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Polyamide 12 Liner for Production Lines – Corrosion Protection, Efficient and Sustainable Revitalization of Mature Onshore Pipeline Infrastructures and New Offshore Pipelines

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Abstract

Thermoplastic liners have been used successfully to line and protect metallic onshore pipelines for many years and have become an indispensable requirement of the oil and gas industry, particularly with water injection and hydrocarbon services. In the case of internally corroded pipes, the use of thermoplastic liners for rehabilitation is an option to extend the lifetime of companies' assets, reduce maintenance cost and increase testing and inspection intervals. For new construction, thermoplastic liners in carbon steel pipes can compete technically and economically with pipelines of CRA, clad pipes and other corrosion inhibition systems. This opens the door for the use of thermoplastic liner for offshore operations. A polymer lined carbon steel can offer significant technical and economic advantages in terms of ease of installation, reliability, weight, flow assurance, material availability and cost. Polyamide 12 (PA12) is a high performance polymer with outstanding mechanical properties and excellent chemical stability. Starting in 2006 the O&G industry is using tailored PA12 grades for crucial applications like barrier and jacket layers of unbonded flexible pipes for offshore production. More than 1000 km of flexible pipes using PA12 have been installed today. This paper introduces the transfer of this successful technology to rigid carbon steel pipelines by using PA12 as liner to stop or control internal corrosion, showing the main benefits in comparison to Polyethylene.

Keywords: Pipeline, rehabilitation, thermoplastic, polyamide 12, polyamide, PA12, liner, polymer, polyethylene

Introduction

A significant amount of investment is still devoured by corrosion damages. In the case of pipeline in Oil & Gas Industries a significant amount of these damages could be avoided. Thermoplastic liner system components, such as pipes, fittings, valves and accessories manufactured from technical thermoplastics are ideally positioned to provide a long term solution for corrosion problems (1). Since the early 60ies of the last century polymers have been extensively used for the rehabilitation of corroded pipelines. Even so the initial focus was on municipal pipelines its potential for other fields of application have been recognized quite early. Polyethylene (PE) became the primary material of choice for liner due to its

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excellent cost-performance balance and today PE liners are established in the Oil & Gas industry as well. In onshore operations PE liners are used to rehabilitate corroded water injection lines as well as production lines. Nevertheless due to an increasing number of matured fields the industry is more often facing the limitations of the PE based rehabilitation of production pipelines. The key issue with PE liners is its tendency to absorb significant quantity of hydrocarbon species resulting in excessive swelling of the liner and significant softening of the PE material. Instability of the liner is caused by this phenomenon and liner collapse, buckling, or inversion is the consequence resulting in loss of production. Nevertheless it has been proven by experience that those issues doesn´t occur at moderate temperatures below 55°C.

Based on more than 50 years of successful history as automotive fuel lines, Polyamide 12 (PA 12) has been used since 2006 in the O&G industry for crucial applications like barrier and jacket layers of unbonded flexible pipes for offshore production. More than 1000 km of flexible pipes using PA 12 have been installed since (2). The polymer shows significant reduced swelling by hydrocarbons compared to PE and no softening effect. By combining the existing onshore liner technologies with the established polymer used in offshore operations a reliable evolution pushing the limits of today's technologies based on PE is in place for onshore rehabilitation. In addition, this evolution opens the door for an alternative corrosion protection strategy of new offshore carbon steel production lines. The lining of offshore carbon steel pipelines has to date been almost exclusively restricted to water injection lines using PE. The current market alternatives to the use of polymer liners providing internal corrosion protection are carbon steel of increased wall thickness with a large corrosion allowance, implement chemical dosing or specify corrosion resistant alloy. A polymer lined carbon steel pipe can offer significant technical and economic advantages in terms of ease of installation, reliability, weight, flow assurance, material availability and cost (1;11).

