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Dew point pressure model for gas condensate reservoirs based on multi-gene genetic programming approach

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ABSTRACT

One of the most critical parameters in characterization of gas condensate reservoirs is dew point pressure (DPP), and its accurate determination is a challenging task in development and management of these reservoirs. Experimental measurement of DPP is a costly and time consuming method. Therefore, searching for a quick, reliable, inexpensive, and robust algorithm for determination of DPP is of great importance. In this paper, first, a new approach based on multi-gene genetic programming (MGGP) to determine DPP of gas condensate reservoirs is presented. Then, a correlation for DPP calculation using MGGP has been developed for gas condensate reservoirs. Finally, the efficiency of the proposed DPP model has been validated by comparing its predictions with the results of other conventional models. It is found that the correlation developed in this work is capable of predicting more accurate values of DPP, with the lowest average relative and absolute errors with respect to the experimental results, and also higher correlation coefficient among the results of all the evaluated DPP correlations. Therefore, it is suggested that the proposed model can be applied effectively for DPP prediction for a wide range of gas properties and reservoir temperatures.

1. Introduction

Gas condensate reservoirs exhibit complex phase and flow behaviors due to formation of condensate bank near the wellbore region and dynamic changes in composition of each phase. Natural production from these reservoirs leads to reservoir pressure drop which causes gas condensation, and liquid drops out in the pore space of the reservoir (see Fig. 1). This phenomenon occurs primarily in the vicinity of the wellbore, and then, propagates in a cylindrical form within the entire drainage volume of the well. The most important effect of liquid condensation is reduction of gas relative permeability and, consequently, loss of production. Therefore, efficient production from gas condensate reservoirs is very sensitive to accurate determination of dew point pressure [1].

In general, there are three methods to calculate the dew point pressure (DPP). The first approach is experimental measurement of DPP of collected laboratory samples. The widely used experimental methods for this purpose include constant composition expansion (CCE) [2] and constant volume depletion (CVD) [3] tests. Although experimental measurement of DPP is very accurate and reliable, it is very costly and time consuming especially in lean gas condensate reservoirs [4].

The second method of dew point pressure calculation is use of empirical correlations. Empirical correlations for DPP predictions have been studied by several investigators [5–14]. The third approach is iterative estimation of DPP using any equation of state (EOS) [15,16]. This approach has convergence problems because matching parameters of selected EOS should be tuned with some experimental data by least squared method. In addition, the EOS approach does not generalize to unseen data, and usually memorizes the data that were used to develop it [17].

In recent decades, the DPP estimation using artificial intelligent techniques such as artificial neural networks (ANNs), adaptive neuro-fuzzy inference system (ANFIS) and support vector machine (SVM) has been investigated in several studies and good predictions have been reported [17–24]. Despite the acceptable performance of ANNs, there is no efficient procedure to select the structure to build such networks. Hence, many trials should be performed to obtain an appropriate configuration. Moreover, the mentioned approaches do not usually give a definite function, in terms of the input values, to calculate the DPP [25–27]. The generated prediction equation can

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Nomenclature

MGGP	Multi-gene genetic programming
M_{C7+}	Molecular weight of heptanes and heavier oil fraction
T_R	Reservoir temperature
X_{int}	Mole fraction of intermediate fraction
X_{vol}	Mole fraction of volatile fraction
X_{C7+}	Mole fraction of heavier fraction
DPP	Dew point pressure
RMSE	Relative mean square error = $\sqrt{1/N\sum((X_{cal}-X_{act})/X_{act})^2}$

be incorporated in commercial engineering software or applied to any reservoir engineering calculation cases without any difficulty.

Recently, the multi-gene genetic programming (MGGP) has been applied successfully to model various complex engineering problems. MGGP is a modified genetic programming (GP) approach for model structure selection combined with the least square technique (LST) for parameter estimation. The MGGP models are validated using experimental data that were not used during the training process. The MGGP-based equations can reliably be used for pre-design purposes. MGGP does not require simplifying assumptions to develop the models. Contrary to artificial neural networks and many other soft computing tools, the MGGP provides constitutive prediction equations. MGGP is able to learn the key information patterns within the multidimensional information domain with high speed, instead of complex rules and mathematical routines [28–31].

This paper proposes a new approach based on MGGP to determine an accurate formula for DPP of gas condensate reservoirs. A large experimental PVT data set of a giant gas condensate field is used to develop the new DPP equation by MGGP. Then, the performance of the MGGP model is compared to the conventional methods by means of some statistical indices. Moreover, the results obtained by MGGP are compared with other artificial learning techniques such as standard GP, ANFIS, and artificial neural network models.

