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# Comparative Analysis of Saturated and Under-saturated oil Viscosity Correlations using Statistical Tools, Niger Delta Case Study

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**Abstract.** Crude oil viscosity is one of the most important fluid properties that affects fluid flow behavior; either in pipeline hydraulics or in the porous media (reservoir). Viscosity is a vital physical property that plays a major role in the petroleum industry, the production processing and transportation of oil due to influence on the flow through porous rock, oil wells, multiphase flow through tubing and piping system. Therefore, the need for accurate determination of viscosity for oil and gas applications cannot be overemphasized. Numerous empirical correlations exist in literature for predicting crude oil viscosity but their accuracy is limited based on range of conditions of application, composition of the crude used in developing the correlation, specific range of data and experimental conditions. In the present work, experimental data of oil viscosity from different samples of Nigerian oil reservoirs were statistically compared with correlation predicted viscosity using the most common viscosity empirical correlations. Validity and accuracy of these empirical models has been confirmed for both saturated and under-saturated Niger Delta oil samples. It was observed that for under-saturated oil viscosities, Elshawarky & Alikhan's correlation gave a better prediction based on the Absolute average percentage error and standard deviation while for the case of saturated oil viscosities Chew and Connally proved to be the closest to the experimental results.

**Keywords:** Viscosity, Statistical analysis, Crude oil

## 1. Introduction

Fluid sampling is a vital aspect of the petroleum engineering. Fluid sampling enables the understanding of the behaviour of various reservoir fluids as they exhibit distinct behaviour based on their composition/properties. Viscosity is an important aspect of fluid sampling as it affects the fluid flow behaviour. Viscosity is generally known as an intensive property of a fluid that causes an internal resistance of the fluid to flow<sup>1</sup>. Crude oil viscosity, a Newtonian fluid is a vital physical property that plays a major role in the petroleum industry, the production processing and transportation of oil due to its influence on the flow through porous rock, oil wells, multiphase flow through tubing and piping system<sup>12</sup>. Crude oil viscosity plays a major controlling and determining role in the successful implementation of secondary recovery process, EOR processes and reservoir simulation modeling. Optimum reservoir management and sound design facilities is hinged on reliable evaluation of viscosity data<sup>1</sup>.



Viscosity is often determined using PVT analysis, however, this laboratory determination of viscosity is expensive and time consuming. An accurate correlation that can reliably determine the viscosity of crude oil in the Niger Delta region will reduce the costs and time involved in the determination of the viscosity of crude oil. There are currently a large number of existing viscosity correlations that has gained acceptance in the industry, such include <sup>1, 3, 4, 9, 16 & 17</sup>, but most of which were differs in terms of regions of the world and different compositions of crude oils, specific range of data and different experimental conditions. Therefore, this posed a serious accuracy and precision concern in the applicability of these correlations for the Niger Delta, where the properties of the fluid may differ from the conditions at which those models were developed. Determination of the most accurate viscosity correlation from the already existing correlations that can accurately represent the viscosity conditions in the Niger Delta will serve as a means for further prediction of the viscosity of crude oils in this region. The purpose of this study is to provide a comparative analysis of existing saturated and under-saturated oil viscosity correlations to determine an accurate oil viscosity correlation that can best fit the oil viscosity conditions in the Niger Delta. Where quick estimates of oil viscosity are required in the Niger Delta, the selected viscosity correlations can be applied.

## 2 METHODOLOGY

The determination of the performance of the correlation involved the use of the available correlations to predict (estimate) the experimental database (measured) for the reservoir oil viscosity property. Comparative analysis on the two values (measured and predicted) was carried out to evaluate the efficiency of the correlation<sup>12</sup>. The performance of the existing correlations in this research- saturated oil, under-saturated oil viscosities were evaluated by using statistical tools to evaluate the accuracy of the correlation with the Niger Delta experimental viscosity

### 2.1 *Correlation Selection and Crude Oil Viscosity Determination*

This research utilizes various viscosity correlations (saturated and under-saturated) to predict the viscosities involved in this research- measured by PVT analysis in the Niger Delta region considered. The PVT input data of the Niger Delta is to be used and from the application of this input data, comparative analysis of the viscosity of crude oils from the various viscosity correlations will be determined. Correlations within the same range of data specified with the Niger Delta were tested. Extensive range of correlations were applied in this research which involved the early viscosity correlations and the recently developed correlations for screening purposes, correlations with an insignificant coefficient of determination value were removed. Correlations within the range of coefficient of determination between 0.9-1 and correlations developed for Niger Delta were then selected for further evaluation using statistical tools. 10 correlations were then selected for under-saturated oil viscosity and 9 were selected for saturated oil viscosity.

