Proceedings of the 7th International Pipeline Conference
IPC 2008
September 29th- October 3rd, 2008, Calgary, Alberta, Canada

IPC2008-64075

THE USE OF REINFORCED THERMOPLASTIC PIPE IN CO_2 FLOOD ENHANCED OIL RECOVERY

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ABSTRACT

Reinforced Thermoplastic Pipe (RTP) is a new technology that is reducing the cost of constructing oil and gas gathering pipelines while improving reliability. The following material will be described: RTP construction, materials, performance, compatibility, joining systems, installation methodologies, and carbon dioxide (CO_2) specific test results.

RTP combines high performing materials such as bimodal high density polyethylene with high strength reinforcing fibers in a unique construction to create a spoolable high pressure pipeline system. This construction is well suited to upstream flow line and gathering applications as well as distribution applications.

The primary benefit of RTP is realized by the installation methodologies available which contribute overall project savings of up to 30-50% for typical oil and gas applications. Additional installation benefits include reduced right of way requirements, reduced safety hazards, and reduced environmental impact. For applications which corrode steel, the additional corrosion resistance benefits of RTP are extremely compelling.

The cost of constructing pipelines has been steadily increasing in past years due to many factors including the rising cost of steel and limited availability of skilled labor. There continues to be a desire to tie in new gas wells faster due to limited construction timeframes. Pipeline corrosion is a major problem for the industry. RTP provides solutions to all of these challenges.

INTRODUCTION

Steel has long provided the best available compromise between the competing needs of oil and gas pipelines, including cost, availability, workability, strength, and reliability. However, steel pipelines have a number of limitations. Corrosion is at the forefront of these limitations, with potential consequences including repair and clean-up costs, monitoring programs, and environmental contamination. Corrosion of steel on the production side of CO_2 flood enhanced oil recovery (EOR) presents a challenge that is typically addressed at high cost.

Installation of steel pipelines also involves large costs due to weight and limited section lengths. The labor and equipment required for handling, joining, and inspection result in economic and environmental costs.

Various alternative materials are available. Polyethylene and other plastics have been used successfully in a variety of applications, but are limited in pressure capacity. Rigid glass-reinforced thermosetting resins have also been used for a number of years in a variety of applications, and have proven to be successful when industry proven installation procedures are strictly followed. However, reliability of joining systems and sensitivity to external loading continue to challenge these types of composites.

Reinforced thermoplastic pipe is another alternative to traditional pipelining materials. RTP is a spoolable composite pipe system that overcomes the inherent limitations of both unreinforced plastics and thermoset resin composites. High pressure capability, cost effectiveness, resistance or immunity to corrosion, joint reliability, ruggedness, and demonstrated efficiency of installation are among the features that make this technology attractive to pipeline operators.

REINFORCED THERMOPLASTIC PIPE TECHNOLOGY

The design and capabilities of RTP are described below, followed by a test summary demonstrating how Flexpipe RTP can be used for CO_2 flood enhanced oil recovery. Where differences between RTP manufacturers exist, Flexpipe product will be described.

Design

Flexpipe RTP consists of a thermoplastic liner that acts as a fluid bladder; a layer of helically wrapped continuous high-strength glass fiber reinforcement; and an external thermoplastic jacket that protects the structural reinforcement layer. This unique, un-bonded, epoxy-free construction provides an excellent combination of strength, corrosion resistance, flexibility, and ruggedness. The pipe is designed using a sophisticated mathematical model developed specifically for the unique construction of the pipe.

The flexibility of RTP allows it to be spooled for efficient handling, transportation, and installation. Flexpipe RTP is manufactured in continuous lengths with no splices, fusions, or joints in any of the materials.

The RTP product classes currently available are intended primarily for oil and gas gathering, oilfield water transfer, and gas distribution and transmission lines. RTP is typically available with pressure ratings from 300 psi to 1500 psi (2.1 MPa to 10.3 MPa) in 2, 3, and 4 inch internal diameter sizes (50, 75, and 100 mm).

