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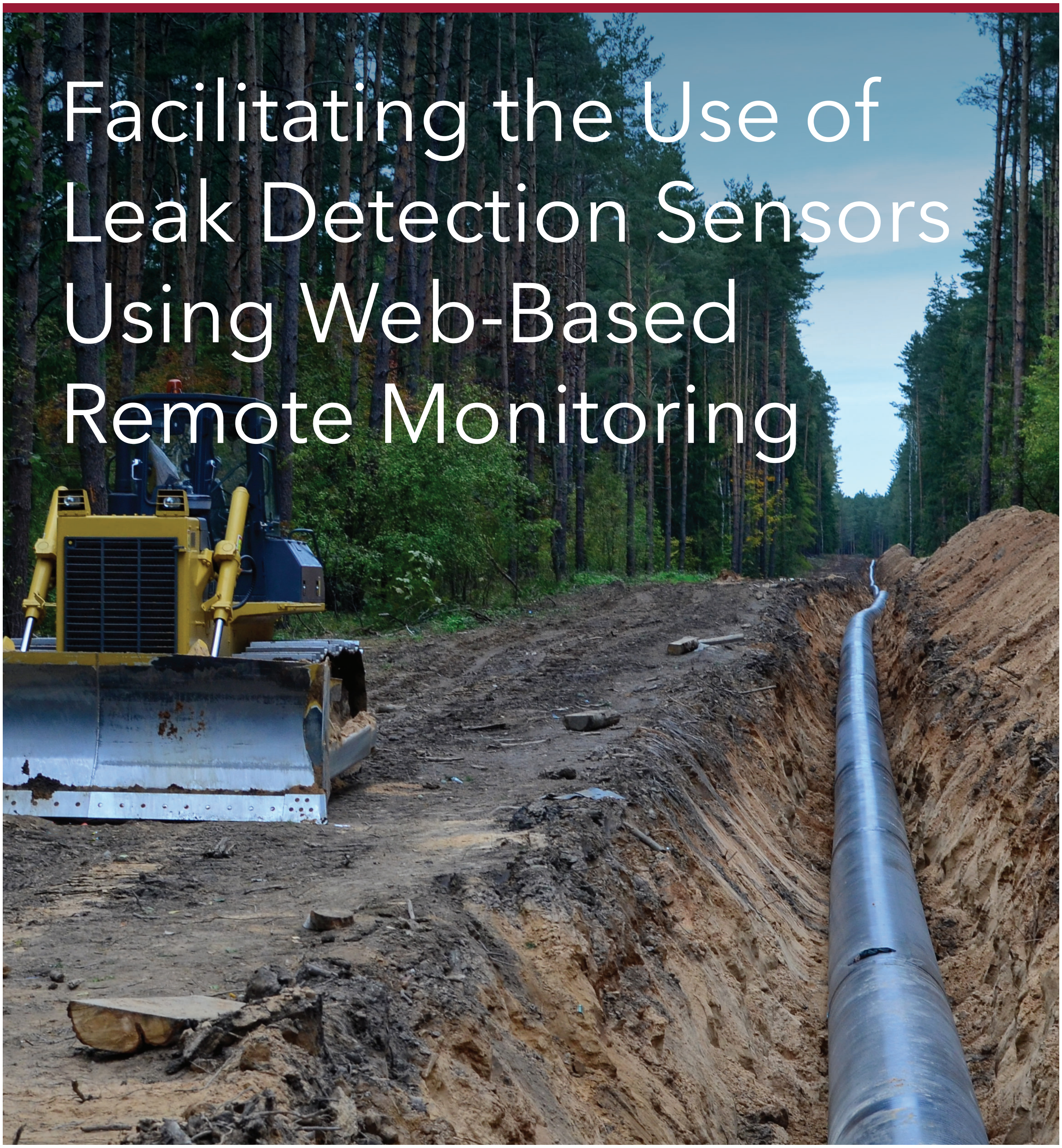
Facilitating the Use of Leak Detection Sensors Using Web-Based Remote Monitoring



