International Journal of Engineering and Technical Research (IJETR)
ISSN: 2321-0869, Volume-2, Issue-10, October 2014

Modeling of the Viscosity behavior of Weathered and Unweathered Bonny Light Crude Oils

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Abstract— **A modified Puttagunta equation having new values of the shape factor and asymptotic limits was developed and used to estimate the kinematic viscosity- temperature behavior of Bonny Light crude oil which has undergone various degrees of weathering. The crude oil weathering process was simulated experimentally. One of the three parameters of the viscosity model was found to be constant and correlations for the variations of the other two parameters with changes in temperature and extent of weathering obtained. Overall average absolute deviations (AAD %) values of 3.09 and 3.22 were obtained with values of other goodness of fit indicators further validating the model.**

Index Terms— **Correlation, Crude oil, Models, Viscosity, Weathering.**

I. INTRODUCTION

One of the inevitable challenges encountered during oil exploration, production and transportation is the occurrence of oil spills which can arise from a variety of sources. With the rise in oil exploration activities to meet the increasing dependence of man on fossil fuels for energy, it becomes imperative to gain greater insight of the behavior and fate of spilled oil [1, 2]. Spilled oil undergoes various transport and transformational processes collectively known as weathering [1, 3, 4, 5, 6], resulting in marked changes in its physical and chemical characteristics. Some of the key weathering processes that determine the behavior and fate of oil spilled on water are evaporation, spreading, dissolution, natural dispersion into the water column, emulsification, advection, turbulent diffusion, hydrolysis, photo- oxidation, biodegradation, and particulation [7, 8]. There are several incentives for studies on the behavior of oil during weathering some of which include forensic oil source identification, monitoring of the oil weathering process in the environment, and characterization of the environmentally important constituents in the oil for environmental impact assessment and evaluation of remediation alternatives [2, 4, 9 10,].

Also of prime importance is the change in viscosity experienced by the oil as it undergoes weathering. Crude oil viscosity is a key parameter whose accurate value has to be obtained for use in the design and operation of crude oil processing and transportation equipment. It is usually preferable to seek a suitable correlation for obtaining this parameter than resorting to expensive and rigorous experimental procedures each time its value is required. This has led to the development of several models of varying complexities for predicting the viscosities of several crude oil types. Generally, simple models that have fewer parameters to be determined are usually more attractive than their complex counterparts, especially when they offer comparative accuracy over similar range of application.

Early correlations like that of Walther [11] formed the foundation and basis for many of the subsequent models developed. Some of the successful and widely used models include those of Amin and Maddox[12], Beg et al[13], Moharam et al[14], Al-Besharah et al[15], Puttagunta et al[16] and Mehrota[17]. Studies by Miadonye and Puttagunta[18] and Abdukareem and Kovo[19] have indicated that the viscosity correlation of Puttagunta at al[16] is the most suitable for accurate prediction of the viscosity-temperature relationship of Nigerian crude oils. This model equation has the form

$$Ln(\zeta) = \{b / [1 - (T - 37.78)/310.93]^s\} + C \qquad (1)$$

In this equation, ζ is the kinematic viscosity (cSt), T is the temperature (^{0}C), C is a constant which gives the asymptotic limit of the decreasing viscosity values (as temperature is increased) for each crude type, b and s are model parameters which are dependent on the crude oil kinematic viscosity at 37.78 ^{0}C.

The objective of this work is to obtain the parameter values of the Puttagunta equation that best describes the viscosity changes experienced by the oil as it undergoes weathering, by regression of the experimental viscosity values.

II. 2.0 MATERIALS AND METHODS

A. Crude Oil Type and Source

Bonny light crude oil sourced from Oredo #2 well, zone B3.0, Nigeria was used for this study. The assay of this crude type indicates that its key properties fall within the following ranges: kinematic viscosity @40^{0}C, 2.5 -7.4 cSt, API gravity,35.3, Pour point, -11.48^{0}C,Specific gravity @ 15^{0}C, 0.813-0.850 [19,20]. This crude was not subjected to further pretreatment before use except for the physical separation of sediments, water and gas from it carried out at the flow station to reduce its Basic Sediments & Water content to below 0.1 wt % to meet pipeline specifications.

Manuscript received October 12, 2014.

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B. Weathering Method and Apparatus

The crude oil weathering was carried out in equipment similar to that described by Mehta[3] which allows for simultaneous spreading and evaporation of the crude oil. The apparatus basically consists of a 2ft X 2ft corrugated iron sheet inclined at an angle of 45^0 over which the oil cascades down and weathers. Other parts of the apparatus are the angle iron support, the perforated pipe that spreads the oil over the corrugated sheet, the pump that circulates the oil, the flexible pipe tubing, and a calibrated cylinder which indicates the degree of weathering. A schematic illustration of the apparatus and the continuous crude oil flow path is shown in fig. 1.

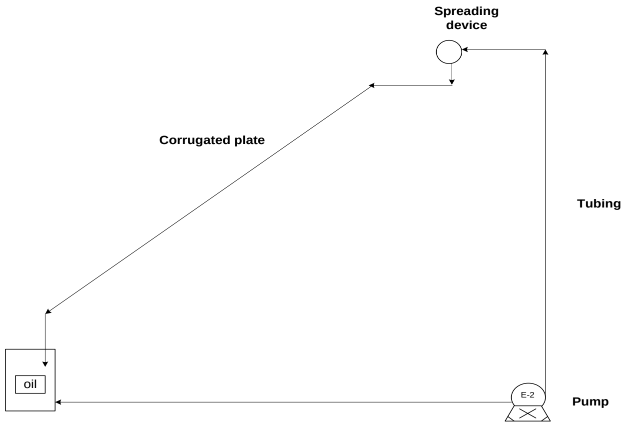

Figure 1: Schematic diagram of apparatus for crude oil weathering.

