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New Viscosity Correlation for Different Iraqi Oil Fields

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Abstract
Viscosity is one of the most important governing parameters of the fluid flow, either in the porous media or in pipelines. So it is important to use an accurate method to calculate the oil viscosity at various operating conditions. In the literature, several empirical correlations have been proposed for predicting crude oil viscosity. However, these correlations are limited to predict the oil viscosity at specified conditions. In the present work, an extensive experimental data of oil viscosities collected from different samples of Iraqi oil reservoirs was applied to develop a new correlation to calculate the oil viscosity at various operating conditions either for dead, saturated or under saturated reservoir. Validity and accuracy of the new correlation was confirmed by comparing the obtained results of this correlation and other ones, with experimental data for Iraqi oil samples. It was observed that the new correlation gave the most accurate agreement with the experimental data.

Keywords: Viscosity, oil, correlation, under saturated oil, dead oil, saturated oil

Introduction
Crude oil viscosity is an important physical property that controls and influences the flow of oil through porous media and pipes. Also, crude oil viscosity plays a key role in designing any EOR process and has influential role in multiphase flow through tubing and piping system [1]. The viscosity, in general, is defined as the internal resistance of the fluid to flow.

The oil viscosity is a strong function of the temperature, pressure, oil gravity, gas gravity, and gas solubility. Whenever possible, oil viscosity should be determined by laboratory measurements at reservoir temperature and pressure. According to the pressure, the viscosity of crude oil can be classified into three categories:

- Dead-Oil Viscosity: The dead-oil viscosity is defined as the viscosity of crude oil at atmospheric pressure (no gas in solution) and system temperature. The knowledge of the Dead oil viscosity is one of the most important factors in developing viscosity empirical correlations because the other viscosities are obtained from it. [2]
- Saturated-Oil Viscosity: The saturated (bubble-point) oil viscosity is defined as the viscosity of the crude oil at the bubble-point pressure and reservoir temperature.
- Undersaturated-Oil Viscosity: The undersaturated oil viscosity is

defined as the viscosity of the crude oil at a pressure above the bubble-point and reservoir temperature [3].

Numerous correlations have been proposed to calculate the oil viscosity. Hence, Seven well known correlations were used to predict viscosity of undersaturated oil; these correlations are Beal (1946) [4]; Beggs and Robinson (1975) [5]; Vasquez and Beggs (1980) [6]; Khan correlation (1987) [7]; Labedi (1992) [8]; Kartoatmodjo and Schmidt (1994) [9] and Petrosky and Farshad (1995) [10] as shown in Table 1

Table 1: Summary of Numerous Viscosity Correlations

Correlations	
Beal correlation, [4]	$\mu_o = \mu_{ob} + 0.001 * (P - P_b) * (0.024 * \mu_{ob}^{1.6} + 0.038 * \mu_{ob}^{0.56})$
Beggs and Robinsons correlation, [5]	$\mu_o = \mu_{ob} * \left(\frac{P}{P_b}\right)^X$ Where : $X = 2.6 * P^{1.187} * exp\left(-11.513 + (-8.98 * 10^{-5}) * P\right)$
Vazquez and Beggs, [6]	$\mu_o = \mu_{ob} * \left(\frac{P}{P_b}\right)^m$ Where: $m = 2.6 * P^{1.187} * \text{antilog}(-3.9 * 10^{-5} * P - 5)$
Khan et.al correlation, [7]	$\mu_o = \mu_{ob} * \exp\left(9.6 * 10^{-5} * (P - P_b)\right)$
Labedi correlation, [8]	$\mu_o = \mu_{ob} + \left[\frac{10^{-2.488} * \mu_{ob}^{0.9036} * P_b^{0.6151}}{10^{0.0197*API}}\right] * \left(\frac{P}{P_b} - 1\right)$
Kartomodjo and Schmidt correlation, [9]	$\mu_o = 1.00081 * \mu_{ob} + 0.001127 * (P - P_b) * (-0.006517 * \mu_{ob}^{1.8148} + 0.038 * \mu_{ob}^{1.590})$
Petrosky and Farshad correlation, [10]	$\mu_o = \mu_{ob} + 1.3449 * 10^{-3} * (P - P_b) * 10^a$ Where: $a = -1.0146 + 1.3322 * \log(\mu_{ob}) - 0.4876 * [\log(\mu_{ob})]^2 - 1.15036 * [\log(\mu_{ob})]^3$

These correlations usually vary in complexity and accuracy depending upon the available data on the crude oil which is at under saturated reservoir pressure.

