Materials & Inspection Engineering Group

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SUBJECT	: The feasibility of using trenched Polyethylene based re-inforced thermoplastic pipes for crude oil flowlines by SPDC in Nigeria	
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Summary

SPDC has to replace hundreds of kilometres of stolen flowlines used in crude oil service. For flowlines with a typical diameter of 3"-6", Re-inforced Thermoplastic Pipe (RTP) might offer an economically and technically attractive alternative to carbon steel. The materials used for RTP are inherent corrosion resistant. RTP is further light in weight, which facilitates transport and can be supplied in continuous lengths, which typically results in high installation rates.

A field pilot is planned in Nigeria in 2007 to understand the local challenges for implementation. The envisaged trenching in swamp areas, including a number of river crossings, is different from previous RTP applications within Shell that so far have been mainly surface laid.

SPDC contracted Shell Global Solutions for technical assistance on various issues related to the envisaged use of RTP. The issue discussed in this note is the permeability of RTP for (hydrocarbon) fluids.

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E&P HSE was consulted for advice on how the As Low As Reasonably Practicable (ALARP) HSE rule as given in the E&P HSE guideline has to be applied for the specific SPDC conditions.

E&P HSE stated that the use of material/equipment that will by design result in the pollution of soil and groundwater and surface water is not acceptable. Standard RTP is therefore unsuitable for the transport of hydrocarbons in buried systems and in aquatic environments. Fugitive emissions i.e. surface laid systems are to a certain extent acceptable but when practicable pre-cautions should be taken to limit these emissions as much as possible.

To quantify the issue, in order to define required precautions for a buried system, the crude oil emission of a Polyethylene based RTP as considered by SPDC was calculated using existing experimental data. The estimated Nigerian (Nkali) crude oil emission of a typical 4" RTP at 40 °C is approx. 30 kg per kilometre per year. Based on risk limits used in the Dutch environmental policy, it was confirmed that such a crude having a Benzene content of 0.12 % could seriously impair humans, plant and animal life after one year of operation. Benzene is one of the most hazardous components in crude oil.

This finding confirms that the buried application of RTP is not feasible for the envisaged application without further measures to prevent the emission. Suitable measures would be the use of metal permeation barriers or a venting system with controlled release.

1. Background

SPDC operates an extensive network of pipelines and flowlines. Two of the main concerns regarding the integrity of this network are corrosion and third party interference. Recently there has been a high rate of vandalisation of Carbon Steel (CS) flowlines in swamp areas of SPDC Western Division. Beginning of 2007, 501 km of CS flowlines have been stolen since production was halted on 18 February 2006. If operations were to resume today, approximately 130 Mbopd will be locked in as a result of stolen flowlines. SPDC Internal studies have shown that approx. 390 km of flowlines in the SPDC Western Division will require replacement upon re-entry into the fields. For flowlines with a typical diameter of 3"-6" Re-inforced Thermoplastic Pipes (RTP) might offer an economically and technically attractive alternative to CS. RTP are produced using polymers and synthetic fibres that are inherently corrosion resistant. RTP is further light in weight, which facilitates transport and can be supplied in continuous lengths, which typically results in high installation rates[i].

Based on RTP temperature and pressure limitations, it is possible to replace 161 km using RTP especially in Jones Creek & Odidi fields. A field pilot is planned in Nigeria in 2007 to understand the local challenges for implementation. The envisaged trenching in swamp areas, including a number of river crossings, is different from previous RTP applications within Shell that so far have been mainly surface laid. RTP pipe systems for use within Shell should comply with TECHNICAL SPECIFICATION SPOOLABLE FIBRE-REINFORCED PLASTIC PIPES, DEP 31.40.10.20-Gen. SPDC contracted Shell Global Solutions for technical assistance on various issues related to the envisaged use of RTP e.g. influence of hydrocarbons, installation and qualification according to the DEP[ii]. This note discusses the issue of the permeation of hydrocarbons through the RTP pipe wall and potential environmental issues arising from this permeation.

i Installation rates of surface laid RTP in PDO Oman reached 1km/day, Lekwhair Oman 2001.

ii See Contract number 115868 for further details.

