CASE STUDY VOL. 5, 2019

ISSN 2394–3750 EISSN 2394–3769

SCIENCE & TECHNOLOGY

Viscosity analysis of crude oil: A case study of Nigeria Crude Oil

Hassan A

Department of Petroleum and Natural Gas Processing, Petroleum Training Institute (PTI), Effurun, Nigeria

Article History

Received: 19 September 2018

Accepted: 30 November 2018

Published: January 2019

Citation

Hassan A. Viscosity analysis of crude oil: A case study of Nigeria Crude Oil. *Science & Technology,* 2019, 5, 19-29

General Note

Article is recommended to print as color digital version in recycled paper.

ABSTRACT

Crude oil transportation is of great paramount considering the safety and economical effect associated with it. Viscosity of crude oil which is the measure of the resistance to shear or flow is an important factor in transporting crude oil. In this research work, four different samples of crude oil well in Nigeria which include Okpai well, Chevron, Hercules, and Total wells were selected and the selected samples were used to analyze and evaluate the viscosity of crude oil. The viscosity, and density were determined at the following temperatures (i.e., 25ºC, 35ºC, 45ºC and 55ºC) using a U-tube viscometer. The results obtained show that an increase in temperature led to a corresponding decrease in density of crude oil. Furthermore, it was observed that viscosity of crude oil is inversely proportional to their temperature. As the temperature of crude oil samples increases, their corresponding viscosity decreases and vice-versa. Thus, a lower temperature such as 25ºC that will bring about increase in viscosity of crude oil will hugely affect the transportation of the product by slowing down the flow process.

Key words: Crude oil, viscosity, fossil fuel, density, temperature, flow

1. INTRODUCTION

Crude oil or petroleum is a fossil fuel that is obtained remains of dead plants and animals millions of years ago. It is natural occurring, and unrefined petroleum product composing of hydrocarbon deposit. However, it can be refined to produce several finished petroleum products such kerosene, petrol, diesel, etc. Crude oil or petroleum is a hydrocarbon mixture that exists as a liquid in natural underground pools or reservoirs [1, 11-13]. It is often called "Black Gold", and it has a ranging viscosity that varies in colour such as black and yellow depending on its hydrocarbon composition [2]. The formation of crude oil or petroleum occurs in three major forms as follow [3-4];

i. The oil and gas we use today began as microscopic plants and animals living in the ocean millions of year ago. However, as these microscopic plants and animals lived, they absorbed energy from the sun that is stored as carbon molecules in their bodies. When these plants and animals died, they formed layer after layer of sediment.

ii. As the dead plants and animals segments became buried in deeper underground, heat and pressure began to rise. The amount of pressure and the degree of heat, along with the type of biomass, determined if the materials became oil or natural gas. Nevertheless, more heat produced lighter oil.

iii. After the formation of oil and natural gas, the products tend to migrate through tiny pores in the surrounding rock. Some oil and natural gas migrate all the way to the surface and escaped. However, other oil and natural gas deposited migrated until they were caught under impermeable layers of rock or clay where they were trapped. These trapped deposits are the oil and natural gas that are exploited today.

The elemental composition of crude oil is given in the Table 1. Carbon has the highest percentage composition. Moreover, crude oils can be classified in some number of ways such as [5]:

Table 1 Elemental Composition of Crude Oil

Elements	Percentage Weight (%)
Carbon	85 – 87
Hydrogen	10 - 14
Sulphur	0.05 – 6
Nitrogen	0.1 – 2
Oxygen	0.05 – 1.5
Trace metals	0.1 – 0.2
Sediments	0.8 – 1.0

Based on the Knowledge of Hydrocarbons essentially dominant in Crude Oil

This involves the use of characterization factor K. This was develop by Waston [6]

$$K_w = \frac{3\sqrt{T^0F+460}}{specific\ gravity} \quad (1)$$

where,

T = Average molar boiling point in Kelvin

K = 12.5 -13.0, if Paraffinic hydrocarbons are dominant, hence paraffin based crude

K = 11.0- 12.0, if Naphthenic hydrocarbons are dominant hence naphthenic based crude

K = 9.8 — 11.0, if Aromatic hydrocarbon are dominant and hence aromatic based crude

Paraffinic Crude Oil

Paraffin is a saturated hydrocarbon with a single bond that haves a general molecular formula of C_nH_{2n+2} (e.g. methane, ethane, propane etc.) [7], the first member of this group is methane (CH_4) also known as swamp gas because it is mostly found in the creeks. The other members of the group are ethane, propane and butane. The residue obtained from refinery prospects are called paraffin waxes, both plastics and solids.

Naphthenic Crude Oil

Naphthenic crude oil is an unsaturated chain compound. The residues obtained from refinery prospects are called Naphthene asphalt. The crude oil that is predominant in these series predominate is called asphalt based crude oil. Asphalts are normally heavy with very high temperatures.

Aromatic Crude Oil

It is a hydrocarbon of unsaturated closed range series. In this group, Benzene is the most common member of the group and it is present in all refinery products.

