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A Case Study Detailing the Design, Planning, Installation and Cost and Environmental Benefit Analysis of a Reinforced Thermoplastic Pipe Pulled Through the Inside of an Existing Offshore Steel Flow Line in the East Malaysia Samarang Field

John R Wright Jr, Polyflow LLC, Khairul Anuar Karim, PETRONAS Carigali and Steve Kennedy, SCG Oil and Gas

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Abstract

PL-112 pipeline is located approximately 52 kilometers offshore Labuan in the Samarang field Sabah Operation. The field experiences shallow water depths between 8 to 10 meters. The 6” pipeline was installed in 1977 utilizing API-5L X-42 grade of carbon steel with a 9.52mm wall thickness and a concrete coating of 25.4mm in thickness. The length of the pipeline was 0.97 km with five times diameter radius in the riser bends (5D Bend). The original design pressure for the pipeline was 1,440 psi for flow of oil, water/brine and gas multi-phase flow.

In 2009, an anchor dragging along the seabed had hooked onto the pipeline causing it to kink and a structural integrity breach of the pipeline occurred. Sectional pipeline replacement has been performed using misalignment flanges to expedite the rectification in order to continue the production. The misalignment flanges and the area adjacent to the repair made it difficult for the operator to perform their routine operational pigging. Furthermore the pipeline also experienced some wall loss at few locations and make it more costly to perform the maintenance and repair.

The project team determined that the current infield drilling and requirements for flexibility in flow delivery options required the line to be in operation for another twenty five (25) years, hence the pipeline replacement project has been initiated. Installation options including new carbon steel pipeline replacement were evaluated together with the installation of a reinforced thermoplastic pipe (“RTP”) pulled thru the inside the existing pipeline. Based on the evaluations, the utilization of RTP was selected as the most cost effective solution to rehabilitate the line to meet a long term integrity requirements. The focus of this paper is to analyze the sizing, installation and performance of the RTP which was implemented and a technical and commercial comparison between RTP and carbon steel pipeline was compared in the conclusions. RTP pipe was selected because:

- Utilized a polymer liner inert to the present flowing fluid environments as well as withstanding any potential future effect of Sulfide Reducing Bacteria (“SRB”s) generating H_2S.
- High strength yet flexible to pull through existing carbon steel of the pipeline without effecting the RTP performance.
- Minimize the equipment requirements because of light weight flexible continuous lengths
- Rapid Installation to minimize downtime and expenses.
- Multiple size options to minimize pressure drop while maintaining critical velocities to move solids and minimize future maintenance expenses.
- Minimal environmental disturbance to the marine life and sea floor.
- Lower CAPEX & OPEX hence improved total life-cycle cost by eliminating corrosion issue and maintenance.

Pipe Sizing Analysis

When evaluating the rehabilitation of existing pipelines, it is important to analyze the right size of the pipe for current and future operating requirements. Proper pipe sizing can minimize the ongoing maintenance by creating critical velocities to move solids with the liquid flow stream, thus preventing solids build up in the pipeline which requires additional operational pigging costs. This must be accomplished without introducing extra pressure drop which may affect the back pressure applied to the formation and potentially reducing production rates. One of the benefits of thermoplastics are their smooth extruded surface compared with carbon steel pipe which reduces flowing pressure drop for comparable diameters. References have shown steel to have a relative roughness of 0.002 in/in versus thermoplastic extruded relative roughness of 0.00005 in/in. This allows for smaller diameter RTP pipes to create critical minimum velocities to move solids while not creating excessive pressure drop.

In the case of PL-112, the average fluid production was comprised of oil and water and a typical flow rate was 1,800bbls/day. The line was used as a bypass line for other flow lines and the production volume could spike to 5,000bbl/day. The maximum inlet pressure is 180 psi to minimize any backpressure against the wells and the ideal pipeline exit pressure flowing into the separator is set at 100 psi. Figure 1 and Figure 2 below shows the impact of flow rate on of a 3.5" RTP Pipe (2.95" ID) compared with a 3.0" ID steel pipe.

