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WAXY CRUDE OIL WELL SURVEILLANCE

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ABSTRACT

Generally, waxy crude oils are difficult to handle because of their high pour points compared to the ambient temperature. Waxy crude oils exhibit non-Newtonian flow behaviour at temperatures below the cloud point because of wax crystallization, which cause production problems. In order to manage waxy crude oils field profitably, a well surveillance process has been developed to enable field engineers to monitor and troubleshoot well problems and recommend timely remedial actions such as wax cutting, solvent soaking and injection of wax inhibitors. The surveillance process includes problem diagnostic charts developed through modeling the temperature profile. With these, the point of deposition in the production tubing can be predicted as well as the critical rate below which severe deposition will take place. Case studies on the application of the process are presented

Keywords: Diagnostic plots, pour-point, Wax appearance temperature, Well surveillance, Waxy crude oil, Wax deposition.

INTRODUCTION

Waxy crude oils are crude oils that precipitate hydrocarbon deposits. There are basically two types of such deposits: paraffins and asphaltenes. Generally, these crude oils are difficult-to-handle because of their high pour points compared to the ambient temperature. They exhibit non-Newtonian flow behaviour at temperatures below the cloud point because of wax crystallization. On further cooling and successive crystallization, gelling occurs at the critical pour point. The pour point is the temperature below which the oil ceases to flow (pour). The pour point is usually about 10 - 20^{o}F lower than the cloud point (Wax Appearance Temperature), which is the temperature at which paraffin particles begin to precipitate out of solution. However, darker crude oils may mask the cloud. In this case, the cloud point is estimated from measurements or observation of the inflection point on a cooling curve. Depending on the flow regime, wax deposition begins on any surface (called cold spot) where temperature is below the critical cloud point and that of the bulk oil.

Of the two kinds of organic deposits, paraffin deposition is the most widespread and more easily handled, whereas asphaltene deposition is much more difficult to treat because of the complex depositional relationship between the crude oil composition, pressure, and temperature (Benallal et al, 2008, Hirchberg et al, 1984). Asphaltenes are insoluble in distillates such as kerosene and diesel oil, and other low molecular weight hydrocarbons such as propane and butane. They are soluble in aromatic solvents such as benzene, toluene and xylene and have some solubility in common solvents, such as carbon tetrachloride and carbon disulfide. Asphaltenes melt slowly, gradually softening to a thick viscous liquid. They burn with a smoky flame, leaving a thin ash or carbonaceous ball. In this work, a surveillance procedure is developed that help operators effectively monitor deposition to prevent unexpected downtime in production operations.

LITERATURE REVIEW

Allen and Roberts (1993) observed that paraffin and asphaltene deposits might resemble each other after a few days. However, paraffins melt over a narrow temperature range, and the hot liquid has a low viscosity. They burn rapidly with less smoke and leave little residue while asphaltenes melt slowly, gradually softening to a thick viscous liquid. They burn with a smoky flame, leaving a thin ash or carbonaceous ball.

In order to prevent complete or partial loss of pipelines due to wax deposition, several works has been carried out by various researchers to ensure the flow of waxy crude oil in pipelines. Pannu and Sariman (2013) studied the thixotropic behaviour of a waxy crude oil from the Malay basin and also explored the effects of temperature. From their study, it was inferred that the extent of thixotropy increases with the reduction in temperature below the Wax Appearance Temperature of the crude oil. Luthi (2013) characterized waxy crude oils and as well conducted an experimental study of the restart of a line blocked with gelled waxy crude and it was shown that the restart of waxy crude flowlines has close connection with the complex rheological properties of gelled crudes and startup pressure propagation. Wax deposition characteristics were also studied by Dwivedi and Sarica (2012), where it was discovered experimentally that paraffin deposition is highly dependent on the thermal effective driving force which is the temperature difference between oil bulk and initial inner pipe wall and also on turbulence effects.

