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Flexpipe Spoolable Composite Pipe Resistance to Low Temperature

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by

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Summary

Flexible, spoolable pipe composites are being used in oil and gas production applications with great success. These materials resistance to external and internal corrosion, abrasion as well as their excellent constructability makes them a strong candidate to more standard constructions using carbon steel or fiberglass pipe.

The scope of this work is to evaluate these materials ability to withstand occasional exposures to very low temperatures associated with Joule Thompson effects encountered in upset operating conditions such as start-ups or transient flow in sweet gas production.
A full scale test program was planned in cooperation with Flexpipe. The results of this work are captured in this report. Laboratory testing on smaller scale have also been planned but the scope has been reduced due to laboratory availability at the time. A literature search has also been performed on this topic and the information has been used to complement the analysis.

The result of this investigation is that HDPE is not affected by low temperatures and was able to maintain its integrity during pressurization as well as during impact testing. The exposure of these composites to occasional low temperatures up to -70 C will not affect the composite ability to withstand the required forces associated with the pressurized operation. Careful riser support and anchoring needs to be implemented to ensure that the thermal expansion and contraction associated with the temperature fluctuations are properly harnessed.

Table of Contents

1. Background

Several competing spoolable composite materials are available on the market. Some of the most popular ones in Canadian applications are Fiberspar, Flexpipe and Wellstream. The work in this document is focused only on the evaluation of Flexpipe. While, the investigation can be extended to other composites, the test results discussed in here are specific to the Flexpipe composite tested.

Flexpipe is a spoolable composite pipeline material composed of a three un-bond layers: An inner high-density polyethylene liner, corrosion and erosion resistant, an outer woven fiberglass reinforcement and an additional external top layer of high-density polythelene. Flexpipe is a CSA Z662 approved composite that can be used in oil and gas applications (with some restrictions on the amount of hydrogen sulphide contents).

The composite relies on the combined action of all three layers for pressure containment. The layered structure offers this material a flexibility that adds to the inherent strength, allowing for long lengths installation with a minimum number of connections.

Flexpipe connections consist of a metallic mandrel and sleeve coupling. The connection is installed by inserting the composite pipe between the mandrel and the sleeve and applying a controlled, radial compressive force to the sleeve through a crimping operation. The plastic deformation of the sleeve over the high density polyethylene/fiberglass composite accounts for the pressure retaining ability of the connection as well as the fitting resistance to tensile loads. Corrosion resistant alloys or coatings can be used for both the mandrel and, if required, for the compression sleeve.

Operations in BCG benefit from great cost savings when using these materials for sweet, wet gas gathering lines. Materials are temporarily subjected to very low temperatures caused by the Jules Thomson effect across the choke when high pressure wells are commissioned. The low temperatures can persist until heat from the reservoir is transported to surface (~1 to 2 hrs) or until the pressure builds up. Based on generic well data, the pressure drops encountered at start-up are 24MPa (wellhead pressure) to 2.5 MPa (pipeline pressure). The gas has a high CO_2 content and the pressure drop can create a refrigeration effect which, based on process modelling data can be as low as -65 C from a normal operating temperature of 25 C.

The evaluation below is intended to qualify the Flexpipe product and generate guidelines for handling the short term thermal transient effect characteristic to these wells.

2. Full Scale Pressure Testing at Low Temperatures

2.1 Materials, set-up and conditioning

A 6 feet long section of Flexpipe was fitted with the 2 end connections of Flexpipe proprietary carbon steel couplings coated with electroless nickel plating. The end connections were completed using the specialized crimping machine. Blind flanges were used to isolate the 6 feet test spool and prepare for pressure testing.

Materials used in the test spool are as follows:

Component	Material	Comments
Pipe grade	4” FP601	600 class pressure class
Fitting assembly	ASTM A350 LF2 mandrel	Flanged Fittings
	+Mild CS with ENP sleeve	
Blind Flanges	ANSI 600 RF B16.5 ASTM A350 Gr LF2, no ENP	With 1/4in NPT connection for pressure ports
	Standard graphite filled SS spiral wound 4” ANSI 600 Flexitallic gaskets	
Studs and nuts	A193 Gr B7 studs	
	+ A194 Gr B8 nuts	
O rings for the fittings	Viton	Rated to –20 C

After the test spool construction, light grade oil specified and supplied by Flexpipe, Fluid 200, (MSDS attached) has been used to fill up the test spool and a conditioning pressure test was carried out at 2100 psi, a temperature of -21 C for a total duration of 8 hours. The conditioning test, carried out at Flexpipe location was used to eliminate errors in the data associated with the normal relaxation and expansion that the pipe will experience as the pressure builds up.

