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Toward prediction of petroleum reservoir fluids properties: A rigorous model for estimation of solution gas-oil ratio

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ABSTRACT

The amount of dissolved gas in production oil has been always a great question in oil and gas industry. Solution gas oil ratio is considered as a representative for the fraction of gas which is dissolved in oil during different stages of oil production. Several experimental methods have been developed for measuring this parameter. However, experimental procedures are usually time consuming, tedious and expensive. Thus, development of analytical equations and empirical correlations for estimation of solution gas oil ratio is of vital importance. In this study, a novel learning approach called least square support vector machine (LSSVM) optimized by coupled simulated annealing (CSA) was developed for calculating solution gas oil ratio as a function of temperature, bubble point pressure, gas specific gravity and oil API. To this end, a large number of data points including more than a thousand data sets from multiple reservoirs covering a wide range of reservoir conditions and pressure-volume-temperature (PVT) properties were gathered from various sources of literature. In addition, several statistical and graphical analyses including Average Absolute Percentage Relative Error (AAPRE), Average Percentage Relative Error (APRE), Root Mean Square Error (RMSE) and Coefficient of Determination (R^2) were carried out to evaluate the accuracy and validity of model and to compare it with the most well-known implicit and explicit correlations of solution gas oil ratio estimation. Moreover, relevancy factor was employed to investigate the impact of each input parameter on solution gas oil ratio showing that bubble point pressure has the greatest effect on solution gas oil ratio. Finally, leverage approach was utilized to detect the data outliers and to find the applicability domain of the proposed model. The results in this study show that the developed model is able to estimate solution gas oil ratio with high accuracy and reliability making it possible to use the model in commercial software packages with various applications in oil and gas industry.

1. Introduction

Having a thorough knowledge about hydrocarbon fluid properties is the basis of every PVT calculation and screening process in different petroleum reservoir engineering areas including reservoir simulation, material balance calculations, well test calculations, etc. Therefore, accurate measurement of fluid pressure-volume-temperature (PVT) properties such as solution gas oil ratio (Rs), dew and bubble point pressure and oil formation volume factor (OFVF) is essential. Two main methods to determine these PVT parameters are experimental measurements and empirical correlations (Danesh, 1998). Generally, experimental procedures for measuring PVT properties are time consuming and expensive.

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Also, the validity of the tests depends on the samples and is associated with the common experimental errors. Therefore, developing empirical correlations for determining the aforementioned PVT properties, is essential and of great importance. These correlations utilize basic PVT properties including temperature, pressure, gas specific gravity, oil API and solubility that are easy to be measured experimentally (Danesh, 1998; Dutta and Gupta, 2010).

Several researchers have attempted to develop correlations for determining PVT properties and in what follows, a short description of these efforts is gathered:

Standing (Standing, 1947) was one of the first authors who proposed chart based correlations for oil formation volume factor and saturation pressure (bubble point pressure). He used 105 California oil samples from 22 different types of crude oils and gas mixtures. Four years later, he formulated his charts to mathematical correlations (Standing, 1951). After gathering about 600 data points from various regions and doing regression analysis, Beggs and Vasquez (Vazquez and Beggs, 1980) proposed some correlations for oil formation volume factor and solution gas oil ratio. Glaso (Glaso, 1980) collected 45 crude oil samples from North sea and developed a correlation for determining bubble point pressure (solution gas oil ratio). In addition, he proposed a correction parameter for reservoir gases with non-hydrocarbon components including N_2, CO_2 and H_2S. Based on Middle East samples, Al-Marhoun (Al-Marhoun, 1988) developed a correlation for determination of PVT properties which is still widely being used in petroleum engineering calculations. El-batanony and Macary (Macary and El-Batanoney, 1993) used laboratory measurements of Suez crude in 1993 to propose a set of PVT correlations. Farshad and Petrosky (Petrosky and Farshad, 1993) proposed empirical correlations for determining OFVF, bubble point pressure and solution gas oil ratio based on Gulf of Mexico samples. Schmidt and Kartoatmodjo (Kartoatmodjo and Schmidt, 1994) used data of various regions in 1994 to propose a set of PVT correlations. Farshad et al. (Frashad et al., 1996) developed a set of correlations in 1996 for determining OFVF, solution gas oil ratio and bubble point pressure based on 98 samples from Colombian crude oils. Al-Shammasi (Al-Shammasi, 1999) developed a set of correlations for calculating bubble point pressure, solution gas oil ratio and OFVF based on a large number of PVT data points. Christman (Dindoruk and Christman, 2004) and Dindoruk proposed the most accurate PVT correlation for Gulf of Mexico crudes in 2004. In 2014, Arabloo et al. (Arabloo et al., 2014) developed two simple yet accurate correlations for prediction of bubble point pressure and oil formation volume factor using constrained multivariable search methods.

