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Implementing ANFIS for prediction of reservoir oil solution gas-oil ratio

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A B S T R A C T

Thorough knowledge of PVT properties of oil and gas reservoirs plays an important role in forecasting the phase behavior of oil reservoirs and designing appropriate actions for optimized production from them. Among these PVT properties, some have a determinative role in gas and oil equilibrium in the hydrocarbon reservoirs. In this study, a powerful computational intelligent model is designed to develop a reliable model for predicting amount of dissolved gas in oil at reservoir conditions as one of the most important PVT properties of reservoir oils. To achieve this model, different Adaptive Neuro-Fuzzy Inference System (ANFIS) models (by changing the training optimization algorithms) are designed. Moreover, prediction accuracy of the developed models has been compared with the number of well-known correlations in literature. The results show that the proposed model has a significantly improved performance in comparison with the other existing correlations.

1. Introduction

Calculations of production engineering, field performance analysis, reservoir studies, design of production facility and planning for future improved oil recovery projects require accurate knowledge of reservoir fluid pressure, volume, and temperature (PVT) properties (Arabloo et al., 2014; Dindoruk and Christman, 2004; Malallah et al., 2006; Valkó and McCain, 2003). Initial gas solubility in reservoir oil is one of these PVT properties which is defined as the amount of dissolved gas in one stock-tank barrel of oil (Kartoatmodjo and Schmidt, 1994; Standing, 1947). Performance evaluation of the reservoir and phase equilibrium between gas and oil are only one of the primary applications of this parameter.

It is possible to determine gas solubility by either the experimental or predictive approaches. Although performing PVT laboratory tests especially differential liberation (vaporization) test on reservoir fluid samples can determine the desired PVT parameter, they are both expensive and time consuming. Another disadvantage of laboratory tests is that in the case of improper fluid sampling from the reservoir, the results of the PVT tests would not be reliable (Asoodeh and Bagheripour, 2012; Danesh, 1998). Utilization of predictive methods has three major branches: calculation of these properties from equations of states such as PR or SRK (Elsharkawy, 2002, 2003; Elsharkawy et al., 2003), empirical correlations such as Standing (Standing, 1947), Vazquez and Beggs (Vazquez and Beggs, 1980), Glaso (1980), Al-Marhoun (Al-Marhoun, 1988), Petrosky and Farshad (Petrosky and Farshad, 1993), Dindoruk and Christman (Dindoruk and Christman, 2004), and finally, application of computational intelligent models (Farasat et al., 2013; Rafiee-Taghanaki et al., 2013; Talebi et al., 2014). Artificial neural network (ANN), Fuzzy logic (FL), support vector regression (SVR) and functional networks (FN) are the most common examples of computational intelligent systems used by engineers to solve different problems in petroleum industry (Rafiee-Taghanaki et al., 2013; Talebi et al., 2014). Accuracy and flexibility of these systems as well as fast processing capability have made them the most common approach among the recent researches (Arabloo and Rafiee-Taghanaki, 2014; Ghiasi et al., 2014). In this study two new models are proposed to predict initial gas solubility of Iranian oil reservoirs based on 157 data sets from unpublished experimental data. In order to develop the models, an efficient system has been implemented. ANFIS (adaptive neuro fuzzy inference system), an adaptive network which permits the usage of neural network topology together with fuzzy logic (Atmaca et al., 2001), has been

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used to simulate the relationship between bubble point pressure, specific gas gravity, oil gravity (API) and reservoir temperature and their dependent variable, initial gas solubility. A Takagi–Sugeno (Takagi and Sugeno, 1985) fuzzy inference system (TS-FIS) based on subtractive clustering method was developed and optimized by both back propagation and hybrid learning method. In fact, it uses a combination of back-propagation and least squares techniques to achieve accurate predictive models.

In the next section a review of the former researches on calculation of initial gas oil ratio is presented. Then, in Section 3, the basic of ANFIS is explained. Section 4 is devoted to data gathering and computational procedure. Results of the models are discussed in Section 5. A comparison between developed models and well-known correlations and also between the two proposed models are presented in Section 5. Finally in the last section, the key results of this study are outlined.

2. Literature review

Developing PVT models for accurate estimation of reservoir fluid properties still has been one of the active areas of research. The following is a review on empirical correlations developed for prediction of solution gas oil ratio (R_s) in hydrocarbon reservoirs:

