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Development and Application of a New Solution for Mitigation of Carrier Pipe Corrosion inside Cased Pipeline Crossings

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Increasing emphasis is being placed upon control of carrier pipe corrosion inside cased pipeline crossings from both an operator and regulatory perspective. Inline inspection associated with pipeline integrity management programs has identified external carrier pipe corrosion inside casings. Many factors contribute to this corrosion concern. Systems designed to proactively mitigate corrosion inside cased crossings were not readily available.

The desire for a proactive carrier pipe corrosion control system led a pipeline operator and a company expert in the manufacture and application of volatile corrosion inhibitor (VCI) chemistry to consider a new corrosion mitigation solution. This effort resulted in the development of a unique product designed to fill the annular space of a casing with a gelatinous product that proactively controls carrier pipe corrosion and prevents intrusion of water, etc. into the annular space. The gel filler has been applied inside cased crossings since late 2011. Electrical resistance (ER) probes have been installed through the casing vents and submerged in the filler to the carrier pipe surface. The probes are monitored remotely with automated technology. The corrosion rate data validates the effectiveness of the VCI filler. This new corrosion control solution produces an excellent opportunity to enhance the integrity of pipelines inside cased crossings.

Key words: carrier pipe, cased pipeline, volatile corrosion inhibitor, VCI, electrical resistance (ER) probe

INTRODUCTION

According to a Southwest Research Institute[1] 2007 study, cased pipe segments are generally believed to be very safe since the time-independent threats, including third party excavation and outside force damage, are largely eliminated. However, external corrosion of carrier pipe inside casings still poses a threat to pipeline safety. Understanding the causes and characteristics of carrier pipe corrosion is an important step forward to better management of corrosion threats within cased crossings.

External corrosion on the carrier pipe can occur due to a variety of factors including:

- A high concentration of diffused oxygen with accumulated condensation at holidays (pinholes and voids) on the carrier pipe coating can lead to an accelerated rate of corrosion.
- General atmospheric corrosion at coating holidays on the carrier pipe.
- Accelerated corrosion at coating holidays in direct contact with an electrolyte such as water or other debris.
- Localized corrosion due to concentration cells or the presence of bacteria, etc.
- For casings located near a compressor station, elevated temperature may accelerate an existing corrosion cell. Elevated temperatures may also cause coating damage and expose the carrier pipe surface.

A major pipeline company has an inventory of over 2,000 cased crossings installed throughout the various regions of Canada and the US. For many years steel casings were commonly installed over sections of pipelines to provide mechanical protection for pipelines constructed under roads and railways. They incorporate electrically isolating spacers and end seals that separate the carrier pipe from the casing. Over time the integrity of the end seals can degrade allowing for the ingress of potentially corrosive groundwater. Pipe movement due to settling and degradation of the isolating spacers may produce a potential contact of the casing to the carrier pipe resulting in an electrical short. These factors may present an elevated risk of external corrosion on the section of piping located within the cased crossing.

Historically, casing rehabilitation programs have included projects to fill the annular space with a di-electric wax in an attempt to mitigate carrier pipe corrosion and prevent intrusion of groundwater. In-line inspection (ILI) of cased pipeline crossings have identified the existence of external corrosion anomalies on the carrier pipe within the annular space inside cased crossings. These anomalies have been identified inside casings filled with wax, as well as un-filled cased crossings. Concern for control of corrosion at areas of disbonded coating inside cased crossings was also a focus due to awareness that portions of the pipeline system was subject to disbondment of tape coating.

This data coupled with other factors and concerns with wax filled casings caused the pipeline company's Integrity Management Team to begin investigating alternative solutions in 2010. The goal of this investigation was to identify solutions that would produce proactive control of carrier pipe corrosion inside cased crossings. A company skilled in the manufacture and application of volatile corrosion inhibitor (VCI) chemistry was consulted for consideration of an ideal carrier pipe corrosion mitigation solution.

