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Development of a robust model for prediction of under-saturated reservoir oil viscosity

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ABSTRACT

Fluid viscosity is considered as one of the most important parameters for reservoir simulation, performance evaluation, designing production facilities, etc. In this communication, a robust model based on Genetic Programming (GP) approach was developed for prediction of under-saturated reservoir oil viscosity. A third order polynomial correlation for prediction of under-saturated oil viscosity as a function of bubble point viscosity, pressure differential (pressure minus bubble point pressure) and pressure ratio (pressure divided by bubble point pressure) was proposed. To this end, a large number of experimental viscosity databank including 601 data sets from various regions covering a wide range of reservoir conditions was collected from literature. Statistical and graphical error analyses were employed to evaluate the performance and accuracy of the model. The results indicate that the developed model is able to estimate oil viscosity with an average absolute percentage relative error of 4.47%. These results in addition to the graphical results confirmed the robustness and superiority of the developed model compared to the most well-known existing correlations of under-saturated oil viscosity. Additionally, the investigation of relative impact of input parameters on under-saturated reservoir oil viscosity demonstrates that bubble point viscosity has the greatest impact on oil viscosity.

1. Introduction

Viscosity is the measure of resistance to fluid flow [1,2]. Crude oil viscosity is an important characteristic of reservoir fluid needed for petroleum engineering analyses including reserve calculation, well testing, enhanced oil recovery (EOR) processes, surface and subsurface facilities design, reservoir simulation and fluid flow in porous media and pipelines. In addition, viscosity is required for numerical simulation and project economics determination [3–16]. Therefore, it is essential to determine the accurate value of crude oil viscosity at different conditions. This property should be determined by conducting laboratory measurements on samples collected from surface (separator) or bottom hole at reservoir temperature and pressure. When laboratory data are not available and in order to save time and money, empirical correlations and equations of states (EOS) are used to predict this property [17–20].

There are two main types of models for prediction of oil viscosity. The first type is the correlations that use oil field data and the second type is the compositional models [5,18,21–27]. Depending on pressure, these correlations can be classified into three categories; dead oil, saturated and under-saturated. The correlations for dead oil viscosity correlate viscosity of crude oil at atmospheric pressure and various temperatures. Saturated oil viscosity correlations are used to predict oil viscosity of saturated reservoirs. In such reservoirs, when pressure decreases, oil viscosity increases because of the released gas. Under-saturated oil viscosity correlations are employed to determine oil viscosity at pressures above the bubble point pressure. Under this condition, when pressure decreases, oil viscosity decreases too. These trends are depicted in Fig. 1. The minimum value of crude oil viscosity is at bubble point pressure [1,17]. Generally, most of the discovered oil reservoirs are at under-saturated conditions meaning that the initial reservoir pressure is above the oil bubble point pressure. In addition, most of the reservoirs remain at under-saturated condition during the course of production, as water flooding projects are usually performed to maintain reservoir pressure above bubble point pressure. Therefore, development of predictive models for estimating under-saturated oil viscosity is

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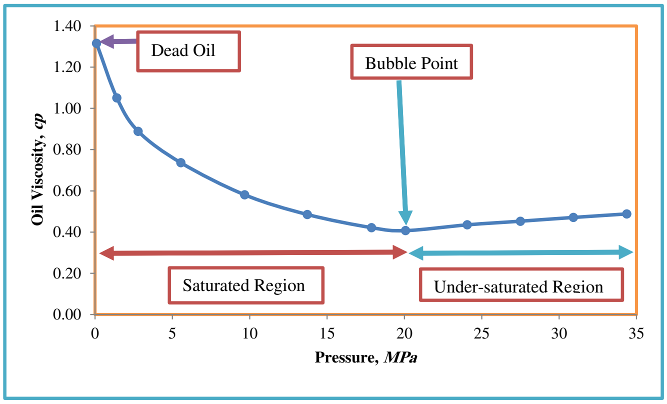

Fig. 1. Viscosity of a typical crude oil sample as a function of pressure [17].

of great importance. Over the past years, several empirical correlations have been developed for determining under-saturated reservoir oil viscosity by using the data of different regions. Some authors have considered reservoir bubble point pressure and bubble point oil viscosity for development of under-saturated oil viscosity correlations, while others have additionally included oil API gravity and dead oil viscosity in their correlations.

