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Crude Oil Transportation:
Nigerian Niger Delta Waxy Crude

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1. Introduction

Crude oil is one actively traded commodity globally. Its demand has been growing steadily over the decades, from 60 million barrels per day to 84 million barrels per day (Hasan et al , 2010). In Nigeria, crude oil production has grown from a little above 1000 barrels per day in 1970 to over 3000 barrels per day in 2010 (Fig. 1.1). The world production was conservatively 73 million barrels per day in the year 2005 and within the range of 72 and 75 million barrel per day between 2005 and 2010.
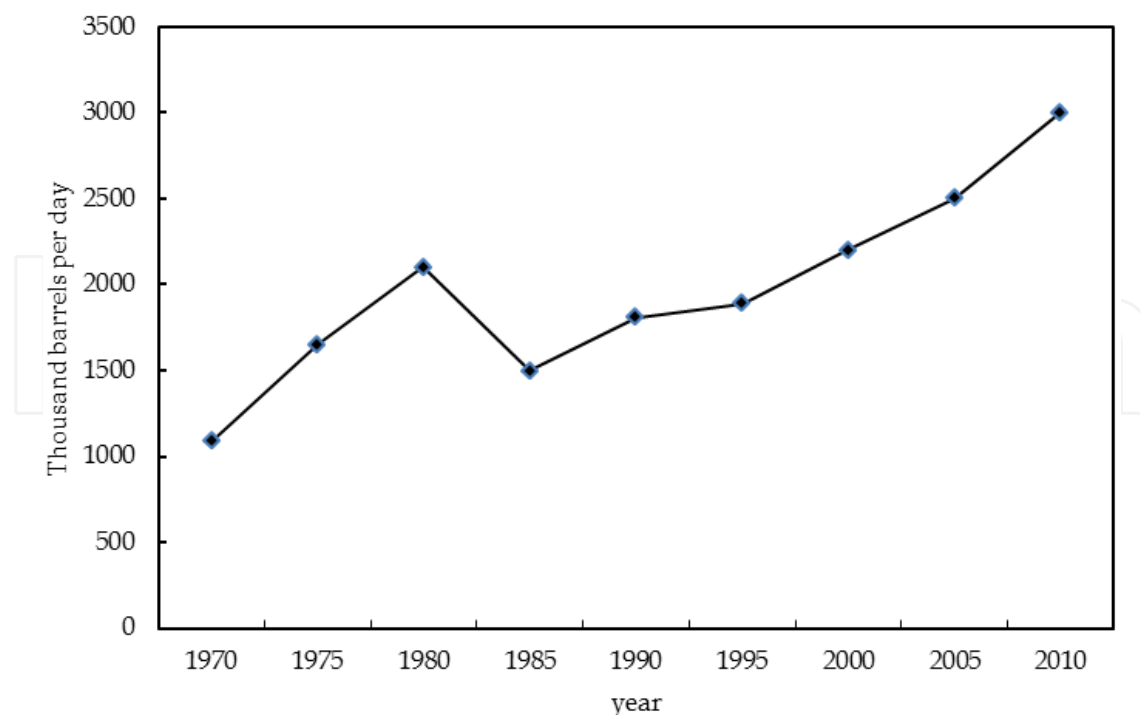

Fig. 1.1. Nigerian crude oil production.

Nigeria is the largest oil producer in Africa and the eleventh largest in the world. ChevronTexaco, ExxonMobil, Total, Agip, and ConocoPhillips are the major multinationals involve in Nigeria oil sector. The main production activity in Nigeria is in the Niger Delta region, which according to master plan, extends over an area of about 70,000 square kilometers which amounts 7.5% of Nigeria's land mass. It lies between latitude 3oN and 6oN and longitude 5oE and 8oE (Fig 1.2). The Niger delta is world's third largest wetland after Holland and Missisippi. It covers a coastline of 560 km, which is about two-thirds of the entire coastline of Nigeria (Fawehinmi, 2007).
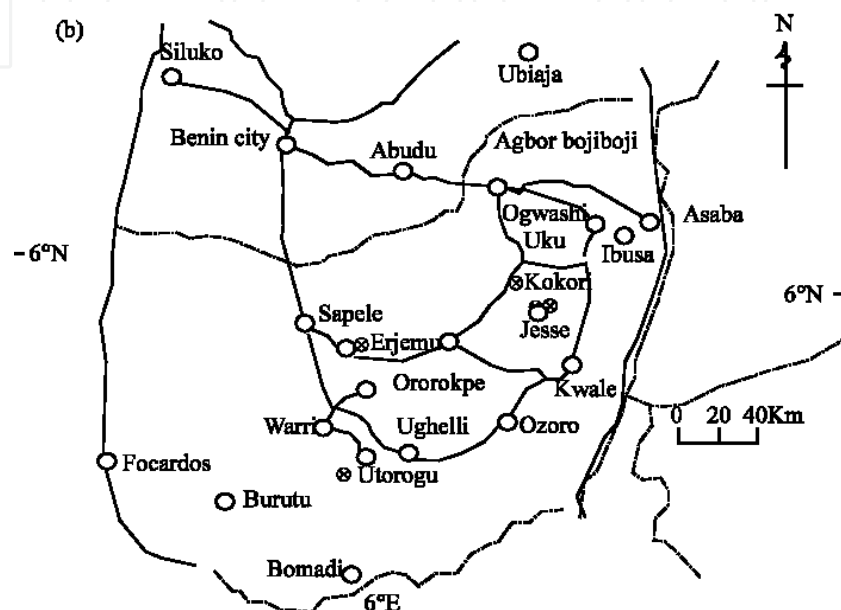

Fig. 1.2. Niger Delta region, Nigeria.

Nigeria has a substantial reserve of paraffinic crude oils (Ajienka and Ikoku, 1997), known for their good quality (low sulphur, high API gravity), and containing moderate to high contents of paraffinic waxes. The data correlated for light, medium and heavy crude oil samples from different sites in Nigeria show densities ranging from 0.813-0.849 g/ml, 0.866-0.886 g/ml, and 0.925-.935 g/ml at 15°C respectively. 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. They exhibit non-Newtonian flow behaviour at temperature below the cloud point due to wax crystallization. Consequently, the pipeline transportation of petroleum crude oil from the production wells to the refineries is threatened.

The Nigerian Niger Delta crude oil, which is the mainstay of Nigerian economy, exhibits waxiness, with deposits in the range of 30-45 % (Adewusi 1997; Fasesan and Adewumi, 2003; Taiwo et al., 2009 and Oladiipo et al., 2009). In fact, pipelines have been known to wax up beyond recovery in Nigeria. Production tubing has also been known to wax up, necessitating frequent wax cutting, using scrapers conveyed by wireline, which is an expensive practice. Billions of dollars has been lost to its prevention and remediation (Oladiipo et. al., 2009). The resultant effect on the petroleum industries include among others, reduced or deferred production, well shut-in, pipeline replacements and/or abandonment. For efficient operation of a pipeline system, steady and continuous flow

without any interruption is desirable (Chang et al., 1999). The difficulties in pipeline transportation are due to this complex nature of crude oil, which cause a variety of difficulties during the production, separation, transportation and refining of oil (Al-Besharah et al., 1987). For example, formation of asphaltic sludge after shutting in a production well temporarily and after stimulation treatment by acid has resulted in partial or complete plugging of the well (Ayala et al., 2007and Escobedo et al., 1997). Relative amount and molecular distribution of wax, resin and asphaltene as well as thermal and shear history of high pour point waxy crude sample directly affects the rheological properties of crude oil (Ajienka and Ikoku, 1997).