2. Scope

The material that RTP is made of, High Density Polyethylene allows to a certain extent the permeation of hydrocarbons. If RTP is applied trenched, special precautions have to be taken to prevent the hydrocarbons to enter into the soil or (ground) water[iii]. To define the need for any special precautions to be taken by SPDC to limit or prevent emission of hydrocarbons into the environment following actions were taken:

- E&P HSE was consulted for advice on how the As Low As Reasonably Practicable (ALARP) HSE rule as given in the E&P HSE guideline has to be applied for the specific SPDC conditions.
- The crude oil emission of a Polyethylene based RTP as considered by SPDC was calculated, based on available permeation data. This result was used as input for the HSE assessment.

3 Theory

All polymeric materials permit to a larger or smaller extent the permeation of fluids. Permeation is the transmission of fluid (gas and liquid) right through the polymer. The transmission is driven by the surface concentration difference between the inside and the outside of the pipe. A clear distinction must here be made for liquids and gasses. For liquids the surface concentration is essentially **pressure independent** until very high pressures (typical several hundreds of bar) are reached. The amount of liquid permeating through a polymer pipe can be calculated using the following equation:

$$Q = P \cdot \frac{\pi \cdot d_i \cdot L \cdot t}{x} \qquad (1)$$

In which;

Q: quantity of permeating liquid [gr];

P: permeability coefficient [g mm / m^2 day];

di: inside diameter of the pipe [m];

L: length of the pipe [m];

t: duration [s];

x: wall thickness of the pipe [mm].

In the current RTP designs the reinforcement fibres (aramid) are not expected to have a significant influence on the permeation rates. This assumption is supported by literature [4]. For permeation calculations the sum of the liner thickness and the outer cover thickness is therefore used as the "effective" wall thickness of the pipe.

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iii Example. In 2001 the NAM (Netherlands) considered the trenched use of RTP for water, gas condensate (WaCo) transport. The condensate typically contains high concentrations of Benzene, Toluene and Xylene. Based on an HSE assessment the application of the standard RTP was not considered feasible for the envisaged application.

4. E&P HSE statements

Maarten Smies, Senior Environmental Adviser for E&P was consulted on the subject of hydrocarbon emission as a result of permeation[iv]. The conditions in Nigeria were recognised as specific with respect to the probability of finding the soil and water in the areas where the installation of the RTP is planned already contaminated because of leakage as a result of vandalisation etc. The existence of pollution should however never by used as an "excuse" to generate further pollution irrespective of how practically insignificant this additional pollution might appear in comparison.

- E&P HSE concluded that the use of material/equipment that will by design result in the pollution of soil and groundwater and surface water, is not acceptable.
- E&P HSE position is that RTP is unsuitable for the transport of hydrocarbons in buried systems and in aquatic environments.
- Surface laid RTP causing fugitive emissions are to a certain extent acceptable but when practicable pre-cautions should be taken to limit these emissions as much as possible. The emissions have to be reported in HSE performance reports.

5. Permeability coefficients of HDPE

The permeability coefficient of HDPE for crude oil had previously been determined as part of two HDPE lined pipe projects one for PDO Oman and one for SPDC Nigeria. Measurements were performed using a light crude from Oman (Yibal) and a light crude from Nigeria (Nkali). Yibal and Nkali crude are similar in composition and properties. Results obtained for both crudes were therefore used in the estimations. Details on the crudes are given in Table 1. Whether the Nkali crude is fully representative for the RTP application currently considered by SPDC needs to be verified. Variations in crude oil compositions have a direct effect on the permeability coefficients.

