Multivariate Statistical Modeling of Crude Oil Viscosity and Mole Percent Components for Reservoir Fluids

Jeremiah Ifeanyi Okoroma a*, Adaobi Stephenie Nwosi-Anele a and Uchenna Daniel Elikee a

a Department of Petroleum Engineering, Rivers State University, Port Harcourt, Nigeria.

Authors’ contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study presents multivariate statistical modeling of PVT properties in a Hydrocarbon Reservoir. Traditionally, these properties are modeled by correlating them with the changes in pressure and temperature associated with them. However, these changes are often a direct corollary of the changing composition as each component’s presence and/or absence contributes to the overall property of the fluid system. In this work, Multiple Linear and Multiple Nonlinear regression models were used to develop a correlation for the crude oil viscosity and the mole percent of the components as they change with pressure and temperature. A fluid system was modelled using the PVT Package of Integrated Production System Modelling (IPM) Suite. The model was then used to perform a differential liberation test simulation to predict the changes in composition of the crude oil. The composition included three lumped crude oil fractions. After the PVT modelling, the generated PVT Composition was used to perform the Multivariate statistical analysis (MVA) and modelling. Two MVA techniques were compared – the Multiple Linear Regression (MLR) and Multiple Non-Linear Regression (MLNR). Analysis of residuals generated from the prediction run based on both techniques showed that the multiple linear regression method had trending residuals, contrary to the law of parametric estimation upon which it is based. However, the multiple nonlinear regression yielded 100% correlation with adequate residual trend and is thus recommended for adaptation to

*Corresponding author: E-mail: jeremiah.okoroma@gmail.com;
distinct fluid systems. It is imperative to note that the accuracy of this adaptive PVT modeling and prediction is hinged primarily on the accuracy of the PVT model used to estimate the compositional variation.

Keywords: PVT modeling; multivariable regression analysis; physical properties; pseudo components.

1. INTRODUCTION

The construction of reservoir models requires accurate determination of PVT properties of reservoir fluids. These fluid properties are always required for many reservoir engineering calculations and ultimately, field management and surveillance decisions: EOR candidate screening, reserve valuation, field performance prediction and monitoring, production operation and optimization [1-9]. Several techniques are often employed in measuring reservoir fluid properties whereby the attempts have been majorly directed towards exploring a fast way of obtaining these data while considering both the economic and technical implications of the predicted data [10]. However, it must be stated that the quality of the data from the fluid properties must not be compromised. The use of some laboratory techniques such as special core analysis (SCAL) is generally employed but these techniques are mostly expensive and very time consuming [11-13]. In many cases, there are usually a lot of uncertainties subject to laboratory test conditions. This experience has necessitated the widespread use of physical models, which are often supported by laboratory tests, in constructing reservoir modes.

Attempts to construct relatively realistic models for hydrocarbon reservoirs in the past have varied depending on the reservoir being studied. A reservoir analysis that contains precisely reported values for reservoir parameters of a homogenous nature can lead to a more accurate forecast of reservoir fluid behavior, but this only applies to reservoirs that are similar. Many circumstances, however, have played a role in the erroneous assessment of such physical behavior. The precision of the physical behavior of the reservoir fluid is affected by the data collecting techniques for reservoir parameters, the quality of the data being measured, and the way the data is interpreted.

This work aim at constructing and generating a model for oil viscosity based on fluid composition and properties rather than the previous reliance on temperature and pressure using statistical and multiple linear regression approach.

2. METHODOLOGY

In this study, a PVT modeling approach assisted with a multivariate analysis (MVA) was employed in determining the physical behavior of reservoir fluids. The general study framework has been presented in Fig. 1 while a more detailed description of the study methodologies is presented and discussed in the following sections below.

2.1 Fluid PVT Model

The fluid PVT model is built using the Petroleum Experts Software PVTP. The original composition of the flow stream and the input PVT data are presented in Tables 1 and 2.
Table 1. Fluid PVT compositional data

| Comp. | Mol %   | Weight % | MW (lb/lb-mol) |
|-------|---------|----------|----------------|
| N₂    | 0.16    | 0.05     | 28.01          |
| CO₂   | 0.91    | 0.43     | 44.01          |
| C₁    | 36.47   | 6.24     | 16.04          |
| C₂    | 9.67    | 3.1      | 30.1           |
| C₃    | 6.95    | 3.27     | 44.1           |
| iC₄   | 1.44    | 0.89     | 58.1           |
| nC₄   | 3.93    | 2.44     | 58.1           |
| iC₅   | 1.44    | 1.11     | 72.2           |
| nC₅   | 1.41    | 1.09     | 72.2           |
| C₆    | 4.33    | 3.97     | 86.2           |
| C₇+   | 33.29   | 77.41    | 218            |

