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Evaluation the Performance of Empirical Correlations for Predicting the Dead Oil Viscosity and Isothermal oil compressibility for Libyan Crude Samples

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ABSTRACT
Understanding the PVT parameters is essential for various petroleum calculations, including the assessment of hydrocarbon flow characteristics, forecasting future performance, designing production facilities, and strategizing enhanced oil recovery methods. Ideally, the PVT properties of hydrocarbons are derived from laboratory analyses conducted on either bottom-hole samples or recombined surface samples. However, laboratory data may not always be accessible due to economic or technical constraints. In such instances, empirical correlations are employed to estimate these properties. These correlations have been formulated based on fluid samples from specific geographical regions. Given the diverse compositions of crude oils across different areas, relying on empirical correlations to predict PVT properties may yield unsatisfactory results when applied to hydrocarbons that behave differently from the fluid samples used to develop the correlations. This study assesses various PVT correlations to estimate the viscosity of dead oil (μod) for Libyan crude oils, utilizing 58 data points, and examines isothermal compressibility (Co) for Libyan crudes with 145 data points across approximately 100 distinct reservoirs. The evaluation criteria employed in this research include statistical and graphical error analysis. Existing correlations were applied to the Libyan dataset, and error analysis was conducted by comparing the predicted values with the original experimental values. The most accurate correlation for each PVT parameter has been identified. The findings indicate that the correlation proposed by Kartoatmodjo & Schmidt yields a dead oil viscosity with an Average Absolute Error Ratio (AAER) of 18.53% and a relative coefficient of R^2 = 0.1512. For isothermal oil compressibility, the correlation by Ahmed (1985) demonstrates the best performance, with an AAER of 31.67% and a relative coefficient of R^2 = 0.104%

Keywords: PVT, Dead oil viscosity, Isothermal oil compressibility

Introduction

In petroleum engineering, characterization of reservoir fluids plays an important role of developing strategies for operating and managing existing reservoir and development of new one. Knowledge of the PVT parameters is a requirement for all types of petroleum calculations such as determination of hydrocarbon flowing properties, predicting future performance, designing production facilities and planning methods of enhanced oil recovery .Ideally the PVT properties of hydrocarbon are traditionally determined from laboratory analysis using either bottom-hole samples or recombined surface samples.

Among the PVT properties is Oil viscosity (μo), is defined as the internal resistance of the fluid to flow. Since it is crucial that all calculations in reservoir performance, production operations and design, and formation evaluation be as good as the PVT properties, therefore precise prediction of μo . There are many empirical correlations for predicting different PVT properties such as the equation of state (EOS), linear or non-linear multiply regression or graphical techniques. [1, 2]

Many correlations already exist in the oil and gas industry such as the: Standing, Glaso Beggs and Vasquez correlations etc. In some cases PVT data are not available or reliable. At these occasions, empirical correlations are used which are developed for PVT properties estimation. Accuracy of the correlations depends on similarity of fluid properties and fluid that used for developing correlations, thus results of the predictions may not be accurate for new samples. [3]

In the absence of PVT experiments the use of correlations provides the only viable option for the prediction of PVT properties for field applications. Correlations are also useful as a check against laboratory results, in making estimates for experimental design and in generalization of properties. [4]

Viscosity

Crude oil viscosity is an important physical property that controls the flow of oil through porous media and pipes. The viscosity, in general, is defined as the internal resistance of the fluid to flow. It ranges from 0.1 cp for near critical to over 100 cp for heavy oil. It is considered the most difficult oil property to calculate with a reasonable accuracy from correlations.Figure1 shows oil viscosity diagram. [5,6]

