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Research Article

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Comparative Study of the Rheological Properties of Niger Delta Crude Oil

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Abstract The rheological properties of crude oil samples from three oil field (Ogini, Ebocha and Ibigwe) in Niger Delta, Nigeria were investigated experimentally using Chandler Automated Viscometer (CAV). These samples were conditioned with an atmospheric consistometer and tested at different temperature conditions (Ambient, 50 ^oC, 70^o C). Thereafter, the samples were placed in a centrifuge and activated for 10 minutes and then placed in a test tube rack for Basic Sediment & Water (BS &W) determination. The density and API gravity of the samples were determined, while the density ranges from 7.50 to 7.83 pounds per gallon, the API gravity ranges from 19.05 to 25.72. The viscosity result obtained shows that the plastic viscosity of Sample A decreased from 148 cp to 25 cp for Ambient to 70 ^oC, Sample B decreased from 2 cp to 1 cp for Ambient to 70 ^oC, and Sample C from 7cp to 1cp for Ambient to 70 ^oC. Similar trend was observed for apparent viscosity. Decrease in speed (revolution per minute) of the CAV, decreased the viscosity as the temperature increases. The shear stress and strain decreased with increase in temperature for all samples.

Keywords Crude Oil, Atmospheric Consistometer, Chandler Automated Viscometer, Temperature, Plastic Viscosity, Basic Sediments & Water

1. Introduction

Rheological measurements of crude oil are essential for successful and economic transportation of the products. Proper measurement of the flow properties of crude oil is necessary for good design of production facilities. The determination of the rheological properties of fluid which enhanced its classification is very important in science and engineering discipline. A clear understanding of the rheological properties of crude oil is vital in the design and construction of petroleum pipelines, subsurface and surface production equipment in the oil industry [1]. Most materials, fluids and their formulations exhibit complex rheological behavior, their viscosity and visco-elasticity changes depending upon the applied external conditions, such as stress, strain, time scale, and temperature. Fluids are generally classified either as Newtonian or non-Newtonian. While the former exhibit a linear relationship between shear stress and shear rate and have no yield stress, the latter have yield stress and are classified as pseudo-plastic fluids, Bingham plastic and dilatant fluids. Rheology generally accounts for non-Newtonian fluid behavior by characterizing the minimum number of functions that are needed to relate stresses with rate change of strains. Various research works have been done on the rheological properties of Nigerian Crude, but variation in crude oil properties and flow assurance problems observed from one field to another makes the research area relevant and prominent. Nigeria waxy crude oil exhibit Non-Newtonian flow and its rheological properties such as viscosity, shear stress and shear rate vary at different temperatures. Similarly, the microstructures of the waxy crude oil are influence by temperature, shear rate and shear history [1]. The viscosity of heavy crude oil decreases over a temperature range of 25-65 ^oC and also exhibited non- Newtonian shear thinning behavior over an examined shear rate change of 0.1-750 s^{-1} with Rheostress R100 [2]. The rheological behavior of crude oil in the presence of water using Rheostress (RS600 rheometer) in first time in a series of samples of light crude oil from Algerian Sahara exhibits Newtonian behavior, while in second time, oil-water emulsions (30 %, 50 % and & 70 %) by volume of water exhibits a non-Newtonian shear thinning behavior over the examined shear rate of 0.1-120S^{-1} [3]. Rheological properties (yield stress) of gelled, waxy North sea oils depends strongly on cooling rate and stress loading rate [4]. Nile blend when observed at different flow and thermal conditions behaves like non-Newtonian fluids, obeying power law model of pseudo plastics fluids and the apparent viscosity is affected not only by oil composition and measurement temperature, but also thermal history, shear rate, and shear action time [5]. The rheological properties (visco-elastic and viscous properties) of bituminous material when tested with dynamic shear rheometer (DSR), gives better result over a wide range of temperature and frequencies, provided the tests are conducted in a linear visco-elastic region [6]. Several authors who explore this area, investigating the rheology of petroleum fluids and their sludge [7-8], transportation of oil and gas through pipeline [9], and non-Newtonian viscosity modeling [10] did not compared different samples. Therefore, this work focuses on comparing the rheological properties of crude oil samples from Niger delta region at different temperatures which will enhance proper design of production and transportation facilities.

2. Materials and Methods

2.1. Materials

The materials used for the experiment were crude oil samples from oil field in Niger Delta (Sample A(Ogini)-1 liter, Sample B (Ebocha)- 1 liter, Sample C (Ibigwe)- 1 liter), test tubes and racks, conical flasks, chandler atmospheric consistometer (CAC), centrifuge bottle, centrifuge, sucker rod, mud balance (weight balance), chandler automated viscometer (CAV)3530 model, cylinders.

