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AN EVALUATION OF THE PERFORMANCE OF DERIVED EMPIRICAL CORRELATIONS FOR PREDICTING THE OIL VISCOSITY OF LIGHT OMANI CRUDE

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Abstract

In the past decades, many correlations for predicting the viscosity of crude oil were proposed. A review of the literature has showed that there is no study aims to investigate the performance of these correlations for predicting the oil viscosity of light Omani crude. Thirty eight oil viscosity correlations describing various conditions are evaluated with Omani crude oil viscosity database using statistical analysis. Twelve of these correlations are for dead oil viscosity, 14 are for saturated oil viscosity and 12 for under saturated oil viscosity. Error estimates for the predicted and measured oil viscosity together with standard deviation for each correlation are presented. Statistical analysis showed that none of the dead oil viscosity correlations was able to satisfactorily predict the Omani dead oil viscosity. The dead oil viscosity correlations were modified by exponentially fitting the viscosity data. For the saturated oil viscosity, the best agreement is obtained with the correlations of Whitson and Brule and Dindoruk and Christman while the worst agreement is obtained with the correlations of Labedi) and Almehaideb. For the under-saturated oil viscosity, Standing, Khan *et al.* and Kartoatmodjo and Schmidt correlations gave the best agreement with Omani crude oil while Vazquez and Beggs correlation attained the worst agreement.

***Keywords**: Dead oil; saturated; undersaturated; viscosity correlations; Omani crude oil.*

1. Introduction

Oil viscosity is one of the most important PVT properties used in the oil industry since it affects oil recovery and the cost of its subsequent transportation through pipelines. Field planning and type of enhanced oil recovery method is also determined to some extent by the viscosity of the fluids at both reservoir and surface conditions. Oil samples from new wells are usually sent for experimental PVT analysis from which detailed compositional and PVT properties are reported to the operators. However, this is both time consuming and cost-intensive. In order to overcome such disadvantages, several studies have produced correlations to allow fast predictions of viscosity, especially when cost and time are an issue. Presently, oil companies use the tuning of validated EOS in their calculations and simulation packages [4]. These equations require compositional analysis from PVT reports [19], which makes them redundant since the idea is to avoid this costly requirement. Hence, many empirical correlations were generated to predict the viscosity from other handy oil properties. There has been intensive work in generating viscosity empirical correlations for undersaturated crude oils [1-3, 9, 12, 16- 18, 20,22,24] , saturated [2-3,5,7-9,11-12,16-18,20,22,25], and dead [2, 6-,7, 9, 10, 12-14, 16, 18, 20, 22, 25]. Due to their merit, empirical correlations best predict the oils with similar composition (i.e. paraffinic, naphthenic, and/or aromatic), which depends on the oil geochemical origins. Hence, some correlations can satisfactorily predict some oils but fail to predict others. For this issue, these correlations should be validated if they were to be used to predict the viscosity of a certain oil system. Assessment of the applicability of these correlations for a crude oil from a certain region [13,15,21,23] is an important step before any improved correlations for a certain crude oil are additionally proposed. This will provide the oil companies dealing with the oil production with simple and relatively trusted predictors that should not require compositional data.

To our knowledge, there is no study which aims to investigate the performance of oil viscosity correlations for predicting light Omani crude. This study assesses the use of some existing correlations to predict the viscosity of under-saturated, saturated, and dead Omani crude oils.

2. Collected Database

Reservoir pressure and temperature, stock-tank oil gravity, solution gas-oil ratio and viscosity measurements corresponding to 646 experimental points of light crude oil have been obtained from around 36 PVT reports from different Omani oil fields. The database has been divided into 240 data points for under-saturated oils, 370 for saturated oils, and 36 for dead oils. Screening analysis was conducted on each PVT report. All unmatched PVT data sets were removed. As such, 6 PVT reports were removed from the analysis. Table 1 summarized the range of the selected data.