The liner and jacket of Flexpipe RTP are manufactured using bimodal pressure-pipe-grade high density polyethylene (HDPE) thermoplastic resin. This leading-edge material meets rigorous standards for high strength as well as excellent resistance to slow crack growth. It also provides excellent wear resistance and impact toughness, and a low-friction internal surface for decreased pressure losses. Colorant and ultra-violet (UV) stabilizers are blended into the material during the extrusion process, providing resistance to weathering.

The fiber reinforcement is constructed from a series of continuous glass fiber rovings manufactured in accordance with ASTM D578. The fiber chemistry and coatings are selected to optimize long-term performance in oilfield environments.

Joining

Flexpipe RTP is terminated or joined by metallic crimp-style fittings which are applied with portable equipment and do not require the application of heat, epoxy or adhesives. The fittings come with O-rings to assist with fluid sealing. The fittings can terminate the pipe with a standard lap-joint flange or with a butt weld transition that allows direct connection to steel using standard field welding procedures. Pipe-to-pipe couplings allow one length of RTP to be connected directly to another.

This joining system significantly reduces the time, effort, and cost of forming pipeline connections. Costly multiple-pass welding procedures and detailed inspections are eliminated, and far fewer joints are required for a given length of pipe. The overall result is faster, less costly installation with less environmental impact.

Qualification And Testing

The design and construction of RTP are governed by industry standards and guidelines regarding qualification, quality control, and testing of composite pipe and accessories. The primary standard specific to this technology is API RP 15S, *Recommended Practice for the Qualification of Spoolable Reinforced Plastic Line Pipe*, published by the American Petroleum Institute (API). This recommended practice includes guidelines for determining material properties, pressure ratings, safety factors and service factors, and minimum performance requirements. It also includes guidelines for manufacturing, quality control tests, and typical installation methods. The recommended practice uses proven ASTM testing methods for establishing long-term performance, and serves as the basis for qualification of the RTP. API RP 15S is the RTP standard referenced in CSA Z662 Clause 13.1 for gathering pipelines and CSA Z662 Clause 12 for distribution pipelines.

Technical Considerations For Operation Of RTP In Gathering And Distribution Applications

RTP has a strong record of successful operation in gathering and distribution applications. Many of the limitations of other pipeline materials are overcome by RTP's inherent material properties and unique design features.

Performance

Flexpipe RTP is designed for a 50-year design life at the rated pressure and temperature in gathering and distribution lines. The determination of the published pressure rating includes a fluid safety factor which takes into account the effects of long-term exposure to various oilfield fluids. Therefore, no additional de-rating is necessary.

RTP pipeline systems display excellent corrosion resistance. The internal and external surfaces of RTP are inherently immune to corrosion. The steel fittings are internally coated for protection from corrosion and moderate erosion, and can be externally protected using moisture-resistant wraps, sacrificial anodes, or both.

The HDPE liner used in RTP is resistant to a wide range of chemicals. Because the liner is not a structural layer, even those chemicals which affect the strength of HDPE are not problematic except at high concentrations or high temperatures. The liner is compatible with aromatics and other solvents in concentrations and temperatures associated with typical gathering applications. RTP can also be used in production environments which contain high levels of chlorides, H_2S, and CO_2.

Permeation of gas molecules through the material of a pipe wall occurs with any pipeline material. Permeation rates are higher for the liner materials used in composite and RTP pipes than for metals. The design of Flexpipe RTP allows any permeated gases to travel axially along the un-bonded reinforcement layer and vent at the fittings. This design prevents the potential problem of liner collapse during pipeline depressurization.

Operating temperatures of Flexpipe RTP are limited by the service temperature range of the HDPE used in the liner (up to 140 °F or 60 °C).

Many plastic materials are susceptible to degradation from exposure to the ultraviolet light found in normal sunlight. Flexpipe RTP is manufactured with stabilizers in the HDPE jacket that provide resistance to ultraviolet light for a minimum 20 year life of outdoor storage or surface operation.

Flow Characteristics

A significant advantage of RTP over traditional pipeline materials is the smoothness of the HDPE liner. Pressure drop due to flow friction is significantly lower in RTP than in steel of approximately the same flow area. A comparison of pressure drops in a one-mile pipeline is shown in Figure 1, as calculated using the Darcy-Weisbach method.