Classification of Crude Oil based on API gravity

$$°API = \frac{141.5}{P15/15} - 131.5 \quad (2)$$

When °API> 31.1, this implies light crude

22.3 ≤ °API<31.1, this implies medium crude

°API< 22.3, this implies heavy crude

Classification of Crude Oil based on Sulphur Content

Crude oil may be classified as sour or sweet crude depending on the sulphur content of such crude [8];

Sour Crude

Crude oil containing free sulphur, hydrogen sulphide (H_2S), or other sulphur-containing compounds in amounts greater than 1% is considered sour crude (SPE definition). As in the case with sour gas, the sulphur must be removed from the crude oil before the oil can be refined and the refiner pays less for oil that contains sulphur. Sour crude is usually processed into heavy oil such as diesel and fuel oil rather than the gasoline to reduce processing costs (i.e., crude oil with sulfur content >0.5 wt% is said to be sour).

Sweet Crude

Oil that contains little or no sulphur is called sweet crude (i.e. crude oil with sulphur content <0.Swt% is said be sweet) [8].

Classification of Crude Oil based on the US Bureau of Mines

This classification is based on;

Key Fraction No 1

The crude is distilled and fraction boiling between 250-275°C is collected at atmospheric pressure. The specific gravity or API gravity is determined.

Key Fraction NO 2

Fraction boiling between 275 -300°C is collected during vacuum distillation at 40 mmHg. The specific gravity or API gravity is determined.

Viscosity is simply the measure of the resistance to fluids shear or flow [9]. The knowledge of viscosity is highly requires in reservoirs simulations and fluid flow through porous media and pipelines, well testing and design of production pipelines, well testing and design to production equipment [10]. Nevertheless, crude oil viscosity can be classified into three (3) regimes [11];

Bubble Point Oil Viscosity

Is the viscosity of crude oil at the bubble point pressure, given temperature point pressure and a given temperature oil viscosity.

Oil Viscosity above the Bubble Point

Oil viscosity above bubble point is defined as the viscosity at a pressure higher than the bubble point pressure and a given temperature.

Oil Viscosity below the Bubble Point

This is the viscosity of crude oil below the bubble point pressure and a given temperature with the lowering of pressure below the bubble point pressure gas is related leaving behind saturated oil at the new pressure.

Viscosity can be further classified into absolute viscosity and the kinematics [10]. Both are measured in metric forms. Dynamic or absolute viscosity is measures in poise, centi-poise, while kinematic viscosity is measured in stokes, centi-stokes. Any engineering activities including piping and pipelines constructions and also flow of crudes or fluids require the knowledge of the viscosity of crude oil to enhance smooth transportation. Viscosity plays a vital role in reservoir simulations as well as in determining the structure of liquids (crude oils). In that regard, the results of this research work can be used to predicts and analyzed the viscosity of some selected Nigerian Crude oil

Determination of Viscosity of Crude Oil

The viscosity of crude oil can be determined in the following ways:

By using Boiling Point Test

Crude oil components have different boiling points. The boiling point test method subjects crude oil to high temperatures and separate whenever each component reaches its boiling point. The lower the temperatures required for separating the crude into its components, the lower the viscosity of the crude oil, and vice versa.

By using Thermodynamic Properties Prediction

This method makes use of critical properties such as pressure and molecular weight to determine the viscosity behavior of crude oil. They measure and compare these characteristics with past experiments before checking the results for similarities, For instance, if past experiments indicate that crude oil of a certain molecular weight had a viscosity of 1000 centipoises when pumped at a pressure of 30,000 pounds per square inch, engineers can determine the possible viscosity of crude oil of a simple molecular weight pumped at a pressure of 60,000 pounds per square inch.

By the use of a Viscometer

In the laboratory, engineers may choose to use a viscometer. Viscometer on the other hand, is an instrument used to measure the viscosity of a fluid in most circumstances. It however works for fluids whose viscosity does not change under varying flow conditions; but rheometers must be used when the viscosity does change with flow conditions. Viscometers usually work by comparing a stationary object and a fluid flow, or vice versa. Hence, a viscometer could be placed in a fluid flow or moved through a stationary fluid. The flow must have a Reynolds number in the laminar region in order to record accurate values. The measure of the resistance is taken by measuring the drag resistance during relative motion through the fluid. There are various types of viscometer which include:

- U-Tube Viscometers
- Falling sphere Viscometers
- Vibrational Viscometers
- Rotational Viscometers etc.

2. MATERIALS AND METHOD

Materials

The materials used in this research work include crude oil samples from:

- Okpai oil well no. (Okp-03)
- Chevron oil well no. (Esc-01)
- Hercules oil well no. (HRN-02) and
- Total oil well no. (OB-12)