2.2. Experimental Procedure

2.2.1. Determination of the Density and Specific Gravity of the Samples

The densities of the samples were measured using a calibrated mud balance, which operates based on the principle of moment.

- The cup of the mud balance was filled with the sample and the lead was screwed on.
- A sucker rod was used to suck out trapped air to ensure that the cup is completely filled.
- The cup and the graduated arm were placed on the knife edge and the rider was moved until the bubble in the spirit level centralizes.
- The density and Specific gravity of the samples were read from the over-side of the graduated arm of the mud balance.

2.2.2. Determination of the Basic Sediments and Water (BS&W)

BS&W is a technical specification of certain impurities in crude oil. The water content can vary greatly from field to field and may be present in large quantity in older fields or if oil extraction was enhanced using secondary recovery mechanism. Suspended solids and water could go a long way in determining the rate and pattern of flow of crude oil. The samples were subjected to a centrifugal force using a centrifuge (which spins the mixture and settles out its constituents by virtue of density difference).

- 100 ml of the sample volume was measured into the centrifuge bottle and corked properly.
- The centrifuge bottle was placed in the bottle holder and fixed properly into the centrifuge.
- The centrifuge was activated for 10mins, after which the samples were brought out and placed in a test tube rack.
- After sedimentation, water and sediments volume were read.

An atmospheric consistometer was used to condition the crude oil samples at the various temperatures. The density, specific gravity, and BS&W were determined before subjecting the samples to temperature change to avoid evaporation losses, loss in weight of the samples and invariably an erroneous result in density and BS&W.

2.2.3. Determination of the Rheology of Samples

The Chandler Automated Viscometer (CAV) 3530 used for this experiment utilizes concentric cylinders with a well defined geometry to measure a fluid's resistance to flow. Due to the small gap between the rotating inner bob and the restrained outer cylinder (sleeve) , the annular flow between the two cylinders is similar to the one confined between two parallel plates where one moves relative to the other. When a fluid sample is confined between the bob and sleeve, rotation of the bob generates a velocity gradient across the gap.

- The sample cup was filled with crude up to the 350 mL scribed line.
- The cup was placed on stage and rotated until the three feet on the cup are engaged in the hole.
- Sample cup and stage was raised until the fluid level meets the scribed line on the rotor and the locking nut tightened on the table.
- The motor was operated at six preset speeds (3, 6, 100, 200, 300, and 600 rpm).
- The reading from the dial in the instrument was observed by viewing through the illuminated lens.
- Dial reading from the pointer was recorded after stabilization.

The rheology of the samples was determined at ambient condition, 50 ˚C and 70 ˚C.

3. Results and Discussion

3.1. Basic Sediment and Water (BS&W)

The results of the BS&W read from the graduated centrifuge bottle are presented in Table 1

Table 1: BS&W of the crude samples

Sample	Sediments (ml)	Water (ml)	B S& W (ml)
A	0.00	0.00	0.00
B	0.30	0.40	0.70
C	0.20	0.30	0.50

The result shows that sample A is sediment and water free, while sample B and C has some percentage of water and sediments in the crude.

3.2. Density of the samples

The densities, specific and API gravities of the samples are presented in Table 2.

Table 2: Density, API and specific gravities of the samples

Sample	Density (ppg)	API Gravity, ^{o}API	Specific gravity
A	7.83	19.05	0.94
B	7.50	25.72	0.90
C	7.75	20.65	0.93

With reference to API classification of crude, sample A and C are heavy while sample B is medium.

3.3. Rheology of the Samples

3.3.1. Shear Stress and Shear Strain

The results of the rheological measurements at different temperatures using CAV are presented in Table 3.shear stress and shear strain readings were obtained from equation 1 and 2 and are presented in Table 4. The result reveals that the temperature is inversely proportional to the dial reading for all samples.

$$\text{Shear stress} = 1.067 \times \text{Reading} \quad (1)$$

$$\text{Shear rate} = 4.24 \times \text{Speed (rpm)} \quad (2)$$

4.24 = Factor from bob and sleeve of viscometer

3.3.2. Plastic viscosity, Yield point and Apparent Viscosity

The plastic viscosity, yield point and apparent viscosity of the samples were calculated from equation 3, 4 and 5 and presented in Table 5

$$PV = \Theta_{600} - \Theta_{300} \quad (3)$$

$$YP = \Theta_{300} - PV \quad (4)$$

$$\mu_a = \frac{\theta 600}{2} \quad (5)$$

Where Θ_{600} and Θ_{300} are dial readings obtain at 600 rpm and 300 rpm respectively.