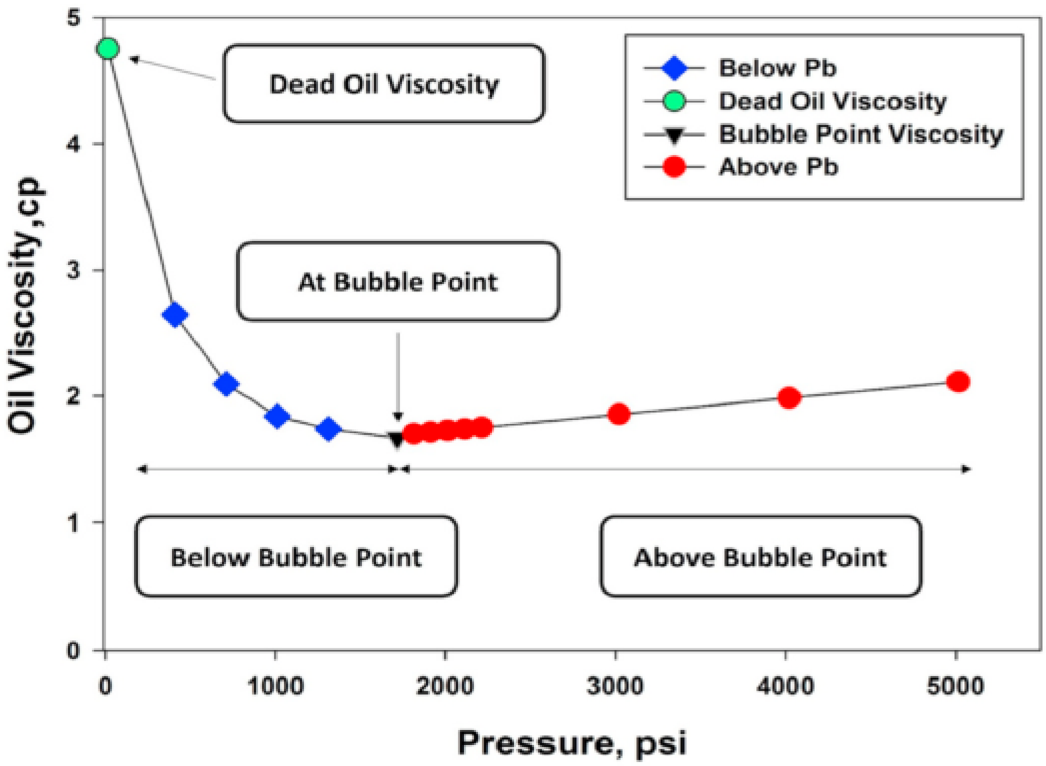


Figure 1: Viscosity versus Pressure [6]

Oil's viscosity is a strong function of the temperature, pressure, oil gravity, gas gravity, gas solubility, and composition of the crude oil. Whenever possible, oil viscosity should be determined by laboratory measurements at reservoir temperature and pressure.

The viscosity usually is reported in standard PVT analyses. If such laboratory data are not available, engineers may refer to published correlations, which usually vary in complexity and accuracy, depending on the available data on the crude oil. Based on the available data on the oil mixture, correlations can be divided into the following two types: correlations based on other measured PVT data, such as API° or Rs, and correlations based on oil composition. [7]

2.7 Dead oil viscosity, μod

The dead oil viscosity (oil with no gas in the solution) is defined as the viscosity of crude oil at atmospheric pressure and system temperature, T. [7]

The following correlations are applied for Dead oil viscosity in this study are shown in the table1

Table 1:Correlation for Dead oil viscosity[3,4,5,6,7,8,9,10,11,12,13,15,16]

Correlation	Equation
Beal (1946)	$\mu od = \left(0.32 + \frac{1.8 * 10^7}{API^{4.53}}\right)\left(\frac{360}{T-260}\right)^a$
Beggs and Robinson (1975)	$\mu od = 10^{A(T-460)^{-1.163}} - 1$
Glaso(1980)	$\mu od = \left(3.141(10^{10})\right) * (T-460)^{-3.444} * \left(Log(API)\right)^A$
Labedi (1992)	$\mu od = \frac{10^{9.224}}{API^{4.7013} * T^{0.6739}}$
Kartomadj and schmidt (1994)	$\mu od = (16 * 10^8) * Tf^{-2.8177} * (LogAPI)^{5.7526Log(Tf)-26.9718}$
Petrosky and farshad (1995)	$\mu od = 2.3511 * 10^7 * T^{-2.10255} * (Log(API))^J$

2.8 Isothermal Compressibility Coefficient of Crude Oil

The isothermal compressibility coefficient is defined as the rate of change in volume with respect to pressure increase per unit volume, all variables other than pressure being constant, including temperature. Mathematically, the isothermal compressibility, c, of a substance is defined by the following expression:

$$c = -\frac{1}{v}\left(\frac{dv}{dp}\right) \dots\dots\dots\dots\dots (1)$$

Isothermal compressibility coefficients are required in solving many reservoir engineering problems, including transient fluid flow problems; also they are required in the determination of the physical properties of the under saturated crude oil. [4,15,16]

For a crude oil system, the isothermal compressibility coefficient of the oil phase, *co*, is categorized into the following two types based on reservoir pressure:

1. At reservoir pressures that are greater than or equal to the bubble-point pressure ($p \geq pb$), the crude oil exists as a single phase with all its dissolved gas still in solution. The isothermal compressibility coefficient of the oil phase, *co*, above the bubble point reflects the changes in the volume associated with oil expansion or compression of the single-phase oil with changing the reservoir pressure. The oil compressibility in this case is termed under saturated isothermal compressibility coefficient.

2. Below the bubble-point pressure, the solution gas is liberated with decreasing reservoir pressure or dissolved with increasing the pressure. The changes of the oil volume as the result of changing the gas solubility must be considered when determining the isothermal compressibility coefficient. The oil compressibility in this case is termed saturated isothermal compressibility coefficient.

3. Several correlations were developed to estimate the oil compressibility at pressures above the bubble-point pressure, that is, an under saturated crude oil system.

