Materials & Inspection Engineering Group

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SUBJECT	: The Influence of the Envisaged Operating Conditions on the Integrity of the Smooth Bore Water Injection Flexibles. Assessment of the potential for explosive decompression damage to the polymer internal pressure sheath.	
PROJECT IDENTIFICATION	: 54009135	
DATE OF ISSUE	: 21 September 2007	
KEYWORDS	: Offshore, Flexible, Water injection, HDPE, Explosive decompression	

Summary

Shell Global Solutions assessed the potential for explosive decompression damage of the Draugen water injection flexible containing an High Density Poly Ethylene Pressure sheath. Damage to the polymer internal pressure sheath during the planned produced water re-injection pilot as a result of explosive decompression is not expected. The total gas pressure of the dissolved gasses in the produced water i.e. 0.75 Bar is far below the level indicated were blistering of HDPE could occur i.e. 100 Bar at 65 °C.

1. Introduction

In 2000 Shell Global Solutions performed a study for Norske Shell titled "The Influence of the Envisaged Operating Conditions on the Integrity of the Smooth Bore WI Flexibles". The outcome of the study was reported in OP.01.20105. Norske Shell asked for extension of the study to support the planned pilot for the application of a Draugen water injection flexible for produced water injection. One of the issues raised by Norske Shell was the potential for explosive decompression damage to the polymers in the Flexible at the operating conditions expected during the pilot.

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This technical note covers the assessment of the potential for explosive decompression damage. The main emphasis of this assessment is on the polymer internal pressure sheath of the flexible. The other polymer sheaths in the flexible i.e. the anti abrasion layer and the external sheath are not exposed to explosive decompression occurring within the bore of the flexible.

2. Scope of work

The following scope of work was agreed between Norske Shell and Shell Global Solutions.

2.1 Objective

Assess the potential for explosive decompression damage to the polymers in the Flexible based on the provided operating conditions. As criteria and reference API 17 J blister resistance will be used.

Deliverable: Safe levels of gas content in the produced water to prevent explosive decompression damage.

2.2 Task I

Gathering and appraising input data (discussion with Norske Shell)

In order to asses the potential of blistering the following data is required.

(a) The polymer used for the liner including information about void size and distribution. Most likely an inspection of a representative sample of the liner for the presence of voids and the maximum size of voids has to be performed. Liners samples of the failed WI flexible are still available at Shell Global Solutions. On request of Norske Shell this sub-task was changed to: Check within API 17J or 17B for this data. Norske Shell indicated to contact the manufacturing specifications and data books to look for limiting constraints.

(b) The temperature in the bore and the temperature of the polymer during decompression.

(c) Total gas pressure in the bore and the partial pressure of the individual gasses.

(d) Decompression rate.

(e) Number of cycles expected in the total service life.

2.3 Task II

Compare the obtained input data items of Task I a to e with the test conditions and results of blistering resistance tests performed by the manufacturers of flexibles on similar polymers. As criteria and reference API 17 J blister resistance will be used.

Based on diffusion and solubility data for the most common gasses the level of absorbed gasses will be calculated.

Assessment of the consequences of differences found in the comparison with respect to the level of blistering resistance or the potential for blistering to occur.

Define whether the levels of gas content in the produced water are low enough exclude the potential for blistering to occur as a result of explosive decompression.

Define safe levels of gas content.

2.4 Task III

If a conclusion cannot be reached as a result of completing Task II, a scope for further work required to reach a conclusion will be defined.

3. Results

3.1 Terminology alignment

Explosive Decompression (ED) or Explosive Decompression Damage is a terminology generally used to indicate the phenomena were under high pressure gasses diffuse into an elastomeric seal and become trapped. In case of rapid decompression, the trapped gasses can causes the elastomer to tear and thus damaging the seal, which can lead to failure. The ED resistance at specific operating conditions of an elastomer seal depends on the elastomeric material used and the quality of manufacturing.