The most popular empirical models presently used in petroleum engineering calculations for predicting under-saturated oil viscosity are those developed by Beal [21], Vazquez and Beggs [28], Petrosky [29], Kartoatmodjo and Schmidt [30], Elsharkawy and Alikhan [31], Hossain [32] and Hemmati-Sarapardeh et al. [17]. The range of input data used in developing each correlation and the origin of data reported by each author is provided in Table 1. In 1946, Beal [21] proposed a graphical correlation to predict under-saturated oil viscosity as a function of reservoir pressure, bubble point pressure and crude viscosity at bubble point pressure. An average deviation of 2.7% was reported for this correlation. In 1976, Vazquez and Beggs [28] presented a correlation for under-saturated oil viscosity by using a large set of PVT measurements. An average percentage error of −7.541% was reported for their model. In 1990, Petrosky [29] presented new empirical correlations for under-saturated oil viscosity from Gulf of Mexico. The reported relative error and standard deviation of his predictions were −0.19% and 4.22%. In 1991, Kartoatmodjo and Schmidt [30] developed a new correlation for predicting under-saturated oil viscosity. Their correlation was based on Beal's correlation. The average reported error for this correlation was −4.29% [18]. In 1999, Elsharkawy and Alikhan [31] developed a correlation for under-saturated crude oil viscosity based on the Middle East crude oil reservoirs and reported an average absolute percentage relative error of 4.9%. In 2005, Hossain [32] used worldwide crude oil databank to present under-saturated viscosity correlation [32]. Very recently, Hemmati-Sarapardeh et al. [17] developed a new under-saturated crude oil viscosity correlation for the Iranian oil reservoirs and reported an average absolute relative error and standard deviation of 1.2% and 0.022, respectively. It is worthwhile to note here that, over the past years, several models for predicting big data have been proposed in various fields of science and technology. More details on these models can be found elsewhere [33–37]. As a matter of fact, application of these models for prediction of important properties in petroleum engineering such as viscosity is of crucial importance.

Although several models have been reported for estimation of under-saturated reservoir oil viscosity, they are associated with three main issues: One is that they are mostly developed for prediction of a specific type of crude oil associated with a specific regional location. Therefore, these models are not able to predict viscosity of different fluid types with high accuracy as they vary significantly with region and thus those models fail to be considered 'universal'. The second issue is that most of the models were developed based on a limited number of data points and therefore, they fail to predict the viscosity of fluids out of their applicability domain. The third issue is that most of these correlations have been developed using multiple regressions, which mostly find a local solution for the objective function.

Moreover, crude oil viscosity varies with reservoir temperature and pressure, bubble point pressure, gas gravity, oil API gravity, solution GOR and chemical composition [1,8,9,18,38–42]. This study focuses on the viscosity of under-saturated crude oils as most of the crude oil reservoirs are at under-saturated condition during the initial history of production and remain under-saturated for a relatively long time. Therefore, the objective of this study is to overcome the aforementioned issues by developing a universal model for predicting the viscosity of under-saturated oil. To this end, the following systematic procedure was utilized:

1. A large number of experimental data including 601 data points covering a wide range of reservoir conditions from various regions were collected from literature [5,7,8,10,13,17,26,43–50] to develop a universal model for predicting the oil viscosity of various crude types. The ranges of PVT data used in this study are summarized in Table 1.
2. A robust technique called Genetic Programming (GP) was developed for estimation of oil viscosity with high accuracy and validity.
3. Various statistical and graphical analyses were employed to evaluate the performance of developed GP model and to compare its predictions with the most well-known previously published correlations of oil viscosity.
4. Trend analysis was performed to make sure that the model predictions are in agreement with the real trend of under-saturated oil viscosity when the input parameters such as reservoir pressure tend to change as shown in Fig. 1.
5. The impact of input parameters was investigated to find out which reservoir property affects oil viscosity most.

2. Model development

Genetic Programming is one the most efficient regression tools for complex problems such as nonlinear systems of equations. It was first

Table 1
The origin and range of data used in previously published models and this study.

Author	Source of data	*P, MPa*	*Pb, MPa*	Bubble point oil viscosity, *cP*	Oil viscosity, *cP*
Beal [21]	USA	–	–	0.142–127	0.16–315
Vazquez and Beggs [28]	Worldwide	0.87–65.50	–	–	0.117–148
Petrosky [29]	Gulf of Mexico	11.03–70.67	10.85–65.86	0.211–3.54	0.22–4.1
Kartoatmodjo and Schmidt [30]	Worldwide	0.17–41.47	0.17–32.92	0.168–184.86	0.168–517
Hossain [32]	Worldwide	2.07–23.44	0.83–43.24	3.6–360	3–517
Hemmati-Sarapardeh et al. [17]	Iran	5.03–86.19	5.03–35.28	0.177–18.15	0.177–31
This Study	Worldwide	1.67–105.52	1.18–43.84	0.083–240	0.09–307