ABSTRACT

This paper presents a case study in adapting report by exception remote monitoring technology to continuously monitor leak detection sensors along a cross-country, high volume liquid products pipeline system. The resulting system enables the operating company to have 24/7 visibility to their leak detection devices as well as immediate alarm notification in the event of a detected leak condition. This technology enables sensors to be distributed anywhere in the system, regardless of the availability of communication connection to the central operations network, using cellular and satellite communication. The web-based data interface enables viewing of data and receipt of alarms through any authorized web-enabled device. The presentation will discuss the sensor and monitoring technology, the data interface used between the sensors and monitors, the various means of facilitating communication to the operating company, and some lessons learned along the way.

Key words: Pipeline, terminal, leak detection, monitoring

INTRODUCTION

Pipeline leak detection is emerging as a prime focus of Pipeline and Hazardous Materials Safety Administration (PHMSA) and other regulatory agencies in the United States, as well as jurisdictions all over the world. The immense volume of buried pipelines and the fact that much of this buried infrastructure is over forty years old[1] combine to present increasing risk of leaks with potentially catastrophic results. During the twenty-year timespan from 2002 through 2021, in the United States alone, the Pipeline and Hazardous Materials Safety Administration (PHMSA) recorded 42 hazardous liquids incidents resulting in 35 fatalities, 80 injuries, and over 147,000 barrels spilled (Figure 1).[2] In many cases, the environmental and human health and safety costs could have been reduced if the leaks were detected much earlier.

Figure 1: PHMSA hazardous liquids pipeline incidents: 2002 - 2021

Monitoring and communication technology has evolved significantly over the past thirty years, particularly through relatively inexpensive low-bandwidth satellite communication and increasingly robust and reliable cellular communication. The expansion of these communication networks has resulted in nearly complete global coverage, greatly facilitating data acquisition from even the most remote pipeline locations. Additionally, monitoring systems, sensors, and field asset control devices have evolved as well, taking advantage of the data communication options currently available. These advances in communication and monitoring technology have enabled the hazardous materials pipeline industry, along with most other industries, to transmit ever-increasing volumes of data from an also increasing number of field locations. Many field sites that were typically nearly inaccessible, except in case of emergency, are now able to both transmit and receive data in near real-time with consistent reliability.

Along with these advances in monitoring and data communication technology has come expectations that pipeline operators can and should have much greater visibility into field assets essential to pipeline integrity, environmental health and safety, and the pipeline assets themselves. This paper involves an ongoing proof of concept combination of sensor and communication technology aimed towards developing a reliable and cost-effective system for continuous leak detection monitoring of pipelines and tanks. This system is applicable to any location where elevated risk of pipeline leaks exists. This also includes areas at high-consequence locations where the risk of a leak may be low, but the resulting damage from unexpected leaks could be catastrophic.

Calendar Year	Number	Fatalities	Injuries	Barrels Spilled	Net Barrels Lost
2002	1	1	0	0	0
2003	2	0	5	0	0
2004	3	5	16	860	860
2005	4	2	2	4,048	3,518
2006	1	0	2	4,513	4,513
2007	5	4	10	12,176	11,961
2008	3	2	2	6,755	5,755
2009	3	4	4	364	364
2010	3	1	3	3,105	3,105
2011	1	0	1	0	0
2012	2	3	4	1,500	1,245
2013	4	1	6	23,703	23,702
2014					
2015	1	1	0	976	976
2016	3	3	9	7,032	5,349
2017	1	1	1	13,465	13,465
2018	1	0	2	48,400	48,400
2019					
2020	3	5	12	21,103	21,103
2021	1	0	1	0	0
Grand Total	**42**	**33**	**80**	**147,998**	**147,315**

EQUIPMENT USED

The systems used in the laboratory system development and testing as well as the field installations currently under evaluation consist of a hydrocarbon sensor, a Resistance Temperature Detector (RTD) sensor control box, an “Ohms to 4-20mA” signal converter, and a cellular communication enabled monitoring device. The monitoring device communicates data to a web-based data portal, providing authorized users access to the data from the field device. The web interface also serves as the data conduit for configuring the monitoring frequency, data reporting frequency, setting sensor alarm recognition thresholds, and generating notification of alarm condition events to the user.

