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FULL LENGTH ARTICLE

Experimental studies on constant mass–volume depletion of gas-condensate systems

M. El Aily [b,*], **M.H.M. Khalil** [a], **S.M. Desouky** [b], **M.H. Batanoni** [b], **M.R.M. Mahmoud** [b]

[a] *Department of Chemistry, Faculty of Science, Ain Shams University, Cairo, Egypt*
[b] *Egyptian Petroleum Research Institute, Cairo, Egypt*

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Abstract This paper presents a new empirical model to estimate dew point pressure P_d for gas condensate reservoirs as a function of routinely measured gas analysis and reservoir temperature. The proposed model was developed based on field and laboratory PVT analysis data of 202 gas-condensate fluid samples representing different gas reservoirs and a wide range of gas properties and reservoir temperatures. Statistical error analysis was used to determine the accuracy of the model. The evaluation shows that correlation coefficient, average relative error (ARE), and average absolute relative error (AARE) are 0.9896, −1.1% and 2.58%, respectively. In addition, results of the proposed model were compared with those published in the literature and ensured its success for capturing the physical trend of gas-condensate systems, and consequently is considered as the most reliable one for the petroleum industry. The accuracy of the model has been also compared to the Soave Redlich Kwong equation of state (SRK-EOS) and the Peng Robinson equation of state (PR-EOS). Gas condensate samples have been used to check the validity of the proposed model against EOS.

1. Introduction

A gas-condensate fluid is a natural hydrocarbon mixture that is predominantly gas and has a critical temperature lower than the reservoir temperature and cricondentherm temperature, which identifies a state on the dewpoint boundary, higher than the reservoir temperature. For gas-condensate fluids, the complete process of isothermal retrograde condensation upon the decrease of pressure at reservoir temperature involves the sequence of states; a single phase, dewpoint, increase in the quantity of the liquid phase to a maximum followed by a decrease in the quantity to a second dewpoint, and finally the single phase sequence as relatively low pressures are reached [1].

It should be noted that there are two kinds of dew points with which an engineer is concerned. The first type, or normal dew point, usually occurs at low pressures as dry gas is compressed to the point where a liquid first forms. The second

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[*] Corresponding author. Tel.: +202 22747847; fax: +202 22747433.
E-mail address: mohamedelaily@yahoo.com (M. El Aily).

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type, sometimes called the retrograde dew point, occurs when a gas mixture containing heavy hydrocarbons in solution is depressurized until a liquid is formed. The first type, as applied to condensate mixtures, would normally be below the atmospheric pressure and would be of no interest in reservoir performance. The second type is of great importance for the reasons stated, and is referred to throughout this study without further qualification.

The pressure and temperature in the formation can be measured, but no reliable way, other than laboratory investigation, has been found to estimate the dewpoint pressure (P_d). Since laboratory investigation is laborious and expensive it is desirable to find a reasonably accurate method to predict P_ds from the composition and other readily available properties normally measured in the fluids.

In gas condensate reservoirs, the well-productivity often declines rapidly when the near-wellbore pressure drops below the dew point pressure. Radial compositional-reservoir simulation models are often used to investigate this productivity decrease. These models clearly show that liquid dropout around wellbore causes the productivity decrease. This ring of increased condensation saturation around the wellbore reduces the effective permeability to gas and results in rapid well-productivity decline. Therefore, it is very important to accurately determine the P_d for gas condensate reservoirs. The experimental determination of P_d at the reservoir temperature for gas condensate reservoirs is relatively time consuming, expensive and sometimes subject to many errors. Thus, there is a need for simple yet accurate methods of predicting the dew point of gas condensate reservoirs [2].

The empirical correlations, proposed in different forms (mathematical expression, graphical, or tabulated) for determining the dewpoint pressures of gas-condensate systems, are considered very limited in the literature. In addition, these correlations were developed based on gas-condensate fluid samples obtained from certain reservoirs of specific regions of the world. Due to varying compositions of gas-condensate fluids from reservoirs of different regions, different empirical correlations may provide unacceptable predictions of dewpoint pressures when they are applied to gas-condensate fluids behaving differently from the fluid samples on which they were developed. Most of these empirical correlations are strongly relating the P_d to the gas-condensate fluid composition. Therefore, there is a great interest to evaluate the accuracy of these empirically derived correlations relative to the experimental dewpoint pressure values for the gas-condensate systems.

Literature review indicates the existence of three types of equations: working charts, empirical correlations and equations of state.

2. Working charts

Sage and Olds; studied the behavior of reservoir fluids from the Paloma field and proposed tables for determining P_d. From the information obtained, the influence of composition on the P_d was determined. They found that removal of the intermediate molecular weight components from the mixtures resulted in a considerable increase in the P_d. Their results also indicate that the effect of change in temperature was relatively minor when compared with the effect of modifying the composition by removing the intermediate components. They also investigated oil and gas samples from San Joaquin Valley fields and developed plots for P_d determination. The P_d is a function of gas/oil ratio, temperature and oil API gravity. It was emphasized that this correlation was applicable to the very narrow range of variables covered in their investigation [3].

Kurata and Katz obtained experimental data on volatile hydrocarbon mixtures. Their investigation was to establish a correlation, which could be used to predict critical properties. Although they used 29 data points of P_ds no attempt was made to correlate them with composition [4].

Reamer and Sage attempted to extend the existing correlation to higher gas-to-oil ratio by studying combinations of five different pairs of fluids. Numerous diagrams depicting the effect of temperature and gas-to-oil ratio on P_d were presented. They concluded that, due to complexity of the influence of composition, it was doubtful that a useful correlation could be established [5].

Organick and Golding presented a correlation for predicting the saturation pressures for gas condensate and volatile oil mixtures. The correlation is given in the form of a set of 14 working charts, each comprising a family of curves, which cannot be readily adapted to computer. The correlation was developed from 214 experimental saturation points for gas condensates and volatile crude oil mixtures. They reported a probable error of about 8% for the gas condensate fluids used in their study. They also indicated that pure components and simple mixtures could not always be treated satisfactorily by their correlation. Therefore, if their correlation is used to predict the saturation pressure of a simple mixture of pure components, the predicted saturation pressure will generally be somewhat high [6].

Potsch and Braeuer proposed a novel graphical method for determining the P_d as a backup for visual readings of the total volume (gas and liquid) during a constant composition expansion and the Z-factor. The P_d is determined from a plot of the number of moles in the cell versus pressure. Graphical intersecting of the straight line in the one phase region with the curve in the two phase region yields the P_d. Although this method does not require a window or through-window cell, yet a high accuracy single Z-factor calculation routine is required. Although empirical correlations are simple yet accurate to some extent, but they have not been able to reliably duplicate the temperature behavior of constant composition fluids [7].

3. Empirical correlations

Nemeth and Kennedy developed a mathematical correlation relating the P_d of a hydrocarbon fluid to its composition, temperature and characteristics of the C_{7+} fraction. The correlation is listed in Appendix A. They used 579 data points of P_d (some were determined experimentally and others were collected from the literature) to develop an 11-coefficient correlation by multiple regression. The correlation covers a pressures range from 1270 to 10790 psia, and temperature from 40 to 320 °F [8].

Humoud presented an empirical correlation to predict the P_d of a gas condensate fluid from readily available field data (74 data sets). The correlation relates the P_d of a gas condensate directly to its reservoir temperature, pseudo-reduced pressure and temperature, primary separator gas oil ratio, the