2. Background

DPP correlations have been studied by several investigators. Eilerts and Smith [6] developed four correlations relating dew point pressures to temperature, composition, molar average boiling point and oil-to-gas volume ratio. Olds et al. [7] studied the behavior of reservoir fluids of Paloma field, and the influence of composition change on the DPP. They indicated that removal of the intermediate molecular weight components from the mixture resulted in a significant increase in DPP. Olds et al. [8] studied experimentally the behavior of five paired samples of oil and gas. Their investigations led to development of a rough correlation relating the retrograde DPP to the gas–oil ratio, temperature and stock tank API oil gravity. The results of this correlation were presented in tabulated and graphical forms.

Reamer and Sage [9] attempted to extend the existing correlations to the higher gas-to-oil ratio by studying combinations of five different pairs of fluids. They presented numerous diagrams which depict the effect of temperature and gas-to-oil ratio on DPP. Because of the complexity of the composition influences, it was doubtful that a useful correlation could be established. Nementh and Kennedy [10] proposed a relationship between DPP of hydrocarbon reservoir fluid and its composition, temperature and characteristics of the heptanes-plus fraction such as molecular weight and specific gravity.

Crogh [11] performed several evaluations to improve the Nemeth–Kennedy correlation. A new correlation was developed using the Nemeth–Kennedy database which correlates DPP with hydrocarbon and non-hydrocarbon reservoir fluid composition, specific gravity and molecular weight of C_{7+} fraction. However, temperature was not considered in their DPP correlation. Carison and Cawston [12] investigated the influence of hydrogen sulfide on DPP. According to their research, as the H_2S content of gas increases, the volume of liquid drop out of gas decreases. Yisheng et al. [13] studied the behavior of reservoir fluids of China's oilfields. They presented a new empirical correlation which predicts the DPP of gas condensate as a function of gas composition, temperature, characteristics of the heptane-plus fraction and average molecular weight of fluid mixture.

Humoud and Al-Marhoun [14] published a new empirical correlation to predict the DPP of gas condensate fluids from readily available field data. This correlation relates the DPP of a gas con-

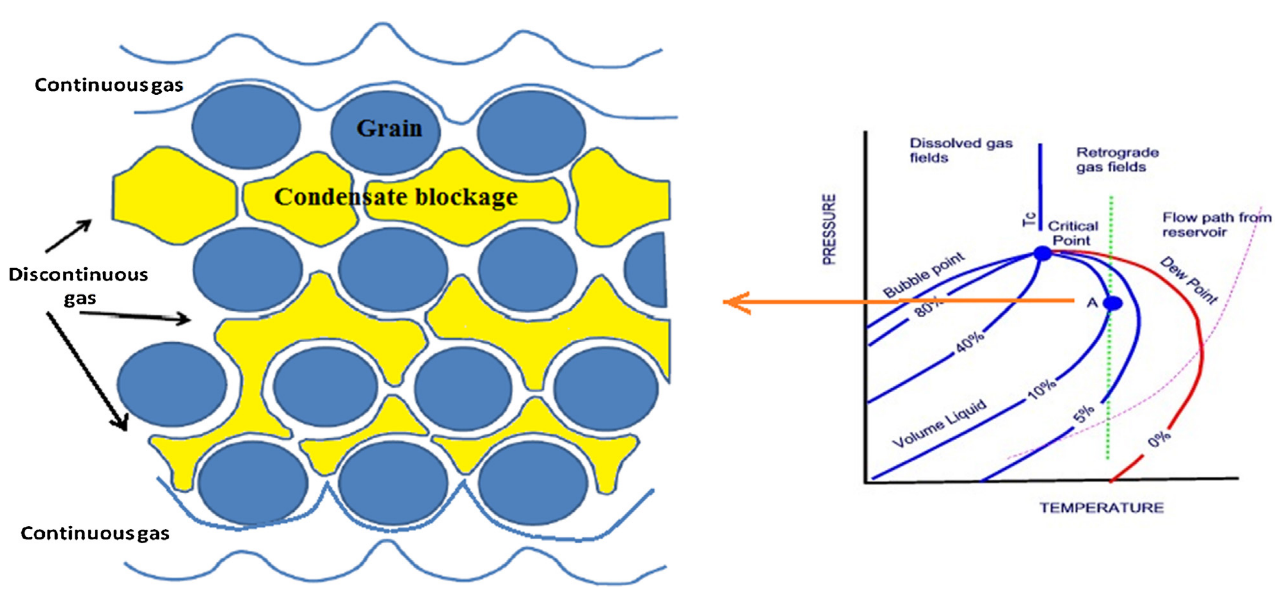

Fig. 1. Condensate block formation in pore spaces of reservoir.