Evaluation of the Performance of Empirical Correlations for Predicting the Undersaturated and Saturated Oil Viscosity of Libyan Crude Samples

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■ **Abstract:**

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 obtained from laboratory analysis using either bottom-hole samples or recombined surface samples However laboratory data are not always available due to economical and/or technical reasons. In this case empirical correlations are used to estimate them. Empirical correlations have been developed based on fluid samples from certain specific regions of the world. Because of the varying compositions of crude oils from different regions, prediction of PVT properties form empirical correlations may not provide satisfactory results when they are applied to hydrocarbon behaving differently from the fluid samples on which the correlations were based. The purpose of this study is to evaluate the most popular correlations for oil viscosity against a set of Libyan PVT Data to recommend the best correlations for Libyan crude oils oil viscosity.

Evaluation of some PVT correlations to estimate undersaturated oil viscosity, (μo) for Libyan crude samples using (804) data points and Saturated oil viscosity at bubble point pressure (μob) for Libyan crude samples using (92) data points for about (100) different reservoirs. Statistical and graphical error analysis is used as evaluation criteria for this study. Existing correlations are applied to Libyan data set and error analysis is performed based on a comparison of the predicted value with the original experimental value. Best correlation has been identified for each PVT parameter. The results of this

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study show that Khan correlation given best result for under saturated oil viscosity with the AAER 5.2 % and relative coefficient R2 0.983 % , for saturated oil viscosity Elsharkway&AliKhan with AAER 27.9 % and relative coefficient R2 0.785 % given the best result.

- **Keywords:** PVT,Saturated oil viscosity,Undersaturated oil viscosity

■ المستخلص:

تعد معرفة خواص النفط والغاز (PVT) مطلبًا لجميع أنواع حسابات النفط مثل تحديد خصائص تدفق الهيدروكربون ، والتنبؤ بالأداء المستقبلي ، وتصميم مرافق الإنتاج وطرق التخطيط للاسترداد الاضافى للنفط. يتم الحصول على خصائص النفط والغاز(PVT) للهيدروكربونات بشكل مثالي من التحليل المختبري باستخدام إما عينات الحفرة السفلية أو عينات السطح المعاد تجميعها ومع ذلك ، لا تتوفر البيانات المختبرية دائمًا لأسباب اقتصادية أو فنية. في هذه الحالة ، يتم استخدام المعادلات الرياضية لتقديرها. تم تطوير المعادلات الرياضية بناءً على عينات السوائل من مناطق معينة من العالم. بسبب التراكيب المتغيرة للزيوت الخام من مناطق مختلفة ، فإن التنبؤ بخصائص PVT فإن المعادلات الرياضية قد لا توفر نتائج مرضية عند تطبيقها على الهيدروكربونات التي تتصرف بشكل مختلف عن عينات السوائل التي استخدمت المعادلات الرياضية. الغرض من هذه الدراسة هو تقييم المعادلات الرياضية الأكثر شيوعًا للتنبؤ بلزوجة النفط باستخدام البيانات المعملية لخواص النفط للحقول الليبية للتوصية بأفضل المعادلات الرياضية للتنبؤ بلزوجة النفط الخام الليبي.

تقييم بعض المعادلات الرياضية لخواص النفط لتقدير لزوجة النفط غير المشبع (μo) لعينات الخام الليبي باستخدام عدد (804) عينة ولزوجة الزيت المشبع عند ضغط نقطة الفقاعة (μob) لعينات الخام الليبي باستخدام (92) عينات لحوالي (100) حقل من الحقول الليبية المختلفة. يستخدم تحليل الخطأ الإحصائي والرسوم البيانية كمعايير تقييم لهذه الدراسة. يتم تطبيق المعادلات الرياضية على مجموعة البيانات الليبية ويتم إجراء تحليل الأخطاء بناءً على مقارنة القيمة المتوقعة مع القيمة الأصلية المتحصل عليها عن طريق المختبرات المعملية. تم تحديد أفضل معادلة رياضية لكل خاصية من خواص PVT. أظهرت نتائج هذه الدراسة أن معادلة خان أعطت أفضل نتيجة لحساب لزوجة الزيت غير المشبع مع AAER٪5.2 والمعامل النسبي 0.983 ٪ R2، و لزوجة الزيت المشبع Elsharkway & AliKhan مع 27.9 ٪ AAER والمعامل النسبي 0.785 ٪ R2 أعطت أفضل نتيجة.