EXPERIMENTAL PROCEDURE

A team comprised of pipeline engineers; along with the engineer and R&D specialists from the corrosion inhibitor company; as well as a pipeline integrity expert from a major corrosion service company began work on this project late 2010 into early 2011. The goal was to create a product that could be used to fill the annular space of a cased crossing and proactively control carrier pipe corrosion while preventing the intrusion of external water/air into the annular space. The team then initially developed a list of criteria defining the features of an ideal casing filler. The criteria for this casing filler are as follows:

- The filler should contain ample quantities of a VCI product designed to mitigate corrosion on the external surface of the carrier pipe and the internal surface of the casing.
- The filler should contain sufficient dosages of a VCI that will migrate on a molecular level under any disbonded coatings to provide corrosion protection on the carrier pipe surface.
- The VCI in the filler should also have a vapor phase component capable of mitigating corrosion within any portions of the annular space that are not completely filled.
- The VCI in the filler should be proven to diffuse through any soil debris inside the annulus and mitigate carrier pipe corrosion on surfaces in contact with the soils.
- In order to ensure a complete fill the product should have the viscosity of water and be at ambient temperature while the casing is being filled. Then once inside the casing, the product should transform into a high viscosity gel within a short time.
- Once transformed into a gel, the viscosity should be sufficiently high to prevent the infiltration of water into the annulus and prevent loss of the filler from the annulus.
- The filler should be electrically conductive and allow flow of CP current to the carrier pipe.
- The product needed to be non-flammable.
- The product needed to be environmentally friendly, non-toxic, free of nitrites and phosphates, made of biodegradable materials.
- Application of the filler should not require excessive carrier pipe surface preparation.
- The casing should not need to be dry before filler application. The filler should be able to combine with nominal quantities of annular space water during installation. The additional water should not reduce the effectiveness of the filler's ability to mitigate corrosion of the annular space metals.
- The product should produce economical corrosion protection and minimal shipping costs.

This list of product specifications was then provided to the R&D group for the VCI company. After an initial review, a determination was made that this product could be developed with a unique combination of recognized chemistries and technical knowledge. The pipeline team then requested that the filler product be developed. By mid-2011 product development of the gel filler was progressing on schedule. The chemists at the VCI company were on track to provide a VCI gel filler product that met all of the criteria listed above. The pipeline team then designed and engineered a pilot project to test application of the filler and begin monitoring its effectiveness for control of corrosion.

VCI BASICS FOR CASINGS[2]

The annular space of a cased pipeline crossing is an ideal environment for the application of VCI technologies and systems. With the development of the VCI filler gel, even greater flexibility is available for casings that may not be totally sealed.

It was important to utilize VCIs which provide corrosion control in all three environments that might potentially exist inside a cased crossing. An amine carboxylate based VCI was selected to meet the following multiphase criteria for corrosion protection.

1. The liquid/solids phase where the metal surfaces are covered with water or soils that have migrated inside the casing or were left inside the casing during the original installation.
2. The region along the interface of vapor and liquid/solids where accelerated corrosion may normally exist.
3. The vapor space exposed to atmospheric corrosion conditions.

The amine carboxylate based VCI product adsorbs onto the metal surface and forms a protective mono-molecular layer on that surface within all 3-phases described above. This molecular layer inhibits the electrochemical reaction on the metal surface. Mitigation of corrosion with VCI chemistry is mature and well proven. VCI products have been in existence for over 30-years and there are multitudes of successful applications within numerous environments similar to the annular space of a casing.

An early documented example of VCI application for cased crossings is contained in the NACE paper published in 2000 entitled "Use of Corrosion Inhibitors on the Alaska Pipeline"[3]. This paper describes the successful application of VCIs to mitigate corrosion inside numerous cased sections along the Alaska Pipeline.

The new gel filler product is designed to totally fill the annular space of cased pipeline crossings with a water viscosity VCI product that transforms into a gel within a short time. This product is produced in 2-parts, with Part A being a high dosage of a specially designed liquid VCI concentrate that is mixed with water in the field. Part B is a unique superabsorbent polymer powder that is added to the liquid stream flowing to the casing then transforms the water viscosity liquid into a high viscosity gel. These are non-hazardous, environmentally friendly products.

CORROSION RATE MONITORING INSIDE THE ANNULAR SPACE

The pipeline team decided it would be important to evaluate the effectiveness of the gel filler and its ability to maintain a non-corrosive environment over long periods of time. Team members were familiar with electrical resistance (ER) corrosion rate probe technology and decided to employ this equipment inside the casing annulus.