Phase changes in petroleum fluids during production, transportation and processing, constitute a challenging and an industrially important phenomenon. Polydisperse nature of hydrocarbons and other organic molecules in petroleum fluids accounts for the complexity of their phase behavior (Mansoori, 2009), which could be reversible or irreversible (Abedi et al., 1998). Generally, heavy fractions have little or no effect on the liquid-vapour phase behaviour of the majority of petroleum fluids. Their main contribution is in solid separation from petroleum fluids, due to changes in the composition, temperature and pressure (Mansoori, 2009; Escobedo and Mansoori, 2010). The main components of the heavy fraction, which participate in the solid phase formation include asphaltenes, diamondoids, petroleum resins and wax. Petroleum wax consist mainly saturated paraffin hydrocarbons with number of carbon atoms in the range of 18–36. Wax may also contain small amounts of naphthenic hydrocarbons with their number of carbon atoms in the range of 30–60. Wax usually exists in intermediate crudes, heavy oils, tar sands and oil shales. The distribution of n-alkanes as a function of the number of carbon-atom in a paraffin wax sample is given in figure 1.3 below.
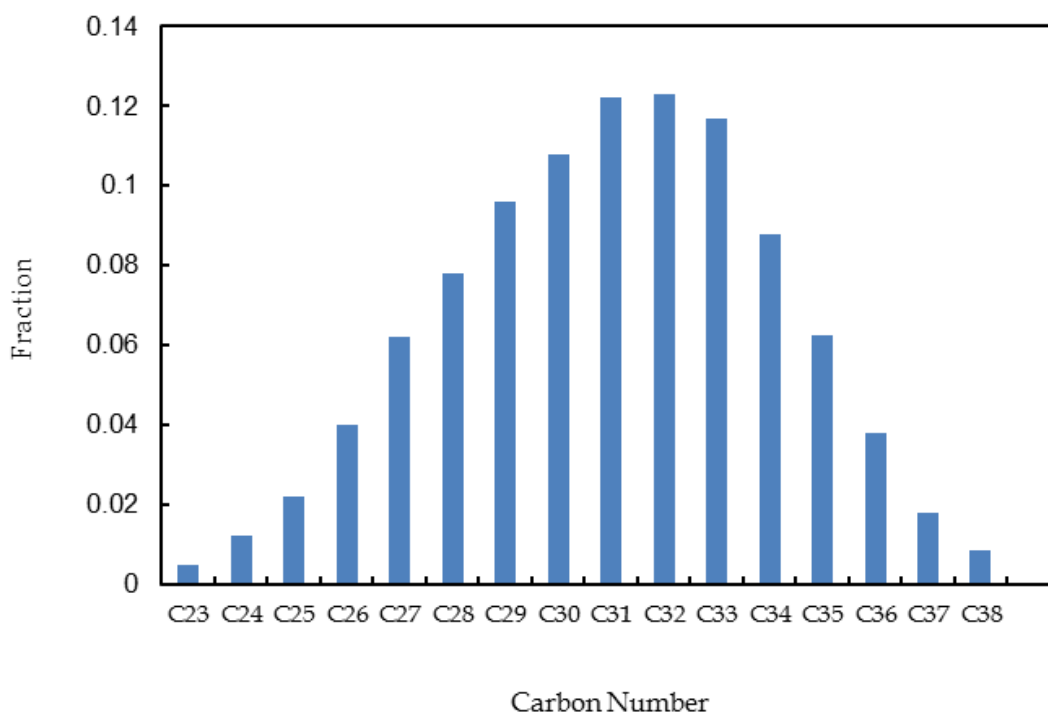

Fig. 1.3. Carbon number distribution of paraffin wax.

Phase equilibrium deal with the various situations in which two or more phases (or state of aggregation) coexist in thermodynamic equilibrium with each other. Reservoir oil contains paraffin wax in solution. The average temperature of the oil in production well is somewhat higher than the atmospheric temperature. When a waxy crude oil is cooled, the heavier paraffinic constituents begin to separate as solid crystals once the solubility limit is exceeded (Karan et al., 2000). Thermodynamically, the solid-liquid phase boundary temperature, that is the maximum temperature at which the solid and liquid phases co-exist in equilibrium at a fixed pressure, is the wax appearance temperature (WAT). This depends on wax concentration, the crystallization habit of wax, and the shear stability of different wax structures (Holder and Winkler, 1965; Hussain et al., 1999).

This contribution therefore present the various phase-transitions, which may occur in petroleum fluids, and a unified perspective of their phase behaviors. Experimental determination of the rheological properties and the characteristics of the crude oil were carried out and the data tested on different established rheological models for ease of simulating the flow behavior of the crude oil. The wax deposition tendencies of crude oil in the pipelines and its influences on the transportation capacity were determined. The various methods of mitigating flow assurance problems and wax deposition inhibition highlighted towards adequate crude oil production.

2. Experimental methods

2.1 Materials

All crude oil samples used in this study were from Niger Delta Oil field in Nigeria, having density and API gravity in the range of 847 - 869 kg/m^3 and 24.4 – 36.5 ^{o} at 15 ^{o}C, respectively. For physical properties measurements, the crude samples were shaken vigorously for one hour to homogenize and presents good representation of samples. Standard methods were employed in determination of the physical properties.

2.2 Rheological properties measurements

The rheological behavior of the crude oil samples were studied using Haake Rheo Stress model RS100 rheometer having several operating test modes. The test sample charged into the rheometer cup was allowed to equilibrate at a particular temperature. The unit was set to desired shear rates and operated at 10 revolution per minute, then the temperature of the test, the shear rate and the shear stress were recorded. The procedure was repeated at various other set temperatures and shear rates. The resulting sample deformation was detected using digital encoder with high impulse resolution. Thus, it allows measurements of small yield values, strains, or shear rates. The rheometer is equipped with a cone and plate sensor.

2.3 Determination of the wax content

Wax content was determined by precipitation method (Coto et al., 2008). It involves samples dissolution in n-pentane, precipitation with acetone:n-pentane mixture in ratio 3:1 and separating by filtration in Buchner funnel using glass microfiber Whatman filter N934.

2.4 Pipeline crude oil transportation simulation

The pipeline transportation system simulated for crude oil experimental measurement comprises the experimental pipe system, the circulating water system and crude oil reservoir system (Fig. 2.1.).

