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USING HPIR CLASS COMPOSITE PIPELINE SYSTEMS TO OVERCOME THE CHALLENGES OF REHABILITATING OR REPLACING A PIPELINE ACROSS A NAVIGABLE WATERWAY AND ENVIRONMENTALLY SENSITIVE WETLANDS

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ABSTRACT

One of the biggest challenges that Pipeline Operators face is the rehabilitation or replacement of long, old pipeline segments that have restrictive right-of-way access, such as those crossing a major waterway or highway or through an environmentally sensitive area where traditional dig and replacement is not an option. Typically, these projects have limited options and have high associated costs. Pipeline downtime is also a major factor in the project planning. Horizontal Directional Drilling and lengthy environmental impact studies are two examples of costly and/or timeconsuming activities common to these projects. Selfmonitoring, high-pressure internal replacement (HPIR class) composite pipeline systems are a viable alternative for replacing these hard to access pipelines, with little disruption to the pipeline right-of-way. HPIR class composite systems are installed into the old pipeline in very long lengths, negating the requirement for multiple excavations along the pipeline.

Although inserted inside the old pipeline, they are not a simple plastic "liner". They are fully structural, transporting highpressure oil, gas and hazardous materials, with no dependence on the corroded steel pipeline. State and federal regulatory codes mandate the replacement of pipelines under certain conditions as part of the integrity management programs implemented as a result of the United States 2002 Pipeline Safety Act. However, these codes do not always consider the impact that traditional trenching and replacement has on public safety, nor on environmentally sensitive areas such as wetlands, national

parks or endangered species habitats. This paper will address the following aspects of pipeline replacement, in hard to access areas, such as those that cross navigable waterways: 1) The traditional methods and limitations related to replacing the pipeline segments in hardto-access areas 2) Composite technologies available today 3) Case study of replacement of regulated pipeline segments using HPIR class composite pipeline systems.

INTRODUCTION

Statistics show that pipelines are the safest mode of transportation for the vast amounts of hazardous liquid and gas produced across the globe. Since the 1800's, they have been laid in the ground using a multitude of available at the time technologies, which advance at an ever increasing rate. Some of the earliest pipelines are still in use, reliably delivering the source of energy that is commonly taken for granted by the average end user.

Method	Avg. Billion Ton-Miles Shipments Per Year	Avg. Incidents/Year	Incidents Per Billion-Ton Miles
Road	34.8	695.2	19.95
Railway	23.9	49.6	2.08
Hazardous Liquid Pipeline	584.1	339.6	0.58
Hazardous Gas Pipeline	338.5	299.2	0.89

Table 1 – Comparison of Transportation Methods (Manhattan Institute for Policy Research, 2013)

Until recently, and for the past century, pipelines have been manufactured out of steel. There are records of metallic pipelines dating back thousands of years being used by the Chinese and Egyptians, especially for transporting water and gas. However, for the purpose of this paper we will consider energy pipelines constructed in the late 1800's and early 1900's up until present day. Steel, by virtue of its reaction with oxygen, microbiological substances, etc. that cause corrosion, has to be carefully protected and maintained to ensure integrity and avoid the release of product flowing through it.

However, these pipelines are getting old and issues associated with structural integrity result in more frequent repairs and ultimate replacement. Along with the various pipeline safety regulations and mandatory pipeline integrity programs, these repairs or replacements have evolved into an industry of its own. Billions of dollars are spent complying with the requirements of various pipeline safety regulations to ensure the various products are delivered with minimum risk to public safety or environmental security.

Comparison of Pipeline Performance by Decade of Construction by Cause of Incident									
		Pre 1930s	1930s	1940s	1950s	1960s	1970s	1980s	1990s
Share of Miles	%	2	7	13	22	23	17	9	7
All Incidents (1669)	Incident %/ Miles %	>4.0	1.2	1.1	0.9	1.0	0.7	0.8	0.5
External Corrosion Incidents (450)	Incident %/ Miles %	>4.0	2.2	1.4	0.7	0.9	0.5	0.6	0.1
Internal Corrosion Incidents (85)	Incident %/ Miles %	>4.0	1.2	0.3	1.1	0.8	0.9	1.4	0.7
Defective Pipe/Seam Incidents (128)	Incident %/ Miles %	3.1	0.5	0.7	1.7	1.6	0.1	0.3	0.0
Defective Weld Incidents (53)	Incident %/ Miles %	>4	1.2	1.1	1.2	0.8	0.7	0.7	0.5
Third-Party Damage Incidents (476)	Incident %/ Miles %	4.0	1.0	1.5	1.0	1.0	0.7	0.6	0.3
Values shown should be interpreted as relative indicators because of data limitations. Values for the 1990s are understated because all pipe was not in place for all years.									