Sensor and Sensor Control Interface

The sensor type used in both the laboratory and field testing for this application use “Polymer Absorption Sensor” (PAS) technology, forms of which have been in use since the 1950s. The current technology in the specific sensors used in this study are a variant of PAS, termed “Elastomer Absorption Sensor” (EAS) technology. The basic principle of this type of heavy hydrocarbon sensor is using a “chem-resistor’ type polymer membrane, which changes in resistance due to an expansion of the polymer matrix upon exposure to certain chemical substances, in this case hydrocarbons. The resistance level is measured and based on the magnitude of the change. A leak condition is indicated for the structure being monitored. This current sensor system elevates the technology using a “smart” data acquisition module enabling progressive leak detection options. The data acquisition module is a “Class1, Div2” rated device providing connection to the sensor via a multi-pin cable connection. It also supplies the data output via a 2-conductor cable transmitting the sensor value in ohms to the monitoring system. The module is powered by an extended life 3.6V lithium, non-rechargeable battery providing voltage to the sensor. Estimated battery life is >10 years.

The sensors are available in lengths up to 80 feet (24.38 meters), with a recommended maximum length of 50 feet (15.24 meters) for “horizontal” applications, as would be the case in most pipeline applications. This particular sensor technology is reactive to liquid hydrocarbons and heavier gases, such as propane, but is not effective for lighter gases, such as methane. The sensor is unaffected by the presence of water, maintaining reliability in any application environment (Figure 2).

The electronic components in the data acquisition module are epoxy enclosed (potted), facilitating both the electrical isolation necessary for the Class1, Div2 rating. It also provides exceptional protection against water, dust, and chemical ingress that could damage the internal components.

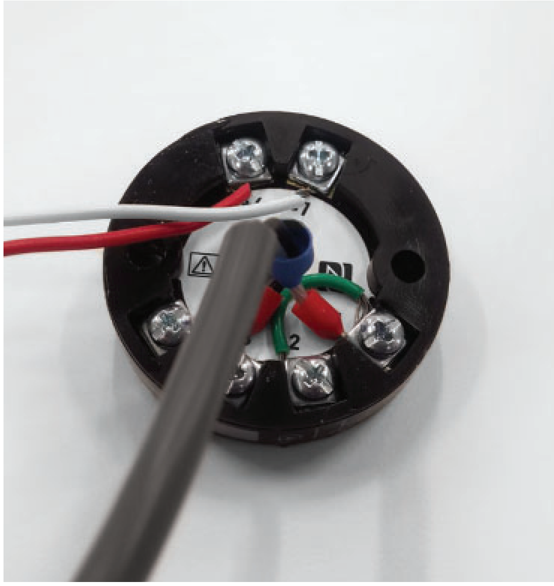
Figure 2: Control Module

Figure 3: Sensor section

Signal Converter

For the laboratory testing as well as the field trials an off-the-shelf, programmable RTD signal converter was used (Figure 4). The output from the sensor data acquisition module is presented in ohms, similar to the output from any common RTD temperature probe interface. The converter is programmable for specific output ranges indicated in degrees Celsius. The range required for the module output is 0°C to 520°C. The output from the module is a 2-wire configuration. The signal converter requires a 3-wire connection. This was enabled using a jumper wire between terminals one and two, with the loop current output from the monitoring system connecting to terminal one and the signal return lead connecting to terminal three on the converter. Terminals six (+) and seven (-) on the signal converter supplied the 4-20mA signal output to the monitoring device.