The following equipment/apparatus were used for density test

- Pyknometer
- Electronic weighing balance
- Thermometer
- Viscometer

Methods

The bath was filled with distilled water, and it was maintained at a constant temperature. The necessary corrections were applied, if any, to all thermometer headings. A clean dry, calibrated viscometer having a range covering the estimated viscosity was selected (i.e. a wide capillary for a very viscous liquid and a narrower capillary for a less viscous liquid), and the flow time was not less than 200 seconds. The viscometer in the bath was set such that the straight portion of the capillary is vertical and the upper filling mark H was about 3cm below the surface of the liquid. Thereafter, the viscometer was allowed to reach the bath temperature and then sufficient quantity of the filtered text liquid X was poured into the filling tube (1) to a point just below the filling mark I-I. The liquid was allowed to flow through the capillary (5), taking care that the liquid column remains unbroken until it reaches a position about 5mm below the filling mark G. Timing tube (2) was closed at this point by arresting its flow with a well — fitted rubber bung. It is desirable that the rubber hung should be fitted with a glass tube and stop clock so that one can apply a considerable, very slight excess pressure to tube (2). More liquid was added to the filling tube (1) to bring the oil surface to just below mark H, and the sample was allowed to reach the bath temperature and any air bubbles to reach to the surface (at least 30 minutes is required). The stopwatch or the bung closing tube (2) was gently manipulated until the level of the liquid was arrested exactly at mark G and the uppermost meniscus of contact of the liquid with the glass coincided with the bottom of mark G. Liquid was added to tube (1) until the upper-most meniscus of its contact with tube (1) coincides with the bottom of mark H. Sufficient time was allowed for this additional amount of sample to reach the bath temperature and the rubber bung was removed or the stop was open to the atmosphere. After that, the liquid was allowed to flow under its own head. The time in seconds for the uppermost ring of contact of the liquid with the glass was measured to rise from the bottom of mark E to the bottom of mark F. The viscometer was cleaned and the procedure was repeated with a different sample supplied. Only one turning per filling is permissible with this type of viscometer.

Determination of Density

A thoroughly cleaned and dried measuring cylinder was weighed using an electronic weighing machine and its weight (W_1) was recorded. 50m1 of the sample was introduced into the measuring cylinder and the weight of the measuring cylinder and the content (W_2) was determined. The density of the substance being the mass per unit volume of the substance is determined by taking the ratio of the mass of the sample to the volume of the sample that corresponds to that mass, The above procedures were repeated for the other samples.

Viscometer Cleaning

The following procedures were followed;

- For liquids which were sufficiently fluid at room temperature, I removed the viscometer from the bath, invert and allow draining.
- I Cleaned thoroughly by rising with suitable solvents and finally with a volatile solvent such as ethyl ether, and then allowed to drain.
- For liquid which do not drain readily, I left the viscometer in the bath, force the liquid back into the filling tube by blowing or by applying a pressure of about 3mbar (approximately 20 in water) in the timing tube and then proceeded as above. Periodically, (or whenever the appearance of the viscometer shown the necessity to do so). I cleaned the instrument with chromic acid mixture.

Principle of the Experiment

In the kinematic viscosity test, the time is measured for a fixed volume of the sample, contained in a glass viscometer, to flow under gravity through a calibrated capillary tube under a reproducible head of liquid and controlled temperature. The time is used to calculate the kinematic viscosity and the results are reported as centistokes. The dynamic viscosity can then be obtained by multiplying the measured kinematic viscosity by the density of the liquid.

3. RESULTS AND DISCUSSION

The results obtained for viscosity and density of the selected crude oils samples collected in Nigeriaare shown in Table 2.

Table 2 Experimental Results of Density and Viscosity of Selected Nigeria Crude Oils

Samples	Temp(^{0}C)	Flow time (S)	V(Centistokes)	Density (g/cm^3)	μ(cp)
Okpai Crude Oil	25	3007	105.25	0.925	97.35
	35	2232	78.12	0.917	71.64
	45	1506	52.71	0.910	47.97

	55	1155	40.43	0.902	36.47
	65	850	29.75	0.895	26.63
Total Crude Oil	25	1072	37.52	0.862	32.34
	35	801	28.01	0.854	23.92
	45	613	21.46	0.846	18.16
	55	478	16.73	0.840	14.05
	65	391	13.69	0.832	11.39
Chevron Crude Oil	25	918	32.13	0.842	27.05
	35	697	24.40	0.834	20.35
	45	533	18.66	0.826	15.41
	55	421	14.74	0.820	12.09
	65	337	11.79	0.812	9.57
Hercules Crude Oil	25	761	26.64	0.833	22.19
	35	594	20.79	0.826	17.17
	45	421	14.74	0.819	12.07
	55	371	12.99	0.812	10.55
	65	313	10.96	0.805	8.82

Figure 1 shows the graph of kinematic viscosity against temperature for Okpai crude oil. Figure 2 shows the graph of kinematic viscosity against temperature for Total crude oil. Figure 3 shows the graph of kinematic viscosity against temperature for Chevron crude oil.