Since, the objective of this study is to use an accurate correlation to calculate the oil viscosity at various operating conditions. In the literature, several empirical correlations have been proposed for calculating the dead, saturated, and under saturated oil viscosity.

The Present Work

The developed correlation is based on (612) field data sets collected from different Iraqi fields in Khasib, Rumaila, and Mishrif formations. Each data set contains Temperature, Gas oil ratios, API gravity, saturated pressure. These data were divided into six groups according to formations; a set that consisted of (516) was used to cross-validate the relationship established during the training process and, the second group which consisted of (96) was used to test the correlation to evaluate their accuracy and trend stability.

Reservoir oil viscosities have been measured at various pressures above and below the bubble point pressure for different temperatures.

Error Analysis

Two criteria were used to compare the performance and accuracy of this correlation with those of seven correlations. These criteria are:

a. The average absolute relative error,

Eq. 1:

$$AARE = \frac{1}{N}\sum_{i=1}^{N}\left[\left|\frac{x_{experimental\ (i)} - x_{calculated\ (i)}}{x_{experimental\ (i)}}\right|\right] * 100\% \quad \ldots(1)$$

b. The standard deviation error, Eq. 2:

$$SD = \sqrt{\left(\frac{1}{N-1}\sum_{i=1}^{N}\left[\left|\frac{x_{experimental\ (i)} - x_{calculated\ (i)}}{x_{experimental\ (i)}}\right|\right] - AARE\right)^2} \quad \ldots(2)$$

The New Correlation

The suggested form of the viscosity correlation should first maintain the physics before the trails that could be made to find the best fitness. The formulation should involve all dependable parameters affecting crude oil viscosity to provide the reliability for the proposed correlation.

A successful trail was made to collect all trained data which are above, at and below bubble point pressure in one new correlation, considered to be a superior correlation to other available correlations.

Therefore, the suggested correlation can be applied for pressure values that are above or below bubble point pressure; this characteristic may support the reliability other than available correlations in the literatures that used two different formulas to be applied for pressure values that are larger or less than bubble point pressures.

Generating the new formula established on the dimensionless fitting between $\left(\frac{\mu_o}{\mu_{od}}\right)$ and $\left(\frac{P}{P_b}\right)$, it is found that this relation takes excellent fitters and unique for all the collected samples for all fields. However, the relationship was adjusted with reservoir temperature, saturation pressure, API gravity and solution gas-oil ratio which control the viscosity calculations.

The suggested formula can be written using the following form:

$$\mu_o = \left(\frac{\mu_{od}}{A}\right) * [B * C^2 - (2.1933 * B - 0.1364) * C + A] \quad \ldots(3)$$

Where:

$$A = \log\left(\frac{P_b * API}{T}\right)$$

$$B = \frac{GOR - 118.68}{5.7534}$$

$$C = \frac{P}{P_b}$$

The Applications of Present Work

The predicted viscosity using the presented model given in Equation 3 has been compared with the actual field data and other seven well known correlations available to the literature (Beal, [4]; Beggs and Robinson, [5]; Vasquez and Beggs, [6]; Khan correlation, [7]; Labedi, [8]; Kartoatmodjo and Schmidt, [9] and Petrosky and Farshad, [10]) as shown in Figures 1,2,3,4,5,6.

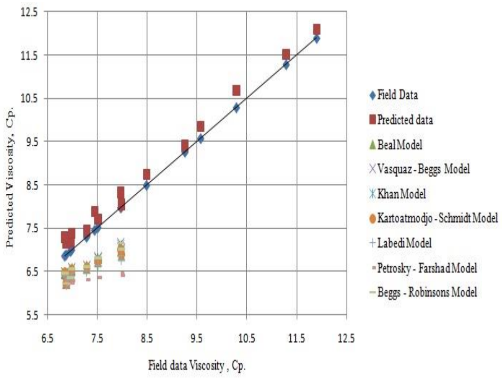

Fig. 1: Results of comparison between new and other correlation with the actual data for AD1-K2