Table 2. Fluid Properties

| Parameter                  | Value   | Unit   |
|----------------------------|---------|--------|
| Temperature                | 220     | °F     |
| Depth                      | 8692    | Ft     |
| Pressure                   | 4100    | Psig   |
| Bubble point Pressure, Pb  | 2620    | Psig   |
| Density at Pb              | 40.967  | lb/cu-ft |
| Specific gravity           | 0.8515  | -      |
| API gravity                | 34.5    | °API   |

2.2 PVT Model Construction Algorithm

The PVT Package of Petroleum Experts was used to build the PVT EOS Model and the stepwise procedures are outlined as follows [14-15]:

- Step 1: Create a New File
- Step 2: Select Equation of State and Volume Shift Options
- Step 3: Select Components
- Step 4: Enter Composition
- Step 5: Initialize the Pseudo Component Properties
- Step 6: Match the Surface Volumetric Properties (Density, GOR etc.) using the Auto-match feature
- Step 7: Find the Pseudo Distribution (Whitson Alpha Factor) and Split the Pseudo
- Step 8: Use BI Coefficients to Improve Match on Saturation Pressure
- Step 9: Select Match Parameters
- Step 10: Use Regression to Match Fluid
- Step 11: Check and Refine the Fluid Characterization
- Step 12: Calculate and Export

The component selection and the composition entry in steps 3 and 4 respectively enables the specification of the various components of the oil package using the PCTP feature of the PVTP simulator as shown in Fig. 2.

The pseudo is the greatest unknown within the composition and is always composed of a mixture of many compounds with a wide variety of individual properties. Hence, the steps 5 to 9 were aimed at characterizing the C7+ lump (pseudo) component and establishing the corresponding EOS PVT matching as described in Fig. 3. The lumped fraction was split into three components and the final composition of the fluid sample is shown in Fig. 4.

The primary aim of building a PVT model was to generate the compositional change in the fluid with changes in pressure. These changes were estimated as a differential liberation computation. This was done in other to correlate the liquid viscosity with the changes in composition. These properties were generated between the ranges of 200 to 3000psig.
Fig. 2. Fluid Composition Input phase

Fig. 3. Pseudocomponent Properties phase

Fig. 4. Final Composition phase
3. RESULTS AND DISCUSSION

Following the outlined stepwise procedures in section 2.2, the resulting phase envelop from the PVT characterization of the specified fluid samples are shown in Fig. 5. The diagram suggests that the fluid sample analyzed is a typical ordinary black oil system [16-17].

3.1 PVT Simulation

Following the Differential Liberation (DL) simulation run, the compositional changes were obtained. The DL was chosen as it best simulates what the oil passes through within the reservoir. The composition of the components in the liquid phase form the DL test is presented in Table 3. Table 4 shows the PVT properties variation with pressure and results indicates an increase in viscosity with increasing pressure. This is often correlated with the evolution of lighter end/fractions of the multicomponent crude oil mixture. However, whenever models of crude oil viscosity were developed based on a correlation of crude oil viscosity with pressure and temperature, primarily because they are easier to measure than the crude composition. Viscosity prediction then relies on the application of the viscosity correlation such as Beggs and Brill which are not usually very accurate.

However, with just one compositional analysis results, we can estimate prospective changes in composition based on PVT models, tuned to match the fluid under study. The results of Table 4 are correlated with the changes in composition displayed in Table 3 to ascertain which components affect the crude oil viscosity the most. Multivariate statistical analysis is subsequently used to obtain a crude oil viscosity model adapted to the fluid under study and suitable for future predictions.