The problem of waxy crude oils can vary from very minor to extremely severe and can affect both the production history and economics of production operations. The severity of the problem may worsen with the age of the field. Progressive deposition and accumulation of paraffin wax at the sand face and perforations, production tubing, surface flowlines and storage vessels can limit the production capacity of a well. Deposition leads to loss of production, increase in downtime and locked-in potential due to waxed up tubing in some wells. It also leads to increase in operating expenses and minimization of profitability.

Mechanical means of handling, for instance, wax cutting, can lead to wear and tear of production tubing and other problems. The most severe problems are gelling and start-up pressure requirements after shut down, as well as blockage of pore space. These problems are more severe offshore where it is difficult to pressurize the system at intermediate points, thus leading to loss of flowlines and abandonment of wells. Apart from these problems, waxy crude oils are desirable because of their low sulphur content and lightness (generally >30 API).

Similar to global trend of occurrence, the most prevalent of the types of depositional problems in Nigeria is paraffin deposition. It is a problem in almost all the producing companies. In Nigeria, pipelines have been known to wax up beyond recovery. Production tubings have also been known to wax up, necessitating frequent wax cutting, which is expensive.

There are many fields in the Niger Delta producing high pour point crude oils. Some of these crude oils have pour points greater than 77^{o}F, the average ambient temperature. Thus wax deposition takes place in the production tubing. These fields are located onshore, swamp and offshore environments. The most common method of handling the situation is by wax cutting, using mechanical scrapper and solvent stimulation. The frequency of wax cutting depends on the pour point and severity of the problem.

There are basically two methods of handling waxy crude oils, removal and preventive methods. Removal methods allow some deposition to take place before removal. These include mechanical, thermal, chemical control techniques and a combination of the three. While the preventive methods retard wax deposition and improve pumpability. They work best when chemicals are injected about the cloud-point and when well is flowing (Price, 1971). Preventive methods are economical because they minimize downtime and downhole problems. These methods include chemical methods, use of emulsion, heat treatment and production/completion techniques.

The objectives of this study are to develop waxy crude oil diagnostic charts with which the depth at which wax deposition is expected in the production tubing can be predicted. This will help in completion design of new wells in the reservoir. The diagnostic charts are also useful in estimating the critical rate region below which wax deposition is expected to take place. Finally, the study is aimed at developing a surveillance flowchart to improve on the methods of monitoring and handling waxy crude oil wells and to optimize productivity.

CAUSES OF DEPOSITION

The primary cause of wax deposition is reduced solubility due to changes in the equilibrium condition of the solution as a result of temperature reduction. Allen and Roberts [3] also reported that paraffin could precipitate from crude oil when equilibrium conditions change slightly, causing a loss of solubility of the paraffin in the crude. Points of deposition are nucleating materials such as formation fines and corrosion products.

Holder and Winkler (1965), established that just 2% waxes in a hydrocarbon stream can give rise to a high pour point. Tuttle (1983) confirmed this. Loss of gas and light hydrocarbons from crude oil and drop in pressure can also decrease paraffin solubility. Reistle (1927) reported that the presence of water also enhances wax precipitation. Newberry et al (1986) reported that the total dissolved solid (TDS) of produced water in the range of 1000,000 to 400,000 ppm aggravated paraffin problems in the North Michigan Niagara field. Allen and Roberts (1993) also reported that water-oil ratio has some effect on paraffin deposition. Other causes of precipitation particularly at the wellbore and pore spaces are the alternate wetting and drying of sand surfaces in pumping wells in which expanding gases tend to chill the sand face. Causes of deposition have also been investigated (Bilderback and McDougall 1969; Jeffries- Harris and Coppel, 1969; Barker, 1987).

