U.S. and Canada. This document will 1) make specific recommendations of acceptance criteria for biomethane based on assessments of the raw biogas feedstock, 2) discuss monitoring instrumentation and techniques, and 3) explain monitoring periodicity and why it is needed.

Results

In 2018, considerable data mining was conducted and a literature search initiated.

The previous risk assessment utilized in a past U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration project was reviewed.

A risk model based on a previous project was selected to be the starting point for the risk calculator. The revision for biomethane justification will include user-selected inputs for gas source as analyzed constituents and their concentrations. The consequence will be a prediction of impact based on the two prior inputs, data generated from the data-mining effort, and published information on the impact on infrastructure materials of construction.

An advisory committee (subset of sponsors) was formed to provide input and guidance.

Data collection from laboratory analyses, various research projects, and the literature survey was completed and data curation completed.

The primary criteria for removal was the obvious presence of a significant amount of air in a sample. The list of trace gas constituents and component materials was developed. Compatibility and chemical interaction reports were reviewed for some of the gas constituents. Directed acyclic graphs were drawn of the completed constituents to summarize the incompatibilities and illustrate the magnitude of risks.

Statistical data and estimated risks were added to the risk calculator.

The first draft of the risk calculator was finished and sent to sponsors for review. Based on initial feedback, the embedded links were removed and formatting errors fixed.

Preliminary risks were determined based on reference materials and graphs.

Status

Literature data on the impact of gas constituents on metallic surfaces is being reviewed. The possibility of using statistical software to perform a surface-response data assessment will be evaluated.

The project team is finalizing the format for the risk model.

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Robot for Remote Methane Detection

In this project, researchers evaluated a robotic device for use as a remotely operated methane-detection unit to reduce worker exposure to potentially hazardous situations.

Project Description

First responders are often in situations where they are investigating a leak in a potentially hazardous environment. To determine the methane concentrations within buildings or structures, first responders use handheld methane-detection tools that require putting themselves in environments with potentially high concentrations of methane.

The overall objective for this project is to develop tools that allow operators to remotely assess leaks and methane concentrations while limiting exposure to hazardous environments.

As a preliminary investigation, in Phase 1 of this project, a robot system prototype was used as a deployment platform for a remote-sensing technology already in development.

Deliverables

The primary deliverable will be a laboratory-tested, robot-based methane-detection device that can be certified intrinsically safe in later phases.

Benefits

Determining the methane concentrations within a building can help to mitigate a potential leak event and allows for a more effective and efficient utility response.

Having a remotely operated robot-based methane-detection system can provide a safer method for investigating a leak when the potential for high methane concentrations exist inside of a structure.

Technical Concept & Approach

Specific tasks for this project included:

- Project Scoping and Evaluation of Current Procedures
- Technology Evaluation of the Robotic Platform
- Prototype Assembly, and
- Laboratory Testing.

Included with the robot is an attached PTZ (pan-tilt-zoom) camera, a battery, a remote controller, and a set of stabilizing bars, an extended manipulator arm for opening doors, and external equipment to display the robot's audio/video output. The robot body has two rubber tracks for movement, along with four attached flippers with tracks. The front flippers can be moved up and down to position the robot while climbing stairs, moving objects, opening doors, etc. The body of the robot also contains a stationary camera on the front for navigation while driving as well as a flashlight and infrared camera for visibility in the dark.

Results

In 2018, the project team procured a robot for testing. The test procedure included testing the capability of the robot to serve as an inspection tool in buildings. The testing also included evaluation of the robot's ease of use and ability to traverse obstacle courses, climb stairs, and open doors.

The robot proved to be capable of accomplishing many of the tasks; however, there were a few areas

where testing revealed some limitations, especially when the extended arm attachment was added.

Subsequently, additional testing was conducted that included:

- Operating the robot on stairs with different materials
- Trying many different door handles, and
- Evaluating signal strength in different environments similar to both residential and commercial spaces.

After gaining familiarity with the robot's controls and functions, a series of obstacle courses were assembled with four scenarios for testing the robot.

For the robot to be effective in patrolling buildings and homes, it needs to climb stairs consistently well and in a timely manner. Researchers developed a methodology to test the robot's effectiveness in climbing industrial stairwells, wooden stairs, and carpeted stairs.

Another critical component of searching a building is opening doors. The project team tested doors with varying handles to determine the robot's consistent success or failure. These included round knobs, long handles, pull handles, and push handles.

A major factor in using a robot to inspect structures is signal strength. For initial tests, researchers tested the robot's signal limitations within a building. It is important to note that the facility is made with metal materials with walls of painted cement and contain many metal cabinets and equipment. This is important because radio signals can be disrupted trying to penetrate these materials. A test was performed to evaluate the signal strength when the robot was driven along an indirect path. As the operator remained stationary, the robot was driven through the hallways until the signal was lost and the operator could not control the robot. As demonstrated, the robot performs very well when navigating at short distances with few obstacles. The robot should perform well in a more residential environment where material construction would be less likely to block the signal's path to the robot.

The project team evaluated the robot for possible use as a methane-detection tool. Researchers also took the opportunity to test the robot in conjunction with a portable methane gas analyzer. This test was performed by attaching the gas analyzer to the robot and navigating a planned path around a known leak.

Due to the sensor's high sensitivity, sudden changes in movement and level can affect the accuracy of the data. The robot experienced trouble navigating the sand. This test also demonstrated the restrictions presented when attaching multiple devices to the robot. While the robot was only operated in an open-air space during this test, in a real application the attachments would hinder the robot's ability to navigate stairs and doors as they restricted the robot's movements and arm operation.

Continued evaluation of the robot in 2019 focused on the communications and navigation range of the robot with its controller, the robot's ability to turn a valve, and the robot's ability to navigate a residential property. Results of the testing were mixed. The robot proved to be adept at working specific valves that were in good working order, but had problems navigating steps with the manipulator arm attached, failing to climb residential carpeted interior stairs and wooden exterior stairs.

Another small test was completed to test the robot's ability to operate valves. Two pipe nipples were attached on either side of a lever valve and the setup was placed in a vise. The robot was able to turn the lever valve with relative ease.

Status

Evaluation of the robot was completed in 2019. A Final Report is being completed for sponsor review.

Suggestions will be made to the continue the project to further evaluate the robot's capability in aiding the utility industry.

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Drone-Based Methane Detection

The objective for this project is to identify unmanned aerial vehicle (UAV, drone) platforms that can be used by utilities to detect methane/leaks on natural gas distribution and transmission systems.

Project Description

New technologies and techniques of methane/leak detection are being introduced on a continual basis, with advancements moving from handheld devices to mobile platforms such as vehicles and unmanned aerial vehicles (UAVs).

UAVs for methane detection are still in the development stages for use in the natural gas industry. This project focuses on a preliminary assessment to determine the applicability of UAVs for detecting distribution methane leaks.

Researchers note that UAV-based systems have some significant hurdles to overcome before being useful for finding distribution-sized leaks. The two largest factors limiting applicability are:

1. Limitations on where UAVs can fly, and
2. Limitations on methane-sensing capabilities.

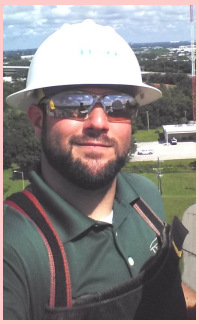
Several off-the-shelf UAV-based methane systems are currently on the market; however, their applicability to distribution use cases is uncertain. In particular, most systems have focused on identifying large point leaks and may not have the sensitivity for use on distribution leaks. The objective of this project is to identify UAV platforms that can be used by utilities to detect methane/leaks.

Deliverables

The main project deliverables will be:

1. Specific recommendations on whether existing UAV-based methane-sensing technology is sufficient for distribution-style leak detection
2. Recommendations on whether new technology can or should be developed, and
3. A Final Report.

Additional phases will be proposed if a technology is identified that needs testing or to further develop the technology if no adequate technology currently exists.



"Technology advancements in methane sensors and drones have become a great match for us to help find safer and more cost-efficient methods for locating leaks. We are constantly looking to get the best technology in the field, and this project has been valuable with helping us do so."

- Nick Margarone
Corporate Engineering
TECO Peoples Gas, An Emera Company

Benefits

The use of UAVs for methane detection presents opportunities for more efficient leak surveying and detection. UAVs present the potential for surveys over pipelines to be conducted faster and more frequently, reducing the risk for potentially hazardous leaks that may arise between typically scheduled surveys.

Drones may also allow for remote surveying, which is beneficial when surveying difficult-to-access locations or investigating areas without directly exposing personnel to hazardous gas environments.

Technical Concept & Approach

The main activities for this project include an evaluation of current protocols, practices, and technology, and an exploration of the potential for using existing UAV-based methane-sensing technology.

Efforts were conducted to:

- Understand current use cases where a UAV-based methane-sensor would be the fastest and most efficient leak-detection platform
- Identify leak size requirements for detection capabilities
- Determine how a drone could improve current processes
- Identify other use cases that would benefit from the use of a drone, and
- Determine the likelihood of utility company drone adoption.

Results

In 2018, several existing technologies were identified with the potential for evaluation within this project. An interim report was produced to summarize the information found and elicit sponsor feedback.

Researchers identified three specific areas to explore:

1. Methane sensors that can be mounted to customer-owned drones
2. Methane-sensing drone platforms where the sensor and drone area delivered as a package; and
3. Methane-sensing drone full-service providers.

During field tests, research determined that there are significant logistical and practical hurdles for pairing available sensors with drones and data retrieval. Furthermore, the sales and advertising brochures for the sensors tested did not always match capabilities of the units sent for evaluation, particularly pertaining to performance specificationss and ease of pairing to a particular drone.

In 2019, the project team explored testing of a full drone system; examined new drone-based sensing platforms that are being developed; and had extensive discussions with various following drone companies/ service providers regarding their methane/ethane detection solutions.

One technology was identified as most likely to be able to perform significant demonstrations and testing.

Status

The examination of currently available methane-sensing technologies for UAVs is ongoing. Researchers continue to contact sensor/platform developers for detailed information on technology.

Researchers will conduct field testing of the selected technologies for aboveground and belowground distribution leaks. Field testing will yield information on the usability of drones, ease of pairing independent sensors with a popular well-suited drones, and results from testing leak-detection capabilities at given heights, speeds, and leak concentrations.

Efforts are under way to identify a field site for testing the usability and detection capability of three types of methane sensors on drones.

As drone technology continues to advance, researchers found that there are some important aspects and concepts that need to be considered, including: flight planning, flight zone area, flying environment, flight height, payload, and flight path.

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Evaluation of 'Point-and-Shoot' Methane-Detection Technologies

A variety of new laser-based "point-and-shoot" methane-detection tools have the potential to provide significant savings in performing leak surveys. In this project, these technologies are being evaluated for their effectiveness in locating gas leaks.

Project Description

Laser-based "point-and-shoot" methane-detection instruments allow the user to scan aboveground assets quickly from 20 to 100 feet away. In recent years, several new point-and-shoot technologies have been introduced as commercially available products or instruments that can be rented on a weekly or monthly basis.

Among the new instruments are some that are less expensive, lighter, and more sophisticated than the main technology used today. The objective for this project was to evaluate how well these instruments perform compared to the commonly used Remote Methane Leak Detector for initial leak identification.

Deliverables

The deliverables for this project include:

- Details on the use and effectiveness of the tools tested
- Pros and cons of each technology
- Recommended ideal-use scenarios, and
- A Final Report.

Benefits

Laser-based point-and-shoot instruments can provide faster surveying and leak investigation because crews do not have to walk or drive over the survey or potential leak locations. Instead, the technician can stand in one location and scan up to 100 feet in each direction without moving.

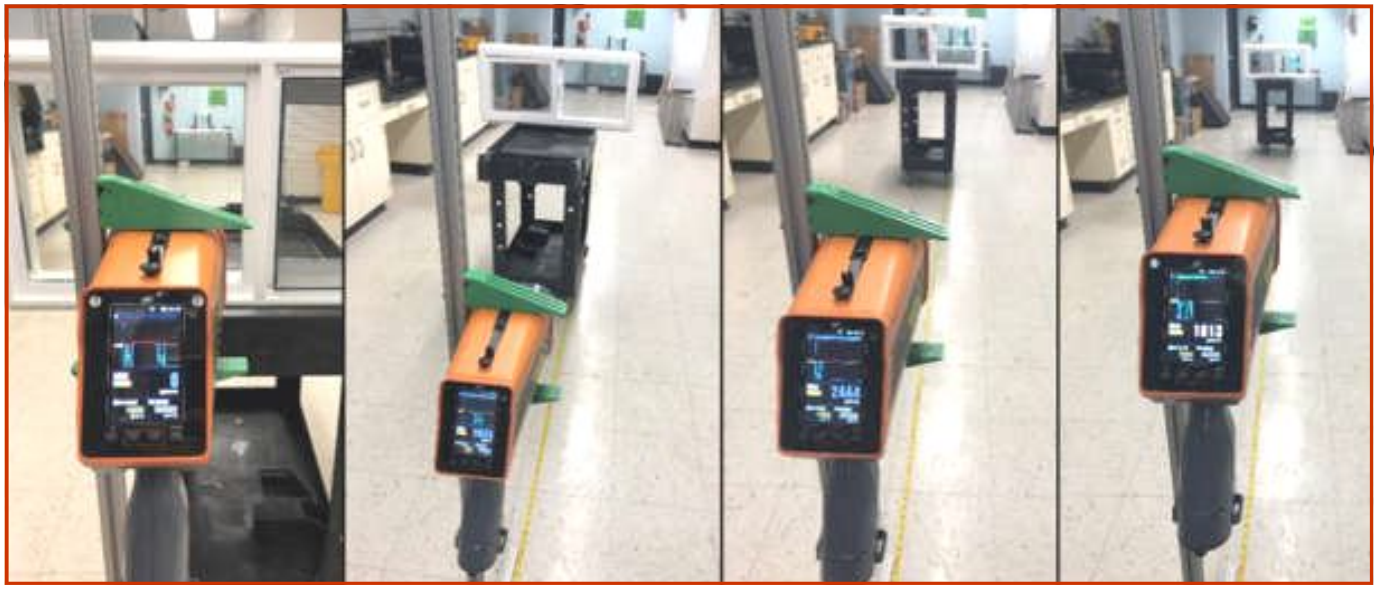
These tools also increase safety because the technician is scanning, instead walking, directly over the pipe or aboveground asset. This minimizes movement and the need to access areas with unseen hazards.

The evaluation of these tools will help utility operators in their decision making to provide more cost-effective leak surveying.

Technical Concept & Approach

- **Technology Coordination and Test Design**

  The test parameters for field testing will be designed under this task. Researchers will design a test that will incorporate a range of leak sizes for both above- and below-ground leak scenarios.



- **Controlled Field Testing**

  Researchers performed controlled field testing. These tests included a currently used detector as a control to compare new instruments with industry standard equipment. Simulations of different leak sizes in two types of soil were conducted. The testing also included aboveground leak simulations from customer meters and regulators at different sizes to determine relative detection limits of the technologies. Since the controlled releases will be metered, the technologies will be tested under a range of concentrations and leak flow rates.

- **Leak Facility Field Testing**

  The project team and sponsors will identify two hosts for field testing at a utility training facility.

  Product evaluations will involve:

  - Testing the ability of the different point-and-shoot techniques to identify leaks
  - Evaluating the portability, durability, and ease of use of the equipment, and
  - Comparing new technologies to the currently used equipment.

Results

Several technologies were selected for evaluation.

In 2019, extensive laboratory and outdoor field testing was completed for several products.

Sensors were tested during high- and low-volume simulated leaks at multiple distances.

Testing of five sensors was conducted to assess the impact of different backgrounds on the accuracy of readings. The sensors were held at a fixed height and aimed at a transparent bag containing a fixed concentration of methane. Backgrounds tested include brick, concrete, wood painted white, wood painted black, white plastic, black plastic, white siding, blue cinder block wall, untreated wood, mirror, rusty sheet metal, and shaved ice.

The influence of glass on sensor performance was assessed at various angles from the methane source as well as with multiple distances between the laser, glass, and methane source. Researchers also tested the effect of the conelike nature of the beam by placing a one-inch barrier and one inch of slit in front of the sensor.

Laboratory testing revealed several interesting aspects of the sensor performance. In particular, there was a wide range of reported concentrations for the standardized methane source. This indicates that in terms of absolute concentration, the sensors do not perform well, and, therefore, may be difficult to use for leak grading in the future. Also, the sensors are capable of measuring through windows, as long as there is no UV coating and as long as the user performs the measurement at an angle.

The impact of measurement-beam width can be seen when trying to measure leaks from a distance or around obstructions.

The laboratory testing was driven by sponsor feedback and questions about how different materials or scenarios affect the measurements made by these “point-and-shoot”-type systems.

A rain test was designed to show the impact that environmental factors may have on the measurements. For this test, a shower head was used to simulate rain in the laboratory. The methane source was placed directly behind the rain with a light-brown metal cabinet for a background.

Status

Analysis of the testing results is ongoing. A Final Report is being prepared.

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Impact of RNG on End-Use Applications

Research is being conducted to determine the effects of trace constituents in renewable natural gas on end-use applications. Information from prior projects and the technical literature is being leveraged to evaluate the impact potential trace constituents may pose.

Project Description

Raw biogas contains more than just methane and carbon dioxide. Metals, halocarbons, siloxanes, and mercury have all been detected in various quantities in renewable natural gas (RNG) sources. These trace constituents in RNG can lead to the buildup of acids, amalgamates, and deposits on burners, nozzles, orifices, and in residential gas lines. However, mitigation technologies have been developed that can be implemented before RNG is introduced into the pipeline or just prior to end use to prevent future leaks, damage, or hazardous incidents.

Extensive research was conducted on assessing the gas quality associated with various types of RNG. OTD supported the development of several guidance documents and companies are cautiously engaging with more developers. This new project involves a study that focuses on constituent issues to help alleviate concerns with regards to using RNG as a part of today's natural gas supply.

A compilation of gas quality projects found several compounds that could have significant effects if given enough time in the pipeline without taking action. Siloxanes have been shown to lead to significant accumulation of silica deposits. During testing, an unvented oven was shown to reach complete failure after 7,500 hours of use.

Mercury is another concern as it is particularly detrimental to the durability of aluminum. Mercury, when brought into direct contact with aluminum, forms an amalgamate and weakens the aluminum. This can have particularly serious consequences if aluminum parts are not replaced in a timely fashion. Additionally, aluminum containing catalysts could be poisoned and no longer function as intended.

Halocarbons are a third example. They can form acids in the presence of water or upon combustion that can result in fluids with slow corrosive properties. Similar to the amalgam formed by mercury and aluminum, the acids weaken iron-containing parts, leading to malfunction and possible failure.

In a previous project, OTD supported the development of a Biomethane Guidance Document to help demonstrate that biomethane is safe to use if properly processed. Results from this new project will supplement the guidance document by focusing on the impact to end-use applications.

Mercury damage to aluminum.

Deliverables

The deliverables for this project include:

- Technical information on potential impacts of trace constituents on end-use applications
- Recommendations on mitigation/preventative measures and maintenance activities
- Recommendations for follow-on research, and
- A Final Report detailing project results.

Benefits

Small quantities of seemingly insignificant components can pose safety risks as well as contribute to damage in end-use applications (e.g., burner tips, compressor stations, and natural gas-fueled vehicles). Identifying these possible long-term effects can help to diminish future issues and avoid costly repairs and replacements.

Technical Concept & Approach

Several potential constituents and hazards were identified from previous projects. Through this project, researchers are tabulating and evaluating each constituent potentially present in RNG with a thorough scientific review and assessment based on chemical, physical, and/or microbial possibility. Chemical and material interactions will be examined along with by-products of combustion.

The evaluation methodology will be similar to that used in a previous project investigating the impact of RNG and other gas on non-metallic materials of pipeline construction. Justifications will be made based on a literature review and probable chemical interactions.

Silica deposits on water-heater burner.

Recommendations with a special focus on RNG impacts to end-use applications will be developed, following the framework of previous guidance documents and reports.

Potential mitigation/preventative measures and maintenance activities will be explored and discussed. Sponsors will be requested to provide input and commentary as the final version progresses.

As part of the recommendations, a gap analysis will be performed to determine if laboratory testing would be required in a Phase 2 of the project.

Results

A list of appliances was compiled using several engineers as expert references as well as U.S. Department of Energy resources and previous research. The components list is taken from various trace constituents quality guides.

Compatibility and chemical resistance charts were collected for all the materials in the current list. The charts highlight key weaknesses that will be the basis of continued research. Each chart was evaluated and linked to each appliance component in the materials list.

Of all the components assessed, chlorofluorocarbon (CFC) combustibility is the least understood for end-use applications. CFC-12 has been observed in landfill-derived RNG sites at single ppm levels and is extremely stable and nonflammable. Incomplete combustion of CFC-12 is known to generate toxic byproducts such as dioxins, vinyl chloride, polyaromatic hydrocarbons, and other halocarbons.

Status

The project team continues to edit the appliance materials list to fill gaps in information.

Research is focused on interactions between trace constituents and vulnerable components.

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Trace Constituent Database

The goal of this project is to create an on-line searchable database that will compile natural gas and renewable gas major, minor, and trace constituent concentrations. The database will also include sampling and measurement techniques.

Project Description

In recent years, significant research has focused on characterizing the chemical and biological composition of renewable gas derived from various biomass sources (e.g., livestock waste, landfills, and wastewater treatment plant sludge).

Through OTD-supported projects, researchers collected biogas samples (raw biogas and post-cleanup biomethane) and analyzed more than 300 chemical constituents. These studies were used as the basis for several company-specific requirements for biogas injection.

In subsequent years, new feedstock sources were sampled since these original guidance documents were created.

The objective of this new project is to develop a computer database of gas measurement technology that could be easily accessed by the natural gas industry. It would be a source for actual concentration and composition data found in industry samples.

The plan is to create an on-line searchable database that will compile information on natural gas and renewable gas major, minor, and trace constituent concentrations, along with sampling and measurement techniques.

Researchers are investigating the constituents of biomethane obtained from a variety of sources, including livestock operations.

Deliverable

The deliverable for this project will be a searchable database of gas constituent concentrations and sample methodology. It will be available through a selected portal.

Benefits

No single database of information on methods, measurement-related issues, and actual concentration data for the natural gas industry is currently available. One mission of the GQRC is to aggregate gas-quality information, and this project fulfills this goal.

A gas-quality database would help gas companies to document the measurement technologies they use and their compatibility with standard measurement techniques.

This database would also benefit the gas industry and consumers by providing industry workers with reliable knowledge of prevailing technologies to accurately conduct composition and energy measurements.

Technical Concept & Approach

Existing data will be organized into a master list of data for uploading into the selected database. New data will be added via a thorough search of renewable gas analyses performed by gas chromatography. This data will be supplemented with information found during a search of scientific literature. Data will be blinded as to exact origin, but will be identified as to feedstock and completeness of upgrade from the raw biogas.

Results

Two database solutions were investigated for use on the project. One is a commercially-available solution to databasing that advertises ease of use. There are a couple of caveats to using this product. 1) The data would have to be uploaded onto their servers as they are a cloud-based product, and 2) it is also quite expensive to have the database hosted.

After discussion with database consultants, researchers chose a course of action that would be to use the server the GTI laboratory information management software (LIMS) uses, (and the database software it uses, MSSQL) and eventually having that database be able to generate reports using Microsoft Power BI. According to the company website "Microsoft Power BI is a business intelligence platform that provides nontechnical business users with tools for aggregating, analyzing, visualizing and sharing data. Users can download an application for Windows 10, called Power BI Desktop, and native mobile apps for Windows, Android and iOS devices."

Status

Data mining for natural gas quality constituents is completed for GTI data and literature searching for other data is under way. If any project sponsor has data they are willing to share it can be included anonymously.