- Correlation of Liquid Viscosity with Compositional Changes

The changes in the mole percent of the components are visually analyzed in this section, to ascertain which components have similar strong correlation with the liquid viscosity as presented in Fig. 6.
Table 3. Composition in the liquid phase with Differential Liberation PVT Simulation

| Pressure (psig) | N2  | CO2 | C1   | C2   | C3   | iC4 | nC4 | iC5 | nC5 | C6   | C7-C9 | C10-C12 | C13-C29 |
|-----------------|-----|-----|------|------|------|-----|-----|-----|-----|------|-------|----------|----------|
| 3000            | 0.16| 0.91| 36.47| 9.67 | 6.95 | 1.44| 3.93| 1.44| 1.41| 4.33 | 10.2436| 7.4777 | 15.5687  |
| 1800            | 0.1037| 0.8563| 29.082| 9.3505| 7.2737| 1.5616| 4.3183| 1.6188| 1.5936| 4.9777| 12.0036| 8.8299 | 18.4303  |
| 1600            | 0.0838| 0.832| 26.1864| 9.1972| 7.3905| 1.6087| 4.4701| 1.6897| 1.6664| 5.2361| 12.7053| 9.3678 | 19.5661  |
| 1400            | 0.0653| 0.8025| 23.1485| 8.9993| 7.499 | 1.6571| 4.6282| 1.7649| 1.744 | 5.5127| 13.457 | 9.9429 | 20.7786  |
| 1200            | 0.0486| 0.766| 19.961| 8.7409| 7.5926| 1.7064| 4.792 | 1.8449| 1.8266| 5.81  | 14.267 | 10.5619 | 22.0821  |
| 1000            | 0.0338| 0.7203| 16.6192| 8.3976| 7.6602| 1.7555| 4.9597| 1.9299| 1.9148| 6.1314| 15.147 | 11.2341 | 23.4963  |
| 800             | 0.0214| 0.6616| 13.1242| 7.9288| 7.6812| 1.8022| 5.1277| 2.0201| 2.0091| 6.4819| 16.1152| 11.9742 | 25.0524  |
| 600             | 0.0117| 0.5832| 9.4911| 7.2586| 7.6132| 1.8417| 5.2865| 2.1155| 2.11  | 6.8695| 17.2042| 12.8085 | 26.8063  |
| 400             | 0.0049| 0.4713| 5.7758| 6.2165| 7.3448| 1.86  | 5.4075| 2.2138| 2.2171| 7.31  | 18.4893| 13.7989 | 28.889   |
| 200             | 0.0011| 0.2897| 2.2021| 4.2764| 6.4132| 1.7889| 5.3414| 2.2956| 2.3186| 7.8521| 20.2465| 15.1789 | 31.7956  |

Table 4. PVT Properties variation with pressure using Differential Liberation experiment

| Pressure (psig) | Gas Density (EOS) (Kg/m³) | Oil Density (EOS) (Kg/m³) | Interfacial Tension (dyne/cm) | Gas Viscosity (centipoise) | Oil Viscosity (centipoise) | Gas FVF (ft³/scf) | Oil FVF (RB/STB) | Gas Oil Ratio (scf/STB) |
|-----------------|----------------------------|---------------------------|-----------------------------|---------------------------|--------------------------|------------------|------------------|-----------------------|
| 3000            | 107.828                    | 686.152                   | 0.0168115                   | 0.42618                   | 0.00888048              | 1.44048          | 784.104          |                       |
| 1800            | 107.828                    | 702.126                   | 0.0168115                   | 0.480994                  | 0.00888048              | 1.35483          | 566.38           |                       |
| 1600            | 95.2921                    | 711.104                   | 0.0160374                   | 0.523487                  | 0.0100612               | 1.32122          | 497.63           |                       |
| 1400            | 83.0925                    | 720.018                   | 0.0153548                   | 0.569742                  | 0.011597                | 1.28935          | 432.556          |                       |
| 1200            | 71.249                     | 728.903                   | 0.014754                    | 0.620218                  | 0.0136625               | 1.25889          | 370.568          |                       |
| 1000            | 59.7721                    | 737.812                   | 0.0142218                   | 0.67553                   | 0.0165705               | 1.22948          | 311.092          |                       |
| 800             | 48.6562                    | 746.826                   | 0.0137398                   | 0.736627                  | 0.0209408               | 1.20062          | 253.415          |                       |
| 600             | 37.865                     | 756.105                   | 0.0132785                   | 0.805288                  | 0.0282011               | 1.17156          | 196.43           |                       |
| 400             | 27.2849                    | 766.054                   | 0.0127777                   | 0.885921                  | 0.0425419               | 1.14051          | 137.751          |                       |
| 200             | 16.4797                    | 778.247                   | 0.0120557                   | 0.99622                   | 0.0838821               | 1.1008           | 68.711           |                       |
Fig. 6 show that the Methane (C1) exhibits a negative correlation with the viscosity. Also, the lighter ends, which include Ethane (C2) to Propane (C3) and the impurities, CO$_2$ and N$_2$, exhibit correlations with slightly variable gradients than the others. These components are excluded from the following multivariate analysis to reduce noisiness of results.