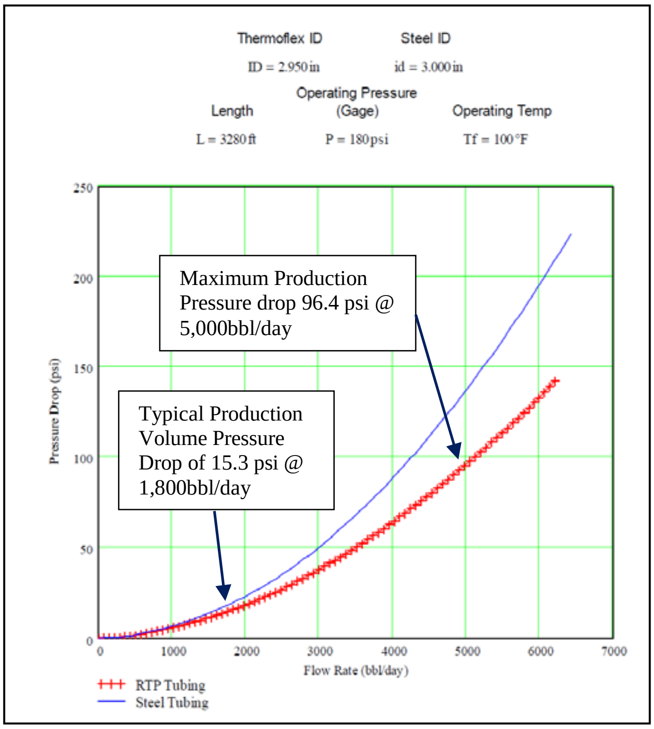

Figure 1: Impact of Flow Rate and Pressure Drop on RTP Pipe and Carbon Steel Pipeline

Refer to Figure 1, at 1,800bbl/day the pressure drop was modeled at 15.3 psi which is within the design parameters requested. However when flow is bypassed into the PL-112 line and reaches 5,000bbl/day of production the pressure drop increases to 96.4 psi which is slightly higher than the design parameters of 80 psi pressure drop. Before moving to a larger size pipe the product velocity was analyzed.

Refering to Figure 2, at 1,800 bbl/day, the flowing velocity is slightly above the minimum velocity the pipe manufacturer suggests for carrying solids in the flow stream which is 2ft/sec (0.61m/sec).

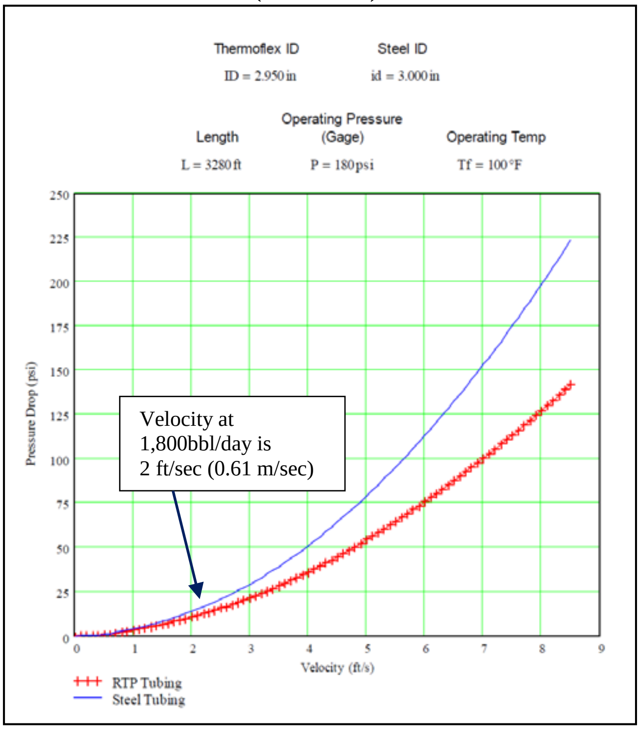

Figure 2: Flowing Velocity of Product

Sand is a potential issue with the flow line so maintaining minimum velocities to carry the sand in the flow stream will minimize future requirement for pigging the line to remove solids. Moving to a 4.5" RTP Pipe (3.83" ID) would decrease the minimum velocity at 1,800bbl/day to 1.3ft/sec (0.39m/sec). To optimise overall project expenditure, it was concluded to go with the 3.5" RTP pipe and operate with slightly higher pressure drops at maximum design flow rates which would only occur intermittently, but eliminate the need to clean solids from the pipeline on a ongoing basis.