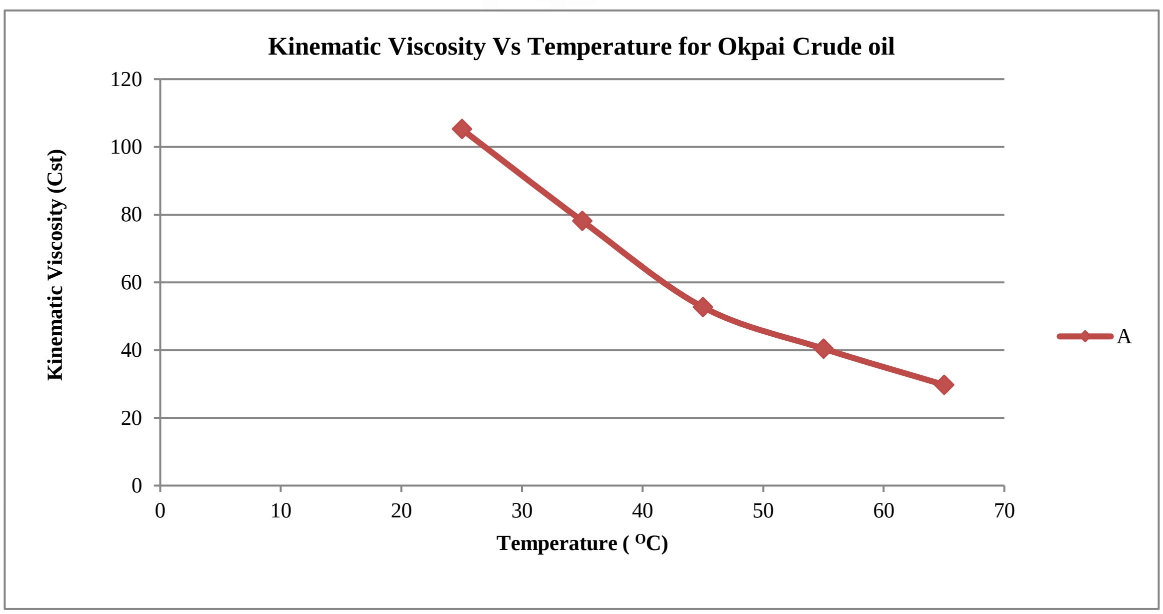

Figure 1 Graph of Kinematic Viscosity against Temperature for Okpai Crude Oil

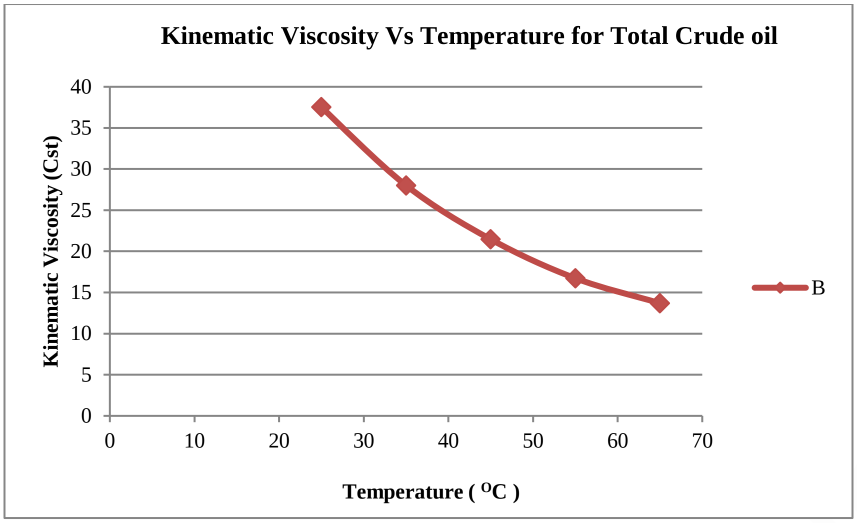

Figure 2 Graph of Kinematic Viscosity against Temperature for Total crude oil

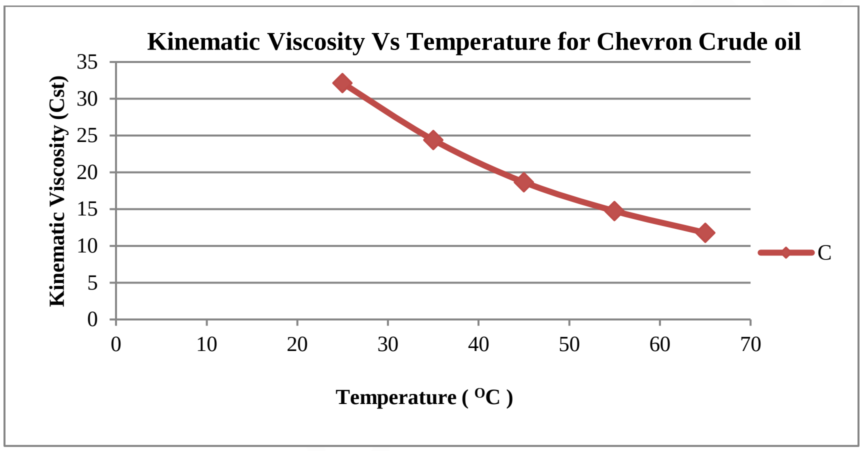

Figure 3 Graph of Kinematic Viscosity against Temperature for Chevron Crude Oil

Figure 4 shows the graph of kinematic viscosity against temperature for Hercules crude oil. Figure 5 shows the graph of kinematic viscosity against temperature for all crude oil samples. Figure 6 shows the graph of dynamic viscosity against temperature for Okpai crude oil.