3.2 Multivariate Statistical Analysis

Two tools of Multivariate Analysis (MVA) are utilized to correlate the compositional variation with the liquid viscosity, namely multiple linear regression and nonlinear regression.

3.2.1 Multiple Linear Regression (MLR)

The multiple linear regression was run to generate a linear model that incorporates the impacts of the mole composition of the various components into one. The results in Table 5 summarize the basic statistical result of the simulation.

The correlation matrix shown in Table 6 portrays the nature of the correlation between the dependent variable (DV) and the independent variables (IV) while Table 7 displays the goodness of fit coefficients of the model.

In this case, 99.2% of the variability of the liquid viscosity is explained by the variation in composition. The remainder of the variability is due to some effects (other explanatory variables) that have not been included in this analysis. The analysis of variance results in Table 9 enable us to determine whether or not the explanatory variables bring significant information (null hypothesis H0) to the model. In other words, it’s a way of ascertaining whether it is valid to use the mean to describe the whole population, or whether the information brought by the explanatory variables is of value or not.

- Regression Model – MLR

Table 10 gives details on the model. This table is helpful when predictions are needed, or when there is need to compare the coefficients of the model for a given set of data with the ones obtained for another set of data. The viscosity of oil model is given in Equation (1).

Following the above analysis, the standardized regression coefficients (referred to as beta coefficients) are presented in Table 11 and Fig. 7. They allow for the direct comparison of the relative influence of the explanatory variables on the dependent variable, and their significance.

Using the generated linear regression, predictions of the liquid viscosity were made and the residuals computed. These residuals, given the assumptions of the linear regression model, should be normally distributed, meaning that 95% of the residuals should be in the interval $[-1.96, 1.96]$. All values outside this interval are potential outliers, or might suggest that the normality assumption is wrong. The predictions and Residuals of the Oil Viscosity are presented in Table 12.
Table 5. MLR Analysis

| Variable     | Observations | Obs. with missing data | Obs. without missing data | Minimum | Maximum | Mean | Std. Deviation |
|--------------|--------------|-------------------------|---------------------------|---------|---------|------|----------------|
| Oil Visc (cP) | 10           | 0                       | 10                        | 0.424   | 0.960   | 0.649| 0.177          |
| iC4          | 10           | 0                       | 10                        | 1.440   | 1.860   | 1.702| 0.135          |
| nC4          | 10           | 0                       | 10                        | 3.930   | 5.408   | 4.826| 0.489          |
| iC5          | 10           | 0                       | 10                        | 1.440   | 2.296   | 1.893| 0.273          |
| nC5          | 10           | 0                       | 10                        | 1.410   | 2.319   | 1.881| 0.288          |
| C6           | 10           | 0                       | 10                        | 4.330   | 7.852   | 6.051| 1.096          |
| C7-C9        | 10           | 0                       | 10                        | 10.244  | 20.247  | 14.988| 3.084          |
| C10-C12      | 10           | 0                       | 10                        | 7.478   | 15.179  | 11.117| 2.369          |
| C13-C29      | 10           | 0                       | 10                        | 15.569  | 31.796  | 23.247| 4.990          |

Table 6. Correlation Matrix for MLR

|           | iC4    | nC4    | iC5    | nC5    | C6     | C7-C9  | C10-C12 | C13-C29 | Oil Visc (cP) |
|-----------|--------|--------|--------|--------|--------|--------|---------|---------|---------------|
| iC4       | 1      | 0.987  | 0.943  | 0.936  | 0.914  | 0.902  | 0.901   | 0.901   | 0.874         |
| nC4       | 0.987  | 1      | 0.984  | 0.980  | 0.968  | 0.960  | 0.959   | 0.959   | 0.940         |
| iC5       | 0.943  | 0.984  | 1      | 1.000  | 0.997  | 0.994  | 0.994   | 0.994   | 0.983         |
| nC5       | 0.936  | 0.980  | 1      | 0.998  | 0.996  | 0.996  | 0.996   | 0.996   | 0.986         |
| C6        | 0.914  | 0.968  | 0.997  | 0.998  | 1      | 1.000  | 0.999   | 0.999   | 0.992         |
| C7-C9     | 0.902  | 0.960  | 0.994  | 0.996  | 1.000  | 1      | 1.000   | 1.000   | 0.994         |
| C10-C12   | 0.901  | 0.959  | 0.994  | 0.996  | 0.999  | 1.000  | 1       | 1.000   | 0.994         |
| C13-C29   | 0.901  | 0.959  | 0.994  | 0.996  | 0.999  | 1.000  | 1       | 1       | 0.994         |
| Oil Visc (cP) | 0.874  | 0.940  | 0.983  | 0.986  | 0.992  | 0.994  | 0.994   | 1       |               |