Figure 4: Signal converter



Monitoring Device and Web Interface

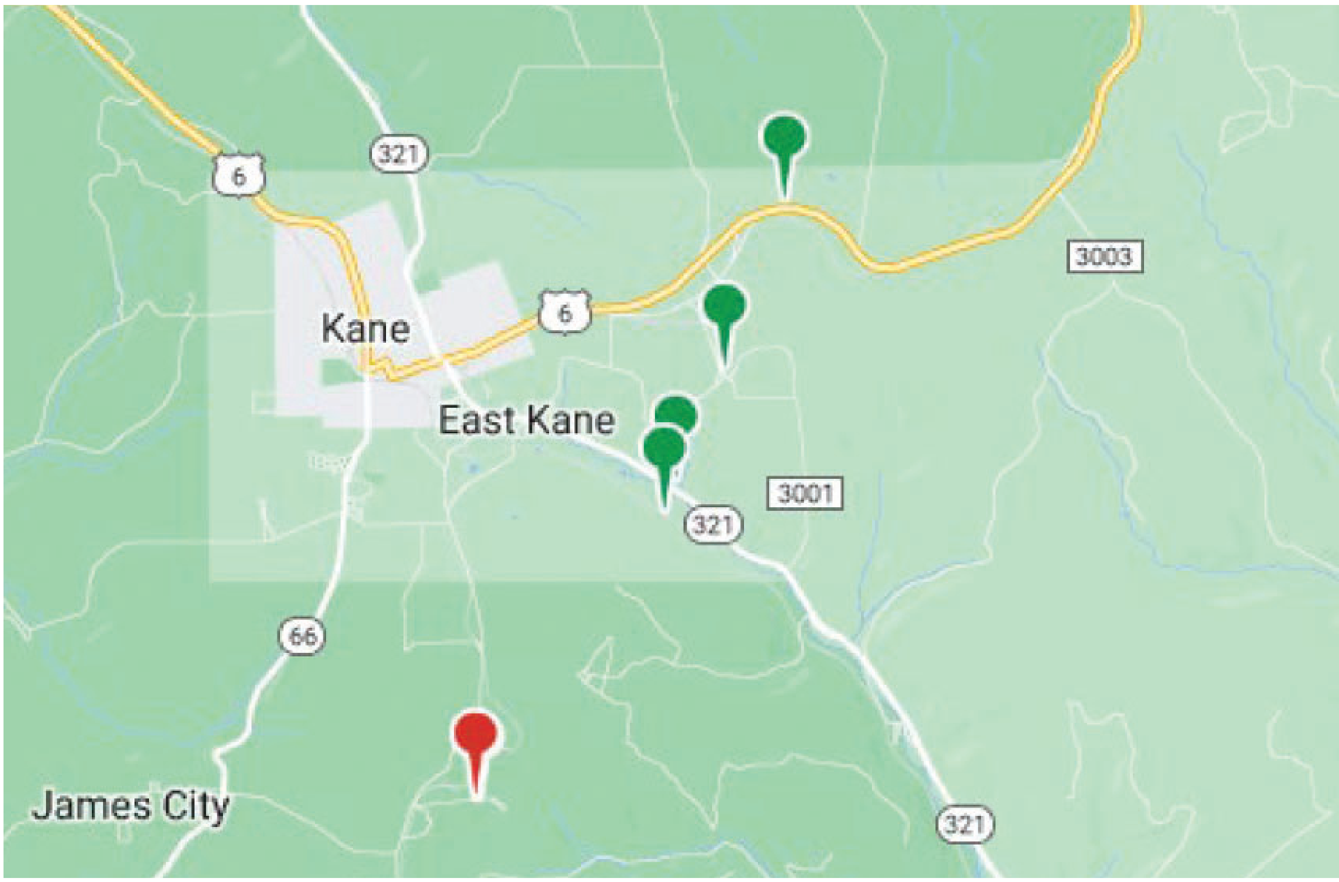
Two different monitoring devices were used in this project. For the initial testing and configuration steps, the monitoring device used was a 4-channel sensor/transducer monitoring unit. This device was selected for the initial configuration and testing due to the ability for configurations and data measurements to be displayed on the front panel LCD interface. The initial configuration settings required some trial and error to arrive at the required “temperature” range from the signal converter. Adjustments were also needed to get the proper ohms value settings for the 4-20mA signal to come into the monitoring device from the signal converter. The device used in these initial steps required external power. Many of the applications targeted for this system will not have external power available, so once these critical configuration values were determined, the application was duplicated on simpler, battery-operation-capable, 2-channel devices. The final in-house lab testing and field trials used the 2-channel battery-operated devices (Figure 5).