Table 2 – Comparison of Pipeline Performance by Decade (John Keifner/Cheryl Trench, 2001)

Whether or not a pipeline is considered at risk is dependent on numerous factors including age, the location, the external environment that the pipeline is located in, the product that flows through the pipeline, operating conditions of the system (pressure, temperature) and how the pipeline is maintained. As previously stated, a well-maintained pipeline flowing a relatively non-corrosive product is designed to, and can last several decades. Alternatively, a relatively young pipeline flowing an extremely corrosive product may have to be replaced after only a few years.

Generally speaking, the necessary repairs and replacements are carried out in a routine manner and the capital required to do this is a regular part of the pipeline operator's annual budget. However, the relative cost for such repair and replacement is dependent on the location of the pipeline and the ease in which it can be accessed. Excavations and replacement procedures of pipelines that have readily accessible right-of-way are routinely carried out with everyday technologies. The issue arises on those pipelines that cannot be easily accessed.

Some examples of locations where there are pipelines that cannot be easily accessed for repairs or replacement are those that pass through high consequence urbanized locations, that cross major highways or rivers, go through environmentally sensitive wetlands, national parks and forests or through protected In such locations, there are special procedures that result in an extended duration and cost to complete the replacement project. What may normally be a simple repair or replacement that would take a few days or weeks may be elevated to a major project that can take several months or years with costs far exceeding the original allocated budget. These factors can make the project prohibitive and delay the work that should be carried out sooner than later, having potentially disastrous consequences.

The causes of the releases of hazardous product from a pipeline are dominated by corrosion, excavation damage and material failure, all of which can be dramatically reduced by the use of the modern non-corrosive composite systems.

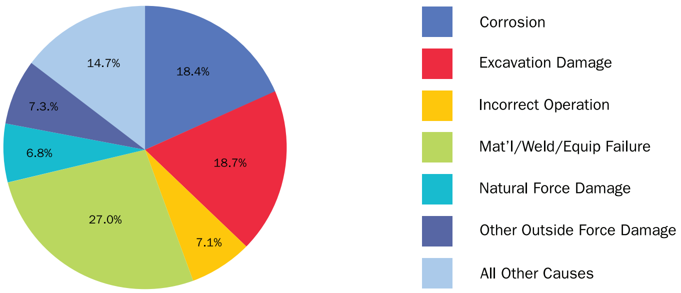

Chart 1 – US Pipeline Incident Causes (US DOT, 2013)

The potential damage resulting from an unintended release of a hazardous liquid or gas can be devastating to the environment and public in the vicinity of the event, as well as to the operator who is faced with various levels of penalties imposed as a result of this damage. As we have seen in recent years, the repairs and cleanup operations and associated criminal and civil lawsuits can last several years and have dramatic repercussions to the company's employees, reputation and shareholder value.

BENEFITS OF COMPOSITE PIPELINES

The primary benefit of composite pipe relative to steel pipe is that composites based on polymers do not "rust" or "corrode". Also, composite pipe can be substantially lighter and more flexible owing to the lower weight and stiffness of polymers and the very high strength to weight ratios of available high strength fibers. The key feature of all composite design is that a combination of materials can be used in the construction with each material being selected to optimally meet the requirements of that component. In a typical composite pipe, there is a liner material layer, a strength material layer, and an outer protective material layer. The material and construction of each layer can be changed as needed for best achieving a particular pipeline's needs.

While the core pipe component of a composite system has excellent corrosion and chemical resistance, negating the need for lifetime corrosion programs, one should also consider that hydrolysis, for example, is a form of corrosion and can have a material effect on certain external high strength materials. Since certain transported fluids and external environments may not be fully compatible with all composite pipe components, it is important to specify the proper individual components during the project engineering phase.

In summary, the two key components of the composite pipe are a thermoplastic liner for containing the fluid and a high strength fiber layer for providing the hoop and axial strength. The core liner and high-strength fiber properties provide opportunities for new solutions to piping problems, which include: lower density, greater strength to weight ratio, much lower thermal conductivity, smoother surface for lower resistance to fluid flow, lower stiffness, and greater ductility (leading for example to the ability to tolerate smaller bend radii).