V- Valves; P – Pressure gauge; FM – Flow Meter; PM – Pump;
W_{IN} & W_{OUT} - Heating/cooling Water IN and OUT; JT- jacketed Tank
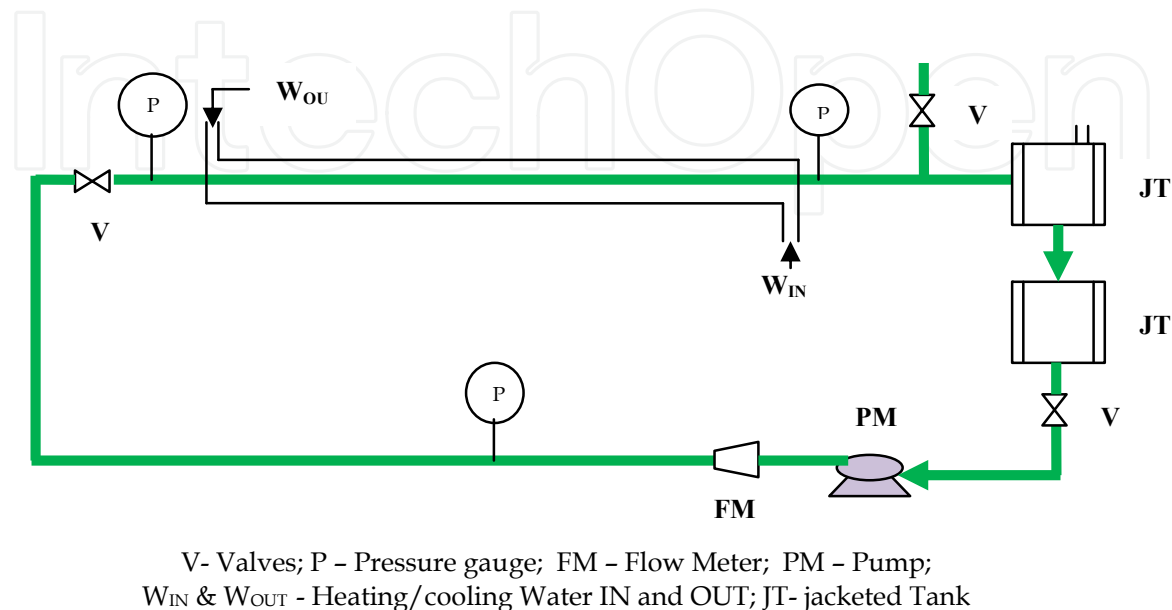

Fig. 2.1. Simulated pipeline transportation system.

The experimental pipe system and water circulation system are arranged in shell and tube mode. The water jacket around the reservoir tank can control the oil temperature in the pipe system while water circulation system controls the wall temperature of the test section. The internal diameter of pipe at both the test and reference section is 20.47 mm with the total length of 2.75 m.

2.4.1 Wax deposition in simulated transportation flow line

The differential pressure of the test section and the reference section were measured during the wax transportation experiment. The wall temperature of the test section was varied and the differential pressure measured. The data collected were used to calculate the extent of the wax deposition and to elucidate on the mechanism of deposition. Carbon number distribution of paraffin wax determined by gas chromatography technique using the IP 372/ 85 methods.

2.5 Evaluation tests of flow improvers

Effectiveness of some flow improvers for the waxy crude oils was determined through the pour point test (using Herzog MC 850 pour point test equipment) according to the ASTM-97 and kinematic viscosity by the IP 71 procedures. The dynamic inhibitive strength of these modifiers was equally experimented using the simulated crude oil pipeline transportation.

3. Results and discussions

3.1 Rheological behaviour and modelling

Rheology is the science of the deformation of matter. It involves the study of the change in form and flow of matter in term of elasticity, viscosity and plasticity under applied stresses or strains. The rheological behavior of waxy oil is crucial in the design of pipeline, flow handling equipment and processing purposes in the oil industry. The study of the rheological characteristics of crude oil is significant to lowering the energy consumption and ensuring safety and cost effectiveness in pipeline transportation of waxy crudes. Figure 3.1 shows a typical rheogram in terms of shear stress and shear rate. Shear stress increases asymptotically and significantly with shear rate. Several researchers have investigated models to describe the rheological properties of waxy oils (Davenport and Somper, 1971; Matveenko et al., 1995 and Remizov et al., 2000). Generally the behaviour can be broadly grouped into two; Newtonian and non-Newtonian fluids. Whereas the Newtonian fluids exhibit a linear relationship between shear stress and shear rate, the non-Newtonian fluids do not. The non-Newtonian fluids have yield stress, which is the upper limit of stress before flow occurs. At this point, the range of reversible elastic deformation ends and range of irreversible deformation or visco-elastic viscous flow occur (Chang et al., 2000). The existence of yield stress behavior depends upon the degree on interlocking structure developed by waxing and fragility of the network (Philip et al., 2011).

Modeling analysis carried out by fitting the rheological data to three models are reported in Table 3.1. The models include

Bingham plastic,

$$\tau = \tau_o + \mu_P \gamma \tag{3.1}$$

Casson,

$$\tau^{1/2} = \tau_o + \mu\gamma^{1/2} \tag{3.2}$$

and Power law,

$$\tau = m\gamma^n \tag{3.3}$$

where γ is the applied shear rate (s^{-1}) and τ is the corresponding shear stress in Pa, m and n are consistency index in Pa s and flow behavior index, the τ_o and μ are the apparent yield stress in Pa and the apparent viscosity in Pa s. Bingham model predicted very adequately the flow behavior of the crude oil over the tested range of shear rates. This observation suggests Nigerian Niger Delta waxy crude oil exhibits plastic behavior. Table 3.1 reports the highest regression correlation coefficient, R^2, of 0.992 for the Bingham model. This is similar to an earlier work on waxy crudes from this area (Taiwo et al., 2009), with good prediction of the yield stress within percentage deviation of 2.88 ± 0.15.

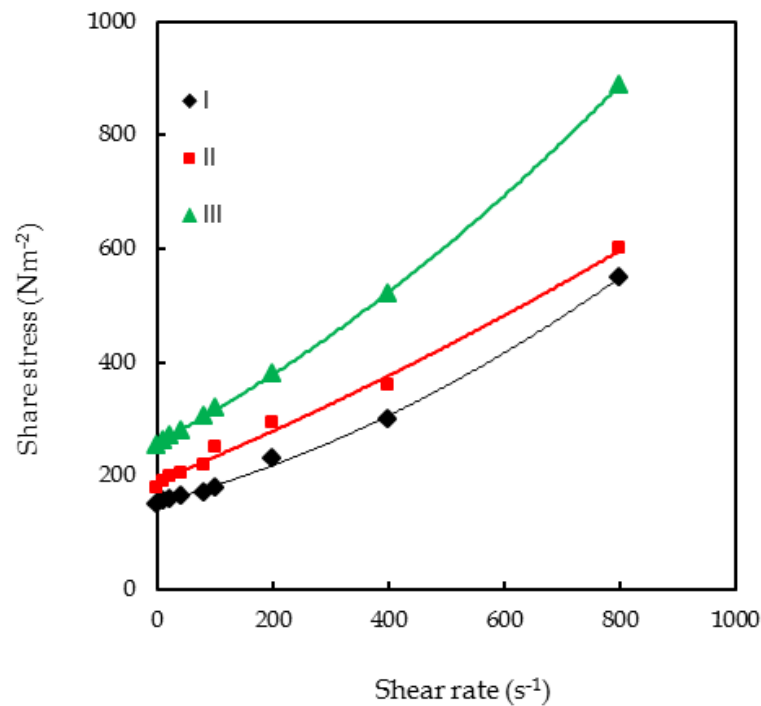Fig. 3.1. Rheogram of the waxy crude samples.