Figure 5: Monitoring device

Web-based Data Interface

The field monitoring device communicates via cellular communication to a secure web portal, enabling authorized users to access the monitor data, configure the alarm thresholds, configure the sampling and reporting frequency, and receive alarm notifications in the event a leak condition is detected. Alarm notifications are delivered immediately from the web portal to authorized users vie email and/or text messaging. The interface includes an interactive asset mapping feature displaying the locations and alarm status of sensors in the field, enabling swift recognition of areas requiring attention (Figure 6).

Figure 6: "Map View" of field sites showing "normal" (green) and "alarm" (red) status pins



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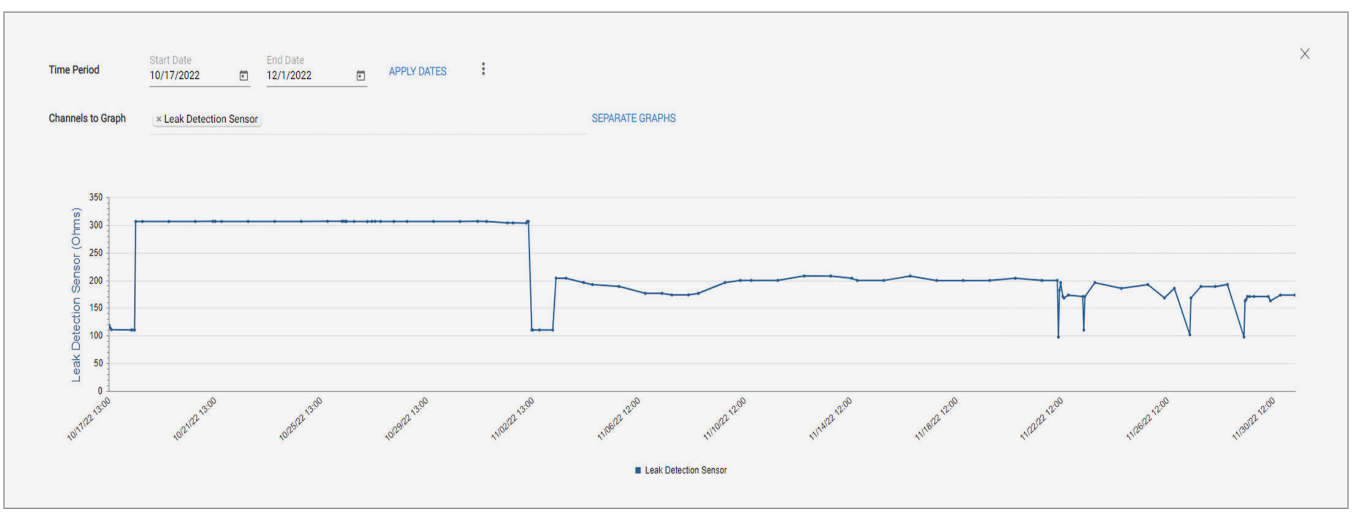
INITIAL TESTING AND FIELD TRIALS

The first task was to test the sensor output range and configure the monitoring system to accommodate the sensor output. A test system was set up and a series of tests were run using a mixture of naphtha and alcohol to trigger the sensor. When the correct configuration values were determined for the signal converter and the monitoring system, these values were tested across several monitoring platforms for validation.

The next step was producing a basic, controlled proof-of-concept demonstration for the end-user company. A system was configured using a 4-channel, externally powered monitoring device. This system provided more configuration capability in the event the parameters required any additional tweaking. The sensor was inserted into a PVC tube and contaminated with fuel oil (Figure 7). The monitoring system detected and transmitted the alarm notification shortly following the saturation of the sensor. The sensor was "cleaned" and the test re-run several times over the next 45 days, using different amounts of contaminant and different lengths of exposure. The alarm and return to normal periods can be seen on the graphed data pulled from the web interface (Figure 8). Eventually, the sensor was contaminated to the extent it was unable to be cleaned for further use. Following the success of the proof-of-concept testing, sites were selected for installation of long-term field trials.