- **المفاتيح:** الحجم والضغط ودرجة الحرارة، لزوجة الزيت الغير المشبع، لزوجة الزيت المشبع

■ 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)

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. (2)

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. (3)

■ 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. (4) (5)

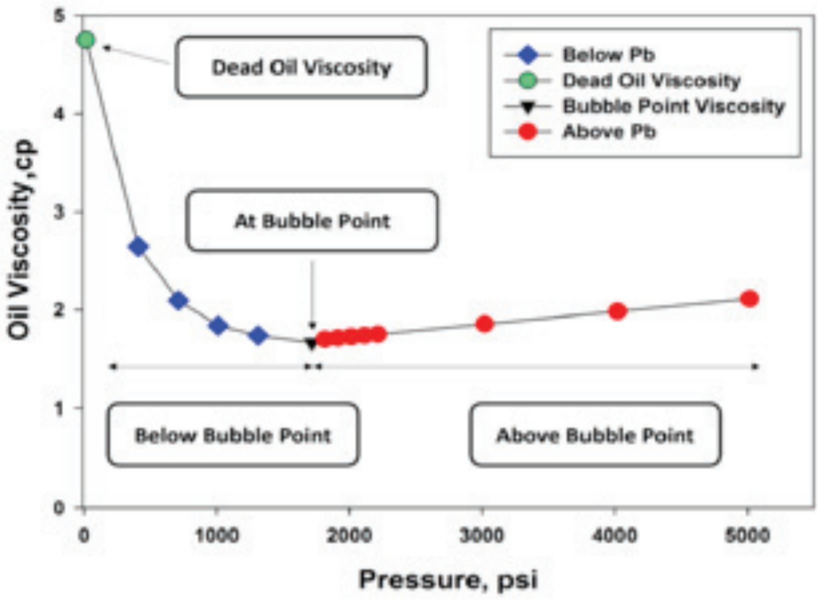

Figure 1: Viscosity versus Pressure (5)

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. (6) (7)

- **Uundersaturated Oil Viscosity, μo**

Under saturated oil viscosity is defined as the viscosity of the crude oil at a pressure above the bubble-point and reservoir temperature. (7)

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

Table 1:Correlation for undersaturated oil viscosity

Correlation	Equation
Beal (1946) [8]	$\mu o = \mu ob + 0.001 * (P - Pb) * \left(0.024 * \mu ob^{1.6} + 0.038 * \mu ob^{0.56}\right)$
Beggs and Robinson (1975) [9]	$\mu o = \mu ob * \left(\frac{P}{Pb}\right)^{x}$ $X = 2.6 * P^{1.187} * \exp\left(-11.513 + \left(-8.98 * 10^{-5}\right) * p\right)$
Vazquez and Beggs (1980) [10]	$\mu o = \mu ob * (\frac{P}{Pb})^{m}$ $m = 2.6 * P^{1.187} * 10^{a}$ $a = -\left(3.9 * 10^{-5}\right) - P$
Khan et al (1987) [11]	$\mu o = \mu ob * \exp\left(9.6 * 10^{-5}(P - Pb)\right)$
Labedi (1992) [12]	$\mu o = \mu ob - \left(1 - \frac{p}{pb}\right) * \left(\frac{10^{-2.488} * \mu od^{0.9036} * pb^{0.6131}}{10^{0.01976*API}}\right)$
Kartomadj and schmidt (1994) [13]	$\mu o = 1.00081 * \mu ob + 0.001127 * (P - Pb)$ $* \left(-00.006517 * \mu ob^{1.8148} + 0.038 * \mu ob^{1.590}\right)$
Petrosky and farshad (1995) [14]	$\mu o = \mu ob + 1.3449 * 10^{-3} * (P - Pb) * 10^{a}$ $a = -1.0146 * 1.3322 * Log(\mu ob) - 0.4876 * Log(\mu ob)^{2}$ $- 1.1536 * Log(\mu ob)^{3}$
Elsharkawy and Ali khan (1999) [15]	$\mu o = \mu ob + 10^{-2.0771} * (p - pb) * (\mu od^{1.19279} * \mu ob^{-0.40712}$ $* pb^{-0.7941}$
Elsharkawy and Gharbi (2000) [16]	$\mu o = \mu ob + m * (P - Pb)$ $m = (-5612 + 9481 * \mu od - 1459 * \mu od^{2} + 81 * \mu od^{3}) * 10^{-8}$
Khazam (2016) [17]	$\mu o = \mu ob * +(5.36473 * 10^{-4}\mu od + 6.32 * 10^{-6} * API)^{1.96518}$ $* \Delta P^{1.4744}$

● Saturated Oil Viscosity, m_{ob}

The saturated (bubble-point) oil viscosity is defined as the viscosity of the crude oil at any pressure less than or equal to the bubble-point pressure. [7]