Sample	Bingham Plastic			Casson			Power Law		
	τ_o	μ_P	R^2	τ_o	μ	R^2	m	n	R^2
I	139.4	0.487	0.983	113.0	0.387	0.898	66.09	0.259	0.766
II	184.9	0.505	0.991	149.8	0.385	0.944	91.20	0.240	0.836
III	244.0	0.779	0.992	197.4	0.485	0.919	501.19	0.253	0.800

Table 3.1. Rheological Parameters and Correlation Coefficients of Models.

According to Bogne and Doughty (1966), the rheological characteristics of materials form a continuous spectrum of behavior, ranging from the perfectly elastic Hookean solid at one extreme, to that of purely viscous Newtonian fluid at the other. Between these idealized extremes is the behavior of real materials that include, among others, non-Hookean solids, non-Newtonian fluids, and viscoelastic substances. The waxy crude oil generally belongs to the non-Newtonian fluids while the Nigerian Niger delta waxy crude showed plastic behavior, which is time dependent non-Newtonian fluid.

3.2 Temperature effect

Temperature has a strong effect on viscosity and viscous behavior. This effect provides the flow behavior curve in terms of the viscosity-shear rate or viscosity-shear stress relationships. Fig. 3.2 shows the effect of temperature on shear stress-shear rate behavior over the temperature range of 25 – 55 ^{o}C experimented. The crude oil shows non-Newtonian shear thinning (viscosity reduction) behavior over the range of shear rates studied. By definition, yield stress, τ_o, is the limiting stress below which a sample behaves as a solid. At low stress, the elastic deformation takes place, which disappears when the applied stress is released (Guozhong and Gang , 2010). Chang et al., (1998) described the
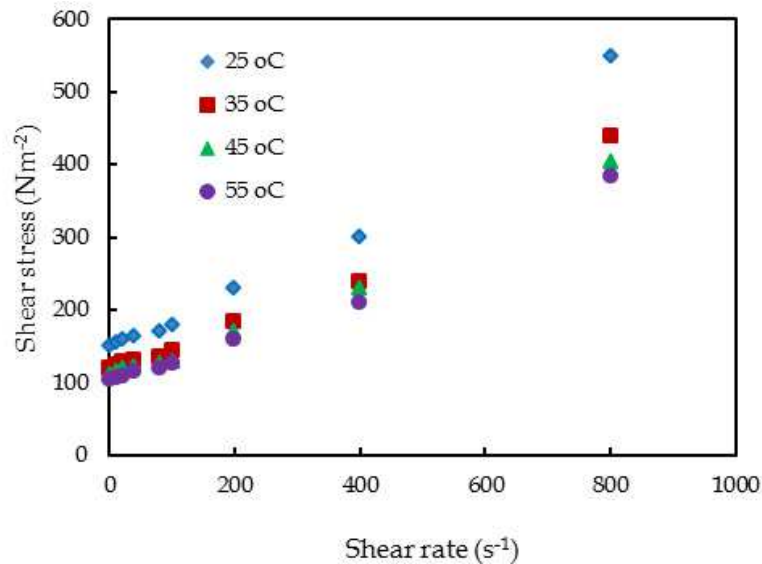
Fig. 3.2. Shear stress as a function of shear rate with varying temperature (Sample I).

yielding behavior of a waxy crude oil as having three distinct characteristics—an elastic response, a creep and a fracture. The shear stress at the point of fracture is the value of practical importance and is usually taken as the yield stress. Above the yield stress point, the applied stress leads to unlimited deformation which causes the sample to start flow (Ghannam and Esmail, 2005). The yield point, which is required to start the flow, decreases with temperature from 150 Nm^{-2} at room temperature of 25 ^{o}C to 104 Nm^{-2} at the temperature of 55 ^{o}C. Similar trend ensued for the other samples. At a higher cooling rate, the rate of wax precipitation is higher. Hence, a higher stress is necessary either to aggregate the crystals, or to breakdown the structure.

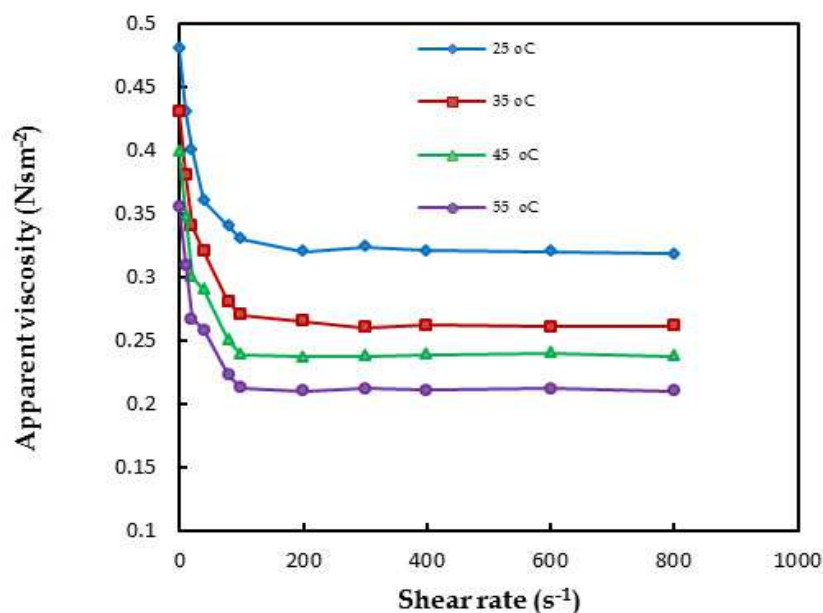In addition, the apparent viscosity decreases considerably with increasing temperature (Fig 3.3).

Fig. 3.3. Effect of temperature on viscosity of the crude.

Viscosity differences are relatively larger at low shear rates than at high shear rates. At high temperature, wax in the crude oil could not agglomerate and form aggregates, and hence reducing the oil viscosity. At high shear rate, ($\geq$ 100 s^{-1}), an almost constant viscosity was observed with increasing share rate. This could result from effective dispersion of wax agglomerates in the continuous phase originally immobilized within the agglomerate, after being completely broken down into the basic particles.

The observed variation with temperature is attributable to the strong effect of temperature on the viscosity of wax and asphaltene components in crude oil. At high temperature, the ordered structure of these chemical components are destroyed, and hence reducing the oil viscosity (Khan, 1996). As the shear rate increases, the chain type molecules disentangled, stretched, and reoriented parallel to the driving force, and hence reduced the heavy crude oil viscosity (Ghannam and Esmail,1998, 2006).

