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Mitigating Potential Risk of Paraffin Wax Deposition on Oil Pipelines in Niger Delta

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Abstract: Some physicochemical properties of 10 samples of crude oil from different well heads for laboratory analysis have been studied. ASTM-D97 Laboratory Method was used by preheating oil sample to 60-75°C then cooled at the rate of 0.15°C min^{-1}. The temperature of first occurrence of turbidity was taken as Wax Appearance Temperature (WAT) crude oil samples were found to be characterized with basic sediment and water ranges from 0.1-90% (BS and W), API gravity ranges from light crude (24.1@78°F) to heavy crude (39.8@79°F), viscosity (cst) at 40°F ranges from 18.42-25.20, wax content (wt.%) ranges from traces from 6-10% and composition of crude oil laboratory results proves that Nigerian crude have high content of paraffins in excess of 5%, high basic sediment which have high tendency to clog the internal pipe diameter. The knowledge provided in this study has direct application to paraffinic crude oils productivity enhancement in terms of costs reduction (cleaning and deposits removal) and oil production improvement. Correct selection of a prevention treatment will avoid extremely expensive and inefficient trial-and-error procedures. The strategy employed in this study was to use temperature and fluid characterization analysis of Niger Delta crude to predict the potential for wax related problems in Niger Delta oilfields as evident in the research.

Key words: Crude oil, wax deposition, pipelines, API gravity, viscosity, temperature, Niger Delta

INTRODUCTION

Wax precipitation and deposition is one of the common oilfield problems on land, offshore, deepwater offshore and internationally. Wax can be defined in a context as a long chain n-paraffin hydrocarbon which presents itself as a mix of paraffin crystals and oil. It varies in quantity with each crude oil composition. Wax appearance in the flow stream is not necessarily synonymous to simultaneous deposition occurrence. Heat flux from the liquid to the pipe and to the surrounding media is essential. Crystals slowly begin to adhere to the surface and the rate of this deposition is inversely proportional to the fluid velocity. Precipitated paraffin compound may move with the flow stream and increases its viscosity and friction. Deposition on a surface depends on the paraffin compound Wax Appearance Temperature (WAT), the temperature of the oil and of the surface, the flow stream mixture velocity and time. Time is an important ingredient in the control of wax deposits.

In 2009, total oil production in Nigeria was slightly >2.2 million bbl day^{-1}, making it the largest oil producer in Africa (Fig. 1). Crude oil production averaged 1.8 million bbl day^{-1} for the year. Recent offshore oil developments combined with the restart of some shut-in onshore production have boosted crude production to an average of 2.03 million bbl day^{-1} for the first quarter of 2010 and in 2011; the production rate is about 2.458 million bbl day^{-1} (http://www.indexmundi.com/nigeria/oil_production.html)

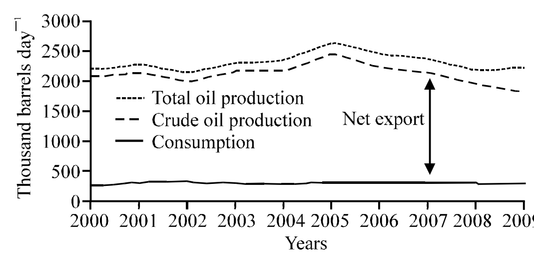

Fig. 1: Nigeria's oil production and consumption profile

When the crude oil is produced in offshore deepwater reservoirs the solubility of these hydrocarbons is sufficiently high to keep them fully dissolved in the mixture and the crude oil behaves as a Newtonian fluid (Singh *et al*., 2000). However, when the crude oil is being transported in pipelines under the sea environment where the temperature is lower than the cloud point the paraffin wax is precipitated due to heat loss to the surroundings (Lee, 2008) and serves to block and reduce the flow