### 2.2 *Comparative Analysis of the Selected Correlations and the Experimental Data*

Comparative analysis to measure the agreement between the computed and measured viscosity data was done using the statistical tools. These statistical tools assist in making judgments on the variations in the computed results from the selected correlations and the experimental viscosity in determining performance of the selected correlations. The statistical tools applied in this research for the comparative analysis are outlined below:

### 2.3 *Average Absolute Percentage Relative Error, AARE*

This is a measure of the relative absolute deviation of the estimated values of the oil viscosity determined from the various correlations against the experimental values of the oil viscosity. It indicates the relative absolute deviation in percentage from the experimental values; the lower the

value of the average absolute percentage relative error, the more accurate the correlation.  $E_r$  is expressed as:  $AARE = \frac{1}{n} \sum_{i=1}^n |E_i|$

Where  $E_i$  is relative deviation of the estimated (predicted) value from an experimental value and is defined as:

$$E_i = \left[ \frac{(\mu)_{exp} - (\mu)_{est}}{(\mu)_{exp}} \right] \times 100 \quad (1)$$

Where n=number of samples

#### 2.4 Standard deviation using Statistical Package for Social Science (SPSS)

The standard deviation ( $S_r$ ) is a measure of the percent relative spread or dispersion of the oil viscosity data distribution:

$$S_r = \sqrt{\frac{1}{n-1} \sum_{i=1}^n [\mu_i - \mu_{mean}]^2} \quad (2)$$

Where n=number of sample

$\mu_i$  = oil viscosity for each sample

$\mu_{mean}$  = mean oil viscosity

The standard deviation is generated from the paired sample test on SPSS. The lower the value of standard deviation means a smaller value of scatter. The difference between the standard deviation of the experimental data from the standard deviation using the various correlations indicates the measure of the relative spread from the experimental data. The accuracy of the correlation is determined by the value of the difference in standard deviation. Smaller value indicates better accuracy.

#### 2.5 Coefficient of Determination, $R^2$ (Graphically)

The coefficient of determination is a simple statistical parameter that tells how the model/correlation fits the data and thereby represents a measure of the utility of the model. The  $R^2$  in this study will be determined by making cross plots of the experimental oil viscosity against the predicted oil viscosities from the correlations. The closer the value of the  $R^2$  is to 1, the better the model/correlation for oil viscosity fits the data acquired from the Niger Delta.  $R^2$  is expressed as:

$$R^2 = 1 - \frac{SSE}{SS_{yy}} \quad (3)$$

SSE measures deviations of experimental values from their predicted values:

$$SSE = \sum_{i=1}^n (\mu_{experimental} - \mu_{calc})^2 \quad (4)$$

$SS_{yy}$  measures deviations of the experimental values from their mean value

$$SS_{yy} = \sum_{i=1}^n (\mu_{experimental} - \mu_{mean})^2 \quad (5)$$

### 3 Materials

This research involves viscosity input data for bottom-hole samples taken from the Niger Delta region. The bottom-hole samples had been flash separated to obtain solution gas oil ratio, gas relative density and oil API gravity. Viscosity data had been obtained by rolling ball viscometer for various pressures and temperatures. The viscosity of the reservoir fluid data consists of different data sets based on the classifications of the viscosity of the crude oil. Four wells were utilized for the analysis.

The total pressure points for the four wells are 26 points for under-saturated oil viscosity and 23 points for the saturated oil viscosity. The range of data for the four wells is outlined at the various pressures.

**Table 1: Fluid property**

PVT property	Range
Oil Viscosity above Bubble Point (cp)	0.2-13
Oil Viscosity below Bubble Point (cp)	0.2-35
Bubble Point Pressure (psia)	1100-2400
Solution Gas Oil Ratio ( $R_s$ )	27-1200
Relative Oil Density	0.6-0.9
Relative Gas Density	0.5-0.95
Pressure (psia)	165-6100

#### 4. RESULTS AND DISCUSSION

The generated results from the comparative analysis using statistical tools are outlined below. These results include the calculated oil viscosities using correlations, graphical analysis, average absolute relative error, and standard deviation from the paired samples test using Statistical Package for Social Science (SPSS) to support the evaluation of the accuracy of the correlations in selecting the correlation with the least error from the overall analysis of these results generated from statistical measures.

