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Research article

Prediction of gas compressibility factor using intelligent models

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Abstract

The gas compressibility factor, also known as Z-factor, plays the determinative role for obtaining thermodynamic properties of gas reservoir. Typically, empirical correlations have been applied to determine this important property. However, weak performance and some limitations of these correlations have persuaded the researchers to use intelligent models instead. In this work, prediction of Z-factor is aimed using different popular intelligent models in order to find the accurate one. The developed intelligent models are including Artificial Neural Network (ANN), Fuzzy Interface System (FIS) and Adaptive Neuro-Fuzzy System (ANFIS). Also optimization of equation of state (EOS) by Genetic Algorithm (GA) is done as well. The validity of developed intelligent models was tested using 1038 series of published data points in literature. It was observed that the accuracy of intelligent predicting models for Z-factor is significantly better than conventional empirical models. Also, results showed the improvement of optimized EOS predictions when coupled with GA optimization. Moreover, of the three intelligent models, ANN model outperforms other models considering all data and 263 field data points of an Iranian offshore gas condensate with R^2 of 0.9999, while the R^2 for best empirical correlation was about 0.8334.

Keywords: Z-factor; Gas condensate; Empirical correlation; Intelligent models

1. Introduction

Obtaining fluid properties from gas and oil reservoirs has been of great importance to many researchers and petroleum engineers. The significance of this knowledge becomes more brilliant when the oil and gas capacity of reservoirs, dissolved gas, aquifer model and other reservoir properties depends directly or indirectly on fluid properties [1]. For this purpose, the pressure, volume and temperature (PVT) analysis should be applied to find the aforementioned parameters. This can be made in PVT laboratory or by using proper correlations [2].

For the case of gas condensate and gas reservoir, estimation of Z-factor plays a key role for determination of other properties. Obtaining the accurate Z-factor has been the subject of controversy among researchers. High expenses and inaccessibility to some well-equipped laboratories are the reasons for researchers to be reluctant to use the direct measurement of Z-factor. The common ways for prediction of Z-factor are EOS and empirical correlations. The EOS have been developed and extended for vapor liquid equilibrium (VLE) calculations [3], estimation of critical properties [4] and prediction of volumetric properties of gas mixture as well [5,6]. The point that should be considered about EOS is that despite the accurate results attained from developed and modified EOS in comparison to empirical correlations, a bit more difficulties are involved in solution process and more involving parameters are dealt with. On the other hand, the foible point of empirical

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correlations is that they are usually developed based on specific data set. A good illustration is Sanjari and Lay investigation which concluded to an empirical correlation for Z-factor using Khangiran Refinery data set [7]. Another example is Heidarian et al. study on gas compressibility factor which led to empirical correlation based on limited experimental data [8]. Likewise, Azizi et al. [9]generated a correlation using extracted data from Standing-Katz chart [10] or investigation of Farzaneh-Gord and Rahbari [11]who used measurable real time properties for developing the empirical correlation. An interesting example is Jarrahian and Heidarian [12] study in which they proposed a new EOS for sour and sweet natural gases when the composition is unknown. They tried to lessen the input variables in compare to other empirical correlations.

The fundamental tool for estimation of thermophysical properties of hydrocarbon fluids is EOS. Overall, EOS have their own mixing rules which cause complexity in solution process. The EOS based on statistical-mechanical theory yield more accurate results. On the other hand, empirical correlations are widely used in petroleum engineering applications simply as they are practical and easy to use. That is to say, the chief reason which makes the petroleum engineers tend to deal with these kind of correlations is that they are explicit in Z with straight forward solution procedure [13].