Membrane and immersion tests were used to determine the permeability coefficients. In the membrane test HDPE disk are used to cover aluminium cups filled with crude oil. The weight loss due to the permeation of the crude oil through the HDPE membrane is measured as a function of time. The experiment was performed at two different temperatures i.e. 38 °C and 60 °C. In Table 2 the Yibal crude oil permeability of HDPE is given as a function of temperature. The permeability coefficient at 23 °C and 50 °C were calculated assuming that the coefficient exhibits an Arrhenius type behaviour as indicated in general literature about this subject.

In the immersion test the weight change and rate of change of in crude oil immersed HDPE specimens are determined. From this data the permeation coefficient can be determined. These tests were done at different temperatures. Data is given in Table 2.

6. Results

The crude oil emission of a 4" and a 6" RTP were calculated using previous experimental data. The results are given in Tables 2 and 3. Temperatures of the produced oil in SPDC are approx. 40 °C. The estimates at 40 °C are therefore considered to give the best estimate for SPDC conditions.

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iv Meeting held in Rijswijk in May 2007 and captured in an E-mail date 31.05.2007.

7. Discussion of results

E&P HSE position is that RTP is unsuitable for the transport of hydrocarbons in buried systems and in aquatic environments without further measures. The estimated Nkali crude oil emission of a typical 4" RTP at 40 °C is approx. 30 kg per kilometre per year, which cannot be classified as practically insignificant. For the sole purpose to demonstrate that this level of emission could seriously impair humans, plant and animal life the following assessment has been performed. Note that Dutch law benzene level criteria were used in absence of Nigerian law criteria. Benzene was selected as it is one of the most hazardous components in crude oil.

The Dutch law defines environmental quality standards for soil and ground water based on scientific studies such as contained in the report "Environmental Risk Limits in The Netherlands"[v]. The target values (healthy soil) for benzene (as an example) in dry soil and ground water, as mentioned in this report are given in Table 4, as well as the values for the "intervention level" i.e. the concentration above which the risk of adverse effects (on human beings and ecosystems) is unacceptable. Intervention levels indicate when the functional properties of the soil for humans, plant and animal life, are seriously impaired or threatened. They are representative of the level of contamination above which there is a serious case of soil contamination and action must be taken to remediate the soil. The intervention levels should not been seen and certainly not be used as upper limits to which chemicals can be emitted into the soil or water without breaching the law.

Table 4 shows that the intervention level for Benzene pollution in the Netherlands is 1 mg/kg soil. To be legally considered as soil pollution at least 25 m^3 of soil should have this level on average. Knowing the specific weight of sand is 1400 kg/m^3 the maximum legally allowed amount of a polluting chemical in 25 m^3 can be calculated:

$$Q = V \cdot \rho \cdot \frac{conc_i}{1000} \tag{2}$$

Q: quantity of chemical [g]

V: Volume of soil [m^3]

ρ: Density of soil [kg/m^3]

$conc_i$: Intervention level [mg/kg]

For Benzene with a $conc_i$ of 1 this gives a quantity of:

$$Q = 25 \cdot 1400 \cdot \frac{1}{1000} = 35g$$

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v Environmental Risk Limits in The Netherlands [Risiconiveaus voor milieukwaliteit in Nederland] Bruijn J de, Crommentuijn T, Leeuwen K van, Plassche E van der, Sijm D, Weiden M van der 1999, RIVM Rapport 601640001. This report, produced by the National Institute of Public Health and the Environment (RIVM), documents risk limits, i.e. Maximum Permissible Concentrations (MPCs) and Negligible Concentrations (NCs) for approximately 200 substances in water, soil, sediment and air from the last decade in the framework of the project, 'Setting Integrated Environmental Quality Standards'. The objective was to present the procedures to derive the environmental risk limits to interested parties involved in environmental policy or environmental risk assessment of chemical substances. These risk limits are the non-regulatory standards used in the Dutch environmental policy. These environmental quality standards, their application and policy framework are described in the policy document: Setting Integrated Environmental Quality Standards: environmental standards for soil, water and air. (Ministry of VROM 97759/h/12-97).