Figure 7: Proof-of-concept testing set-up

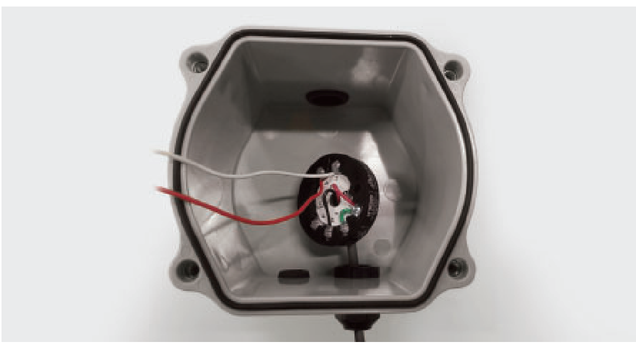
Figure 8: 45-day graph of data showing alarm periods (>150 ohms) and normal periods



Multi-site field testing

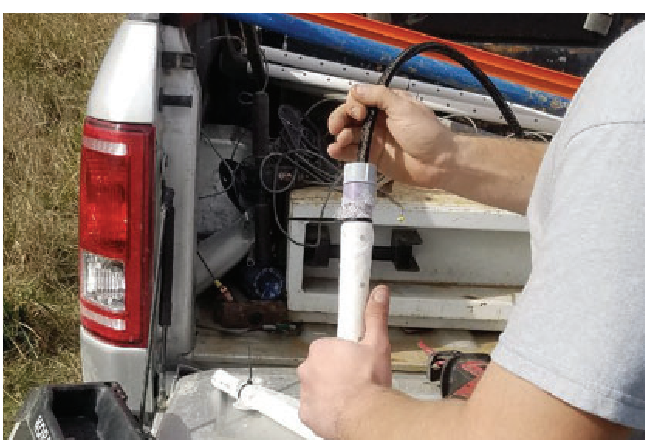
Battery-powered, 2-channel monitoring devices were selected for the field test applications. These systems were configured and prepared for installation in advance. The "ohms to 4-20mA" signal converters were installed inside the monitor enclosure and pre-wired to the monitoring system. The connection point for the sensor control box was supplied via a 2-conductor communication cable connected to the signal converter inside the monitor (Figure 9).

Figure 9: Signal converter installed within the monitor enclosure



Field testing was started at three valve-site locations. The sensors used were 4 feet (1.22 meters) in length. The sensors were inserted inside mesh-covered, perforated PVC tubing to protect the sensor element from the soil while allowing hydrocarbons a path to contact the sensor (Figure 10).

Figure 10: Inserting the sensor into the protective sleeve



The sensor was secured to a metal brace. The sensor data acquisition module and the remote monitoring unit were attached to the top of the metal brace and the final connections were secured (Figure 11).

Figure 11: Assembled system prepared for field installation

When the installation was completed, a "pushbutton" test was done to confirm connectivity to the web interface and to verify the sensors were reading in the expected ranges. The three field test sites are now undergoing a long-term (3 to 6 months) performance evaluation.

Figure 12: Installation completed

DIGITAL TRANSFORMATION

This type of sensor is currently used in many tank and pipeline applications. Typically, the sensor is monitored via a traditional SCADA data acquisition system. The monitoring is present for alarm condition detection and notification of relevant personnel for remedial action. The sensor technology excels at this application. This type of monitoring also enables installation in areas in the system where the SCADA network is unavailable or not a cost-effective option. The monitoring used in the system enables the user to combine the occurrence of a leak in the pipeline, tank, block valve, or any other monitored structure, with other data monitored over the same network. Cathodic protection data, corrosion rate data, AC interference data, and other factors potentially contributing to a structure failure can be evaluated and compared in the system, in real time. This enables the user to determine likely causal factors and generate corresponding preventive steps, reducing the likelihood of future failures. Ultimately, the correlation of multiple data points in a web-based cloud data model facilitates continual process improvement and preventive action through the application of machine learning and similar artificial intelligence technologies. The pipeline systems in use today are expected to last longer. They are also predicted to safely and reliably transport the energy that is the lifeblood of infrastructure and industry worldwide. Personnel available to oversee these increasingly complex systems are in short supply, necessitating the use of all the technological advances available to operate these essential pipeline networks effectively and efficiently. Web-based monitoring and cloud-base artificial intelligence are rapidly evolving as the means to use ever-increasing volumes of data efficiently.