Material Selection

The RTP pipe was constructed with internal layer of Fortron Polyphenylene Sulfide (PPS), reinforced with aramid fibers and jacketed with Nylon (refer to Figure 3)

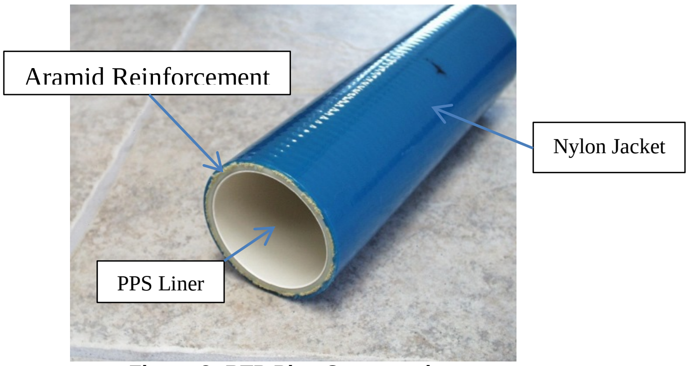

Figure 3: RTP Pipe Construction

The Fortron PPS was selected because of its resistance to hydrocarbons, Brine, CO_2 and H_2S as well as its extremely low rates of permeation of the compounds present in the flow stream. The Chemical compatibility acceptability was primarily based upon a chemical aging study contracted to an independent test lab in London, England that tested the PPS in the NORSOK M710 solution at elevated temperature to determine if there was any negative effect of the solution on the polymer. The composition of NORSOK M710 Solution is tabulated in Table 1.

Volume (%)	Composition
30	3% CO_2, 2% H_2S, 95% CH_4
10	Distilled water (conductivity < 5 μS)
60	70% heptane, 20% cyclohexane, 10% toluene

Table 1: Composition of NORSOK M710 Solution

Dog bone samples were aged in the above solution at various temperatures ranging from 140°C to 190°C to look at the change in weight, dimensions, physical strength and elongation. Results showed an immediate change in properties from dry as molded samples but then stabilization of properties occurred regardless of aging temperature. The Figure 4 below showing a sampling of the properties recorded. In this case, tensile strength as a function of aging time was recorded for various temperatures. For up to 170°C the properties stabilized after 20 days then remained relatively constant.

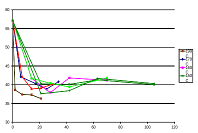

Figure 4: Tensile Strength of Fortron PPS (MPa) as a function of Ageing (Days) from 140-190C

Permeation through the liner does not necessarily damage the liner but rather can create operational issues such as build up gas pressure in the reinforcement layer creating issues with the outer jacket. In the case of the rehabilitation of a carbon steel pipeline, a build up of gas in the annulus between the RTP and the steel pipe can create non desirable issues. The Figure 5 is comparing various polymers permeation rates in CO_2 at various temperature to show a side by side comparisons. From the chart, it shows that polyethylene, a common polymer used in the oilfield has significant permeation rate compared to the other engineering plastics and Fortron (PPS) showed significantly lower levels of permeation.

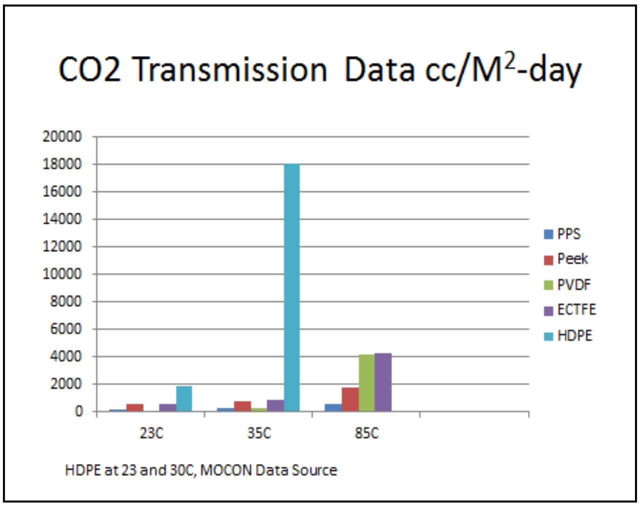

Figure 5: Comparison of CO_2 Permeation Rate for Polymer

Aramid fibers were selected as reinforcement because of its strength, cyclic/fatigue resistance and excellent fluid compatibility in hydrocarbons, brine, CO_2 and H_2S under 65°C. The jacket material selected was nylon because of its hydrocarbon resistance to potential residual oil in the existing steel pipeline and because of its excellent abrasion resistance.

Pre-planning of the Project

Some analysis were performed during the earlier stages of the project to ensure a sound project execution, which were the detail analysis of the existing pipeline, platform layout, topside piping configurations and equipment space available to perform the rehabilitation .