The cardinal objective was to achieve a continuous and even spread of the crude oil over the corrugated plate such that weathering by spreading and evaporation would occur. Crude oil was poured into the calibrated cylinder and circulated by the pump at a flow rate of 2 liters/min through the tubing to the perforated pipe spreading device. It then flowed over the inclined corrugated plate from where it was channeled back into the calibrated cylinder. The pump re-circulated the crude oil continuously throughout the duration of the experiment. The initial volume of crude oil in the calibrated cylinder when steady state flow rate had been achieved was noted and the degree of weathering obtained from the drop in the volume of oil in the cylinder. Weathered oil samples were drawn off for analysis when the crude oil had evaporated by 15%, 20%,30%,40%,60% and 85% based on the initial volume of the oil.

C. DETERMINATION OF CRUDE OIL VISCOSITIES

The kinematic viscosity values of the crude oil samples were determined with the ASTM [D- 445-6] method for both the unweathered samples and the samples that had undergone various degrees of weathering. A total of 49 data points were obtained at 10^0C intervals between a temperature range of 40^0C and 100^0C.

III. RESULTS AND DISCUSSION

The variation of viscosity with temperature is shown in table 1 below:

From the experimental data, the following observations were made:

1. At a constant temperature, the kinematic viscosity increases with increase in the degree or extent of weathering.

2. At a particular degree of weathering, the kinematic viscosity decreases with increase in temperature.

3. The decrease in kinematic viscosity with temperature for a particular degree of weathering varies for the weathered and unweathered samples as follows:
(a) For the unweathered sample, the kinematic viscosity decreases at almost a constant rate with change in temperature.
(b) For the weathered samples, the rate of decrease is higher at low temperatures, and then decreases as temperature increases.
4. Increase in the kinematic viscosity with degree of weathering at constant temperature is higher at low temperatures than at high temperatures generally.

5. Decrease in kinematic viscosity at constant degree of weathering and with increase in temperature is less for lower degrees of weathering and higher at higher degrees of weathering. Thus the rate of kinematic viscosity decrease with temperature and constant degree of weathering increases with increase in degree of weathering.

To fit the data to the Puttagunta model, equation (1) is rearranged to give equation (2) below:

Kinematic viscosity,

$$\zeta = \exp[\, b/(1 + (T - 37.78)/310.93)^{s} + C\,] \qquad (2)$$

The kinematic viscosity data was fit to equation (2) using the curve fitting toolbox of Matlab 7.0 and the numerical fit results obtained is as shown in table (2) below.

The model as presented fits accurately to the data at all levels of weathering with $R^2 > 0.99$ and overall AAD(%) of 3.09,but the following observations were also made;

1. The values of the parameters (b,s & C) obtained for the unweathered sample are different from those obtained at various degrees of weathering.

2. The value of the parameter "b" oscillates, thus "b" could be treated as a constant that does not change with changes in the degree of weathering. The oscillation may be due to minor fit computation and experimental errors.

3. The value of "s" tends to increase with increase in degree of weathering from 15 % to 85 % with minor oscillation.

4. The value of "C" also tends to increase from negative to positive values as degree of weathering increases, with minor oscillation.

Based on observation 2, we obtain an average value of "b". The average value of "b" of 1.9725 which has a maximum deviation of $\pm$ 0.2115 from all the calculated values of "b" was used to fit the model again to validate the assumption that the "b" is constant or otherwise reject it. The parameter values obtained from the new fit is given in table 3 below;

The following observations were made in the fit with the value of "b" held constant at 1.9725;

1. The data fit accurately to the model with $R^2 > 0.99$ and overall AAD (%) of 3.22. The assumption that "b" is constant at all degrees of weathering is validated because from the results from the numerical fit remained relatively the same with the previously obtained values.

2. The value of "s" increases with increase in degree of weathering. Keeping "b" constant has made this previous observation more profound.

3. The value of "C" clearly increases with increase in degree of weathering. Keeping "b" constant helped remove all oscillations in the value of "C" that were observed in the previous fit results that considered "b" as a variable parameter with respect to degree of weathering.

4. Observation of increase in "C" & "s" agree with general observation of the data that an increase in "C" causes the kinematic viscosity to decrease with increasing temperature, and increase in "s" causes the kinematic viscosity to increase with increasing degree of weathering, even though the temperature may remain constant.

Since "b" is held constant, it is useful to get an insight into the variation in the parameters "C" and "s" as crude oil weathering progresses. A model fit for increase in "C" and "s" with degree of weathering is given below;

$$C = 0.2011 \exp(1.281y) - 1.201 \exp(-8.68y), \quad (R^2 = 0.9802)$$

$$s = 8.559 \exp(0.3948y) - 8.719 \exp(-8.121y), \quad (R^2 = 0.9298)$$

Where y represents degree of weathering in decimals (i.e. 0.15, 0.20,…0.85) and not in percentages.

IV. CONCLUSIONS

Better understanding of the viscosity variations accompanying the crude oil weathering process is of utmost importance to the oil industry and is especially useful for the recovery and treatment of weathered crudes. A modified Puttagunta model was presented with parameters accounting for the effects of temperature and degree of weathering on Bonny Light crude oil. The predicted viscosities compared favourably with the experimental data, with AAD < 5% for all samples and other goodness of fit indicators within acceptable limits.

V. NOMENCLATURE

AAD = average absolute deviation (%)
b = parameter in the viscosity model
C = parameter in the viscosity model
RMST = root mean square total
R^2 = coefficient of determination
s = parameter in the viscosity model
SST = sum of squares for treatments
y = degree of weathering (in decimals)

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