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Reservoir oil viscosity determination using an intelligent approach

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HIGHLIGHTS

- A reliable viscosity model for oil systems has been developed.
- A large database consisting of over 1000 data have been used to develop it.
- Its reliability is successfully examined against independent data.

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ABSTRACT

Viscosity of crude oil is a fundamental factor in simulating reservoirs, forecasting production as well as planning thermal enhanced oil recovery methods which make its accurate determination necessary. Experimentally determination of reservoir oil viscosity is costly and time consuming. Hence, searching for quick and accurate determination of reservoir oil viscosity is inevitable. The objective of this study is to present a reliable, and predictive model namely, Least-Squares Support Vector Machine (LSSVM) to predict reservoir oil viscosity. To this end, three LSSVM models have been developed for prediction of reservoir oil viscosity in the three regions including, under-saturated, saturated and dead oil. These models have been developed and tested using more than 1000 series of experimental PVT data of Iranian oil reservoirs. These data include oil API gravity, reservoir temperature, solution gas oil ratio, and saturation pressure. The ranges of data used to develop these new models cover almost all Iranian oil reservoirs PVT data and consequently the developed models could be reliable for prediction of other Iranian oil reservoirs viscosity. In-depth comparative studies have been carried out between these new models and the most frequently used oil viscosity correlations for prediction of reservoir oil viscosity. The results show that the developed LSSVM models significantly outperform the existing correlations and provide predictions in acceptable agreement with experimental data. Furthermore, it is shown that the proposed models are capable of simulating the actual physical trend of the oil viscosity with variation of oil API gravity, temperature, and pressure.

1. Introduction

Viscosity of crude oil is an important parameter for evaluating performance of the reservoir, reservoir simulation, designing production facilities and utilizing the best scenario for production [1–5]. Hence, accurate determination of this parameter is crucial for the petroleum industry. The common approach to determine the viscosity is laboratory analysis on the bottomhole samples or recombined liquids and gases collected from the separators at the surface. When PVT data are not available, in order to save time and cost, fluid properties are determined by empirical correlations and equation of states (EOS).

Depending on the input variables, it is possible to divide correlations used for determining oil viscosity in two classes [4]: The first class uses common oil field data such as reservoir temperature, saturation pressure, oil API gravity, and solution gas oil ratio. The second one is empirical or semi empirical models that use

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Nomenclature

AARD	Average Absolute Relative Deviations	SCF	standard cubic feet
API	oil API gravity	STB	standard tank barrel
E_i	percent relative error	STD	Standard Deviation Errors
GOR	gas oil ratio, SCF/STB	T	temperature, K
LSSVM	Lest-Squares Supported Vector Machine	μ_o	oil viscosity, cP
N	number of data points	μ_{ob}	bubble point oil viscosity, cP
P	pressure, MPa	μ_{od}	dead oil viscosity, cP
P_b	bubble point pressure, MPa		
R^2	squared correlation coefficients		
RMSE	Root Mean Square Error		

some characteristics not used in the first approach such as reservoir fluid composition, critical temperature, acentric factor, pour point temperature, molar mass, and normal boiling point [6–8].

In the past decades, several correlations have been developed to predict viscosity of crude oils. Some correlations are specific to certain regions and fail to correctly predict the viscosity for other regions due to differences in crude oil nature and compositions. These correlations are developed for three different conditions namely, under-saturated, saturated and the dead oil. A typical viscosity curve at reservoir temperature as a function of pressure is illustrated in Fig. 1. Therefore, crude oil viscosity correlations can also be categorized in three types: The first ones estimate dead oil viscosity at ambient pressure and various temperatures. The second ones are used to predict saturated oil viscosity. The third ones are under-saturated oil viscosity correlations which are employed to determine the viscosity at pressures above the bubble point pressure.