TECHNOLOGIES AVAILABLE TODAY

Composite pipeline systems have been in development for decades now. The rigorous testing in accordance with various ASTM and API standards, notably ASTM F2896-11 and API 15S, that has been carried out and that is ongoing has culminated in systems that are being deployed into suitable pipelines in various locations in North America.

In order to address those pipelines that are in need of replacement but are in hard or impossible to reach locations, composite system can be manufactured and inserted in very long lengths (miles between connectors) into the degraded steel host pipeline. A portable factory can be set up in a temporary, climate-controlled enclosure near the pipeline section that is in need of replacement. The various materials required to manufacture the system are delivered to site and quality checked before being assembled to form the fully structural, self-monitoring composite system.

The composite pipe systems used today are designed, manufactured and tested in accordance with industry standards such as ASTM F2896-11, “Standard Specification for Reinforced Polyethylene Composite Pipe For The Transport Of Oil And Gas And Hazardous Liquids”, and API Recommended Practice 15S, “ Qualification of Spoolable Reinforced Plastic

Line Pipe".

The latest composite systems use a non-corrosive core pipe, which is wrapped in a high strength fabric to allow for operating pressures up to one thousand pounds per square inch. Longitudinal pulling tapes are added to allow the system to be pulled long distances, up to several miles, into a steel host pipeline and a protective cover is added to ensure that there is no damage to the composite pipeline system during its insertion. The system is mechanically folded into a "C" shape, which reduces the diameter by approximately thirty percent to facilitate the insertion and reduce the pulling tensions as it travels through the host pipe.

Integral to these composite systems are different operating considerations than with steel pipe that have to be addressed in the design phase of a project. Composite systems have different permeation characteristics, different collapse considerations, and pigging operations are unique to the noncorroding non-metallic core pipes.

The system allows complete replacement of a section of pipeline several miles in length without the need to expose the entire pipeline section. Access is only required at each end of the replacement section to allow for entry and exit from the pipeline, and connectors are only attached at the entry and exit points. This helps ensure minimal risk to public safety and environmental security.

CASE STUDY – RIVER CROSSING

A gas distribution operator installed an XPL-300 series HPIR Class system into two parallel 2,500 feet long intrastate natural gas pipelines crossing a major river with a maximum allowable operating pressure of 230 psi.

The work was carried out pursuant to a state waiver to waive compliance with specific pipeline safety requirements of 49 CFR §§ 192.53(c), 192.121, 192.123, and 192.619(a).

The steel pipelines are 1930's and 1950's vintage six-inch and had a grade 3 leak that necessitated a replacement or repair.

The parallel pipelines travel through a levee, under the north channel of the river, through an island that the Army Corps of Engineers constructed during World War II, under the navigable south channel of the river, under an adjoining wetland area, to the termination point of a more recently installed 8” system.

The operator chose to replace these pipelines by installing the XPL-300 system for the following reasons:

- To reduce corrosion issues using composite material
- On-site fabrication and installation of XPL-300
- Substantial cost reduction versus a directional drill through rock across the river
- Shutoff valves already existing on each side of river

One unique feature of the HPIR system in this installation was the Hyper-View® embedded fiber optic monitoring system that would allow the operator to continually monitor for anomalies such as leaks or movement that may be caused by subsidence or a third party impact. This system uses the latest fiber optic technology available on the market – acoustic/temperature data. Positioning is accurate to within one meter along the complete length of the pipeline and can be tied into an existing SCADA system, control room or mobile device such as a smartphone or tablet.

The pipeline contour made the composite insertion technically challenging with multiple bends and offsets due to river, its banks and the island. A digitized “pull model elevation” and contour map was made from original operator provided data and refined with tension data from beta pulls.

The four phases of the project are next summarized to show the key parameters and decision points addressed by the project team to ensure a successful manufacturing and simultaneous installation of the composite pipe

Phase I – Engineering

During the engineering phase, the host pipe data is analyzed and models are developed to assess installation pull tension parameters. The end terminations and fiber optic requirements are planned and reviewed by the project team. Operating parameters are defined and the project team performs and reviews flow and systems modeling.

Phase II – Design and Design Verification

From the engineering phase a design is chosen and further refined for specific operating parameters.