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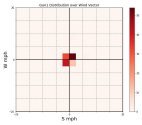
Evaluation and Demonstration of Stationary Continuous Methane-Monitoring Systems



A field demonstration of advanced stationary continuous methane-monitoring systems is under way. Researchers are evaluating the tools for potential use at a variety of gas facilities.

Project Description

In this project, a research team is evaluating and demonstrating new and advanced stationary continuous methane-monitoring systems for potential use at natural gas facilities such as compressor stations, terminals, gas storage facilities, city gates, and metering and regulating stations.

The project involves field demonstrations of commercially available systems as well as a few near/pre-commercial systems.

Deliverables

In addition to monthly summaries of instrument data, deliverables for this project include interim reports and a Final Report detailing results.

Benefits

Information of continuous-monitoring systems will help gas utilities chose the correct instruments for specific situations.

Technical Concept & Approach

A protocol was developed for the necessary metrics needed to evaluate four leak-detection instruments at a metering and regulating station located in California.

Instrument-user requirements were identified and matched with desired sampling methods and platforms prior to instrument acquisition. Sampling methods are the intended process for which field data is obtained (e.g., vehicle survey, walking survey, and continuous monitoring).

Researchers gathered user requirements from the perspective of analysts, controllers, site operators, and leak-detection engineers. Understanding how these users will interact with the instrumentation and resulting data will aid in the selection of instruments that meet performance requirements associated with leak-detection limits, data communication, data management, and instrument-maintenance requirements.

Incorporating applicable leak-detection regulations (both existing and pending) is important to ensure that instrument performance will ultimately be able to meet regulatory requirements. Leak-detection instruments were embedded within a robust leak-detection system as recommended in the American Petroleum Institute (API) RP 1175.

The monitoring site is a 500-square-foot station. Local meteorological conditions are very dry and windy with occasional wind gusts up to 100 mph. Sandy soil coupled with windy conditions could potentially create significant dust levels. Temperatures average approximately 100ºF in the summer, with highs peaking at approximately 115º-120ºF. The site consists of two medium-sized taps of similar configuration with operating flows of approximately 570 psi at the inlet and 340 psi at the outlet. Both taps are capable of operating at the same time but are typically designed such that

one can be closed for maintenance while the other continues flow. Each tap consists of flanged connections, differential pressure gauges, pressure meters, regulators, medium and small valves, and numerous small threaded connections around each of the valves and regulators.

Results

An initial site visit was conducted in January 2019. A controlled methane release was completed in February to determine best possible sampling configurations for each of the instrument types.

A protocol was developed to: 1) outline the process and justification used for instrument selection, and 2) design the necessary metrics needed to evaluate leak-detection instruments.

Selected instruments were installed at the site on May 22-23, 2019. Controlled release testing was performed on site to quality check instrument performance. Additional controlled releases are scheduled every six weeks throughout the duration of the project. To accommodate the release tests, the site owner installed a pipe manifold with various orifices which can be individually closed or opened to control the flow rate of a release. The smallest orifice would provide a flow rate of 10 scfh or equivalent to a sizable leak at a station. Opening multiple orifices at the same time enables larger flow rates.

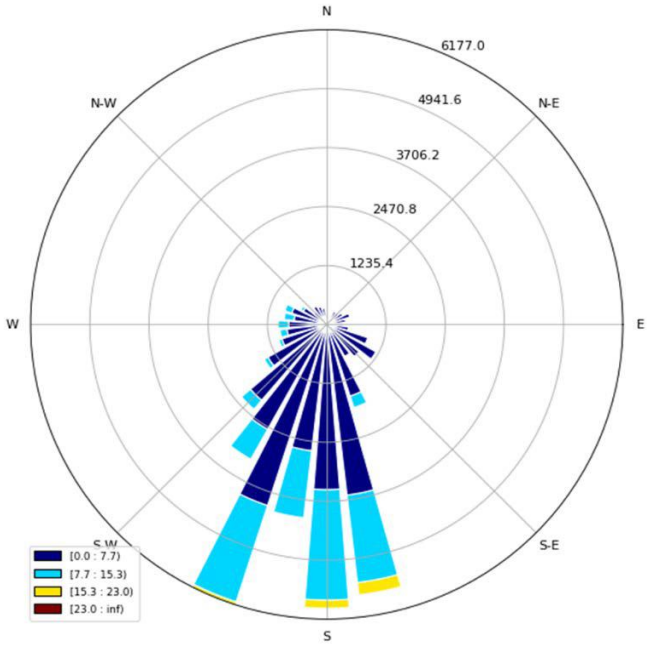
Prior to the releases, a thorough leak survey was performed and followed up with an application of soap solution at every connection in the facility to check if another source of methane could be present onsite. The leak survey on August 20, 2019, did not find any leak at the station. Further, the elevated concentrations appear to be wind-dependent (stronger in the morning when wind speed is low and lower in the afternoon when wind picks up), thus supporting the hypothesis that there is an open fugitive leak upwind of the sensors.

The controlled releases were conducted for roughly 10 minutes each to allow time for the instruments to detect the gas plumes.

Sensor installation took less than three hours since the sensor panels and laser transceivers were pre-assembled prior to site installation.

The two laser sensors are mounted on a tripod that has a height of approximately five feet. The heavy-duty tripod was reinforced with sandbags and anchored to the ground for additional durability against the wind.

After installation, conference calls were held with each instrument provider to design data-management, data-storage, and data-visualization procedures.



All data sets were normalized to one-minute intervals. The average concentration over each minute of data was calculated and retained. This data will be used to determine reasonable alarm thresholds for the instruments to prevent an excessive number of false positives.

A different representation of the methane concentration data was developed. The "concentration roses" used previously did not accurately portray the interaction of the methane plume and the wind. The roses essentially tried to display three-dimensional data with only two axes: number of occurrences and direction. The wind velocity was not properly visualized. A casual inspection of a concentration rose can give an erroneous impression of the methane reading source direction. The new representation provides a density distribution of the concentration data points over the wind direction and velocity.

Status

Data analysis on information received from the instruments continues.

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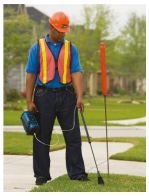
Advanced Leak-Detection Technologies for Grading Leaks



Researchers are exploring the possibilities for new open-path methane detectors to be incorporated into leak-classification/grading procedures. A project team is gathering existing information on the performance of these sensors, creating data comparing new methods to existing methods, evaluating any potential safety risks, and producing a recommended procedure.

Project Description

Current procedures for classifying gas leaks are based on well-established methods and the equipment used for leak detection. However, there are an abundance of new methane-detection technologies entering the market that have the potential to improve leak detection and classification efficiency.

Researchers identified at least one technology to use and test for this project. The instrument is currently a prototype instrument weighing less than three pounds that uses passive, open-path sampling (no pump). This system can be used to generate data to look for potential correlations between current instruments and techniques used for leak classification.

Each company has its own procedures for grading of leaks that are usually based on the Gas Piping and Technology Committee (GPTC) standards for leak grading. Although often based on the same overall grading classification, the procedures for measuring and determining the grade of a leak can vary widely between companies. For instance, not all companies can currently use an aboveground open-path methane detection system for leak classification and many companies are required to do leak classifications from bar holes based on the GTPC guidelines.

Obstacles to adoption can be utility commissions, regulators, or internal company policies. Understanding the barriers and generating data showing how well new technologies perform compared to existing well-established techniques and equipment is a first step toward removing these hurdles.

In this project, researchers are exploring the possibilities for new open-path methane detectors to be incorporated into leak-classification/grading procedures.

A project team will compile existing information on the performance of these sensors, create data comparing new methods to existing methods, evaluate any potential safety risks of using aboveground measurement to grade leaks, and produce a recommended procedure for using the technology for leak classification/grading.

Deliverables

Key deliverables for this project include:

- Existing data summary
- New technique correlation data
- Leak-classification procedure (if warranted), and
- Quarterly and Final Reports

Benefits

Two important issues are associated with identifying and classifying leaks – 1) labor costs required to perform identification and classification, and 2) the accuracy and repeatability of the measurement device. Both issues can impact the costs of finding and grading/classifying leaks through potential inefficiencies in equipment that may cause increased labor time to find the leaks or repeated visits needed to find missed leaks.

Some companies are restricted to specific types of technology and, therefore, cannot currently use a whole group of new methane-detection technologies known as open-path sensors for leak identification and classification. These sensors have the potential to more

quickly examine large areas for leaks, reducing labor costs and increasing efficiency by covering large leak areas.

Technical Concept & Approach

This project explores pathways for incorporating open-path methane detectors into company leak-classification procedures. The project focuses on three major tasks: 1) compiling existing information on the performance of new sensors and barriers to use, 2) creating new data comparing new methods to existing methods, and 3) producing a recommended procedure for using the technology for leak classification/grading.

The project team is reaching out to project sponsors to determine roadblocks for individual companies that may be preventing the use of open-path methane sensors in leak classification.

A field test was designed based on gaps in knowledge. Testing focuses on the ability of the technology to 1) quantify concentrations aboveground; and 2) quantify concentrations above bar holes. The testing will also examine how the aboveground concentrations correlate to classifications determined above and in bar holes.

The range of leak scenarios required to demonstrate the effectiveness of the new instruments/methods are limited. Therefore, from the onset of the project, sponsors will be asked to participate in real-world testing on real leaks where the new systems can be compared to existing bar-holing techniques. Field testing will help to determine whether correlations exist between the initial surface-leak identification concentrations, the bar hole concentrations, and the ultimate leak grade. Once the existing data and new data are compiled, the information and lessons learned will be combined into a written procedure on the best ways to utilize open-path methane sensors for leak classification.

Results

Several project sponsors were contacted regarding their leak-classification protocols. This information, along with information collected in a literature search, was used to develop two reports.

Recent advancements in laser optics and miniature technologies have paved the way for the development of a novel open-path methane sensor with potentially high sensitivity. Leak-detection devices also offer multiple purposes. They are used to not only detect and localize leak sources, but also to grade the severity of a leak. For a new sensor to be practical, it should ideally be capable of performing leak detection, localization, and grading to minimize leak surveys. However, potential constraints exist with the use of open-path passive-sampling sensors as a means of measuring underground leaks. Specifically, the absence of a probe and pump means that the instrument must be placed on the ground surface to reliably read the concentration of any gas plume that emanates from the ground. Additionally, there exists challenges when using surface concentration to estimate belowground conditions as there can be multiple atmospheric and/or subsurface conditions that complicate aboveground and belowground correlation.

"It can be a long process to bring new technology from the lab to the field. This project is accelerating that process for an important advancement in leak survey technology. The results of this project will help improve our leak survey in a way that makes our system safer for both our customers and the environment."

- Ford Eimon
Gas Engineer
Pacific Gas and Electric Company

The purpose of the protocol is to develop the necessary metrics needed to evaluate a lightweight, open-path methane sensor with potentially high sensitivity at field sites located in California and Illinois.

Researchers identified a new sensor that has the potential to improve leak detection and classification efficiency. The instrument is currently a prototype originally designed by the NASA Jet Propulsion Laboratory to find methane on Mars as a part of NASA's Mars Rover program. The newer, miniature version is more lightweight and sensitive than traditional instruments of similar size and function. The system uses multiple mirrors and a laser that are coupled to the appropriate analysis region for measuring concentrations of trace methane. The sensor is configured to detect a portion of the emitted light impinging on the detector to generate a corresponding signal. The electronic system then adjusts the wavelength range of the emitted light from the laser to measure the gas concentration. The instrument is called "Open Path" because the laser is exposed to the atmosphere via a porous housing – even though the laser is technically contained within a structure.

Status

Field testing is under way.

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OptoMole® Leak-Detection System

In this project, researchers are investigating the performance of the OptoMole® leak detection system for use in casings, vaults, and other confined spaces. The mobile, all-optical system can rapidly locate gas ingress points in underground service cable ducts.

Project Description

Methane escaping from leaking gas mains often finds its way to the ground surface via underground utility ducts (telephone, cable TV, etc.), where its often reported to the gas utilities by the public. Locating the actual gas escape point is labor intensive and involves a number of excavations on public roads and sidewalks, causing transportation disruption and incurring significant costs to repair and reinstate.

This project focuses on an assessment of an intrinsically safe product that provides accurate methane readings in dry or wet conditions, and would allow operators to complete investigations in a timely manner.

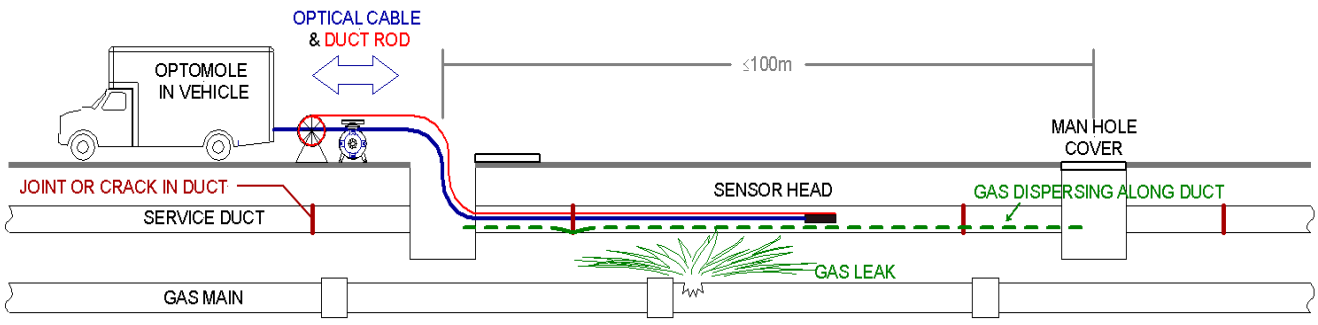
OptoSci Ltd., a UK-based company, is developing optical-based technology for monitoring combustible gases in industries such as mining, gas storage, gas distribution, and landfill operations. The company currently has two main products for methane sensing – the Opto-Sniff® for expansive methane detection and the Opto-Mole® (currently in the early stages of commercial availability) for use in more contained areas such as utility ducts and other confined spaces.

These mobile, all-optical gas detection systems rapidly locate gas ingress points in underground service cable ducts. The systems transmit a low-power laser signal via a fiber optic cable to a compact sensor head which is passed through a buried service duct. Analyzing the return laser signal allows the systems to instantly display the changing methane concentration in the duct, highlight the gas ingress points, and direct the operator to the potential gas main leakage sites.

In this project, researchers are investigating the performance of the OptoMole system for use in casings, vaults, and other confined spaces. In addition, the project team will determine if the OptoMole system can be used as a more portable device to assist operators with methane leaks in bar holes during rainy or wet conditions.

Deliverables

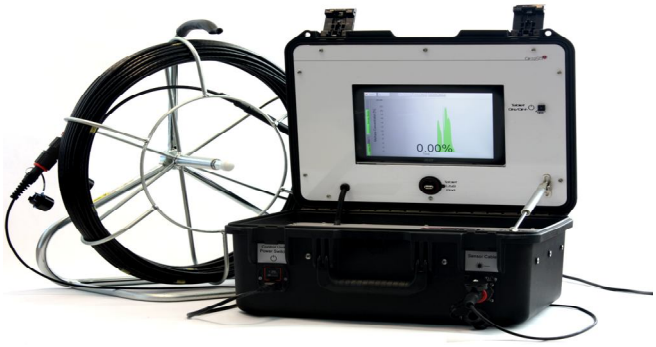
The main project deliverables will include a report detailing discussions with OptoSci on developing a portable optical detection device for methane detection in bar holes. In addition, an evaluation report will be created detailing the current OptoMole's capabilities and limitations for leak investigation in casings, vaults, and other confined spaces; and in bar holes and other wet-environment conditions. An investigative report on the OptoMole technology will include results of laboratory tests and field deployments at a sponsor utility site.



Deploying OptoMole for leak detection in a duct.

Benefits

Current combustible gas indicators (CGIs) operate by filtering particulates from the air intake to monitor for leaks. Their effectiveness is greatly diminished in wet conditions. At times, rain can persist for multiple days, making it challenging to conduct leak surveys and causing potential risk to customers. Having a tool that can operate in all conditions (including wet) will allow operators to conduct leak investigations in poor weather, saving time and reducing the risk of a missed leak.



Technical Concept & Approach

The OptoMole evaluation focuses on testing the:

- Accuracy of the sensor in reading methane concentrations
- Functionality of the sensor in humid or wet conditions
- Maneuverability of the sensor in congested conduits and in navigating bends
- Safety of the sensor, and
- Ease of deployment into electrical/shared utility conduits and for other applications such as surveying bar holes/casings.

Many of the available leak detection devices are not able to operate in wet conditions. Their intake cannot handle large amounts of moisture for sampling purposes. Part of the OptoMole investigation includes an assessment of the technology following complete submersion in water that may or may not have high sediment concentrations.

The overall approach of this project is to consult with OptoSci on their technology and its viability to produce accurate leak information in casings, vaults, other confined spaces, and in bar-hole type conditions while being redesigned into a more portable device. Inquiries will be made into the detection levels of methane following water submersion and if the technology can consistently perform in these conditions.

If the viability of this new product progresses positively in the field, the project team can organize demonstrations with supporting sponsors to display and outline the economic and practical purpose of the device.

Results/Status

This project was initiated in the summer of 2019 with a training session by OptoSci for project personnel. A laboratory and field demonstration was held in the fourth quarter of 2019.

The research team conducted project scheduling, budgeting, and establishment of a test plan. Planned future activities include coordinating laboratory and field demonstrations in Brooklyn, NY. OptoSci will be showcasing the instrument to determine the requirements for field deployment.

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OTD Operations Technology Development

A Framework for Company-Specific Emission Factor Development

The goal of this project is to develop a framework that uses statistical approaches to properly sample emissions from assets for establishing company-specific emission factors. Developing company-specific emission factors is a key step in guiding the industry towards more accurate emission inventories.

Project Description

Several utility companies in the United States are now required by legislation to achieve substantial reductions in their methane emissions before a given deadline. In New York and California, a common goal is a 40% reduction from 1990 levels by 2030.

State and federal regulators rely on emission inventories provided by utility companies in accordance with reporting programs to track emission levels. The approach applied by these programs to calculate emissions from a majority of assets (including meter sets and plastic pipes), is to use national emission factors in conjunction with activity factors (i.e., pipeline length or number of assets). There is little year-to-year variation because of the cost and labor involved to develop new national-level emission factors, and activity factors tend to stay consistent.

While this approach offers a standardized process, it limits companies' ability to show progress in emissions reduction, since the only way to reduce emissions is to reduce the number of assets or numbers of miles of pipe.

Company-specific emission factors can fill the gap and improve the overall accuracy in characterizing the benefits of their programs. However, a standardized methodology that produces company-specific data and can be performed periodically is still needed. Furthermore, collecting emission rate data is a laborious process. Current hardware for leak quantification is not very portable and lengthy measurement duration makes the process resource intensive when scaled over a large area or numerous distributed assets.

A sampling plan that would generate a statistically significant estimate of network emissions with minimal resource requirements would allow companies to develop company-specific emission factors.

The objective for this project is to develop a framework that uses statistical approaches to properly sample emissions from assets for establishing company-specific emission factors.

Deliverables

The main deliverable will be a framework that guides the development of sampling in a manner that accurately represents each asset, as well as a statistical analysis process for generating company-specific emission factors. A Final report will summarize the findings and include examples highlighting the application of the framework.

Benefits

Company-specific emission factors would offer the means of demonstrating to regulators and stakeholders accurate methane emissions reductions resulting from infrastructure upgrades and improved maintenance practices.

Additionally, effectiveness of emission-abatement programs can be quantified with periodic revisions of company-specific emission factors.

A framework for developing company-specific emission factors is a key step in guiding the industry towards more accurate emission inventories.

Technical Concept & Approach

This project focuses on the development of a framework for a statistical-sampling approach to generate company-specific emission factors considering the time, resource, and cost constraints that utilities have.

Key aspects of this framework will include:

- Sampling method selection
- Measurement of sample representativeness
- Probabilistic analysis of collected data, and
- Generation of representative emission factors.

The main objective of the framework is to allow companies to have a standardized approach for planning, collecting, analyzing, and validating data to establish company-specific emission factors. This will allow companies to visualize an emission factor study as a series of manageable steps and focus on executing the tasks.

Determining factors that affect emission rates and categorizing samples by these factors (e.g., pipe material and meter type) is important to recognize emission rate differences within an asset type. The project team will provide examples on how different assets can be stratified. Researchers will also review commercially available sampling methods and their measurement uncertainties.

A sampling plan will be designed for companies to initiate their own measurement campaigns. To allow for flexibility in experimental design, rather than prescribing a sample size, researchers will include statistical approaches for assessing the expected confidence level from a given sample size and how well a sample generalizes to the population.

Researchers will determine probabilistic approaches to analyze collected data. The selected approach will produce a representative emission factor for each asset class as the output as well as confidence intervals to represent uncertainty in the result.

One approach that has been used extensively is Bayesian analysis to generate probability distributions of emission rates followed by a bootstrap procedure to provide confidence intervals. This approach (among others) will be explored.

A framework will be developed that is envisioned to be a set of sampling plans, sampling procedures, probabilistic analysis tools, and statistical tests intended for generating company-specific emission factors and can be used repeatedly. This framework will serve as a reference to select appropriate sampling methods, design a sampling plan, and calculate the emission factors.

Results / Status

This project was initiated in the fall of 2019 with scoping discussions that resulted in an approach consisting of two methods: Method 1 - Walking Close Proximity Survey Framework (Point of Leak) and Method 2 – Mobile/Remote Survey Framework (Standoff from Leak).

Method 1 includes the sample method, sample plan, data analysis, and framework. The various forms of sampling plans are being explored (e.g., pure random, stratified random, and aggregate of multiple geographic samples). Additionally, researchers will add/address other statistical sample plans and dynamic sample plans for below and above ground assets.

Method 2 will begin in 2020 and will follow the original 12-month period of performance. Method 2 will begin with a plan on how a utility would/could start with national data and findings, and then over time, feed in their own survey data and validations to reinforce or washout the prior national data.

The team began researching techniques available for the walking survey (close proximity measurement). Once completed, the team will transition effort to the mobile/remote methods (Method 2) – where both above and below ground leaks will be considered.

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Impacts on Repairing Non-Hazardous Leaks vs. Monitoring

Researchers are developing a White Paper that identifies net positive or net negative air-quality impacts surrounding the repair of non-hazardous leaks vs. long-term monitoring.

Project Description

Gas utilities currently prioritize the repair of non-hazardous leaks based on their potential to become hazardous over time. If a leak worsens, it can be re-classified to hazardous and fixed immediately. Other non-hazardous leaks are regularly monitored and analyzed to determine the optimal process of addressing the repair. However, the process of prioritizing leak repair currently lacks analysis related to the risk associated with the remediation, repair, and/or replacement of buried pipeline assets. In some situations, digging up a pipeline for repair could significantly impact the environment (such as increased emissions and/or broader adverse environmental impacts to soil, water, and wildlife habitat).

Environmental Impact Statements conducted by utilities describe the types of air-quality impacts associated with pipeline excavation. Specific impacts may be amplified depending on pipeline location and depth.

Construction activities associated with pipeline excavation will generate NO_x and other emissions due to the use of equipment powered by diesel fuel or gasoline engines. Likewise, there is the potential for increased methane emissions if portions of the pipeline require gas purging in preparation for repair. Additionally, excavation could result in the generation of dust due to the disturbance of soil and other dust-generating activities. Risk of pipeline damage also increases anytime a pipeline is exposed for repair or replacement. This also could increase emissions.

The objective of this project is to determine the inventory emission impacts associated with digging up and repairing small-hole, non-hazardous pipeline leaks vs. long-term monitoring.

Deliverables

The deliverables for this project will include a White Paper that identifies net positive or net negative air-quality risk factors surrounding the small-hole repair of non-hazardous leaks.