The following correlations are applied for saturated viscosity in this study are shown in the table2

Table 2: Correlation for saturated oil viscosity

Correlation	Equation
Chew-Connally Correlation (1959) (18)	$\mu ob = (10)^{a} * (\mu od)^{b}$ $a = Rs\left(2.2 * (10^{-7})Rs - 7.4 * (10^{-4})\right)$ $b = \frac{0.68}{10^{c}} + \frac{0.25}{10^{d}} + \frac{0.062}{10^{e}}$ $c = 8.62 * (10^{-5})Rs$ $d = 1.1 * (10^{-3})Rs$ $e = 3.74 * (10^{-3})Rs$
Aziz, Govier and Fogarasi (1972) (19)	$\mu ob = A * (\mu od^{b})$ $a = 0.20 + (0.80 * 10^{-0.00081Rs})$ $b = 0.43 + (0.57 * 10^{-0.00072Rs})$
Beggs-Robinson's (1975) (9)	$\mu ob = a * (\mu od)^{b}$ $a = 10.715 * (Rs + 100)^{-0.515}$ $b = 5.44 * (Rs + 155)^{-0.338}$
Bergman (2007) (20)	$\mu ob = A * (\mu od)^{b}$ $A = \exp(4.768 - 0.8359 * \ln(Rs * 300))$ $b = 0.555 + \frac{133.5}{Rs + 300}$
Labedi (1992) (12)	$\mu ob = \left(10^{(2.344 - 0.03542 * API)}\right) * \left(\frac{\mu od^{0.6447}}{Pb^{0.426}}\right)$
Almehaideb (1997) (21)	$\mu ob = 6.59927 * 10^{5} * Rs^{-0.597627} * Tf^{-0.941624} * \gamma g^{-0.555208} * API^{-1.487449}$
Elsharkway and Ali khan (1999) (15)	$\mu ob = A * (\mu od)^{b}$ $A = 1241.932 * (Rs + 641.026)^{-1.12410}$ $b = 1768.841 * (Rs + 1180.335)^{-1.06622}$
A. Naseri and M. Nikazar (2005) (22)	$\mu ob = 10^{1.1145} * Pb^{-0.4956} * \mu od^{0.9961}$
Khazam(2016) (17)	$\mu ob = \left(10^{(9.658 * API^{-0.696})}\right) * (\frac{\mu od}{Rs})^{0.3873}$

• 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 (R2). 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 under saturated oil viscosity, (μo) for Libyan crudes using (804) data points and and Saturated oil viscosity at bubble point pressure (μob) 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 under saturated oil viscosity, saturated oil viscosity, 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
(Under saturated oil viscosity (cp	0.1050	6.584
(Saturated oil viscosity at bubble point (cp	0.105	3.811
(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

Undersaturated Oil Viscosity:

In this study, Elsharkawy&AliKhan, Khan, Labedi, Beal, Bgggs and Robinson, Vazquez and bags, Kartomodj and Schmidt, Petrosky and Farshad, khazam, Elsharkawy and Gharbi for Under-Saturated 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 Under-Saturated Oil Viscosity is shown in the Table 4

Table 4: Statistical accuracy of undersaturated oil viscosity

CORRELATION	% ,ARE	% ,AARE	R^2
Elsharkawy&AliKhan	-1.83	9.3	0.965
Khan	0.59	5.2	0.983
Labedi	10.63	11.25	0.946
Beal	4.79	6.37	0.976
Bgggs and Robinson	-8.80	13.6	0.870
Vazquez and baggs	-8.78	13.62	0.869
Kartomodj and schmidt	8.92	9.86	0.971
Petrosky and Farshad	-0.04	5.89	0.971
khazam	1.86	7.50	0.974
Elsharkawy and Gharbi	4.31	8.56	0.954

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 3 khan correlation outperforms the rest of correlations studied with lowest Average Absolute Error 5.2 % and R^2 0.983 % For Under-saturated Oil Viscosity. The Error diagrams is shown in figure 2, Also Cross plots for the some of the correlations are presented in Figures (3-5).