A sizing pig was run through the existing carbon steel pipeline to make sure the 3.5" RTP pipe can be pulled through the pipeline without any restrictions. A polyurethene (PU) coated foam pig with a 6" gauging plate was pushed through the pipeline to assure that there were no collapsed areas and the kinked area did not cause a restriction that would prevent a successful pull thru of the RTP pipe. The PL-112 showed acceptable openings to pull through the existing carbon steel pipelines.

Topside platform survey was performed to verify the riser dimensions, topside piping layouts, current equipment availability and platform deck space availability. This involved technicians traveling to both platforms at the termination of each side of the pipeline.

It was first verified that the current bends at the base of the risers were having a 6" 5D bend radius. This was not deemed acceptable for pulling through a 3.5" RTP pipe inside the existing 6" carbon steel pipeline. A 6" 12D bend radius is required to provide sufficient size of bend radius for the pull through (Refer to Figure 6). Even though a tighter radius could be implemented for the project, the generous 12D radius cost no more to fabricate and assured an easy pull through the existing pipeline.

Figure 6: Replacement of 20D Riser Bottom Bend to allow for smooth RTP Pull-thru

The existing risers had 6” ANSI 600 RTJ flanges. In order to seal off against the existing flanges and connect to the topside piping, a custom made double faced flanges were designed to allow the 3.5” RTP terminations to match with the 6” RTJ flange on the existing riser pipe and a 4” RTJ to match up to the topside piping. Dimensions were all measured to ease the preparation of drawings for fabrications and ease the development of work plan for the project (refer to Figure 15).

Lastly, the pulley layout and tie down points to locate the pulling rope over the riser opening was determined and sketched out for the work plan.

After the platform visit, all of the data was compiled into a detailed work procedure outlining the step by step procedures, a listing of equipment requirements, and fabrication drawings for all modifications for the surface equipment.

RTP Installation Process

The details discussion on the replacement of the riser bottom bends and repair of the kinked area have been excluded in this paper because they are standard conventional technologies requiring off the shelf components. The focus of the installation is from the point of conducting cleaning activities for the existing pipeline as integrity check by pushing a pig through the line with the proper bend radii in the elbows to accept the RTP piping.

The first step was to clean the existing line by running a scraping pig through the line. It was run in one direction three times and then run twice through the line in the opposite direction in order to knock out any rough or sharp areas that may have the potential to damage the pipe.

The next step was to insert the pulling rope through the line. A synthetic rope constructed from Technora aramid fiber and jacketed with a nylon cover was deployed because of its high strength, low weight and excellent creep resistance. The rated tensile load was 9,090kg to meet a minimum five (5) times safety factor over the maximum pull force required to pull the 3.5” RTP through the existing steel line. The lightweight rope required only 60 psi of pigging pressure to be pulled with a foam pig through the line, thus minimizing any potential damage to the existing carbon steel pipeline. The process of pulling the rope through the existing steel line requires a foam pig with an eyehook on the back end attached to a clevis which is attached to the eye of the rope. The pig is inserted into the pipeline. The rope is passed through a lubricator which is attached to the pig launcher to allow for a seal around the rope as water pressure moves the pig along the pipeline.

Figure 7: Retrievel of Foam Pig Attached with Pulling Rope

The largest change to the original work plan occurred because the crane on the pipe deployment platform was inoperable. The pipe was required to be pulled from a DP2 vessel over a temporary gooseneck constructed on the platform directly over the pipe. Figure 8 shows the temporary sheave scaffolding, and Figure 9 visualizes the pulling of pipe from the boat. A standard winch is used to pull the rope through the pipeline and designed to match with the tensile strength of the rope. A load cell to monitor the tensile load during pulling is set between the entry point into the riser and the winch.

Figure 8: Erecting Scaffolding and Sheave prior to Pull Thru

Figure 9: Pulling Process off the Vessel

Care must be taken during the pulling process to keep back tension against the reels of RTP pipe being unspooled and to avoid the pipe from creating an excessive loop between the riser pipe opening and the boat. This did occur once and kinked the RTP pipe creating the need to repair the kinked portion using splice coupling.

