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Predicting the Dead Oil Viscosity of Reservoir Fluids: a case study of the Niger Delta

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Abstract

Knowledge of the Dead-oil viscosity is one of the most important factors in developing viscosity empirical correlations because other viscosities are obtained from it. A better accuracy of its model will enhance the accuracy of the overall viscosity parameters. This paper developed a new dead oil viscosity using laboratory PVT experimental data obtained from different oil wells across the Niger Delta. The Model was developed starting with the knowledge of Linear and Non-Linear Multiple regression analyses. A Matrix system was adopted to solve the experimental equations through MATLAB in conjunction with Microsoft Excel Application. Multiple statistical analyses were adopted to ascertain the accuracy of the derived model. The empirical correlation gave a Percent Mean Relative Error of -6.67776, Percent Mean Absolute Relative Error of 25.55437 and a 0.6728 Coefficient of Correlation. It also gave better performance plot, compared with those of existing correlations.

Keywords: Dead oil viscosity, Pressure, Volume, Temperature, Multiple statistical analyses.

1. Introduction

The determination of viscosity is required for evaluation of the pressure drop resulting from flow through porous media, tubing or pipelines. Viscosity is a necessary property for ascertaining well productivity or to properly size tubing, pipelines and pumps.

For gas and liquid samples taken from the outlets of test separators, the composition of the well fluid is normally obtained by mathematically re-combining the measured gas and liquid compositions in the molar proportions based on measured or derived molar masses, densities and the measured GOR corrected for differences in meter factors as a result of using measured fluid properties rather than estimates. The gas and liquid samples are then physically recombined in the ratio corresponding with the corrected test separator GOR. This re-combined well fluid sample is then used for various experiments designed to determine the relationships between pressure, volume and temperature (PVT) for the reservoir fluid in question.

The most common method for obtaining the viscosity of crude oil that contains dissolved gas is first to estimate the viscosity of the gas-free or dead oil and then to correct this value for dissolved gas. The dead-oil viscosity (μ_{od}) depends on API gravity (Y_{API}) of the stock-tank oil and the Reservoir temperature (T) (Beggs & Robinson, 1975).

Over the years, several empirical correlations have been developed for determining viscosity properties of crude oils using data from different geographical locations (Ikiensikimama, 2009), with hardly any recognized correlation from the Niger Delta.

Therefore, in this paper is a newly developed empirical model from available PVT data across different oil wells in the Niger Delta.

Pvt Data for The Study

The PVT analyses of 250 reservoir fluid samples from 250 laboratory PVT reports from the Niger Delta region were validated and used for this study. For the dead oil viscosity, 246 experimental data sets were collated. The ranges for the entire data used are shown in Table 1. The data sets collated were obtained from conventional PVT reports that derived the various fluid properties from differential liberation processes.

Methodology

The Models were developed using Linear and Non-Linear Multiple regression analyses with MATRIX through MATLAB (Palm, 1998) in conjunction with Microsoft Excel Application.

Non-Linear multiple regression is achieved by reducing the non-linear relationship to a linear one by appropriate transformation of variable.

To develop the dead oil viscosity correlation for the Niger Delta crude, the below general relationship is used

$$\mu_{od} = f(\gamma_{API}, T) \qquad (1)$$

This can be transformed to non-linear equation below:

$$\mu_{od} = k.\gamma_{API}^{a}.T^{b} \qquad (2)$$

Equation (2) can be reduced to linear form by logarithm transformation:

$$\log \mu_{od} = \log k + a \log \gamma_{API} + b \log T \qquad (3)$$

let $y = \log \mu_{od}$, $k' = \log k$, $X_1 = \log \gamma_{API}$, $X_2 = \log T$

Therefore,

$$y = k' + aX_1 + bX_2 \qquad (4)$$

Equation (4) is the linear combination of independent variables (X_1 and X_2) that will correlate as closely as possible with the dependent variables (y) on a sample of size n which the properties y, X_1 and X_2 are measured.