##### 4.1 Graphical Analysis

Graphical analysis was carried out by constructing plots of experimental oil viscosities against the calculated oil viscosity to show the coefficient of determination.

##### 4.2 Comparative Analysis Using Average Absolute Relative Error:

The average absolute relative error analysis for the Under-saturated and Saturated oil viscosity was determined and ranked according to its increasing error. From table 2: Saturated Oil Viscosity ranking based on average absolute relative error, Chew & Connally<sup>6</sup> shows the lowest average absolute relative error of 7.4% with Kahn<sup>10</sup> showing the largest error of 18.1% due to the inverse viscosity trend.

From table 3: Under-saturated Oil Viscosity ranking based on average absolute relative error, Elsharkawy te al<sup>7</sup> shows the lowest average absolute relative error of 3.985% with Vasquez & Beggs<sup>15</sup>, showing the largest error of 15.568%.

Table 2: Saturated Oil Viscosity ranking based on average absolute relative error.

<b>RANKING BASED ON AVERAGE ABSOLUTE RELATIVE ERROR</b>	
<b>Correlations</b>	<b>AARE(%)</b>
(Chew & Connally, 1959)	7.413
(Elsharkawy, A. M.; Alikhan, A. A., 1999)	10.715
(Naseri, Nikazar, & Mousavi Dehgani, 2005)	12.843
(Beggs & Robinson, 1975)	17.683
(Kahn, 1987)	18.075

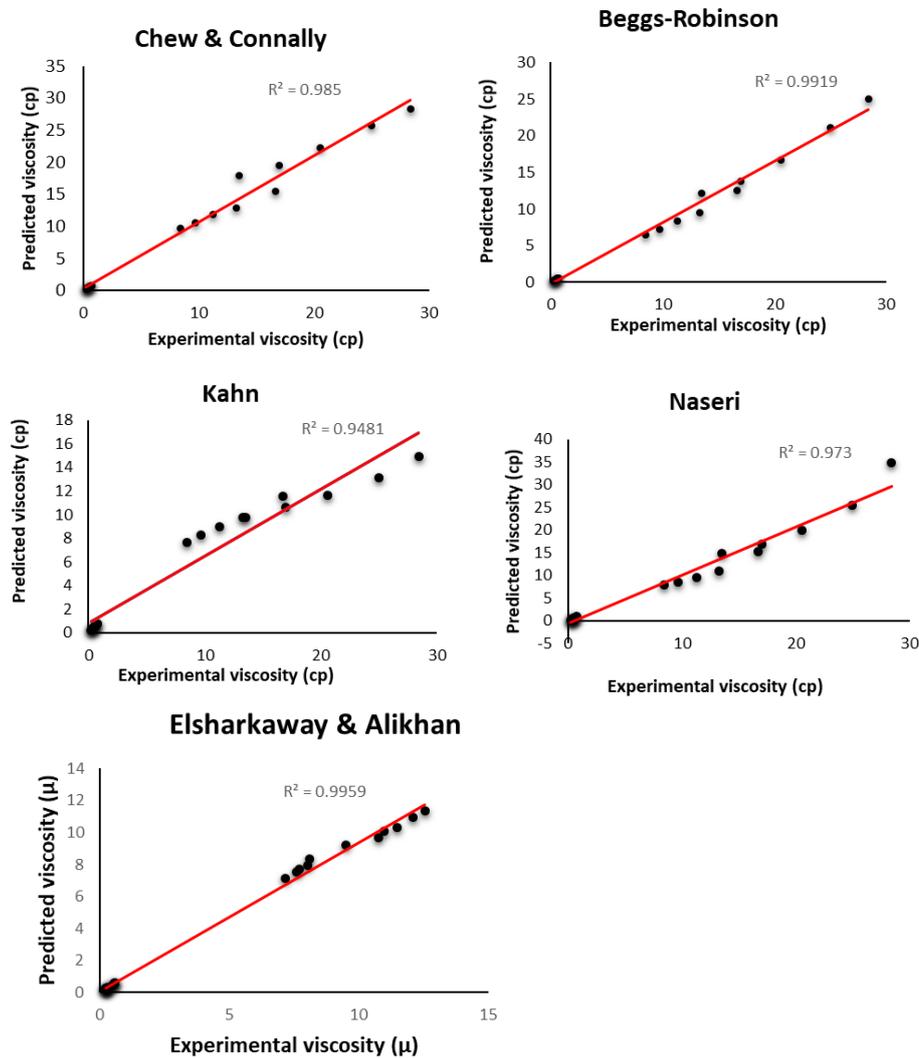


Figure 1: Predicted versus experimentally measured saturated oil viscosity

Table 3: Under-saturated Oil Viscosity ranking based on average absolute relative error.

