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Robust correlation to predict dew point pressure of gas condensate reservoirs

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ABSTRACT

When the bottom-hole flowing pressure in a gas condensate reservoir drops below the dew point pressure, liquid starts to build up around the well bore resulting in gas productivity decline.

For this reason it is important to be able to accurately either measure or estimate the dew point pressure. The condensate formed in the reservoir will not flow until its saturation reaches the critical saturation and in many cases it might not be entirely recovered. It order to maximize gas production and condensate recovery, the reservoir pressure must be maintained close to the dew point pressure. Several attempts have been made to predict the dew point pressure in case the gas sample becomes unavailable or measured value is unreliable. Unfortunately, most of these attempts have minor success rates and are based on limited data.

In this paper we present a robust, cheap, and easy model for predicting the dew point pressure for gas condensate reservoirs. The new model is an intelligent based model called “Gene Expression Programming” that is carried out to generate a precise and accurate correlation to estimate the dew point pressure in condensate gas reservoirs. The new model has been trained and tested using a large data bank collected for the literature. Precision of the suggested correlation has been compared to published correlations. The validity of this model has also been compared to experimental data and other published correlations.

1. Introduction

Huge amounts of time, energy, and money are routinely spent and dedicated for the model to carefully, characterize effective gas condensate reservoirs as the most valuable types of hydrocarbon reservoirs. Gas deliverability losses as a result of condensate blockage; represent great challenges to the project economically. Therefore, a great degree of accuracy is definitely required to obtain and estimate vital parameters such as dew point pressure of gas condensate reservoirs [1–6].

Because of their inverse thermo-dynamical behaviors, having a very detailed knowledge and observing physical trends of reservoir temperature and pressure, as two most influencing parameters, through proposing cheaper, faster and non-laboratorial methods such as empirically derived equations, equation of state (EOS) and gained from cutting-edge mathematical solutions have mostly drawn related experts' attentions [7–16]. For instance, researchers have made great attempts to put forward techniques based on modern soft computing methods to measure factors such as dew point pressure which is defined as a pressure type border that passing it causes forming condensate bank in vicinity of the well bore, although the referred vital, critical and crucial attribute which behaves extremely non-linear can be reported from running some conventional, time-consuming and very much expensive experiments such as constant composition expansion (CCE) and constant volume depletion (CVD) which their generated results might adversely be affected with some inherent technical and monetary constraints such as restricted experimental budgets,

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having not abilities to acquire enough representative samples, analyzing incompletely due to the limited number of samples and natural errors of each test [17–26].

Calculations of dew point pressures (DPP) for retrograde gas condensate reservoirs is possible using the equation of state (EOS) which requires splitting the heptane plus fraction into several pseudo-fractions, characterization of each of the sub-fractions, and choice of the EOS. Even with proper characterization and splitting schemes, there is no guarantee that the EOS calculations are accurate unless the EOS is properly tuned to some experimental data such as constant volume depletion or constant composition expansion. The DPP can also be calculated using equilibrium ratios (*K*-values). However, the method involves trial and error as the *K*-values are dependent on the pressure and most of *K*-value approaches at high pressures are not precise [29].

Kurata and Katz (1942) studied the behavior of gas condensate reservoirs and volatile oils. They tried to correlate the DPP to fluid properties using measurements of 49 gas condensate samples [28]. Olds et al. (1945 and 1949) made the first attempts to estimate the DPP for gas condensate reservoirs. Olds et al. (1945) investigated the gas condensate fluid behavior of Paloma filed [29,30]. They found that the dew point pressure is strongly dependent of reservoir fluid composition. They observed that the removal of the intermediate fraction from the mixture resulted in a significant increase in the DPP. They also observed that the temperature has little effect on the DPP compared to the effect of the intermediate fraction. Olds et al. (1949) also studied the behavior of San Joaquin Valley fields' gas condensate samples. They presented a graphical correlation of DPP as a function of API gravity, and gas–oil ratio (GOR) of the produced condensate. This correlation has a limited application as it covers a very narrow range of gas condensate compositions. Later, Reamer and Sage (1950) made an attempt to correlate the DPP to gas condensate fluid properties using five gas condensate samples [31]. They presented various diagrams showing the effect of temperature and GOR on DPP. Reamer and Sage could not establish a useful correlation owing to the complication of the affection of composition on the DPP.