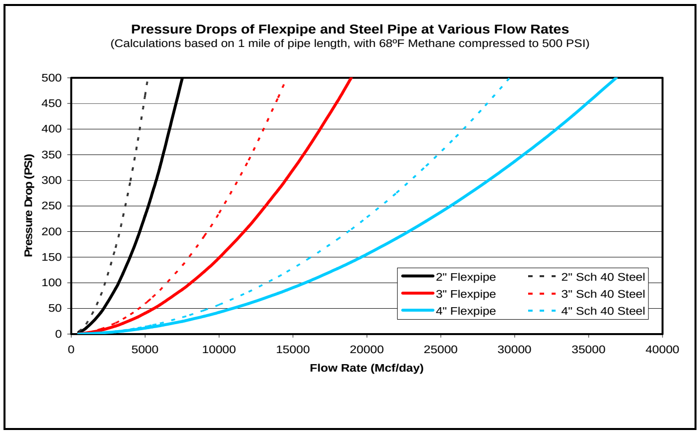

FIGURE 1 - REPRESENTATIVE PRESSURE DROPS FOR FLEXPIPE RTP VERSUS STEEL PIPE

INSTALLATION OF RTP

Ease of installation and associated project cost reduction is the primary benefit of RTP compared to other pipeline materials. The long continuous spooled lengths and rugged protective jacket allow for simple and quick installation. A variety of options for new pipeline installations and remediation of failed pipelines allow the most efficient method to be chosen for each particular project.

Installation Methods

RTP can be installed very quickly using conventional trenching methods. Unspooling the pipe from the transportation spools can be accomplished with very little time, equipment, or manpower. The fittings can be installed above ground before lowering the pipe into the trench, or installed afterward in bell holes. Required trench sizes are smaller than those typically used for steel pipe installation (see Figure 2). Bedding and backfilling requirements are similar to those for steel pipelines.

FIGURE 2 - CHAIN TRENCHING

Long continuous lines can be very efficiently installed using a pipeline plow, such as the one shown in Figure 3, which is able to trench, install the pipe, and cover the trench in a single-pass operation. Coupling fittings can also be plowed in.

FIGURE 3 - PIPELINE PLOW

For remediation of a failed pipeline, RTP can be pulled through with the existing pipeline acting as a conduit, as shown in Figure 4. If the conduit is large enough, coupling fittings can also be installed in this manner. The RTP then acts as a freestanding liner and does not depend on the conduit for structural support.

FIGURE 4 - INSERTION AS A FREE-STANDING LINER

Finally, RTP can be used for temporary or permanent installations on the surface. A white jacket option is offered to limit solar heating.

Other Installation Benefits

The inherent efficiencies of RTP installation have the additional benefit of reducing environmental impact. Reduced or eliminated needs for heavy equipment, smaller trench sizes, smaller right of ways, and shorter work durations all contribute to reducing the amount of ground disturbance and environmental impact. RTP has been chosen for a number of environmentally sensitive areas for these reasons.

The reduced needs listed above, plus the inherent reduction in crew size, also result in improved safety performance when installing RTP.

Flexpipe RTP Installations In CO_2 EOR

Flexpipe RTP has been successfully installed and operated on the production side of a low pressure CO_2 flood enhanced oil recovery project in Alberta, Canada. As part of an ongoing project with a U.S. based customer using high pressure CO_2 EOR, application specific testing was conducted in order to verify suitability for use at 750 psig (5.2 MPa) and 135 °F (57 °C). The results are reported below.

CO_2 TEST STUDY

Introduction

CO_2 (carbon dioxide) is injected down hole by some energy producers to enhance oil recovery. An oil, water, and CO_2 emulsion is produced which is very corrosive to steel. Flexpipe RTP products with thermoplastic liners have been installed to resolve corrosion issues and to deliver a less costly alternative to steel pipe. A concern with CO_2 is that it can permeate into piping materials and potentially cause subsequent damage to the pipe. If the pipeline is depressurized rapidly, there is potential for blistering of the pipe as CO_2 will try to escape back into the pipeline. If blistering occurs, this could weaken the materials and lead to premature failure of the pipe. The purpose of this study is to investigate and test the effects on Flexpipe RTP of rapid depressurization of high pressure CO_2 gas.

