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Rapid method for the estimation of dew point pressures in gas condensate reservoirs

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ABSTRACT

The production of condensate, in addition to gas can improve the recovery factor of gas condensate reservoirs, as well as increase the economic feasibility of the reservoir. Dew point pressure (DPP) is regarded as one of the vital parameters for characterizing a gas condensate reservoir. The accurate estimation of DPP is however still a major challenge for reservoir engineers. In this study, a consistent, accurate, and simple-to-use model is proposed for the prediction of DPP in gas condensate reservoirs using a reliable soft-computing approach known as gene expression programming (GEP). The computational approach utilizes a comprehensive dataset of DPP, as well as properties of C_{7+}, reservoir temperature, and hydrocarbon and non-hydrocarbon reservoir fluid compositions. The model proposed is compared to three well-known empirical correlations. The proposed model produces an average absolute relative deviation of approximately 7.88% and is clearly superior to previously published methods for the prediction of dew point pressure in gas condensate reservoirs.

1. Introduction

There is a growing realization of the importance of gas condensate reservoirs as a considerable hydrocarbon resource in terms of energy supply. In these reservoirs, well deliverability often reduces when the bottom-hole pressure drops below the dew point pressure (DPP). As a definition, dew point pressure is the pressure at which a considerably larger amount of the vapor phase is in equilibrium with a significantly smaller amount of liquid phase [1]. As a result, the dew point pressure plays a significant role in hydrocarbon reservoir engineering, resulting in the reservoirs being classified using dew point pressure. Gas condensate reservoirs are different in their thermodynamic and flow behavior compared to common gas reservoirs.

In the operation of gas reservoirs, there are two kinds of dew points that engineers are focused on [2,3]. The first type is the normal dew point pressure which occurs at low pressures when dry gas is compressed to a point at which the first droplets begin to form. This type of dew point pressure is not important for engineers because the pressure to achieve this dew point pressure is lower than atmospheric pressure, while the pressure of reservoirs are greater than atmospheric pressure [3,16]. The second type is retrograde dew point pressure. In this type of DPP, with a decrease in dew point pressure, at a specific pressure liquids start to form. At such a condition, the single phase fluid transforms into a liquid and gas/vapor phase. This pressure is often called the dew point or saturation pressure. By further decreasing the pressure, the volume of liquid reaches a maximum. Further decrease of pressure causes vaporization of the condensates and consequently a decrease in the amount of liquid. Such reservoirs are called retrograde condensate gas reservoirs [16]. The phase diagram for gas condensate reservoirs clearly shows this behavior (Fig. 1). Therefore, it can be concluded that the first type of dew point pressure does not matter in the performance of gas reservoirs, while the second type is very important in gas well performance.

As a consequence, the accurate prediction of dew point pressure in gas condensate reservoirs is important to evaluate their performance because of a reduction in the rate of gas condensate production with an increase of liquid [4]. A number of researchers have studied the effect of dew point pressure on well productivity, *e.g.* Fevang [5], Afidick and Bette. [6], Fan et al. [7], Barnum et al. [8], and Eilerts and Smits [9]. The studies conclude that there is a considerable reduction in well generation in gas condensate wells under certain conditions, *e.g.* near wellbore condensate aggregation. The determination of the dew point pressure in gas condensate reservoirs has been investigated by several researchers who have attempted to determine this important property either experimentally or theoretically. For the determination of the DPP experimentally, the constant composition expansion (CCE) and constant volume depletion (CVD)

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Nomenclature

DPP	dew point pressure
CCE	constant composition expansion
CVD	constant volume depletion
GA	genetic algorithm
GEP	gene expression programming
GP	gene programming
ET	expression tree
EoS	equations of state
MW_{C7+}	molecular weight of pentane plus fraction
SP_{C7+}	specific gravity of pentane plus fraction
T_R	reservoir temperature,°F
P_d	dew point pressure, Psia
E_i	percent relative deviation
ARD	average relative deviation
AARD	average absolute relative deviation
RMSE	root mean square error
SD	standard deviation
R^2	coefficient of determination

are the two most commonly-used laboratory measurement methods [1]. Laboratory measurement of DPP is reliable, however, it is expensive and time-consuming. Hence, there is a preference to determine DPP using empirical methods and equations of state (EoS) [1].

EoSs are usually not able to accurately simulate the phase behavior of light oil and gas condensate reservoirs, particularly in the retrograde region [2]. Hence, a consistent, accurate, efficient, and simple-to-use model is proposed in this study for the determination of dew point pressures of retrograde gas condensate reservoirs. To this end, the gene expression programming (GEP) [10] computational scheme was implemented to develop the model using a database of 562 experimental data points from CVD tests. The model developed is compared to three well-known empirically derived correlations. An analysis is also conducted to detect the suspended and/or outlier data points existing in the dataset of DPP.