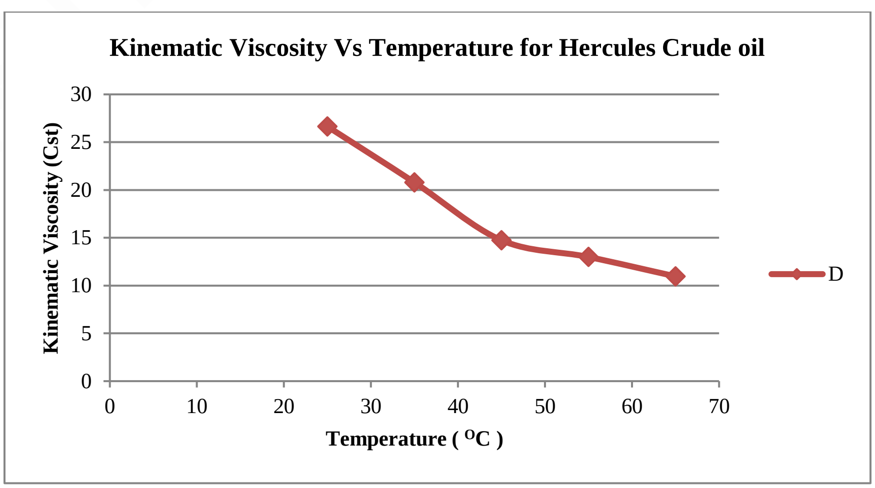

Figure 4 Graph of Kinematic Viscosity against Temperature for Total crude oil

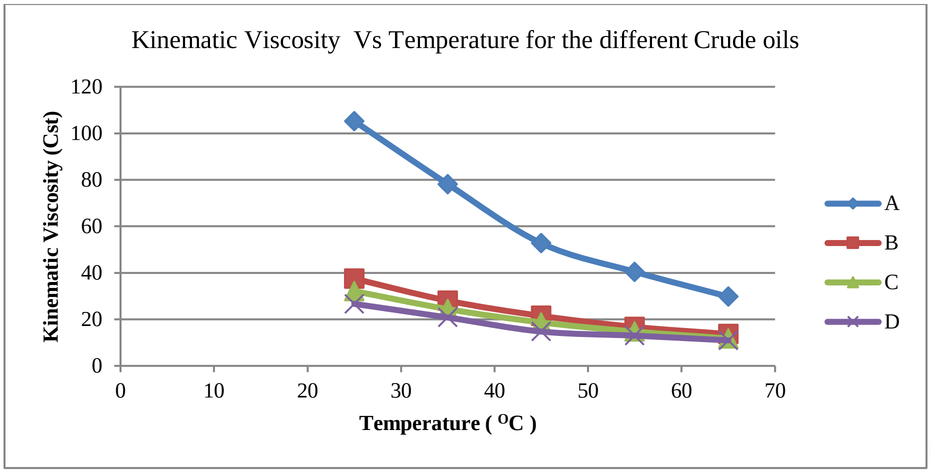

Figure 5 Graph of Kinematic Viscosity against Temperature for all crude oil samples

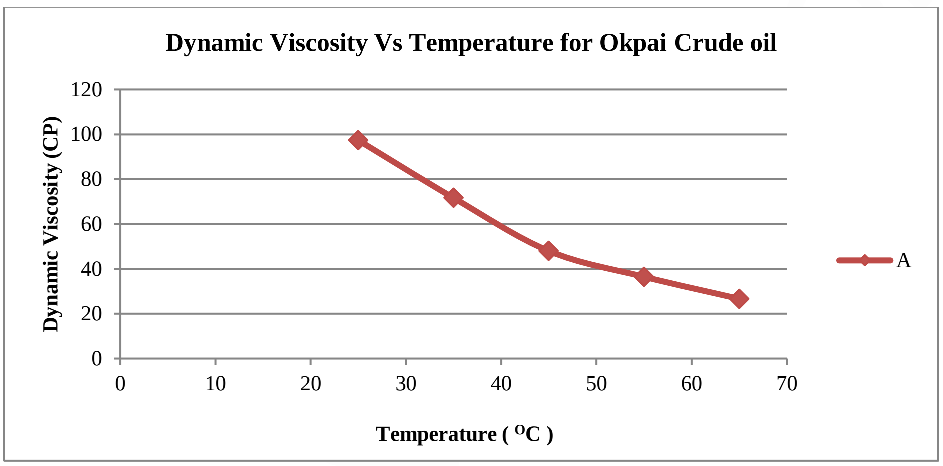

Figure 6 Graph of Dynamic Viscosity against Temperature for Okpai Crude Oil

Figure 7 shows the graph of dynamic viscosity against temperature for total crude oil. Figure 8 shows the graph of dynamic viscosity against temperature for Chevron crude oil. Figure 9 shows the graph of dynamic viscosity against temperature for Hercules crude oil.