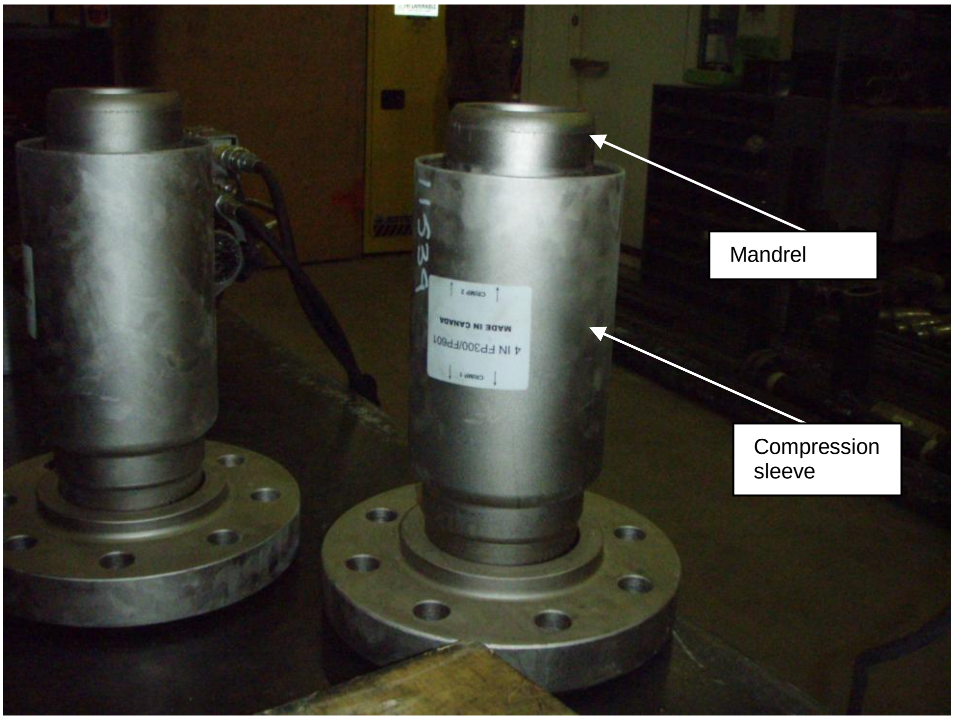

Fig. 1 Flexpipe end connections used for the test spool

2.2 Low Temperature Pressure Testing

A low temperature pressure test of the test spool was carried out at the Electronic Test Centre. The centre had a large cold room able to accommodate the test spool and the required test temperatures of – 70 C. While the cold room had a number of different thermocouples for controlling and recording the temperature inside and outside of the test room, a pressure transducer was not available and arrangements were made for one to be installed and calibrated for recording the pressure inside the test spool.

The test spool, filled with test oil, Fluid 200, was placed in the middle of the cold room and the pressure and temperature transducers were connected to the pipe through the blind flanges, see Fig 2. The temperature during the test was monitored at different locations. The data was collected using separate data acquisition systems for the pressure and temperature. Oil was selected as the test media for safety reasons, to protect against a leak or a burst that would have been much more damaging if air would have been used instead of an incompressible fluid.

Fig 2. Flexpipe test spool in the cold chamber at ETC

Longer set-up issues encountered on the first day, forced a shorter total exposure time of the pipe. As a result, the pipe spool was pressurized to approximately 2000 psi and exposed to temperatures as low as -60 C for approximately seven continuous hours. During this time, both the pressure and temperature were monitored, Fig 3 and Fig 4. However, an un-expected plugging of the pressure port was encountered due to the oil inside the tests spool becoming very viscous at the low temperature of the test. As a result the pressure indications were high, approaching the maximum rating of the composite pipe.

The test was finished at the end of the day and the spool pipe examined for damage, embrittlement or leaks. None were observed on the composite pipe. However flaking and peeling the electroless nickel plating on the carbon steel fittings was noted.

The test fluid was sampled after test. The pour point was measured at -54 C which indicates considerable thickening of the fluid would occur at -60 C.