The following correlations are applied for oil compressibility in this study are shown in the table2

Table 2: Correlation for oil compressibility [4, 15, 16]

Correlation	Equation
Vasquez and Beggs (1980)	$Co = \frac{-C1 + 5Rsb + C2(T - 460) - C3 * \gamma g + C4 * API}{10^5 P}$
Ahmed (1985)	$Co = \left(\frac{c1 + c2(Rs \left(\frac{\gamma g}{\gamma o}\right)^{0.5} + 1.25(T - 460)^{1.175}}{c4\ \gamma o + C5\ Rs\gamma g} \right) * e^{(c3 * P)}$
Petrosky and Farshad(1993)	$Co = 1.0705 * 10^{-7} * Rsb^{0.69357} * \gamma g^{0.1885} * API^{3272} * T^{0.6729} * P^{-0.5}$

Error Analysis

Statistical error analysis is used to analysis errors in order to check the performance and the accuracy of the developed models. The difference (error) occurs due to randomness or because the estimator does not account for information that could produce a more accurate estimate. In trying to ascertain whether the error measures in the training process are reliable, it should be considered whether the model under consideration is likely to have over fitted the data. The overall data must split into training, validation and testing subsets. The error measures in the training, validation and testing datasets are very important. Indeed, the model's performance in the testing dataset is the best guide to its ability to predict the future. However, it should be expect that the errors made in predicting the future could be larger than those made in fitting the past. For the purpose of communicating model results to others, it is usually best to report Absolute (AE) and Absolute Relative Percent Error (ARE), and multiple regression coefficients (R^2). The error term can be defined as the deviation of the calculated value from the true value. [6] [7]

Cross Plot

In this technique, all the estimated values are plotted vs. the experimental values, and thus a cross plot is formed. A45° straight line is drawn on the cross plot on which estimated value is equal to experimental value. The closer the plotted data points are to this line, the bitterns the prediction it. [7]

Procedures of Evaluating Empirical Correlations

All the data points used in this study are exclusively obtained from Libya, mostly for reservoirs from Sirte, Ghadames and Murzuq basins, the data used in this study were obtained from analysis of 100 samples from different Libyan reservoirs. The experimentally obtained for dead oil viscosity for Libyan crudes using (58) data points and (154) data points for Isothermal Compressibility above bubble point pressure for Libyan crudes.

The data were collected from various reservoirs/fields of different chemical compositions throughout Libyan oil fields. Table 3 presents the description of data utilized in this study with a wide range of dead oil viscosity, isothermal compressibility and Solution gas oil ratio of the crude oil, reservoir temperature, gas relative density, and API oil gravity. Analyzing the data detected seven observations that were identified as outliers. Outliers of a few data points that are not in the range are removed.

Table 3: Data range

PVT Property	Minimum	Maximum
Tank-oil gravity (API)	27.5	52.3
Pressure above bubble point (Psi)	122	8500
Pressure at bubble point (psi)	122	6273
Reservoir temperature (F)	85	303.1
Average surface gas gravity(Air=1)	0.7	1.567
Dead oil viscosity (cp)	0.1	5.036
Bubble point the Solution gas oil ratio (scf/STB)	18	3772

Dead Oil Viscosity:

In this study, Beggs& Robinson, Beal, Glaso, Labedi, Petrosky and Farshad and Kartoatmodjo&schmidts for Dead Oil Viscosity were evaluated using Libyan data. Statistical error analysis was used to evaluate the performance of the correlations. The average absolute error, coefficient and standard deviation were the major statistical parameters used as comparative criteria for the testing of the evaluated Correlations. The statistical accuracy of Dead Oil Viscosity is shown in the Table 4.

Table 4: Statistical accuracy of Dead oil viscosity

CORRELATION	ARE, %	AARE,%	R^2
Beggs& Robinson	-26.48	57.76	0.0762
Beal	12.47	49.18	0.0731
Glaso	9.08	45.67	0.1777
Labedi	-29.91	54.54	0.3464

Petrosky&farshad	-1.91	44.58	0.2061
Kartoatmodjo&schmidts	48.94	18.53	0.1512

Graphical analysis (cross plot) of relative errors is a plot of the measured value versus experimental value. A perfect correlation would plots a straight line with a slope of 45º. From the Table 4 Kartoatmodjo & schmidts correlation outperforms the rest of correlations studied with AAER 18.53% and relative coefficient $R^2$0.1512. The Error diagrams is shown in figure 2, Also Cross plots for the correlations are presented in Figures (3-4).