"As operators, we are occasionally posed with questions or perspectives from interested parties that sometimes are not based on science. This project to examine the environmental aspect of repairing vs. monitoring natural gas leaks is one means of developing objective data of the impact of operations on the environment."

- Rick Trieste
Dept. Manager R&D
Consolidated Edison Company of New York

Benefits

The ability to quantify impacts associated with repairing non-hazardous leaks vs. long-term monitoring will: 1) improve methods used to prioritize non-hazardous leak repair, 2) provide information that could improve emissions management and environmental stewardship, and 3) result in leak-repair timing decisions that are defensible and understandable by regulators.

Additionally, operators that have had recent engagements with their state public service commissions have greatly benefited from demonstrating the *entire* spectrum of risk – to include risk associated with remediation, repair, and replacement operations – as compared to the risk of leaving the leak in place. By demonstrating a more holistic risk-assessment approach, the understanding of risk was greatly improved.

Technical Concept & Approach

Emission impacts associated with digging up and repairing small-hole, non-hazardous pipeline leaks vs. long-term monitoring will be inventoried and evaluated.

Specific tasks include:

Project Scoping

The project team will select and prioritize a list of sites to visit as well as select the type of data needed for quantifying environmental impact during pipeline excavation and repair.

Data Collection

Data will be collected according to the following parameters:

- Data will be delineated by process component, preparation, excavation (unpaved and/or paved), repair, handling and removal of solid waste, and repaving.
- Equipment inventory for repair jobs will be performed.
- Air Emission Inventory (AEI)-style data collection will be conducted.
- Both pipeline and non-pipeline sources will be included (such as off-road and on-road mobile sources) associated with excavation and repair.
- Compounds of interest will be assessed for inclusion in the inventory.

Site Visits

Site characteristics for selected study areas will be defined and include: sites with small-hole repairs; sites with Grade 2 or 3 leaks; risk factors to be inventoried for each site, and types of equipment used during the repair will be verified.

Travel will be minimized or eliminated if site supervisor can effectively feed data into a table, on a form, and/or sends pictures that will inform the emissions inventory.

Project staff will attend the site repair if possible – recognizing that small-hole repair jobs get scheduled and finished in a matter of days, sometimes hours.

Comparative Analysis and White Paper

The comparative analysis and White Paper will include the following components:

- The various risk aspects associated with the repair will be categorized by process type as well as totaled.
- Results will determine a net positive impact of repair or a net negative impact of repair.
- Data generated or gathered during the project will be used to determine leak rate thresholds by which repairs of non-hazardous leaks could be prioritized in the future.

Results / Status

A kick-off call was held on December 13, 2019, where individual action items associated with each task were discussed.

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RMDs - Sensor Drift and False Negatives

Researchers is under way to determine if a residential methane detector (RMD) that experiences a long-term exposure to low concentrations of methane will exhibit sensor drift resulting in a false negative alarm.

Project Description

A false negative on a residential methane detector (RMD) is the absence of an alarm that improperly indicates methane is not present, when in reality methane is present. Confirming that an accurate response will occur even when the RMD is exposed to low but constant methane concentrations is critical if these devices are to be deployed to the general public or used for gas facility monitoring applications.

As part of OTD's current RMD research program, extensive testing was conducted on three U.S.-manufactured RMD devices with large market shares. More limited tests were done on a few international devices from Japan and Europe. Results show that these devices perform well at 25% LEL and can often alarm down to 10% LEL. Accurate performance at 10% LEL is the critical threshold for the program and the level being recommended.

The specific sensors used in RMDs vary with each manufacturer, but, in general, are based on the same scientific principle: semiconductor Micro-Electro-Mechanical Systems (MEMS) technology. Over time, these sensors are known to experience a slight drift and the electronics are adjusted accordingly to ensure appropriate response over the estimated device lifetime.

What is unknown is how the RMDs will behave after a long-term exposure to an atmosphere containing a low-level amount of methane, lower than the % LEL alarm levels.

In this project, testing is being conducted to determine if detectors will alarm as expected when the concentration rises to the trigger level, or will the constant low exposure to methane cause a drift in the sensor response and create a false negative and fail to alarm.

Deliverable

The deliverable for this project will be a report summarizing the data on the responsiveness of RMDs after exposure to long-term and low-level concentrations of methane.

Benefits

Broader use of RMDs can warn customers of increased levels of methane before they reach combustible levels. Having an accurate and stable early-warning system in homes can improve safety and prevent unfortunate events from occurring due to unreported or undetected gas leaks.

Technical Concept & Approach

This project is designed to answer the false negative question through a series of tests on RMDs previously exposed to low levels of methane.

A new RMD test chamber will be designed and constructed with the capability of trickle-flowing methane gas and integrated sensors for monitoring and maintaining methane concentration, relative humidity, and temperature. Tickle flowing the gas will be necessary to keep the methane concentration constant and avoid leaks over the test duration.

Safety shutoffs will be added to cut off flowing gas if power and/or ventilation is lost. This test setup will be available for use on future sensor projects requiring flowing methane gas.

A series of tests will be conducted to evaluate RMD performance after exposure to long-term, low concentrations of methane.

An initial test matrix suggests:

- A minimum of three detectors for each test will be tested, from each manufacturer. At least three different manufacturers will be tested.
- Confirm performance at 10% LEL methane exposure of all devices used in study. Each subsequent test will require fresh devices (minimum of 12 devices per manufacturer).
- Expose devices to 250 ppmv methane (0.5% LEL) for one week, test at 10% LEL.
- Expose devices to 500 ppmv methane (1% LEL) for one week, test at 10% LEL.
- Expose devices to 1500 ppmv methane (3% LEL) for one week, test at 10% LEL.
- Expose devices to 2500 ppmv methane (5% LEL) for one week, test at 10% LEL.

Results / Status

This project kicked off in the first quarter of 2020. The test matrix was finalized and testing will continue in 2020.

A testing chamber will be redesigned.

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Hydrogen Working Group

The goal of this project is to develop and facilitate a focused Working Group of utilities that want to establish a comprehensive strategy for hydrogen blending into their systems. An workshop will be held to identify needs and develop a research/project roadmap.

Project Description

Advancing hydrogen as a viable energy storage strategy and fuel is integral to meeting aggressive renewable energy goals and emissions reductions. Leveraging the natural gas infrastructure will be critical to achieving these objectives. However, understanding the consequences of mixing hydrogen with natural gas throughout the North American natural gas distribution system is important for maintaining a safe and reliable network.

For successful implementation of blending hydrogen into the natural gas system, key issues must be addressed that include impacts to: compliance, safety, integrity, consumers, end users, and the environment. While there have been a handful of studies investigating the introduction of hydrogen into natural gas pipelines, many of these have been special projects driven by individual companies or organizations. A collaborative and concerted effort is needed to drive the hydrogen market to scale and make it a viable opportunity for natural gas system operators.

A Working Group is needed to discuss a holistic technical strategy for hydrogen incorporation into the natural gas system inclusive of best practices, lessons learned, end-use appliance issues, generation, blending practices, regulatory concerns, and the continual collection/review/summary of published papers and research on hydrogen blending.

For this project, a research team will develop and facilitate a Working Group of operators that want to establish a sound and complete technical strategy for hydrogen blending into their natural gas networks.

A workshop will be held to identify needs and develop a research/project roadmap that outlines the elements needed for successful implementation of hydrogen blending into natural gas pipelines.

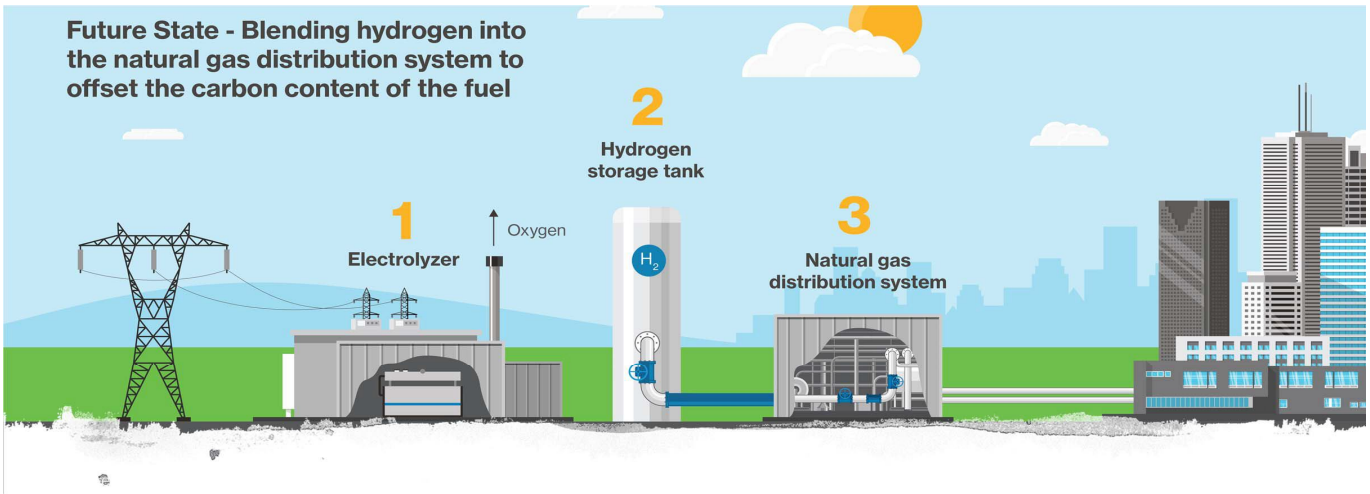
Deliverables

This project will produce the following deliverables:

- Final Report documenting the findings from a workshop
- Roadmap,
- Hydrogen information site.

Benefits

Adding hydrogen to natural gas can significantly reduce greenhouse gas emissions from gas use and will play a key role in the path to de-carbonization. However, unlike other fuels (e.g., biomethane) that have been injected into natural gas pipelines, hydrogen can



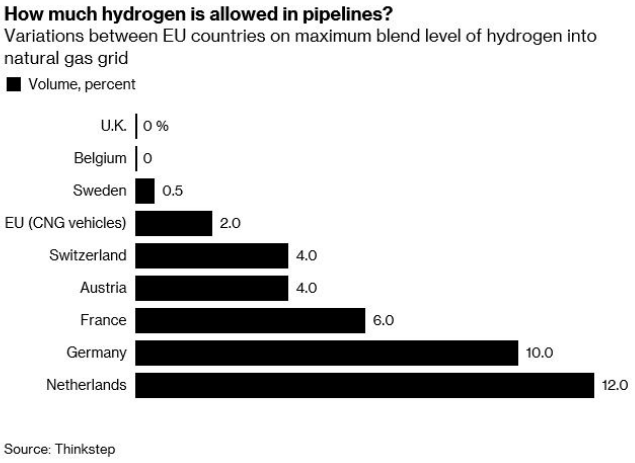
have potential impacts to infrastructure and end-use applications. Limited research has been performed at scale to assess these impacts. Establishing a focused Working Group on hydrogen will allow operators to share experiences, current efforts, and streamline the process for identifying and addressing technical gaps and other barriers to implementing hydrogen.

Technical Concept & Approach

Activities of the Working Group include an initial workshop to memorialize challenges and goals, map a strategic plan at the utility level, and prioritize next steps for developments of research projects/programs, position papers, and other studies.

The project will leverage practical knowledge of the members. A goal will be to lay out a general strategy and define successful implementation of the integration of hydrogen as a storage strategy and fuel source.

The project team will also develop a web-based library of information through literature collection and a proactive interview process with industry-leading operators in hydrogen blending. This will provide a constantly refreshed source of information on hydrogen and use in the natural gas network.



Results / Status

The project team is working to develop a hydrogen roadmap. The initial meeting for the development was schedule in the first quarter of 2020, but has been postponed. The roadmap development will continue in 2020.

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INTELLIGENT UTILITIES

Developments in this area include the use of advanced data-collection, management, and information technologies to improve the safety, reliability, and efficiency of natural gas operations.

Efforts are being made to develop, commercialize, and implement technologies to automate data collection, reduce manual data entry, enhance data quantity, and reduce data-entry backlogs.

The program is aimed at delivering software, hardware, standards, and procedures to improve the accuracy, consistency, completeness, and relevancy of information and ensure regulatory compliance.

Current efforts include the development of a process visualization and reporting capability, smart phone tools, wearable computing technology, and the development of industry-supported standards for transmission tracking and traceability.

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Remote QA/QC: Fusion Inspection and Reporting

This project focuses on the development of a visualization and reporting process to perform inspections remotely and adhere to code regulations related to field-based plastic pipe fusions. Researchers are addressing the capture of user identity, images, GPS location, and additional information required to support regulatory compliance.

Project Description

Investigations conducted by state public service commissions and the National Transportation Safety Board are leading to recommendations of increased operational scrutiny and reporting compliance in the natural gas industry. The goal of this project is to provide utilities with the capability to capture inspection-related data directly in the field as operational activities are being performed, and provide a real-time visual representation of the work for monitoring and remote-inspection purposes.

The underlying process and data-storage protocols will be developed with the intention of system flexibility for integration with existing systems and the ability to add operational activities to the developed platform.

The initial case study in this project is focused on plastic fusion inspections. Specifically, the project addresses new regulatory requirements in New York state for the visual-inspection reporting and data recording, as well as a requirement for a second visual inspection by someone other than the person performing the fusion.

Data required for recording are the location (GPS coordinates), identification of the fuser and inspector, and the date the fusion was completed. Also required is inspection record keeping of each fusion uncovered during routine operations. In addition, an auditable database containing this information must be kept.

Technology elements and processes developed under the OTD Intelligent Utility Program (e.g., mobile data collection, remote QA/QC, and excavation encroachment detection) will be used and enhanced to develop a prototype system.

Deliverables

- A fusion inspection data requirements document
- A mobile technology platform prototype
- A web-based application
- A three-month pilot project with one utility
- A Final Report
- A sponsor webinar, and
- Documentation of the fusion inspection data-collection and monitoring process.

Training images.

Benefits

Through this project, a mobile technology platform and process were developed to enable utilities to effectively comply with new regulations, with the goal of potentially performing real-time inspections from a centralized location, eliminating the need for a second qualified inspector on site.

This system can be used in conjunction with a suitable field-based inspection sampling program. The platform and process will be flexible enough to apply to other inspection activities and data-management needs resulting from the expected integrity verification process being developed by the U.S. Department of Transportation's Pipeline and Hazardous Materials and Safety Administration.

While service-based companies are focused on providing point-of-entry capability for capturing data and geospatially-tagged features for data storage, this effort focuses on streamlining and centralizing the inspection process for compliance and operational efficiency.

Technical Concept & Approach

In this project, the objective is to develop a fully functional prototype pipe fusion and reporting system for testing in a pilot project prior to commercialization.

Specific tasks include:

- Survey/Regulation Data Requirements
- Mobile Technology Development
- Web-Based Monitoring and Reporting Application Development
- Field Demonstration Project, and
- Commercialization Strategy

Results

The main concept and approach behind this project was to demonstrate the ability for a fusion inspector to perform a code-based regulatory compliant inspection on a fusion from a remote location, capturing spatial data about the fusion, data about the fusion process, and photos documenting the in-field condition of the completed fusion. By leveraging the most recent advancements with mobile devices, researchers were able to successfully define and develop a workflow system that allows for an inspector to, in real time, virtually inspect and review an activity completed by a gas utility work crew in the field from a back-office computer.

In order to achieve this, the project team developed a process that could fulfill the various visualization and reporting capabilities similar to the field-based inspections by capturing all the fusion-related data required for inspection. This included capturing the identity of the fusion operator, photos of the various fusion activities, and GPS location of the fusion, as well as any additional data determined by the project sponsors required to support compliance to changing regulations.

Researchers were able to successfully showcase this process by partnering with a sponsor on a pilot project.

In 2017, the project team developed a web application that is used for collecting and processing data for this project. The web application is available on the Gas Technology Institute web server.

In 2018, the project team built and trained the AI library for fusion-specific gas system components.

In early 2019, researchers initiated project planning and holding meetings to discuss the project timeline. The project team continued to enhance the capabilities of the AI platform to include image recognition and optical character recognition capabilities. This process included developing a database to hold all of the data collected from the AI process and store it in a way that is accessible and related to the photo.

The research team also began developing requirements to build the web application to be utilized by the office-based personnel for reviewing fusions that have been installed/captured in the field.

Researcher collaborated with internal subject-matter experts to update the joint/fusion assessment survey.

Status

The project team continues to investigate the AI portion of the project. The requirements and the use case documentation for the web application were completed.

Commercialization options were discussed and will be re-evaluated after development is complete.

Overall the *Remote Quality Assurance/Quality Control (QA/QC) Fusion Inspection and Reporting* project was successful because researchers were able to demonstrate that through the use of technology, it is possible to remotely inspect work conducted out in the field in real time.

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Internet of Things (IoT) Technology for Gas Operations Monitoring

For this project, researchers examined the current Internet of Things (IoT) technology offerings, with the goal of identifying monitoring applications for gas utilities and, subsequently, demonstrating a base-use case.

Project Description

The fundamental premise of this project is that IoT technology is creating opportunities to perform facility monitoring in completely new ways. Traditional supervisory control and data-acquisition (SCADA) systems have depended on hard wire links or dedicated radio systems for communication. SCADA installations often entail the use of power lines. While the traditional alternative is to use AMR/AMI (automated meter reading/advanced metering infrastructure) systems for monitoring, the AMI approach requires the utility to build their own support infrastructure and typically requires that all components be purchased from a single AMI vendor.

IoT technology is the confluence of low-cost sensors, processors, and ubiquitous wireless communications. The IoT approach to monitoring makes use of multiple technologies that have been commoditized as a result of the rapid expansion of the Internet and wireless connectivity. By contrast to SCADA or AMI, IoT can be deployed on an ad hoc basis as long as some type of wireless coverage is in place. The hardware costs are such that even low-volume deployments can be inexpensive, and scaling to larger deployments improves economies further. Initial IoT offerings were based on cellular or WiFi connectivity for communication. Presently, there are several new wireless carrier services entering the market specifically designed for machine to machine (M2M) communication. These new carriers are creating competition in the IoT communication space, lowering cost per point monitored.

The objective of this project was to examine the current IoT technology offerings with the goal of identifying monitoring applications for gas utilities and, subsequently, demonstrating a base-use case.

Deliverables

A base-use case that is an appropriate fit for IoT monitoring was developed. The case is regulator station monitoring. A design for a monitoring system was prepared from the use case specification and current offerings in IoT technology. The design takes into account the appropriate safety considerations for natural gas installations.

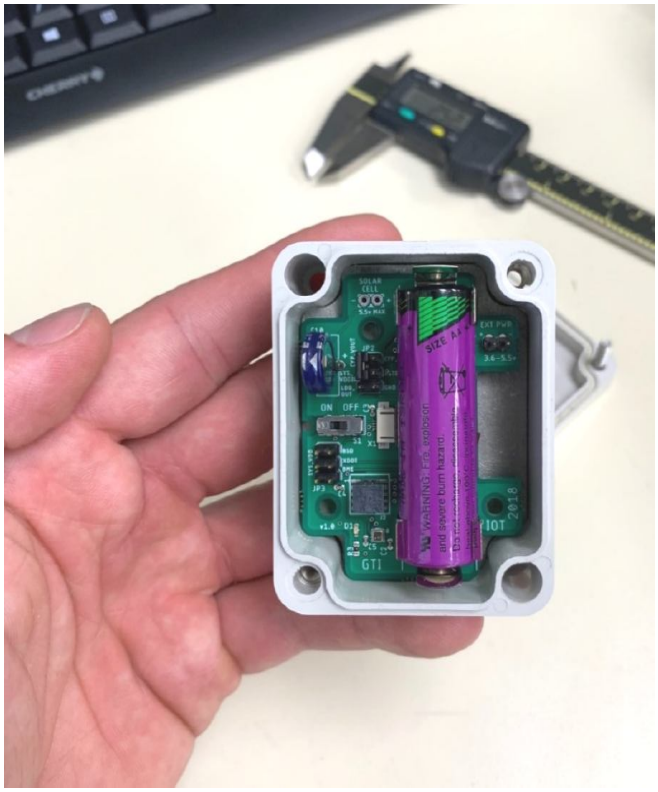
Benefits

The current growth in IoT technology presents an opportunity to use monitoring systems to automatically capture operations data rather than requiring personnel to visit. The communication channels and the connected hardware are rapidly becoming commodities, and the competition in this space is creating low-cost options for enhanced monitoring-system performance.

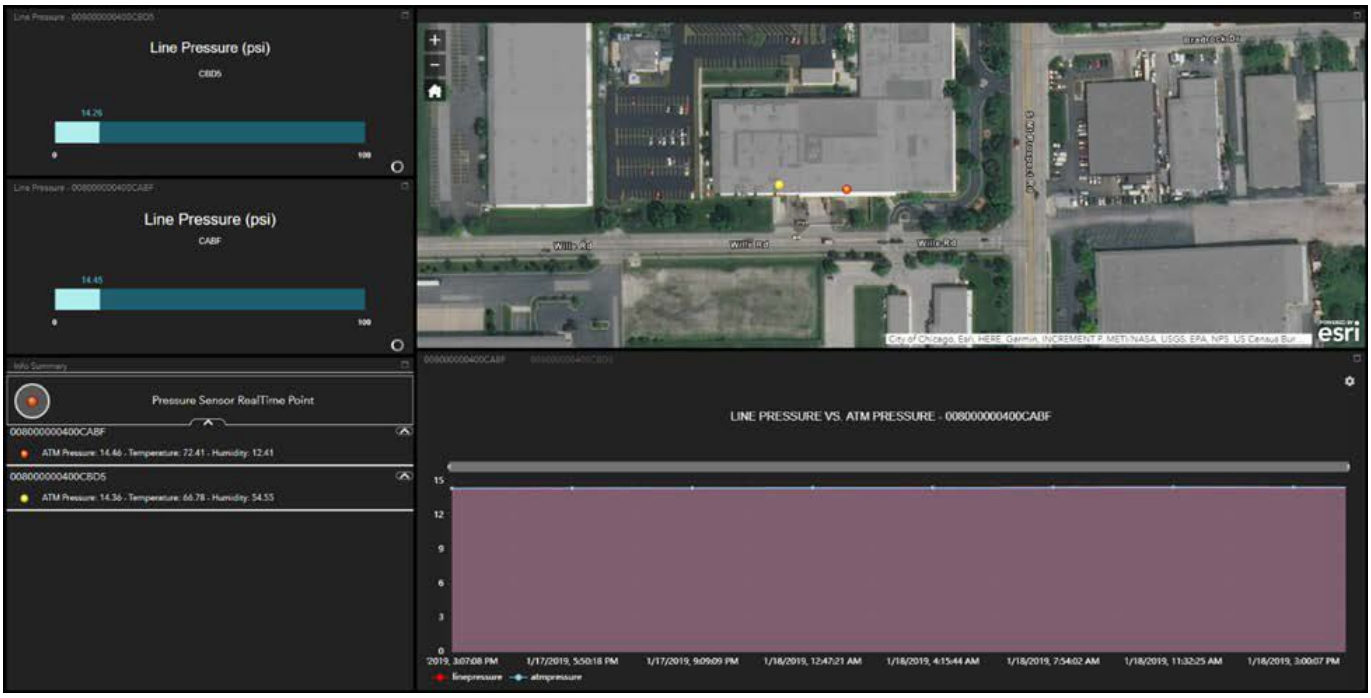
Technical Concept & Approach

This project involved two basic activities:

1. The first action was to determine a test application that fits the M2M/IoT profile.
2. Offerings from several IoT vendors were reviewed and cover such areas as hardware form factors, wireless coverage areas, rate structure for data transfer, and power requirements.



PCB in housing.



Dashboard

A field demonstration was conducted made based on the outcome of these two activities.