Table 1: Range of some parameters of the data points

Parameter	Minimum	Maximum
Tank-oil gravity (^{o}API)	34.78	59.90
Bubble point pressure, P_b (psia)	56.6	5717.67
Pressure below bubble point, P_{bb} (psia)	24.96	5217.46
Bubble point solution GOR, R_{sb} (scf/stb)	20.7	487.89
Reservoir temperature, T (^{o}F)	135.42	271.22
Under saturated oil viscosity, μ_o (cp)	0.71	17.5
Bubble point viscosity, μ_{ob} (cp)	0.23	14.3
Dead oil viscosity, μ_{od} (cp)	0.8	13.1

3. Evaluation of oil viscosity correlations with light Omani crude oil

Thirty eight oil viscosity correlations have been identified from the literature and are considered in this analysis. These correlations were grouped based on their usage into three categories namely; dead, saturated and under saturated oil viscosity correlations. These correlations are specific and were originally proposed for crude oils from certain regions. Thus, their performances outside their specified region or conditions should be investigated. In the interest of determining the optimum correlation for light Omani crude oil, the performance of these correlations was evaluated by comparing their prediction results with the measured oil viscosities.

The accuracy of the predictions was evaluated using statistical error analysis. The average percent error (APE), average absolute percent error (AAPE) and standard deviation (SD) were used for the statistical error analysis.

The average percent error is defined as

$$APE = \left[\frac{1}{n}\sum_{k=1}^{n}\frac{(\mu)_{pred} - (\mu)_{meas}}{(\mu)_{meas}}\right] \times 100 \quad (1)$$

where subscripts "pred" and "meas" represent the predicted and measured values, respectively.

The average percent error is used to quantify the degree of over-prediction or under-prediction of the experimental data. Positive values indicate over-prediction while negative values indicate underprediction.

The average absolute percent error (AAPE) is calculated to evaluate the prediction capability of the correlations. Unlike the average percent error (APE), the absolute errors are considered so that the positive and negative errors are not canceled out. The equation is given by:

$$AAPE = \left[\frac{1}{n}\sum_{k=1}^{n}\left|\frac{(\mu)_{pred} - (\mu)_{meas}}{(\mu)_{meas}}\right|\right] \times 100 \quad (2)$$

The standard deviation of the predicted value from the experimental is used to measure how close the predictions are to the experimental data. The equation which is also known as the root mean square percent error can be expressed as:

$$SD = \left[\sqrt{\frac{1}{n-1}\sum_{k=1}^{n}\left(\frac{(\mu)_{pred} - (\mu)_{meas}}{(\mu)_{meas}}\right)^2}\right] \times 100 \quad (3)$$

3.1. Comparison with dead oil viscosity correlations

The comparison of the accuracy of the 12 dead oil viscosity correlations against the dead oil viscosity measurements is shown in Table 2. Out of the 12 correlations, Kartoatmodjo and Schmidt correlation [16] gave the best agreement with the data as shown from the values of the three statistical indicators. The correlation has an average percent error of 31.23%, average absolute percent error of 42.3% and standard deviation of 51.69%. The worst agreement was obtained with Glaso [14] correlation with an average percent error, average absolute percent error and standard deviation of about 71%.

Table 2 Comparison of the accuracy of dead oil viscosity correlations against the Omani dead crude oil viscosity

Dead Oil Correlation	Statistical Parameters		
	APE, %	AAPE, %	SD, %
Beal (1946) [6]	-68.07	68.07	68.99
Beggs and Robinson (1975) [7]	-53.36	53.36	55.65
Standing (1977) [22]	-68.16	68.16	69.08
Glaso (1980) [14]	-71.26	71.26	71.92
Al-Khafaji et al. (1987) [2]	-68.95	68.95	70.18
Egbogah and Ng (1990) [10]	-61.33	61.33	62.89
Labedi (1992) [18]	-66.31	66.31	67.41
Kartoatmodjo and Schmidt (1994) [16]	31.23	42.30	51.69
Petrosky and Farshad (1995) [20]	-67.66	67.66	68.49
Elsharkawy and Alikhan (1999) [11]	-58.24	58.24	60.17
Whitson and Brule (2000) [25]	-59.20	59.20	60.95
Elsharkawy and Gharbi (2001) [12]	-62.79	62.79	64.55

Fig. 1 shows the comparison of Kartoatmodjo and Schmidt [16] (best correlation for dead oil) and Glaso [14] correlations with the experimental dead oil viscosities. It is clear that Kartoatmodjo and Schmidt [16] correlation better predict the data in comparison to Glaso [16] correlation. The comparison clearly reveals that Kartoatmodjo and Schmidt [16] correlation overpredicts the viscosity of the Omani dead oil above 2 cp (APE = 31.23%), whereas Glaso [16] correlation highly under predicts the viscosity in the whole range invistigated (APE = -71.26%).