MECHANISM OF DEPOSITION

The severity of paraffin deposition depends predominantly on the composition (wax content) of the crude oil, the cloud and pour points. It also depends on the rate of evolution of gas, well depth, formation temperature, the ambient and operating temperatures, pressure drop, previous shear history, pipe roughness and production practices (Reistle, 1927, Brewster, 1927, Perkins 1971). Hunt (1962) reported that the mechanism of paraffin deposition involves direct precipitation of paraffin wax on or adjacent to the pipe wall and growth of the deposit by diffusion of paraffin molecules from solution. Burger et al (1981) reported the most detailed study on the mechanism of paraffin deposition. On the mechanism of asphaltene deposition, Hirschberg et al (1984) reported that this was due to the flocculation of the colloidal particles in a complex relationship of temperature, pressure, and composition.

METHODS OF DETECTING DEPOSITION

Apart from the knowledge of the pour point and the wax content, an indicator to watch on the onset of paraffin deposition is accumulation of paraffin deposits in stock tanks. This is an indication that paraffin deposition may be expected soon in the flowline, tubing and possibly later in the wellbore (Allen and Roberts, 1993).

Other field methods of detecting wax deposition are:

i. Visual analysis of produced crude oils and wireline equipment to detect the type of deposit. Knowledge of the type of crude oil can be helpful. Jeffries-Harris and Coppel (1969) used this approach to confirm asphaltene deposition in the wellbore.
ii. Unusual drop both in wellhead pressure and temperature.
iii. Unusual drop in production rate and unexpected quit in production.

Experience in the handling of waxy crude oils has shown that there is no alternative to experimental study with the actual crude oil to predict if wax deposition will take place and the feasibility of chemical injection. This fact is illustrated in Table 1.

Table 1: Comparison of Three Waxy Crude Oils (Sifferman, 1979)

Sample Crude Oil	**API Gravity**	**Pour Point**		**Average Carbon Number**	**Observations**
		(°F)	**(°C)**		
Amna	36	75	24	21.6	Unloading problems in the tanker at the North Sea temperature of 45°F.
Dickinson	34	95	35	18.5	Flows at room temperature of about 70°F.
Udang	40	100	38	20	Solid at room temperature of about 70°F.

Note: No correlation between API gravity and pour point. Pour point is not a sole indicator of a crude oil's flow properties (Sifferman, 1979). Viscosity, gel strength and pour point are better used to characterize a crude oil's rheology.

EVALUATION OF METHODS OF HANDLING WAXY CRUDE

There has been no universally successful treatment of wax. Each method has been applied with limited success. The handling of waxy crude is an individual field problem. The composition and texture of the deposit, the point of deposition in the flow system, the type of problem such as start-up or gelling and the operational and environmental conditions dictate the type of handling methods.

There are basically two types of methods of handling waxy crude oils: removal methods and preventive methods. While the preventive methods prevent wax precipitation and thus prevent downtime but increase production cost, the removal methods result in production downtime and also increase production cost.

Uhde and Kopp (1971) observed that the ideal method to handle waxy crude would be to change the non-Newtonian flow behaviour to Newtonian flow with minimum expenditure and minimum disturbance of production operations without undesirable side-effects and a resultant reduction in operational risks.

Removal methods

Removal methods are methods in which paraffin wax is allowed to build up for periodic removal. The frequency of removal depends on the severity of the problem. These methods include:

i. Mechanical methods of wireline wax cutting and pigging. Wireline wax cutting is commonly used in Shell Petroleum Development Company (SPDC). Pig traps are recommended on flowlines likely to handle waxy crude oils. Wax cutting leads to production downtime. On the long run, frequent wax cutting can be very expensive. It is difficult to achieve complete clearing of the tubing and wireline failures are common.
ii. Thermal Methods. These involve heat tracing of pipeline, hot oiling and tubing-tubing connection of high temperature non-waxy crude oil well with waxy crude oil well (Uhde and Kopp, 1971). The limitations include cost of energy, impracticability of heating in hostile environments, and possibility of formation damage due to re-precipitation of wax in low temperature formation (Baker, 1987).
iii. Chemical Methods. These involve the use of organic solvents to dissolve wax deposit and diluents to reduce the concentration of wax. A major handicap of these methods is the volume and thus cost of chemicals.
iv. Combination Methods: These involve combinations of the above methods.