<b>RANKING BASED ON AVERAGE ABSOLUTE RELATIVE ERROR</b>	
Correlations	AARE (%)
(Elsharkawy, A. M.; Alikhan, A. A., 1999)	3.985
(Kahn, 1987)	5.845
(Bergman & Sutton, 2006)	5.876
(Kartoatmodjo & Schmidt, 1994)	9.232
(Vasquez & Beggs, 1980)	15.568

#### 4.3 Paired Sample T- Test Results Showing Standard Deviation:

The database for the T-test is a combination of all the four wells into one database in order to have a generalized result for the comparative analysis. Conclusion will then be drawn from the generalized result.

From Table 4: Mean and Standard Deviation difference between experimental and the correlations, the following can be inferred; Elsharkawy et al.<sup>7</sup> shows the least deviation from the

experimental standard deviation and Vasquez & Beggs<sup>15</sup> with the largest deviation from the experimental standard deviation.

From Table 5: Mean and Standard Deviation difference between experimental and the correlations, the following can be inferred; Chew & Connally<sup>6</sup> shows the least deviation from the experimental standard deviation and Isehunwa<sup>9</sup> with the largest deviation from the experimental standard deviation.

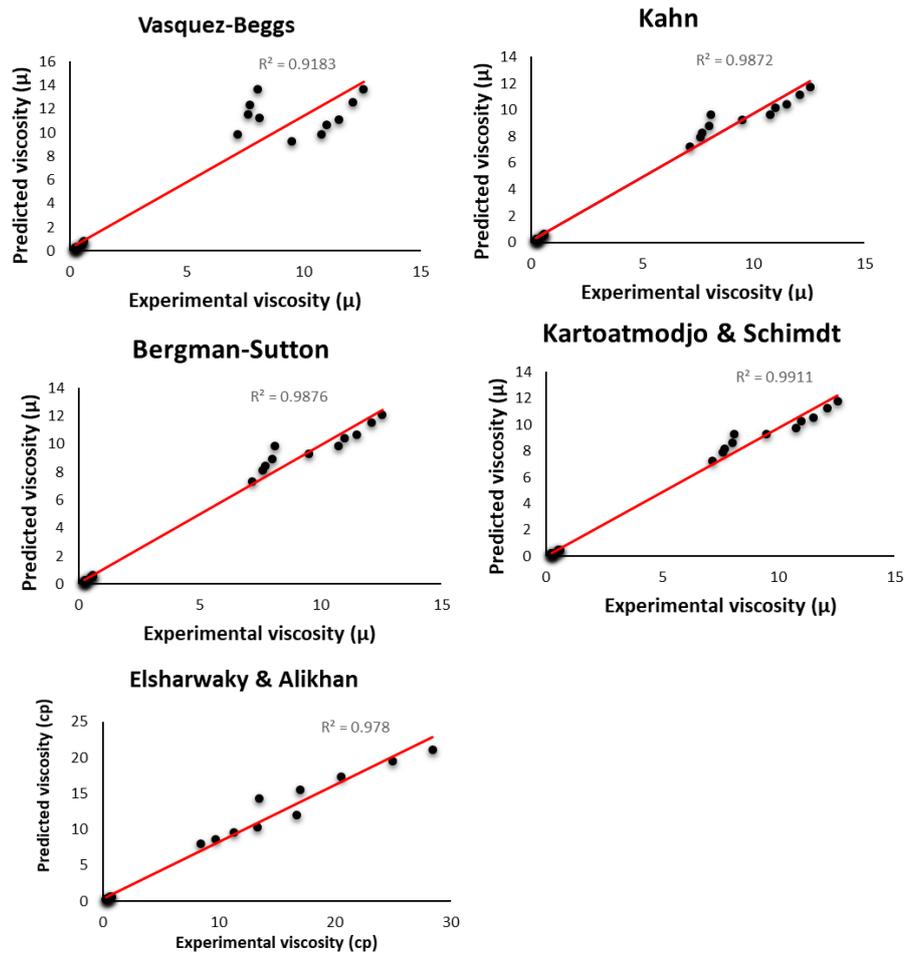


Figure 2: Predicted versus experimentally measured under-saturated oil viscosity

Table 4: Mean and Standard Deviation Viscosity difference between experimental and the correlations (Under-saturated)