Blistering in principle is similar to Explosive Decompression Damage but generally used for other polymer materials than elastomers. The resistance of most polymers to ED is significantly higher than that of elastomers. Damage as a result of ED generally only occurs as a result of poor quality of the polymer such as voids, inclusion etc.

3.2 Task I, Input data provided

(a) Polymer
High Density Polyethylene (HDPE), density 0.947 g/cm^3.
It is assumed that polymer used for the internal pressure sheath of the flexible is similar to the HDPE provided for the previous Draugen NWIT 10" water injection flexible TR 846061 (Source Data Book of TR846061 provided by Coflexip date 30/03/1995). The HDPE used for this flexible was a FINATHENE 3802 B with a density of 0.947 g/cm^3. Flexibles supplied for water injection service are certified for the transport of Chloride free water (< 20 ppm). Since no gas is considered present in the transported fluid (water) no information about blistering resistance of the HDPE is provided nor are specification with regards to blistering resistance mentioned. This is in line with the applicable Recommended Practice for Flexible Pipe API 17B. According to API 17B, the blistering resistance of the polymer internal pressure sheath of a flexible should be taken into consideration when gas is present in the transported fluid. No specific request for providing void size and void distribution within the polymer of the internal pressure sheath of a flexible is mentioned in API 17B.

(b) The temperature in the bore and the temperature of the polymer during decompression. Max operating temperature is 65 °C.
Shut-down temp for system will be 71°C.

(c) Total gas pressure in the bore and the partial pressure of the individual gasses.
Norske Shell provided the data required to determine of the partial gas pressures of the individual gasses. The calculations performed to determine these pressures on the basis of the provided data are given in Appendix 1.

(d) Decompression rate
Bore pressure as a function of time and the decompression rates calculated are given in Appendix 2.

(e) Number of cycles expected in the total service life
120 cycles

3.3 Task II

The anticipated explosive decompression conditions of polymer internal pressure sheath of the Draugen water injection flexible during the planned pilot are collected in Table 1.

Table 1
Explosive decompression conditions of polymer internal pressure sheath of the Draugen water injection flexible during the planned pilot

Temperature [°C]	Pressure [Bar]	Decompression rate [Bar/min]	Fluid	# Cycles
65 Max operating temperature 71 Shut-down temperature	160 Liquid pressure Total of all Partial Gas pressures 0.75, see Appendix 1	890 Liquid Gas decompression	Water with traces of other chemicals. Liquid/vapour 67:1 (m^3 liquid: m^3 gas at standard conditions)	120 In the total service life

The blistering specifications, references to polymer blistering characteristics and requirements as found in API 17B and API 17J are given in Appendix 3.

Literture data about the blistering characteristics of HDPE

Blistering Characteristics of HDPE are given in API 17B, though in such vague terms that they are not considered to provide a firm basis for a practical evaluation of operational limitations.
Since the suppliers of flexible pipe seems to use HDPE mainly as internal pressure sheath material for application with no gas present in the transported fluid, blistering resistance test data of HDPE as described in API 17J seems not be available. Tests performed by Elf Atochem[i] were done at 100 °C, a temperature far above the recommended maximum operating temperature of HDPE. For defining a clear upper limit for HDPE this data is of little use however it indicates that HDPE even under these stringed conditions can survive several depressurisations.

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i Thierry P. Vasselin, Use of Polyamide 11 in Corrosive Applications, Elf Atochem North America, Inc. http://www.atofinachemicals.com/techpol/Rilsan_Liners/papers_usepolyamide.cfm

Literature was searched for additional technical publications about the blistering characteristics of HDPE, results are given in the reference list. The relation and various limits in terms of temperature and maximum gas pressure are presented in Figure 2-1. Decompression rates in the references are surprisingly not given precisely but indicated as "a drop of 1000 bar in some seconds".

4. Discussion of results

The analysis of the anticipated operating conditions during the produced water re-injection pilot revealed that the actual total gas pressure in the flexible is very low i.e. approx. 0.75Bar.