Table 7. Goodness of Fit for MLR

| Observations | Sum of weights | DF | R²  | Adjusted R² | MSE | RMSE | MAPE | DW | Cp | AIC | SBC | PC |
|--------------|----------------|----|-----|-------------|-----|------|------|----|----|-----|-----|----|
| 10           | 10             | 7  | 0.992| 0.99        | 0   | 0.018| 2.309| 1.529| 3  | -77.933| -77.025| 0.015|

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Table 8. Analysis of Variance (Oil Visc, cp) – MLR

| Source     | DF | Sum of squares | Mean squares | F       |
|------------|----|----------------|--------------|---------|
| Model      | 2  | 0.279          | 0.139        | 431.312 |
| Error      | 7  | 0.002          | 0.000        |         |
| Corrected Total | 9  | 0.281          |              |         |

Computed against model $Y=\text{Mean}(Y)$

Table 9. Model Parameters (Oil Visc, cp) for MLR

| Source     | Value | Standard Error | $t$     | $Pr > |t|$   | Lower bound (95%) | Upper bound (95%) |
|------------|-------|----------------|---------|---------|-------------------|-------------------|
| Intercept  | 0.043 | 0.122          | 0.354   | 0.734   | -0.245            | 0.331             |
| iC4        | -2.669| 0.275          | -9.719  | < 0.0001| -3.319            | -2.020            |
| nC4        | 1.067 | 0.076          | 14.073  | < 0.0001| 0.888             | 1.246             |
| iC5        | 0.000 | 0.000          |         |         |                   |                   |
| nC5        | 0.000 | 0.000          |         |         |                   |                   |
| C6         | 0.000 | 0.000          |         |         |                   |                   |
| C7-C9      | 0.000 | 0.000          |         |         |                   |                   |
| C10-C12    | 0.000 | 0.000          |         |         |                   |                   |
| C13-C29    | 0.000 | 0.000          |         |         |                   |                   |

$\mu_{ij} = 4.31688873429061 \times 10^{-2} - 2.66928717451177 C_4 + 1.06694810925145 n C_4$  

(1)

Table 10. Standardized coefficients (Oil Visc (cP)) for MLR

| Source     | Value | Standard Error | $t$     | $Pr > |t|$   | Lower bound (95%) | Upper bound (95%) |
|------------|-------|----------------|---------|---------|-------------------|-------------------|
| iC4        | -2.039| 0.210          | -9.719  | < 0.0001| -2.535            | -1.543            |
| nC4        | 2.952 | 0.210          | 14.073  | < 0.0001| 2.456             | 3.448             |
| iC5        | 0.000 | 0.000          |         |         |                   |                   |
| nC5        | 0.000 | 0.000          |         |         |                   |                   |
| C6         | 0.000 | 0.000          |         |         |                   |                   |
| C7-C9      | 0.000 | 0.000          |         |         |                   |                   |
| C10-C12    | 0.000 | 0.000          |         |         |                   |                   |
| C13-C29    | 0.000 | 0.000          |         |         |                   |                   |
Table 11. Predictions and Residuals (Oil Visc, cp) for MLR