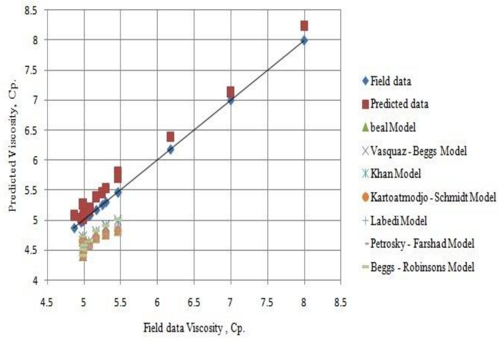

Fig. 2: Results of comparison between new and other correlation with the actual data for AD2-K2

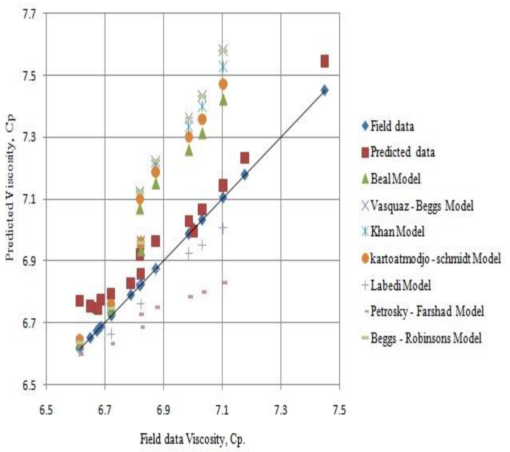

Fig. 3: Results of comparison between new and other correlation with the actual data for AD3-K2

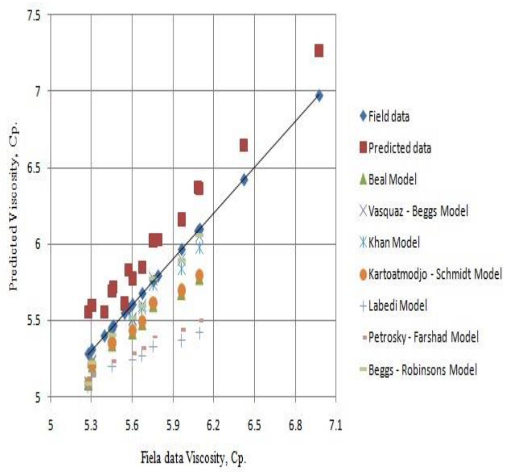

Fig. 5: Results of comparison between new and other correlation with the actual data for AD1- Ru3

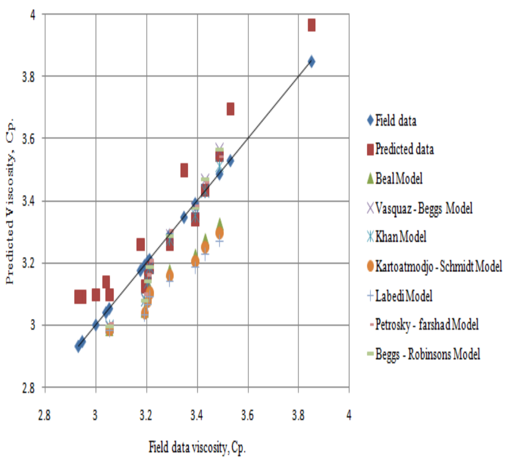

Fig. 4: Results of comparison between new and other correlation with the actual data for AD1- Ru1

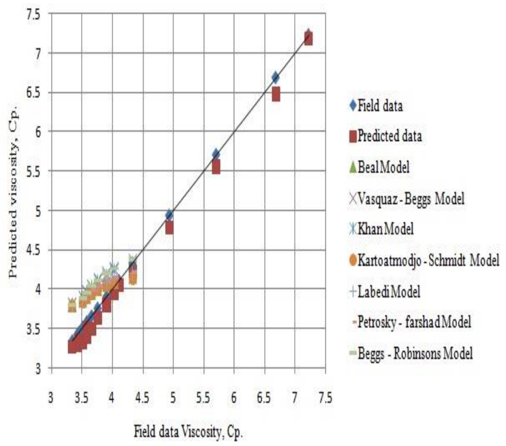

Fig. 6: Results of comparison between new and other correlation with the actual data for AD1- MI4

Table 2: The Standard Deviation error % between the new correlation and the seven correlations for different formations