The result shows that the plastic and apparent viscosity of the samples decreases with increase in temperature. While sample B has no yield at all the temperature conditions, sample C has a slight yield at 50^{o}C and sample A yielded at all the temperature conditions.

Table 3: Rheology of the crude samples

Sample	Temperature conditions									
		Ambient			50°C			70° C		
A	Speed (rpm)	Dial reading			Dial reading			Dial reading		
		Increasing speed	Decreasing Speed	Average	Increasing speed	Decreasing Speed	Average	Increasing speed	Decreasing Speed	Average
	600	300		300	136		136	60		60
	300	152	150	151	73	70	71.5	35	28	31.5
	200	105	102	103.5	54	49	51.5	27	19	23
	100	55	51	53	25	23	24	15	9	12
	6	6	5	5.5	2	1	1.5	1	0	0.5
	3	4	2	3	2	1	1.5	0	0	0
B	Speed (rpm)	Dial reading			Dial reading			Dial reading		
		Increasing speed	Decreasing Speed	Average	Increasing speed	Decreasing Speed	Average	Increasing speed	Decreasing Speed	Average
	600	4		4	3		3	2		2
	300	2	2	2	1	1	1	1	1	1
	200	2	1	1.5	1	1	1	1	1	1
	100	1	1	1	1	0	0.5	1	0	0.5
	6	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0
C	Speed (rpm)	Dial reading			Dial reading			Dial reading		
		Increasing speed	Decreasing Speed	Average	Increasing speed	Decreasing Speed	Average	Increasing speed	Decreasing Speed	Average
	600	13		13	4		4	2		2
	300	6	6	6	2	3	2.5	1	1	1
	200	7	5	6	1	1	1	1	0	0.5
	100	5	2	3.5	1	0	0.5	0	0	0
	6	3	0	1.5	1	0	0.5	0	0	0
	3	2	0	1	0	0	0	0	0	0

Table 4: Shear stress and Shear rate of samples at Ambient, 50°C and 70°C

Speed (rpm)	Shear strain (1/sec)	Sample A			Sample B			Sample C		
		Shear stress at Ambient	Shear stress at 50 °C	Shear stress at 70 °C	Shear stress at Ambient	Shear stress at 50 °C	Shear stress at 70 °C	Shear stress at Ambient	Shear stress at 50 °C	Shear stress at 70 °C
600	2544	320.1	145.11	64.02	4.27	3.2	2.13	13.87	4.27	2.13
300	1272	161.12	76.3	33.61	2.13	1.07	1.07	6.4	2.67	1.07
200	848	110.43	54.95	24.54	1.6	1.07	1.07	6.4	1.07	0.53
100	424	56.55	25.61	12.8	1.07	0.53	0.53	3.73	0.53	0
6	25.44	5.87	1.6	0.53	0	0	0	1.6	0.53	0
3	12.72	3.2	1.6	0	0	0	0	1.07	0	0

The graphical presentation of the Shear stress and Shear strain at ambient, 50 °C, and 70 °C for all the samples are presented in Figure 1, 2 and 3.

Table 5: Plastic viscosity, Yield point and Apparent viscosity of the samples

Sample	Rheological Properties								
	Ambient			50 °C			70 °C		
	Plastic Viscosity (cp)	Yield point ($Ib/100ft^2$)	Apparent viscosity (cp)	Plastic Viscosity (cp)	Yield point ($Ib/100ft^2$)	Apparent viscosity(cp)	Plastic Viscosity (cp)	Yield point ($Ib/100ft^2$)	Apparent viscosity(cp)
A	149	2	150	64.5	7	68	28.5	3	30
B	2	0	2	2	-1	1.5	1	0	1
C	7	-1	6.5	1.5	1	2	1	0	1