It has been realized that the prediction of the above correlations can be improved to better predict the Omani dead oil viscosity. The dead oil correlations were tuned using the following equation:

$$\mu_{mod} = C_1 \exp(C_2 \mu_{dead}) \quad (4)$$

where μ_{mod} is the oil viscosity after tuning the correlated viscosity (μ_{dead}), C_1 and C_2 are tuning parameters. The performance of all the modified correlations were found to better predict the dead oil viscosity results as shown from the values of the statistical parameters in Table 3. The standard deviation is found to decrease to around 27% while the average percent error and average absolute percent error falls to around 4 and 20% respectively.

Fig. 2 shows the spread of the data around the correlations of Kartoatmodjo and Schmidt [16] and Glaso [14] before and after the modification. It is obvious that the modified correlations can better predict the data where the majority of the data points are oriented on a straight line at a 45 degrees slope.

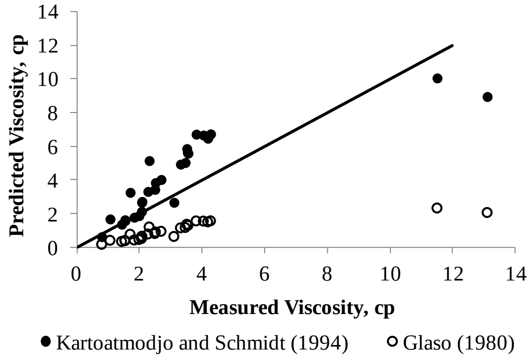

Fig. 1 Comparison of Glaso [14] and Kartoatmodjo and Schmidt [16] correlations with Omani dead crude oil viscosity

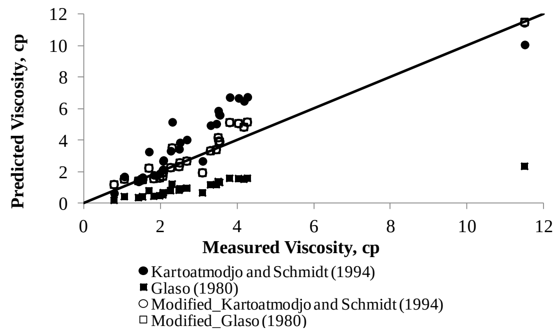

Fig. 2 Comparison of Glaso [14] and Kartoatmodjo and Schmidt [16] correlations before and after modification with Omani dead crude oil viscosity data

Table 3 Comparison of the accuracy of modified dead oil viscosity correlations against Omani dead crude oil viscosity

Modified Dead Oil Viscosity Correlation	Statistical Parameters				
	C_1	C_2	APE, %	AAPE, %	SD, %
Beal (1946) [6]	0.996	0.9411	4.01	20.61	27.52
Beggs and Robinson (1975) [7]	0.961	0.6904	4.05	21.28	27.89
Standing (1977) [22]	0.995	0.9443	4.00	20.61	27.52
Glaso (1980) [14]	0.973	1.0576	3.70	19.03	26.06
Al-Khafaji et al. (1987) [2]	1.098	0.8428	4.15	21.52	28.26
Egbogah and Ng (1990) [10]	0.882	0.9009	4.17	21.26	31.26
Labedi (1992) [18]	1.074	0.8056	3.64	18.93	25.28
Kartoatmodjo et Schmidt (1994) [16]	1.008	0.2415	3.70	19.01	26.02
Petrosky and Farshad (1995) [20]	0.8834	1.0595	3.67	19.44	25.86
Elsharkawy and Alikhan (1999) [11]	0.9089	0.8107	4.13	21.45	29.95
Whitson and Brule (2000) [25]	0.8804	0.8629	4.29	21.43	31.47
Elsharkawy and Gharbi (2001) [12]	1.125	0.6906	4.12	20.51	27.50

3.2 Comparison with saturated oil viscosity correlations

Table 4 shows the comparative results of the measured saturated oil viscosities and the calculated values by 14 empirical correlations. Apart from the correlations of Labedi [18] and Almehaideb [3], most of the correlations listed in Table 4 satisfactorily predicted the viscosity of Omani saturated oil. The correlations of Whitson and Brule [25] and Dindoruk and Christman [9] are the only two correlations that can predict more than 80% of the saturated oil viscosity data within ±10% (see Fig. 2). They are also quite few correlations that can predict more than 90% of the data within ±20%.