Preventive methods

These methods are based on the maxim that "prevention is better than cure" if it is cheaper. Preventive methods inhibit or retard wax deposition and improve pumpability. They work best when chemicals are injected about the cloud point (Price, 1971) and when well is flowing. Preventive methods are economical because they minimize downtime and downhole problems. Preventive methods include:

i. Chemical methods where wax crystal modifiers, paraffin dispersants or pour point depressants are injected to modify the crystal structure or co-crystallise with the wax crystals or depress the pour point to a manageable level. The most suitable chemical is selected based on its cost-effectiveness in terms of optimum dosage and unit cost of chemical.
ii. Use of Emulsion. Inducing oil-in-water emulsion has been reported to improve the pumpability of waxy crude oils (Sifferman, 1971; Marsden and Raghavan, 1978). This may probably be the reason why waxy crude oil fields are able to produce with minimum problem as water cut increases (provided the total dissolved solids of formation water are low). The problems with these methods are the stability of the emulsion and the additional cost of handling and separating the emulsion.
iii. Heat Treatment: Heating a waxy crude oil flowline above the cloud point can prevent wax deposition. The disadvantages are as indicated in thermal methods of removal above.
iv. Production/Completion Techniques: These include the use of plastic or coated pipes, application of back pressures, minimizing pressure drawdown and use of improved handling facilities.

Figure 1 summarizes the handling methods. All these methods have their own limited capabilities. The choice of any method of treatment depends on the severity of the problem, operational environment, the location in the flow system where deposition takes place and of course, the workover economics.