ER probes are commonly used on a daily basis to evaluate the corrosiveness of many type environments inside flowing pipelines and other structures. ER probes can be installed as part of a casing integrity program before inhibitor is applied in order to identify casings with corrosive environments. They are also very useful after VCI is applied to evaluate the inhibitor effectiveness over the long term.

An ER probe had already been custom developed by a leading U.S. company for application inside of casings. The probe is designed to be lowered down through a casing vent to the carrier pipe surface. It has a shield that prevents contact of the probe sensing element with the carrier pipe. See Figure 1.

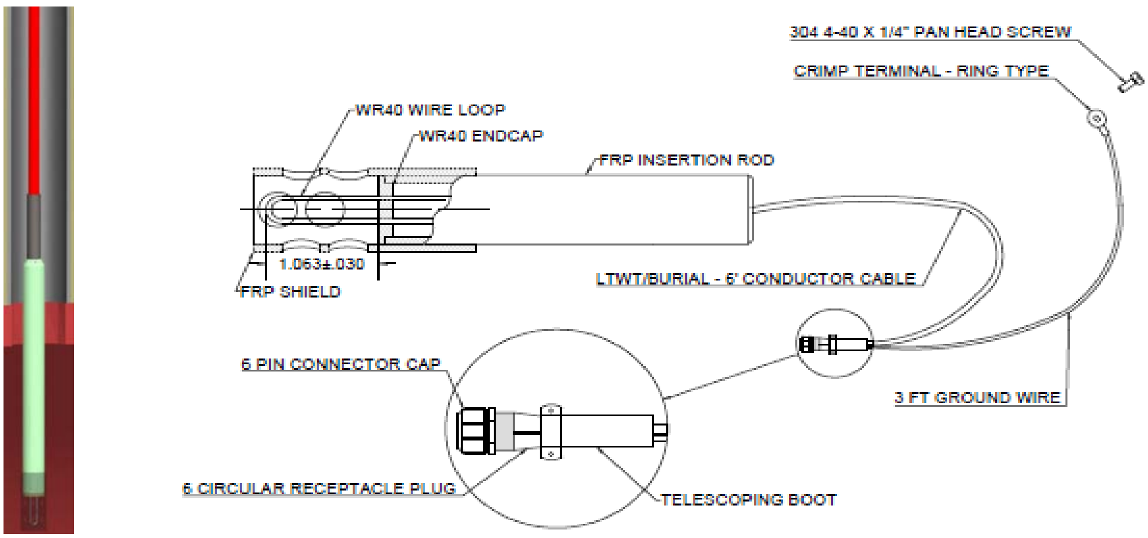

FIGURE 1: Custom ER probe for casings.

Multi-function Corrosion Control Monitoring System

A new and unique automated monitoring system was custom designed for use on the pilot project and also future casing applications. See NACE Paper 2741 “Corrosion Rate Monitoring in Pipeline Casings” for additional information[4]. The system is multi-purpose and capable of monitoring cathodic protection pipe-to-soil potentials on the pipeline 1-foot (0.3 meters) from the casing, the casing potential and corrosion rates from the ER probe installed inside of the casing annulus. The system incorporates remote monitoring technology designed to capture pipe-to-soil variances in real-time with immediate notification transmission of readings outside of acceptable, pre-set parameters. This method of benchmarking and verification of cathodic protection and corrosion rate inhibitor performance provides a comprehensive, pro-active data set through the transmission of actionable alarm data and increased frequency of logged data accessibility. The system produces a permanent, ongoing verification of VCI and CP system effectiveness as external influences vary.

The monitoring systems are equipped with the capacity to measure CP applied and polarized pipe-to-soil “off” potentials and if applicable, induced AC potential and corrosion current by utilizing a dual coupon test station design. Values are measured at pre-determined time intervals and stored on SD memory cards located on board the device. The monitor systems are equipped with either satellite or cellular communication capability and readings are transmitted to the web interface at a user defined time interval. Interrogation, monitoring, re-configuration or system trouble-shooting can also be accomplished through an internet connection. See Figure 2.