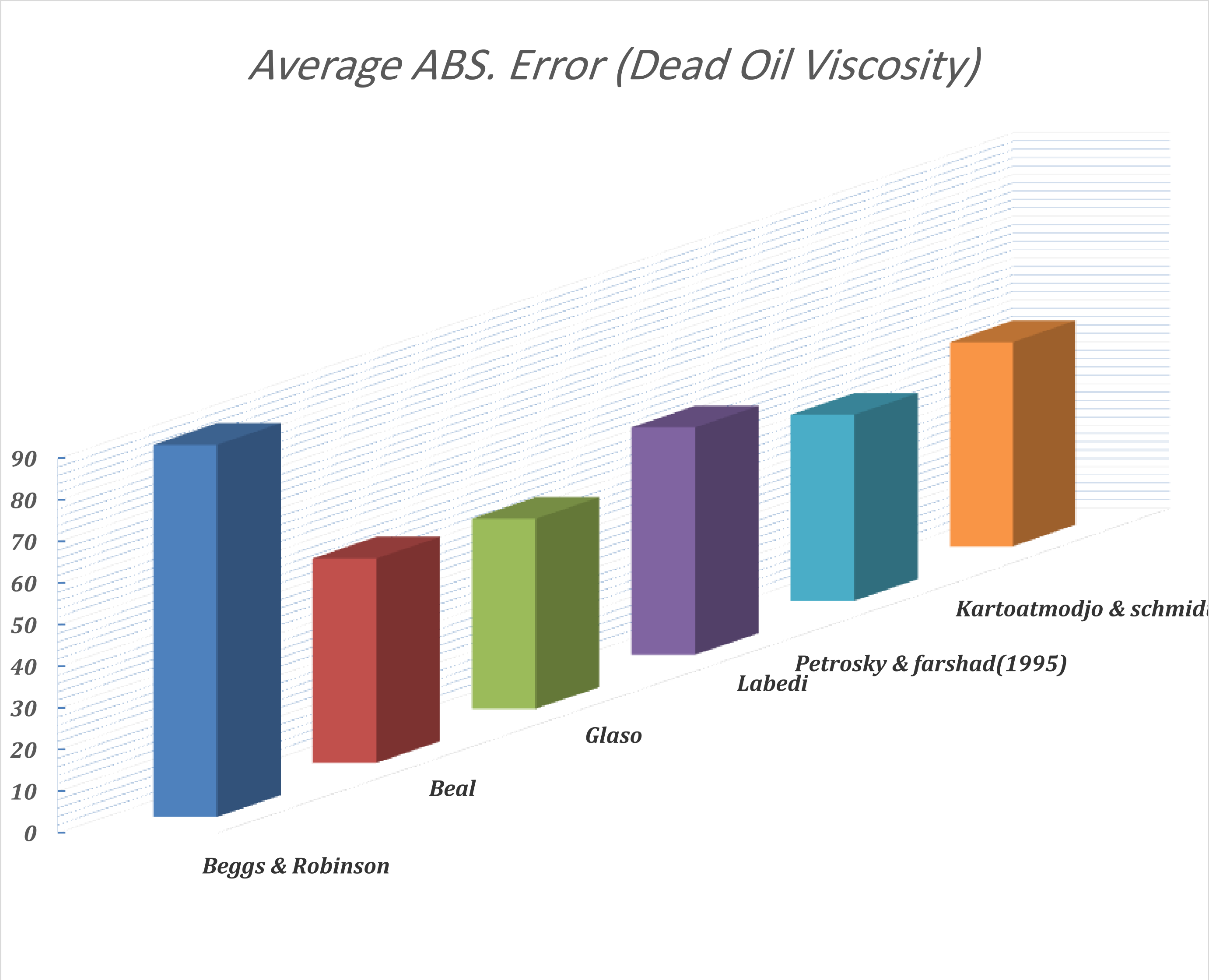
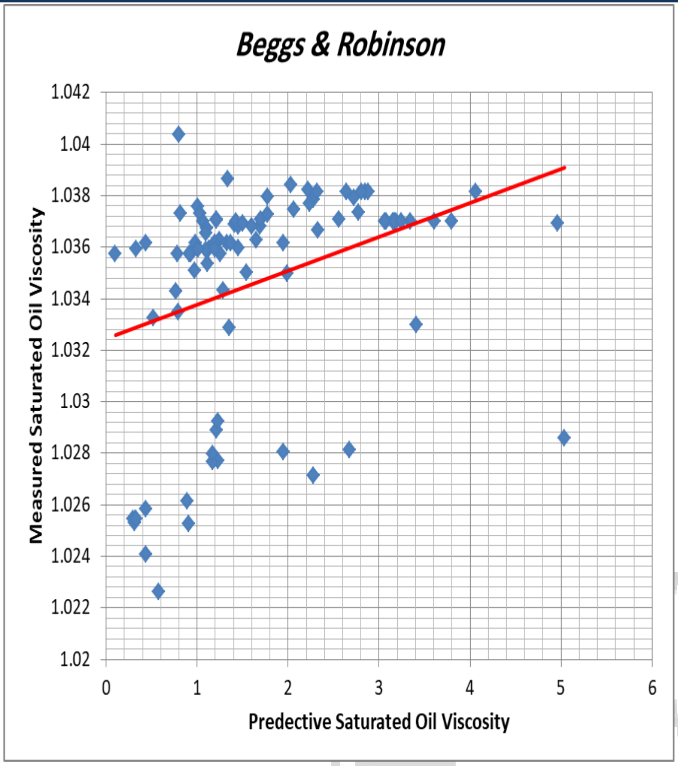