| Observation | Wt | Oil Visc (cp) | Pred (Oil Visc (cp)) | Residual | Std. residual | Std. dev. on pred. (Mean) | Lower bound 95% (Mean) | Upper bound 95% (Mean) | Std. dev. on pred. (Observation) | Lower bound 95% (Observation) | Upper bound 95% (Observation) |
|-------------|----|---------------|----------------------|---------|---------------|--------------------------|----------------------|---------------------|-------------------------------|-----------------------------|-----------------------------|
| Obs1        | 1  | 0.424         | 0.383                | 0.032   | 1.774         | 0.013                    | 0.361                | 0.424               | 0.022                         | 0.340                       | 0.445                       |
| Obs2        | 1  | 0.459         | 0.482                | -0.023  | -1.282        | 0.008                    | 0.462                | 0.502               | 0.020                         | 0.435                       | 0.529                       |
| Obs3        | 1  | 0.502         | 0.518                | 0.017   | -0.942        | 0.007                    | 0.501                | 0.536               | 0.019                         | 0.473                       | 0.564                       |
| Obs4        | 1  | 0.547         | 0.558                | 0.010   | -0.583        | 0.007                    | 0.542                | 0.574               | 0.019                         | 0.513                       | 0.603                       |
| Obs5        | 1  | 0.597         | 0.601                | 0.004   | -0.208        | 0.007                    | 0.585                | 0.617               | 0.019                         | 0.556                       | 0.647                       |
| Obs6        | 1  | 0.652         | 0.649                | 0.003   | 0.158         | 0.008                    | 0.631                | 0.667               | 0.019                         | 0.603                       | 0.695                       |
| Obs7        | 1  | 0.712         | 0.704                | 0.008   | 0.447         | 0.008                    | 0.684                | 0.723               | 0.020                         | 0.657                       | 0.750                       |
| Obs8        | 1  | 0.778         | 0.768                | 0.011   | 0.597         | 0.009                    | 0.747                | 0.789               | 0.020                         | 0.720                       | 0.815                       |
| Obs9        | 1  | 0.856         | 0.848                | 0.009   | 0.443         | 0.009                    | 0.826                | 0.869               | 0.020                         | 0.800                       | 0.895                       |
| Obs10       | 1  | 0.960         | 0.967                | 0.007   | -0.403        | 0.017                    | 0.927                | 1.007               | 0.025                         | 0.909                       | 1.026                       |
Fig. 8. Standard Residuals for (a) observed Oil Viscosity (b) Predicted Oil Viscosity (MLR)

Fig. 9. Standardized Residuals for Each Observation (MLR)

Fig. 10. Actual Oil Viscosity versus Predicted Oil Viscosity (MLR)
Table 12. Statistical Analysis for MNLR

| Variable       | Observations | Obs. with missing data | Obs. without missing data | Minimum | Maximum | Mean  | Std. deviation |
|----------------|--------------|------------------------|---------------------------|---------|---------|-------|----------------|
| Oil Visc (cP)  | 10           | 0                      | 10                        | 0.426   | 0.996   | 0.672 | 0.184          |
| iC4            | 10           | 0                      | 10                        | 1.440   | 1.860   | 1.702 | 0.135          |
| nC4            | 10           | 0                      | 10                        | 3.930   | 5.408   | 4.826 | 0.489          |
| iC5            | 10           | 0                      | 10                        | 1.440   | 2.296   | 1.893 | 0.273          |
| nC5            | 10           | 0                      | 10                        | 1.410   | 2.319   | 1.881 | 0.288          |
| C6             | 10           | 0                      | 10                        | 4.330   | 7.852   | 6.051 | 1.096          |
| C7-C9          | 10           | 0                      | 10                        | 10.244  | 20.247  | 14.988| 3.084          |
| C10-C12        | 10           | 0                      | 10                        | 7.478   | 15.179  | 11.117| 2.369          |
| C13-C29        | 10           | 0                      | 10                        | 15.569  | 31.796  | 23.247| 4.990          |

Table 13. Correlation Matrix for MNLR

| Variables       | iC4    | nC4    | iC5    | nC5    | C6     | C7-C9  | C10-C12 | C13-C29 | Oil Visc (cP) |
|-----------------|--------|--------|--------|--------|--------|--------|---------|---------|---------------|
| iC4             | 1.000  | 0.987  | 0.943  | 0.936  | 0.914  | 0.902  | 0.901   | 0.901   | 0.880         |
| nC4             | 0.987  | 1.000  | 0.984  | 0.980  | 0.968  | 0.960  | 0.959   | 0.959   | 0.944         |
| iC5             | 0.943  | 0.984  | 1.000  | 1.000  | 0.997  | 0.994  | 0.994   | 0.994   | 0.986         |
| nC5             | 0.936  | 0.980  | 1.000  | 1.000  | 0.998  | 0.996  | 0.996   | 0.996   | 0.989         |
| C6              | 0.914  | 0.968  | 0.997  | 0.996  | 1.000  | 1.000  | 1.000   | 1.000   | 0.995         |
| C7-C9           | 0.902  | 0.966  | 0.994  | 0.996  | 1.000  | 1.000  | 1.000   | 1.000   | 0.997         |
| C10-C12         | 0.901  | 0.959  | 0.994  | 0.996  | 0.999  | 1.000  | 1.000   | 1.000   | 0.997         |
| C13-C29         | 0.901  | 0.959  | 0.994  | 0.996  | 0.999  | 1.000  | 1.000   | 1.000   | 0.997         |
| Oil Visc (cP)   | 0.880  | 0.944  | 0.986  | 0.989  | 0.995  | 0.997  | 0.997   | 0.997   | 1.000         |