2. Literature survey

Over the years, many research studies have been conducted to propose a global model for the prediction of DPP in gas condensate systems, on the basis of temperature, hydrocarbon composition, and C_{7+}. In 1942, Kurata [11] developed a correlation to predict the critical properties of volatile hydrocarbon mixtures. To this end, they neglected the effect of composition due to a limited number of DPP data for the model development. Eilerts and Smith [9] proposed a relationship between temperature, pressure, composition, boiling point of the fluid, and gas oil ratio based on research in the Palam field. In 1945, Olds and Lacey [12] developed a correlation to predict the dew point pressure (in graphical and tabular forms) by using the characteristics of oil and gas samples obtained from the primary separator of a well in the Paloma field. They also studied the impact of the elimination of intermediate molecular weight on DPP. They showed that the intermediate molecular weight components have a significant influence on DPP.

Table 1
Ranges, averages and units of the variables implemented for the development of the GEP-based model for the prediction of dew point pressures.

Property	Unit	Min.	Max.	Avg.
Dew-point pressure, DPP	Psia	1405	10,790	4747.2
Reservoir temperature, T_R	°F	40	320	205.15
Molecular weight, MW $_{C7+}$	–	106	235	148.2
Specific gravity, SG_{C7+}	–	0.7330	0.8681	0.788
Nitrogen, N_2	Mole fraction	0.0000	0.4322	0.010
Carbon dioxide, CO_2	Mole fraction	0.0000	0.9192	0.015
Hydrogen sulfide, H_2S	Mole fraction	0.0000	0.2986	0.006
Methane, C_1	Mole fraction	0.0349	0.9668	0.802
Ethane, C_2	Mole fraction	0.0037	0.1513	0.057
Propane, C_3	Mole fraction	0.0011	0.1090	0.030
Butanes, C_4	Mole fraction	0.0017	0.2030	0.020
Pentanes, C_5	Mole fraction	0.0006	0.0631	0.012
Hexanes, C_6	Mole fraction	0.0004	0.0510	0.009
Heptane-plus, C_{7+}	Mole fraction	0.0019	0.1356	0.037

Olds and Lacey [13] experimentally studied the volumetric behavior for various mixtures of gas condensate samples which were collected from the San Joaquin Valley field. The correlation developed by them provided a relationship between the retrograde DPP and gas–oil ratio, temperature, and stock tank API oil gravity. The results obtained showed that the effect of temperature was minimal in comparison with the influence of modifying the compositions. Modification of the composition was undertaken by eliminating the intermediate components [39]. In 1950, Reamer [14] investigated existing correlations, with respect to higher gas–oil ratio samples by combining five different pairs of fluids from a typical field in Louisiana. In their study, the effect of temperature and gas–oil ratio on DPP was investigated. They concluded that the complexity of the effect of composition on DPP is the main reason for a lack of a global model for predicting DPP.

In 1952, Organick [15] studied the dew point pressure in condensate gas and volatile-oil mixtures. They introduced a simple correlation in the form of working charts which had an error of approxi-

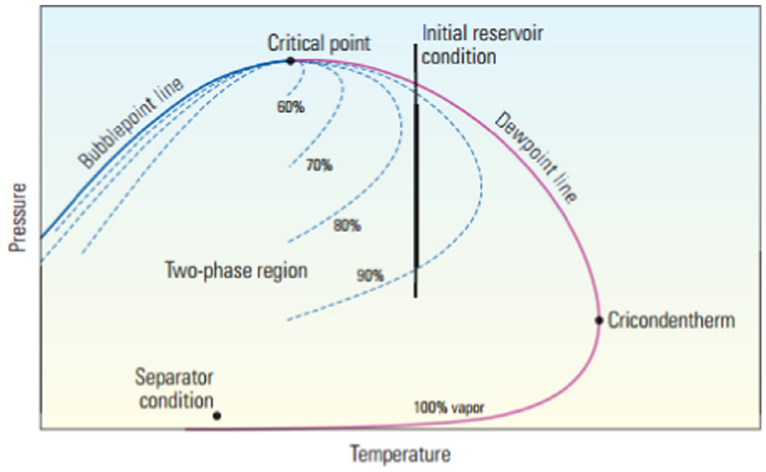

Fig. 1. A representative phase diagram of the gas condensate fluid [7].