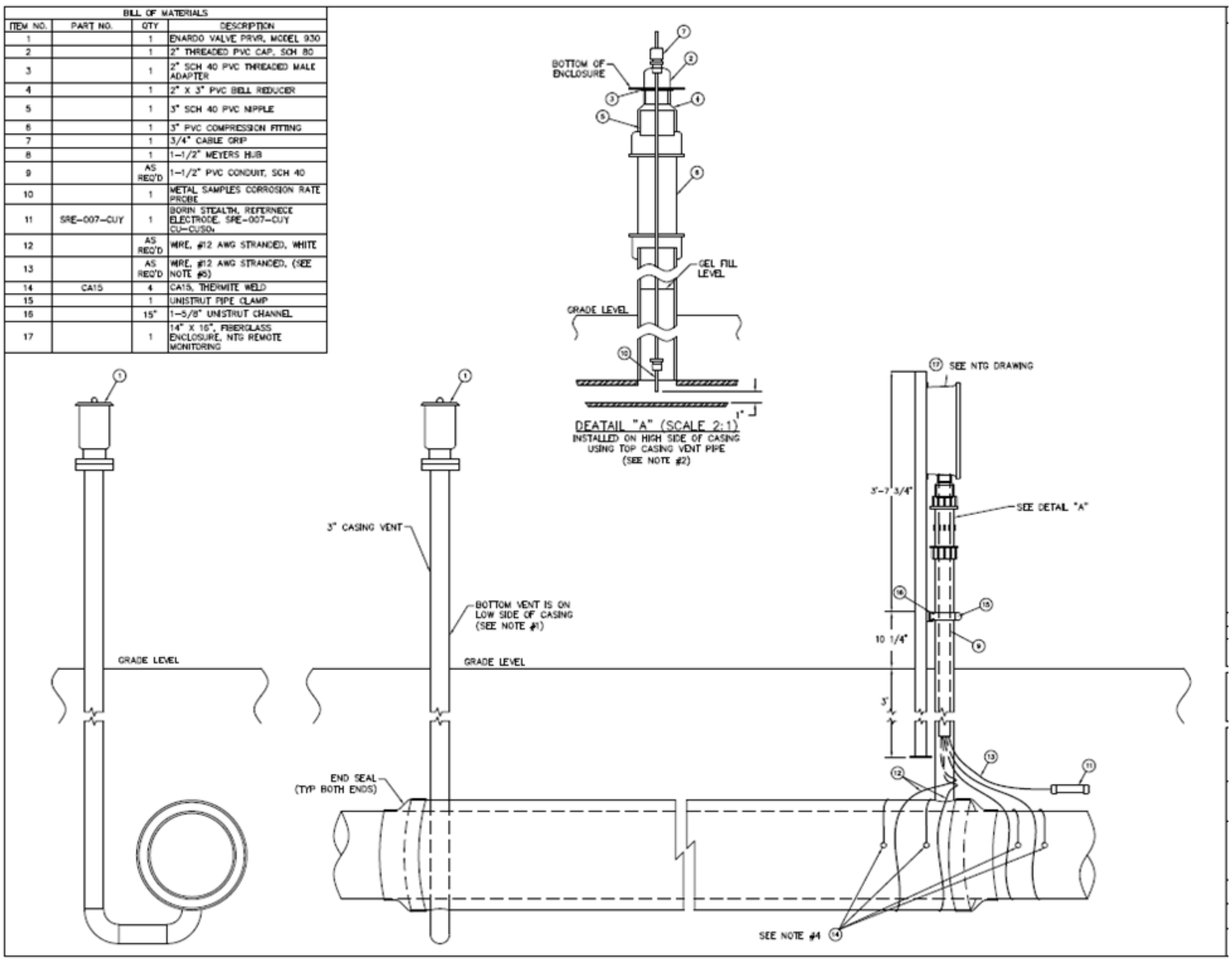

Figure 2: Remote monitoring system schematic.

INITIAL CASING FIELD STUDY

The pipeline company performed integrated data analysis on their Chicago Region pipeline system. Data from ILI and CP surveillance were correlated and utilized to identify and improve prioritization of vulnerable cased crossing locations. This approach enabled more comprehensive monitoring and remediation programs to be established.

