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A viscosity prediction model for Kuwaiti heavy crude oils at elevated temperatures

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A B S T R A C T

Viscosity is a key fluid property for characterization, evaluation, management and development of petroleum reservoirs. The accurate prediction of dynamic viscosity will be helpful for heavy oil recovery methods including primary production, thermal production, and enhanced oil recovery (EOR). Reservoir oil viscosity is usually measured isothermally at reservoir temperature. However, at temperatures other than reservoir, dynamic viscosity is estimated by empirical correlations. Most of the published correlations have been performing well at the reservoir temperature, especially for conventional crudes. However, the published literature has lack of reliable methods for viscosity estimation due to an acute shortage of dead oil data at elevated temperatures. These methods are essential and employed in planning thermal recovery methods (Kuwait as well as worldwide). In this study, the API gravity and viscosity of 50 dead crude oil samples collected from various areas of Kuwaiti oil fields were measured. These oil samples have API gravity ranging from 10° to 20°. The viscosities were determined at temperatures ranging from 20 °C to 160 °C. Consequently the results of the heavy oil viscosity data were used to develop a reliable model and to compare the proposed model with the published models. Both quantitative and qualitative analytical methods were implemented using statistical parameters and performance plot, respectively. From the general evaluation it has been shown that the proposed model has the lowest average absolute error of 11.04% and highest coefficients of correlation of 92% for training and 96% for the testing data. The performance of the proposed correlation has also been tested using dead heavy crude oil data from the region as well as various parts of the world. Compositional data of heavy oil viscosity has been used to compare predicted viscosity from the proposed correlation with that from Lorenz–Bray–Clark (LBC) and Pederson models. These comparisons show that the proposed correlation performed better than the other correlations, corresponding state and EOS-based methods for the dead heavy crude oils considered.

1. Introduction

The properties of petroleum reservoir fluids are essential for optimizing their production and transportation. Viscosity plays an important role in the calculations of fluid flow through reservoir rock, pressure loss (with implications for the designs of tubing and pipelines), and the design of surface facilities, reservoir simulations, and predictions of oil recovery. The thermal oil recovery of heavy crude oils is designed to meet the industry demand for improving oil production. Because it is necessary to consider the variation of viscosity with temperature in engineering activities, including piping and pipeline construction for enhanced transportation, thermal expansion is the key property for increasing the productivity of heavy oils. Modern reservoir engineering practices require accurate information concerning the thermodynamic and transport fluid properties, in addition to the reservoir rock properties, to perform material balance calculations. Viscosity is often the limiting factor in heavy oil production.

The viscosity of oils has been studied for many years. Although the viscosity is affected by pressure and gas content, it is primarily a function of oil gravity and temperature (Batzle et al., 2004). Accurate prediction of the physical properties of oil is required to design appropriate recovery, storage, transportation, and processing systems for crude oil handling (Quail et al., 1987). Heavy oils are characterized by high viscosities, ranging from 100 CP to 10,000 CP at the reservoir temperature, as defined by the World Petroleum Congress, and have low API gravity, ranging from 10° to 22°, as defined by the U.S. Department of Energy (Nehring et al., 1983). Heavy oils have a low API gravity compared with conventional oil and are particularly known for the difficulty associated with achieving accurate measurements of their fluid properties.

The uncertainty of heavy oil fluid property measurements affects the quality of the data, which in turn affects the accuracy

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Nomenclature

API	specific gravity @ 15.56 °C (deg)
T	temperature, (°C)
MRE	mean relative error (%)
AARE	absolute average relative error (%)
SD	standard deviation
RMSE	root mean square error
μ	dynamic viscosity (CP)

of the production forecast (Zabel et al., 2008) and the recovery processes, such as the steam-assisted gravity drainage (SAGD) process. An optimal recovery process must be a function of oil mobility (permeability/viscosity ratio). Therefore, a comprehensive and well-defined mapping of the reservoir oil mobility based on viscosity is essential for the effective exploration and design optimization of production strategies, particularly in biodegraded heavy oil and bitumen reservoirs (Adams et al., 2008, 2009). For live oils, the variation in dynamic viscosity with changes in temperature and pressure is typically predicted empirically (Sattarina et al., 2007).

The reservoir oil viscosity is typically measured isothermally at the reservoir temperature. However, at temperatures other than the reservoir condition, these data are estimated using empirical correlations (Naseri et al., 2005). The viscosity of crude oil varies depending on its origin and type, as well as the nature of its chemical composition, particularly the polar components, for which intermolecular interactions can occur. For this reason, developing a comprehensive model of viscosity to include different regions of the world appears to be a difficult task. The various approaches to addressing this issue have been the topic of numerous studies, as reported in the following section.