The project team fully analyzed the requirements of regulator monitoring (or other use case) provided by the sponsors and reviewed the most recent offerings of IoT hardware and services to determine the best match to the use case. Given the rapid development pace in this field, it is not to be assumed that the hardware used for the EEN mobile solution will be applicable to stationary sensors.

Results

The first IoT use case being investigated was remote pressure monitoring. Suitable low-power pressure sensors were selected and tested. One sensor measures the absolute line pressure and another the ambient atmospheric pressure. The local temperature and humidity were also measured. Several Long-Range, Low-Power Radio (LoRa) modules were acquired and tested.

A set of IoT pressure sensor prototypes were produced and tested. These are capable of measuring line pressure up to 87 psi, along with barometric pressure, temperature, and humidity. A solar cell was incorporated into the prototypes to supplement the primary battery. (Prototypes can be provided to sponsors on request.)

Several off-the-shelf IoT modules were identified as good candidates for evaluation. Each module contains the ability to interface with one or more sensors and contains one or more transceivers for communicating wirelessly. Specifications such as power consumption, wireless protocols, programming environment, and community support were all considered.

A total of 12 PC boards were manufactured. The line pressure sensor, battery, housing, and other large components needed for completion were added.

The device can withstand a wide variety of environmental conditions, including temperature swings from -40ºC to 85ºC, rain, snow, dirt, and sand. A pressure equalizer vent maintains equivalent pressures from the inside to the outside while keeping rain/dust out.

A base station gateway was installed and tested to verify device features, wireless characteristics, and power consumption. The ideal IoT device will have a high battery lifetime and/or a power draw that is low enough to work with energy harvesting.

Power consumption is managed by rigorous software timing of how often the various sensors and other modules are powered up and operated.

Status

This project was completed with the release of a Final Report in December 2019.

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Tracking and Traceability Marking Standard for Natural Gas Transmission Components

The goal of this project is to enable the capture of key information required for physically documenting and geospatially modeling new or repaired gas transmission systems to meet the regulatory requirements.

Project Description

This project is focused on the development of a new marking standard for natural gas transmission components. By designing the marking standard specific to the various components encountered in a natural gas transmission system, and taking advantage of newer barcoding technologies, it is believed that the standard will provide value not only in the gas industry, but potentially to other utilities as well. The development of a new standard provides a comprehensive path to accommodate the wide variety of components found in a natural gas transmission system.

The specific goal for this project is to enable the capture of key information required for physically documenting and geospatially modeling new or repaired gas transmission systems to meet the latest regulatory requirements.

Three major developments are being pursued:

1. Development of a machine-readable marking standard for all steel natural gas transmission system components
2. Construction of automated field-data-collection processes linking the required manufacturers' inspection and test documentation and supporting the automated definition of each field-installed component, and
3. Acquiring industry acceptance for publication of the standard under one or more standards organizations.

Deliverables

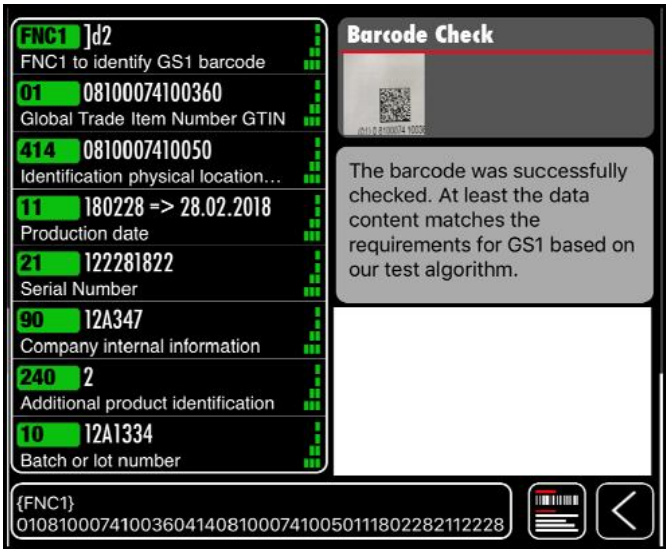
Deliverables include:

- A working protoype system capable of being transported to industry conferences to demonstrate the new standard's use in manufacturing, shipping, warehousing, and construction
- A Final Report in the form of a purchasing document for invoking the use of the new marking standard, and
- An implementation roadmap and recommendations for the new transmission marking standard.

Benefits

The development of field-data-collection processes to document the installed components and associate the proper inspection and test documentation is contingent on a properly designed electronic marking system that links the manufacturers' inspection and test documentation and associated product data. Performing these processes manually requires significant labor, can result in errors leading to construction delays, and may result in additional testing to prove component specification compliance.

The experiences of using intelligently marked plastic distribution components has shown to significantly reduce the time to document a new or repaired natural gas distribution system. With the establishment of the marking standard for natural gas transmission lines, utilities should be better equipped to construct their transmission facilities and implement controls over establishing the required documentation.



Sample software to identify components.

Technical Concept & Approach

In addition to marking standards development, efforts will be made to:

- Establish new application identifiers for fields (Utility Component Type and Heat Number) required to support the new transmission marking standard developed in Phase 1.
- Establish a voting membership at GS1. The GS1 voting members will be formed from the core industry group members who are currently in the Phase 1 project and new trading partners, utilities, distributors, and manufacturers added in 2019 and 2020.
- Continue the build demonstration mobile software technology to use in pilot systems for collecting key information from marks on transmission components.
- Conduct pilot programs to demonstrate the new standard's ability to provide accurate track and traceability for components used in the construction of natural gas pipelines.
- Develop processes, procedures, and protocols to stage and manage inspection and test documentation for components.

Results

The project team reviewed manufacturing standards and marking requirements for the many different transmission components and found that the marking standards primarily focused on identification of the product, almost exclusively, in a human-readable form. After reading a number of the manufacturing standards, researchers identified GS1 standards, the original marking standard developed and put into use in 1974 for marking products in retail operations. After studying the GS1 standards, it appears that using a marking standard not tied specifically to the manufacturing processes could yield results that would not be controlled by a specific manufacturing standards group. By adopting an existing standard marking architecture (GS1), many of the challenges of the project might be solved.

The GS1 standard's architecture has been used by many key industries to achieve a high degree of tracking and traceability. GS1 standards are made available in the public domain and are not propriety to any specific industry.

A White Paper was prepared to address the myriad challenges associated with solving the transmission tracking and traceability needs of the natural gas utility industry.

In 2018, considerable progress was made in defining the individual properties that are to be included in the new mark for the transmission components. The marking standard is being organized by component class with specific rules developed for each class of components. The architecture sets three levels of information to be included in a utility mark, covering product definition, quality and security, and graphic/geospatial modeling properties. Researchers are developing a structured specification for each of the properties to be included in the marks for each class of component.

The project purchased a small-scale inventory and manufacturing management software product for development and demonstration of processes required to automate and manage the marking processes recommended by the new standards. This system is capable of creating the new marking standard for application on many different types of transmission components.

In 2019, research continued on the final set of marking standards for the project. The standards are intelligent GS1-based functions contained in a 2D barcode and a standard set of attributes for each component class, pipe, valves, assemblies, fittings, and general utility components. Additional plastic fitting components were added to show the use of GS1 standards for marking distribution plastic components.

The project team completed the scope for the development of the first phase of software to run on iPhone and iPad for scanning direct part marks on transmission components that comply with the standards from this project. Initial activities of this development will build a scanning tool for assisting the manufacturers with developing 2D barcodes that comply with the marking standard. The application development is planned to continue into the Phase 2 of this project and will provide advanced features of connecting to the GS1 Global Data Synchronization Network.

Status

Researchers are completing marking guidelines for publication.

Two pilot programs are being established for the demonstration of marking guidelines and its integration with GS1's synchronization network.

The project needs more participation by utilities demonstrating project backing and support.

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GNSS Smart Applications for Field Data Collection

Efforts are under way to increase the quality and consistency of location data collected by the natural gas industry through the use of Global Navigation Satellite System (GNSS) receivers. The approach is to automate certain steps of the data-collection process and reduce the burden on field-data-collection personnel.

Project Description

For several years, OTD has supported research into the evolving nature of Global Navigation Satellite System (GNSS) technologies for the natural gas industry via the GNSS Consortium project. Through the consortium, various GNSS receivers were investigated under real-world testing scenarios mimicking typical gas-industry workflows.

In Phase 1 of this project, a research team created a prototype hardware add-on which helps the field-data-collection personnel apply the correct operating procedures while handling the GNSS receiver. The system also increases safety by allowing data-collection steps to be broken down into two phases so that the user is only required to handle one device at a time. Ten prototypes were assembled, provisional patents were filed, and commercialization planning initiated.

The new technology helps ensure consistency and verifies that quality thresholds are satisfied.

The current Phase 2 includes hardening the physical form-factor to better support durability in the field. Researchers will also offer to support field pilots of the second-generation prototype to allow customers to learn more about the product and to provide comments on its real-world application.

The goal is to develop sufficient documentation so any vendor could assemble the hardware and configure the software in an on-demand fashion for any customer.

Deliverables

This goal for this project is to produce a software and hardware technology that operates between the user's existing GNSS receiver and existing field-data-collection smart devices.

The technology will help ensure consistency and verify that quality thresholds are satisfied through automated data collection. Additionally, the technology will reorganize the collection process so that the field-data collector is required to operate and handle fewer components during any given step.

Benefits

Data quality is an important issue for any organization operating in today's information technology environment. High-quality data allows for detailed and reliable analysis that can support optimizations to business efficiency and improve input to risk assessments and management.

GNSS devices offer many customized functions and automations that assist the data collector in improving accuracy. However, due to the large geographic nature of natural gas piping systems and the distribution of job functions, it may not be financially practical to place an expensive device in every data collector's hands. The hardware device being pursued in this project will provide access to accuracy-helping functions at a financially feasible price point.

Increasingly, it is necessary to pair field-collected data with high-quality geographic locations suitable for mapmaking and other geographic information system analysis functions. Research into GNSS devices shows

Phase 2 beta prototypes ready for testing.

that the best predictors of quality are first the capabilities of the hardware device itself and, as close second, the techniques and practices used by the field-data collector. Standardizing the collection process through smart automations can increase the accuracy of the GNSS position.

Technical Concept & Approach

Initially, the project team analyzed the technical requirements of the project, solicited input from the project sponsors, and compared options already on the market.

Researchers produced an initial set of design documentation and a functional prototype suitable for validating the feasibility of the project

Test-case documentation is being created based on the requirements and design documentation. The test cases exercise each function, service, and design element. Researchers will execute each test case multiple times and record the actual results of the test. In cases where the actual results do not satisfy the expected results, the project team will re-work the prototype until the system passes all tests.

In Phase 2, a set of second-generation prototype units will be built. The hardware subsystems and customer software modules will be updated to support Bluetooth connections to various mobile devices. Researchers will construct up to 20 duplicates of each prototype for each company who is interested in on-site field demonstrations, training, or pilot-project implementations.

Results

In Phase 1, a total of 10 prototype units were assembled and field tested. Candidates for commercialization and additional development were identified and interviewed.

The project team completed an evaluation of existing technology, concluding that the objectives of this project are distinctly unique. As a pre-requisite step, researchers identified and documented product requirements and uses cases. This document defines the specific functions and value of the system.

Employing the model-driven approach, a common information technology practice, researchers identified a set of hardware and software components which could be used as a platform to realize the previously documented requirements specifications. A Single Board Computer (SBC) running an embedded Linux Operating System was selected, specifically the Raspberry Pi 3 (RPI3), as the primary computer environment. The RPI3 fell under the weight and size requirements, is available as a low-cost consumer product, and is supported by many open-source organizations.

"Capturing high-quality geospatial coordinates of our assets is a vital component of producing traceable, verifiable, and complete as-built records. The GNSS Smart Automation box will automate a major step in the data-collection process instead of relying on the field user to optimize the quality of the GNSS at the time it is recorded."

- Stephen Jeong
Senior Gas Engineer
Gas Operations R&D and Innovation
Pacific Gas & Electric Company

Another key reason for choosing the RPI3 is the availability of an all-in-one sensor system and LED display called the Sense HAT. The Sense HAT is designed for the RPI3, is programmable via Python, and contains the nine degrees of freedom sensors required to detect a perpendicular orientation.

A set of custom software scripts were written which encapsulate the required algorithms for automating the collection of high-quality point estimates from the GNSS device. The software scripts also include accepting user command via the Sense HAT's joystick and displaying status indicators and messages.

In 2019, Phase 2 was initiated. Researchers completed development of the new software components and the creation of a 3D printed case. A sturdy, field-ready case replaces the alpha prototype case use during Phase 1, which was a less-sturdy design made from off-the-shelf components. The system was demonstrated at the AGA Operations Conference.

The project team prepared two Phase 2 beta prototypes for systems testing. All system testing scripts were finalized and formatted for live field-based testing.

A three-phase approach was chosen for unit testing, integration testing, and systems testing.

Status

The Phase 2 effort is complete. The project team conducted a demonstration early in 2020. Phase 3 continues optimizing the technology for commercialization.

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Low-Cost RTK Base Station

The objective for this project is to promote the wide adoption of high-accuracy Global Navigation Satellite System (GNSS) technology by removing barriers to the implementation of real-time kinematic (RTK) technology. Research is focused on increasing access to data and creating an inventory of publicly available base stations.

Project Description

The natural gas industry is motivated to place high-quality Global Navigation Satellite Systems (GNSS) technology in the hands of an increasing number of personnel. Consequently, gas utilities hold a special interest in lowering the per-user cost of systems so that achieving high-quality data is economically feasible.

As part of the GNSS Consortium, OTD supported a formalized receiver testing program conducted that indicated that real-time kinetic (RTK) GNSS systems are the most reliable and efficient methods for achieving high-accuracy position estimates. RTK receivers not only produce points that are both accurate and precise to a few centimeters, they also do a better job coping with the various problems associated with difficult real-world data-collection environments.

In recent years, researchers have been collaborating with several gas utilities in efforts to remove barriers to implementing these systems across individual utilities. In 2016, research was completed on a project sponsored by Gas Technology Institute's Sustaining Membership Program (SMP) to investigate the possibility of creating low-cost RTK base stations as an alternative to fixed-base stations. The SMP project developed two versions of proof-of-concept portable base stations. The project proved that temporary portable base stations, which run on batteries and register their own location at boot up, are feasible.

Prototype developed through the SMP program.

This project builds on the SMP project and focuses on increasing access to base-station data by creating an inventory of publicly available base stations, testing a publicly available base station at a long distance, and continuing the development of low-cost, portable, base-station technology.

In Phase 1, researchers tested the performance of low-cost RTK base stations in conjunction with low-cost RTK rover receivers. The current Phase 2 involves a pilot projects to further evaluate the system.

Deliverables

Project deliverables include:

- A catalog of publicly available base stations
- A base station comparison report
- Prototype hardware
- Prototype software source and deployment
- Requirements analysis documentation
- Design documentation, and
- Test cases and test-case results.

Follow-on steps include discussions with potential vendors, enhancements of the technology as needed, operator field tests, and pilot programs.

Benefits

Gas utilities share a common strategic goal to be safe, reliable, and compliant suppliers of natural gas. More and more, the business activities and processes necessary to achieve safety, reliability, and compliancy goals either produce and/or rely on high-quality data. Achieving these goals at a lower cost would contribute to the efficiency of the organization.

Technical Concept & Approach

Specific tasks in this project include:

- **Cataloging and Testing Publicly Available RTK Base Stations**

  Some states offer publicly available RTK base station networks that provide a free connection via the internet to RTK correction data. The project team researched and documented a full list of free base stations operating in the United States. One drawback to public base station data is that the effectiveness of the correction data degrades the further away the receiver unit is from the base. Researchers conducted a comparison test between the accuracy of a traditional, private, fixed-location base station and a public base station a distance away.

- **Portable Base Station Design and Development**

  Researchers detailed the requirements and design for a portable base station. All documentation will contain sufficient detail so that a third-party commercial vendor could reproduce the unit upon request.

- **Prototype Testing and Re-Work**

  This task includes creating test-case documentation based on the requirements and design documentation. The test cases exercise each function and design element. Researchers executed each test case multiple times and recorded the actual results of the test. In cases where the actual results do not satisfy the expected results, the project team re-worked the prototype until the system passed all tests.

- **Pilot Projects**

  The system is being evaluated in a pilot projects with a program sponsor.

Results

The project team completed an intensive search for free-to-use public base stations. Documentation cataloging these base stations and the lessons learned is included in a report issued in August 2018.

The results of testing were somewhat unexpected. The original hypothesis was that if a high-cost system may reliably produce one to two centimeters in accuracy and precision, a lower-cost alternative RTK system could be found which would produce about 30 centimeters or one foot. However, testing revealed that the lower-cost units produced similar accuracies and precision value to higher-cost systems when the unit was able to achieve an RTK fix solution; but the lower-cost units took longer to acquire an RTK fix, lost RTK fix status more frequently, and in some cases could not acquire an RTK fix solution. In other words, the trade-off for low-cost systems was shown to be in reliability and performance rather than in precision and accuracy.

In 2018, the research team completed testing and compiled the test reports for the Final Report.

In 2019, Phase 2 was initiated with the development of pilot projects designed to help project sponsors and pilot site volunteers better understand the capabilities and limitations inherent in low-cost RTK Systems. A newer system was released that is based on a dual radio band technology (the first version is based on a single radio band system), which will be used in the pilot projects.

Researchers are very pleased with the reliability, precision, and accuracy new system. On average, the system produced horizontal locations when achieving an RTK fix that was 1.7 centimeters from the actually known point with a precision of 2.5 centimeters under real-world conditions. Additionally, the system produced vertical measurements averaging 0.7 centimeters below the know elevation with a 1.8 centimeters standard error.

Status

Researchers continue to prepare for on-site demonstrations.

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Integrity-Management Module and GIS Platform for Mobile Data Collection

The objective of this project is to develop a component-based software system to support the collection of data produced by gas-system field activities such as integrity assessments, examinations and evaluations, repairs, prevention, and detection.

Project Description

Collecting integrity-assessment data as digital records can streamline the process of merging all of the records needed for analysis by a gas utility's integrity management risk models.

The objective of this project is to develop a component-based software system consisting of two major components: 1) a core mobile geographic information system (GIS) platform and 2) an integrity-management module supporting the collection of data produced by gas-system field activities such as integrity assessments, examinations and evaluations, repairs, prevention, and detection.

The component-based approach to systems development delivers maximum flexibility during commercialization and implementation. For example, a utility that has already implemented a field-data-collection solution can extend its existing system by adding on an integrity-management module developed through this project. On the other hand, a utility with no existing field system can deploy both the mobile GIS platform and the integrity-management module.

Another advantage of the component-based system is that researchers can re-use the core GIS platform component to develop new module components. In the end, time to market will be shorter and development costs will be lower compared to re-creating the full solution for each product.

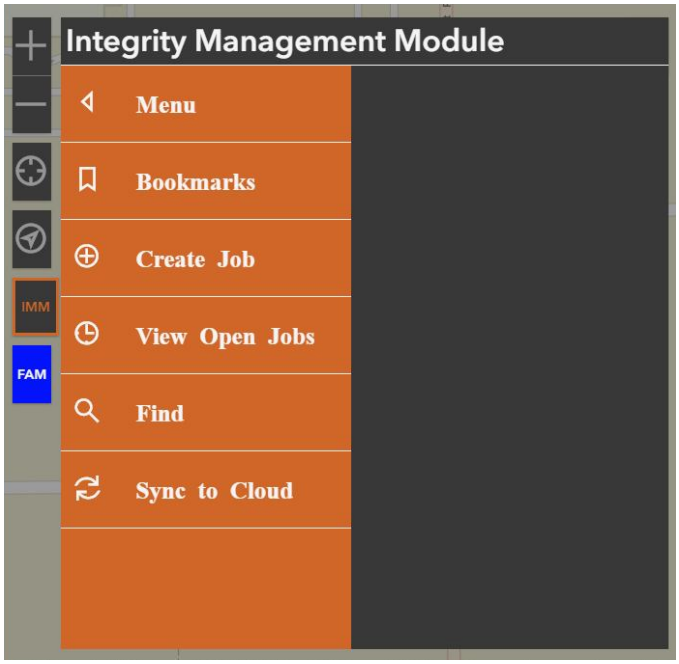
The module will contain all the business logic necessary to support integrity-management data-collection activities. The core GIS platform will support common field workflows and support communication with the module.

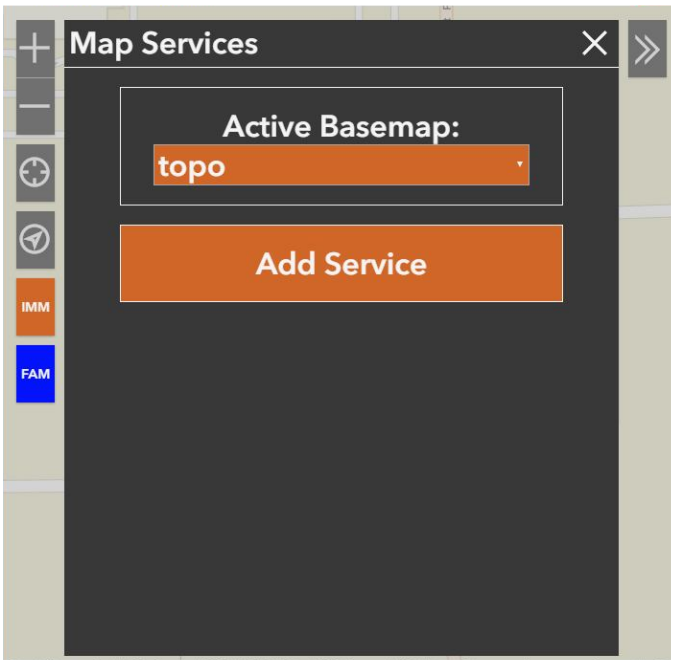
The ultimate goal is to produce a viable, competitive, tested, and commercial-ready product.

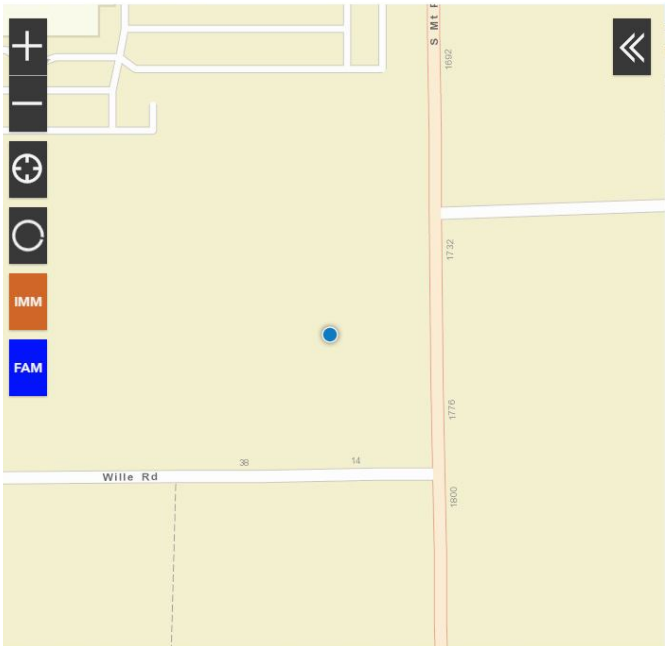
Deliverables

Project deliverables will include:

- Software and source code
- Requirements-analysis documentation
- Design documentation, and
- Test cases and test-case results.







Tracking global navigational satellite system location.

Benefits

Accurate, meaningful, and connected data collected in the field by gas operations personnel will continue to become more and more critical to the safe, reliable, and compliant operation of natural gas delivery systems. Migrating existing processes to or creating new business process based on digital record-collection systems provides an opportunity to improve the quality of an organization's data.