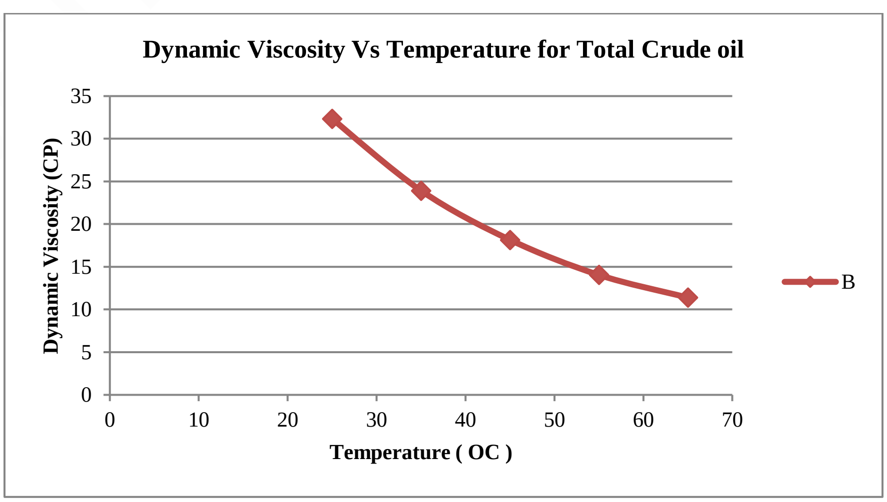

Figure 7 Graph of Dynamic Viscosity against Temperature for Total Crude Oil.

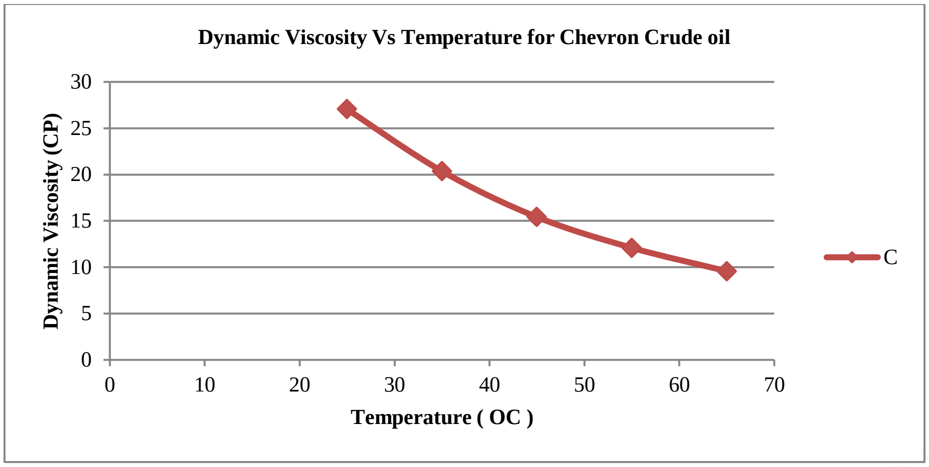

Figure 8 Graph of Dynamic Viscosity against Temperature for Chevron Crude Oil

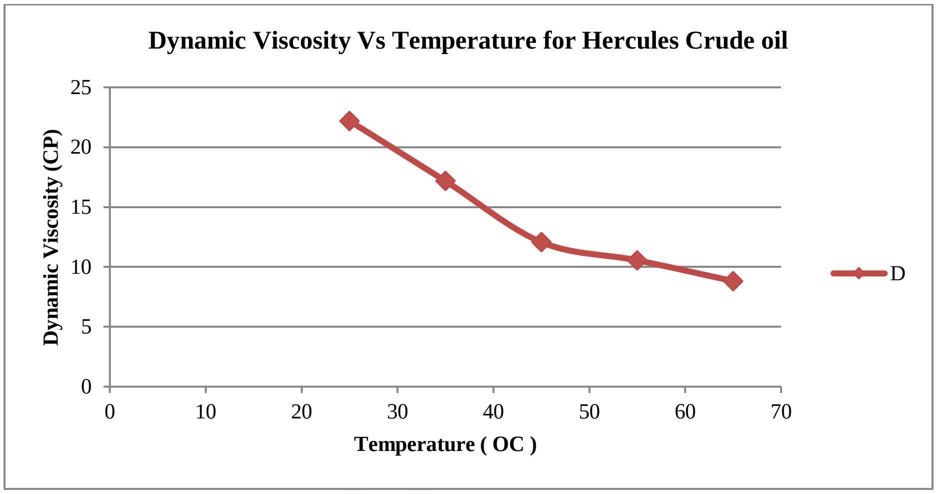

Figure 9 Graph of Dynamic Viscosity against Temperature for Hercules Crude Oil

Figure 10 shows the graph of dynamic viscosity against temperature for all crude oil. Figure 11 shows the graph of density against temperature for Okpai crude oil. Figure 12 shows the graph of density against temperature for Total crude oil. Figure 13 shows the graph of density against temperature for Chevron crude oil.