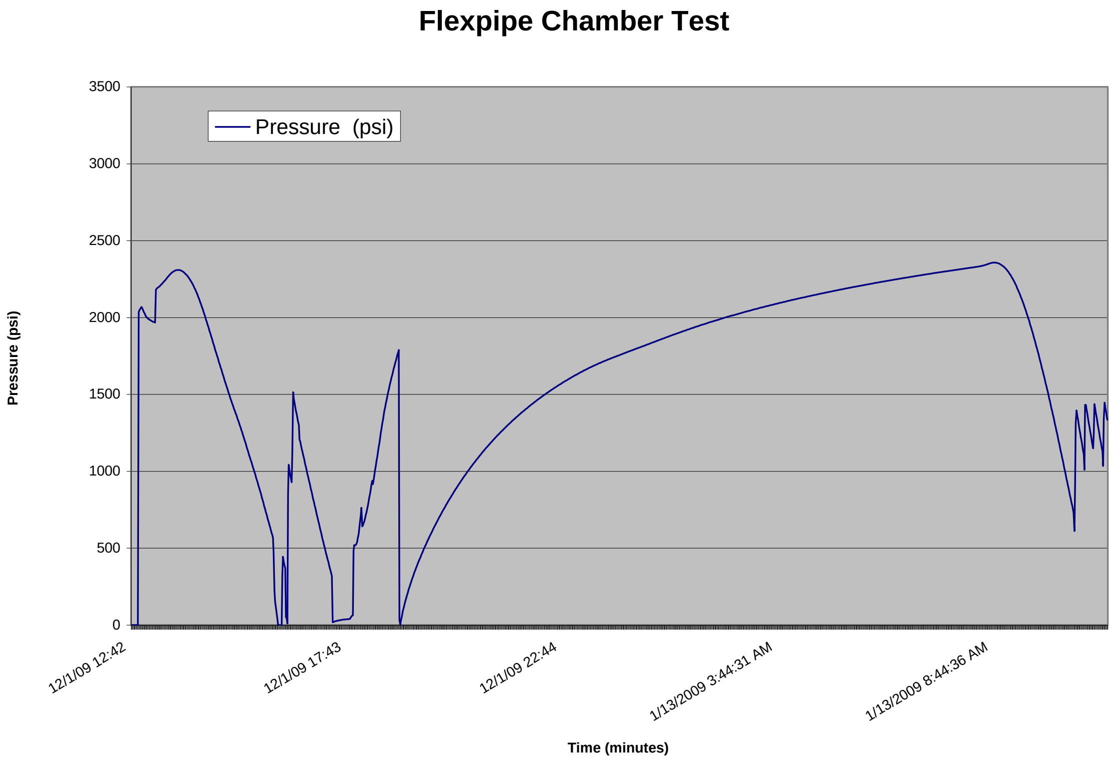

Fig3. Pressure recording versus time

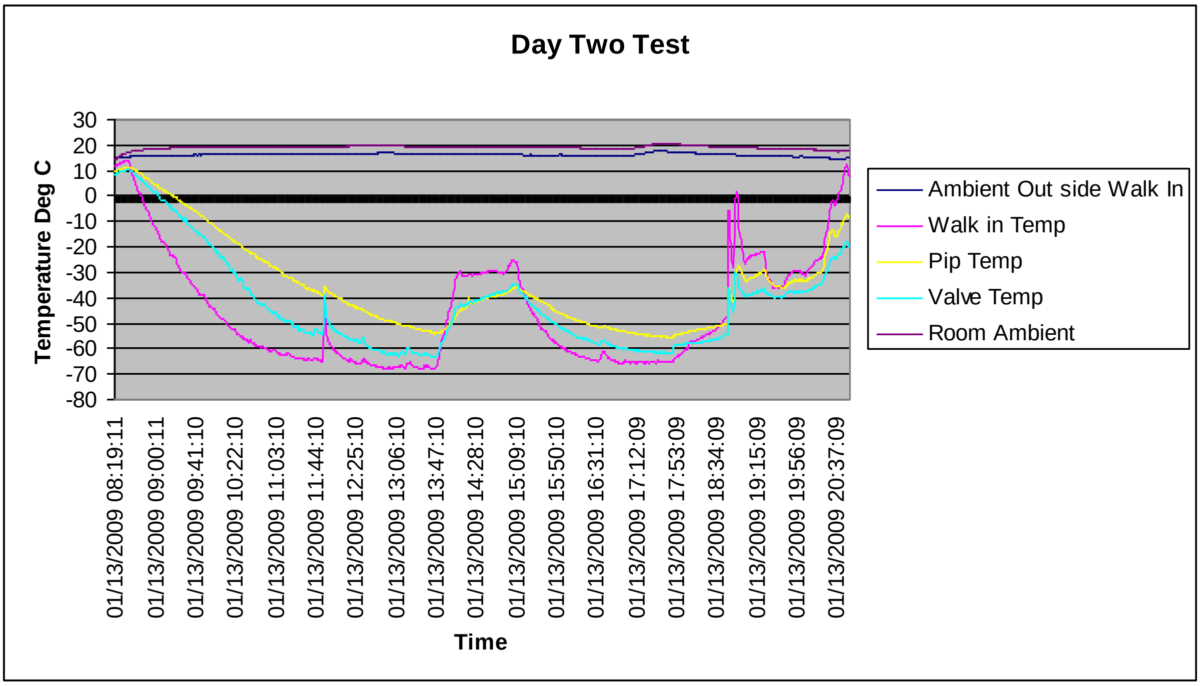

Fig. 4 Temperature versus time

3. Low Temperature Impact Testing

A full scale impact testing was carried out on a sample of the composite from the same production run as the test spool. The test procedure has been developed by Flexpipe and the acceptance was based on a fail no fail criteria. A couple of different shaped 5 kg weights , Fig. 5, were dropped on the pipe spool that was preliminary chilled to – 60 C. The weights were dropped from a height of approximately 4 m.
The impact resulted in the development of some indentations (plastic deformation) in the pipe wall, Fig 6. However no cracking or tearing has been observed.

Fig. 5 Drop weights

Fig. 6 Drop weight mark on the pipe (frosted due to chilling). No cracks were observed.

4. Results and Discussion

The full scale pressure testing at 2000 psi covered in this report has been successful in demonstrating that the Flexpipe composite is largely un-affected by the cold temperature exposure down to – 60 to -65 C. No leaks at the crimped connections were noted and no external or internal cracks were seen on the HDPE pipe. A full scale impact test was also simulated on an un-pressurized but chilled composite and it also validated the material resistance to external damage when exposed to cold conditions. In spite of a slight plastic deformation at the location of the weight drop, no cracks, punctures or crazes were noted in the outer HDPE casing of the composite.

It is important to consider the fact that the full scale testing, while the best validation method for a composite material was not followed up by a more detailed laboratory evaluation of the HDPE polymer which constitutes the bulk of the Flexpipe composite. The laboratory evaluation of material properties at low temperatures would benefit and complement the full scale testing by assessing mechanical/material properties such as modulus of elasticity, glass transition temperature, impact strength using standardized equipment/methods and perhaps percent crystallization to frame the quality of the HDPE