Methodology

As mentioned in the introduction one of the key characteristic of liner materials is its swelling behavior and the resulting impact on mechanical performance. Therefore comprehensive compatibility tests in different types of hydrocarbons have been made to investigate the performance limitations of polyethylene (PE), cross-linked polyethylene (PE-X), and PA 12 in liner applications.

General comparison of PE 100 and PA 12

A general characterization by determining the basic mechanical and thermal properties of PE 100 and un-plasticized PA 12 have been done. In addition tensile tests after saturation of the test specimen in a crude oil at 60°C (PE 100) and 105°C (PA 12) was done in the temperature range from 23 to 100°C. The length swelling of was measured as well. The specimens for all tests were taken from extruded pipes as showed in Figure 1.

Hydrocarbon compatibility

Fluid compatibility tests have been performed with PE 100, PE-X, and PA 12 in different hydrocarbons like light crude oil and diesel oil. Tensile specimens were aged fully immersed in the hydrocarbon at 80° till saturation. PE 100 has been measured at 60°C as well because it is reported that PE 100 could operate successfully up to about 55°C in onshore production pipelines. Those data can be considered as a benchmark. After 3, 7, 14, 21, and 42 days specimens were retrieved from the ageing environment and weight change and length swelling measured. After 42d the specimen could be considered as saturated in the media because no further weight change did occur. On virgin material as well as on aged material tensile tests were performed at 40 to 100°C to determine the tensile modulus after saturation.

Results e discussions

General comparison of PE 100 and PA 12

Table 1 allows a direct comparison of both materials and illustrates quite well the operation window of PA 12. The tensile modulus is an important factor related to the liner capability to resist collapse. A higher tensile modulus results in a higher collapse resistance of the liner (4). In addition, the PA 12 material shows very little length swelling even at 105°C compared to PE 100 at 60°C. The swelling of liner material influences its resistance against buckling in operation (4). Those subjects are discussed in more detail later in this paper.

Hydrocarbon compatibility

Figure 2 shows a good mechanical strength of PA 12 for temperatures up to 100°C. The tensile modulus remains always higher than the tensile modulus of PE 100 at its considered maximum operation temperature of 55°C. This added safety in mechanical strength plus the significant reduced swelling results in a stable liner in operation even at temperature significantly above 55°C.

Figure 3 shows the weight change of PE 100, PE-X 83% cross linking level and PA 12 as a function of time. The data show that PE materials show very similar weight change . This was expected because even so the PE-X is cross linked its chemical backbone is still based on PE. A very similar solubility of hydrocarbons in PE and PE-X has also been illustrated by Whelton et.al. (5). Further work on this subject is ongoing by the authors currently and is going to be published once further results are available. The PA 12 material shows significant less mass change (Figure 3).

Close-fit or tight-fit liner designs and installation methods have been developed over the past. Predominantly the roller-box and swaging technologies are used if it comes to such designs today. The idea is to install a liner having an outer diameter exceeding the inner diameter of the host pipe by an OD reduction installation method. After insertion of the liner the material tends to revert to its original OD until it is kept in the host pipe. With this concept a very stable liner-host pipe system can be achieved further supporting the stability of the liner resulting in increased safety against buckling and collapsing of the liner (6). Considering this design it becomes obvious that the liner material should be dimensional stable over the entire operation lifetime. Some mass and volume swelling are acceptable and further supports the close-fit design. Not acceptable on the other hand is any shrinkage of the liner during service. Shrinkage of the liner introduces the risk of the liner becoming a loose fit liner losing the additional support by the host pipe and finally losing part of its stability. Figure 3 shows, that a plasticized liner material introduces such risk. In service the hydrocarbons are extracting the plasticizer of the liner material resulting in a weight loss and consequently in a shrinkage of the entire liner. In the case of a shutdown, for example for maintenance purposes, the liner could become a loose liner able to move in the pipeline.

