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New tools to determine bubble point pressure of crude oils: Experimental and modeling study

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ABSTRACT

Adequate Knowledge of reservoir fluid characteristics (e.g., bubble point pressure) plays a crucial role while conducting modeling/simulation of production processes in petroleum reservoirs. Although many efforts have been made to obtain proper correlations for prediction of bubble point pressure (BPP) of reservoir fluids, there is still relatively high magnitude of error with the developed predictive tools available in the literature. To fill this lacuna, a robust and effective technique, called gene expression programming (GEP), is employed to determine BPP of crude oil samples as a function of temperature, oil composition, molecular weight of C_{7+}, and specific gravity of C_{7+}. The GEP method is built based on the experimental (or real) data used for training and testing phases in order to develop an appropriate correlation. The previous predictive methods are also reported in this study and employed to calculate BPP as a function of independent parameters when the same data bank is utilized. Comparing the outputs obtained from the previous models with the BPP values predicted by the GEP technique, it was found that the GEP approach exhibits higher accuracy and lower uncertainty on the basis of statistical analysis in terms of coefficient of determination (R^2) and mean squared error (MSE). Great precision attained in this study through using GEP recommends linking reservoir simulator packages with the GEP tool when thermodynamic properties such as BPP are required for modeling and optimization purposes.

1. Introduction

In general, all calculations in chemical/petroleum engineering are strongly affected by fluid thermodynamic properties that might be determined through experimental works, analytical/theoretical models, empirical equations and statistical correlations. In other words, modeling simulation of hydrocarbon reservoirs, operation and design of surface facilities, determination of inflow performance, estimation of oil/gas in place, and analysis of well testing and material balance data are strongly dependent on the fluid PVT properties like density and bubble point pressure (BPP) which are important parameters in order to make a proper plan for reservoir development (Kloubek, 1972; Holcomb and Outcalt, 1999; Mishchuk et al., 2000; Fainerman et al., 2004; Sun et al., 2005; Fainerman et al., 2006; Yazaydın and Martin, 2007; Bandyopadhyay and Sharma, 2011; Dixit et al., 2012; Adeleke et al., 2013; Li and Yang, 2013; Simjoo et al., 2013).

BPP is defined as the maximum pressure at which the first gas bubble evolves from the corresponding liquid phase (Farasat et al., 2013). BPP, which is obtained from some routine laboratory methodologies such as Constant Composition Expansion (CCE) (Zheng et al., 2000; Shen et al., 2001), is commonly used to compute other important PVT characteristics including oil viscosity (μ_o), oil density (ρ_o) and oil formation volume factor (B_o). Thus, accurate prediction of this property appears to be vital to determine the subsequent parameters that are required for reservoir simulation and design of equipment involved in oil production processes (Bandyopadhyay and Sharma, 2011; Ahmadi et al., 2014a).

Although, available experimental procedures result in reliable data, they are still taken into account as lengthy and costly methods (Baker et al., 2003). In addition, the laboratory tests are significantly affected by the quality and quantity of the fluid samples collected particularly when the pressure near the wellbore goes below BPP (Proett and Chin, 2000; Dong et al., 2007;

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Nomenclature

Abbreviations

BPP	bubble point pressure
GEP	gene expression programming
CCE	Constant Composition Expansion
EOS	equation of state
ANN	Artificial Neural Network
ANFIS	Adaptive Neuro-Fuzzy Inference System
SVM	Support Vector Machine
GOR	gas oil ratio
GA	genetic algorithms
ET	expression tree

Variables

T	temperature
Vol./Inter.	the mole percentage ratio of volatile components (e.g., C_1 and N_2) to intermediate components (e.g., C_2–C_6, CO_2 and H_2S)
Mw	molecular weight
SG	specific gravity
N	number of the data points
y^{exp}	experimental values of the output
y^{pre}	predicted values of the output