grade used in the manufacturing of the test spool. These properties need to be evaluated not only as a function of temperature but also taking into account environmental aspects such as the presence of permeating gases, methanol/glycol chemicals that may have a softening effect on the HDPE as well as any other chemicals that might have been used for condensate inhibition. In the table below are presented the basic mechanical properties tested at CRC on exposed and un-exposed HDPE specimens taken from the actual composite. This data was the result of testing run at room temperature and shows that no significant material degradation has been observed.

Flexpipe HDPE Liner Mechanical Properties

Test Environment	Modulus (MPa)	Tensile Strength at Yield (MPa)	Strain at Yield (%)	Strain at Break (%)
unexposed	1131	26.0	12.5	858
exposed	1115	25.9	13.0	880

A literature search on the HDPE properties and performance at low temperatures was performed and a summary of the findings are presented below:

4.1 Minimum/Maximum Service Temperature

High density polyethylene has very good mechanical properties at low temperatures. In fact it has much better impact strength, modulus of elasticity and tensile strength at low temperatures then many other materials including fiberglass. This material was found to resist temperatures as low as -70 C, but in published guides, the HDPE is not actually recommended for operating below -40 C, (ref 3). However, other publications (ref1) show that HDPE has been successfully used in arctic applications, being able to sustain continuous operation at – 60 C.

The degradation mechanism associated with the exposure to low temperature is embrittlement which consists of an upward shift of the modulus of elasticity and some loss of the toughness of the material. However, the ductility of the material is not dramatically affected. The embrittlement associated with the low temperature exposure is reversible as opposed to any embrittlement encountered due to chemical degradation. However, if exposure to strong chemicals is encountered as well as a low temperature exposure, the embrittlement effects may be much worsened.