Materials necessary to manufacture 250 feet of the XPL-300 composite system were delivered to the portable factory location. As per standard operating procedures;

- The high strength materials were quality assurance tested by a third party laboratory.
- The manufactured XPL-300 was verified to design criteria through multiple burst tests, and witnessed by operator representatives
- Test results are reported and agreed by project team

Input	Value
MAOP	230 psi
Maximum operating temp F	120 F
Design Life	50 year
Host Pipe ID	5.25"
Short term Burst pressure (low bound)	2,188 psi
XPL-300 ID	4.36"
Design Factor (DF) @ 120 F	0.232
Design Factor (DF) @ 120 F with 0.75 Bend service factor (based on previous testing and reported in a PRCI project)	0.309

Table 3 – XPL-300 series HPIR Class System Design

Phase III – Host Pipe Preparation and Beta Pulls

In this phase of the operation, crews were mobilized to site and pigging operations were undertaken to confirm the internal condition of the host pipe. These operations included abrasive foam pigs for cleaning, gauge pigs for internal diameter confirmation, and pigs to install ropes into the host pipeline.

During the pigging operations the east line proved impassable at the start of the operation. A damaged chill ring was eventually dislodged and removed, making the line suitable for installation.

Subsequent to the pigging operations, a pre-manufactured 100-foot section of C-formed XPL-300 was pulled through each host pipe to verify that no damage to the system would occur during the installation.

The beta section was also run under back tension conditions to help in assessing the sensitivity of the predicted pull forces to the various inputs and assumptions.

A key geometry parameter of the host pipe that affects the total required pull force is the total bend angle. The total bend angle is simply the sum of the bend angles from all bends in the host pipeline. The original simulations of the pull-in that were carried out prior to the beta pipe pull-in testing, estimated the total bend angle to be between 150 and 430 degrees. Beta testing allowed this range to be narrowed based on the relationship between pull tension, back tension, and expected friction coefficient. The post beta pull-in simulations use a total bend angle of 302 degrees. All of these bends are in the vertical plane except for the two 37 degree horizontal bends located on the island (74 degrees total in the horizontal plane).

Input	Value
Host ID	5.25
XPL-300 C-Form Maximum Diameter	4.08”
Core Pipe OD	4.790”
Core Pipe DR	22.4
Composite Weight	2.15 lb/ft
Number of Axial Tapes	6
Core Pipe Modulus	160,000 psi
HT Tape Modulus	10.0E06 psi
C-Form Pipe Bending Stiffness (EI)	3.31E06 lb-in^2
Baseline Friction Coefficient	0.2
Pull Rope Weight (UHMWPE)	0.102 lb/ft
Tail Rope Weight (steel)	0.236 lb/ft

Table 4 – Key Modeling Inputs for Predicted Pull Forces

A number of simulations were carried out for the job and below is an example.

Phase IV – Manufacturing and Installation

The portable factory was mobilized and set-up on the job site, at which time the various materials were delivered. The portable factory was calibrated prior to manufacturing the first section of pipe, which was then cut off and tested.

As per standard operating procedures;

- The high strength materials were quality assurance tested by a third party laboratory prior to delivery to site.
- The first section of manufactured pipe was verified to design criteria through multiple burst tests, and witnessed by operator representatives and the responsible state regulator
- Test results were within tolerance and met the special permit requirements and the manufacturing company quality requirements
- The average burst pressure for the various test sections for the 230-psi operating design was 2,800 psi.

Operations commenced and the first 2,500 feet of C-formed pipe were manufactured and simultaneously pulled into the east pipeline. The system included the deployment of the HPIR-View® fiber optic monitoring cable.

During the re-rounding of the inserted composite system on the east line, a leak was

detected. The leak location was quickly and accurately identified with the HPIR-View® fiber optics monitoring system using acoustic and temperature data. The section was recovered and a new section reinstalled.
Operations moved to the west pipeline while recovery work was underway, and the west line was again pigged and a beta section pulled through. As a corollary event and demonstrating the substantial value of the HPIR-View fiber optics systems, the pigging events in the west line were recorded by the installed HPIR-View in the east line.

Manufacturing and simultaneous installation operations in the west line were undertaken at a rate of 3 feet per minute, and were successfully completed in approximately 15 hours for a total produced length of 2,850 feet.