Table 14. Goodness of Fit for MNLR

| Observations | DF | R²  | SSE | MSE | RMSE |
|--------------|----|-----|-----|-----|------|
| 10           | -7 | 1   | 0   |     |      |
Table 15. Model Parameters

| Parameter | Value   | Standard error |
|-----------|---------|----------------|
| pr1       | -10.556 | 65535.000      |
| pr2       | 37.420  | 65535.000      |
| pr3       | 10.248  | 65535.000      |
| pr4       | -24.491 | 65535.000      |
| pr5       | -8.632  | 65535.000      |
| pr6       | -36.366 | 65535.000      |
| pr7       | 19.523  | 65535.000      |
| pr8       | 3.683   | 65535.000      |
| pr9       | -6.928  | 65535.000      |
| pr10      | -6.357  | 65535.000      |
| pr11      | 0.000   | 0.000          |
| pr12      | 0.000   | 0.000          |
| pr13      | 0.000   | 0.000          |
| pr14      | 0.402   | 65535.000      |
| pr15      | 0.000   | 0.000          |
| pr16      | 0.000   | 0.000          |
| pr17      | 0.000   | 0.000          |

Table 16. Prediction and Residuals Based on Fit Regression Model for MNLR

| Observations | iC4   | nC4   | iC5   | nC5   | C6    | C7-C9  | C10-C12 | C13-C29 | Oil Visc (cP) | Pred(Oil Visc (cP)) | Residuals |
|--------------|-------|-------|-------|-------|-------|--------|---------|---------|---------------|----------------------|-----------|
| Obs1         | 1.440 | 3.930 | 1.440 | 1.410 | 4.330 | 10.244 | 7.478   | 15.569  | 0.426         | 0.426                | 0.000     |
| Obs2         | 1.562 | 4.318 | 1.619 | 1.594 | 4.978 | 12.004 | 8.830   | 18.430  | 0.481         | 0.481                | 0.000     |
| Obs3         | 1.609 | 4.470 | 1.690 | 1.666 | 5.236 | 12.705 | 9.368   | 19.566  | 0.523         | 0.523                | 0.000     |
| Obs4         | 1.657 | 4.628 | 1.765 | 1.744 | 5.513 | 13.457 | 9.943   | 20.779  | 0.570         | 0.570                | 0.000     |
| Obs5         | 1.706 | 4.792 | 1.845 | 1.827 | 5.810 | 14.267 | 10.562  | 22.082  | 0.620         | 0.620                | 0.000     |
| Obs6         | 1.756 | 4.960 | 1.930 | 1.915 | 6.131 | 15.147 | 11.234  | 23.496  | 0.676         | 0.676                | 0.000     |
| Obs7         | 1.802 | 5.128 | 2.020 | 2.009 | 6.482 | 16.115 | 11.974  | 25.052  | 0.737         | 0.737                | 0.000     |
| Obs8         | 1.842 | 5.287 | 2.116 | 2.110 | 6.870 | 17.204 | 12.809  | 26.806  | 0.805         | 0.805                | 0.000     |
| Obs9         | 1.860 | 5.408 | 2.214 | 2.217 | 7.311 | 18.489 | 13.799  | 28.889  | 0.886         | 0.886                | 0.000     |
| Obs10        | 1.789 | 5.341 | 2.296 | 2.319 | 7.852 | 20.247 | 15.179  | 31.796  | 0.996         | 0.996                | 0.000     |
Fig. 8 shows the standardized residuals versus the predicted oil viscosity. A trend been identified indicates that the model is not correct as there is an auto correlation in the residuals, which is contrary to one of the assumptions of parametric linear regression. This would imply that there is a hidden “trending” error in the model predictions. Fig. 9 shows the standardized residuals for each observation. It is used primarily to identify outliers and no one is observed.