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efficiency (Singh *et al*., 2000). Flow assurance is the term given to a study of the complex phenomena involved with transportation of produced fluids (Scott *et al*., 2004). The accumulation of wax in subsea pipelines is a special problem since the temperature is usually quite low. Ronningsen *et al*. (1991) stated that wax may range from normal alkanes from 20-40 carbon atoms to high proportion of high molecular weight iso-alkanes. According to Scott *et al*. (2004), waxes are a multitude of higher molecular weight paraffinic components mainly soluble in the liquid phase of black oils and condensates. As the fluid cools, each wax component becomes less soluble until the higher molecular weight components solidify. This onset of crystallization is known as the cloud point or wax appearance temperature. As the fluid cools further, even the lower molecular weight molecules also solidify adding to the solid fraction. In other words, the slow buildup of wax layers in pipelines and flow lines is caused by the solidification of the paraffinic fractions because of cold seabed temperatures. According to Banki *et al*. (2008), the deposition in production tubings and pipelines is undesirable because of the decrease in the flow rate and other operational complexities. Denney also stated that the deposition rate depends mainly on crude-oil characteristics, the heat flux through the pipeline and the shear stress at the wall.

The earlier the problem is diagnosed in the life of a reservoir (or well), the easier it will be to design a preventive or control management plan that will reduce or eliminate some of the technical and economic problems associated with wax deposition. Technical issues associated with wax deposition include: Permeability reduction and formation damage when it occurs around the wellbore and its vicinity, reduction in the interior diameter and eventual plugging of production strings and flow channels, changes in the reservoir fluid composition and fluid rheology due to phase separation as wax solid precipitates. Additional strain on pumping equipment owing to increased pressure drop along flow channel consequent to rheological changes as wax begins to crystallize. Limiting influence on the operating capacity of the entire production system.

The critical role of economics in crude oil production makes wax deposition a significant economic concern to the industry due to the following: Capital investment and operating costs are increased when developing paraffinic crude oil fields. This could cause serious financial strain on the operator of such a field or even lead to abandonment when it becomes uneconomical due to blockage of facilities by wax deposits. UK LASMO abandoned and decommissioned its platform in November, 1994 due to recurrence of wax blockage. The US Minerals Management Service published 51 severe wax related plugs reported in Gulf of Mexico flow lines between 1992 and 2002.

Lost production, risk element in development, a problem that could jeopardize the development of marginal fields given the prevailing economic situation. The additional cost of controlling and managing wax puts a greater risk of abandonment on such fields. Hence, control of wax deposition is essential. To address the issue of wax deposition, three important phenomena have to be considered: wax precipitation, dynamic wax deposition and heat transfer from the wellbore. Wax plug which is obtained from wax deposition is a gel that contains solid wax crystals and trapped liquid (Venkatesan and Creek, 2007). Wax precipitation is a thermodynamic phenomenon that will lead to deposition of solid wax crystals (Fig. 2).

There are numerous methods used to handle paraffin deposition. These can be divided into two categories: removal (mechanical, thermal, chemical) and prevention/predictive or inhibition (dispersants, crystal modifiers). Usage of an effective paraffin inhibitor has a potential for significant savings versus removal procedures. Since paraffin characteristics and contents vary drastically from reservoir to reservoir, production problems and solutions also vary. Methods that are effective in one system are not always successful in other reservoirs or even in various wells within the same reservoir (Allen and Roberts, 1993; Del Carmen, 2001).

The rheological behaviour of waxy oil is thus considered to have crucial importance in the design of pipeline, flow handling equipment and processing purposes. Similar to global trend of occurrence, Nigeria has a substantial reserve of paraffinic crude oils (Ajienka and Ikoku, 1990). Characteristically, waxy crude oils have undesirably high pour points and are difficult to handle where the flowing and ambient temperatures are about or less than the pour point. In Nigeria, pipelines have been known to have wax problems that were beyond recovery (Izombe-Ashland). Production tubings have also been known to wax up (Ebocha, Agip), necessitating

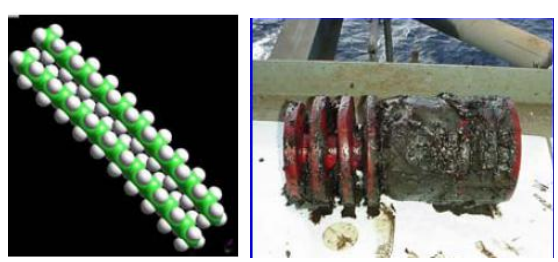

Fig. 2: Picture of wax model and the scraper coated with wax

frequent wax cutting which is quite expensive as reported in the literatures (Mgbonu, 1984; Ajienka and Ikoku, 1990; Adewusi, 1996).