3.3 Wax deposition characteristics

Fig. 3.4 shows the wax deposited as a function of temperature for the three Nigerian crude oils samples. Sample II has the highest percentage wax content of 33.5% with wax appearance temperature (WAT) of 43.5 ^{o}C while for sample I the wax content is 10.5 % with WAT of 35 ^{o}C.
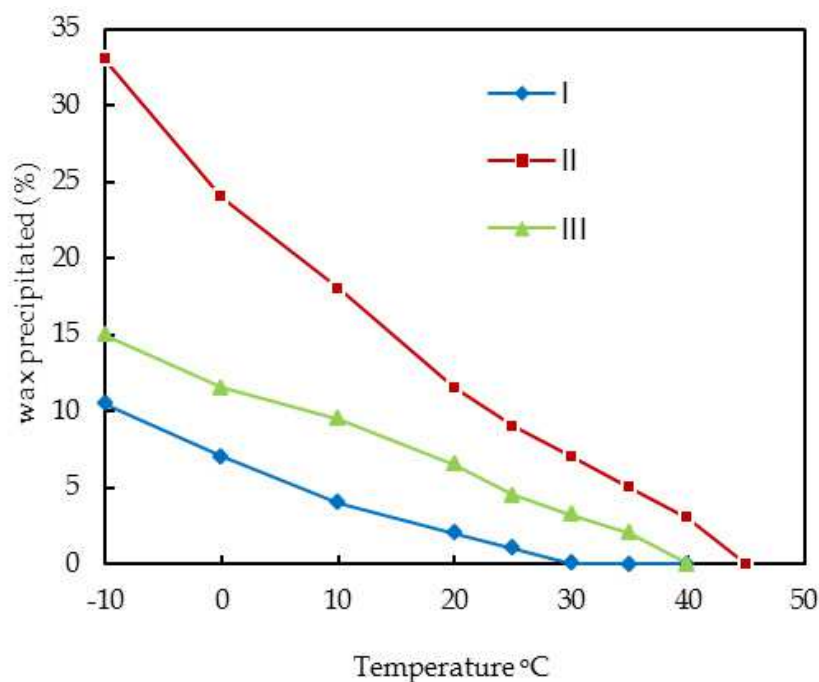

Fig. 3.4. Wax precpitation as a function of temperature.

The wax appearance temperature (WAT) and the pour point temperature (PPT) are good pointers to the temperature regime, in which a waxy crude oil is expected to start to show non-Newtonian behavior. Their determination is an important step in the study of rheological behavior of such systems. In fact, WAT is probably the most important flow assurance measurement for waxy crudes. Pour point represents the lowest temperature at which the crude oil can be stored or handled without congealing in the tanks or pipelines. Usually, it is 10-20 °C lower than the cloud point (Ajienka, 1983). The pour point of samples experimented were in the range of 18 and 32 °C. As the fluid cools below WAT, crystal size tends to increase and crystal aggregation is usual, particularly under quiescent and low shear condition, such that the solid-like behavior of the waxy suspension increases. At some point between the WAT and pour point, a transition can be determined depending on wax development and is thus strongly affected by thermal and shear conditions. This is considered an indication of initial development of interlocking network (Lopes-da-Silva and Coutinho, 2004).

3.4 Wax deposition rate in flow system

As trot to understanding the deposition pattern and hence the flow assurance of the oil samples, simulated transportation flow pipe described in section 2.4 was developed. It is a modification to earlier work (Taiwo et al., 2009), with consideration for the idea of Guozhong and Gang (2010). As expected, the wax deposit thickness showed inverse proportionality with wall temperature and direct relation with temperature difference between the oil and pipe wall (Fig 3.5). In addition, a monotonic increase with time was observed. The low thickness observed at 42 °C wall temperature is significant of closeness to the WAT of oil sample which is 43.5 °C. In addition, the average wax deposition rate (mm/d) increases with increased difference in temperature as shown in Fig. 3.6.
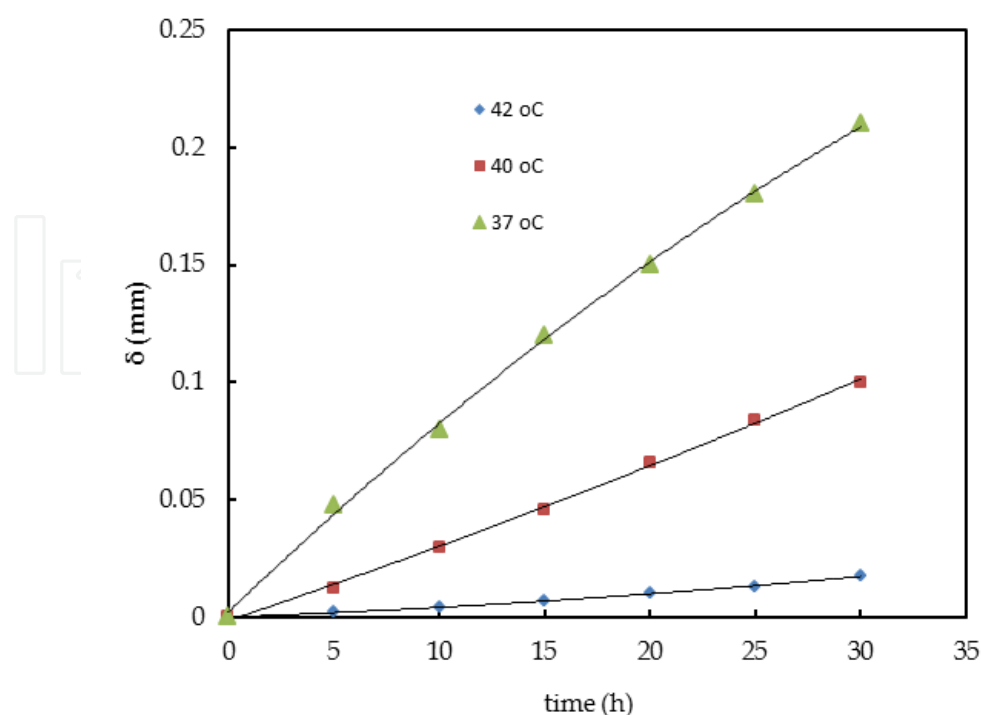

Fig. 3.5. Wax deposit thickness variation with time as a function of wall temperature.

The average wax deposition rates reported in Fig. 3.6 were at temperature differences of 3 °C, 5 °C and 8 °C respectively, at 30 h deposition time. Generally, gradual increase in deposition rate with increasing temperature difference was observed. However, at zero °C temperature difference, experimental results showed that no deposition occur because there is no driving force for lateral diffusion of the wax molecules. When the oil temperature is 50 °C, the average wax deposition rate was zero at temperature difference of 3 °C, corresponding to the wall temperature of 47 °C, which is slightly above the WAT of the crude sample. Under this condition, the paraffin molecule super saturation concentration is very low, thus, its wax deposition power tend to zero. However, at 5 °C temperature difference, the deposition rate was 0.025 mm/d. This observation was due to lateral diffusion of the wax in crude oil. When temperature difference increased to 8 °C, the rate increased to 0.10 mm/d. It reflects wall temperature of 42 °C which is lower than the WAT of the crude oil sample.
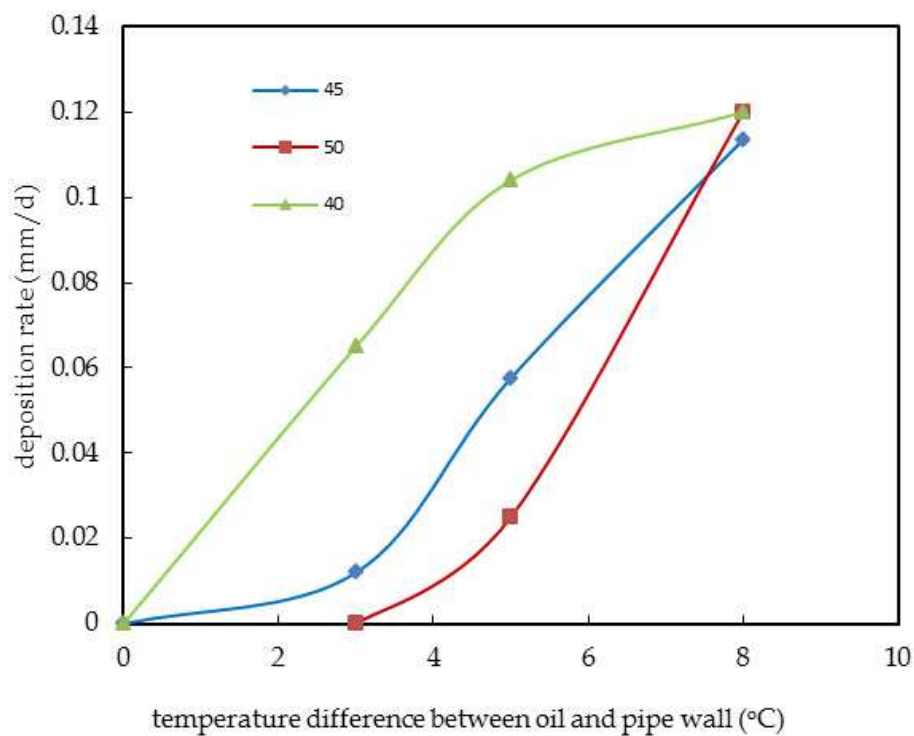