Test Procedure

A test procedure was designed in accordance with API RP15S Appendix D, “Blowdown Test Procedure”.

Single Cycle Depressurization Testing

A six foot (2 m) length of 4 inch (100 mm) 1500 psi (10.3 MPa) Flexpipe RTP was chosen for this study, complete with Flexpipe crimp style test end fittings including standard 75 durometer fluoroelastomer O-ring seals. An additional four 75 durometer fluoroelastomer O-rings were placed loosely inside the test pipe in order to observe the effect of the high pressure CO_2 gas on the O-ring material. The test pipe was then placed in an isolated pressure vessel. Leak testing of the pipe and tubing was performed using 1500 psi nitrogen to ensure that there was no leakage. The pressure vessel was equipped with external heat tapes and insulation for temperature control.

The test pipe was initially filled with CO_2 gas at 800 psi (5.5 MPa) and 70 °F (21 °C) and then pressurized with nitrogen to obtain a total pressure of 1500 psi.

The vessel was then heated to 140 °F (82 °C). The pipe temperature was confirmed to also be 140 °F +/-4 °F (+/-2 °C). As the pipe was heated to 140 °F, the pressure increased to 1650 psi (11.4 MPa). There was no pressure loss for the duration of the test. Pornchai *et al.* [1] reported that 2 mm (0.079”) thickness HDPE samples become saturated with CO_2 within 24 hours when exposed to CO_2 at room temperature and 800 psi. Considering temperature and thickness effects of the Flexpipe test, the time for full saturation is conservatively estimated to be no longer than 60 hours.

The pipe was held for 140 hours at 140 °F and 1650 psi. Prior to rapid depressurization of the test pipe, a ¼” valve on the pressure vessel itself was opened and monitored for presence of CO_2. A concentration of 0.7% was observed. The presence of CO_2 is attributable to CO_2 gas permeating through the Flexpipe liner and exiting through the vent holes in the Flexpipe fittings. This is an indication of complete CO_2 saturation of the liner.

The experimental set-up is shown in Figure 5.

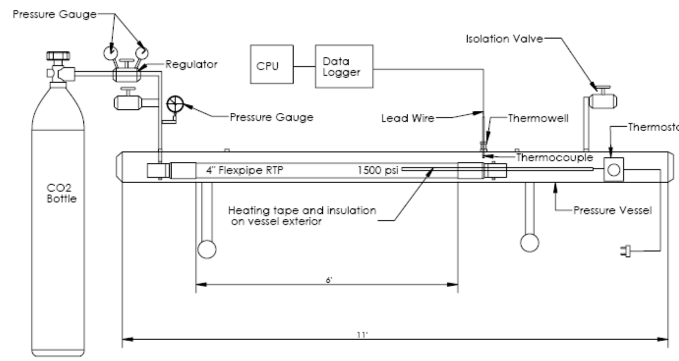

FIGURE 5 – EXPERIMENTAL TEST SET-UP

At the end of the 140 hour test period, the test pipe was depressurized at 1000 psi/min (6.9 MPa/min) from 1650 psi to 0 psi. The pipe was removed from the vessel, inspected, and then dissected. Visual inspection was completed for each layer of the dissected pipe (jacket, glass fiber reinforcement, and liner), as well as the loose O-rings, the fitting, and the installed fitting O-rings. An optical microscope was also used to inspect for surface blemishes, cracks and voids.

ASTM D638 Type-I dumbbell tensile bar specimens were cut from the liner and tensile tested according to ASTM D638.

Mulitple Cycle Depressurization Testing

Subsequent to the single cycle test, a second test pipe 10 feet (3 m) long was tested through 10 cycles following a similar procedure to that described above. Dumbbell tensile bar specimens were cut from the previously tested pipe (single cycle test described above) and placed loosely inside the second test pipe. Additional loose dumbbell specimens (cut from the same spool of pipe as the second test pipe and not previously exposed to CO_2) were also placed inside the test pipe. In addition, some soft nitrile and neoprene gasket samples were left loose in the pipe for comparison purposes. Three 95 durometer fluoroelastomer O-rings were placed loosely inside the test pipe for the final 5 cycles.