In 1947, the first predictive correlation was proposed by Standing (Standing, 1947) based on 105 experimental data points of 22 gas–oil mixtures of California oil fields. He published his graphical correlation assuming R_s as a function of saturation pressure, reservoir temperature, gravity of dissolved gas and API gravity of stock tank oil. Nearly all of the researchers after him followed his assumption of considering gas solubility as a function of the above mentioned parameters. In 1980, Vasques and Beggs (Vazquez and Beggs, 1980) developed an empirical correlation for prediction of gas solubility based on 5008 data sets. They subdivided the oil mixtures into two categories: crudes with API gravity more than 30 and crudes with API gravity less than 30. The equation was directly obtained by regression analysis rather than rearranging the bubble point pressure correlation and rewriting in terms of R_s. In 1980, Glaso (Glaso, 1980) proposed empirical correlations for predicting PVT properties using 45 North Sea crude oil samples. The correlation of gas solubility was originally developed for saturation pressure as a function of API, gas gravity and reservoir temperature as well as solution gas oil ratio and then rearranged for gas solubility. In 1988, Al-Marhoun (Al-Marhoun, 1988) published empirical correlations for prediction of PVT properties. The bubble point pressure correlation was proposed based on 160 experimental datasets of the Middle Eastern crude oils. By rearranging and solving the correlation for solution gas oil ratio a new equation is obtained which can be used for gas solubility prediction. In 1990, Rollins et al. (Rollins et al., 1990) proposed an empirical equation to estimate gas oil ratio (GOR) of stock tank utilizing data from two stage separators of 301 samples of black oil. Assuming stock tank gas oil ratio as a function of stock tank oil specific gravity, separator-gas specific gravity, separator pressure and separator temperature, they proposed a graphical correlation for determination of total solution gas oil ratio. In 1993, Petrosky and Farshad (Petrosky and Farshad, 1993) implemented a nonlinear multiple regression analysis in order to develop an empirical correlation for prediction of gas solubility. Performance of their study was clearly shown by comparing the results with other empirical correlations. In 1994, Kartoatmodjo and Schmidt (Kartoatmodjo and Schmidt, 1994) proposed nine empirical correlations for several PVT properties using a data bank of crude properties from different geographical regions including a total of 5392 data points. In 1996, Frashad et al. (Frashad et al., 1996) presented new empirical correlations for estimating bubble point pressure, gas solubility, oil formation volume factor and isothermal compressibility. To develop the correlations, they implemented the database consisting of 98 PVT laboratory analysis for Colombian crude oils. They proposed three different gas solubility correlations based on single-stage, two-stage and three-stage separation data. In 2004, Dindoruk and Christman (Dindoruk and Christman, 2004) used more than 100 PVT reports from the Gulf of Mexico Oils and developed empirical correlations for various PVT properties. They proposed correlation for gas solubility as a function of bubble point pressure, gas specific gravity, API gravity and temperature. Comparison between their proposed correlation and Standing (Standing, 1947) and Petrosky-Farshad (Petrosky and Farshad, 1993) correlations showed that their model has better accuracy for prediction of PVT behavior of Gulf of Mexico Oils.

In the past few years, artificial neural networks (ANN) have attracted many attentions in petroleum engineering and many researchers have benefitted from ANNs to generate more precise oil PVT models. ANN models process the data in a parallel-distributed manner that efficiently can identify patterns in a data set even in complicated cases (Olatunji et al., 2011). Feed forward neural networks that uses back propagation training algorithm are one of the most popular ANNs (Mahmoud and Olatunji, 2009) and have been applied successfully by many researchers to predict PVT properties. (Gharbi and El-sharkawy, 1997; Osman et al., 2001) Garbi and Elsharkawy in 1997 (Gharbi and El-sharkawy, 1997) trained ANNs by 498 PVT data sets taking from literature and unpublished sources and proposed their models in which two neural networks are trained separately to estimate saturation pressure and oil formation volume factor (B_{ob}) of Middle East crude oils, respectively. They also used a separate 22 data sets for testing the models and evaluating their accuracy. After that, Elsharkawy (Elsharkawy, 1998) developed an ANN model with two hidden layers radial basis function for estimation of both oil and gas systems PVT properties. Results for estimated oil formation volume factor (Bo) indicated better predictions compared to those of published empirical correlations. In 1999, Varotsis et al. (Varotsis et al., 1999) applied ANNs to propose a novel method to approximate PVT properties of reservoir oil and gas condensates systems. Examination of the model including all fluids type revealed a lower level of error compared to tuned equation of state models. Osman and Al-Marhoun (Osman and Al-Marhoun, 2005) applied radial basis functions and multilayer perceptron neural networks and developed two intelligent models to predict oil field brines PVT properties. In 2009, Khoukhi et al. (Khoukhi et al., 2011) published predictive models based on three different artificial intelligent models. Artificial neural network (ANN), support vector regression (SVR) and functional networks (FN) were implemented to predict gas solubility for a range of reservoir pressures by using three different data sets. Khoukhi et al. (Khoukhi et al., 2011) concluded that support vector regression (SVR) has best prediction results for gas solubility. In 2010, Dutta and Gupta (Dutta and Gupta, 2010) proposed correlations for saturation pressure (P_b), solution gas oil ratio and some other PVT properties of Indian west coast crude using ANN model based on multilayer perceptron and bayesian regularization coupled with hybrid genetic algorithm (GA) as an optimizer. Their model used 372 data sets for solution gas oil ratio and bubble point pressure. They also modified the constant coefficients of Standing (Standing, 1947), Vasquez-Beggs (Vazquez and Beggs, 1980), Glaso (Glaso, 1980), Al-Marhoun (Al-Marhoun, 1988) and Dindoruk-Christman (Dindoruk and Christman, 2004) correlations for prediction of gas solubility.

In 2012, Ikiensikimama and Ajienka (Ikiensikimama and Ajienka, 2012) proposed a five constant coefficients empirical correlation for the Niger Delta crude gas solubility using 250 conventional PVT reports. According to API of crudes, they divided data