Fig. 3.6. Variation of deposition rate with temperature difference.

At the oil temperature of 45 °C, the average wax deposition rate increases with the fall in the wall temperature. When the temperature difference between the oil and the wall is 8 ° C (the wall temperature is 37 °C), the average wax deposition rate is 0.12 mm/d and higher than that experienced for 50 °C oil temperature. For the oil temperature of 40 °C, deposition rate is generally higher than other temperature conditions. However, at higher temperature

difference, the deposition rate almost assumed same value. This may be due to wax content in the crude.

The theory of the molecular diffusion suggests gradual wax deposition in the pipe as the wall temperature decreases. However, at low wall temperature of the test section, the differential pressure of the test section increased sharply. This rapid increase of the differential pressure should therefore not be the resultant effect of the wax deposition, since a gradual increase in wax deposition was observed (Figs. 3.4 and 3.5). A fast increase of the oil viscosity near the wall could have resulted from the drop in wall temperature, thereby distorting the flow regime in the test section due to the radial differential temperature; this makes the differential pressure of the test section increase suddenly. Mansoori, (2009) attributes this observation to phase transition which influence the Gibbs energy of the system hence sudden change in pressure drop.

3.5 Doping of waxy crude

Wax build-up in tubing and flow lines is a typical flow assurance problem. This makes transportation of such waxy crudes un-economically feasible. To improve mobility of the oils, viscosity reduction is imminent. This can be done by heating, blending of the oils with lighter oils or other solvents having pour-point depressing effect (Hemant et al., 2008). In addition there are applications of microwaves, ultrasound irradiation, magnetic fields, lining and coating pipelines with fiber-reinforced plastics to reduce the wettability of paraffin with the wall of the pipe, and covering the inner wall surfaces with polypropylene (Hemant et al., 2008). Pipeline heating is usually deployed for small distances (with insulation) and moving the oil as quickly as possible. This passive insulation becomes in effective when longer pipe length oil transport is required. High backpressure will set in requiring expensive booster pumps. Electrically heated subsea pipeline is considered an alternative (Langner and Brass, 2001). Even then, the complexity of the pipeline design required and need to heat whole pipe length makes the configuration costly to deploy and operate (Martinez-Paloua et al., 2011). Doping with solvent, which keeps the wax in solution, is therefore essential in ensuring oil mobility. Based on evaluation of preliminary studies (Adewusi, 1998; Fasesan and Adewumi, 2003; Bello et al., 2005a, 2005b, 2006 and Taiwo et al., 2009), xylene based pour point depression solvents were considered. Table 3.2 reports some solvents for improving the transportation of Niger Delta waxy crudes. Xylene (X) and tri chloro ethylene (TCE) are good pour point depressant based on the work of Adewusi (1998) and Bello et al., (2005a), while Taiwo et al., (2009) showed tri ethanol amine (TEA) to be very good wax deposition inhibitor (Table 3.2). These three solvents further confirm their wax inhibition strength from the report of the present experimentation (Table 3.3). Xylene reduced the pour point from 32 °C to 18 °C for sample II that has the highest wax content of 30.5 percent, while TCE and TEA reduced it to 19.5 and 17 °C, respectively. Pour point depressants (PPDs) accomplish this task by modifying the size and shape of wax crystals and inhibit the formation of large wax crystal lattices (Wang et al., 2003). Generally, the PPDs create barrier to the formation of the interlocking crystal wax network (Wang et al. 1999). As a result, the altered shape and smaller size of the wax crystals reduce the formation of the interlocking networks and reduces the pour point (Hemant et al., 2008) by preventing wax agglomeration (Hafiz and Khidr, 2007). In some cases pendant chains in the

additive co-crystallize with the wax and the polar end groups disrupts the orthorhombic crystal structure into a compact pyramidal form (Hemant et al., 2008).

Trichloroethylene, xylene and tri ethanolamine actively decreased the pour point of the samples and their wax deposition potentials on doping. The oxygen containing groups in the doping agents take the role of inhibiting the growth of waxes and poisoning them by adsorptive surface poisoning mechanism. The PPDs on adsorption on the surface of the wax renders its nuclei inactive for further growth. The waxes then occur in small sized particles distributed within the crude oil samples, thus cannot form net-like structure required for solidification and deposition.

| Pour Point Depressant | Adewusi, 1998 Bello et. al., 2005 | | Taiwo et al 2009 | | | | | |
| | EB | | FL | | BL | | EL | |
	Wax deposition (g/g)	Pour point (°F)	Wax deposition (g/g)	Pour point (°C)	Wax deposition (g/g)	Pour point (°C)	Wax deposition (g/g)	Pour point (°C)
No additive	0.05	36	0.25	28	0.28	33	0.335	36
Methyl Ethyl Ketone	0.037	22	0.15	22	0.185	18	0.188	25
Tri Ethanol Amine	-	-	0.085	18	0.106	23	0.107	16
Xylene	0.013	17	0.115	17	0.143	17	0.154	18
Cyclo-hexanone	0.028	18	-	-	-	-	-	-
Tri Chloro Ethylene	0.009	16	-	-	-	-	-	-

Table 3.2 Evaluation of various solvents for flow improver.

| Pour Point Depressant | I | | II | | III | |
	Wax deposition (g/g)	Pour point (°C)	Wax deposition (g/g)	Pour point (°C)	Wax deposition (g/g)	Pour point (°C)
No additive	0.105	18	0.305	32	0.150	27
Methyl Ethyl Ketone	0.069	14	0.164	23.5	0.084	21.5
Tri Ethanol Amine	0.040	12	0.092	17	0.053	18.5
Xylene	0.054	11.5	0.130	18	0.067	17.5
Cyclo-hexanone	0.052	12.5	0.182	22	0.076	18
Tri Chloro Ethylene	0.048	11	0.171	19.5	0.062	17

Table 3.3 Screening of common solvents for flow improver.