Technical Concept & Approach

Commercialization of the mobile GIS software platform and integrity-management module will follow a three-phased development approach.

The objective of Phase 1 was to produce a pre-prototype of the integrity management module and the core GIS platform. Specific Phase 1 tasks included:

- **Requirements Definition**

  Researchers documented a list of required system functions by gathering information from internal subject-matter experts, project sponsors, regulations, and standards related to data collection for integrity assessments.

- **Design and Development**

  The design documentation specifically calls out the structure of the module and the communication between the module and the core GIS software. The design documents contain sufficient detail to support the construction of the pre-prototype system and will support creation of detailed implementation guides in later phases.

- **Testing and Re-Work**

  This task included creating test-case documentation based on the requirements and design documentation. The test cases exercise each function, service, and design element.

In Phase 2, researchers will further develop the software system. A beta prototype will be produced in Phase 3. The beta prototype will be further tested and improved via pilot projects and demonstrations.

Results

During Phase 1, a module was built covering the basic data-collection requirements associated with integrity-management field activities such as assessments, examinations and evaluations, repairs, prevention and detection. In order to support development, testing and demonstration, a simple core GIS application was also created.

The solution accomplished research goals, but not without challenges, the most significant of which was developing a software module which is compatible with a wide variety of unknown software from various vendors. However, development of the use-case requirements, processes, and structure is still useful.

Status

A Phase 1 Final Report was issued in August 2019.

A follow-on project will be conducted to further develop the software system. A more detailed requirements and design specification will be developed via a rigorous analysis of ASME B31.8s Managing System Integrity of Gas Pipelines and subject-matter expertise. Based on detailed requirements, an alpha prototype will be hardened into a beta prototype.

A second follow-on project will be conducted to mature the prototype created in Phase 2 into a beta prototype based on lessons learned and sponsor feedback to date. The beta prototype will be further tested and improved via pilot projects and demonstrations.

At the conclusion of Phase 3, GTI will have produced a viable, competitive, tested, and commercial-ready product.

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Component Marking and Laser Etching Development

Research is being conducted to improve the durability and readability of data carriers (e.g., barcodes) suitable for use on construction materials. Researchers are investigating improvements in data carriers, 2D barcodes, RFID, intelligent coating systems, and embedded intelligent particles in the bodies components.

Project Description

There are a variety of data carriers used in marking systems serving the sales and inventory management of construction components. However, these same data carriers (e.g., barcodes) fail to adequately perform when the components are placed in long-term storage or are delivered to the field for installation. Barcodes are often unreadable because environmental conditions or handling practices that damage, degrade, or misalign the mark, limiting its readability. Inks, transfer films, and toner-based labels all are perfectly adequate for indoor service, but are quickly compromised when outdoors in the weather.

The natural gas industry has a number of software applications that automate the inventory management of valves, fittings, pipe, and other components for construction and is developing an ever-increasing number of tracking and traceability solutions by reading component attribute data from data carriers that are attached. Unfortunately, these advances can only be brought to full capability when the underpinning technology (the data carriers) is robust and reliable.

The objective of this project is to improve the durability and readability of data carriers suitable for use on construction materials. This project is researching improvements in data carriers, including barcodes, radio frequency identification (RFID), intelligent coating systems, and embedded intelligent particles in the bodies of construction components.

In Phase 1 of the project, preliminary technology was built to directly mark on a carbon steel part not using an intermediary label or tag. The marking process uses a laser to engrave a 2D barcode directly on the surface of the component. The Direct Part Marking (DPM) process has inherent advantages over the application of labels, tags, or other surface-applied marks. The DPM is not affected by UV if the part is stored outdoors, unlike ink-based printing. The direct part marks can withstand the preheat conditions common to welded assemblies.

Phase 2 research focuses on data carriers that may be read by a machine during transportation, storage, and eventual incorporation into a network service delivery system or structure.

Deliverables

Deliverables include:

- A report of available data carriers that could improve the readability of an intelligent mark for steel components, and

(Left) Laser-etched barcode samples before testing; (right) after corrosion testing.

- Test results and a report analyzing the results of the laser etching research.

Benefits

This research is designed to enable and increase process efficiency throughout a number of purchasing, transportation, warehousing, and construction activities. This project will make possible the development of software systems improving fundamental business processes.

Technical Concept & Approach

Efforts are under way to optimize anti-corrosion formulations (aerosol and concentrated) developed in Phase 1 to extend the useful life of a 2D barcode for DPM and enhance the readability of 2D direct part marks. The project team is investigating quick-drying top-coating technologies to improve the overall resiliency of 2D barcodes on carbon steel. Preliminary success of Phase 1 anti-corrosion formulations has extended the useful life of a 2D barcode to 17 salt spray treatments. Coated 2D barcode samples were readable after 54 salt spray cycles.

Research performed in Phase 1 used a manual 20-watt laser. In Phase 2, researchers will use a 100-watt production laser to develop processes to support production marking processes, speed to etch, resistance to damage, optimization of anticorrosion properties, compliance with data matrix barcode standards, optimized reflectance, and contrast properties.

Results

In 2018, setup of the laser at laboratory facilities was completed, followed by training and use of the laser with online resources. The test equipment was used to produce a number of samples to test the improved corrosion resistance of laser-etched marks and evaluate the metallurgical effects of the laser-etching processes on the base metal.

The project is testing four different application methods of the corrosion-resistant materials applied to the barcode during the laser-etching process. The first two application methods of coating (electro-spray and ink-based coatings applied through blotting processes) were tested to gauge suitability for application purposes. Polymer-based, and electro-spinning application processes were tested in 2019.

The project team evaluated the impact of the thermal processes of laser etching the base material. The results of the evaluations did not show any adverse changes in the mechanical or chemical properties of the base metal. There was also no evidence of any changes in the granular structure of the base metal.

Untreated 2D barcodes control samples were tested to be unreadable in less than an hour when exposed to simple high-humidity conditions. The treated test samples showed marked resistance to corrosion when exposed to an aggressive corrosion condition of a periodic bath of saline solution, approximately the same consistency as sea water. Treated 2D barcode samples were readable through 80 hours of testing.

Accelerated corrosion tests were completed in 2019. A total of 55 unique suspensions of zinc oxide were generated and used in a variety of ways to build a total of 100 test samples.

The project team is also testing a fast-setting, UV-cured, optically clear epoxy overlay to provide extra protection for the new 2D barcode etch to extend its service life in the atmosphere.

Researchers tested epoxy overlay materials to increase corrosion and abrasion protection for the direct part marking applied with the laser etching and treatment processes. The initial epoxy material formulation proved to be to reflective and made the underlying 2D barcode difficult to read. Subsequently, samples were received of three new formulations with matt finishes for additional testing.

Status

The following activities are under way:

- Evaluation of laser equipment
- Production testing to optimize cycle times with production laser
- Development of criteria from production testing processes to document and program all laser operations for use at a production marking facility, and
- Initiate optimization work for refinement of anti-corrosion agents applied to laser-etched barcodes, application methods, and light contrast properties of barcodes.

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Microsoft HoloLens Platform Enhancement

The objective for this project was to identify and potentially develop hardware to improve the usefulness of the Microsoft HoloLens and other holographic technologies. Researchers are defining new capabilities to be built into the HoloLens platform that are specific for the natural gas industry.

Project Description

In recent years, researchers have explored new computing platforms for the natural gas industry that aim to change the way data collection occurs and streamline processes used in the field.

Devices such as the Microsoft HoloLens provide a new experience for field workers to interact with data and the environment around them. Paired with other computing systems (e.g., the utility's GIS, work-management systems, and asset-management systems), these visual-based computing platforms can provide many benefits to utilities.

The objective for this project was to identify and potentially develop hardware to improve the usefulness of the Microsoft HoloLens and other augmented/virtual/mixed-reality devices in field situations.

Building off an ongoing project sponsored by Gas Technology Institute's Sustaining Membership Program (SMP), research focused on defining new capabilities to be built into the Microsoft HoloLens platform and others that are specific for the gas industry and tailored to the specific needs of the sponsors.

Deliverables

The deliverables for this project include a Final Report detailing the use of devices in the real world.

Benefits

Augmented, mixed, and virtual reality can provide next-generation capabilities to capture data, analyze data in different ways, and fundamentally change the way a gas utility collects data in the field.

These visual-based computing platforms can provide benefits to utilities, including a hands-free workflow, spatial visualization of field data, virtual walkthroughs, and remote support. Developing hands-free workflows and improving remote support or assistance can increase safety and the productivity of workers in the field. In addition, situational awareness can be improved through interactions supported by the Microsoft HoloLens.

Technical Concept & Approach

The scope of this project enhances the completed SMP project, in which researchers demonstrated the functionality of holographic computing using the Microsoft HoloLens. The goal is to expand the capabilities of the software through further development of spatial data visualizations and the development of additional functionality.

Specific tasks included:

- **Technology Development**

  This task included the review of the previous SMP project deliverables and an expansion upon the lessons learned. In addition, this task incorporated a review and development of any field-specific hardware required to integrate with the Microsoft HoloLens platform, including:

  - Visual aids to enhance outdoor viewing
  - Integration with satellite/high-accuracy positioning devices, and
  - Integration with hard hats.

- **Data Integration**

  This task supported the integration of gas-specific datasets and visual support of items for the Microsoft HoloLens or other platforms. The project team identified the different data types commonly found within a gas system GIS and developed functionality and support to display this data within the platforms.

- **Pilot Project**

  In cooperation with a project sponsor, the research team obtained HoloLens equipment, set up and integrated the sponsor's GIS, and conducted a supported three-month pilot project with a specific use case within a sponsor's company.

Results

Initial activities included the identification of mixed-reality devices to be evaluated as part of the project.

Researchers re-visited the Microsoft HoloLens platform using the vGIS software from Meemim. A number of updates have occurred to the hardware (HoloLens) and the software (vGIS) platforms. The new updates improved functionality and added features to the software platform.

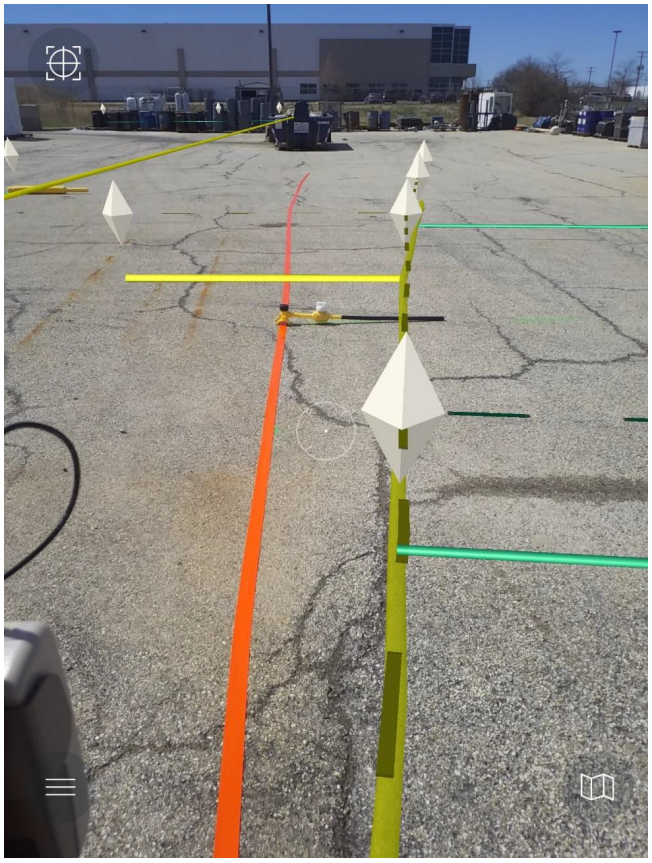
The project team developed a test plan to exercise the ability of the different platforms to display the holograms and evaluate the accuracy. The results of the testing provided areas for improvement in both a hardware and software. The underlying technology and capabilities of the hardware and software platforms will be constantly evolving and will benefit from more widespread consumer adoption.

Researchers tested the vGIS application on the Microsoft HoloLens, an iOS device (iPad Pro), and an Android device (Samsung Galaxy Tablet).

Improvements to the user experience include:

- *A Personalization Option* – allowing the user the ability to change between base maps
- *Background Data Processing* – endless and seamless scrolling functionally, and
- *Surface Scanning* – scan the surface around you to determine the height of your device, plus the ability to center and locate structures below the ground, eliminating the illusion of floating objects.

Additionally, visual improvements were added to allow a user to switch between views based upon the job they are working on, as well as the option to designate a fixed height for a user.



Holographic Images: The orange line represents "real-world" asset (pipe) and the yellow line represents HoloLens projected asset (pipe).

A *Group Option* was also added, allowing a utility to segment their company into groups or subgroups to control the level of access to specific data based upon unique permission or customized viewing options based upon personalized groupings.

A Final Report was issued in May 2019.

Status

Successful completion of this project created additional pilot-project opportunities with gas utilities and furthers the development of the platform.

Overall, the functionality is showing promise, although there are many technological hurdles to overcome before it will be useful for all potential applications. The combination of cutting-edge hardware and software required to enable the most beneficial use cases need to be refined to allow users the best experience.

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Technology for 24/7 Leak Detection

The objective for this project is to integrate a suite of existing technologies into a prototype 24/7 leak-monitoring system. Researchers are investigating state-of-the-art methane sensing, wireless connectivity, and web-hosting technologies.

Project Description

The increasing necessity to detect, monitor, and mitigate methane emissions drives the need to automate some tasks in this area. Routine patrols of construction sites or high-consequence areas now require visits by personnel. There are also facilities, such as gates or large regulator stations, that need periodic attention. Automated monitoring of these areas would allow personnel to be dispatched where most needed.

OTD has sponsored several efforts that involve measuring leak concentration or flow and delivering the data wirelessly. These projects produced prototype tools that address specific use cases, such as:

- Investigative tools for first responders
- Leak classification by flow rate, and
- Unattended monitoring of known leaks.

The use cases that these past/ongoing efforts addressed have all been reactive: a leak call was made and mitigation is in progress. They are monitors rather than detectors. A suite of base technologies was developed in these projects that can be redeployed or extended. The objective for this new project is to integrate a suite of existing technologies into a prototype 24/7 leak-monitoring system. The system will use state-of-the-art methane sensing, wireless connectivity, and web-hosting technology. Several use cases and the data requirements for continual monitoring will be investigated.

Unattended methane sensors.

Deliverables

The following deliverables are expected to result from this project:

- A use case specification for an automated leak-detection system for temporary deployment
- Description of the data that the sponsors require from a leak-detection system
- A reference design for the component modules required to construct prototypes of the leak-detection systems
- Construction and testing of prototypes, and
- Deployment of the prototypes at utility test sites.

Benefits

The deployment of an automated system for continual leak monitoring would provide benefit in terms of resource allocation and scheduling. Personnel could be freed from some routine leak-patrol activities. Information provided by the monitor can be used to target personnel activities where they are most required.

Technical Concept & Approach

The scope of this project is to define and prototype an automated 24/7 leak-detection system. The system will need high sensitivity and the ability to operate with little or no operator attention for extended periods of time.

It is anticipated that the prototype systems will make use of wireless technologies from earlier projects. The specific technology is a low-power, long-range radio standard: LoRaWAN.

Specific activities include:

- **Project Scoping**

  The project team will define the requirements for a 24/7 detection system. There is a need to differentiate temporary and permanent use cases as these will have different requirements. A temporary system could be deployed for weeks or months at a construction site or other active area. Permanent detectors could be placed at stations containing utility assets or along high-consequence lines. The sensor types and ranges will be defined. The range and sensitivity of the methane sensor will be determined.

- **Preparation of a Reference Design**

  The design will be as modular as possible to support the re-use of hardware between temporary and permanent installations. A modular power supply that can be battery- or mains-powered will be developed. Interchangeable housings to adapt for different sizes of battery packs will designed. Standard modules for the core processor, radio connectivity, and sensors will be common to all designs. A module for cellular connectivity will be developed so one node can be a cell gateway in the absence of public coverage.

- **Construction and Testing of Prototypes**

  In addition to electronics and power modules, the project team will fabricate housings specific to permanent and temporary detector nodes. Researchers anticipate building several copies each of the temporary and of the permanent leak-detector nodes. Functional and range testing of the prototypes will be conducted.

- **Deployment of Prototypes**

  Test sites for the leak detector nodes will be solicited from the sponsors. The first step in a deployment will be to verify who the data recipients are in the testing utilities and their specific information needs. The project team will provide training with the detector prototypes and assist in deployment.

- **Data Analysis and reporting**

  Investigators will capture test deployment data traffic that will be maintained specifically for this project's data. The research team will use the data to analyze the detector system performance. The data and findings will be provided to the sponsors on a regular basis.

Results

The path being followed is to develop common processor and sensor modules, but several versions of the power supply and communication modules. This will allow the maximum amount of re-use but still allow some customization for different missions.

One of the objectives of this project is to develop a framework of software and hardware modules for methane (and other) sensors that can be re-used with multiple communication systems. In support of this, a new methane sensor type, an environmental sensor, and a new communication platform were investigated.

Sensors are being investigated that provide sensitivity to methane down to 0.1% gas by volume, low-power operation, and quick (30-45 seconds) warm-up time.

In addition, the sensors have:

- Long-term stability (one-year) of calibration
- Built-in serial interface that simplifies support hardware
- Real-time auto-gas calibration and built-in environmental compensation, and
- No catalyst (therefore poison-resistant) and intrinsically safe.

A third sensor was investigated that senses volatile organic compounds, pressure, temperature, and humidity.

Status

The project team is developing use cases for continuous leak monitoring. Researchers are building a set of standard modules for communication, power, processing, and sensing that can be re-used in different combinations to cover multiple use cases. Methane sensors are currently being investigated. Additional environmental sensors that provide temperature, humidity, barometric pressure, and the presence of volatile organic compounds are also being investigated. These sensors would complement the primary goal of gathering methane data.

Researchers are soliciting customer feedback on their 24/7 monitoring applications. Prototypes for temporary or permanent monitoring can be prepared based on this.

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Incorporating Pipeline Safety Management Concepts into Existing Programs

Researchers are using business-analysis processes to develop methods to improve overall organizational safety by broadly implementing pipeline safety management concepts across existing programs and technology platforms.

Project Description

Gas industry regulations, specifications, standards, and best practices change or update frequently. Additionally, new equipment, changing personnel, and an increasing amount of documentation to collect make some of these processes complicated, leading to difficulty in achieving and maintaining the highest-quality safety practices.

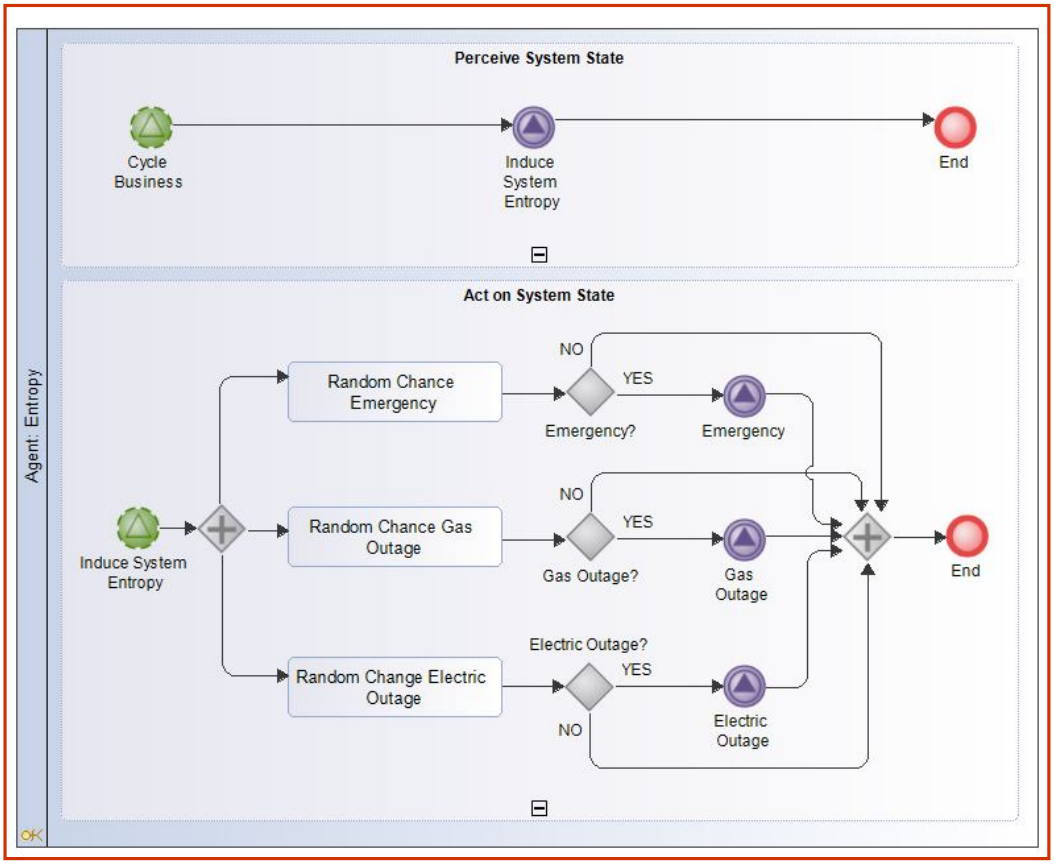
New business-analysis tools and techniques can help to manage organizational transformations required to keep pace with these mandated changes. Using a standardized approach, utilities can learn from each other to find process-improvement opportunities that can be implemented in an efficient manner. The analysis known as Business Process Modeling and Notation (BPMN) allows for even complex processes to be better understood and executed by leveraging a process that identifies gaps, clarifies needs, and provides the necessary link between process design and actual implementation. These process models also allow for companies to more clearly understand how change will affect their organization.

For this project, the research team will facilitate the knowledge transfer of existing best practices while also evaluate how to update current business processes to adopt those best practices. The objective is to improve overall organizational safety by broadly implementing pipeline safety management concepts across existing programs and technology platforms used to support the activities of those programs.

Deliverables

The project deliverables include:

- All BPMN documentation
- Recommendations



- Implementation at one utility
- A Final Report, and
- A webinar presenting project results.

This initial project phase will address the safety aspects common to most utilities. Future phases could include pilot-project implementations of transformed processes on an on-demand basis.

Benefits

- Increased safety via broader application of pipeline safety management concepts into more programs and
- Reduced costs associated with risks and unintended consequences related to business changes.

Technical Concept & Approach

The scope of this project includes applying business-analysis techniques and tools to gather requirements, record existing processes, identify gaps, and provide implementation recommendations including best practices. The project team will research and identify the techniques that are best suited for managing business changes that incorporate pipeline safety management practices into existing programs.

Researchers will elicit requirements from stakeholders using standardized best practices. This will be comprised of any or all of the following: interviewing system users, brainstorming, documenting observations, gathering survey information, and/or reviewing existing regulations and standards from regulating authorities.

Based on the requirements collected, the project team will provide analysis documentation. This may involve consulting additional subject-matter experts, incorporating requirements and regulation materials, and considering business goals. The conditions that will factor into the design will include elements to ensure that the plan will be generic enough for most utilities to implement the plan in an effective manner while minimizing organizational change.

Researchers will leverage methodologies from past projects to document business processes, requirements, data models, and other specifications based on information collected.

The project team will provide a recommended approach for implementing the best practices and transferring the knowledge compiled in previous tasks. Plans are to involve one utility in the implementation of these best practices.

Results

In 2018, researchers reviewed a host of literature related to safety management of pipeline systems. Based on requirements and some updated recommendations, documents and model diagrams were created. These will further comprehension of the updated recommendations and their impact on pipeline system safety protocols and workflows.

In 2019, the project team continued documenting associated reference materials using business analysis techniques. This type of documentation will continue throughout the project as more information is gathered and more business processes are exposed.