Organick and Golding (1952) presented a graphical correlation to estimate the saturation pressure for gas condensates and volatile oils as a function of modified weight average equivalent molecular weight and a molal average boiling point [32]. Their graphical correlation is presented in the form of 14 working charts, each including a group of plots that cannot be used for computer calculations. Organick and Golding stated that simple mixtures and pure components cannot be properly predicted using their correlation.

Nemeth and Kennedy (1967) were the first to present a mathematical correlation to predict the DPP for gas condensate reservoirs [33]. They correlated the DPP to reservoir temperature and gas condensate compositions. Later, Elsharkawy (2001 and 2002) presented another mathematical correlation to determine the DPP for gas condensate reservoirs that is based on a large data bank of experimental measurements and collected DPP [12,27]. Elsharkawy also presented calculations of DPP using SRK and PR EOS and two different characterization schemes of the heptane plus fraction. His correlation showed that DPP calculation is dependent on EOS and characterization methods.

Morch et al. (2006) presented measurements and EOS modeling of DPP of five synthetic natural gas condensate samples [34]. Their results showed a considerable deviation between DPP calculated by EOS and measurements. Esmaeilzadah and Samadi (2008) also made attempts to study gas condensate behavior using EOS [35].

Loul et al. (2012) presented measurements and predictions of DPP of five synthetic natural gas mixtures [36]. They used PR EOS to model the DPP curve for five synthetic and two real gas condensate samples. Loul et al. found that the binary interaction number has a great effect on the DPP calculations using the EOS. Hosseinkhni et al. (2014) used an expert system to calculate the DPP for gas condensate reservoirs. However, they did not present neither a mathematical model nor a graphical method to calculate the DPP for gas condensate reservoir [37]. Finally, Galatro and Cordero (2014) also measured the DPP of gas condensate samples [38]. They presented a comparison of DPP calculation using various schemes of characterization and binary interaction number, and PR and SRK EOS. Marruffo el al. also presented a model to estimate dew point pressure and heptane plus content of gas condensate [39].

In addition, it has been noticed that EOS's are not acceptably predicting the behavior of gas condensates [40–44]. Therefore, many attempts based on specified advantages of soft computing approaches such as dealing effectively with non-linearity, ambiguity and uncertainty of the referenced issue have been made to overcome hurdles of petroleum engineering issues such as phase behavior determination and to present more handy, precise and appropriate solutions [45–55]. For example, a special kind of an ANN to predict P_d through taking a set of thermo dynamical and compositional parameters as input was implemented by Jalali et al. [43]. Besides, Nowroozi et al. conducted an ANFIS to foresee P_d by considering mostly compositional factors [53].

The determination of the dew point pressure from constant volume depletion and constant composition expansion is very expensive and time consuming. Therefore, developing a new high performance and precise correlation for estimating dew point pressure for gas condensate reservoirs is the objective of the current study. Throughout this work Gene Expression Programming (GEP) is proposed to develop a new and user friendly correlation with a high degree of efficiency for estimating the dew point pressure (P_{dew}) in condensate gas reservoirs. This study overcomes previous problems as it has successful been applied to the predicting of many reservoir engineering parameters. Gas condensate data from literature, as well as from the northern Persian Gulf oil fields located in the south of Iran are used for the development of the proposed model, testing its accuracy, and validity in comparison to the previously published methods.

2. Gene Expression Programming (GEP) approach

2.1. Genetic programming

Genetic programming (GP) is a subset of evolutionary based methods with a countless aptitude to spontaneously develop programs of computer. GP inspired from principle of Darwinian natural selection for the addressed evolutionary algorithm same as genetic algorithm. The theory of genetic programming (GP) was firstly proposed and evolved by Koza after such tests on symbolic regression. The main distinction between genetic programming and original genetic algorithm summarized to the demonstration of the final solution. The referred target outcomes of genetic programming (GP) are computer based softwares which are demonstrated as tree topologies and formulated in a language of function based programming [47] while original genetic algorithm generates a string of numbers which illustrates the final solution. Put it this way, through genetic programming (GP), the developing individuals are parse trees than can assorted in length all the time run in favor of fixed-length binary