Table 1 - Comparison of PE 100 and PA 12

Property	Test Method Standard	PE 100	PA 12	Unit
Yield stress (23°C)	ASTM D638	23.8	38.2	MPa
Yield strain (23°C)		12	6,8	%
Strain at break (23°C)		> 200	> 200	%
Tensile Modulus (23°C)		1050	1320	MPa
Melting range	ISO 11357			
DSC, 2nd heating		135	176	°C
Tensile modulus	ISO 527-1			
23 °C	ISO 527-2	980	1300	MPa
40 °C		519	523	MPa
60 °C		305	372	MPa
80 °C		140	302	MPa
100 °C		86	249	MPa
Tensile modulus, sat. in light crude	ISO 527-1			
23 °C	ISO 527-2	393	770	MPa
40 °C		299	441	MPa
60 °C		183	336	MPa
80 °C		118	293	MPa
100 °C		76	259	MPa
Poisson ratio	ASTM D638			
23 °C		--	0.43	--
100 °C		--	0.45	--
Length swelling in oil				
60 °C		4.1		%
105 °C			2.2	%
CHARPY impact strength	ISO 179/1eU			
23 °C		N	N	kJ/m^2
-30 °C		N	N	kJ/m^2
CHARPY notched impact strength	ISO 179/1eA			
23 °C		40	54	kJ/m^2
-30 °C		10	15	kJ/m^2
Thermal Expansion Coefficient	ISO 11359	2.0	1,4	10^{-4} K^{-1}
Thermal Conductivity Coefficient	ASTM C177	0.40	0.24	W/(m.K)