It is suggested that the reduction of the measured viscosity is due to the interactions between the hydroxyl functions or the delocalized unpaired electron over the π-orbital especially in the phenyl group of PPD and some functionalities of the wax (Gateau et al., 2004). This could have premised the performance of TEAX and TCEX. With 0.1 volume fraction of TEA or TCE in TEAX or TCEX binary, the shear thinning behavior is enhanced, and the viscosity as well as the pour point decreases as the temperature increases (Figs 3.7 and 3.8). TEAX improved the rheological characteristic behavior better than TCEX. The reduction of viscosity on the addition of the solvents is due to the dissolution of paraffin wax, the effect xylene on the effectiveness of these dopants is significant and play a major role in reducing the viscosity. This observation gave credence to the report of Chanda et al., (1998).
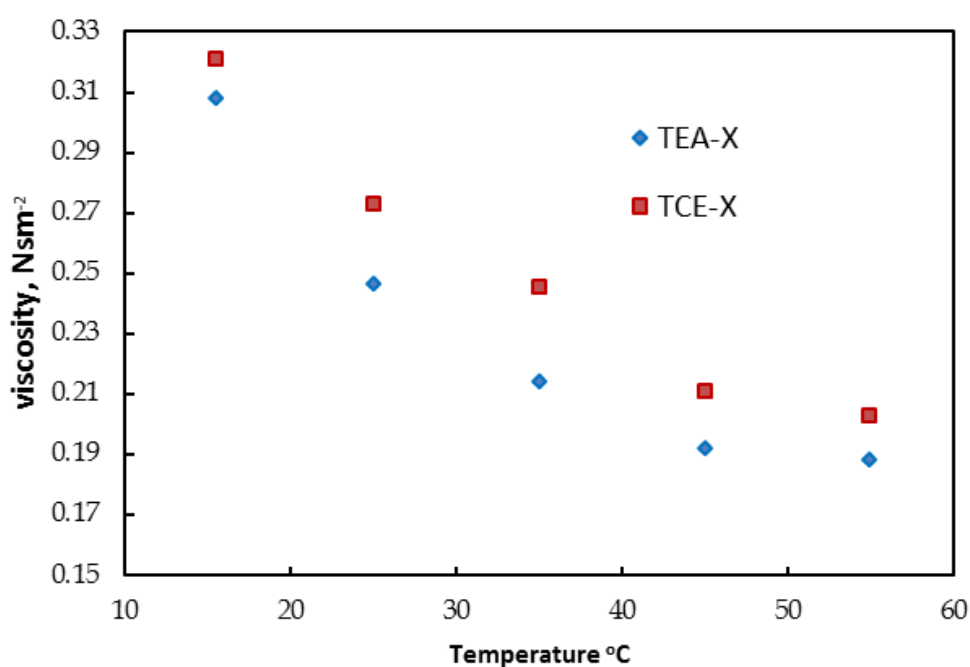
Fig. 3.7. Viscosity variation for doped sample II with temperature.

3.6 Hydrocarbon distribution in the crude oil wax

The crude oil samples wax had similar hydrocarbon distributions. The carbon number distribution of the paraffin wax is shown in Fig. 3.9. Samples I and III had very identical carbon number distribution, and all samples showed the same peak carbon number. This ranged between C31 and C33 indicative of paraffinic wax, although tailing to C38 an occurrence of naphthenic crude.