This level would be exceeded by 1 km of RTP after one year of service at 40 °C having a Benzene content of 0.12 %. Typical Benzene content values for Nigerian crude are around 1 %, which means that this level would already be reached after a few months.

7.1 Feasibility of using standard HDPE based RTP for the envisaged application

The application of standard HDPE based RTP is not feasible for the envisaged application without further measures to prevent the emission into the environment. Suitable measures would be the use of permeation barriers or a venting system with controlled release.

7.1.1 Permeation barrier

Permeation barrier can be made from other polymers, having a lower permeability, or metal. Polymeric barriers will still have a certain level of permeability; while with metal barriers zero permeation can be obtained. Permeation barriers can be applied in the cross-section of polymer pipe at different locations:

(a) In the bore in direct contact with the transported fluids.

(b) Integrated in the pipe wall.

(c) On the outside of the pipe.

For pipe systems considered for the transport of non-abrasive fluids a barrier can be placed directly in the bore. Due to the direct contact with the transported fluids good chemical resistance (e.g. corrosion resistance for metals) is required. For reasons of protection against abrasion and the transported fluid, barriers are in most applications integrated in the pipe wall. In 2001, the use of an integrated metal foil was and still is seen as the most attractive option to resolve the permeation issue of RTP pipe. The development of such a barrier was therefore pursued by Shell Global Solutions sponsored by NAM and other operating units [1]. Resource constrains seriously hampered the development. Integrated metal permeation barrier are commercially available in Non-reinforced HDPE pipe systems such as the SLA system from EGAPLAS. The impermeability of this system has been proven up to 1780 mg/litre benzene in water (almost the maximum solubility of Benzene in water). The Dutch KIWA Institute carried out the verification of the diffusion resistance and has certified the system for use in the Netherlands. Within Shell the SLA system has been applied in Pernis and Moerdijk for drinking water lines in contaminated soil. This permeation barrier technology offers a good basis for a fast track development of a barrier for reinforced pipes. Commercial interests however seem to hamper a cooperation between the IP owners and the RTP manufacturers.

In 2005 an external permeation barrier based on a metal foil has been applied on a RTP for hydrocarbon service in Brunei (BSP). The foil was not bonded to the pipe. Such a system is only possible when the gas and vapour pressure build up between the pipe and the foil is less than 5 bar. For higher pressures venting would be required. Limiting factor is the tear strength of the foil and or the bonding strength of the foil overlaps.

7.1.2. Venting of the gasses and vapours

Venting of permeated gasses and vapour is quite common, many polymer pipe systems in petrol stations are based on this concept. Another typical example oil and gas industry example is the venting of the annular space of flexible pipes used offshore. Suppliers such as Wellstream and Technip claim that the permeated gases and vapour through the liner of their RTP pipes can effectively be transported along the reinforcement of their pipes and vented of at the joints. These claims will have to be validated since no validated performance test reports were provided.

Alternatively to transport along the reinforcement, fluids emitted through the RTP pipe wall can be collected in a separate carrier pipe. The annulus between RTP and carrier pipe can be vented either periodically of continuously. This technique is similar to the operation of thermoplastic lined pipes as used by Shell in Oman and Canada. To avoid again permeation of hydrocarbons through the external pipe wall in the environment, the external pipe is best equipped with an aluminium permeation barrier. To limit the cost of the carrier pipe the partial pressure of the gas inside the annulus should be low for example below 1 Bar.

Compared to an integrated barrier, venting will have an impact on CAPEX/OPEX. Continuous venting at a certain rate could require the installation of a blower. Depending on how much gas and vapour will permeate through RTP into the annulus, the air blown into annulus might at a certain point along the line, possibly form an explosive mixture. Having an explosive mixture should be avoided but when it forms then how to dispose it in a save way. Also the possible environmental impact needs to be assessed. Using Nitrogen is an option but most likely will result in high OPEX.