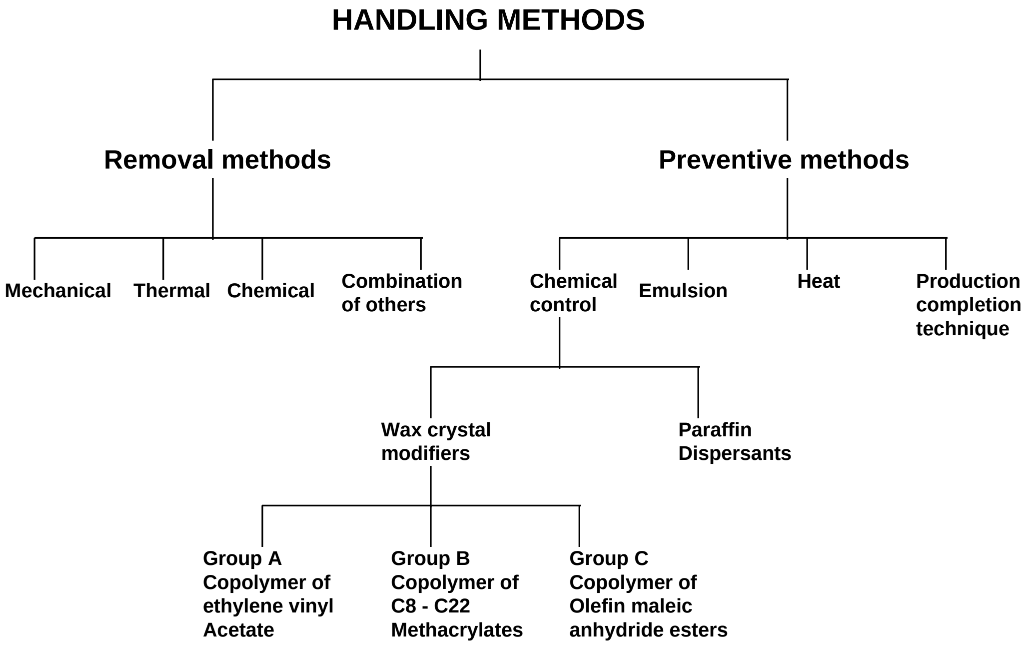

Figure 1: Methods of Handling Waxy Crude Oils

Fulford and Richard (1975) reported that paraffin deposition in oil fields is an expensive and time-consuming problem. It was estimated in 1969 that paraffin control in the USA production industry costs in excess of five million US dollars annually. These are direct costs and do not include production losses, increased horsepower requirements, damage or increased wear to equipment, and manpower attention. Ajienka and Ikoku (1991) conducted a comparative economic evaluation of methods of handling waxy crude oils. Mechanical wax cutting technique was compared to chemical treatment with pour point depressant. A sensitivity study on the various cost elements was conducted to identify the critical parameters, which affect profitability.

WAXY CRUDE OIL WELL SURVEILLANCE

Well surveillance is the process of monitoring production trends of wells periodically to identify economic opportunities by unlocking well potentials and troubleshoot well problems and recommend remedial actions such as bean down, acid/solvent stimulation, repair, sand control, etc.

Allen and Roberts, (1993) defined surveillance as the monitoring of assets to optimally recover the oil and gas reserves in a timely fashion through safe and profitable operations. Surveillance is a team effort of management, operations, engineering, geologic and service companies.

The surveillance process comprises of the following:

(i) Problem Definition (ii) Diagnosis and Checks (iii) Remedial Action/ Treatment and (iv) Post Treatment Evaluation.

A summary of the surveillance process modeling is shown in Figure 2.

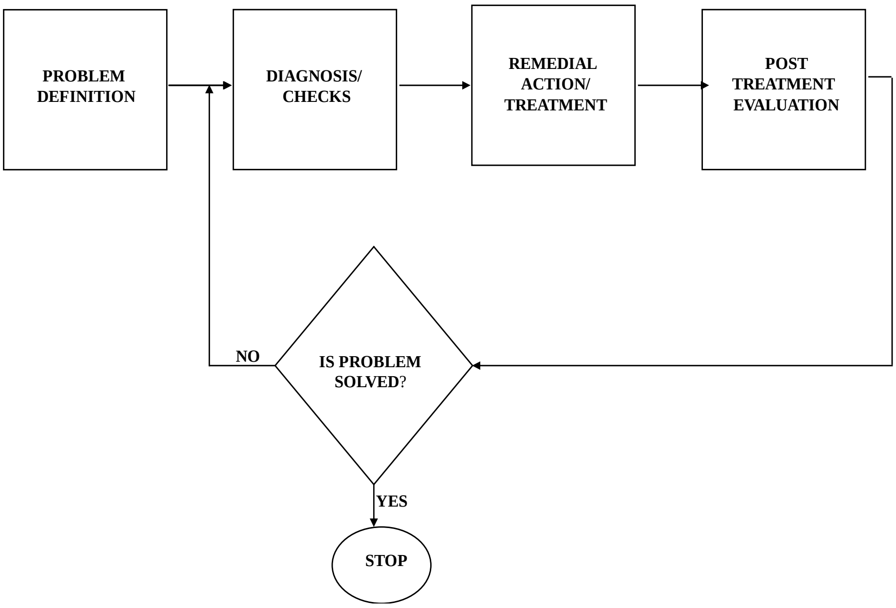

Figure 2: Surveillance Process Modeling

Problem definition: This involves certain observations in production test data of waxy crude oil wells, such as sudden decrease in rate, wellhead temperature and pressure and increase in GOR.