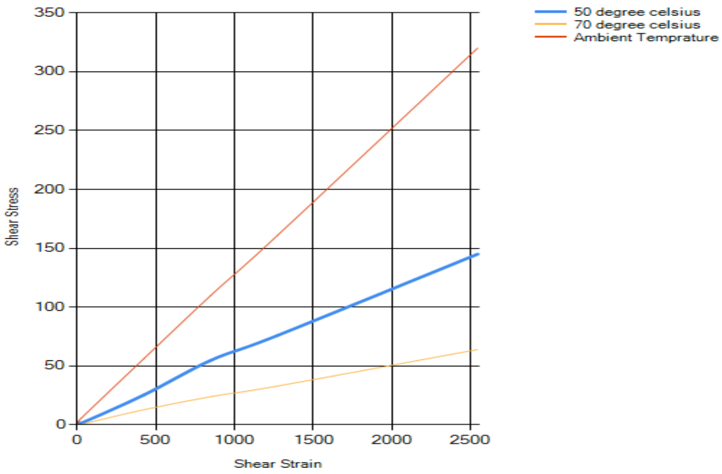

Figure 1: Shear stress Vs Shear strain for Sample A

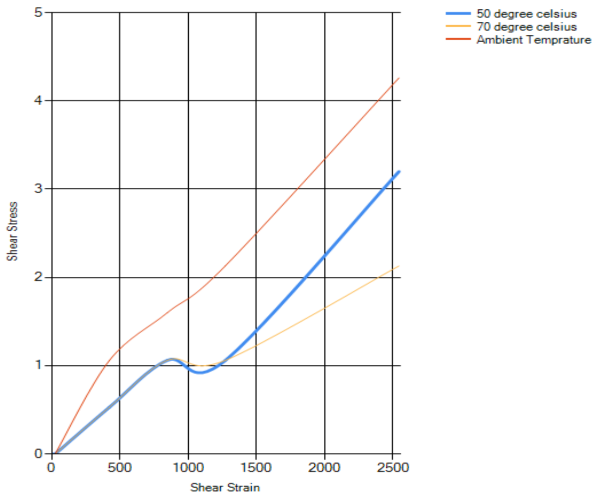

Figure 2: Shear stress Vs Shear strain for Sample B

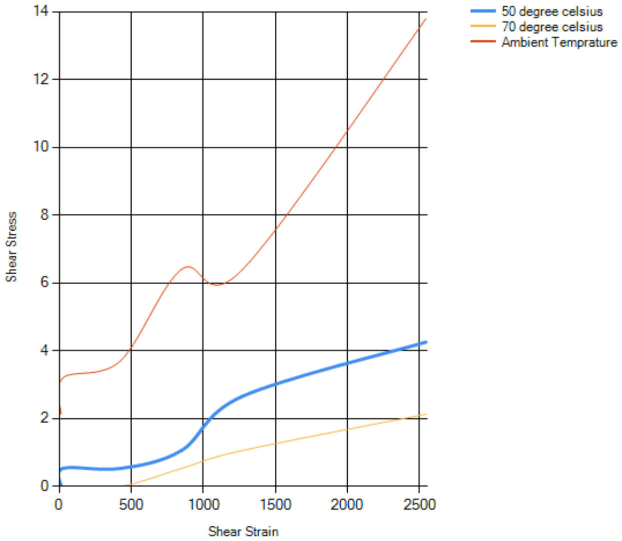

Figure 3: Shear stress Vs Shear strain for Sample C

3.4. Model for the shear stress and Shear strain for the samples

The models generated for shear strain, shear stress at Ambient, 50 °C, and 70 °C for sample A are presented in equation 6, 7, 8 and 9

$$\gamma = 4.24 * rpm - 3 * 10^{-13} \quad (6)$$

$$\tau_1 = 0.529rpm + 2.881 \quad (7)$$

$$\tau_2 = 0.241rpm + 2.119 \quad (8)$$

$$\tau_3 = 0.106rpm + 1.237 \quad (9)$$

Decrease in the speed of rotation decreases the shear strain and shear stress as the temperature increases for all samples.

Similarly, the models for shear stress at Ambient, 50°C, and 70°C for sample B are presented in equation 10, 11, and 12

$$\tau_4 = 0.007rpm + 0.096 \quad (10)$$

$$\tau_5 = 0.005rpm - 0.063 \quad (11)$$

$$\tau_6 = 0.003rpm + 0.093 \quad (12)$$

The relationship between the speed and shear stress for Sample C are within the range of the previous sample.

4. Conclusion

The result of this study has shown that Sample A (heavy crude) with high yield point (2Ib/100ft^2 at ambient, 7Ib/100ft^2 at 50°C, and 3Ib/100ft^2 at 70°C) exhibit non- Newtonian behavior while Sample B (medium crude), and Sample C (heavy crude) with no or slight yield exhibit Newtonian behavior. The effect of temperature on the rheological properties of crude is significant, as the result reveals that increase in the temperature of the samples decreased the viscosity which in turns enhances the flowing ability of the crude. Therefore, it can be inferred that flow of crude oil through pipelines and proper distribution can be achieved if the rheological properties of the crude is known. With the determination of the API gravity, and BS& W, proper treatment and processing can be done to meet API market specification before shipment.

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