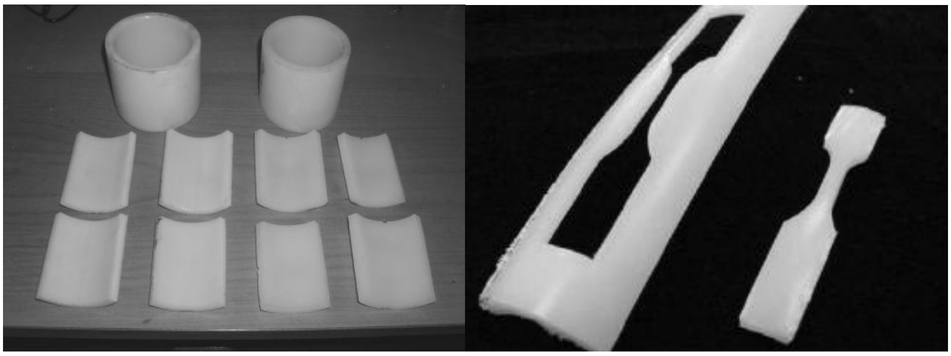

Figure 1 – All specimens were taken from extruded pipes

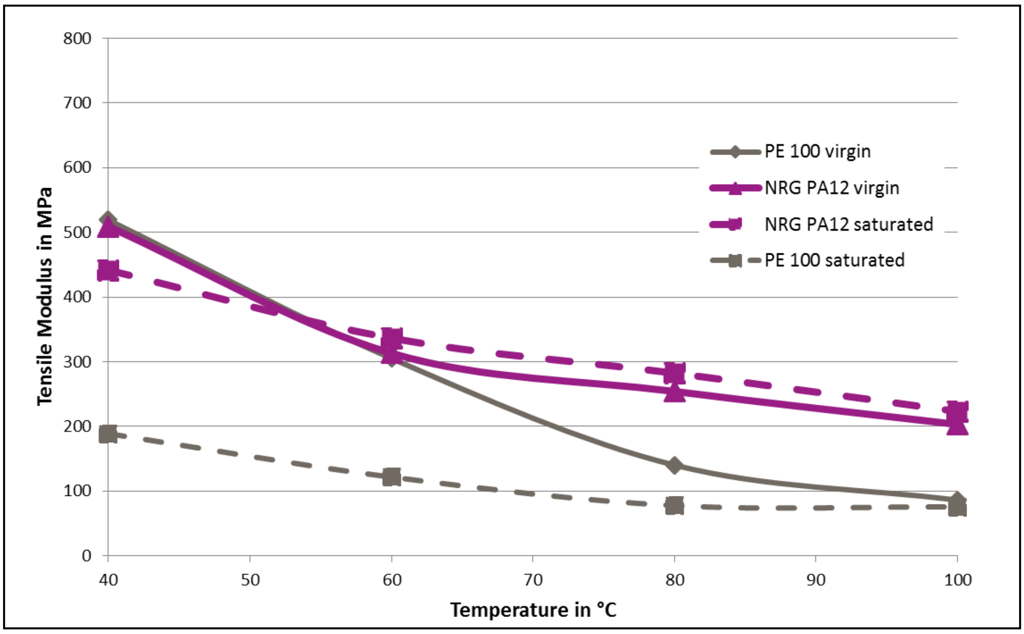

Figure 2 - Tensile modulus vs temperature for before and after saturation in diesel oil at 80°C

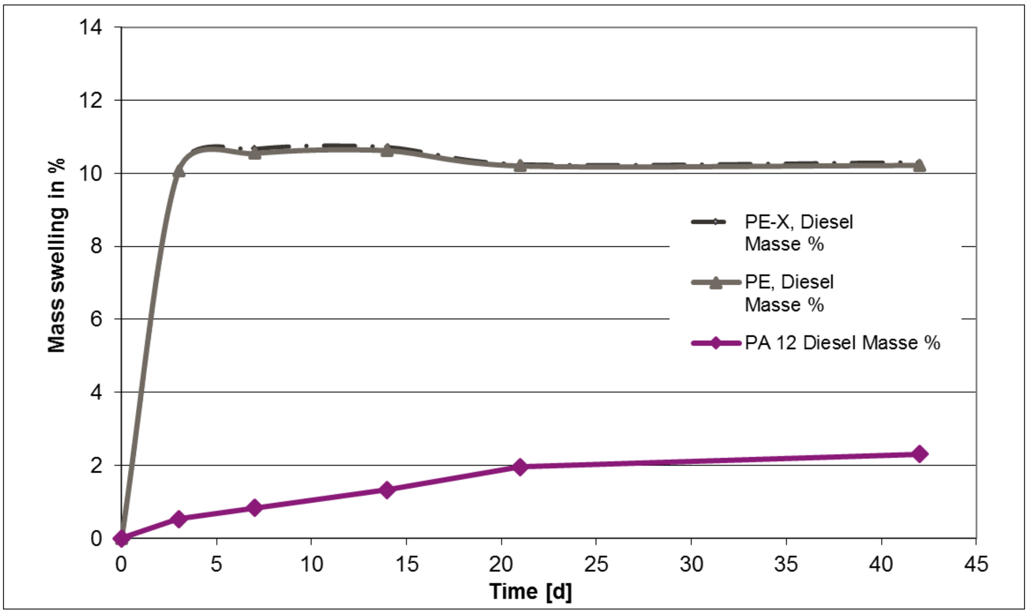

Figure 3 – PE 100 and PE-X show very similar weight change in hydrocarbons at 80°C while PA 12 material shows significant less mass change

Hydrolysis to be considered for PA´s application window

Polyamides are known for their sensitivity to hydrolysis at elevated temperatures. Therefore a method for lifetime prediction for multi-phase production has been developed and is established in the offshore industry to predict the lifetime of PA based unbonded flexible pipes. API 17TR2 describes such method. Depending on the application of PA the indicative property and its acceptance criterion needs to be defined. For unbonded flexible pipes those are 50% elongation at break and/or a corrected inherent viscosity (CIV) of 1,20 dl/g. The CIV is an indirect method to indicate the level of molecular degradation.