Equation (4) can be written for any observation point i as:

$$y_i = k' + aX_{i1} + bX_{i2}, \quad i = 1,2, \ldots n \qquad (5)$$

The n equations for the 245 experiment measurements can be expressed in matrix form as:

$$\begin{pmatrix} 1 & X_{1,1} & X_{1,2} \\ 1 & X_{2,1} & X_{2,2} \\ \vdots & \vdots & \vdots \\ 1 & X_{245,1} & X_{245,2} \end{pmatrix} \begin{pmatrix} k \\ a \\ \vdots \\ b \end{pmatrix} = \begin{pmatrix} y_i \\ y_2 \\ \\ y_{245} \end{pmatrix}$$

or can be simplified as:

$$\mathbf{X}\,\hat{\mathbf{z}} = \mathbf{y} \qquad (6)$$

X is an nx3 matrix, $\hat{z}$ is a vector, and y is also an n vector. The solution to the system $\mathbf{X}\hat{\mathbf{z}} = \mathbf{y}$ is:

$$\hat{\mathbf{z}} = (\mathbf{X}^T\mathbf{X})^{-1}\mathbf{X}^T\mathbf{y} \qquad (7)$$

Model Accuracy Screening

Multiple statistical parameters were adopted to ascertain the accuracy of the empirical correlation. These are:

Percent Mean Relative Error: The lower the value E_r, the more equally distributed is the error between positive and negative values.

$$\% MRE = E_r = \frac{1}{n}\sum_{i}^{n} E_i$$

where $$E_i = \left[\frac{(\mu_{od})_{exp} - (\mu_{od})_{est}}{(\mu_{od})_{exp}}\right] x\,100$$

Percent Mean Absolute Relative Error: It indicates the relative absolute deviation in percent from the experimental values. A lower value of E_a implies better agreement between the estimated and the experimental values.

$$\% MAR = E_a = \frac{1}{n}\sum_{i=1}^{n} |E_i|$$

Correlation Coefficient: This describes the extent of association between the experimental dead oil viscosity and predicted dead oil viscosity values obtained from the correlation. The value of the correlation coefficient varies from -1.0 to +10. The coefficient of zero indicates no relationship between the experimental and the predicted values. A +1.0 coefficient indicates a perfect positive relationship while a -1.0 coefficient indicates a perfect negative relationship.

$$r = \sqrt{1 - \sum_{i=1}^{n}\left[(\mu_{od})_{exp} - (\mu_{od})_{ext}\right]_i^2 \Big/ \sum_{i=1}^{n}\left[(\mu_{od})_{exp} - \bar{\mu}_{od}\right]_i^2}$$

$$\bar{\mu}_{od} = \frac{1}{n}\sum_{i=1}^{n}\left[(P_{od})_{exp}\right]_i$$

where $(\mu_{od})_{exp}$, $(\mu_{od})_{est}$ and $\bar{\mu}_{od}$ represent the experimental value, estimated values and experimental mean respectively for a property such as the oil dead viscosity

Performance Plots: This is a plot of the predicted versus measured dead oil viscosity with a 45^o reference line to readily ascertain the correlation's fitness and accuracy. A perfect correlation would plot as a straight line with a slope of 45^o. The visual examination of the performance plot gives a basis for a compromise where necessary.

Although, Al-Marhoun (2003) pointed out that the most important indicator of the accuracy of an empirical correlation is the percent MAE; having assessed different combinations of available criteria found in the literature, it became clear that no one parameter is outstanding to be used in making the choice and that these different independent assessments are not sufficient to make an excellent choice. Therefore, to make a brilliant selection, multiple combinations of these statistical parameters should be adopted in the selection criteria of the best empirical PVT correlations (Ikiensikimama, 2009).

Model Result

After imputing the PVT data into MATLAB, and defining the matrix solution i.e. equation (7), the following results were obtained for $\hat{\mathbf{z}}$**:**

$$\hat{z} = \begin{pmatrix} k' = 7.4173 \\ a = -2.9986 \\ b = -1.1226 \end{pmatrix}$$

Substitute the vector $\hat{z}$ into equation (2).

Therefore, the new modeled dead oil viscosity correlation for Niger Delta crude is:

$$\mu_{od} = 10^{7.4173} . \gamma_{API}^{-2.9986} . T^{-1.1226}$$

Discussion

The %MAR measures the mean value of the absolute relative deviation of the measured value from the experimental data. A lower value of E_a implies better agreement between the estimated and the experimental values. Al-Marhoun in 2003 pointed out that the most important indicator of the accuracy of an empirical correlation is the %MAR [6]. From Table 2, %MAR= 25.55437 for this study. This represents the best result amongst other recognized correlations.

Table 1. Data range for the Study.