Researchers interviewed subject-matter experts that have previously gone through various forms of gap analysis related to programs to better understand how the business analysis approach can help supplement these programs. Additionally, a survey was issued to discern the status of industry adoption of pipeline safety management systems.

The project team hosted a webinar to update the project sponsors more specifically on the project progress.

Researchers completed the requirements and design task, and started the BPMN documentation of reference materials (focusing on API RP 1173). Of the survey respondents, all had performed some sort of formal review or gap analysis of their compliance with API RP 1173. All companies were following the guidance from 1173 and all were working on formalizing a program or improving upon their current program.

All companies also had some form of tangible support from leadership/management – most having dedicated or partially-dedicated budgets and staff.

Status

Researchers are completing BPMN documentation of all reference materials.

A webinar will be scheduled with the sponsoring companies to describe progress in more detail.

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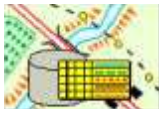
Utilizing Feature Class Representation in ArcGIS



Through this project, experts provided a demonstration of tools within the ArcGIS mapping system that will help utilities manage and maintain both spatially accurate GIS data as well as cartographically appealing maps.

Project Description

Natural gas utilities often maintain critical data in geographic information systems (GIS) acting as a centralized data repository for gas system components. As such, industry experts note a need to more simply maintain both Global Navigation Satellite System (GNSS) location data as well as a cartographically appealing presentation of the data within GIS.

Currently, GIS analysts or database administrators are often forced to duplicate data, creating disparate systems and issues with data maintenance. However, new applications allow users to maintain both the spatially accurate GNSS position as well as provide the more cartographically appealing position within the same feature class.

In this project, research focused on a tool called *Feature Class Representations* from Esri, an international supplier of GIS software. The tool allows users to specify and store a series of rules that dictate the way the features are represented. Creating feature class representations for existing data would allow users to display their data in whichever way is appropriate for the specific use case without having to create redundant data or maintain additional databases.

This project involved the development of step-by-step instructions in the form of a user guide. The project team demonstrated tools within the ArcGIS system for maps and geographic information that will help utilities manage and maintain data.

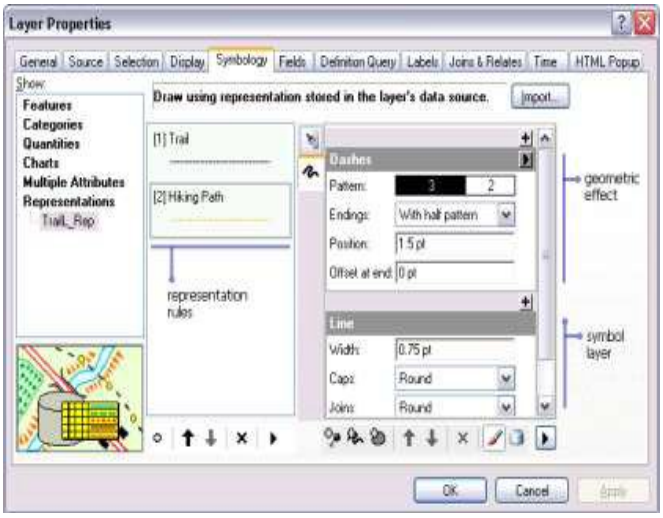
The goal is to remove implementation barriers associated with incorporating high-accuracy GNSS coordinates into a GIS system that contains legacy geometries. For example, when GNSS data is collected and added to a legacy GIS, there is often a spatial offset between new and old data. Therefore, although the new GNSS data is more accurate, data managers hesitate to add the new data because the positional offset creates confusion for anyone viewing the map cartographically.

Deliverables

The project deliverables included a webinar demonstration of the representations tools and detailed documentation on using the tools for purposes relevant to the natural gas industry.

Trails, roads, and rivers drawn with conventional symbology

Trails, roads, and rivers drawn with representation symbology



Existing tools within Esri's ArcMap help utilities manage both spatially accurate data and cartographically appealing maps

Benefits

For most utilities, GNSS data is stored in GIS. However, the same assets were most likely originally digitized from various paper or other analog sources. The original GIS data was built to maintain a cartographic standard, allowing printed versions of these maps to be easy to read and understandable to field users.

This project focused on providing value by allowing for the maintenance of both spatial representations of the data – the actual GNSS location as well as the more readable GIS position – in the same feature class without having to unnecessarily duplicate data or create complicated maps.

Technical Concept & Approach

For this project, investigators evaluated the feature class representation tools, using the latest version of Esri's ArcMap. During this task, documentation on using the tools were created in the form of a user guide to implement the tools at any utility using Esri products.

A webinar-style demonstration of the tools was held to maximize the participation for all utilities. The demonstration provided insight into how the tools could be used specifically for the natural gas industry.

Results

In 2018, the research team began to collect sample data used for the product evaluation. A sponsor was able to provide a sample base data as well as high-accuracy satellite field data to be used in the evaluation. Researchers were able to successfully create the feature class representations for point and line features within the sample data. (Originally, this process was only thought to be possible for point data.)

During the second quarter of 2019, the project team held a webinar to demonstrate the Feature Class Representation Tools using a sample dataset. The webinar marked the completion of the evaluation of the tools, which then allowed researchers to begin assembling the user documentation and Final Report. A user guide will provide more detail about how to use the tools, what has learned from this project, and recommendations for implementing these tools related to natural gas infrastructure GIS data sets. .

In completing the tool analysis, researchers found that representation editing works well, but the behavior of the editor is slightly different than the editor that is used to directly edit the underlying feature classes. From the work performed during the edit sessions, the team also found feature representation editing to be more useful than originally anticipated in that it is designed and supports editing of all features composed of points, arcs, and polygons.

Status

This project was completed in 2019. A Final Report is was issued in August 2019.

Project representative spoke directly with several representations experts. They confirmed that this was the only tool available to do anything related to maintaining two separate geometries for a single feature in the same feature class.

Sample data set.

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Smart Phone Tools

The objective of this project is to evaluate and test Smart Phone applications which may serve as tools for increased safety or productivity for gas utility personnel. The focus will be on apps that a user can download and deploy themselves and will evaluate the accuracy and reliability of these applications.

Project Description

The operation and maintenance activities of natural gas systems must be performed by personnel with access to outside sources of information. Through exposure to technologies which impact their personal lives, company personnel force new technologies into the enterprise. This phenomenon occurs in every modern business and is referred to as the "consumerization of the enterprise" or the "consumerization of IT."

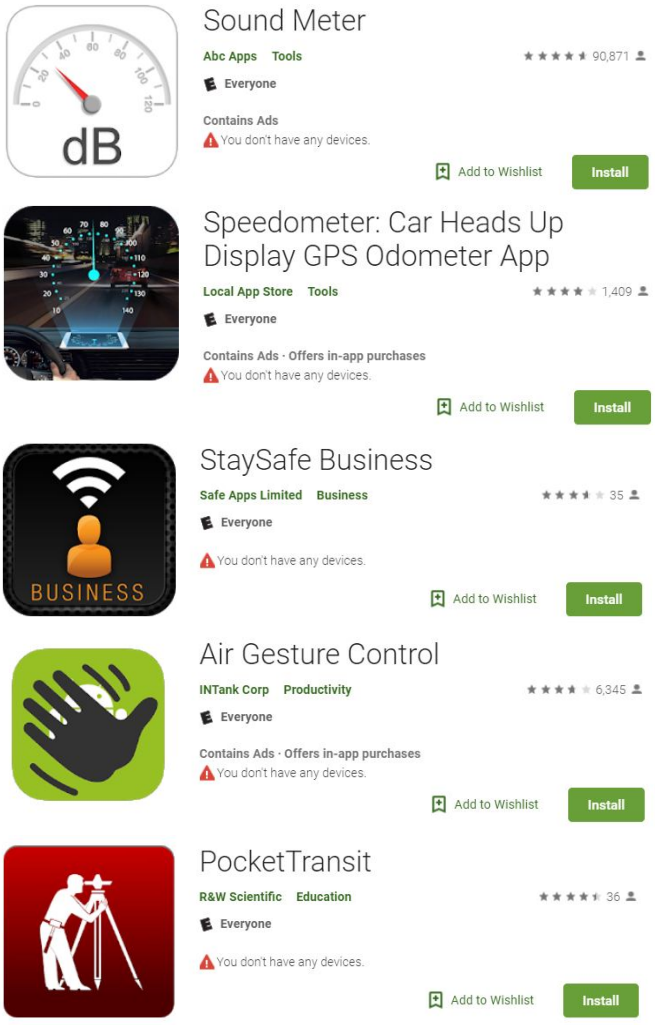
The current marketplace contains many freely or inexpensively available tools. In this project, researchers will evaluate and rigorously test available Smart Phone applications which may serve as tools for increased safety or productivity for gas utility personnel. The focus is on apps which the user can download and deploy themselves, rather than on expensive enterprise applications which require expert deployments and ongoing maintenance. These include the types of apps employees may already be using without official recognition or accessibility from the company.

Examples which could be valuable to examine include decibel meter apps. It may be useful for an employee to measure decibel sound levels while making the decision whether to use noise-attenuating personal-protective equipment. However, do these apps report accurate results under various conditions? Is there a chance personnel will be mis-led into making a decision which compromises safety?

Other examples of potential applications include:

- Heads up windshield displays for drivers; the phone screen lays on the dashboard and projects information on the windshield.
- Situational awareness companions; for users in hazardous scenarios, the app communicates real-time position and status information for better safety support.
- Infra-red (IR) testers; digital cameras can detect a wider range of light, including IR. These can be used to verify the operation of equipment using IR communication.
- Touchless gesture-control apps; allows the phone to read the user's hand movements and convert them into commands, such as "take a picture."
- Measurement apps, such as measuring objects in photos, virtual tape measures, arc tracing, virtual theodolite, bubble level, clinometer, etc.

This project will evaluate the accuracy and reliability of such apps and provide recommendations for their appropriate use by gas utility employees. The project



Examples of potential applications.

will also report on mobile cybersecurity threats, how they manifest, and the steps that can be taken to reduce the likelihood that they can be deployed against a Smart Phone.

Deliverables

The project team will produce a compiled report containing the results of each test for each selected application.

A Final Report will be provided.

Benefits

Smart Phones are carried by nearly all utility personnel and provide a low-cost means to deploy additional productivity and safety tools throughout an organization.

In some cases, employees may be self-deploying solutions on their smart devices without official sanction from the company. Correct operation and use is critical to producing value. In fact, incorrect operation and usage can produce undesirable results, including safety concerns and loss of efficiency.

Although these tools may be widely available, they may or may not be accurate or reliable. This project will provide an assessment of available Smart Phone apps.

Technical Concept & Approach

Specific tasks include:

- **Select Applications and Design Tests**

  A final list of up to five apps will be defined. A set of evaluation criteria will be identified. For example, decibel meter apps may be compared to purpose-built decibel meter devices and tested for accuracy at varying frequencies and decibel level combinations. A testing plan will be created for each app. Additionally, any equipment required to execute the testing plans will be acquired. For example, a silent speaker chamber will be sourced for testing the decibel meter apps.

- **Execute Testing Plan**

  The testing plan will be executed and the results compiled into reports.

- **Checklist for Cybersecurity Concerns**

  The project team will conduct a survey of reports, documents, and studies produced by reputable authoritative bodies in the area of mobile cybersecurity. Researchers will compile a list of possible threats posed by mobile application usage and the common mechanisms by which threats manifest.

  A checklist will be created which can be used to reduce the likelihood that those common security threat mechanisms can deployed against a Smart Phone. Because Android and iOS devices are fundamentally different, a separate checklist will be created for each.

Results

In 2019, researchers identified applications in several categories to potentially evaluate in depth. Some of the apps referenced in the proposal were excluded from further consideration due to quality or feasibility issues, and other apps were added to the list. Information from outside groups that evaluated some of the apps under consideration was also reviewed. Additionally, an initial review of resources on app cybersecurity was conducted.

Status

The project team is eliciting feedback from sponsors on applications that are under consideration and which, if any, should also be considered.

Application testing will be design and initiated in 2020.

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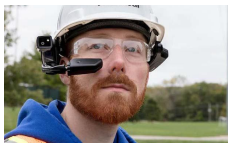
Wearable Computing Technology



Researchers are evaluating emerging wearable computing technology and its application for supporting natural gas field-crew operation tasks. The product provides a means to supplement the field technician's subject-matter knowledge by supplying real-time digital access to documents and data.

Project Description

The information technology industry rapidly inundates the consumer market with new products that are often supplied with plausible arguments for improved business value. However, it is very difficult to know whether these products will make a real impact or change in business goals. This project is designed to provide a logical framework for exploring wearable technologies as a means to better achieve business goals for safety and quality.

In this project, researchers are evaluating a commercially available product to represent the current state of the wearable market. The product provides a means to supplement the field technician's subject-matter knowledge by supplying real-time digital access to documents and data.

Field-accessible documentation was selected as the use-case scenario for evaluating the performance of the device. The result will be provide a useful knowledge set for evaluating additional wearable technologies or for further implementation of the product.

Deliverables

An evaluation report aggregating reviewer assessments of the key evaluation parameters will be created. Additional evaluation exercises may be warranted either to evaluate new questions about, or applications for, the product, or to explore alternate technologies on the market.

Benefits

Wearable computing technologies – particularly headset-style systems – allow the user to interact with data and documents in real-time while allowing the user's hands to remain free for other work. For example, a user may hands-on engage a system component while simultaneously interacting with the documentation for that component in real time. Such systems have the potential to increase safety and quality of the field crews' work by supplementing their innate subject-matter knowledge with access to data and documentation, while also saving valuable time.

Technical Concept & Approach

Several key evaluation parameters were established, including factors such as comfort, clarity, ease of use, etc. related to wearable technology. The project team and sponsors consider these parameters and select options of top importance.

Researchers will compile and catalog each evaluator's assessment of the product based on the key evaluation

Communication channels will be established, and regular remote-access meetings scheduled.

The project team will obtain, learn to use, and set up five units. Once the devices are ready, units will be loaned to those participating in the evaluation for trial and review.

Results

In 2019, the project team initiated activities, including identifying project resources and validating the basic assumptions noted in the proposal.

Five devices and supporting peripherals were ordered. Testing and training was initiated.

The project team also created a list of evaluation criteria and scripted steps to guide users through an evaluation experience with the hardware. An online survey for evaluators to provide feedback on their experience was also created. A call with each sponsor participating in the evaluation was conducted with the purpose of introducing basic hardware and software use and functionality.

Status

The following activities are scheduled for 2020:

- Make available the online survey for reporting feedback on the devices and
- Plan and conduct feedback phone calls for a discussion about the evaluation experience with all evaluating sponsors.

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Laser Range Finder

In this project, researches advanced the functionality of the LocusView Laser Ranger Finder for mapping utility assets. Features were developed for establishing the estimated accuracy of data collected via the laser range finder and integrate an advanced laser range finder with ultrasound capabilities.

Project Description

In Phase 1 of this project, a workflow and calculations were developed to utilize a laser range finder to map assets with high-accuracy GPS in areas with GPS signal blockage.

The workflow and calculations were implemented into software and tested. Testing of the solution at National Geodetic Survey monuments were conducted to determine if spatial data meets or exceeds six-inch minimum accuracy requirement.

Deliverables

Deliverables include:

- A design document
- Prototype, and
- Field Test Report.

Benefits

Advancement of the Laser Range Finder will improve the ability to locate assets in a more timely and economical way.

Technical Concept & Approach

Advancements include:

- A method to calculate the estimated spatial accuracy of data collected with the laser range finder and to be displayed on mobile and web, and capture/refine the spatial locations of line vertices via laser offset
- A method to determine the location of an asset that is not accessible by GPS, and
- Testing the accuracy improvement with the collection of three reference points instead of two points.

The project team created a design document to define the methodology and workflow and developed a prototype based on the design document for field testing.

The prototype was field tested for conformance to the design document, accuracy, and ease of use. The prototype will be modified based on the results of the first round of testing and will be re-deployed for a second round of testing.

This method uses two highly accurate reference points (typically within six inches or better) at known distances to the asset. Two circles are created which are centered on their respective reference point, each with a radius equal to the distance between the asset and the reference point. These two circles intersect at two locations: the true location of the asset is located at one of the two intersections.

The primary key to a successful calculation is to establish very accurate distances between the asset and each reference point.

Results / Status

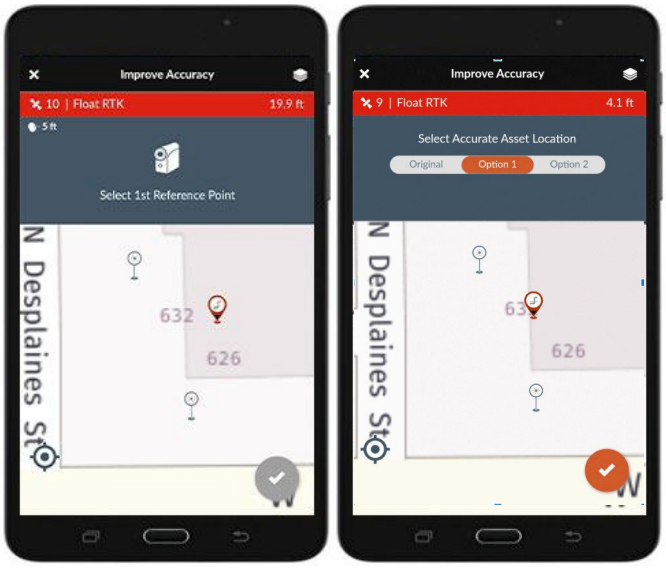
In March 2019, a White Paper was issued to outline the spatial and mathematical processes used during the Laser Range Finder offset process in LocusView Mobile.

To assist the end user in this process, LocusView Mobile also captures the azimuth (compass direction) between the asset and the reference point utilizing the internal compass of the range finder. By establishing the compass direction between the asset and the reference point (typically accurate to within three degrees) LocusView Mobile can make an educated suggestion as to the point which is true.

The calculation of the elevation (i.e., vertical location) is a simple mathematical calculation that utilizes three components:

- **Elevation of Reference Point 1**

  The LocusView Mobile application utilizes the elevation value from Reference Point 1 only. The reason for this is that regardless of which reference point elevation is used in the calculation, the outcome will be the same as long as the end user took an accurate shot with the range finder. Elevation values from both reference points are not required.



- **Range Finder Vertical Distance**

  The range finder calculates and stores three values, one of which is the vertical distance between the rangefinder and the reference point. The vertical distance is recorded in feet.

- **Eye Height**

  To establish the accurate elevation of the asset, the eye height must be used to offset the vertical distance returned from the range finder. The eye height value is equivalent to the distance between the range finder and the asset.

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Augmented Reality (AR) Technology for Performing O&M Tasks

AR technology can help bridge knowledge gaps and can be used by field personnel within the natural gas industry to assist with performing O&M tasks. The goal of this project is to demonstrate the value of this technology and identify intuitive software applications and hardware equipment preferred by the natural gas industry.

Project Description

It is estimated that 40% -50% of the utility workforce will retire over the next five years. This will leave the industry with a burdening knowledge gap. Although new employees will be well-educated and technology savvy, less experienced workers will not have the real-world expertise of their predecessors in identifying abnormalities, assessing causes of failures in the field, or working with industry tools and equipment. In addition, these new workers are being tasked with knowing and performing more work activities earlier in their careers than their predecessors.

Augmented Reality (AR) technology can help bridge this knowledge gap and also aid employees that do not perform the same type of work on a regular basis.

The objective of this project is to identify and evaluate AR software applications and hardware equipment (i.e., wearables and handheld) that can be used by field personnel within the natural gas industry to assist with performing operations and maintenance (O&M) tasks. The goal is to demonstrate the value of this technology and identify intuitive software applications and hardware equipment preferred by the natural gas industry.

Deliverables

The deliverables for this project will include a Final Report detailing the AR software applications and hardware equipment best suited for the natural gas industry. This report will also highlight findings from a project sponsor pilot study.

Benefits

AR technology has been proven to improve the following:

- Accuracy of work performed
- Employee productivity
- Safety of employees
- Compliance documentation
- Collaboration and communications, and
- Customer service.

AR technology allows field personnel to access O&M procedures, checklists, troubleshooting tips, previous maintenance records, and training aids, and communicate with subject matter experts in remote locations to assist and provide guidance on their activities, all hands-free. Also, this technology allows for video recording and photos of the work being performed or completed.

Technical Concept & Approach

Specific tasks include:

- **Identification and Evaluation of AR Software Applications**

  The project team will identify and evaluate potential software applications that may work well within the natural gas industry. The goal is to identify up to three applications to into evaluations during a pilot study task using different hardware equipment (i.e., wearables, tablets, etc.). Project sponsors will select which type of work activity (i.e., leak investigation, valve inspection, etc.) to use as part of the evaluation process.

- **Identification and Evaluation of AR Hardware Equipment**

  Researchers will identify and evaluate potential AR hardware equipment that may work well within the natural gas industry. The goal is to identify three wearables and two tablet-type hardware pieces of equipment to test with project sponsors. Sponsors will be given the opportunity to select which equipment to test.

- **Develop and Program Procedure Content into AR Application**

  This task includes the project team members working directly with the AR software service providers to develop and add the O&M procedures selected by the project sponsors to enter into the AR application. Types of documentation will include work procedures, checklists, manufacturers installation guides, training guides and videos, etc. Also, local field testing of the AR technology and calibrating the hardware equipment (i.e., Smart Phone, tablet, Smart Glasses). Additional performance enhancements will be made at this time (for example, conference calling while performing a work activity).

- **Pilot Study**

  A pilot study with project sponsors using the AR software application and hardware equipment will be conducted. The specific procedures for each participating project sponsor can be used in the pilot study. The duration of the pilot study for each project sponsor will be determined by the total number participating in the study.

Results

In 2019, a project sponsor survey was prepared to provide a better understanding of how project sponsors would like to use the AR technology and identify which types of procedures that they would like to see as part of the pilot project for evaluating the technology.

The project team is identifying potential AR software applications and hardware equipment to evaluate.

Status

In 2020, the project plans to complete project scoping activities and analyze the project sponsor survey.

Researchers will finalize a listing of potential AR software applications and hardware equipment. Approved AR hardware equipment will be acquired and the necessary licensing to evaluate AR software applications arranged.

Discussions with project sponsors will be held to determine potential companies to pilot the AR technology.

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High-Accuracy Mapping of Leak Surveys

Researchers are developing a framework to couple high-sensitivity methane/ethane sensors with high-accuracy Global Navigation Satellite Systems for on-foot leak investigations and walking surveys. This has the potential to reduce the amount of time that technicians need to spend investigating, documenting, and tracking a leak.

Project Description

There are several limitations to the use of current analyzers in high-accuracy mapping of walking leak surveys.

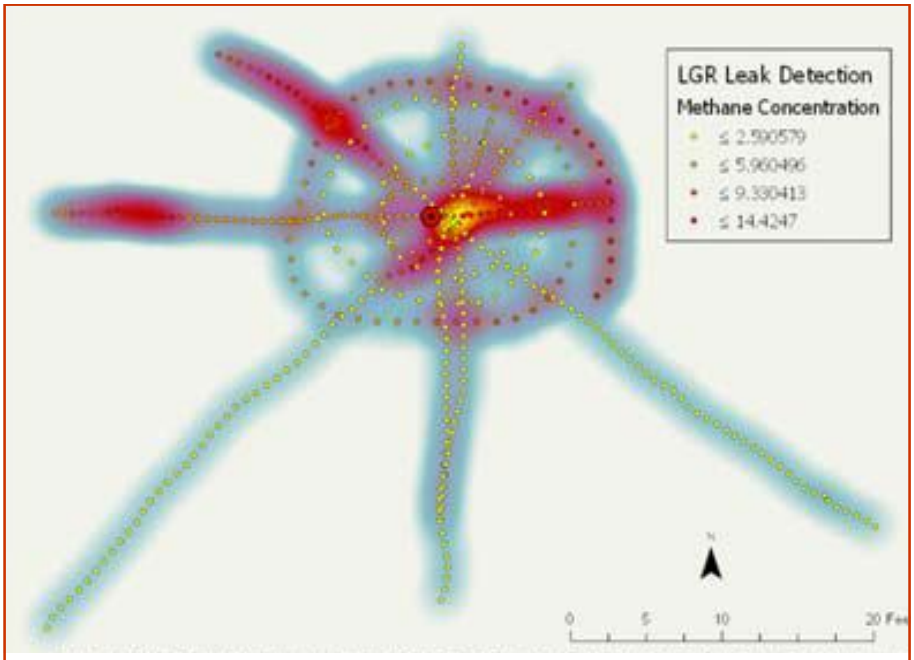
First, the resolution is not capable of the granularity of measurements needed to create the type of "breadcrumb" map presented in the illustration below.