Liner in carbon steel pipes neither face dynamic forces nor high strains over the entire lifetime as unbonded flexible pipes might. Therefore its minimum mechanical performance to guarantee safe operation is different. Considering a maximum strain of 3% in operation the authors do propose to set the acceptance criterion to 8% elongation at break. This correlates to a safety factor of about 2.5. Based on this acceptance criterion a comprehensive lifetime study following API 17TR2 has been done and will be introduced in more detail in a separate paper. Figure 4 gives an overview of the application window of PA 12 based on the above compatibility study and the hydrolysis study made. It shows that PA 12 allows broadening the application window of liners in multi-phase production significantly over PE. In hydrous environment (existing water-cut, independent on the level of the water-cut) a PA 12 liner can operate at an operation temperature of about 80°C. In situations where no water is involved the application can be pushed to 100°C due to the good mechanical stability of the material.

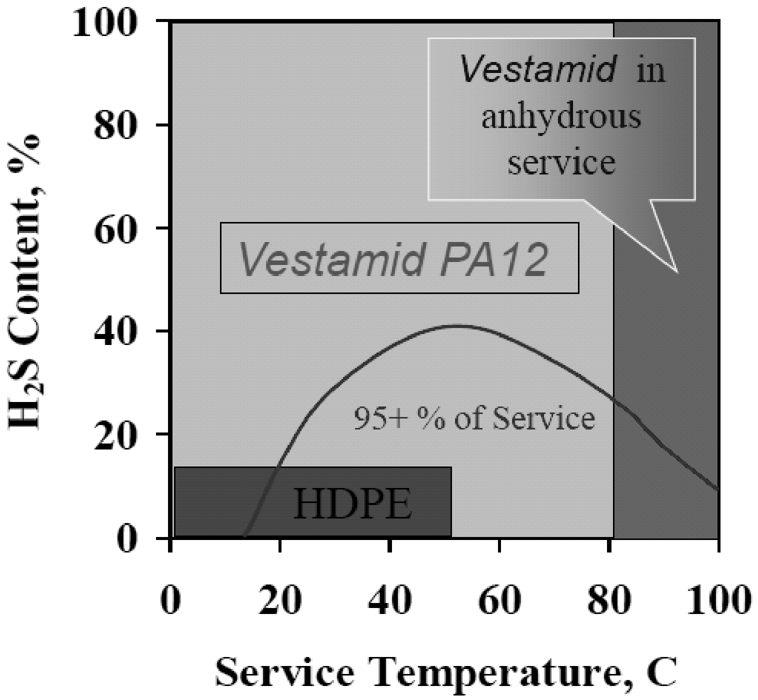

Figure 4: PA 12 liner can be applied at temperature up to 80°C in multi-phase operations. In addition PA12 is known for its inherent compatibility against H_2S (EN ISO 23936-1)

Cost benefit

The cost benefit of polymer lining technology has been confirmed as the subject of a report by Atkins Boreas (11) which demonstrates its competitive price when compared with increased corrosion allowance or corrosion resistant alloy alternatives. Although engineering polymers are more costly than polyethylene, carbon steel pipe lined with an engineering polymer remains cost competitive when compared with metallic alternatives as shown in Figure 5. The Figure 5 showed that a PA 12 lined carbon steel solution offers a material cost reduction of 50% and more depending on the clad or CRA solution. This plus the challenges on availability of clad and CRA pipes makes the polymer lined solution an interesting candidate for O&G field development. In the case of rehabilitation of matured carbon steel pipe it could be considered that the remaining lifetime expectations are much lower than 30 years.