Diagnosis: The process involves:

i. Keeping records of all waxy crude oil wells such as cloud/pour point, yield value, wax content of crude, Total Dissolved Solid (TDS) of produced water, chemical composition (paraffin or asphaltenes) tubing size etc.
ii. Elimination of other possible causes of well problem by comparison with offset wells, examining well performance history etc.
iii. Development of waxy crude oil diagnostic plots, e.g
    a. Depth versus flowing/static temperature profiles. Flowing temperature at various expected flow rates. Determination of critical region for wax deposition
    b. Wellhead temperature versus objective flow rate plots. Determination of critical production rate below which wax deposition is expected
iv. Carrying out temperature survey and calibration of diagnostic plots. Prediction of critical rate and time for treatment based on performance history.
v. Check the following: GOR history, critical rate, well head temperature (WHT), wellhead pressure (WHP) and observed sudden changes, current water-cut and TDS.

These are summarized in Surveillance Spreadsheet provided in the appendix

Remedial action /treatment: This involves: a) Preventive methods: b) Remedial methods: Wax cutting, solvent soaking, wax inhibitor injection (if injection materials are available). Choice of method is based on economics and technical feasibility.

Post treatment evaluation: Check flow rate, wellhead temperature, well head pressure, GOR.

WAXY CRUDE OIL DIAGNOSTIC PLOTS

These plots are basically used in the prediction of depth and critical rate at which wax is expected to deposit on the production tubing as a function of flowing/static temperatures and wellhead temperature respectively. The predicted results are compared with actual measurements.

Simulation: In order to derive diagnostic plots, actual temperature survey data at different depths should be used in the calibration of the software e.g. TEMPEST. From the results of the simulation, the diagnostic plots: Depth versus Temperature and Wellhead Temperature versus Flowrate are generated.

Prediction: Based on the diagnostic plots, the critical depth and rate at which wax is expected to deposit in the tubing can be established.

Waxy Crude Oil Surveillance Flowchart: This is a summary of the process involved in screening and identifying waxy crude oil wells, possible causes of wax deposition and the recommended remedial action. Appendix 1 gives the surveillance spreadsheet containing vital components of production that should be looked out for when monitoring wax deposition.

CASE STUDIES

Waxy crude oil well surveillance was conducted for two fields in the Niger Delta. The basic assumptions in the estimation of flowing tubing head temperatures were:

i. Ambient temperature of 77 ^{o}F
ii. Hole sizes, deviations and casing strings as per actual wells suspended.
iii. Constant bottom hole temperature over time.
iv. Range of wellhead pressures and rates from well production potentials

Based on the output data generated from the software, TEMPEST, diagnostic plots were made using the EXCEL software, The pour point for the crude A was estimated to be within the range of 65 -70 ^{o}F. The cloud point was generally difficult to estimate. However, it was estimated to be some 10 - 25 oF above the pour point. Fig. 3 shows the critical depth region for wax deposition in the tubing to be 500 - 800 ft. This depth range corresponds with the various depths from which wax cutting operations were reported in all the wells investigated. Figure 4 shows the plot of wellhead temperature versus production rate. Using the field cloud point range, the critical rate region for wax deposition has been estimated as 700 - 1700 stb/d. Wells producing below the critical region would almost certainly be expected to deposit wax.