Fig. 10 shows a plot of the actual liquid viscosity against the predicted liquid viscosity. The predicted is in agreement with the actual viscosity.

### 3.2.2 Multiple Non-Linear Regression (MNLR) Results

The summary of the statistical parameters obtained from the simulation of the Multiple Non-linear regression is presented in Table 13. The number of observations, missing values, the number of non-missing values, the mean and the standard deviation (unbiased) are displayed for the dependent variables (in blue) and the quantitative explanatory variables. The corresponding correlation matrix is presented in Table 14. It shows a very strong correlation between the dependent variable, oil viscosity and independent variables, the components’ mole percent.

The nonlinear regression was run with a convergence criterion of 0.00001 and maximum iterations of 200. The $R^2$ (coefficient of determination) indicates the % of variability of the dependent variable which is explained by the explanatory variables. The closer to 1 the $R^2$ is, the better the fit. The Goodness of fit is presented in Table 15.

Table 15 shows that 100% of the variation in the liquid viscosity can be explained by the variation in the composition of the components. Consequently, the model to be fit would give a “statistically” perfect prediction of liquid viscosities.

#### Regression Model – MNLR

The regression takes the form displayed in Equation 2 below.

$$Y = Pr_1 + X_1Pr_2 + X_2Pr_3 + X_3Pr_4 + X_4Pr_5 + X_5Pr_6 + X_6Pr_7 + X_7Pr_8 + X_8Pr_9 + X_9^2Pr_{10} + X_{10}^2Pr_{11} + X_{11}^2Pr_{12} + X_{12}^2Pr_{13} + X_{13}^2Pr_{14} + X_{14}^2Pr_{15} + X_{15}^2Pr_{16} + X_{16}^2Pr_{17}$$  \( (2) \)

The parameters that fit the data used for this study are tabulated in Table 16 and the stop iteration condition was set at 200 iterations and 0.00001 convergence.

$$\mu_{oil} = -10.559298514411 + 37.4204046018315iC_4 + 10.2484865732932nC_4 - 24.9133466046391iC_5 - 8.63182580540697nC_5 - 36.3656238777595C_6 + 19.5227042940771C_{7_{-9}} + 3.6828451753329C_{10_{-12}} - 6.35682264979521C_{13_{-29}} - 6.9283730700242iC_4^2 + 0.401830336219369C_6^2$$  \( (3) \)

Equation (3) is used to make predictions of the oil viscosity. It is important to note that this equation was based on the lumping rule selected during the PVT model building. The results of the prediction are given in Table 17.

![Fig. 11. Actual Liquid Viscosity versus Predicted Liquid Viscosity Based on MNLR](image-url)
Fig. 12. Residuals from MLNR prediction

Fig. 11 shows the predicted values versus the observed values. Confidence intervals allow identifying potential outliers. There is obviously an excellent prediction of the liquid viscosity with the computed model.

Fig. 12 shows the residuals. These residuals, given the assumptions of the linear regression model, should be normally distributed, meaning that 95% of the residuals should be in the interval [-1.96, 1.96] which the predicted was within the range.

It can be seen that the residuals are well within the accepted limits. They are very minute to be precise, implying very little difference between measured viscosity and simulated viscosity.

4. CONCLUSION

This work has modeled the oil viscosity from reservoir fluid composition and properties using the Multiple Linear and Nonlinear regression techniques. These properties are often modeled primarily based on their dependence on temperature and pressure. However, variation in these properties is often a direct corollary of the changes in the inherent component composition. Such a model, when built, can be adapted to any reservoir fluid system. When built, PVT simulation results of compositional variations can be used to predict future viscosity changes, accurately. Two MVA techniques were compared – the Multiple Linear Regression (MLR) and Multiple Non-Linear Regression (MLNR). The MLR model revealed that 99.2% of the variation in the crude oil viscosity could be explained by the variation in mole percent of the heavier ends. Subsequently, the generated linear model was used to predict the viscosity as a QC technique. The residuals generated were found to follow a pattern when standardized and plotted against the oil viscosity. This revealed that there was an inherent error propagated through the prediction. As such the MLR model was not ideal although it correlated highly positively. On the other hand, the MLNR model revealed a 100% correlation between the crude oil viscosity and composition. Further analysis revealed a “statistically” perfect prediction of crude oil viscosity. Summarily, the Multiple Non-Linear Model is the most ideal to model the effects of changes in composition on crude oil viscosity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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