Second, the analyzers were created for specific applications and do not typically have a readily available way to integrate data into an automated system.

In addition, there is a lack of capability to determine ethane concentrations in near real time. The determination of whether ethane is present allows the operator to distinguish between natural gas and other sources of methane, such as sewer gas. Pairing the product with one of the newly developed high-accuracy methane sensors would alleviate these issues.

The concept for this project originated while performing field testing on OTD project (7.17.e) *Evaluation of Methane Detection Devices for Utility Operations,* which focuses on the evaluation of new advanced methane detection devices for walking leak surveys, leak investigations, and stationary remote monitoring. During the project's field evaluation task, researchers determined that it would be beneficial to have real-time spatial location information when conducting both leak surveys and leak investigations. That capability could provide a technician with information allowing them to more effectively detect and pinpoint the location of a leak.

Coupling the readings of a high-sensitivity methane/ethane sensor with the spatial location capabilities of a high-accuracy Global Navigation Satellite System (GNSS) in real time will have clear advantages over current methods. Furthermore, presenting the information on a map via an application will make it possible to improve mapping and tracking of leaks by walking leak survey crews to more effectively and efficiently track and document leak locations. The app can be used to generate a detailed diagram of the methane/ethane concentrations in an area, highlighting where the highest concentrations of methane are located,



Post-processing results produce high-accuracy point locations of methane concentration readings on a "breadcrumb" map.

leading the technician to the leak location. The map and concentrations can then be saved to generate forms used for tracking and repair crews to document that the leak has been fixed.

Additionally, the high-accuracy spatial location component can be used to address any issues arising from multiple callouts where crews are not able to pinpoint a leak. All the information collected during the leak surveys and investigations can be stored for later use and analysis by others, helping resolve any ambiguities with leak investigations.

For this project, a research team will develop a framework to couple high-sensitivity methane/ethane sensors with high-accuracy GNSS systems for on-foot leak investigations and walking surveys.

The project team will focus on real-time data visualization and compatibility with multiple methane/ethane detectors and GNSS devices.

Deliverables

The project deliverables will include:

- A Field-Tested System – Outputting real-time high-accuracy spatial point location of gas detection device methane/ethane readings
- Field Testing Results – Including GNSS and gas detection device measurement results
- One to two on-site demonstrations of the field-tested system, and
- Quarterly and Final Reports.

Benefits

Advancements in both high-sensitivity methane/ethane sensors and high-accuracy GNSS devices are driving technology ever smaller and less expensive. It has now become feasible to combine these technologies for use in walking surveys and on-foot leak investigations.

Development of a streamlined method for combining, storing, and visualizing data from high-sensitivity methane/ethane sensors and high-accuracy GNSS devices used for on-foot activities can:

- Increase efficacy of locating leaks
- Automate documentation of leak location to remove ambiguities, and
- Increase efficiency in tracking leak location and repair.

All of these have the potential to reduce the amount of time that technicians need to spend investigating, documenting, and tracking a leak.

Technical Concept & Approach

In this project, research is focused on evaluating the ability of an existing solution to integrate the readings of an approved gas detection device with the precise spatial location capabilities of a high-accuracy GNSS system, and presenting that information to a technician in real time while preserving the historical records for compliance validation.

Activities include:

- An evaluation of a system that can pair data from an approved gas detection device with a high-accuracy GNSS system
- An evaluation of the ability to visualize the information in real time
- Simulated leak testing of the developed system, and
- Field testing of the developed system on simulated leaks.

Thorough testing of the existing product usability, data collection, accuracy, and output will be conducted.

The project has two research goals: The first goal is to balance the accuracy of GNSS/GPS options with costs, attempting to keep the ultimate product cost low while providing location accuracy within reason. The second goal is to ensure that the product operates with gas detectors currently in operation by our sponsors.

Results / Status

This project was initiated in the third quarter of 2019 with feedback from sponsors and the selection of existing leak detection sensors.

Discussions will be held to determine if a new full system must be developed or whether an existing system can be adapted.

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RISK & DECISION ANALYSIS / MODELS

In this area, researchers are developing models, methodologies, implementation protocols, and case studies that will allow natural gas system operators to more effectively manage operations data and improve the decision-making process.

Programs in this area employ a multi-disciplinary process that includes risk assessment, characterization, communication and management, and related research for decisions optimization. The output of the program includes predictive models, calculators, and databases that describe the complex and interconnected behavior of utility infrastructure systems and their risks.

Initiatives include the development of a risk model for locates and a risk-based methodology for remote-controlled valve and automatic shut-off valve programs.

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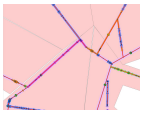
Determining Data-Quality Implications



In this program, the goals are to develop a methodology, implementation protocols, and case studies that will allow natural gas system operators to more effectively manage operations data and improve the decision-making process.

Project Description

One example of data-quality standards applicable to the natural gas industry is the *ASCE 38-02 Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data* – a standard for quality levels for utility-location-data collected as part of subsurface utility engineering operations. There are also record-keeping practices that assign qualitative scores to the health of data and records. Two such standards are:

- *GARP - Generally Accepted Record-Keeping Principles*® and the Information Maturity Model, both defined by ARMA International (Association of Records Managers and Administrators), and
- *ISO 15489-1 - Information and Documentation - Records Management*.

These standards provide methods to rank records and data with categories such as: accountability, compliance, transparency, availability, integrity, protection, retention, and disposition. The objective for this project is to develop a methodology, implementation protocols, and case studies that will allow operators to:

- Construct a pedigree (i.e., data source and quality) analysis of their pipeline system databases that quantifies gaps, consistencies, default value rationale, etc.
- Calculate a "Health Index" parameter on their database entries at the individual data point and roll up to pipeline-segment level, and
- Facilitate risk-management activities by demonstrating how the Health Index can be used to prioritize measures, data collection, risk ranking, and unknown-threat determination.

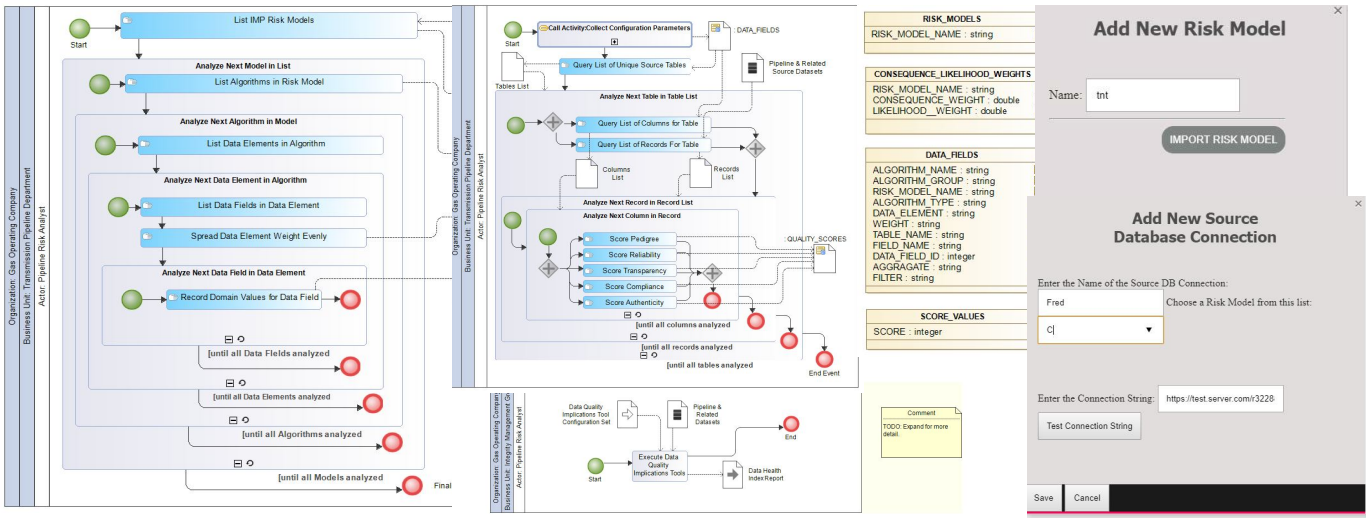
In Phase 1, researchers developed a process for quantifying the impact that poor-quality data has on the results produced by a utility's integrity management risk models. The current Phase 2 will enhance the tool and automate key functions to reduce barriers to implementation.

Deliverables

The deliverables include a formal methodology and a set of guidelines to assist operators in implementing the data-quality standard. A Final Report and implementation protocol were also developed.

Benefits

Natural gas system operators collect large amounts of data for engineering, operational, and regulatory-compliance purposes. While many operators are now using enhanced data-collection and record-keeping methods, the information within databases is often of unknown quality. A data-quality methodology allows operators to factor the quality and reliability of data into the decision-making process. By knowing where



data is suspect or sparse, operators can then assign resources to correct or fill those gaps.

Quantitative pedigree rankings of data, along with a weighting assignment on their importance to risk, allows operators to decide in which order to correct deficiencies or enact enhancements. The benefit of committing resources to developing more appropriate values can then be methodically assessed.

A Health Index parameter allows operators to immediately see areas of the database that need attention. If data is time sensitive and has reached its useful life (e.g., survey data), it will automatically decrease the Health Index score. It will also provide a way to show continuous process improvement to leadership, commissions, and the public by quantitatively demonstrating an upward trend of the Health Index over time.

Technical Concept & Approach

In this project, researchers identified potential data-quality standards and performed an assessment to determine their applicability for the natural gas distribution and transmission industry.

A method to investigate and conduct a pedigree analysis of a pipeline or system database space was developed to quantify gaps, consistency, integrity, default value rationale, and similar attributes of data.

A Health Index parameter was developed for database entries at the individual datum level, as well as a roll up calculation of health at the pipeline-segment level.

Business Process Model and Notation (BPMN) was used to map out the protocols and work processes. This ensures easier integration into the end users business processes and related software systems.

Results

For this project, researchers successfully devised a systematic process and supporting technology for quantifying the impact poor-quality data has on the results produced by a utility's integrity management risk models. Since it would be impractical to assess data quality by re-measuring the actual true value and compare it to the value recorded in the dataset, the Data Quality Implication (DQI) tool determines quality by examining the practices, techniques, and tools used to collect and store the data.

The project team identified a set of existing standards and regulatory guidance which specify parameters for such practices, techniques, and tools, and created a scoring system which indicates the degree of conformity to these standards. The DQI tool analyzes the model's source data and provides the utility with an easy-to-understand and actionable set of data quality reports.

The system produces two types of reports – data health reports and data compliance reports.

The Phase 1 Final Report for this project – issued 2017 – includes an appendix that contains a matrix of the data elements, a sensitivity analysis, the DQI design requirements, an implementation plan, and three synthetic utility case studies.

In Phase 2, the project team reviewed candidate schemas for the geographic information system (GIS) sample dataset. A cloud-based server and database were built. Information supplied along with member risk models, publicly available Energy Information Administration (EIA) data, and pilot data guidelines were used to populate the data model. A sample pilot data system was created with realistic GIS data matched to the data model.

Researchers continued to build the pilot data system, including setting up a cloud environment, database, creating sample data and loading into the a model.

The new dataset was forged from member risk models and EIA GIS data. In 2019, the dataset was greatly improved with a wide-ranging set of automated scripts to further enhance the quality and weight of the data. This pilot dataset was built to provide realistic results and information for users to identify data-quality gaps and risk-ranking insights for sponsor assessments.

The project team completed the design files and specifications, including templates for sharing and publishing readable documents. Much of the latter half of 2019 was devoted to creating the user interface, which will guide the user process of importing risk models and data, identifying components and their weights, running rule sets, and exporting reports.

Status

Researchers continue updating the data-quality algorithms as well as scoring and reporting scripts. Development activities are ongoing in creating a useful user interface.

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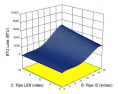
Best Practices and Methodology for Implementing RCV and ASV Programs



In this project, efforts focused on the investigation of industry best practices and the development of a risk-based methodology guideline for implementing remote-controlled valve (RCV) and automatic shut-off valve (ASV) programs.

Project Description

Existing studies found that most casualties and property damage are incurred in the first 30 seconds to three minutes following a pipeline rupture, and that delays in stopping the gas flow after a rupture and fire have little effect on the size of the area impacted. However, these studies also acknowledge that there may be additional risks in delaying gas shutoff following a fire, including additional property damage and reduced site access for first responders.

National Transportation Safety Board accident reports noted that the lack of nearby automatic shutoff or remote control valves prevented the operator from stopping the flow of gas sooner, which contributed to the severity and extent of property damage and increased risk to residents and emergency responders.

While there is information available to assess the benefits and challenges of the valves, there is little information provided as to how a utility should evaluate risk in its system to develop an effective RCV or ASV program. A utility also needs to fully understand the security risks associated with implementing RCVs.

The goal of this project was to develop a systematic risk-based approach to assess key elements of utility risk-management systems for the most effective implementation of the programs. This risk-based guideline can be used by each utility to evaluate their systems and satisfy U.S. Department of Transportation regulation Subpart O 192.935 (c), as well as enhance the safety of operating the pipeline system. It was also designed such that it can be integrated into an EDSS (Enterprise Decision Support System) platform.

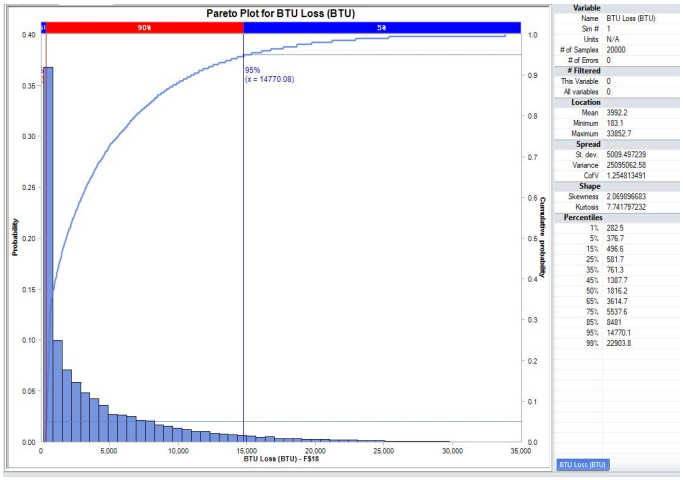
Deliverables

The deliverables from this project include:

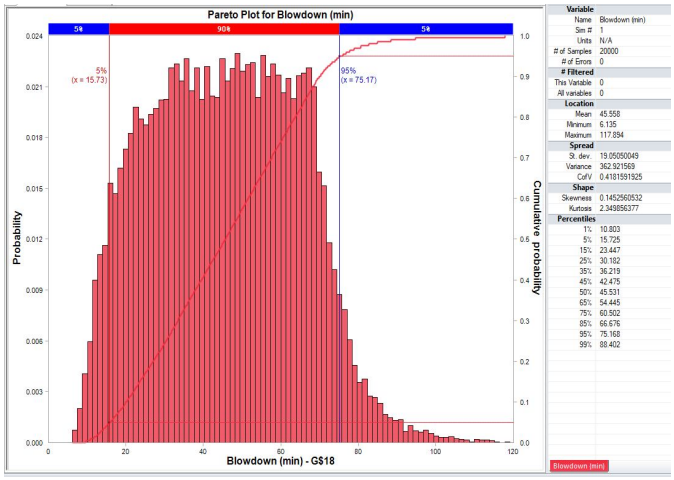
- An investigation of industry best practices
- A risk-assessment methodology and valve-placement process
- A security assessment for automated valves, and
- A Final Report.

Benefits

The primary benefit of RCVs and ASVs are that they normally close more rapidly than a manually operated valve that requires operating personnel to travel to the valve location. The safety benefits of quickly responding to pipeline incidents have been analyzed in the context of valve placement and the effects of reducing the time to stop the flow of gas after a rupture.



BTU Loss (BTU)



Blowdown Time (min)

Hydraulic study – Excel-based model calculator.

A security risk associated with implementation of remote-controlled valves is the potential for an outside entity to gain control of the valve and either exercise the valve and create outages, or perhaps prevent closure in the event of a rupture. A second component of this project was to assess and evaluate the current cybersecurity concerns and measures employed by the industry.

Technical Concept & Approach

For the investigation of best practices, project representatives engaged utilities that have well-established RCV and ASV programs to develop general guidelines specific to valve location selection and implementation. Transmission companies, in particular, have been using RCVs and ASVs for decades. Although their systems and criteria may likely be different, there are lessons to be learned in terms of control methodology, hardware, software, cybersafety, etc. This task includes identifying relevant elements of utility risk-management plans in assessing whether installing RCVs and ASVs will increase the safety and reduce risk of operating the pipelines.

The project team developed a systematic approach to assess risk-management systems by utilizing event trees.

Hydraulic modeling runs provide determining factors that have the greatest influence on rupture energy release and blowdown times. Various scenarios were modeled using randomly generated and selected rupture locations (based on risk and consequences of a pipeline rupture) of a select group of systems. Researchers then evaluated the effects of added valves and valve modifications, taking into consideration various inputs such as valve types, closure times, pressures, ambient temperatures and gas loads, and high-consequence areas.

The deliverable is a process on optimized placement of automated valves. This approach will also lend itself to be implemented as a stand-alone process or eventually integrated into an EDSS.

Researchers engaged a cybersecurity expert to perform an analysis of communication security risks in operating RCVs and ASVs.

Results

In 2017, the project team surveyed the SME Group to collect system loop details to be used, in part, to construct the project's synthetic pipeline loops/systems needed for flow and pressure modeling.

A model was created to evaluate valve closure times on Btu release from a full line break. Researchers were successful in simulating several sequenced events to show differences in flow rates, total Btu loss, and blowdown time when valves are closed at different times after a line break. A transient case was also created that will be used to run various scenarios with manual, remote, and automated shutoff valves.

A cybersecurity survey was conducted and results presented in a report to sponsors.

As part of ongoing cybersecurity analysis of core gas technologies in the operational environment, OTD sought to research the cybersecurity aspects of RCVs and ASVs. Particularly, OTD sought to identify potential threat vectors and any relevant standards or best practices that can be used by the industry to understand and mitigate cyber security risks associated with implementing these devices.

Status

This project was completed with Final Report issued in March 2019.

The report then contains the following sections:

- Summary of an SME survey and interview results of current (or lack of) automated valve programs
- Organized summary of utility automated valve program/process reviews
- Risk-based hydraulic modeling approach, execution, results, conclusions, and recommendations for use, including the use of contour plots and a user-friendly Excel-based hydraulic model calculator, and
- Cybersecurity utility survey results, industry standards and research review, threat analysis, gap analysis, and conclusions/recommendations.

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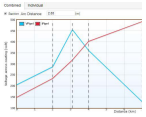
Model of AC Earth Faults and Associated Risks



In this program, research is being conducted to develop methods to quantify the extent to which buried gas pipes are exposed to ground (or earth) faults in nearby AC power systems and to examine the risks caused by this exposure.

Project Description

The transient nature of AC power line earth faults presents the risk that infrastructure damage can occur and go unnoted for a significant period. In previous OTD-sponsored projects, researchers instrumented a small number of sites to detect both AC faults and lightning events. Other efforts addressed modeling the consequences of steady-state interference, rather than transient faults.

The objective of this project is to develop methods to quantify the extent to which buried gas pipes are exposed to ground (or earth) faults in nearby AC power systems and to examine the risks caused by this exposure.

A prototype system was developed in early phases of the project. The current Phase 3 focus is to perform demonstrations of the prototype system.

Deliverables

The deliverables will include an analysis of the current state of AC earth fault investigation in the gas industry. Plans are to construct a GIS-based pipeline and power line model that accounts for the electrical interactions between the two and other incidental buried structures. This model will take into account pipe and coating parameters, soil conductivity, other infrastructures, and information on electrical equipment.

Benefits

The currents created on pipelines by AC ground/earth faults can be quite severe – hundreds of amps in extreme cases. These fault events have the energy to damage pipelines and coatings. Improved knowledge would allow utilities to plan inspections and mitigation efforts.

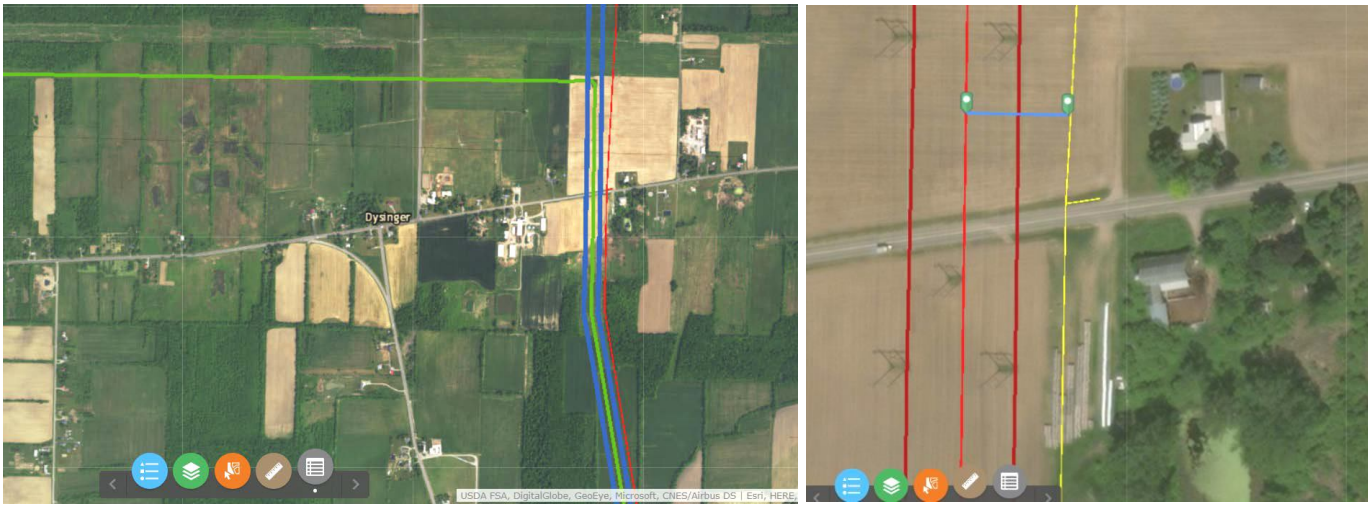
Technical Concept & Approach

Initial efforts are to develop or adapt a GIS model for a specific pipeline system and create a corresponding overlay of the electric infrastructure. At first, the model would be applied to areas containing critical gas lines and high-voltage lines: areas that are likely to be well documented.

It will be necessary to capture data on the electric infrastructure and on other buried infrastructures in the area of interest. Data on earth faults, possibly as indicated by outages, would also be sought from local electrical utilities.

A sponsor survey was developed to help determine the methodologies used by utilities to predict the incidence of AC earth faults, how utilities are informed of AC earth faults, and other information.