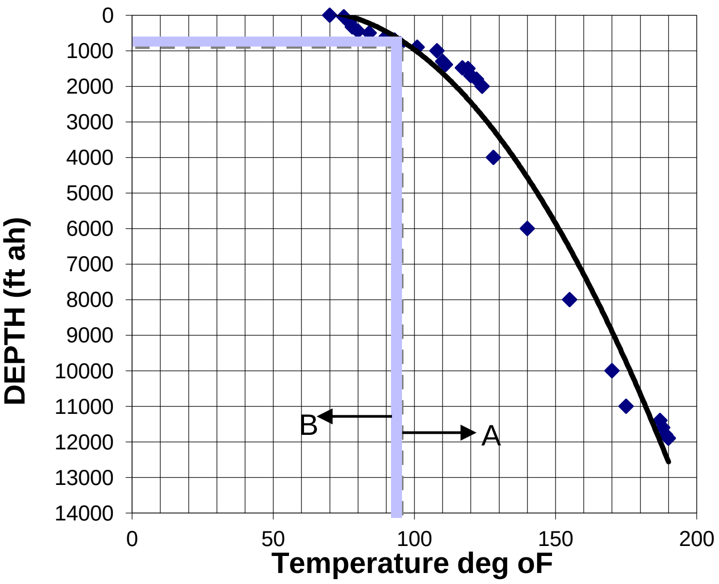

Figure 3: Waxy Crude Oil Diagnostic Chart (Depth vs Flowing Temperature)

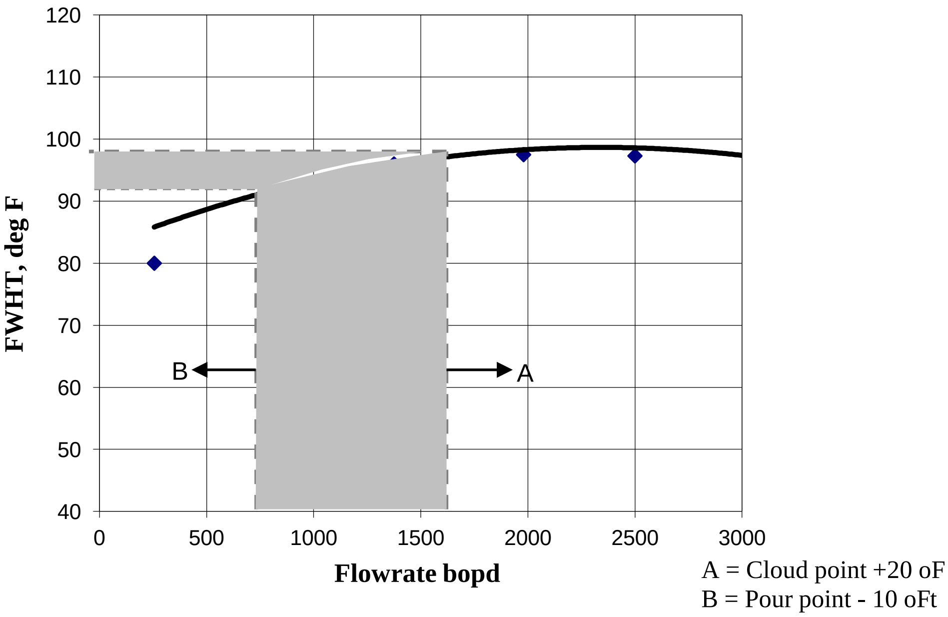

Figure 4: Waxy Crude Oil Diagnostic Chart (Wellhead Temperature vs. Flowrate)

Table 2 summarizes the results of the case studies. On the Effect of Tubing Size, a relationship between the severity of wax cutting and tubing size was observed (Ajienka 1993). The severity ranges are as shown below:

Tubing Size (inches)	**Severity Range**
23/8	Fortnightly - Quarterly
27/8	Monthly - Quarterly
31/2	Quarterly - Semi-annually

Table 2: Parameters of wax cutting in Fields A and B of Niger Delta

Well	Reservoir	Tubing Size(in)	Rate (Stb/d)	GOR (Scf/stb)	BSW (%)	WHP (psig)	Wax Cut Depth Range (ft)	Remarks
A-12	M1000X	2-7/8 3-1/2	439	2000	0	1000	35 - 385	Rate critical region.
A-22	M1000X	3 -1/2	1732	1640	27	1378	10 -1500	Rate within critical region
A-25	M1000X	2-3/8 3 -1/2	1406	1393	0.1 (traces)	1465	6 - 2000	Rate within critical region.
B-04	M2000X	2 -3/8	539	1465	81	240	10 - 1600	Rate below critical region
B-12	D2000B	2 -3/8	1213	400	41	1000	25 - 2500	Rate within critical region
B-39	C3000N	2 -3/8	925	303	3	126	50 - 1300	Rate within critical region