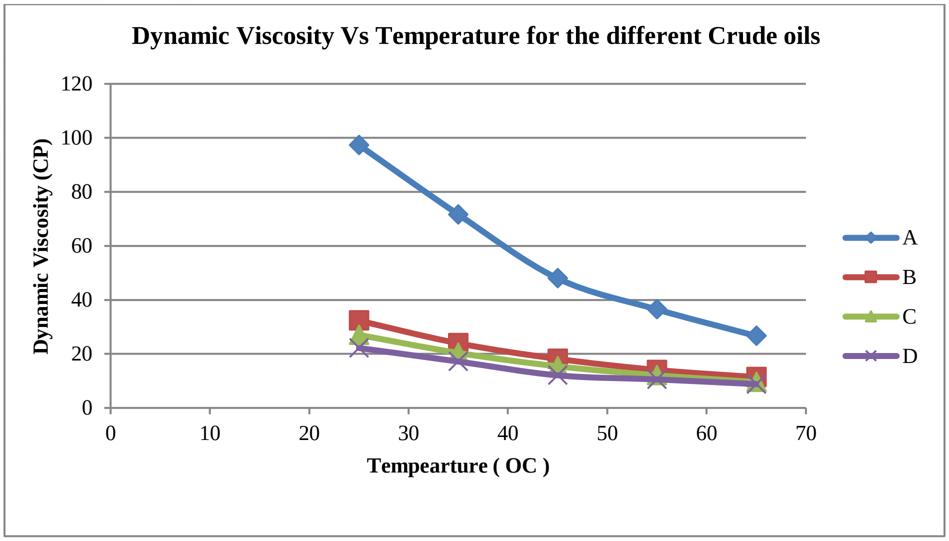

Figure 10 Graph of Dynamic Viscosity against Temperature for all Crude Oil

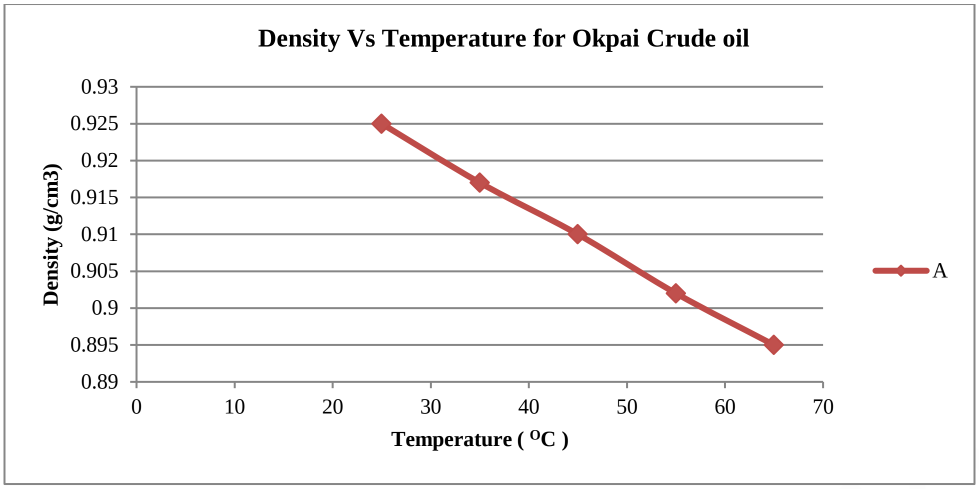

Figure 11 Graph of Density against Temperature for Okpai Crude Oil

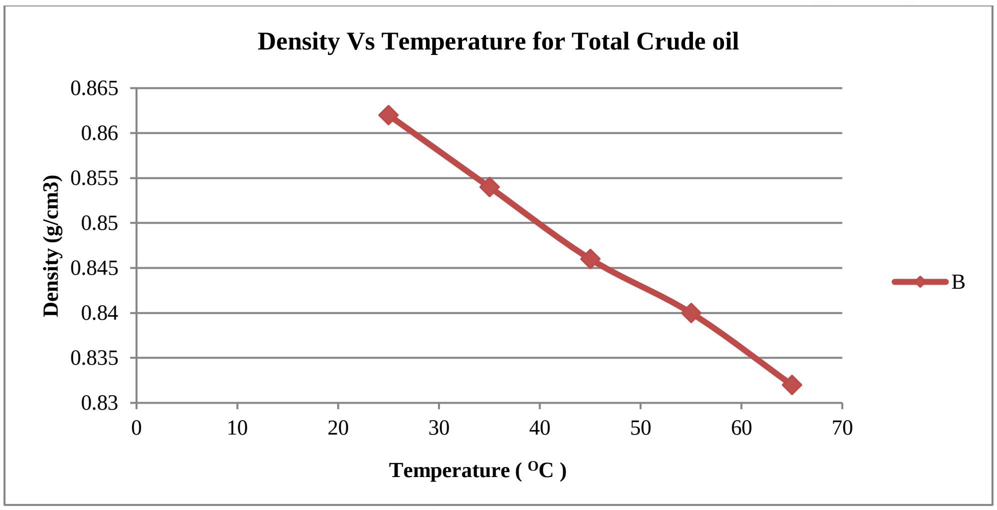

Figure 12 Graph of density against Temperature for Total Crude Oil.