The complexity of EOS makes them difficult to apply especially for mixtures with large number of components. Also, questionable and unreliable predictions of Z-factor using empirical correlations at some pressures and temperatures have led the researchers to seek for easier, more reliable and valid prediction for z-factor. On the other hand, application of intelligent models becomes important to compensate weakness of conventional methods. The intelligent systems are widely used as robust tools to predict the petroleum properties and also other engineering parameters [14–16]. A good example of using intelligent models in reservoir engineering is Saemi et al. work [17], in which they predicted reservoir permeability using linked Adaptive Neural Network and Genetic Algorithm (GA). Other examples of intelligent models usage in reservoir fluid properties are prediction of bubble point pressure by ANN [18], minimum miscibility pressure (MMP) by least square support vector machine (LSSVM) [19], dew point pressure using Fuzzy Logic model [20], Z-factor of natural gas [21] and sour gasusing Adaptive Neuro Fuzzy Inference System (ANFIS) and ANN model [22] and condensate to gas ratio by LSSVM model [23]. In another study, Ganji-Azad et al. applied the ANFIS model to predict reservoir fluid PVT properties [24]. Moreover, Fayazi et al. [25] and Rafiee-Taghanaki [26] proposed a robust model for prediction of gas compressibility factor by application LSSVM.

In this study, experimental PVT data of gas condensate reservoir are used to compare and analyze accuracy of empirical correlations and EOS coupled with intelligent models. In the following sections, the application of intelligent models will be presented in two parts. The first part includes improvement and optimization of Van Der Waals and Redlich Kwong equation of state by implementation of experimental data using Genetic Algorithm [27]. Second part is allocated to employ the Fuzzy Logic (FIS), ANFIS and ANN predicting models and suggest the best intelligent model for predicting gas Z-factor. These intelligent models are trained by share of experimental data, while the remaining data are used for validation and test. Some of these intelligent models are utilized to predict the gas Z-factor in previous works, and their ability will be evaluated and compared with empirical correlations comprehensively in the current study.

2. Empirical correlations and equations of state

2.1. Empirical equations

Several empirical correlations have been developed yet to predict Z-factor. These correlations relate the critical properties of mixture, temperate and pressure of reservoir to the Z-factor.

The regression approach is frequently used to generate empirical correlations such as that of Sanjari and Lay (SL) in 2012. They generated an empirical predicting correlation of gas compressibility. They have developed their correlation based on Virial equation of state. They proposed correlation as a function of p_{pr} and T_{pr} within the range of $0.01 \le p_{\mathrm{pr}} \le 15$ and $1.01 \le T_{\mathrm{pr}} \le 3$ [7].

$$Z = 1 + A1p_{\mathrm{pr}} + A2p_{\mathrm{pr}^2} + \frac{A3p_{\mathrm{pr}^{A4}}}{T_{\mathrm{pr}^{A5}}} + \frac{A6p_{\mathrm{pr}^{A4+1}}}{T_{\mathrm{pr}^{A7}}} + \frac{A8p_{\mathrm{pr}^{A4+2}}}{T_{\mathrm{pr}}(A7+1)} \tag{1}$$

Many empirical correlations are adjusted by pseudo reduced temperature and pressure such as that of Shell Oil Company (SOC) which was referenced by Kumar [28].

$$Z = A + Bp_{\mathrm{pr}} + (1-A)\exp(-C) - D\left(\frac{p_{\mathrm{pr}}}{10}\right)^4 \tag{2}$$

2.2. Equations of state

Generally, cubic EOS originated from Van Der Waals equation of state are more applicable for industrial proposes [29]. These EOS are commonly rewritten in cubic polynomial form. Vander Waals (VdW) equation is the basic cubic EOS which modified the ideal gas PVT relations [30]. The cubic polynomial form of VdW EOS, equation (8), can be solved to find the Z-factor:

$$Z^3 - (1+B)Z^2 + AZ - AB = 0 \tag{3}$$

where, $A = \frac{ap}{R^2T^2}$ and $B = \frac{bp}{RT}$. The coefficients a and b are defined as follow:

$$a = 0.421875\frac{R^2T_c^2}{p_c} \tag{4}$$