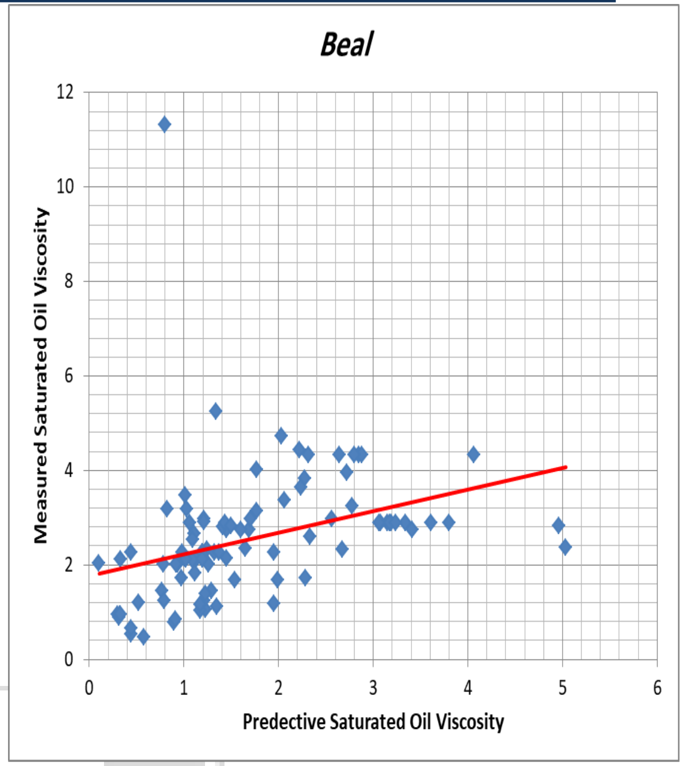
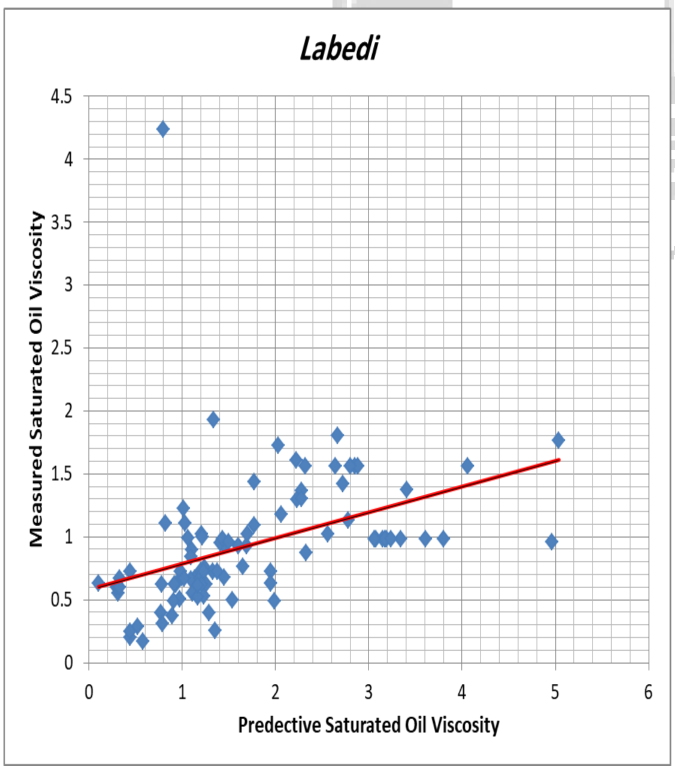