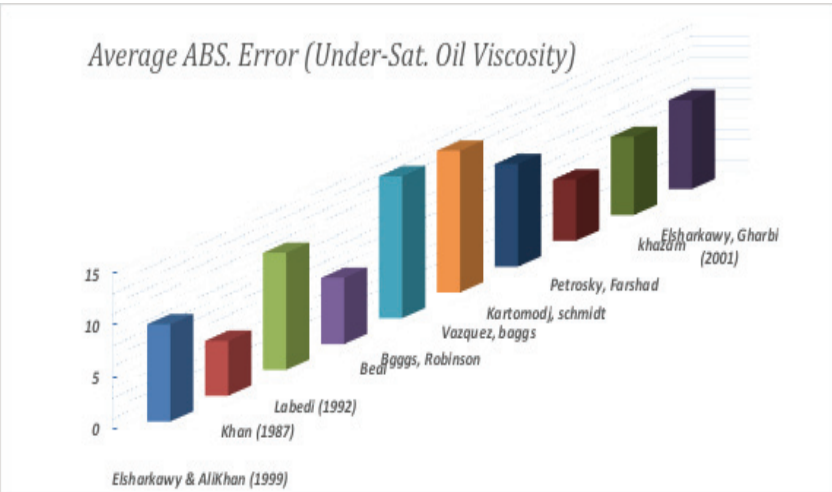

Figure 2: Error diagram for undersaturated oil viscosity

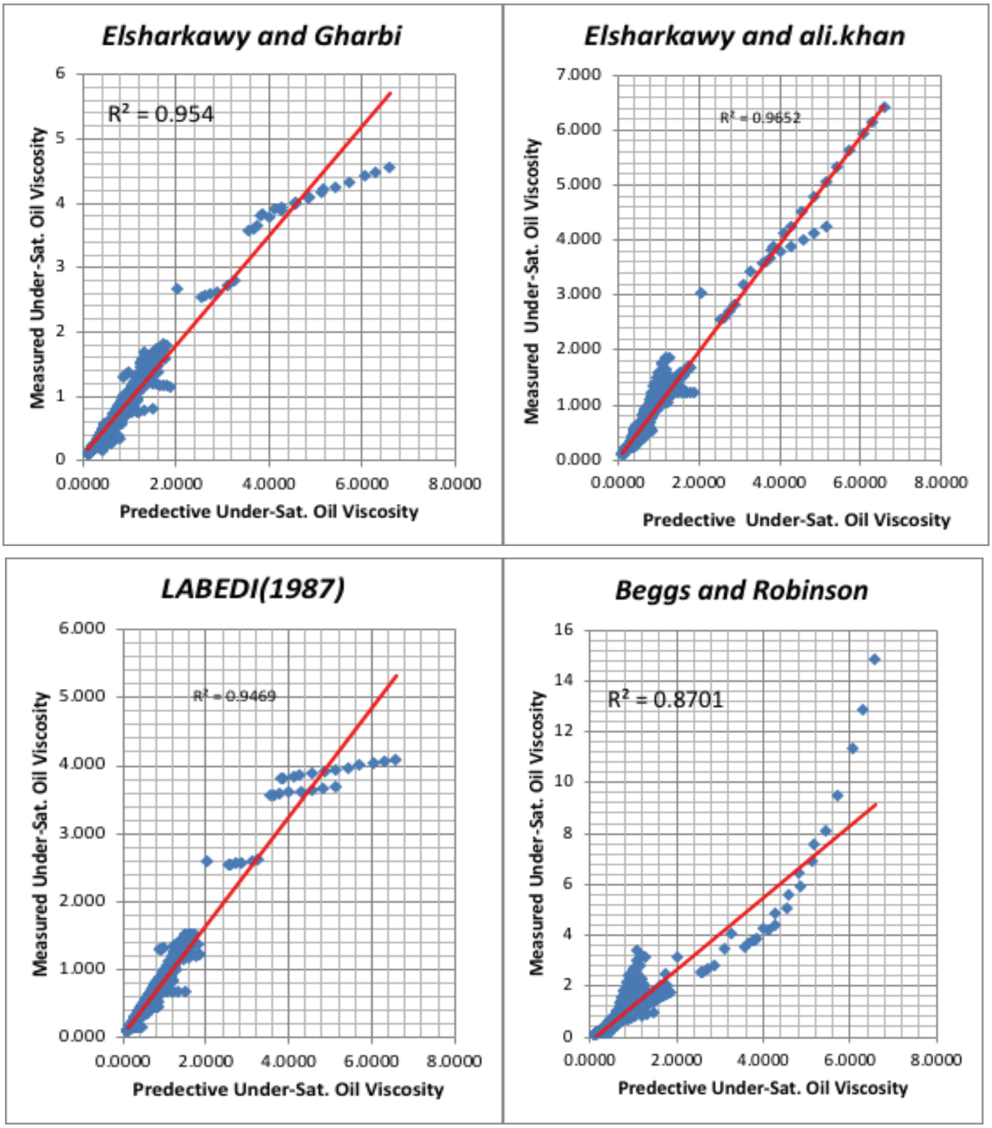

Figure 3: Cross plot for undersaturated oil viscosity

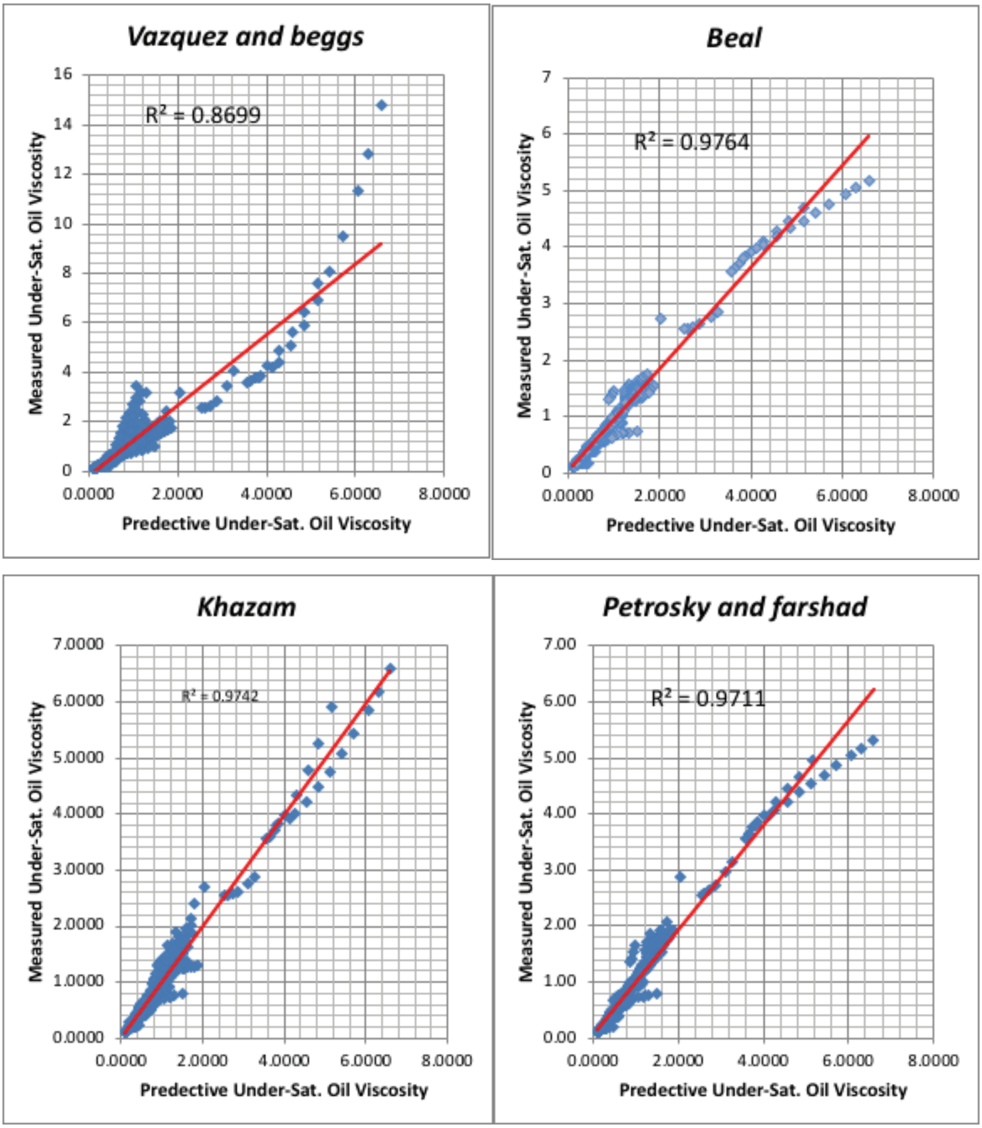

Figure 4: Cross plot for undersaturated oil viscosity

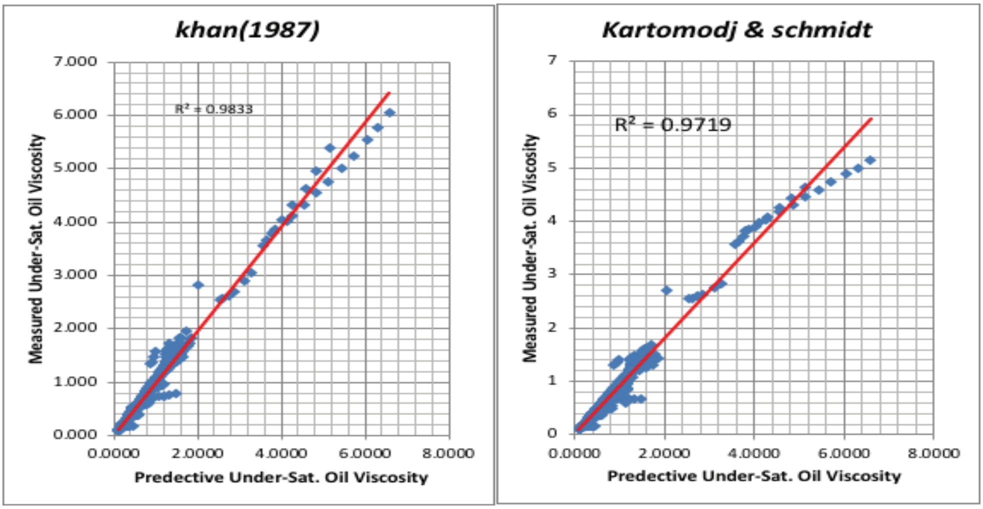

Figure 5: Cross plot for undersaturated oil viscosity

Saturated Oil Viscosity:

In this study, chew-connally, Beggs and Robinson, Elsharkway&AliKhan, Almehaideb, labedi. Aziz and Fogarasi, Bergman, khazam, Nasri-Nikazar, correlations saturated oil viscosity at 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 saturated oil viscosity are shown in Figure (10-9) and Table 5. Elsharkway&AliKhan shows the most outstanding performance with lowest Average Absolute Error27.9 % and correlation coefficient of and R^2 0.785 % respectively.

Table 5: Statistical accuracy of saturated oil viscosity

CORRELATION	% ,ARE	% ,AARE	R2
chew-connally	-13.22	37.12	0.737
Beggs and Robinson	6.93	29.14	0.766
Elsharkway&AliKhan	1.46	27.91	0.785
Almehaideb	-4.19	51.87	0.251
labedi	-22.94	57.42	0.624
Aziz and Fogarasi	-13.17	34.80	0.791
Bergman	-2.14	30.91	0.793
khazam	-16.96	39.68	0.596
Nasri-Nikazar	-6.88	42.50	0.70