CP survey information was evaluated and locations were prioritized based upon electrical isolation status and level of protection. In-line inspection data was prioritized accordingly on locations of high corrosion density that were approaching repair criteria. Priority for repair is summarized by the matrix presented in Table 1.

ILI Data Results	CP Survey Results	Priority	Proposed Action
Ext. ML Indicated	Metallic Short	↓ ↓ ↓ ↓ ↓ ↓ Decreasing Priority	End-seal refurbishment w/ VCI gel injection and RMU installation*
Ext. ML Indicated	Electrolytic Coupling		End-seal refurbishment w/ VCI gel injection and RMU installation**
Ext. ML Indicated	Clear (no short)		Monitor through ILI for indications of ongoing corrosion (growth), and CP for changing status of isolation
No Ext. ML	Metallic Short		
No Ext. ML	Electrolytic Coupling		
No Ext. ML	Clear (no short)		
Wax Filled casing (any ILI condition)	Wax filled casing (any CP condition)		Wax filled casings continue to be monitored for ongoing external corrosion
* Priority for remediation or ultimate casing removal and pipeline repair is established by severity of corrosion damage.			

Table 1: Repair priority matrix.

The results from the Chicago Region's analysis were leveraged and applied for long term planning of repair on the entire system.

Short Term Program Objectives (2011-2012)

- 2011 Q4: Develop and refine conceptual end-seal refurbishment and VCI filler delivery processes at 4 pilot locations.
- 2012 Q1-4: Demonstrate and prove feasibility of the process at 6 to 10 locations within the Chicago Region and establish a system wide prioritized list of locations for rehabilitation.

Long Term Program Objectives (2013–2018+)

- Reduce or eliminate extremely costly reactionary integrity or regulatory driven repairs on pipelines at cased crossings. These repairs had historically cost $1.5 to $3.0+ million.
- Mitigate and monitor corrosion activity at all prioritized cased crossing locations

2011 Casing Remediation Project

A comprehensive pilot project was initiated late 2011 for cased crossing corrosion management at four locations. ILI data had demonstrated limited success with conventional di-electric wax fill and the operator suspected the wax fill may have sometimes compounded the problem due to incomplete fill of the void space, the non-compatibility of the wax with water in the casing and a lack of corrosion control under disbonded coating. Therefore the pilot program was comprised of the following components:

- Modifications to vents and improved end-seal refurbishment process / materials as needed.
- Sealing of the annular space inside each casing with the VCI gel filler.
- Installation of automated monitoring systems designed to measure the real-time rate of corrosion inside the annulus and provide measurement of CP data.

Application of VCI Gel Filler

After inspection / repair of end seals and vents, the VCI gel filer was applied into the casing annulus. Installation was accomplished with a unique set of equipment that was custom constructed for application of the VCI gel filler product. The equipment package was designed by the engineering department of the VCI manufacturer and a major corrosion control service company already experienced with installation of VCI systems in other applications.

Once the installation and support equipment is staged near a casing, the necessary connections are made to the casing vents. Next the VCI concentrate Part A is mixed with water. The ambient temperature liquid mixture is then pumped into a hose connected to a casing vent. The Part B superabsorbent powder is added into the liquid discharge stream as it flows to the casing. After the casing is filled, the powder absorbs the liquid over a short time period and converts it into a gel. The gel surrounds the carrier pipe with a high dosage of VCI that has been proven to provide effective multi-phase inhibition of corrosion for many years. An incomplete fill of the casing due to air pockets, bends, etc. is not a concern because the inhibitor has a vapor phase component that will also provide corrosion control on the carrier pipe surface within any void space. See Figure 3.