Correlation	Standard Deviation Error %					
	AD1-K2	AD2- K2	AD3-K2	AD1-Ru1	AD1-Ru3	AD1-MI4
Beal, [4]	46.54	46.63	50.22	49.62	49.90	48.08
Beggs and Robinson, [5]	47.01	47.42	49.74	50.85	50.94	47.26
Vasquez and Beggs, [6]	47.01	47.42	49.74	50.85	50.94	47.26
Khan, [7]	46.94	47.36	49.83	50.95	50.75	47.41
Labedi, [8]	46.16	46.66	51.29	49.17	48.19	47.90
Kartoatmodjo and Schmidt, [9]	46.72	46.66	49.98	49.39	50.02	48.12
Petrosky and Farshad, [10]	44.75	46.27	50.56	51.04	48.58	47.79
New Model	1.59	1.58	0.55	1.60	1.08	1.30

Results and Discussion

The results shown in Figures 1,2,3,4,5,6 and the obtained standard deviation percentage error between the new and other correlations for all tested formations could be collected to provide the total standard deviation error as shown in Fig. 7; this figure shows the given correlation that provides the most accurate results than the other presented correlations. It gives (1.72 %) standard deviation error compared with the other correlations which give at least double standard deviation error that is obtained by the new correlation. While, the new correlation gives also lower average absolute relative error than the other correlations as shown in Fig. 8. Notice that the present model works for various reservoir conditions.

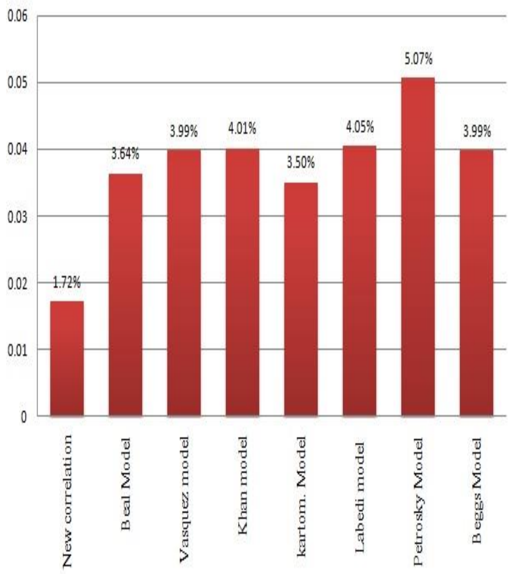

Fig. 7: The total standard deviation error % for the new and the other seven correlations for all formations

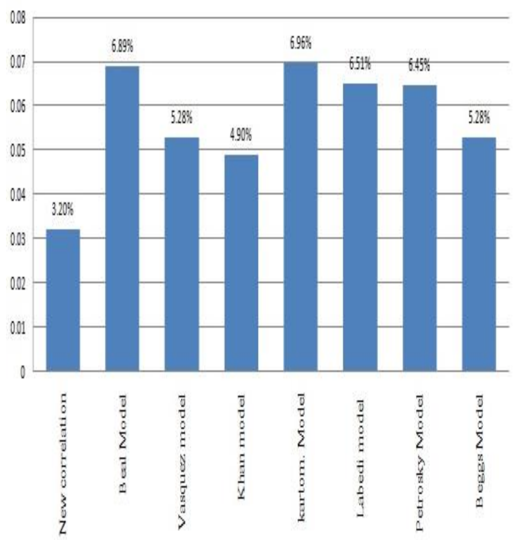

Fig. 8: The average absolute relative error % for the new and the other seven correlations for all formations

Conclusion

It could be concluded that the present correlation can be considered an accurate correlation to predict the most accurate viscosity data for various reservoir and fluid properties below and above bubble point pressure, instead of using different formulas.

Nomenclature

AARE: Average absolute relative error.
AD: Ahdab Field.
K: Khasib Formation.
AD1-K2: well Ahdab 1 – Khasib formation, unit 2.
AD2-K2: well Ahdab2 – Khasib formation, unit2. AD3-K2: well Ahdab3 – Khasib formation, unit2.
Ru: Rumaila Formation.
AD1-Ru1: well Ahdab1 –Rumaila formation, unit1. AD1-Ru3: well Ahdab1 –Rumaila formation, unit3.
MI: Mishrif Formation
AD1-MI4: well Ahdab1 –Mishrif formation, unit4.
EOR: Enhance oil recovery.
GOR: gas-oil ratio, Scf/STB
P: Pressure, psi.
Pb: Bubble point pressure, psi.
SD: Standard deviation.
T: Temperature, ° F.
API: Oil API gravity
μo: oil viscosity, cp.
μob: Oil viscosity at bubble point pressure, cp.
μod: Dead oil viscosity, cp.

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