The provided depressurisation curves indicate a high decompression rate but this is the decompression of the compressed liquid (mainly water). The pressure in the flexible has to drop below 0.75 bar before the dissolved gas will diffuse out and a gas decompression occurs. It is the level of the gas pressure and the temperature that determines the potential for blistering damage of the polymer due to explosive decompression. The total gas pressure of the dissolved gasses in the produced water is far below the level indicated were blistering of HDPE could occur. Although the Recommended Practice for Flexible pipe API 17B showed to be vague in providing operational limitations to prevent the occurrence of blistering, difference between these vague limitations below 200 Bar and the actual gas pressure 0.75 Bar are so significant that the occurrence of blistering can almost already be excluded on this limitations alone. Additional data found support this conclusion. Exact operational limitations have not been explored in great detail for HDPE, potentially related to the fact that the material is seldom considered for high-pressure gas lines. Noticeable is the fact that decompression test of HDPE have been performed and reported performed at a temperature almost 35 to 40°C above the recommended operating temperature of the material, still the material their only starts to show blisters around the 100 Bar gas pressure level. This data however indicates that even at a shutdown temperature of 71 °C i.e. slightly above the general recommended operating temperature of HDPE the potential for blister formation is negligible.

Safe levels of gas content

Blistering of HDPE as a result of explosive decompression at temperatures of around 65°C is expected to occur in the region of 100 Bar gas pressure. The partial pressures of the individual gasses is not important as long as the total gas pressure is below 100 Bar

5. Conclusions

Damage to the polymer internal pressure sheath of the Draugen water injection flexible during the planned produced water re-injection pilot as a result of explosive decompression is not expected. The total gas pressure of the dissolved gasses in the produced water is far below the level indicated were blistering of HDPE could occur.

6. References

1. Jarrin, J. et al, Blistering of Thermoplastic Materials Used in the Petroleum Industry.SPE 28482, 1994.
2. Gaillard-Devaux E., Rupture du polyethylene en temperature par decompression du methane 1995.
3. Dewimille, B., Behaviour of thermoplastic polymers during explosive decompressions in a petroleum environment. Journal de physique IV; Proceedings of international conference, 1993 Vol.3, pages 1559 upto 1564.
4. Janssen, F. Determination of the resistance of crosslinked polyethylene (PEX) to explosive decompression in a CO_2/Water mixture, Shell Global Solutions OG.02.20449 July 2002.

FJ/mv

Appendix 1
Determination of the partial gas pressures in the Water Injection Flexible

Liquid to Vapour Ratio

The measured liquid/vapour ratio of the injection water is:

$$67:1 \text{ (m}^3 \text{ liquid: m}^3 \text{ gas at standard conditions)}$$

[Ref West Lab report Jan. 2001]

Standard conditions are typically 25 °C and 1 atmosphere of pressure,
1 atmosphere is 1.01295 Bar.

Conversion of m^3 gas to mol

The molar volume of a gas is the volume occupied by one mol of that gas at standard temperature and pressure, and this volume is numerically equal to 22.41 litres (dm^3).
1 m^3 (1000 dm^3) of gas at standard conditions thus contains

$$1000/22.41 = 44.6 \text{ mol of gas}$$

Calculation of the Gas concentration

The gas concentration in the water is equal to:

$$44.6/67 = 0.67 \text{ mol/m}^3$$

Conversion to mol fraction

1 m^3 of water has a mass of 1000,000 g. The molecular weight of water is 18 gr.
1 m^3 of water is therefore equal to:

$$1000{,}000/18 = 55{,}556 \text{ mol}$$

The mol fraction of the gas is given by:

$$0.67/55{,}556 = 1.199 \text{ E-05 } mol_{gas}/mol_{h2o}$$

Mol fraction of the individual gasses dissolved in water

Table 1

Gas composition and mol fraction of the individual gasses dissolved in injection water

Component	Value Mol %	mol/mol_{h2o}
CO_2	4.4	5.27E-07
Methane	61.1	7.32E-06
Ethane	15.0	1.80E-06
Propane	12.8	1.53E-06
i-Butane	1.4	1.68E-07
n-Butane	3.4	4.08E-07
i-Pentane	0.6	7.19E-08
n-Pentane	0.6	7.19E-08
C6 and heavier	0.8	9.59E-08

Conversion to partial pressure

The partial pressure of a gas in the vapour space above the water /gas interface is directly proportional to the amount of gas dissolved in water. This is known as Henry's law. Another important consideration of gas solubility is Dalton's law, which states that the total pressure of a mixture of gases is made up of the individual pressures of those gases, and these are in direct relation to their molar or volume ratios in the vapour space.