4.2 Glass transition temperature

Glass transition temperature is a critical material property that dictates the temperature range within which the material has the ability to withstand low temperatures without cracking. High density polyethylene is up to 95% a crystalline thermoplastic. The plasticity, flexibility and ductility of HDPE are accounted for by the 5% amorphous structure of these materials which allow molecules to move within the crystalline structure. As the exposure temperature decreases, the molecules in the non-crystalline areas are prevented from moving due to volume reductions. When the molecules cease to move any further temperature decrease would only allow for vibration. It is this temperature that marks the glass transition (Tg) point for polymeric materials. High density polyethylene has a Tg of -110 C which is a very low temperature for polymers and accounts for this material's excellent low temperature properties. Due to the inherent non-homogeneity of these materials, it is possible that secondary glass transition points are encountered at warmer temperatures, 20 C. While the slope change in this instance is small, there is a risk of for a more brittle behaviour even at warmer temperatures then -110 C. Material testing by fast scanning DSC (ref 7) can detect thes subtle step changes associated with weak glass transitions at higher temperatures.

4.3 Thermal expansion/contraction

Thermal expansion/contraction is very high in these materials. As term for comparison, thermal expansion/contraction coefficient for HDPE is 10 or 12 times higher than that of plain carbon steel, α= 10 or 12x10-5 in/in/F, (ref 1). The effect of thermal contraction on the composite pipe (Flexpipe) is less of a concern as the reinforcing fiberglass weave will be able to accommodate the HDPE pipe movement. A more serious concern associated with this property are the stresses developed in a poorly anchored/supported riser. Thermal expansion and contraction is directly proportional to the length of the pipe exposed to the temperature fluctuation and therefore the longer the riser, the higher the shrinkage on the pipe.

$\Delta L = L\,\alpha(\Delta T)$

However, in spite of the large thermal expansion/contraction in HDPE, the stresses developed in the thermally affected HDPE pipe are much lower than those developed in a similarly loaded carbon steel pipe. This is due to the lower modulus of elasticity of these materials when compared to steel.

Thermal fluctuations on a composite material with high contraction/expansion factors can result in a damage mechanism similar to fatigue damage (cyclic service). The sudden thermal changes can lead to the separation of the fibers in the fiberglass mesh which constituted the reinforcing layer of the pipe. The separation can result in the inner HDPE layer extruding or bulging through the reinforcement. This is a potential risk that needs to be evaluated and monitored through an inspection program.

4.4 Rapid crack propagation

When a pressurized PE pipe is subjected to an instantaneous and intense impact, a pre-existing or consequently initiated crack or flaw can propagate axially at speeds in excess of 100 m/s. Such an event is referred to as RCP or Rapid Crack Propagation. While RCP occurrence in PE pipes is noted to be rare, its consequences can be very significant. Further, RCP failures can be initiated at pressures well below the design stress of the pipe.

At low pressures, where there is insufficient energy to drive the crack, the crack initiates and immediately arrests (stops). At higher pressures, the crack propagates (goes) to the end of the pipe. The critical pressure is shown as the transition between arrest at low pressures and propagation at high pressures. In some work done on HDPE by Dow Chemicals, (ref6) this critical pressure, measured at 0 C was 10 bar (145 psig), see Fig.7. Similarly, at high temperatures the crack initiates and immediately arrests. At low temperatures, the crack propagates to the end of the pipe. The critical temperature is shown as the transition between arrest at high temperatures and propagation at low temperatures. For HDPE materials, (ref6) the critical temperature is 35 F (2 C). This information clearly shows that rapid crack propagation has a potential for occurrence during the time the riser is exposed to low temperatures.

Crack initiation points are necessary for rapid crack propagation. Initiation sites can be tool marks, scratches but can also be manufacturing defects in the HDPE or cold fusion.
With regards to the composite riser, the presence of a layered pipe design, two HDPE layers separated by a fiberglass woven mesh, the probability for rapid crack propagation is lowered when compared to a standalone HDPE pipe. If a crack does initiate in the external layer of the HDPE, the propagation force (gas de-compression force behind the crack) is absent until a crack is initiated on the internal layer of HDPE. The risk for RCP still remain for the inside HDPE layer which is directly exposed to the low temperature event.

More investigations are required in order to determine the potential for rapid crack propagation in such composite materials. A place to start is to perform at least one of the two RCP tests specified in ISO 13477 (RCP test –small scale) or ISO 13478 (RCP test-full scale).