A total of 10 depressurization cycles were carried out to determine their effect on Flexpipe RTP.

For the first 6 cycles, the CO_2 saturation period was approximately 60 hours between each depressurization cycle. The last 4 cycles were completed on the same day with approximately 2.5 hours between each cycle. During the saturation period, pressure and temperature were monitored to ensure they remained constant throughout. Dumbbell, O-ring, nitrile, and neoprene specimens were withdrawn periodically for weighing and visual inspection. Each time these specimens were withdrawn from the test pipe, an approximately 10 inch (250 mm) length of the test pipe was cut from one end to facilitate specimen removal. The fitting was then reinstalled onto the test pipe.

RESULTS AND DISCUSSIONS

Visual Inspection

Single Cycle Deprssurization

No blistering was observed on the jacket inner or outer surfaces. The glass fiber reinforcement layers also did not exhibit any damage. The inner and outer surfaces of the HDPE liner did not show any blisters or abnormalities (see Figure 6). The HDPE liner did not collapse or show any indication of stress deformation.

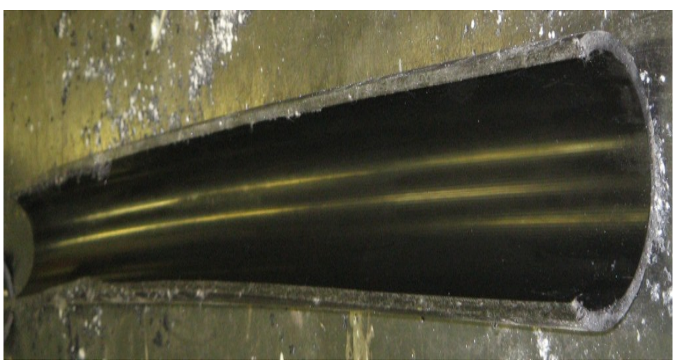

FIGURE 6 – INNER LINER SURFACE AFTER SINGLE CYCLE

Optical micrographs (x100 magnification) of a typical sample of HDPE liner surface exposed only to air were compared to the CO_2 exposed HDPE liner surface. There was no alteration in surface appearance. No cracks, blisters, or voids were observed.

Two of the four loose 75 durometer O-rings that were removed from the pipe had one small blister each. One blister was measured to be 0.050” in diameter and the other was measured to be 0.030” in diameter. None of the four 75 durometer O-ring seals which were installed and compressed in the normal groove locations of the Flexpipe end fittings showed any sign of blistering.

Multiple Cycle Depressurization

No blistering was observed on the jacket inner or outer surfaces. The glass fiber reinforcement layers also did not exhibit any damage. The inner and outer surfaces of the HDPE liner did not show any blisters or abnormalities (see Fig. 7). The HDPE liner did not collapse or show any indication of stress deformation.

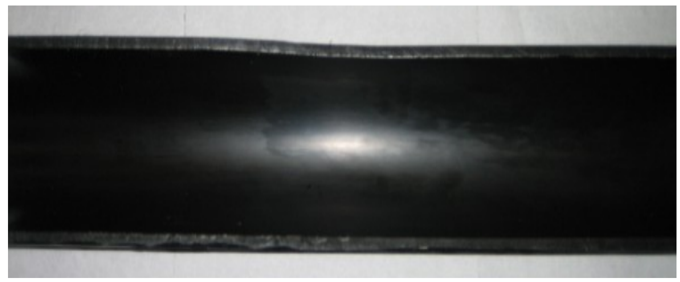

FIGURE 7 – INNER LINER SURFACE AFTER MULTIPLE CYCLES

Optical micrographs of the CO_2 exposed HDPE liner surface at x100 magnification also showed no voids, cracks, or blistering.

The standard 75 durometer fluoroelastomer O-rings that were installed in the normal groove locations of the test pipe end fittings did not blister. Two out of four of the loose 75 durometer O-rings did blister. These blisters were apparent after the first cycle and grew slightly during the subsequent cycles (see Figure 8). The 95 durometer loose O-rings did not blister. Blistering in the nitrile and neoprene soft gasket material specimens are shown in Figure 9.