Henry's law gives:

$$P = H \cdot c$$

In which:

- P is the partial pressure of the gas (atm).
- H is Henry's law constant for a specific gas at a given temperature (atm/mol fraction).
- C is the amount of gas dissolved ($mol_{gas}/\ mol_{h2o}$).

Table 2 gives Henry's law constants for CO_2 and Methane at different temperatures.

The partial pressure of CO_2 and Methane at 60°C is therefore equal to:

- $P_{co2} = 0.341 \times 10^4 \cdot 5.27E\text{-}07 = 0.0018$ atm approx. 0.0018 Bar.
- $P_{ch4} = 0.626 \times 10^4 \cdot 7.32E\text{-}06 = 0.48$ atm approx. 0.48 Bar.

Similar calculations for Ethane and Propane give partial pressures of 0.12 and 0.15 Bar respectively. The total gas pressure of the gas accumulates to approx. 0.75 Bar.

Table 2 *Henry's law constants [atm/mol fraction]*

T [°C]	CO_2	CH_4
0	0.073×10^4	2.24×10^4
10	0.104×10^4	2.97×10^4
20	0.142×10^4	3.76×10^4
30	0.186×10^4	4.49×10^4
40	0.233×10^4	5.20×10^4
50	0.283×10^4	5.77×10^4
60	0.341×10^4	6.26×10^4

Appendix 2
HDPE Blistering resistance
Blistering specifications, references to polymer blistering characteristics and requirements as found in API 17B and API 17J

Summary

The blistering resistance of the polymer internal pressure sheath of a flexible should according to API 17B be taken into consideration when gas is present in the transported fluid.
In API 17B, Table 13 lists typical blistering resistance characteristics for the internal pressure sheath polymer materials. This table is based on an OTC conference paper provided by CSO in 1992.
For HDPE these characteristics are described as: "Good Blistering Resistance at low temperatures and pressures only". However, no indications of the actual temperature and pressure limitations are given as is done for the other polymers in the same table.

Based on the temperature limits given in Table 12 of API 17B, the low temperatures seem to refer to temperatures of approx. 60 °C. The first higher indicated pressure limitation is that of XLPE with 3000 psi (approx. 200 Bar). The pressure limitation of HDPE is therefore definitely < 200 Bar.

API 17 J provides the actual specification for the polymer material for the internal pressure sheath: "If the conveyed fluid contains gas the polymer shall be shown, **by testing**, to not blister or degrade during rapid depressurisation from the maximum pressure and temperature conditions". Test conditions are further described in section 6.2.3.2.1 of API 17J. Requests for HDPE blister resistance test data according to API 17J was send to the 3 main suppliers, of flexible pipe Coflexip, Wellstream and NKT. Wellstream referred to a table in a conference paper from CSO though not the same as in API 17B. The seems to origin from a technical paper issued by Elf Atochem "Use of Polyamide 11 in Corrosive Applications by Thierry P. Vasselin Elf Atochem North America, Inc. The tests of which the results were provided in this table were performed at 100°C, which is far above the recommended maximum operating temperature of HDPE. For defining a clear upper limit of HDPE this data is of little use, however it indicates that HDPE even under these stringed conditions can survive several depressurisations. NKT indicated not to have such data since HDPE was not considered as internal sheath material for high-pressure applications.

CSO sofar has not responded.