8. Conclusions

- The use of Polyethylene based re-inforced thermoplastic pipes for crude oil transport is based on environmental reasons not feasible without further measures.
- A system with an integrated aluminium permeation barrier would be an alternative but is currently not on the market. Several suppliers indicate to be able to prevent emission of the fluids into soil and or (ground) water by venting. These claims need to be validated and the operational impact assessed.

9. Reference

[1] OGEI/0005/04, 16 January 2004, Frans Janssen, Non-Metallic Pipe Systems, Permeation barriers for hydrocarbons and corrosive fluids, Potential cost reductions using RTP for WACO transport by the NAM.

[2] Shell U.K. Exploration and Production, ENGINEERING REFERENCE DOCUMENT,VENTILATION RATE BASED ON FUGITIVE EMISSIONS, Document Number: ES/292 Rev: 3.

[3] Performance Monitoring and Reporting, EP 95-0325, HSE MANUAL.
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[4] JOURNAL OF REINFORCED PLASTICS AND COMPOSITES, 1984 Vol. 3 Nr. 3 pp. 232 – 245.

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Table 1 *PI Gravity, Viscosity and Aniline point of Yibal and Nkali crude*

Crude	API Gravities	Viscosity	Aniline Point
	ASTM D1298		[°C]
Yibal crude	34.9	thin	68.3
Nkali crude	36.1	thin	67

Table 2 *Yibal and Nkali crude oil permeability coefficient of HDPE (density 0.955 gr/cm^3)*

Temperature °C	Permeability coefficient YIBAL **membrane** test Measured at 38 °C and 60 °C (S and P curve fitting) $\frac{gr \cdot mm}{m^2 \cdot day}$	Permeability coefficient YIBAL **ring** uptake Measured at 23 °C, 60 °C and 70 °C $\frac{gr \cdot mm}{m^2 \cdot day}$	Permeability coefficient NKALI **Strip** uptake Measured at 60 °C, 70 °C and 80 °C $\frac{gr \cdot mm}{m^2 \cdot day}$
23	0.2	1.5	0.8
38	1.7	5.4	3.2
50	6.9	13.8	9.0
60	21.0	28.0	20.1

Table 3
Calculated Yibal and Nkali Crude Oil emission
4" RTP dimension:
Inside diameter 88 mm
*Effective wall thickness 12.3 mm**
liner thickness plus protective cover thickness

Temperature °C	Yibal Crude oil emission Data Membrane test method $\frac{gr}{km \cdot day}$	Yibal Crude oil emission Data Membrane test method $\frac{kg}{km \cdot year}$	NKALI Crude oil emission Data strip test method $\frac{gr}{km \cdot day}$	NKALI Crude oil emission Data strip test method $\frac{kg}{km \cdot year}$
23	5	2	18	7
38	37	14	72	26
50	155	57	202	74
60	472	172	452	165

Table 4
Calculated Yibal Crude Oil emission
6" RTP dimension:
Inside diameter 142 mm
*Effective wall thickness 9 mm**
- *liner thickness plus protective cover thickness*

Temperature °C	Yibal Crude oil emission Data membrane test method $\frac{gr}{km \cdot day}$	Yibal Crude oil emission Data membrane test method $\frac{kg}{km \cdot year}$	NKALI Crude oil emission Data strip test method $\frac{gr}{km \cdot day}$	NKALI Crude oil emission Data strip test method $\frac{kg}{km \cdot year}$
23	12	4	40	14
38	82	30	159	58
50	343	125	446	163
60	1041	380	996	364

Table 5 *Target and Intervention levels for Benzene in dry soil and ground water*

	Target value [mg/kg dry soil]	Intervention level [mg/kg dry soil]
Benzene	0.01	1
	Target value (µg/l) Ground water	Intervention value (µg/l) Ground water
Benzene	0.2	30