Parameter	Minimum	Maximum
Tank-oil gravity (^{o}API)	14.87	53.23
Bubblepoint oil FVF (rb/stb)	1.051	3.2705
Bubblepoint pressure (psia)	67	6560
Pressure below bubblepoint (psia)	25	6015
Bubblepoint solution GOR (scf/stb)	19.0	2948.8
Reservoir temperature (^{o}F)	122.3	264.0
Average surface gas gravity (avg.y_g)	0.564	1.294
Undersaturated oil viscosity (cp)	0.137	181.040
Bubblepoint viscosity (cp)	0.132	82.660
Dead oil viscosity (cp)	0.580	167.630

From Figure 1, there were observed deviation of values from the reference line of the performance plot with measured dead oil viscosity above 15cp. When the corresponding API of the deviated dead oil viscosities were traced in the experimental PVT data, it was observed that the APIs were below 22^o. Therefore, any experimental data with API gravity below 22^o deviated from the reference line of the performance plot. Alternatively, experimental data with API gravity above 22^o conformed to the reference line. This phenomenon makes the newly developed correlation well suited for the Niger Delta. It should be recalled that Nigerian crudes are light. The light crude has API gravity above 35^o, the blend is between 26^o and 35^o, medium is between 21^o and 26^o while the heavy has API gravity less than 21 [11]. plot in Figure 1 can and plots in Figure 1. Also, Table 2 summarizes the Performance of this new Dead oil viscosity and compared with other recognized performance Dead oil viscosity with its possible accuracies.

Table 2. Statistical Accuracy of Dead Oil Viscosity

Author	**% MRE**	**% MAE**	**r**
This Study	-6.67776	25.55437	0.6728
Beal	-35.221	56.9630	0.7921
Glaso	-30.2169	48.2727	0.8773
Egbogah & Jack	-50.0179	54.3883	0.8350
Kartoatmodjo & Schmidt	-27.1144	53.2743	0.8584
Petrosky & Farshad	-42.6235	46.4207	0.6641
Dindoruk & Christman	-21.8708	38.1779	0.8979
Beggs & Robinson	-46.8429	51.2494	0.7827

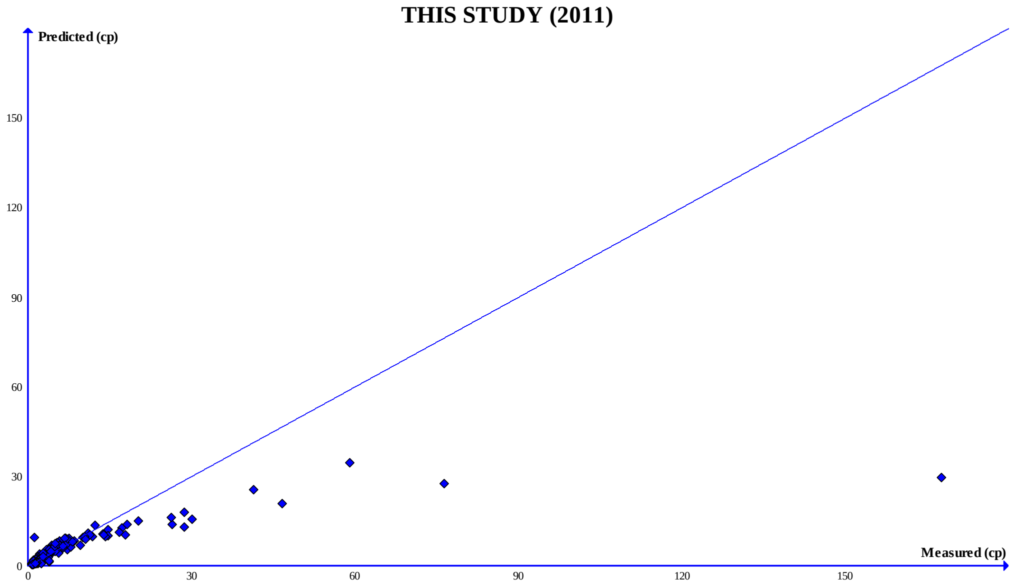

Figure 1. Performance Plot for Dead Oil Viscosity

Conclusion

The result showed that the newly developed dead oil viscosity correlation for this study is recommended for oil API above 22^o, which conforms to the nature of crude oil obtainable from the Niger Delta.

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