Temporary conclusions

Blistering Characteristics of HDPE are given in API 17B, though in such vague terms that they are not considered to provide a firm basis for a practical evaluation of operational limitations. Since the suppliers of flexible pipe seems to use HDPE mainly as internal pressure sheath material for application with no gas present in the transported fluid, blistering resistance test data of HDPE as described in API 17J seems not be available. Tests performed by Elf Atochem were done at a temperature far above the recommended maximum operating temperature of HDPE. For defining a clear upper limit for HDPE this data is of little use however it indicates that HDPE even under these stringed conditions can survive several depressurisations.

Addendum 2.1 Relevant section of API 17B

API 17B

Section 6.2.2.3.1

Gas in the transported fluid is an important consideration in material selection for the polymer layers. The main issues relate to blistering resistance and permeability of the material of the internal pressure sheath; permeability characteristics of the outer sheath, however, will also be required. Table 13 lists typical blistering resistance characteristics for the internal pressure sheath polymer materials.

Polymer Material	Blistering Characteristics
HDPE	Good Blistering Resistance at low temperatures and pressures only
XLPE	Better blistering resistance than HDPE with positive results obtained in excess of 3000 psi
PA-11	Good blistering resistance up to 7500 psi and 100 °C
PVDF	Good blistering resistance up to 7500 psi and 130 °C

A note is added.

Blistering characteristics are taken from [9]. Note that the blistering characteristics will be a function of transported fluid, pressure, depressurisation rate, and temperature. Note: The suitability of a material for a particular application should be verified by the manufacturer.

Reference [9] is:
Bouvard, M., Mollard, M. and Rigeaud, J., “Specifying, Monitoring and Verifying Quality and Reliability of Flexible Pipe,” OTC Paper 6873, Proceedings of Offshore Technology Conference, Houston, Texas, May 1992.

Addendum 2.2 Relevant section of API 17J

API 17J

Section 6.1.2.2.3

Poly materials internal pressure sheath

If the conveyed fluid contains gas the polymer shall be shown, by testing, to not blister or degrade during rapid depressurisation from the maximum pressure and temperature conditions.

Section 6.2.3.2 Blistering Resistance from
SPECIFICATION FOR UNBONDED FLEXIBLE PIPE AIP SPECIFICATION 17J

6.2.3.2.1 Blistering resistance tests shall reflect the design requirements, relating in particular to fluid conditions, pressure, temperature, number of decompressions, and decompression rate. As a minimum, the following conditions shall apply:

(a) Fluid mixtures-Use gas components of specified environment as documented in the test procedure.
(b) Soak time-Use sufficient to ensure saturation.
(c) Test cycles--If available, use expected number of decompressions, or else use 20 cycles as a minimum.
(d) Decompression rate-If available, use expected decompression rate, or else use as a minimum 70 bar per minute.
(e) Thickness-Internal pressure sheath wall thickness as a minimum.
(f) Temperature - Use the expected decompression temperature.
(g) Pressure-Use design pressure as a minimum.
(h) Procedure-After each depressurisation the sample shall be examined at a magnification of x20 for signs of blistering, swelling, and slitting.

6.2.3.2.2 The acceptance criteria shall be that no blister formulation or slitting is observed

Addendum 2.3 Suppliers blistering resistance data

A request was send to the 3 main suppliers, of flexible pipe Coflexip, Wellstream and NKT for HDPE liner blister resistance test data according to API 17J. The following comments were received.

Wellstream

Please note enclosed HDPE blister resistance data obtained from OTC paper 5231, Improved Thermoplastic Materials for Offshore Flexible Pipes. The data was developed by CSO and we have historically utilized the results for the HDPE. We are currently conducting our own blistering tests to confirm and will have results later this year. The blistering data developed in the paper was utilized to cap the maximum operating temperature for the material of 60 °C[ii].