Each individual length of RTP pipe was approximately 300 meter in length requiring duplex 2205 jointless splice coupling to join pipes together. The splice couplings are comprised of a continuous length of stainless steel for an inner liner or insert with two outer ferrules that are swaged onto the pipe located between the insert and the ferrule. The result is a compression union of the two pipe ends together. When the end of a pipe on a reel is almost completed, the winch is stopped. The remaining pipe is removed from the spool and aligned into the coupling machine to swage one side of the splice coupling onto the pipe (See Figure 11). The starter end of the next length of pipe is pulled from the reel and put in line with the coupling machine and swaged onto the splice coupling already attached to the end of the previous length of pipe (See Figure 12). The winch is then activated to slowly pull the pipe into place (aligned with the gooseneck over the riser opening) and the pulling process continues. The winch pulling speed averaged 20 meters per minute.

Figure 10: Duplex Splice Coupling

Figure 11: Splice Coupling Tail of Pipe

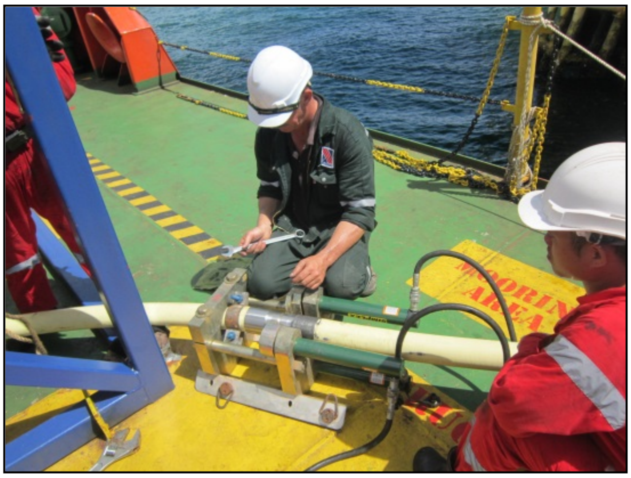

Figure 12: Splicing Lead End on Coupling

During the pulling process, the nylon jacket on the pulling rope was peeling off. It was assumed that the downhole flanges installed during the riser bottom bend modification had a sharp edge that “grabbed” the jacket and ripped it. The pulling process continued but the load cell was removed because the torn jacket was preventing the rope from passing through the load cell. The tension of the rope was then visually monitored to inspect for excess tension indicating a hang up. The exposed fiber in the synthetic rope were being damaged during the pull and eventually snapped approximately 1 meter from the end of the pull. The pulling cone was grabbed with a cable via fishing techniques and the pull was finally completed.

Figure 13: Final Pull Out of the Existing Pipeline

The RTP pipe was pulled approximately three (3) meters beyond the opening to the riser and inspected to see if there was any damage to the pipe. Since the external condition of the RTP was undamaged, it was concluded that the thinner jacket on the rope was wrinkling in the riser bend, getting caught on the sharp flange edge and tore away from the fibers..

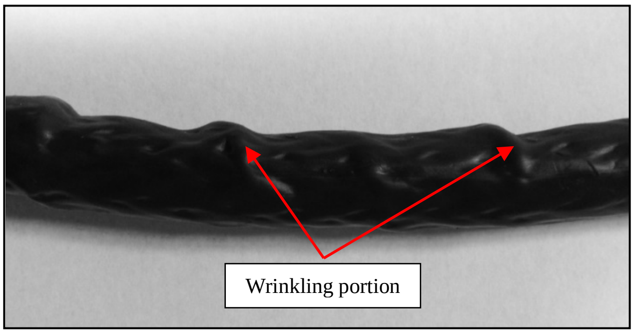

Figure 14: Wrinkling of Pulling Rope When Bent

After the post pull thru inspection, the pipe was cut back and a double faced RTJ ANSI 600# flanged termination coupling was installed to the end of the pipe. Sealing the RTP pipe inside of the steel assures that all above water RTP is encapsulated inside of the carbon steel for any fire concerns. Figure 15 details the flange connection.

Once the topside connections were installed, the new RTP line was hydro-tested for 24 hours at 360 psi. The current MAOP of the line is 180 psi. The pipe RTP needed approximately two (2) hours to stabilize before being hydro-tested for 24 hours.