		Mean	Std. Deviation	Std. Error Mean
Pair 1	EXPERIMENTAL - VASQUEZ- BEGGS	- .78475642866 0258	1.7103611660 63740	.33542942157 8858
Pair 2	EXPERIMENTAL - ELSHARKAWAY and ALIKHAN	.21955200632 7480	.44548969177 6270	.08736771659 5063
Pair 3	EXPERIMENTAL - ALMEHAIDEB	.19644483588 8013	.53895538955 4956	.10569784801 1412
Pair 4	EXPERIMENTAL - BEAL	.11741192269 5281	.49561016229 5201	.09719714956 4543
Pair 5	EXPERIMENTAL - A. HEMMATI	.09898962152 0830	.56847997587 1874	.11148809577 1440
Pair 6	EXPERIMENTAL - BERGMANSUTT ON	- .02552418137 1737	.53842888434 5962	.10559459184 4694
Pair 7	EXPERIMENTAL - ISEHUNWA	.00954690459 2505	.56883085873 1586	.11155690956 1773
Pair 8	EXPERIMENTAL - PETROSKY	.59422897707 2582	1.0128540832 92956	.19863702827 4343
Pair 9	EXPERIMENTAL - KAHN	.05620214747 9362	.56353721447 3395	.11051874050 9060
Pair 10	EXPERIMENTAL - KARTOATMODJ O and SCHIMDT	.08979818601 9134	.47164762210 0586	.09249770879 3482

Table 5: Mean and Standard Deviation viscosity difference between experimental and the correlations (Saturated)

		Paired Differences		
		Mean	Std. Deviation	Std. Error Mean
Pair 1	EXPERIMENTAL - CHEW and CONNALLY	- .547797568282084	1.249623996892070	.286683406309259
Pair 2	EXPERIMENTAL - ISEHUNWA	- 3.301615830486082	6.964456908801230	1.597755992742538
Pair 3	EXPERIMENTAL - BEGGS.ROBINSON	1.675032861855476	1.691537249728671	.388065259515895
Pair 4	EXPERIMENTAL - ABU-KHAMSIN and ALMARHOUN	2.911398170272748	3.916882204135443	.898594405346276
Pair 5	EXPERIMENTAL - KAHN	3.021394464540832	4.261791577850468	.977722042435944
Pair 6	EXPERIMENTAL - KARTOATM ODJO and SCHMIDT	1.846997304642271	2.424607483914645	.556243105270335
Pair 7	EXPERIMENTAL - ELSHARKAWAY and ALIKHAN	1.469701008100454	2.255290248479358	.517399067446014
Pair 8	EXPERIMENTAL - NASERI	- .011853718903746	1.790547072091324	.410779670573617
Pair 9	EXPERIMENTAL - A. HEMMATI	3.527028085172082	4.544927300432159	1.042677832016995

## 5. Conclusion and Recommendation

In this research, the aforementioned objectives were achieved using statistical tools for a Niger Delta case study. From the results of the analysis, the following conclusions can be drawn:

- ❖ Using the correlations from the literature for various regions of the world, deviations from the experimental viscosities were obtained for the Niger Delta case study indicating that the correlations are geographically dependent.

From the comparative analysis for the under-saturated oil viscosities correlations using statistical tools such as average absolute relative error and standard deviation as the screening criteria. Elshawarkay & Alikhan proved to be the best correlation from the assessment showing the lowest average absolute error of 3.985% and lowest standard deviation of 0.4455 in the combined wells from the SPSS.

- ❖ From the comparative analysis for the saturated oil viscosities correlations using statistical tools such as average absolute relative error and standard deviation as the screening criteria. Chew & Connally correlation proved to be the best correlation from the assessment showing the lowest average absolute error of 7.413% and lowest standard deviation of 1.2496 in the combined wells from the SPSS.

However, the following recommendations are given in order to extend this study. The selected viscosity correlations should be applied in prediction of saturated and under-saturated oil viscosities when field viscosity data is unavailable. The performance of the selected viscosity correlations should be evaluated with other available viscosity data from the Niger Delta.

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