CONCLUSIONS/NEXT STEPS

The goal of this undertaking was to design a simple, repeatable, and cost-effective leak detection monitoring system that can be used in nearly any pipeline or terminal application. The results, thus far, are very positive. The system is simple to deploy, and very cost-effective to operate. There are some aspects that can be improved upon, and some lessons learned in developing and testing the application. First, the monitoring unit used in this project is Class1, Div.2 rated and thus is not suitable as is for areas, particularly in terminals, where Class1, Div.1 rated electronics are typically required. Work is now underway to modify the monitoring component to meet this criterion. This system uses cellular communication. Though the cellular network provides adequate coverage throughout most of the U.S. and North America, there are still areas requiring satellite communication. Work is underway to enable a satellite communication option in the battery-operated monitoring platform used in the field trials. Additionally, exploration of other communication topologies such as LoRa, Wi-Fi, wireless HART, and others may expand the feasibility of deployment in applications where conventional wide area communication methods are not suitable. The signal converter used is an "off-the-shelf", programmable device. Normally, this would be a good thing, as it would serve to provide some flexibility in application. However, it was determined during the testing that a specific fixed range is applicable to any length of sensor. For this application and these sensors, programmability of the signal converter becomes an otherwise unnecessary extra step in the configuration/assembly process. Finding or developing a fixed-range sensor in the proper range for the sensor would simplify the system. Ultimately, integrating the data acquisition module, signal converter, and monitoring unit into a single device would provide a simple, one connection, and turn-key system.

The sensors used in these tests produce very good results for detecting liquid hydrocarbons and heavy gases (propane, butane, etc.). Work is ongoing to develop similar sensor types for natural gas applications. In addition, this system model may be applicable for other hazardous materials sensors such as hydrogen sulfide (H2S) and carbon monoxide (CO2). With the elevated attention regarding pipeline leaks by regulatory agencies at every level, there is a great need for reliable and cost-effective leak detection for broad-based pipeline and terminal applications. So far, the initial testing and results seen from this system show a great deal of promise in meeting that need.

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About the Author

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Jamey entered the corrosion/cathodic protection industry in 2005 as a sales and technical support specialist for "NTG." A wholly-owned subsidiary of Elecsys International, "NTG" at the time was a small, but growing supplier of rectifier and test station monitoring systems to the pipeline industry. By 2009 Jamey was focusing more on product development, designing the first comprehensive AC interference monitoring systems, along with new designs of rectifier and test station monitoring systems. Virtually all of Elecsys' current monitoring systems were designed wholly or in part by Jamey.

As Elecsys and the "Watchdog" brand of CP monitoring devices gained widespread acceptance and use in the oil and gas pipeline market, Elecsys began the focus of providing these systems to water and wastewater utilities. As the Elecsys "subject matter expert" regarding CP monitoring, Jamey was instrumental in educating these utilities on the features and benefits of remote monitoring, establishing Elecsys as a leading supplier of monitoring systems to the water/wastewater utilities industry. This paper was initially conceived through the realization that the water and wastewater utilities industry is lagging behind the rest of the pipeline industry in adopting technologies that will greatly benefit their resource allocation and task prioritization of their technical personnel. The benefits of remote monitoring realized by the oil and gas pipeline industry for compliance with mandates could have an even greater impact on the water/wastewater industry for facilitating infrastructure integrity.

Jamey is continuing to develop new monitoring systems and new applications for existing systems, branching out into corrosion rate monitoring and leak detection monitoring, among other applications. Jamey is an AMPP-certified cathodic protection technician (CP2) and is currently the Product Manager for Elecsys remote monitoring products.