As shown from the values of the three indicators (APE, AAPE and SD) given in Table 4, the best agreement is obtained with the correlations of Whitson and Brule [25] and Dindoruk and Christman [9] while the worst agreement is obtained with the correlations of Labedi [18] and Almehaideb [3]. Whitson and Brule [25 and Dindoruk and Christman [9] correlations were found to satisfactorily predict the saturated oil viscosity data as indicated from the average percentage error (APE = -0.24 and -3.03 respectively) while Almehaideb [3] correlation highly underpredicted the data (APE = -41.25). The comparison also revealed that Whitson and Brule [25] and Dindoruk and Christman [9] correlations have better prediction capability than both Labedi [18] and Almehaideb [3] as shown from the AAPE values (7.95 and 7.53% for Whitson and Brule [25] and Dindoruk and Christman [9] correlations respectively and

40.07% and 42.95% for the Labedi [18] and Almehaideb [3] correlations respectively). Finally, from the standard deviation values, the prediction of Whitson and Brule [25] and Dindoruk and Christman [9] correlations are closer to the experimental data.

Table 4 Comparison of the accuracy of saturated oil viscosity correlations against Omani saturated crude oil viscosity

Saturated Correlation	Statistical Parameters		
	APE, %	AAPE, %	SD, %
Aziz et al. (1972) [5]	13.30	17.27	19.44
Beggs and Robinson (1975) [7]	-14.83	15.27	17.86
Standing (1977) [22]	4.94	10.10	13.20
Khan et al. (1987) [17]	13.30	13.62	32.21
Al-Khafaji et al. (1987) [2]	4.37	11.25	14.52
Labedi (1992) [18]	12.12	40.07	150.77
Kartoatmodjo and Schmidt (1994) [16]	3.21	11.18	15.72
De Ghetto (1994) [8]	-3.83	10.47	14.57
Petrosky and Farshad (1995) [20]	-6.83	9.32	12.65
Almehaideb (1997) [3]	-41.25	42.95	45.92
Elsharkawy and Alikhan (1999) [11]	-7.64	9.96	13.44
Whitson and Brule (2000) [25]	-0.24	7.95	12.66
Elsharkawy and Gharbi (2001) [12]	-8.65	17.88	22.28
Dindoruk and Christman (2004) [9]	-3.03	7.53	11.89

3.3. Comparison with undersaturated oil viscosity correlations

All the undersaturated oil correlations considered in this assessment satisfactorily predicted the oil viscosity database as described by the statistical parameters presented in Table 5. A total of 12 correlations were used in the analysis. The correlation of Standing [22], Khan *et al.* [17] and Kartoatmodjo and Schmidt [16] are considered among the best three correlations that can predict viscosity of Omani crude oil (see the performance indicators in Table 5). The worst agreement was obtained with the correlation of Vazquez and Beggs [24].

Table 5 Comparison of the accuracy of under-saturated oil viscosity correlations against Omani crude oil viscosity

Under-saturated Correlation	Statistical Parameters		
	APE, %	AAPE, %	SD, %
Standing (1977) [22]	-2.90	4.25	6.47
Vazquez and Beggs (1980) [24]	14.11	15.03	27.92
Khan et al. (1987) [17]	1.57	3.78	6.63
Al-Khafaji *et al.* (1987) [2]	0.37	6.42	10.13
Abdul-Majeed *et al.* (1990) [1]	-11.25	11.39	14.55
Labedi (1992) [18]	-9.68	9.93	12.73
Kartoatmodjo and Schmidt (1994) [16]	-4.91	5.66	8.04
Petrosky and Farshad (1995) [20]	2.05	7.19	10.40
Almehaideb (1997) [3]	5.60	6.69	9.55
Elsharkawy and Alikhan (1999) [11]	-8.83	9.15	12.25
Elsharkawy and Gharbi (2001) [12]	-10.87	11.04	14.11
Dindoruk and Christman (2004) [9]	6.20	7.04	9.76

Among the 12 correlations investigated, the correlation of Standing [22] and Khan *et al.* [17] were able to correlate around 90% of the experimental data points within ±10% (see Fig.