Intelligent models have been widely used in petroleum and chemical industries over the last decade (Hemmati-Sarapardeh et al., 2014; Kamari et al., 2015; Ahmadi et al., 2014; Ahmadi et al., 2015). Recently, several intelligent methods have been developed by different authors for determining fluid PVT properties. The most well-known intelligent models have been proposed by: Al-Marhoun and Osman (Al-Marhoun and Osman, 2002) who developed new models for estimating oil formation volume factor and bubble point pressure by applying artificial neural network (ANN) on 283 data sets from Saudi reservoirs, El-Sebakhy (El-Sebakhy, 2009) who utilized fuzzy logic inference systems as a predictor for bubble point pressure and oil formation volume factor, Omole et al. (Omole et al., 2009) who employed back propagation neural network for prediction of oil viscosity achieving a value of 0.07 for average absolute relative error, Gharbi and Elsharkway (Gharbi et al., 1999) who collected 5200 experimental data points from various regions to develop ANN based models for predicting PVT properties of different oil crudes. They utilized back-propagation with momentum for error minimization in developing their intelligent models. Other famous intelligent models were developed by Moghadassi et al. (Moghadassi et al., 2009) who used Levenberg–Marquardt algorithm to develop their back propagation ANN model for prediction of PVT properties. They reported a value of 0.0006 for mean square error of their predictive model. Another comparative study was performed by El-Sebakhy et al. (El-Sebakhy et al., 2007) who proposed that the intelligent support vector machine technique is superior to the empirical correlations, neural networks and nonlinear regression methods in estimating PVT properties of crude oil systems.

Generally, solution gas oil ratio is considered to be dependent on bubble point pressure. Thus, by solving the bubble point pressure equations, solution gas oil ratio can be determined. These correlations are called implicit correlations. However, there are some other correlations called explicit correlations that do not follow this rule including: Elsharkawy (Elsharkawy and Alikhan, 1997), Kartoatmadjo (Kartoatmodjo and Schmidt, 1994), Obomanu and Okporibi (Obomanu and Okpobiri, 1987) and Vasquez (Vazquez and Beggs, 1980) correlations. It should be noted that most of the correlations for determining PVT properties are developed based on either a limited number of data points or a specific region with specific crude oil type. Hence, care should be taken while using these correlations for different regions as huge errors may occur.

In this study, a world-wide model for calculating solution gas oil ratio is developed using a wide range reservoir conditions and PVT properties including more than 1000 data points from different regions of the world. To this objective, a robust model namely Least Square Support Vector Machine (LSSVM) is proposed. The inputs of the model are: oil API, gas specific gravity, temperature and bubble point pressure. In addition, several statistical and graphical analyses are employed to evaluate the performance and accuracy of the model and to prove the superiority of the model to the most well-known explicit and implicit PVT correlations. Besides, the relevancy factor is determined to find the relative impact of inputs on solution gas oil ratio. Finally, Leverage approach is employed to shows the applicability domain of the proposed models and to find suspected data points.

2. Data gathering

As it was mentioned earlier, for developing the model in this work, a wide range of reservoir conditions and PVT properties including 1136 data sets was collected from various sources of literature. The proposed model for calculating solution gas oil ratio was assumed to be a function of oil API, gas specific gravity, temperature and bubble point pressure. The following works were used as references for data collection: Abdul-majeed and Salman (Abdul-Majeed et al., 1988), Bello et al. (Bello et al., 2008), Omar and Todd (Omar and Todd, 1993), Moghaddam et al. (Moghadam et al., 2011), Ghetto et al. (Ghetto et al., 1994), Ostermann et al. (Ostermann et al., 1983), Mahmood and Al-Marhoun (Mahmood and Al-Marhoun, 1996), Dokla and Osman (Dokla and Osman, 1992), Al-Marhoun (Al-Marhoun, 1988) and Obomanu and Okpo-biri (Obomanu and Okpobiri, 1987).

A general relationship for solution gas oil ratio was considered as follows:

$$R_s = f(API,\ P_b,\ \gamma_g,\ T_R) \tag{1}$$

In this equation, R_s stands for solution gas oil ratio, API is oil gravity, P_b denotes the bubble point pressure of oil, γ_g is gas specific gravity and T_R is reservoir temperature. As solution gas oil ratio is an input parameter for bubble point pressure, it is generally derived from solving bubble point pressure correlations for solution gas oil ratio. The exceptions to this rule are Elsharkawy (Elsharkawy and Alikhan, 1997), Obomanu and Okporibi (Obomanu and Okpobiri,