The main goal of this research was to design an experimental methodology for potential risk of paraffin wax deposition on oil pipelines in Niger Delta and paraffin deposition control treatments, oriented toward the identification of tailor made preventive or remedial actions, adequate for the particular crude oil composition and physicochemical properties. This technique has direct application to paraffinic crude oils productivity enhancement in terms of costs reduction and oil production improvement, avoiding extremely expensive and inefficient trial-and-error procedures.

MATERIALS AND METHODS

Samples: About 10 paraffinic crude oil samples (Stock Tank Oil, STO) from Niger Delta reservoirs (reference oils) were used for this study.

Reference crude oils characterization

Physicochemical properties: Pour point, API gravity, viscosity wax content and sand content of the 10 reference crude oils were measured.

Crude oil physicochemical properties: Standard test method for API gravity of crude petroleum and petroleum products (Hydrometer Method) was used. Pour point measurements were made following the ASTM D 97 Method (values in °C). API gravity was determined following ASTM D298 Method (values in °API at 60°C). Details of the results are shown in Table 1.

Wax extraction procedure: Centrifuge the crude oil sample for about 5 min to get dry crude required for this test. Weigh out 10 g of dry crude into a beaker and add approximately 50-100 mL of iso-pentane or heptane. The weigh a Millipore filter paper that has been properly dried in an oven and dessicator. Stir the crude oil/iso-pentane mixture and filter through millipore filter apparatus. Filter paper weighs approximately 0.09 g. Collect wax on filter paper, dry on bench top and use very accurate balance to weigh the entire paper and wax deposit. Take this weight (minus weight of paper), divide by 10 and multiply by 100. This is percent heavy wax or heptane insoluble wax. Take fluid in the bottom of your suction flask and add acetone at 2-3 times the volume of i-pentane you initially added. Stir completely.

Transfer fluid and precipitated wax to a beaker. Chill in freezer for 15-30 min. Pre-weigh a centrifuge tube. Then centrifuge the entire fluid for 3-5 min. Carefully, pour off excess fluid, leaving wax in the bottom of the tube. Drain for a few minutes and then place in 120-140° water bath for 30 min to remove excess heptane. You can also let the tubes dry overnight. After dry (and the wax has re-solidified), you can weigh the tube. Subtract the weight of the pre-weighed tube and get the weight of the wax. Divide by 10 and multiply by 100 to get the weight percent of light wax. Use dry oil or it will be hard to filter. It will also throw your percentages off. Use a uniform method of drying for consistency (i.e., dry all of your tests in the water bath or all of them overnight).

Table 1: Crude oil physicochemical characteristics

Well name	Pour point (°F) (ASTM D97)	API gravity @ (°F)	Viscosity (cst)	Viscosity @ 40 (°F)
Well 1	70	37.5@78	18.42	4.65
Well 2	75	36.7@80	25.12	2.42
Well 3	70	35,8@78	22.49	7.84
Well 4	75	27.2@80	19.40	6.59
Well 5	64	27.3@78	26.14	5.62
Well 6	75	27.5@82	23.67	8.99
Well 7	72	24.1@78	23.48	7.84
Well 8	70	39.8@79	25.20	7.59
Well 9	63	29.0@82	20.10	9.04
Well 10	74	29.3@90	24.61	7.39