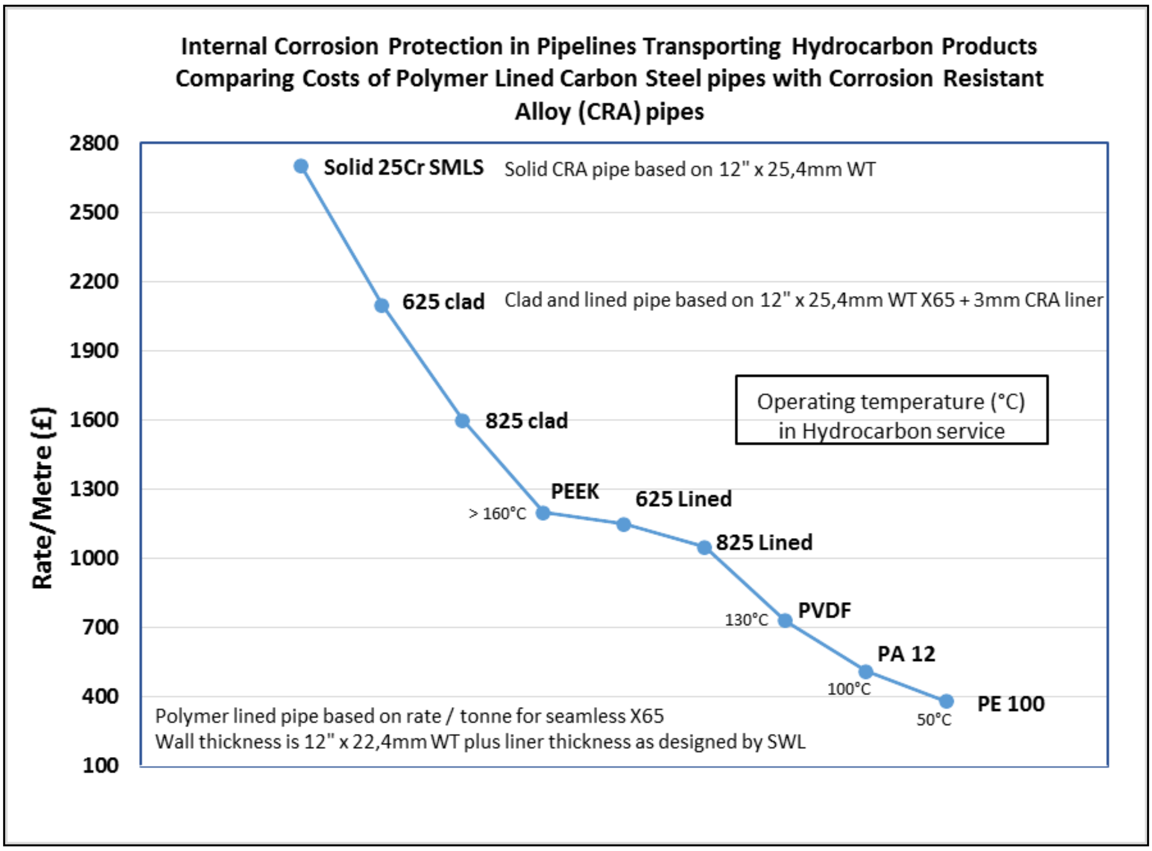

Figure 5: Polymer lining technology demonstrates its competitive price when compared with increased corrosion allowance or corrosion resistant alloy alternatives

Conclusion

The comparison of different liner material shows that PA 12 seems to be a good complement material to PE pushing the current limits of liners in O&G operation. The high mechanical strength and low swelling in hydrocarbons at temperatures above 55°C indicate that a liner design based on PA 12 for reliable and safe operation is possible. By combining PA 12 with existing strong track record in unbonded flexible pipes with the also well-established liner technology an extended application window for liners can be achieved. On the other hand the above introduced work indicates already that PE-X doesn´t show advantages over PE in hydrocarbon application. PE-X is established and looks back to an extensive track record if it comes to water applications. Unfortunately its PE based backbone dominates its limited compatibility in hydrocarbons and it seems that it doesn´t allow higher operational temperatures then PE 100 in hydrocarbons (5). Nevertheless additional work is ongoing to investigate the performance characteristics of PE-X further.
The significant cost advantage of PA 12 plus the above advantages over clad and CRA pipes makes the polymer lined solution an interesting candidate for O&G fields in onshore and offshore projects.

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