Subscripts

exp	experimental
pre	predicted

Nnochiri and Lawal, 2010; Deisman et al., 2013). Considering various drawbacks reported here, development of simple, systematic and accurate ways to determine BPP seems necessary. Numerous techniques such as equation of states (EOSs), empirical relationships, and intelligent models have been developed to obtain the value of BPP. However, there are still some issues with them. For instance, prediction accuracy of EOS models is highly dependent on the type of fluid, mixing rules used, type of EOS selected for computation (Sarkar et al., 1991; Wang and Gmehling, 1999; Wang and Pope, 2000, 2001; Guo et al., 2001; Pires et al., 2001; Nikookar et al., 2008). Standing (1947) also introduced an equation to correlate BPP to gas solubility, temperature, oil gravity and gas gravity. Assuming the Henry's law is valid, Lasater (1958) introduced a model to forecast the saturation pressure (or BPP) of oil samples where no non-hydrocarbon impurities are present in the mixtures. Moreover, a graphical model was obtained based on the North Sea data by Glaso to find the values of BPP, oil formation volume factor (Bo), total formation volume factor (B_t) and oil viscosity (μ_o). This model considers a correction factor if the oil mixture contains some gaseous impurities including H_2, N_2 and H_2S (Glaso, 1980). Velarde et al. (1997) developed a predictive correlation through combining available correlations where a great number of data points were used. Based on the data collected from the oil samples (taken from the Middle East reservoirs), Gharbi and Elsharkawy (1999) applied a conventional smart technique, known as Artificial Neural Network (ANN), to predict important PVT properties including BPP and gas/oil ratio (GOR). Following this study, Gharbi et al. (1999) constructed a multi-layer perceptron ANN system to estimate BPP when a larger volume of data is employed. Given three different PVT databases, El-Sebakhy et al. (2007) obtained a mathematical relationship to determine parameters BPP and B_o using support vector regression technique. Regardless of the advantages reported for the ANN models, this type of predictive tools has its inherent limitations and constrains due to complexities, ambiguities and nonlinear behaviors of reservoirs parameters (Ahmadi, 2012; Ahmadi and Shadizadeh, 2012; Ahmadi et al., 2013a; Ahmadi and Ebadi, 2014; Ahmadi et al., 2014b, 2014c). For instance, they do not provide any linear or non-linear equations to estimate target functions. In addition, obtaining the optimum values for the parameters of the ANN models is not an easy task such that it takes fairly long time through the trial and error procedure if the optimization technique is not available. Therefore, researchers made attempts to get aids from different methods like Adaptive Neuro-Fuzzy Inference System (ANFIS), and Support Vector Machine (SVM). For instance, the first technique has been used to forecast the reservoir characteristics and operational conditions (Ahmadi et al., 2013a, 2013b; Ahmadi and Ebadi, 2014). Support Vector Machine (SVM) modeling has been also conducted to predict BPP when some handy PVT or/and thermodynamic parameters are considered as inputs (Farasat et al., 2013).

The main objective of the research reported in this paper is to introduce a user friendly, effective and quick correlation to calculate BPP of crude oil samples. To gain this goal, a novel Artificial Neural Network in the form of gene expression programming (GEP) is applied through an extensive statistical manner. The GEP technique introduced in this study uses a large number of the real data collected from various sources to attain a non-linear equation in terms of main thermodynamic conditions and properties such as temperature and density (Hoffman et al., 1953; Jacoby and Berry, 1958; Vogel and Yarborough, 1980; Williams et al., 1980; Hong, 1982; Li et al., 1985; Coats and Smart, 1986; Drohm et al., 1988; Jhaveri and Youngren, 1988; Riemens et al., 1988; Ahmed, 1989; Pedersen et al., 1989; Agarwal et al., 1990; Danesh et al., 1991, 1992; Pedersen et al., 1992; Moharam and Fahim, 1995; Wu and Rosenegger, 1999; Wu and Rosenegger, 2000; Elsharkawy, 2003). The real data are divided into different groups to implement training, testing and validation stages. To confirm the capability as well as superiority of the new correlation obtained from GEP modeling, the previous available correlations are employed to estimate the target variable (e.g., BPP). The performance comparison is statistically performed in this study. Further information on the modeling methodology, last works and effectiveness of the new BPP equation is provided in the following sections.

2. Methodology description

2.1. Experimental procedure

First, the sample is placed in a container which is equipped with pressure gauges. Checking the container pressure is conducted through the pressure sensors. The sample is then pressurized to guarantee single phase condition. As a next stage, the quality of the sample is determined by measuring the GOR at laboratory conditions in order to detect whether gas may have been lost through leaking valves. A sight glass is put in the flow line to detect the presence of water phase while transferring the sample to the PVT cell. The transferred sample is brought to reservoir conditions in the PVT cell. Thus, a single stage flash is conducted. The gas and liquid are collected in an equipment which has been built in the mechanical lab. Both phases are in contact to achieve the thermodynamic equilibrium. After that, measurements