Well name	Wax content (wt.%) (cst) (@)100 (°F)	Sand cont. Ibs/'000 bbls	BS and W (%)
Well 1	10.00	Traces	0.05
Well 2	6.34	5	76.00
Well 3	9.30	1	78.00
Well 4	6.04	Traces	90.00
Well 5	7.34	Traces	0.40
Well 6	8.34	Traces	78.00
Well 7	9.45	1	70.00
Well 8	12.00	Traces	0.05
Well 9	5.67	Traces	90.00
Well 10	4.50	Traces	3.00

RESULTS AND DISCUSSION

Crude samples from different oil fields around Nigeria were analyzed in the study. The results of the analysis of physicochemical properties of crude oils are contained in Table 1. The data show that the values of density, specific gravity, viscosity of crude oils assayed increase from light to heavy crude oil. The API gravity of light crude oil is >30° while that of heavy crude oil is <30° (Odebunmi and Adeniyim, 2004). Working on the premises that a difference in their wax content, weight percentage (wt.%) amongst these various crude was responsible for the difference in viscosity behavior as temperature decreases. The higher wax content, the higher the Wax Appearance Temperature (WAT) of crude oil and the higher the cloud point of a crude oil thus the more potential for paraffin problems will be encountered in a well or oil field (Kelechukwu and Yassen, 2008). The viscosity behaviors of most of the crude were very

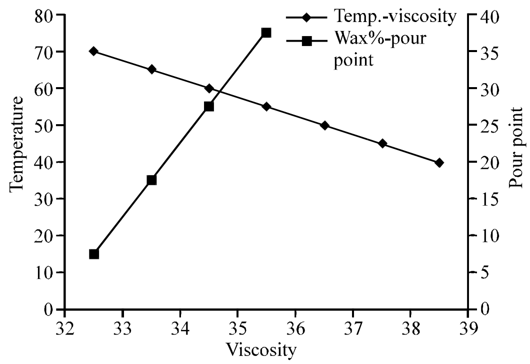

Fig. 3: Temperature-viscosity and wax% pour point plot for well 1

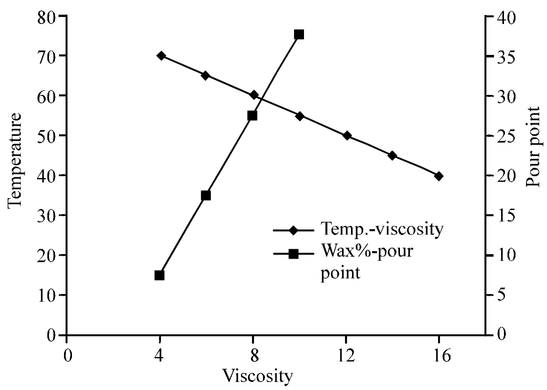

Fig. 4: Temperature-viscosity and wax% pour point plot for well 8

sensitive to temperature change. The increase in viscosity as the temperature decreases exhibited this study show a good agreement within p revious research done (Singh *et al*., 2001). It is evident that the crude differs in their rheological properties due to difference in wax content (Chen *et al*., 2006). From Fig. 3, it shows that Nigeria crude oil exhibits high pour point and high viscosity which indicate potential serious problem particularly in the case of production shutdown and operations. Figure 3 and 4 shows clearly that well 1 and 8 crude exhibits high pour points and high viscosity which indicates potentially serious problem particularly in the case of production.

CONCLUSION

The study provides thermodynamically adduced explanation for probably unfavorable characteristics of some Nigerian crude oil, an attempt to facilitate a better understanding between the crude properties and its behavior at ambient condition. From the oil field samples evaluated in this study, some of the crude oil properties may influence not only its behavior at ambient condition but may exhibit several non Newtonian behaviors, i.e., viscosity varying by several orders of magnitude of a given temperature which has propensity for potential wax problems during production and shutdown operation.

Conclusively, temperature and viscosity, the pour point of this oil is also influenced by the percentage of wax content in the crude which results in differences encountered during evaluation of the rheological behaviour and wax deposition tendencies of crudes.

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