Figure 2: Error diagram for dead oil viscosity.







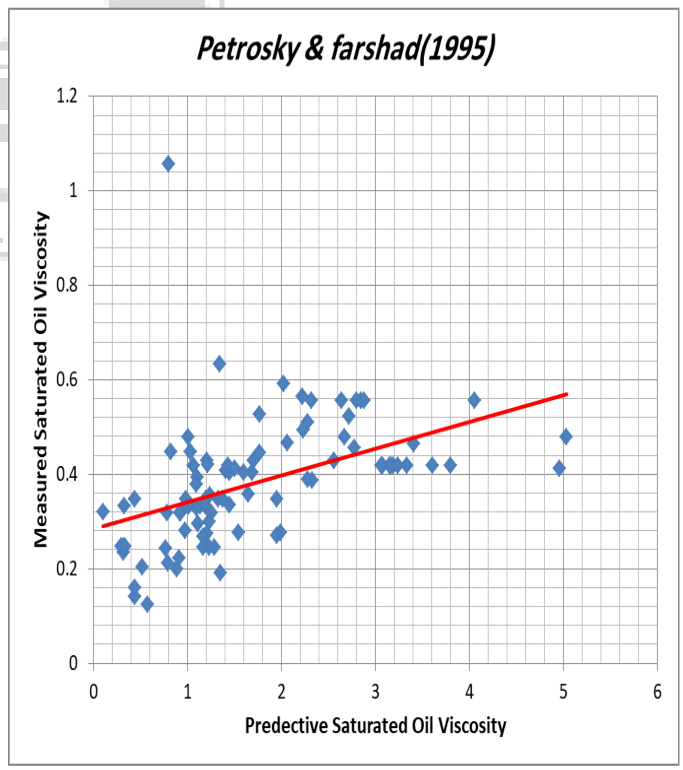


Figure 3: cross plot for dead oil viscosity

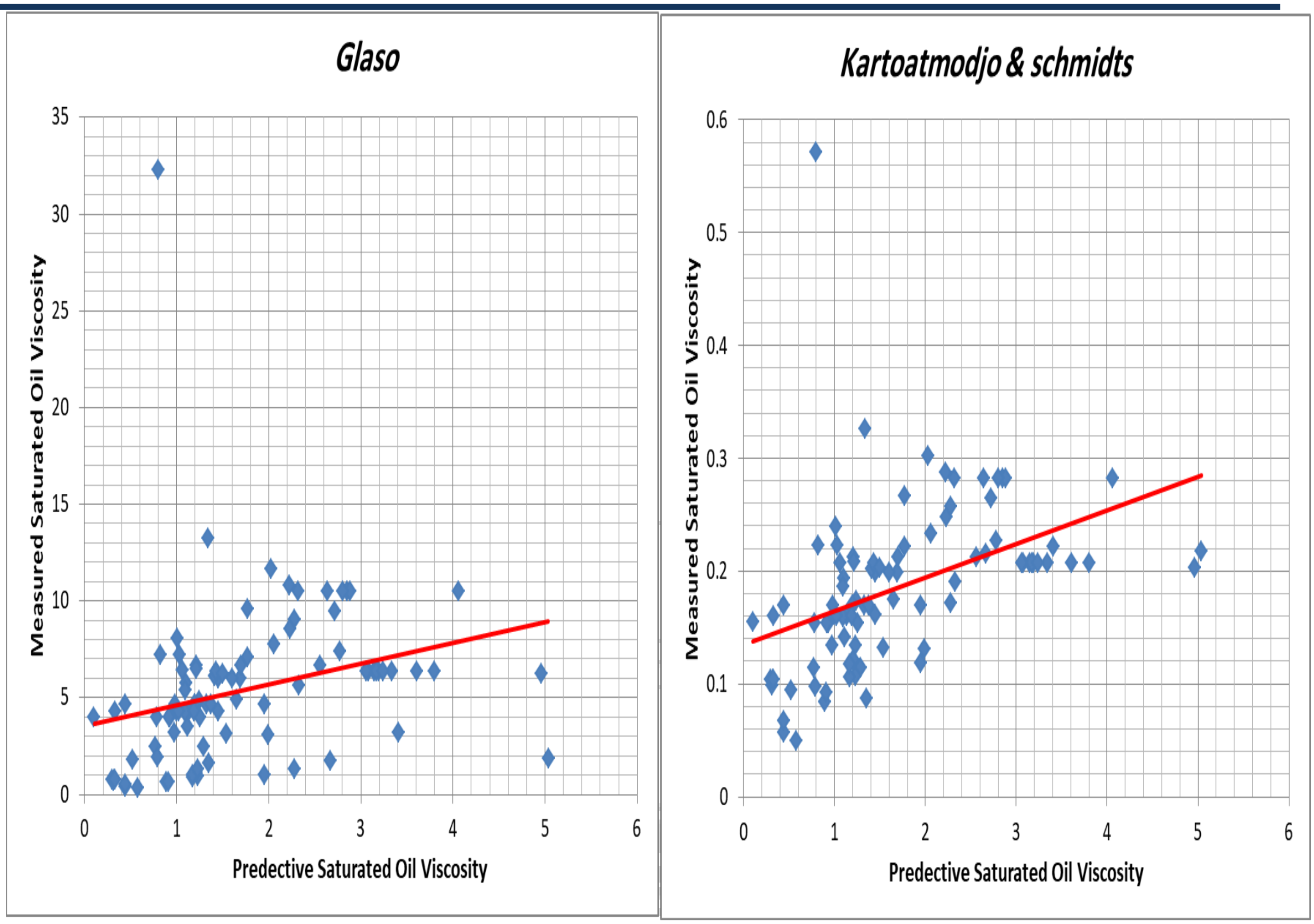


Figure 4: cross plot for dead oil viscosity

Oil compressibility above bubble point pressure:

In this study, Beggs and Robinson, Ahmed, Al-Marhon and Pertrosky & Farshad correlations for oil compressibility above the bubble point were evaluated using Libyan data. Statistical error analysis was used to evaluate the performance of the correlations. The statistical accuracy error diagram and cross plots of oil compressibility are shown in Figure (10-9) and Table 5. Ahmed shows the most outstanding performance with lowest Average Absolute Error 31.67% and R^2 coefficient 0.104% respectively.