FIGURE 8 – LOOSE O-RING BLISTER AT 3 O’CLOCK POSITION

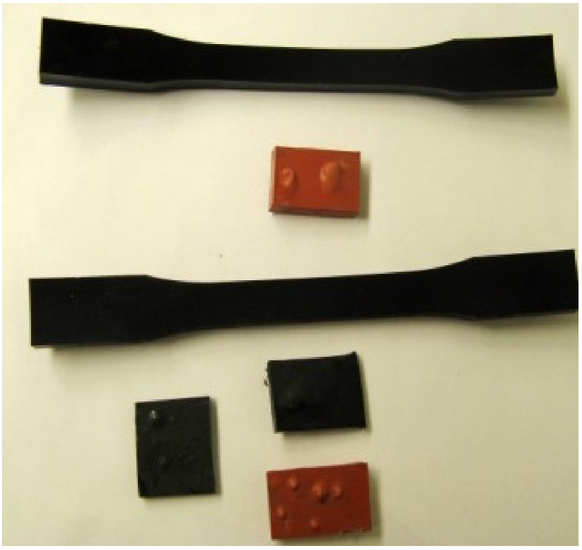

FIGURE 9 – SOFT GASKET BLISTERS ALONGSIDE PE DUMBBELLS WITHOUT BLISTERS

Mechanical Properties

Properties After Single Cycle Depressurization

Mechanical properties of dumbbell specimens cut from the single cycle test pipe liner were tensile tested and compared to base data of air exposed HDPE liner. Average yield strength and elongation at yield remained similar to the baseline data. See Table 1.

Properties After Multiple Cycle Depressurization

Dumbbell specimens were cut from the 10 cycle test pipe liner and tensile tested. They also exhibited similar properties to the baseline data. See Table 1.

TABLE 1 – TENSILE TEST RESULTS FROM SPECIMENS CUT FROM TEST PIPE

Specimen Types	Yield Strength (psi)	Elongation at Yield (%)
Base Case	3516	17.4
Single Cycle	3426	16.9
10 Cycles	3556	16.1

The dumbbell liner specimens which were placed loosely inside the test pipe were all tensile tested for yield strength and elongation at yield. They remained similar to the baseline data. See Table 2.

TABLE 2 – TENSILE TEST RESULTS FROM SPECIMENS PLACED LOOSELY INSIDE THE TEST PIPE

Specimen Types	Yield Strength (psi)	Elongation at Yield (%)
Base Case	3516	17.4
Single Cycle plus 10 Cycles	3605	17.6
10 Cycles	3586	16.8

CONCLUSIONS

Results of this test study indicate that the Flexpipe RTP performed well within the experimental test parameters. No HDPE liner blistering or collapse occurred during multiple rapid depressurization cycles of high pressure CO_2 gas. A small blister was found on several of the standard 75 durometer loose (uncompressed) fluoroelastomer O-rings. No blistering occurred on the 75 durometer compressed O-rings installed in the Flexpipe end fittings. In addition, no blistering was observed in the 95 durometer loose fluoroelastomer O-rings after 5 cycles. The mechanical properties of Flexpipe liner were not deteriorated during the rapid depressurization cycles of high pressure CO_2 gas. After 10 depressurization cycles, mechanical integrity of the pipe remained similar to that of the pipe before testing, as validated by the results of mechanical tests and visual inspection of the pipe samples.

Flexpipe RTP performed well and is recommended for use within the experimental test parameters of 800 psi partial pressure CO_2, up to 1500 psi overall system pressure, 140 °F, and 10 rapid depressurization cycles.

Even though the standard 75 durometer compressed O-rings did not blister during testing, upgrading the O-ring seals to a 95 durometer fluoroelastomer is suggested. This would provide additional protection against O-ring damage during rapid depressurization in high pressure CO_2 applications.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the laboratory work of Saami Muthuswamy of Flexpipe Systems, who carries out his work with diligence and attention to detail.

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[1] Pornchai, R. and Selke, S.E.M., “Strategy to Produce High-Void Fraction in Microcellular Foamed Polyolefin”, CMU Journal (2006), Vol. 5(1).