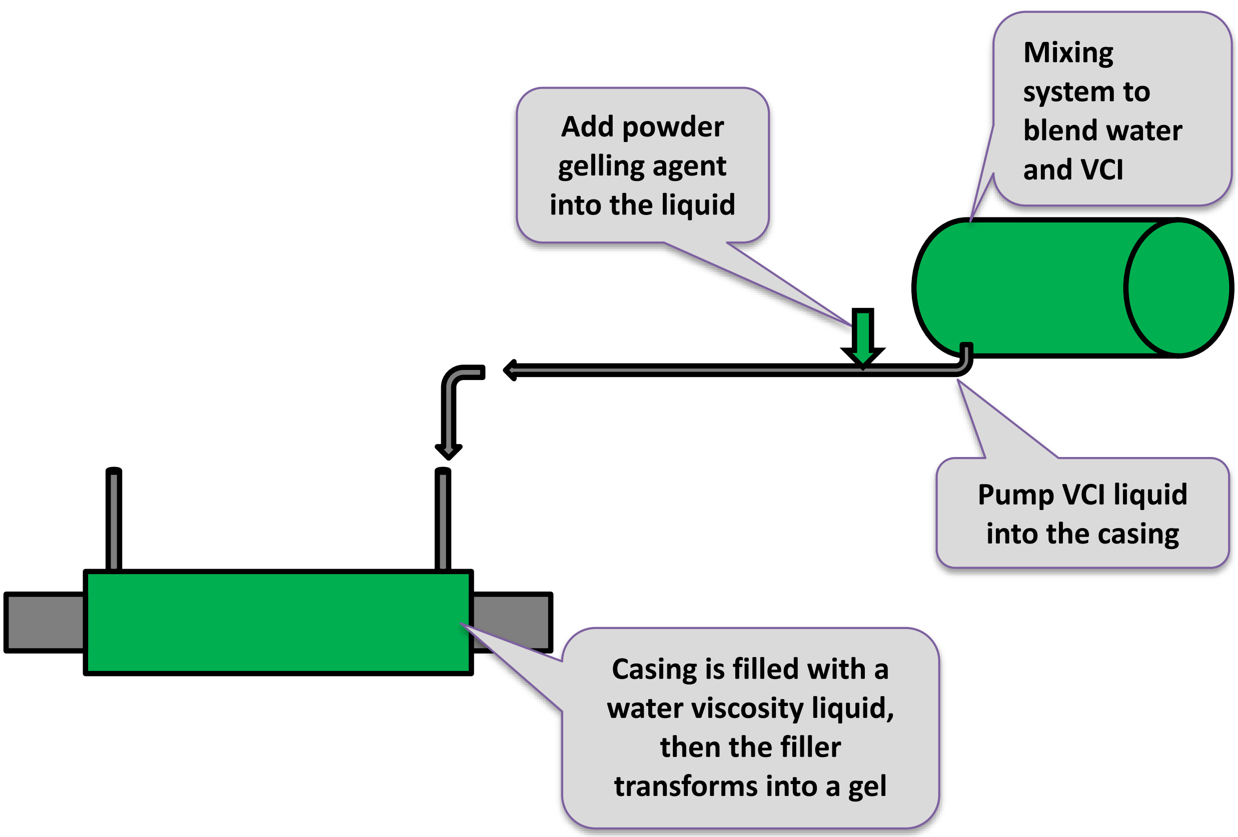

Figure 3: Graphic depiction of casing VCI gel filler system.

Results
At this time seven cased crossings are monitored. The automated corrosion control monitoring systems have been collecting ER probe and CP potential data every three days for 1 to 1.5 years. All data is reported to a website via the remote communication capability of the systems. The corrosion rate at each ER probe is less than 1 mil per year. The CP potentials do not indicate electrical shorts. Additional cased crossings will be addressed in 2013. Future ILI analysis of the carrier pipe inside the cased crossings will produce additional evaluation of corrosion control systems effectiveness.

CONCLUSION

ILI data makes it readily apparent that corrosion does sometimes occur on the carrier pipe inside of wax filled and unfilled cased pipeline crossings. When integrity programs discover carrier pipe corrosion that is coupled with disbonded tape coating concerns inside the annular space, it becomes important to proactively mitigate this corrosion. The Pipeline Integrity team has developed a well-engineered program to mitigate the corrosion through a multi-step process as described in this paper. The development of the amine carboxylate based VCI gel filler designed to satisfy a number of stringent criteria is an integral component of the casing integrity program. The automated multi-function monitoring system developed for cased crossing applications keeps a close watch on the integrity of the corrosion control systems at each cased crossing. As a result of the collaborative processes described in this paper, a number of innovations have resulted to provide a solid foundation for methodically addressing carrier pipe integrity inside cased crossings.

ACKNOWLEDGEMENTS

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