4). Additionally, apart from the Vazquez and Beggs [24] correlation, all the other correlations can predict more than 80% of the data within ±20%.

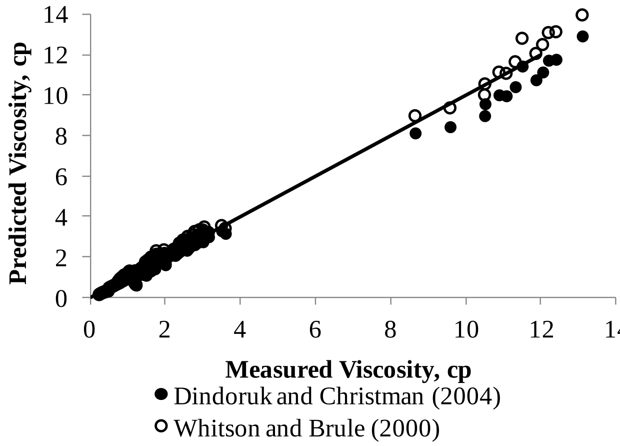

Fig. 3 Comparison of Whitson and Brule [25] and Dindoruk and Christman [9] correlations with Omani saturated crude oil viscosity

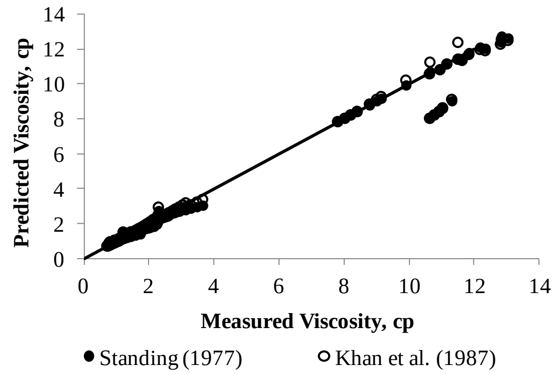

Fig. 4 Comparison of Standing [22] and Khan *et al.* [17] correlations with Omani under-saturated crude oil viscosity

4. Conclusions

Predicting the crude oil viscosity is very crucial to the oil industry. Accurate prediction of the viscosity will lead to a better design of an energy efficient transportation system and helps in determining the enhanced oil recovery method. There has been intensive work in generating viscosity empirical correlations for under-saturated, saturated and deal oil. These correlations are location specific and were originally proposed for crude oils from certain regions.

This work is used to assess the capability of 38 oil viscosity correlations (12 for dead oil, 14 for saturated and 12 for under saturated oil) to predict the viscosity of light Omani crude oil. Data corresponding to 646 experimental points of light crude oil have been obtained from around 36 PVT reports from different Omani oil fields. The data were screened based the oil viscosity properties into under saturated oil (240 data points), 370 for saturated oils (370 data points) and dead oils (36 data points).

Statistical and graphical analysis were used to assess the performance of the correlations. For the dead oil viscosity, none of the correlations investigated were able to reasonably predict the Omani crude oils. Kartoatmodjo and Schmidt [16] correlation gave the best agreement with an APE of 31.23%, AAPE of 42.3% and SD of 51.69%. All the dead oil correlations were modified through introducing tuning parameters to improve their accuracy for Omani dead oil. The performance of the tuned correlations was found to better predict the data where the APE and AAPE decreases to around 4 and 20% respectively. The poor performance of the correlations presented in this study to predict the viscosity of Omani dead oil necessitates the generation of a new correlation.

For saturated oil, the best agreement was achieved with the correlations of Whitson and Brule [25] and Dindoruk and Christman [9] correlations. The viscosity of under-saturated Omani oil was best predicted by three correlations; Standing [22], Khan *et al.* [17] and Kartoatmodjo and Schmidt [16].

The oil viscosity correlations predictions were also tested for the spread of the actual data against the predictions. The correlations of Whitson and Brule [25] and Dindoruk and Christman [9] were the only two correlations that were able to predict more than 80% of the saturated oil viscosity results within ±10%. For the under-saturated oil, the correlation of Standing [22] and Khan *et al.* [17] were able to correlate around 90% of the experimental data points within ±10%.

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