BLISTERING PERFORMANCE OF POLYMERS DURING PRESSURIZATION AND DEPRESSURIZATION CYCLES IN THE PRESENCE OF CRUDE OIL AND METHANE 100 °C

	200 Hours	1000 Hours	2000 Hours	4000 Hours	10000 Hours
PA 11	good	good	good	good	good
HDPE	good	good	fair	poor	poor
Neoprene	poor	poor	poor	poor	poor
Nitrile Rubber	good	fair	poor	poor	poor

NKT

HDPE is normally not used as inner liner in high pressure flexible pipes for transport of hydrocarbons due to its limitations in temperature, high gas permeability or insufficient chemical compatibility. Thus, we have not carried out specific blistering tests.[iii]

CSO

No comment was received at this moment 23.06.2003.

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ii Cobie Loper [Cobie.Loper@wellstream.com] Send: Wed 04/06/2003 19:32

iii From: Niels J. Rishøj [mailto:niels.rishoj@nktflexibles.com], Sent: Wednesday, 18 June 2003 10:54 AM, To: Chang, Jemei OGUS-OGEI/4

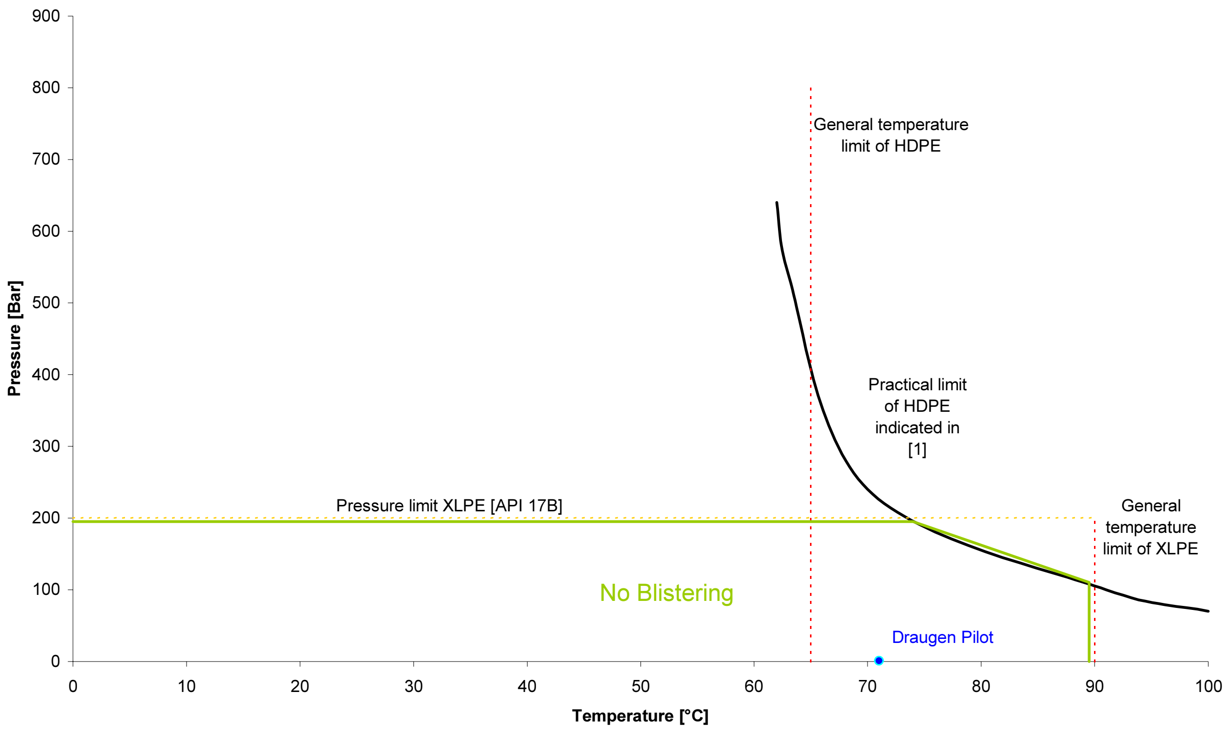

Figure 2-1
Practical limits for HDPE and XLPE to prevent Explosive decompression damage (Blistering). Green line indicate safe limits for HDPE