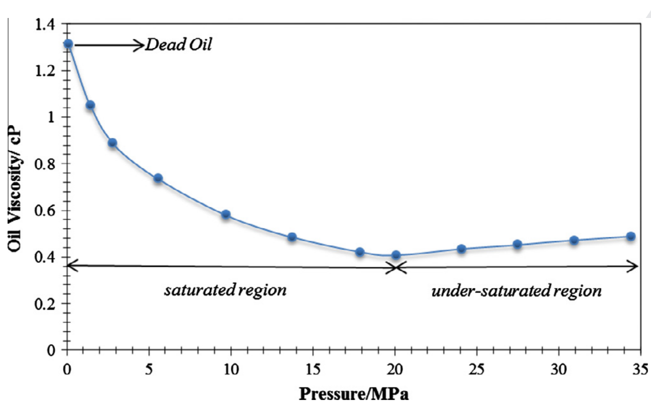

Fig. 1. Typical viscosity trend as a function of pressure.

Dead oil viscosity is one of the most "difficult" properties to be correlated with empirical correlations, because the oil type (depending on paraffin, aromatic, naphthene and asphaltene content) has a great effect on the viscosity. In this study, many well-known dead oil viscosity correlations are collected to comprehensively investigate performance of existing empirical correlations on Iranian crude oil reservoirs data. The most well-known correlations for dead oil viscosity were developed by: Beal [9], Beggs and Robinson [10], Glaso [11], Kaye [12], Al-Khafaji et al. [13], Petrosky [14], Egbogah and Ng [15], Labedi [16], Kartoatmodjo and Schmidt [17], Bennison [18], Elsharkawy and Alikhan [5], Hossain et al. [19], Naseri et al. [4] and Alomair et al. [20]. Table 1 gives the summary of the ranges and origin of the data used in aforementioned correlations.

All the latter correlations correlate the dead oil viscosity with temperature and API oil gravity while some others have correlated this property to normally unavailable properties in most common PVT reports such as acentric factor, critical temperature, molar mass and normal boiling point [21,22].

On the other hand, some empirical and semi empirical correlations have been proposed from corresponding state equations by Teja and Rice [23], Johnson et al. [24], and Johnson and Svreck [25]. These models use multiple computations and fluid composition as input of the model, but yet the accuracy of the results is not acceptable [4,5].

The second type of proposed correlations is for saturated oil viscosity. Presence of dissolved gas decreases the viscosity of the live oil to a lower value than the dead oil condition. This has a significant effect on the pressure drop and should be precisely accounted for by any viscosity model [26]. Numerous correlations has been developed for this region, however most of these ones do not predict the viscosity of Iranian oil's viscosity satisfactorily. In order to investigate the validity of the correlations for Iranian oil, 13 well-known correlations for saturated oil have been gathered in this

Table 1
The origin and PVT data ranges used in dead oil viscosity correlations.

Author	Source of data	T (K)	API	μ_{od} (cP)
Beal [9]	US	310–394	10.1–52	0.865–1550
Beggs and Robinson [10]	–	294–419	16–58	–
Glaso [11]	North Sea	283–422	20–48	0.6–39
Kaye [12]	Offshore California	334–412	7–41	–
Al-Khafaji et al. [13]	–	289–422	15–51	–
Petrosky [14]	Gulf of Mexico	319–415	25–46	0.72–10.25
Egbogah and Ng [15]	–	288–353	5–58	–
Labedi [16]	Libya	311–425	32–48	0.66–4.79
Kartoatmodjo and Schmidt [17]	Worldwide	300–433	14–59	0.5–586
Bennison [18]	North Sea	277–422	11–20	6.4–8396
Elsharkawy and Alikhan [5]	Middle East	311–422	20–48	0.6–33.7
Hossain et al. [19]	Worldwide	273–375	7–22	12–451
Naseri et al. [4]	Iran	314–421	17–44	0.75–54
Alomair et al. [20]	Kuwait	293–433	10–20	1.78–11360

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