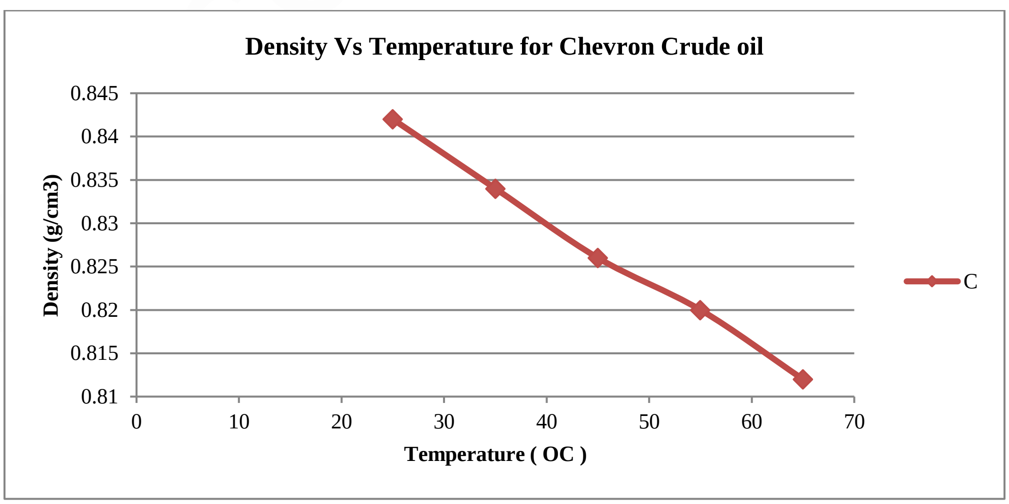

Figure 13 Graph of Density against Temperature for Chevron crude oil.

The understanding of viscosity in fluids especially in the crude oil industry is of great important considering the roles it plays during transportation of the product via pipeline. Pipeline for carry crude oil products are specially constructed with knowledge of viscosity analysis. In this research work, selected crude oil wells in Nigeria were used to evaluate the effect of viscosity on crude oil at different temperature. The results obtained with the experimentation of four different oil well samples collected in Nigeria shown that their viscosity varies. The kinematic viscosity results of the four crude oils samples viaOkpai well, chevron, Hercules, and Total, revealed that Okpai oils is highly viscous and its time of flow where at the respective temperatures of 25ºC, 35ºC, 45ºC and 55ºC was greater when compared to that of the other three other crude oils temperature. Moreover, the results showed that the product would be difficult to transport mostly at 25ºC through pipeline. More energy would therefore require to transports the product with such viciousness from the well to the refinery. The viscosity of Okpai and Total especially, when passing through the U-tube capillary was high and this was due to their thick textures. The graph of temperatures against the different sample of shows that increase in temperature brought about decrease in viscosity of the various samples used. Similarly, increase in temperature of the crude oils brought about a corresponding decrease in the density of the crude oils as depicted in the graph.

4. CONCLUSION

Having successfully carried out this research work on viscosity analysis of crude oil; a case study of Nigeria crude oil**,** it can be deduce that viscosity affects the transportation of Okpai well, Chevron, Hercules, and Total crude oil. Besides, the viscosity of each crude oil samples varies; some are thicker textures than others. Also the density of the various crude oils determined show that increase in temperature lead to corresponding decrease in their densities respectively. However, drop in temperature brings about increase in viscosity, thus more energy is required for the transportation of the products via pipeline. Therefore, in siting a pipeline for crude oil transportation, temperature, viscosity, and density of the crude oil must be properly considered.

REFERENCE

1. Cyril, "Comparative Viscosity Analysis of some Nigerian Crude Oil"(Project Review), 2013.
2. O.S. Isehunwa, Olamijoke and A.A. Makinde, "A Correlation to Predict the Viscosity of Light Crude Oils", 2006
3. P. Alfon, J.W. Soedarsono, D. Priadi, and S. Sulistijono, "Pipeline Material ReliabilityAnalysis Regarding to Probability of Failure Using Corrosion Degradation Model." Advanced Materials Research, 422, 705-715, 2012
4. V.Batac, and M. Tatlonghari, "The Behavior of Exchange Rates, Crude Oil Prices, and Money Supply and their Effects on Philippine Stock Market Performance: A Cointegration Analysis", Rev. Integr. Bus. Econ. Res. 2(2), 60 -227, 2013
5. M. Joly, L. Moro and J. M. Pinto, "Planning and scheduling for petroleum refineries using mathematical programming." Brazilian Journal of Chemical Engineering, 19, 207-228, 2002
6. L.O. Oyenkunle and O.A. Famakum, "Studies of Nigerian crude and characterization of crude oil mixture petroleum science and technology", 22 (5&6): 665 – 675, 2004
7. J. Kendall and K.P.Monroe, "The Viscosity of Liquid"Journal of Acs, Vol. 39 (1917), 1787-1806, 1917
8. J.G.Speight, Handbook of Petroleum analysis John Wiley and sons publication, New York, 2001
9. R.S. Khurmi, and J.K. Gupta, A Textbook of Machine Design, S. Chand and Company LTD, Ram Nagar, New Delhi, 2009
10. R.K. Rajput, A Textbook of Fluid Mechanics and Hydraulic Machines, S. Chand and Company LTD, Ram Nagar, New Delhi, 2009
11. Ukpaka CP. Performance Evaluation of Batch Reactor for Sodium Benzoate Production. Discovery, 2018, 54(274), 387-396
12. Karkush MO, Abdul Kareem MS. Impacts of petroleum fuel oil contamination on the geotechnical properties of fine-grained soils. Indian Journal of Engineering, 2018, 15, 228-237
13. Shaker M Arafat, Amany M Basuny, Hanaa M Soliman. Olive waste oil an economical source for biodiesel. Discovery, 2017, 53(260), 429-436