Recorded operational variables included;

- Maximum line tension for pull-in was 4,010 lbs , well within the established safety limits of ropes, winch and pulling tapes
- Manufacturing data:
    - o Core pipe fusions, all recorded with data logger, were within tolerance
    - o Core pipe third party ultrasonic testing all recorded and were within tolerance
    - o Wrap angle electronic and physical measurements all recorded and were within tolerance
    - o Manufacturing verification burst testing all recorded and were within tolerance
    - o Physical diameter measurements of produced pipe recorded and within tolerance
- The composite system was pulled though and 50 feet of the leading end was inspected by the operator and the state regulator to confirm no pull-through damage

The west line system was then re-rounded with 70-psi pneumatic pressure, and final production connectors were installed. The XPL-300 was subsequently leak tested to 110 psi and then strength tested to 360 psi for 24 hours, both of which were witnessed by the operator and the state regulator.

The re-rounding process was also monitored by using the fiber optic system, and completion was verified by the transport of a hard foam pig, witnessed by the operator and the state regulator

Upon completion of the west line, operations moved to the east line, Using the same metrics and procedures as the west line, the east line was successfully manufactured, installed and tested during July of 2013.

The project was successfully completed and all predetermined objectives were accomplished. In addition, the benefit of installing a composite HPIR Class system with the HPIRView fiber optic monitoring capability was demonstrated under challenging field conditions.

The two systems, along with direct assessment sections installed for future evaluation, were connected to the main pipeline system and commissioned on Aug 9, 2013.

CONCLUSION

The pipeline industry is gravitating to twenty-first century tools and processes developed to fill technology gaps that have prevented the replacement and repair of these aging pipelines. With the integrity of the aging pipeline network in North America becoming increasingly more of a media focus, and regulators sharpening the pencil on integrity management programs, the HPIR-class composite pipeline solution is a new and welcome innovation in the operator's quest for zero incidents. Such technologies are revolutionizing the way that every-day pipeline rehabilitation and replacements are carried out, especially in the areas that were previously considered difficult or impossible to address.

	Year	Number	Fatalti-ties	Injuries	Property Damage as Reported
	1994	467	22	120	$160,596,517
	1995	349	21	64	$53,427,112
	1996	381	53	127	$114,467,631
	1997	346	10	77	$79,757,922
	1998	389	21	81	$126,851,351
	1999	339	22	108	$130,110,339
	2000	380	38	81	$191,822,840
	2001	341	7	61	$63,092,462
	2002	643	12	49	$102,107,740
	2003	672	12	71	$139,007,814
	2004	672	23	60	$271,844,536
	2005	720	14	48	$1,246,757,189
	2006	639	21	36	$150,925,566
	2007	615	15	50	$154,505,410
	2008	660	8	57	$565,819,340
	2009	628	13	64	$179,120,183
	2010	590	22	109	$1,610,425,380
	2011	597	14	56	$378,946,588
	2012	570	12	58	$213,569,455
	2013	622	10	46	$309,271,166
Totals		10,620	370	1423	$6,242,426,541
2014 YTD		145	1	9	$16,873,713

	Year	Number	Fatalities	Injuries	Property Damage as Reported
3 Year Average (2011-2013)		596	12	53	$300,595,736
5 Year Average (2009-2013)		601	14	67	$538,266,554
10 Year Average (2004-2013)		631	15	58	$508,118,481

Table 5 – All Pipeline Incidents in the United States (US DOT, 2013)

From a public safety standpoint, the composite systems can predict and reduce the number of incidents that cause injury, or worse to the general public. Many of these incidents cause major damage to property. The cost of these incidents in the United States alone for the past twenty years has run to over six billion dollars and claimed the lives of 377 people (US DOT, 2013).

The case study presented in this paper is an example of how HPIR class composite pipeline systems can enable the replacement of degraded pipelines in environmentally sensitive locations, without the need to cause excessive damage to the area or disrupt the habitats of wildlife. This system does not require the entire pipeline right-of-way to be disrupted; only the points of entry and exit from the pipeline section need to be excavated. Environmental impact studies and the associated time and cost to complete them are avoided and the pipeline can be returned to as-built condition or better quickly, greatly reducing revenue losses from the shut-down pipeline.

The major advantage of this type of composite pipeline installation is in the installation. The time and procedures required to complete a replacement project offer a major advantage over regular "dig-and-replace", as seen in the case study of this paper. Depending on the location, the cost of a HPIR class solution may be only a small fraction of the dig and replace method.

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