The dynamic inhibitive strength of the flow improvers tested by applying the doping agents into the crude samples in the reservoir tanks of the simulated pipeline transportation set-up, showed a marked reduction relative to that obtained for undoped samples. This showed that the PPD apart from lowering the pour point of the waxy crude caused reduction in pressure build-up by keeping the wax particles in solution and hence reduced viscosity of crude samples. Wax deposition was not feasible in the test pipe surfaces even at 8 °C temperature difference between the oil temperature and the wall temperature. The moderately higher-pressure drop with TCEX over the TEAX modified crude samples further confirms the strength of TEAX in wax crystal modification (Fig 3.10). Plate 3.1 showed the wax dispersed in crude oil sample upon modification. This evidently supports the view of Azevedo and Teixeira (2003) that shear dispersion play significant role in wax deposit removal thus affecting the rate of wax accumulation.
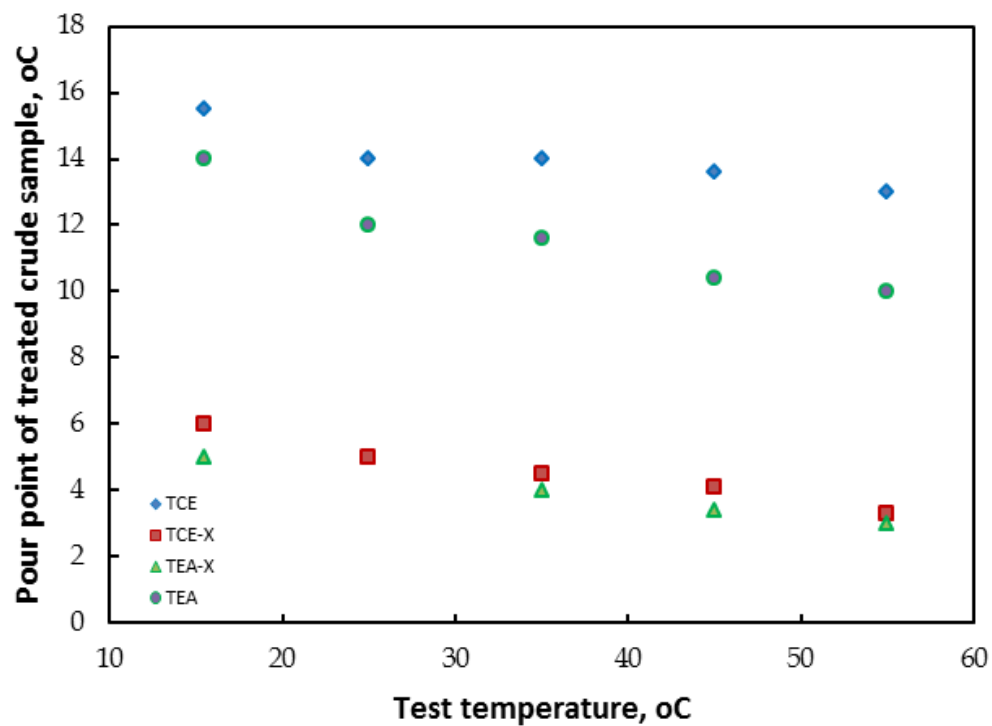
Fig. 3.8. Pour point depression test for sample II at varying test temperature.
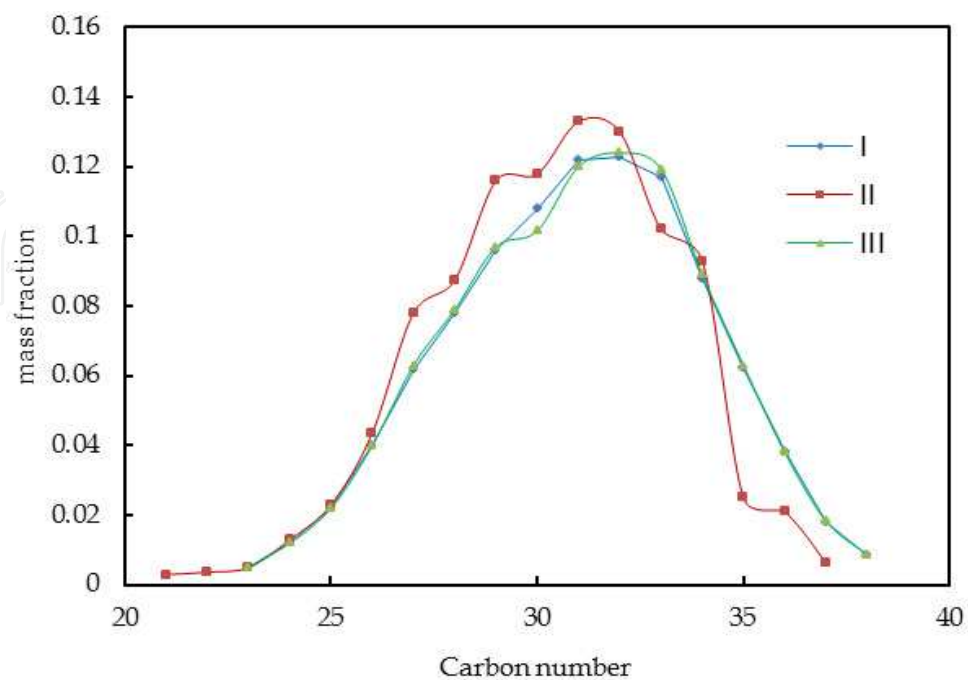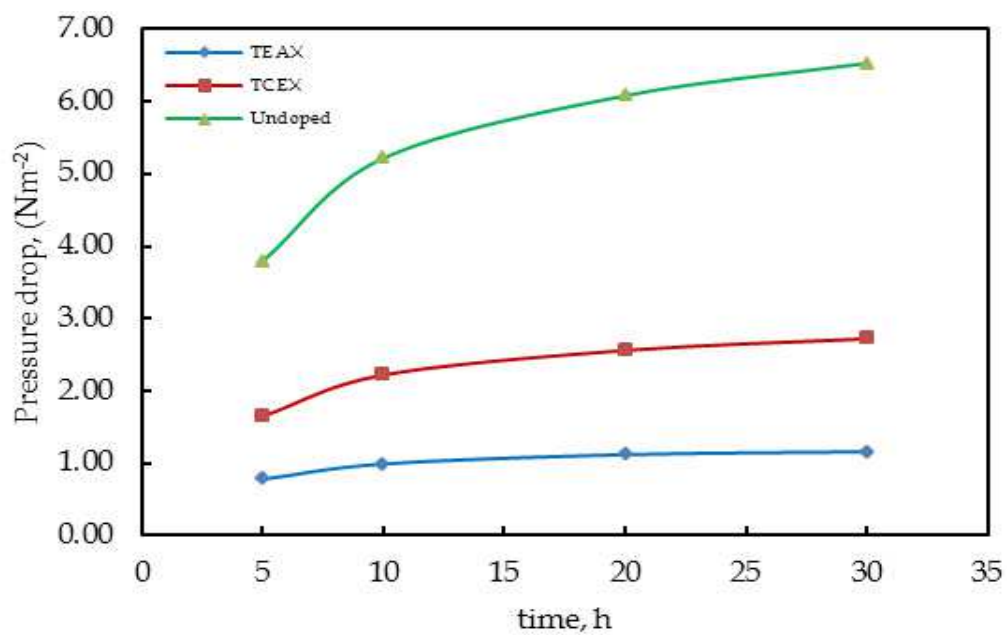
Fig. 3.9. Hydrocarbon distribution in wax samples.

Fig. 3.10. Variation of pressure drop with time for doped and undoped sample in dynamic test.
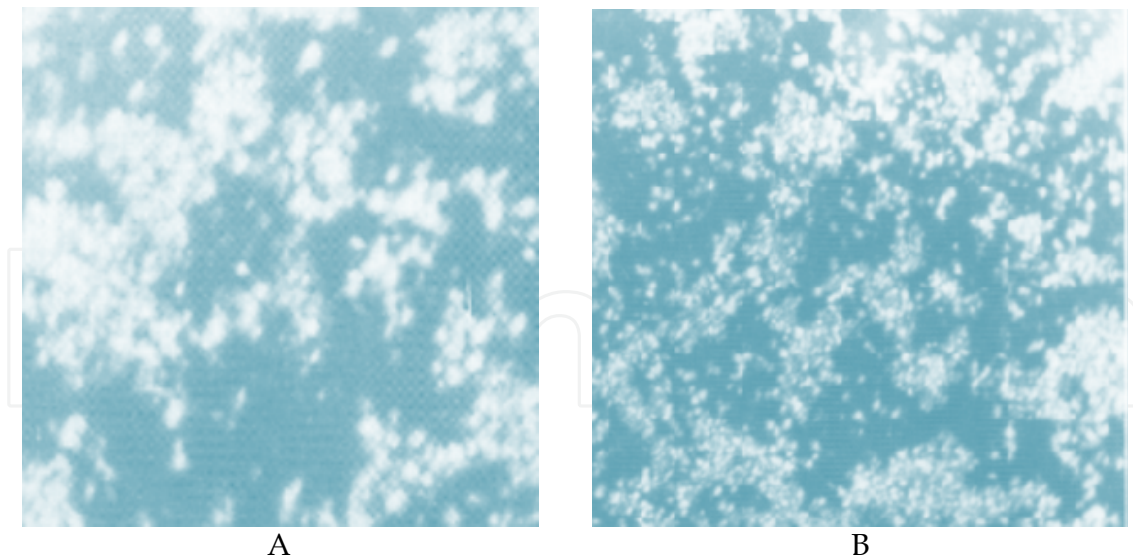
Plate 3.1. Micrograph of crude sample at X 500 magnification (A: undoped B: doped)

4. Conclusion

A study of transportation of waxy Nigerian Niger Delta crude oil using flow improver was performed. This study has been able to highlight the significance of TEA in improving the flow of this crude oil by significantly lowering the pour point and wax deposition potentials of the crude sample. The crude oil had been established to show plastic behaviour with Bingham non-newtonian model adequately predicts its rheological behaviour with occurrence of yield stress. The simulated pipeline transportation system for experimentation revealed mass diffusion mechanism for transport and deposition of waxes on the tube wall. The characteristics and behaviour of solvent modified crude oils should help in addressing cost-effective solution to flow assurance problems in the industry.

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6. References

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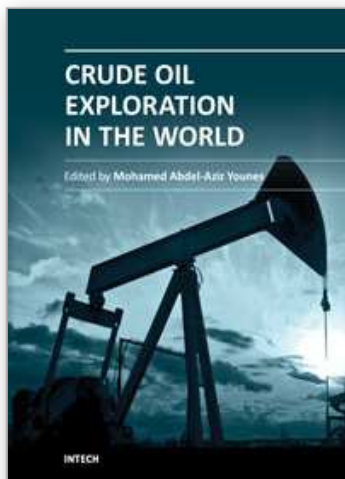
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