The inference to be drawn from this is that since wax deposition decreases the internal diameter of the production tubing, it is better to use larger diameter production tubing as long as the tubing capacity can handle the well potential. On the prediction of maximum permissible downtime to avoid gelling of flowlines, restartability after shutdown is a major problem in waxy crude oil handling. To restart a flowline that has developed a gelling structure, two conditions must be satisfied:

i. There must be enough available pump pressure to apply a shear stress to initiate flow. This limiting shear stress is known as the static yield value of the crude oil. Care must be taken to ensure that this static yield stress does not exceed the burst pressure of the pipe.

ii. When the oil has yielded, the shearing stress must rapidly breakdown the gelled structure in a reasonable time to give lower viscosities and hence increased flowrates. Several studies have been conducted on the effect of flow interruption on the pumpability of waxy crude oils (Economides and Chaney, 1983).

The transport properties of crude oil should be used to predict the acceptable downtime to prevent complete gelling in the flowlines (Ajienka and Ikoku, 1990). Estimates for a 90 ^{o}F pour point crude in the Niger Delta predicted that the maximum permissible downtimes for the 6" flowline and 4" test line are about 5 and 6 hours respectively. Therefore, the need for injection of pour point depressants into the flowlines particularly at downtimes to ensure restartability cannot be over-emphasized.

CONCLUSIONS

i. Prediction of flowing and static temperature profiles in the production tubing is necessary for effective well surveillance. Every waxy crude oil well should have such diagnostic plots. From these, the critical depth for wax deposition should be predicted. Confirm that this depth range corresponds to the various depths from which wax cutting operations were reported in the wells investigated.
ii. Prediction of the cloud point and the critical rate region for wax deposition are necessary. Wells producing below the critical rate region would almost certainly be expected to cut wax.
iii. Waxy crude oil surveillance flowcharts are developed with which waxy crude oil wells can be monitored effectively and production optimized.
iv. A waxy crude oil surveillance spreadsheet is developed to facilitate updating records of waxy crude oil wells and to prepare monthly surveillance reports promptly.

RECOMMENDATIONS

The following recommendations are made:
i. Wax cutting sequence should be strictly followed to prevent tubing blockage. Thus avoiding loss of production, high production downtime and minimization of profitability.
ii. Waxy crude oil intervals should be sampled and analyzed monthly to obtain certain parameters, such as TDS of water-cut, wax content etc.
iii. Carry out temperature (flowing and static) surveys as a function depth every six months.
iv. There should be proper updates of wax cutting depths.
v. Sensitivity on temperature gradient should be carried out using software in order to confirm the actual temperature measurements as well as the depth of wax deposition.
vi. A detailed economic evaluation of methods of handling waxy crude oils is imperative in order to optimize oil production and revenue, maximize profits and obtain a good return on investment.
vii. Elaborate tests should be performed at the discovery of a field to advise on special well completion practices and subsequently to serve as a means of predicting severity of wax deposition.

NOMENCLATURE

TDS = Total Dissolved Solids, ppm
GOR = Gas Oil Ratio, scf/stb
Rsi = Solution GOR, scf/stb
BS&W= Basic Sediments and Water, %
WHT = Well Head Temperature, ^{o}F
WHP = Well Head Pressure, psi

TEMPEST= Software for modeling temperature profiles in wells
Tc = Cloud Point, ^{o}F
Tp = Pour Point, ^{o}F

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Appendix 1: Surveillance Spreadsheet

Well	Res.	Tubing size inches	Well potential stb/d	Current Rate Stb/d	Crit. Rate Stb/d	GOR/ Rsi	Tc °F	Tp °F	WHT °F	WHP psi	BS&W %	TDS ppm	Wax cont %	Crit. Depth ftah	Any temp survey	Handling Method/ Frequency