Table 5: Statistical accuracy of Oil Compressibility

CORRELATION	ARE, %	AARE,%	R^2
Vasques and Beggs	-46.35	53.11	0.50
Ahmed(1985)	11.65	31.67	0.104
Almarhon	54.36	54.36	0.017
Pertrosky and Farshad	-21.93	48.87	0.059

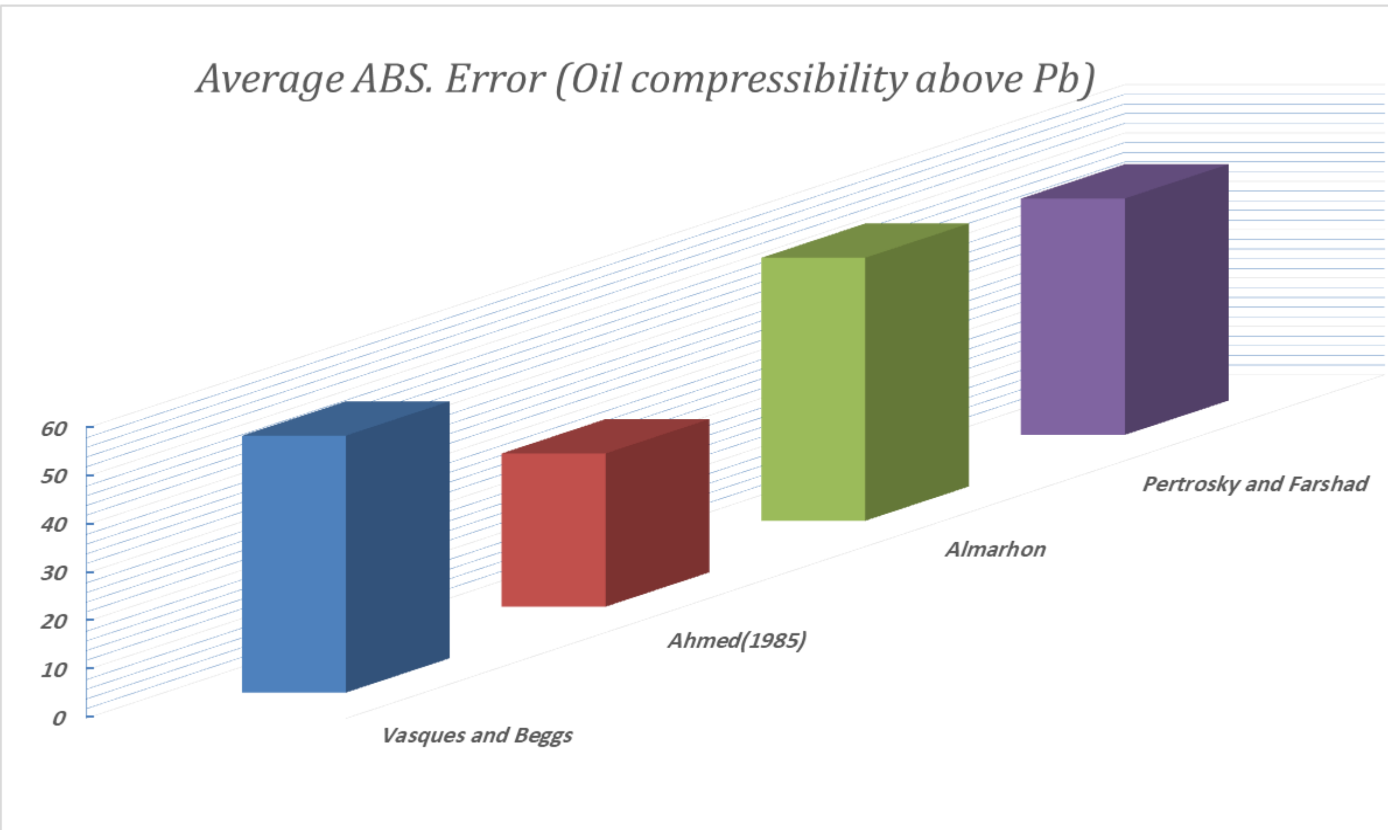


Figure 5: Error diagram for oil compressibility above Pb pressure

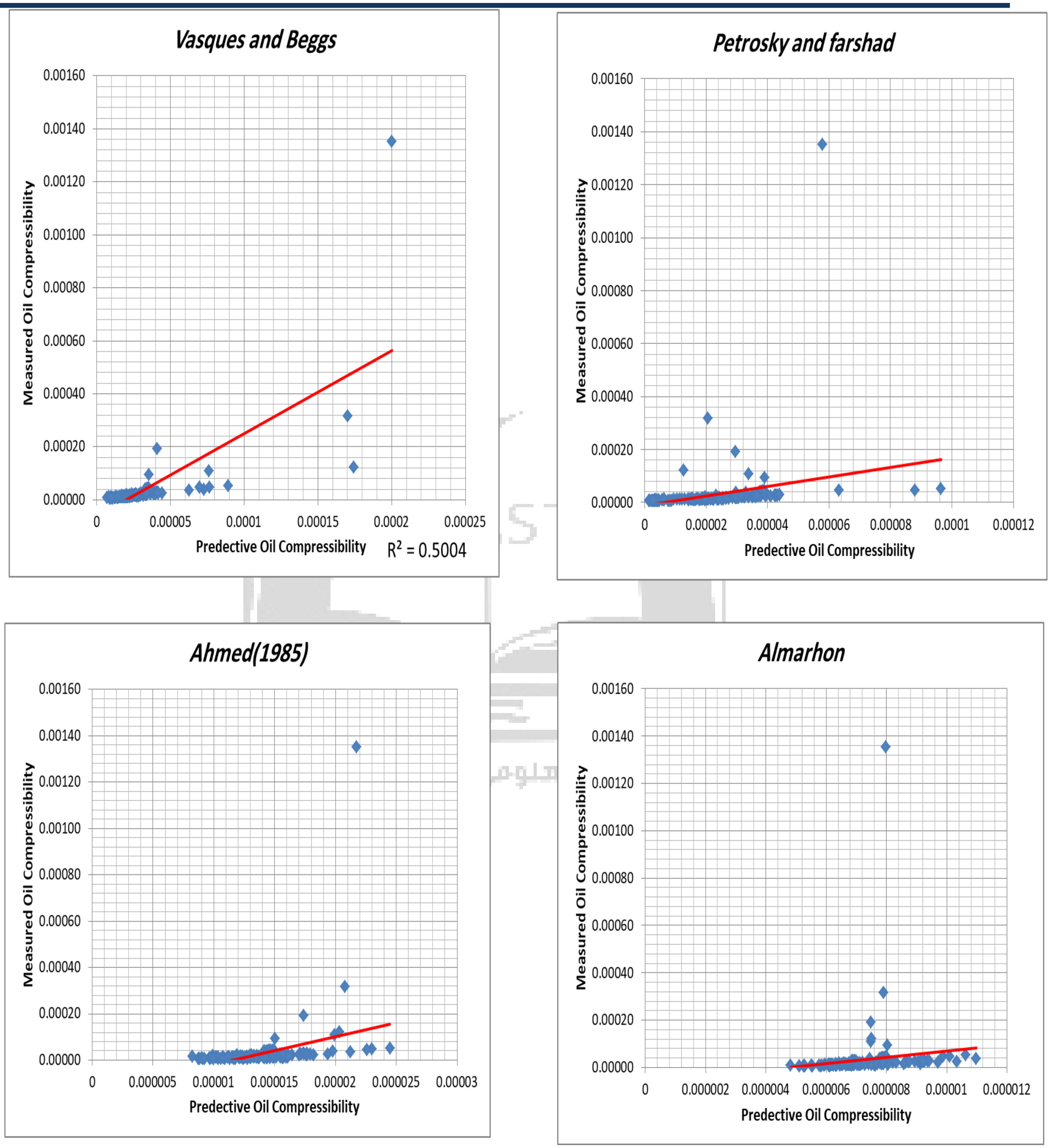


Figure 6: Crossplot for oil compressibility above Pb pressure.

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Conclusion

Several empirical models for estimating the dead oil viscosity of crude oils have been evaluated using samples data of crude oils from the selected Libyan oil reservoirs. Good agreements between the predicted and experimental values have been observed. It can be concluded that, Kartoatmodjo & schmidts correlations is the best and accurate for dead oil viscosity with AAER 18.53% and relative coefficient $R^2$0.151 and Ahmed correlation is best for prediction of oil compressibility above bubble point pressure with lowest Average Absolute Error 31.67% and R^2 coefficient 0.104% respectively.

Recommendations

The following recommendations are made for future works:

Study should be conducted to develop new correlation for dead oil viscosity and oil compressibility above Pb pressure to be more accurate for Libyan crude. Also, Artificial Neural network model will be proposed for future study to predict dead oil viscosity and oil compressibility above Pb pressure for Libyan crude.

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