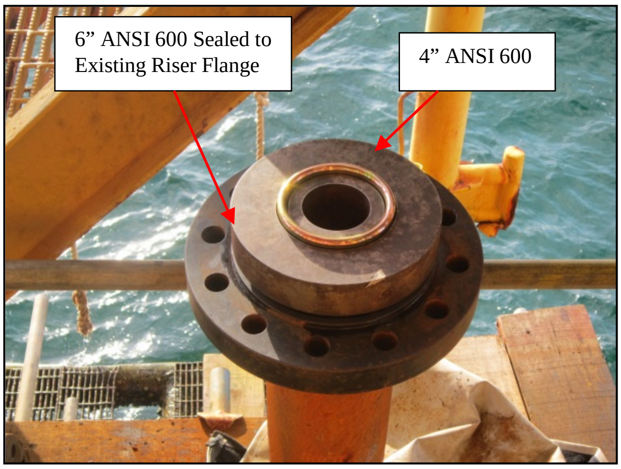

Figure 15: End Termination to Existing Riser

Figure 16: Hydrotest Pressure Chart

Results

The line has been operating for more than 13 months, flowing between 1,800bbl/day and 7,000bbl/day. It was noted by production that when operating at 7,000bbl/day, the pressure drop created back pressure against the formation choking production during these bypass flow periods.

There was no operational pigging and chemical treatment carried out on the line line since the line was put back in operation with the RTP pipe.

The total cost of installation, including riser modifications, vessel costs and installation, was 67% lower than the projected costs for a conventional installation of a carbon steel pipeline. The Figure 17 shows the percentage of installation and materials, the rework of the steel pipeline and vessel costs incurred, and the cost savings versus a new steel line.

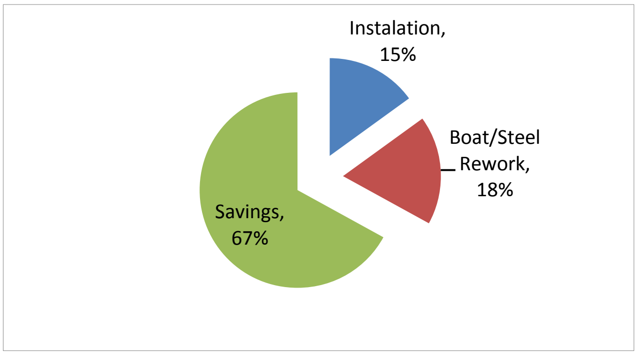

Figure 17: Distribution of Cost Savings (%)

If rework to the damaged pipeline from the anchor were not necessary, the risers had a suitable bend radius not requiring replacement, and both the pulling winch and pipe can be staged and installed from the platforms, then installation would be 15% of the cost of laying a new conventional steel line.

The total installation campaign for this project was 18 days which includes the removal and replacement of riser bottom bends and subsea kinked portion and Waiting on Weather (WOW) downtime. The installation of the RTP was three days.

Lessons Learned

It is extremely important to spend the time to analyze the pipeline, platforms and equipment prior to the project execution. During the project execution, it is being observed that improper lifting method of RTP spools during transportation had damaged the RTP since RTP prone to buckle/kink when it is not handled properly. Besides that, operational issues on the crane's malfunction at platform and unavailability of dedicated work boat for project team to assist equipment and personnel transfer also cause significant delays to the project. It is essential to inspect the existing lines using gauging pig for internal inspection and ROV for external inspection to know the current condition and configuration of the pipeline. A detail audit of the platforms ahead of time is essential to assure space to perform the work, equipment availability and capability and the location of the risers with piping details to develop a detailed work plan.

The existing rope protective jacket was too thin resulting in a stripping of the rope jacket during the pulling operation. For an improvement, after the completion of the project testing was performed on three (3) alternative jackets to protect the internal synthetic fibers. The first was a heavier polymer jacket that resists wrinkling at the minimum bend radius the rope will experience. The second option was an exterior fiber braid woven over the inner synthetic rope to provide abrasion resistance. The last option was a combination of a thicker polymer jacket with a braided fiber over the polymer jacket. (See Figures 18, 19 & 20)


Figure 18: Thicker Polymer Jacket Pulling Rope


Figure 19: Braided Jacket Pulling Rope


Figure 20: Polymer & Braided Jacket Pulling Rope

In all cases the rope was spooled on an 8" diameter spool with no wrinkling. Drag tests are still being conducted but initial results show excellent resistance to abrasion.

Conclusion

Overall, the pipeline rehabilitation using RTP installation was a success and incurred 67% less capital cost compared to an installation using conventional carbon steel pipeline. Proper planning and analysis of the pipeline to be rehabilitated shall be executed at earlier stage to ensure smoother installation process and better achievement to the project in term of schedule and expenditure. Spending a small amount of capital to inspect the condition of the existing pipeline prior to the project execution saves significant time and money during the execution. Besides that, detailed platform evaluation including piping configurations, deck space availability and equipment capability assures more reliable project plan and adherence to timelines.