2. An overview of published oil viscosity correlations

This study conducted a detailed literature review of various correlations to estimate the viscosity of crude oil. These correlations can be divided into three categories, including dead, saturated, and under saturated. For the purpose of this research, only dead, heavy μ_{od} (oil with no gas in the solution) correlations will be discussed.

Table 1 explains the different published correlations that can be considered for the purpose of comparing Kuwait dead-heavy oils. These correlations were divided into three groups based on their range of API and/or temperature values. Group A comprises the correlations that are outside the range of the viscosity–temperature–API gravity data described in this study and includes the Glaso (1980), Labedi (1992), Petrosky and Farshad (1995) and Elsharkawy and Alikhan (1999) correlations. Group B comprises the correlations that fully cover the range of the viscosity–temperature–API gravity data and includes the Beal (modified form as Standing, 1981), Egbogah and Ng (1990), De Ghetto et al. (1995), Bennison (1998) and Hossain et al. (2005) correlations. Group C includes the correlations that partially cover the range of these parameters from the entire databank and includes the Beggs and Robinson (1975), Al-Khafaji et al. (1987), Kartoatmodjo (1990) and Naseri et al. (2005) correlations.

Table 1
Comparison of the range of application of the dead-heavy oil correlations.

	Developer	API range (deg)	Temperature range (°C)
Group A	Glaso (1980)	20.1–48.1	10–149
	Labedi (1992)	32.2–48	38–152
	Petrosky and Farshad (1995)	25.4–46.1	46–142
	Elsharkawy and Alikhan (1999)	19.9–48	38–149
Group B	Standing (1981)	10.1–52.5	38–149
	Egbogah and Ng (1990)	5–58	15–80
	De Ghetto et al. (1995)	10–22.3	24–146
	Bennison (1998)	10–22	10–121
	Hossain et al. (2005)	7.1–21.8	0–93
Group C	Beggs-Robinson (1975)	16–58	24–146
	Al-Khafaji et al. (1987)	15–51	16–149
	Kartoatmodjo (1990)	14.4–58.9	24–160
	Naseri et al. (2005)	17–44	41–246

Many correlations utilize the oil API gravity and temperature to determine dead oil viscosity. Beal (1946) presented a dead oil dynamic viscosity correlation as a function of API gravity and temperature using 655 viscosity data points collected from 492 oil fields in the United States at a temperature of 38 °C and 98 data points at temperatures above 38 °C.

Using the same input variables, Beggs and Robinson (1975) published a similar correlation that was developed with 460 data points from 93 different oil samples.

Glaso (1980) realized that paraffinic crudes and naphthenic crudes have the same API gravity but not the same viscosity at a given temperature. For the same reason, the author published a dead oil viscosity correlation with the suggestion of an adjustment to the API gravity.

Al-Khafaji et al. (1987) presented a modified form of Beal's correlation for predicting the viscosity of dead crude oil from the Middle East. Egbogah and Ng (1990) presented two different correlations for predicting the viscosity of dead oil. The first correlation was a modified form of the Beggs and Robinson (1975) correlation using 394 data points, and in the second correlation, Egbogah and Ng introduced the pour point (T_p) as a new parameter for estimating the dead oil viscosity (Egbogah and Ng, 1990; De Ghetto et al., 1995). Additionally, Svrcek and Mehrotra (1988) presented a one-parameter viscosity equation for bitumen.

The application of dead oil viscosity correlations to crude oils from different sources results in significant errors. These deviations are attributed to the difference in asphaltic and paraffinic oils and/or the mixed nature of the oils (Sattarina et al., 2007). Using a large databank of crude oils from different parts of the world, Kartoatmodjo presented a modified form of Glaso's correlation (Kartoatmodjo 1990). Labedi (1992) presented a correlation for African dead oils, in particular, from Libya. Puttagunta et al. (1988) published a viscosity correlation for Athabasca and Cold Lake heavy oil and bitumen that depends on a single-point viscosity measurement at a temperature of 30 °C and atmospheric pressure. Another correlation was later developed for heavy oil viscosity with dissolved gas (Puttagunta et al., 1993). Petrosky and Farshad (1995) presented a correlation for estimating the viscosity of dead oil recovered from the Gulf of Mexico. De Ghetto et al. (1995) published a set of two modified correlations for dead oil (extra heavy oil and heavy oil) viscosity predictions, and Bennison (1998) presented a new correlation for the viscosity of heavy dead oil from the North Sea. Elsharkawy and Alikhan (1999) presented crude oil viscosity correlations for Middle East crudes. Argillier et al. (2001) analyzed the rheology of heavy oil with contents of asphaltene and resin by dividing heavy oil crudes into two groups as a non-colloidal liquid (the maltene) and a dark brown powder (the asphaltene); their rheological experiment with the mixture of