The project team will develop a set of models and documents which express the detailed design of the



Mapping data shows the gas transmission pipeline in red, a 345 kV overhead electric line in blue, and a 230 kV overhead electric line in green.

system, such as geographic area(s) of interest, a GIS-based inventory of the major pipelines and power lines in the area, pipe and coating types, soil conductivity, and other data.

A beta prototype of a GIS-based system for the prediction of earth faults and their severity was constructed. The overlay of the electric power system onto the pipeline GIS was constructed using existing utility records supplemented by geospatial imagery. Imagery is used to identify the locations of major power lines and associated towers.

The likelihood of earth faults will be estimated from the electrical equipment types and driving functions, such as weather and power loading. A basic electrical model will be constructed to estimate the influence of an earth fault on a nearby pipeline. The primary inputs to this model are the relative geo-locations of the towers, associated metallic subsurface structures, and pipelines along with the soil conductivity in the area of interest. The combination of these elements will provide an estimate of where the highest likelihood of earth fault conditions should occur, along with the degree of coupling between these faults and the pipelines. This will provide a "heat map" of areas that should be of concern.

The prototype of a GIS-based system for the prediction of earth faults will be demonstrated for project sponsors. The demonstration will be facilitated via a conference call/webinar format.

Results

Development focuses on three major components of the predictive risk model:

1. A Business Process Modeling Notation (BPMN) model that captures the process steps for setting up and running the risk model
2. A physics model that predicts the current and voltage levels on the pipeline over various parameter ranges, and
3. A risk model that uses inputs from the BPMN model and calculated values from the physics model to quantify the pipeline risk for a given set of inputs.

Prototype versions of these components were constructed and tested using published data. The physics model and risk model appear to be functioning correctly. The data used was drawn from open literature describing pipe and powerline interactions. The basic assumptions in the prototype models are drawn from the experience of the investigators. It factors in the soil resistivity, coating resistance, and separation distances.

A prototype of an AC fault risk model was constructed that makes use of input data described in the BPMN diagram and data calculated from the physics model. From these, it generates the probability distribution of risks one would expect to find on the pipeline.

In 2018, researchers became aware of the release of a commercial software package that substantially duplicates some the physics model. The product has a very well developed GIS/map type interface for entering the geometry of the pipes and conductors. The project team obtained a trial license and conducted an evaluation, finding positive results with respect to user interface and numerical agreement. The company is agreeable to providing the research team with additional features that are needed for the risk model. The initial step in the evaluation was to participate in an on-line training session in which technical experts walked project personnel through the setup and execution of test cases.

Researchers developed code to extract pipeline location data from the repository it is stored in into the physics model. This will allow future data received in this format to be readily imported into the model.

Further advancement and verification of the physics model will require real-world data from the utilities.

During 2019, researchers met via webinar to review and better understand the application programming interface (API). Post-webinar, the API was tested with the risk model.

Status

Efforts are under way to:

- Use a simulation to populate the risk model node probability tables
- Quantify the network model for risk analysis, and
- Further pursue what instrumentation may be able to capture powerline currents for inclusion in the model.

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Knowledge Management System

This project involved the design of a software system to manage the gas industry knowledge base of expertise, regulations, business processes, and best practices. The system is designed to automatically read, infer, and connect related concepts from a variety of informational sources.

Project Description

According to the U.S. Department of Energy, a significant percentage of the natural gas utility workforce is approaching retirement age. The wave of retirements is expected to peak in 2020 and continue for another decade. The retirement of key employees makes it a challenge to carry out critical functions without proper replacement. New, skilled employees are difficult to find and need significant training before they can fully replace the retiring employees.

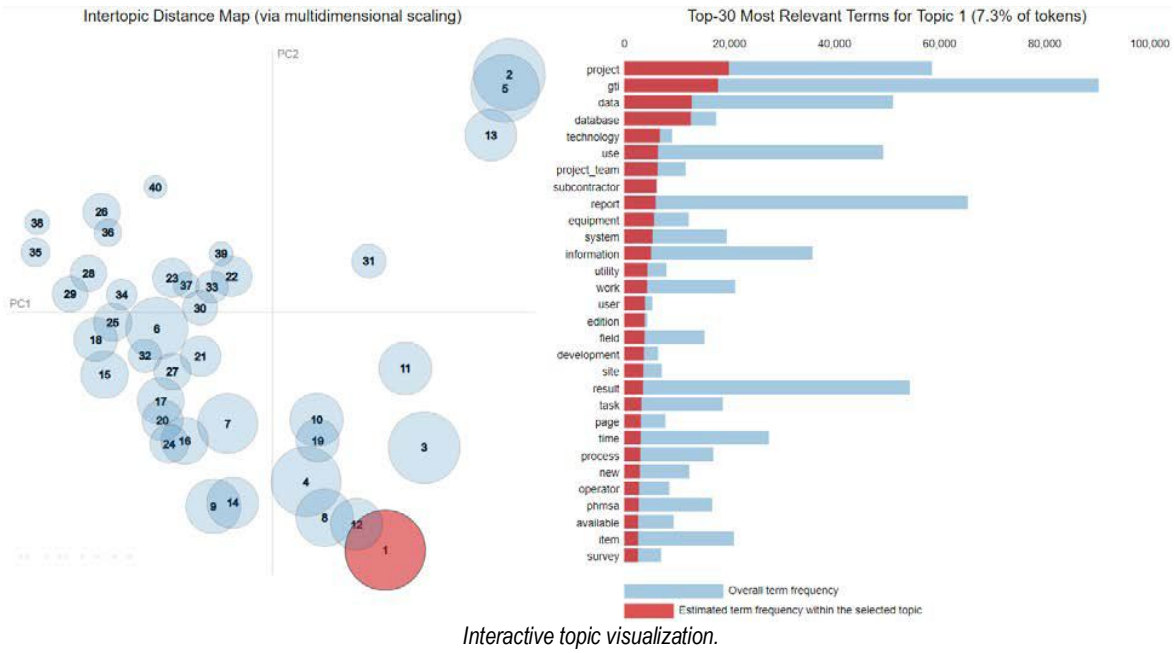
To address this issue, this project focused on the design of a system to capture and store organizational explicit and tacit knowledge. The system will be useful to improve knowledge transfer from departing employees to new employees.

The objective was to design a system that would store a wide range of knowledge related to:

- Explicit and tacit technical know-how from field experience
- Business processes and best practices
- Modern methods of natural gas operations
- Legacy and historic designs, engineering, and operations information, and
- Local, state, and federal regulations and legal requirements.

The system automatically reads, infers, and connects related concepts from a variety of informational sources (e.g., interviews, regulations, standards, project reports, and surveys) and provides a single platform to improve the transfer of institutional knowledge from retiring employees and subject-matter experts (SMEs) to new employees. It also assists in improving the understanding of risk management and compliance initiatives for pipeline integrity, operational efficiency, and safety.

Using an automated document-mining process, combined with process mapping and consultation with SMEs, the project team constructed a "Knowledge Map" of an organization. With the knowledge map, researchers can move on to formulating processes to periodically revisit the organization's knowledge state, revise how key individuals are systematically debriefed, and address how the most current information is captured.



Interactive topic visualization.

Deliverables

The primary deliverable from this project is a knowledge management system to read, extract, and manage explicit and tacit knowledge. The knowledge generated by the system could be used for risk assessments, compliance initiatives, improved knowledge transfer, and pipeline integrity management.

Other deliverables are the gathered documentations during the project, such as SME interviews, surveys, industry reports, etc. A Final Report was prepared detailing the system and the findings.

Benefits

Specifically, a knowledge management system can:

- Streamline management of the organizational knowledge into one platform
- Improve knowledge-transfer procedures from retiring employees to the new employees
- Analyze and establish links between business processes, regulations, and technical subject-matter expertise
- Reduce the search effort needed for employees to find relevant information from documents, reports, and project data (which can be spread across multiple locations and departments)
- Enrich training curricula with the knowledge extracted and/or recovered
- Extract vital information from documents, and
- Establish a base platform to develop a mobile application to support field operations.

Technical Concept & Approach

The knowledge management system applies off-the-shelf technology to capture the knowledge state in an organization.

The project team conducted interviews with SMEs to gather experienced knowledge on gas utility operations, regulations, business processes, best practices, and technical standards. The primary focus was on designing a practical and consistent system to manage knowledge on natural gas pipeline integrity programs and, specifically, to address the AMSE B31.8S standard *Managing System Integrity of Gas Pipelines.*

The design process follows industry standard processes, such as Unified Modeling Language and Business Process Management Notation.

Results

Research focused on:

- Collecting and reviewing past project reports to build a project-subject-matter repository. (Collected documents were categorized into 15 topics, which served as the baseline for calibrating topic modeling algorithms.)
- Establishing an unstructured database for storage, utilizing natural language processing to automatically extract information from reports.
- Developing models to infer summary information related to each document.
- Investigating open-source ontology visualization platforms. The team will identify the most promising solution to visualize the retrieved textual database.

Open-source ontology visualization platforms were investigated, and the most promising platform employed to visualize the retrieved textual database.

The project team researched, identified, and assembled in excess of 180 Final Reports that are of relevance to the project subject matter repository.

Researchers evaluated the performance of eight weighting methods. To provide a reasonable method of evaluation, the opinions from SMEs were considered as a baseline. The optimal method was identified and topic modeling was conducted.

In 2019, researchers compared the results of two topic modeling methods and optimized the model parameters utilizing similarity and coherent measures. Furthermore, scatter and word plots were generated, and a project domain knowledge ontology graph was developed from project reports.

The project team facilitated a webinar to review the Final Report.

Status

This project was completed in 2019. A Final Report was issued in June.

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Modernizing Tools to Assess Third-Party Damage Risk

Researchers are developing detailed procedures to modernize third-party-risk assessment models by incorporating state-of-the-art physics models, detection techniques, data analytics, regulations, and data sources to the models.

Project Description

To minimize the potential interference from third parties, natural gas utilities have been utilizing qualitative, semi-quantitative, or quantitative approaches to evaluating the associated risk.

The outputs from risk assessments enable gas operators to evaluate risk of a specific pipeline segment, rank the pipeline segments, identify significant threats at certain locations, and track the risk evolution over time. However, these models often require updating, considering developments in detection and alarming technologies, data analytics, and regulations. For example, a widely used third-party-damage risk tool has not yet been considered in the probability calculations and the consequence analysis is not incorporated.

In this project, researchers will build a risk model that can provide not only mean-risk estimation, but also more information for making informative decisions.

The objective is to develop detailed procedures to modernize third-party-risk assessment models by incorporating state-of-the-art physics models, detection techniques, data analytics, regulations, and data sources.

The enhanced risk model(s) will bring the outdated variables, hypothesis, and formulas up to date and be flexible to include additional components if missing from the current models.

Deliverables

Deliverables include a modernized third-party-damage risk-assessment model(s), a detailed user manual, and an application with a user-friendly interface.

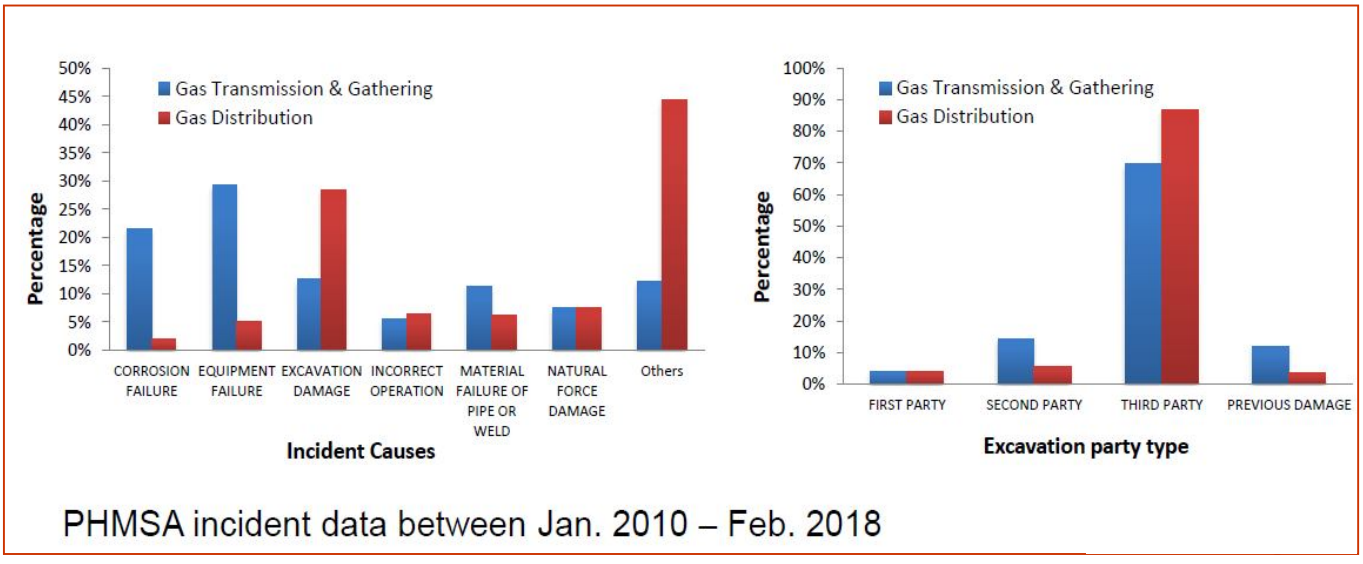
Benefits

The developed/updated third-party-damage model(s) will ultimately be capable of improving the risk-assessment accuracy and resolution in spatial and temporal domains, reducing the operational cost of unnecessary mitigation/prevision operations, and ensuring continuous system integrity and reliability under the threat of third-party damage.

Technical Concept & Approach

- **Data Collection and Model Selection**

  Focus is on the relevant data that can be used for computing the failure (occurrence) probability of root causes. It is expected that the updated model will be able to periodically download, extract, and analyze the data to automatically update the system. The project team will solicit third-party-risk assessment models from utilities, investigate the overlaps among them, and develop generalized procedures that can be used by most utilities.



- **Identification of Components Update**

  Researchers will identify the relevant components of target models that can be modernized from the technical point of view. Feasibility and gap analysis will be performed to gain insights from the customers' point of view.

- **Modernization of Risk Model and User Interface**

  This task will focus on the technical details for model modernization. If needed, researchers will develop Bayesian networks including the existing functionalities and the newly extended capabilities. The probabilistic network has the advantage of modeling information flow in both the forward and backward directions, which is beneficial for performing root-cause diagnosis and failure-rate prognosis analysis. Considering the sponsors' preference, the project team will develop a user-friendly interface, which includes all the customizable inputs from users and shows the output as failure rates or probabilistic distributions.

- **Model Verification and Demonstration**

  This task will verify the accuracy/uncertainty, efficiency, and limitation of the modernized risk models. Within the definition domain, the outputs for various input combinations will be generated and they should fall within an acceptable range. For cases without actual validation data, the failure rate from the risk model should be consistent with historical databases and conceptual understanding.

Results

In 2018, the project team developed a survey for sponsors and also mapped out the business process for third-party excavation. Researchers reviewed more than 50 relevant technical reports and papers that documented advancement over the past 20 years. Throughout the initial literature review, various data sources were identified that can be potentially utilized for calibrating the developed third-party risk models. Furthermore, the third-party excavation processes were mapped out in order to help identify contributing factors affecting the risk of pipeline right-of-way interference.

In 2019, potential models were reviewed. A gap analysis was conducted to identify outdated model components and missing data items. Researchers identified the difference between distribution and transmission systems for the third-party-damage risk model and developed the quantitative expressions for different use cases. The damage probability was rationalized for the first time in consideration of the reviewed literature, data processing, and survey responses.

"Enbridge is excited about having an updated and current model for assessing third-party damage risk. This new model will better equip our risk-assessment group with completing accurate and realistic assessments of third-party damages. This in turn will have a positive impact on delivering natural gas in a safe and reliable manner."

- David Furdas
Senior Engineer, Innovation & Technology
Innovation & Technology
Enbridge Gas Inc.

By analyzing multiple data sources, researchers realized that the data corresponding to damages and excavations should be carefully partitioned to obtain the damage rate. The overall objective of this project is to estimate the damage rate given excavations. However, different data partitions will give us results corresponding to different use cases. Within each group, the excavations can be filtered based on the facilities adjacent to a specific excavation. Similarly, the damage data can also be portioned in the same manner.

The project received the ticket and damage data from sponsors. From them, the total number of notified excavations can be extracted, as well as the corresponding damages resulted from different root causes. Other attributes (e.g., excavation equipment used, pipeline diameter, waiting time before excavation) can also be plotted.

Given the pipeline damages, the project team is exploring the possibility of estimating other unknown quantities.

After performing detailed analysis, researchers developed a modernized model using Bayesian network considering the majority of the causal factors. The probabilistic model can analyze the third-party-damage risk with slight changes corresponding to transmission and distribution systems.

Status

Researchers continue to collect data through data calls and survey responses. Data is being processed from a sponsor and integrated for Bayesian network quantification.

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Risk Model for Locates

Researchers developed a casual risk model that calculates the likelihood of excavation damage due to a locating issue. The likelihood calculation is based on factors such as an assessment of vendors, workload levels, local weather, physical characteristics of the facility, complexity of the job site, and potential hazards or other safety issues.

Project Description

Locating issues are one of the leading causes of known damage to underground natural gas facilities. To prevent damage, regulations require that excavators must request facility owners to locate and mark any existing underground facilities in the planned excavation zone. A risk model for the locating process will identify the most important risk factors in the process and quantify their effects on the probability of excavation damage.

For this project, a risk model was developed that calculates the likelihood of damage to an underground facility based on factors such as an assessment of vendors, workload levels, local weather, physical characteristics of the facility, complexity of the job site, and potential hazards or other safety issues.

Deliverables

The main deliverable from this project is a risk model for locates in the form of a software tool. Operators and software vendors can incorporate the tool into their existing risk-modeling toolset. Follow-on projects will develop a web-based user dash-board and an interface to connect to sponsors' databases.

A Final Report details the project methodology and key findings.

Benefits

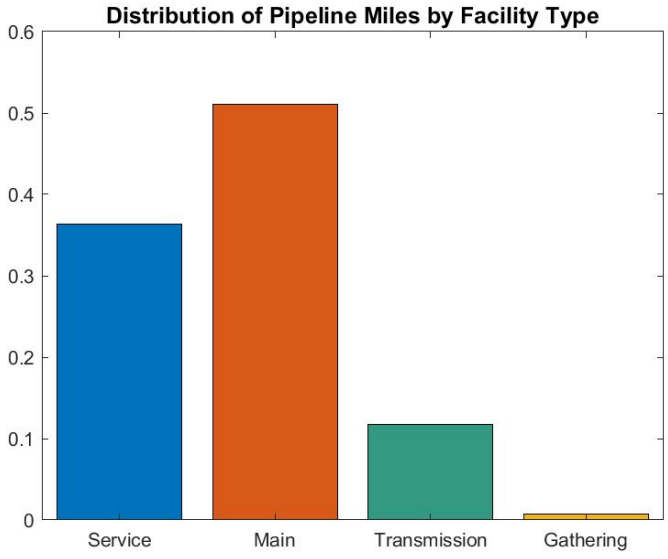
A risk model for locates will reduce system risk and improve safety by assisting operators in understanding the risk of the job that is to be performed. Based on the risk ranking from the model, utilities can take additional safety measures, such as requiring a supervisor on site to oversee the excavation. The model will help to determine the risk of failure due to incorrect locates.

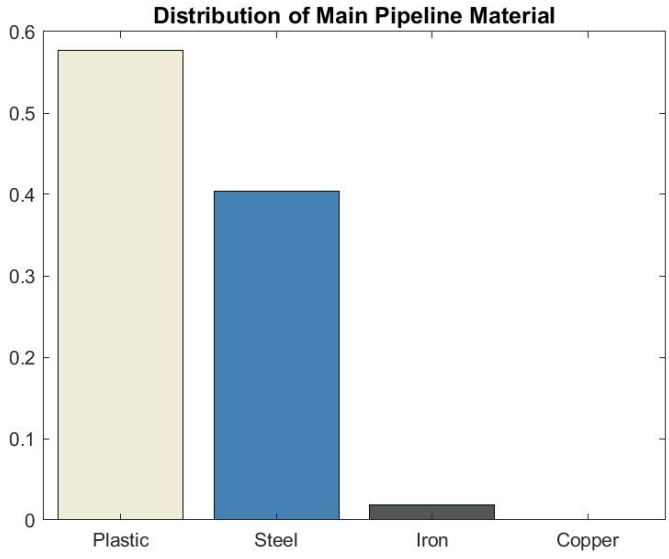
Technical Concept & Approach

Researchers created a risk model that proactively calculates the likelihood of damage due to activities and processes associated with locates.

A comprehensive literature search on modern methods of risk assessment was reviewed to design the risk model. Critical parameters that affect the risk calculations were identified. A Bayesian network approach was implemented to model the risk. (Bayesian networks combine opinions of subject-matter experts, industry best practices, physics-based models, and historical data-driven models

The risk model was developed by leveraging industry standard platforms. The project team will create a simple web-based user dashboard for operators. The model will be tested and updated as necessary.





Results

The Final Report details the development of a Bayesian network model that quantifies the probability of excavation damage to an underground facility due to a locating issue. Researchers used business process modeling to form causal pathways and the effects of stakeholders' actions in the locating process. The project team also identified primary and secondary data sources necessary to develop a comprehensive model. Augmenting the primary dataset with nontraditional data sources – such as historical weather, census, and United States Department of Agriculture soil survey datasets (and through data harmonization methods, feature engineering, statistical modeling, and machine learning methods) – was key in elucidating causal and predictive factors affecting probabilities of excavation damage.

The underground facility density risk factor – defined here as the probability that an underground facility exists in the excavation zone – is the leading risk factor in determining the probability of damage to an underground facility for a given excavation job. Favorable conditions of other risk factors (e.g., locate ticket priority, workload level, and locator competence) serve to ameliorate the underground density risk factor. This risk factor calculated using statewide pipeline mileage data and housing statistics may be used to prioritize locate ticket requests and minimize underground facility damage.

The underground facility density risk factor is an industry-known risk factor. This contributes to the body of knowledge by defining a method to quantify the risk factor and propagate its effects to other risk factors.

This report also discusses the need for research in natural-language processing applied to risk modeling. Incident reports include narrative descriptions of the incidents which are rich sources of information and may yield additional insights if leveraged appropriately. Other suggestions contained in the report include:

1. The use of data-harmonization methods to identify duplicated locate tickets and reduce retransmission
2. The tracking of locator error rates to optimize resource deployment, and
3. The use of the ground-penetrating radar soil suitability index to effectively plan locate jobs.

There are about two damage incidents per 1,000 locate requests. Given the low probability of damage on a single ticket, Bayesian probability and inference methods may be more appropriate to model such events than methods that rely on long-run probabilities. Bayesian networks are probabilistic graphical models that combine beliefs and opinions of subject-matter experts, physics-based models, and historical data-driven models using Bayesian probabilities.

"Traditional risk-assessment methods are reactive, analyzing past dig-ins to assess risk. However, this project sheds light on other non-traditional data sources for assessing risk – population, asset density, ticket volume fluctuations per locator, etc. – that provide insight into other drivers that may contribute to the risk of a dig-in."

- Aaron Rezendez
Engineer, R&D and Innovation
Pacific Gas and Electric Company

The rest of the report is as follows:

- Data: Sources and Description describes the primary and secondary sources of data, the relevance of each dataset, data access methods, descriptive statistics, and possible alternative uses of the datasets.
- The Methods section provide comprehensive, yet concise, descriptions of the business process and quantitative methods employed in model development.
- The Model Development section discusses specifics of developing a Bayesian network model to quantify effects of locating issues on the probability of excavation damage using the datasets and methods discussed prior.
- The report concludes with Discussions and Future Work.

Status

This project was completed with a Final Report issued in February 2020.

Future phases will focus on conducting pilot studies, automating the systems for implementation, and commercialization of the risk model.

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