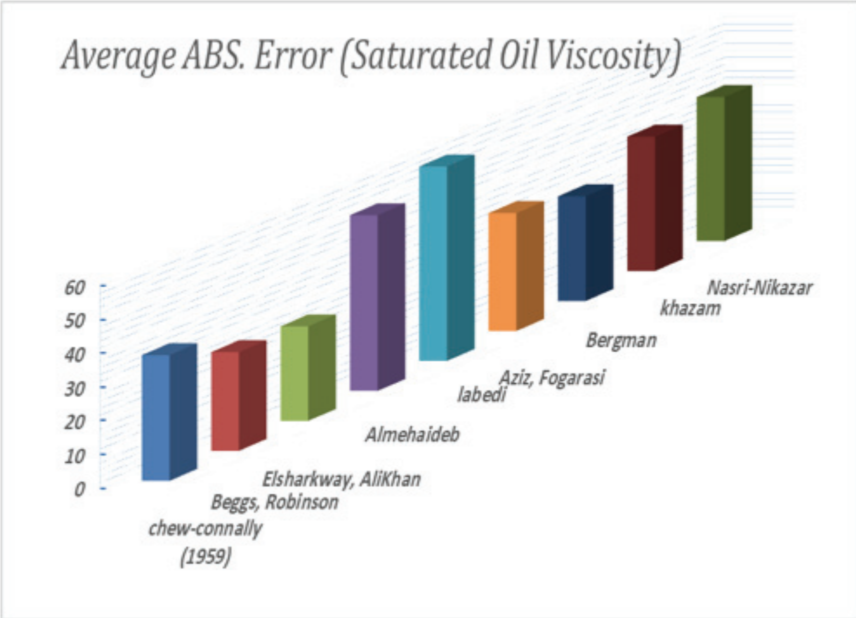

Figure 6: Error diagram for saturated oil viscosity

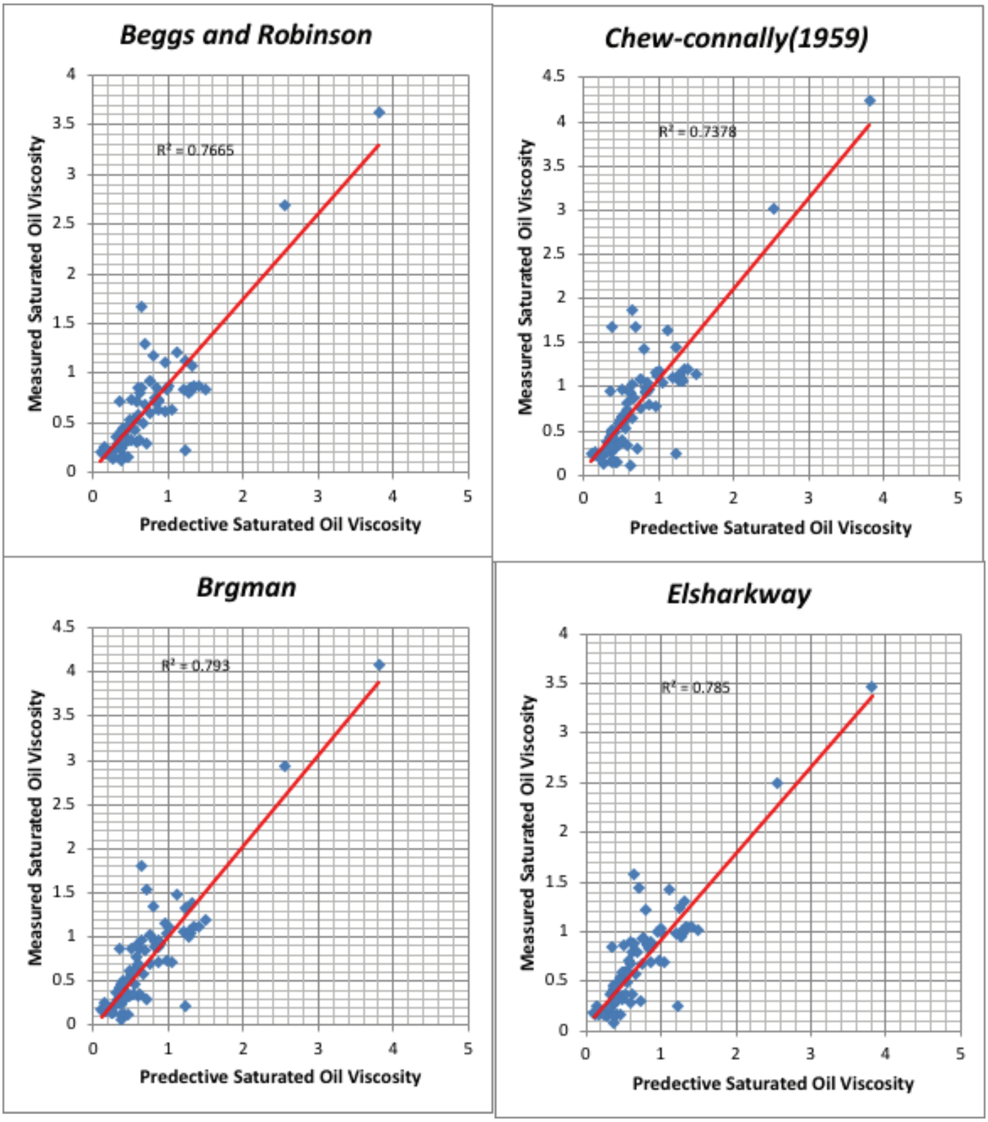

Figure 7: Cross plot for saturated oil viscosity

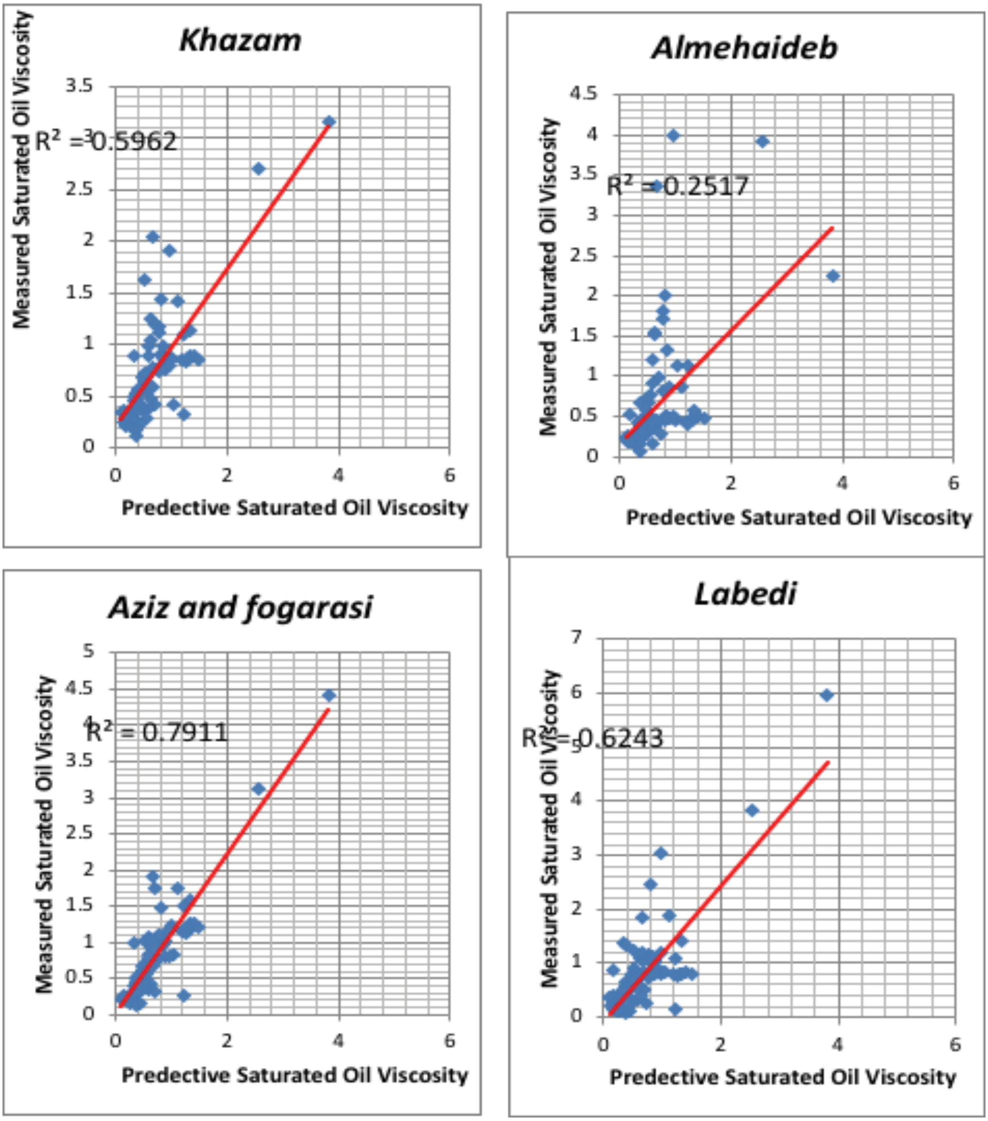

Figure 8: Cross plot for saturated oil viscosity

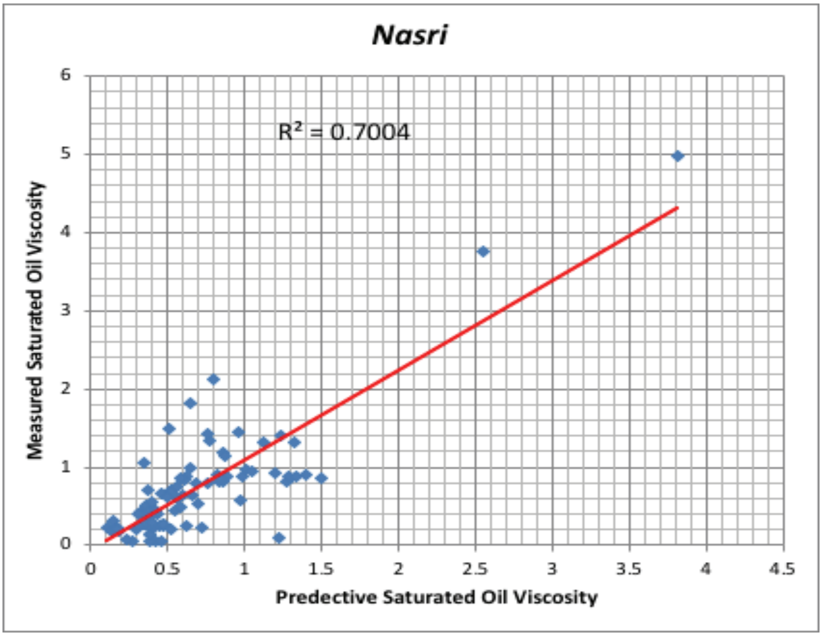

Figure 9: Cross plot for saturated oil viscosity

■ Conclusion

Several empirical models for estimating the undersaturated and saturated 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, khan correlations is the best and accurate for undersaturated oil viscosity with with relative coefficient 0.983 % and average absolute error 5.2 % and Al Elsharkway&AliKhan correlation is best for prediction of saturated oil viscosity at bubble point pressure with relative coefficient 0.785 % and average absolute error 27.9 % .

■ Recomendations

The following recommendations are made for future works:

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

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