PE Material	S4 Critical Pressure ($P_{C,S4}$) at 32°F (0°C)	Full Scale Critical Pressure ($P_{C,FS}$) at 0°C
Unimodal MDPE	1 bar (15 psig)	6.2 bar (90 psig)
Bimodal MDPE	10 bar (145 psig)	38.6 bar (560 psig)
Unimodal HDPE	2 bar (30 psig)	9.8 bar (140 psig)
Bimodal HDPE (PE 100+)	12 bar (180 psig)	45.8 bar (665 psig)

PE Material	Critical Temperature (T_C) at 5 bar (75 psig)
Unimodal MDPE	15°C (60°F)
Bimodal MDPE	-2°C (28°F)
Unimodal HDPE	9°C (48°F)
Bimodal HDPE	-17°C (1°F)

Fig. 7 Rapid Crack Propagation - Critical Pressure and Temperature

5. Conclusions

1. Full scale testing at low temperature and constant load pressure confirmed the composite ability to withstand test conditions without generating leaks in the end connections, cracking or crazing the HDPE carrier. The testing was done in pressure and temperatures simulating those encountered during the well start-up. However the test medium used was an incompressible fluid due to the hazards associated with the gas testing. As a result, the effect of the gas chemistry on the HDPE (permeation, softening etc) was not taken into account during these tests. Nevertheless, at low temperatures the permeation effects are negligible.

2. Impact tests were done on an un-pressurized composite pipe spool using 5kg drop weights from a height of 4m. The test used a pass/fail method and was based on Flexpipe procedure. Impact tests were successful in proving composite pipe resistance to low temperature impact.

3. Inherent material properties of the HDPE (glass transition, modulus of elasticity, thermal expansion/contraction, ductility, impact strength) are essential in determining material's resistance to low temperatures. As the temperature drops, the modulus of the HDPE increases. As a result, the pipe becomes stiffer but it retains its ductility. Literature references indicate that HDPE has been successfully used in arctic applications at continuous exposures to temperatures as low as – 60 C. When designing for such operating conditions, the effect of thermal contraction needs to be considered by providing adequate riser support and anchoring.

4. HDPE has an good resistance to low temperatures (down to -70 F) due to its high amount of crystalline structure and low glass transition temperature. These materials have a glass transition temperature of -110 C, however it is not unusual for some grades to have a second step change at warmer temperature increasing the risk for a brittle behaviour even at temperatures around 20 C.

5. Rapid Crack Propagation (RCP) is a failure mechanism that can be triggered in HDPE pipe by the pressures and temperature below the RCP critical point as well as the presence of an initiation factor (mechanical damage, manufacturing defect, etc). The Flexpipe composite risk for RCP appears to be low due to the composite aspect of the pressure retaining wall. A RCP testing (ref 8, 9) would be beneficial in assessing the potential for rapid crack propagation in these materials.

6. Flexpipe being a layered composite has an excellent ability to withstand temperature fluctuations as the layered structure of the pipe wall will create an inherent isolation of each layer.

7. There is a potential for Flexpipe to fail due to cyclic thermal fatigue caused by the separation of fibres in the fiberglass mesh that reinforces the pipe.

6. Recommendations

1. Flexpipe risers can survive well start-up conditions involving sharp temperatures drops to – 60 C provided that the following are considered:

   a. Thermal contraction of these materials is 10 times higher than that of steels and a stress analysis is recommended to ensure that the risers have adequate support and anchoring to prevent exceeding the maximum allowable stresses in the composite.

   b. When ordering these materials, it is recommended that the HDPE manufacturer used is able to provide material datasheets specifying and certifying the basic properties of their product (tensile, modulus, Tg, etc).

   c. A through riser inspection and further protection against any mechanical damage (from tool marks to cuts) is required to prevent any crack initiation sites

   d. When installing the risers, it is recommended that any girth fusions in HDPE inner or outer layer are avoided for the whole length of the riser to ensure that no crack initiation point (cold fusion) are present in the areas directly subjected to JT effects.

   e. Risers shall be physically protected against mechanical damage especially during the start-up operations when they are most susceptible but also during normal operation

   f. Any chemistry changes in the pipeline (gas chemistry changes, water cut concentration changes, hot oil treatment, methanol, glycol or diesel batches) must be discussed with a materials specialist to understand the impact on the HPDE properties (permeation related swelling, softening, etc. (that will affect the low temperature resistance and pressure rating.

   g. Riser inspection prior and after the exposure to thermal cycle is required in order to observe any bulges in the outer HDPE layer that might be the result of fiberglass weave failure.

2. If other spoolable or non-metallic materials are considered for use in similar conditions, a thorough technical assessment of the composite materials used is required to ensure that all aspects mentioned in 1 above are considered.

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Appendix A. Test Fluid

Fluid 200 - 50
Centistokes - MSDS

Bibliographic Information

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