



Mathematical modeling of gas-condensate mixture PVT-properties including presence of brine in reservoir



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ARTICLE INFO

Article history:

Received 22 July 2015

Received in revised form

11 September 2015

Accepted 11 September 2015

Available online 15 September 2015

Keywords:

PVT-Properties

Gas-condensate system

Huron–Vidal mixing rule

Three-phase equilibria

Equation of state

ABSTRACT

The article is considering a recent mathematical method of phase equilibria calculation of natural gas condensate systems taking into account the presence of brine in reservoir media. This method is based on a three-parameter Peng – Robinson (PR) cubic equation of state (EoS) and Huron–Vidal (HV) mixing rule.

The applicability of the PVT-modeling method is illustrated by comparison of the calculation results and experimental data by the examples of binary mixtures of water with methane, ethane, propane, n-butane, nitrogen, carbon dioxide and hydrogen sulfide. The new values of HV mixing rule parameters are proposed, allowing to improve the accuracy of phase equilibria calculation for binary mixtures of natural gas condensate systems component and water in a wide range of pressure and temperature.

A comparison of the results of engineering formulas (Bukacek method) based and a mathematical method (EoS and HV mixing rule) based calculations of hydrocarbon (HC) mixture water content was made.

The effect of the residual water presence on the gas condensate system phase behavior at reservoir development is evaluated on the base of constant volume depletion (CVD) test mathematical modeling with the application of the discussed method of phase equilibria calculation.

Examples of residual water presence effect on the PVT-properties of natural gas condensate systems distinguished by initial reservoir conditions, potential content of stable condensate (C₅₊) and mixture composition are considered.

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1. Introduction

Natural gas condensate hydrocarbon (HC) mixture contacts with mineralized water solution (brine) both in the form of residual water and edge and underlying waters in reservoir. Therefore, HC mixture can contain some water vapor at reservoir thermobaric conditions. Their concentration (water content) in the reservoir gas depends on pressure, mixture composition and water salinity [1,2].

Presence of brine in the collector pores has some influence on the phase behavior of HC systems and its PVT-properties at all stages of reservoir development and hence affect the dew point, a pressure of maximum condensation, condensate recovery factor and recovery of hydrocarbon components [3–5]. This point has a particular relevance for gas condensate systems with high initial

reservoir temperature [6].

The issue of the influence of residual water on PVT-properties of reservoir HC systems is considered in many sources on development of gas condensate fields [7,8]. The results of experimental researches of the water content of gas for binary systems “water – gas” [9,10] as well as for multicomponent systems [4] are introduced in literature. The example of the phase diagram for natural gas condensate system in the presence of water is presented in Fig. 1 [3]. Empirical formulas were developed to calculate water content of natural HC systems [2,11]. They are used extensively in engineering practice.

Mathematical methods accounting the presence of brine in a multicomponent mixture at PVT-properties of natural gas condensate systems modeling are based on the use of equations of state (EoS) [2,6,12] or the activity coefficients [13–15].

One of the advanced and convenient method for multiphase equilibrium modeling in the system “natural multicomponent HC mixture – brine” at the design and monitoring of the gas

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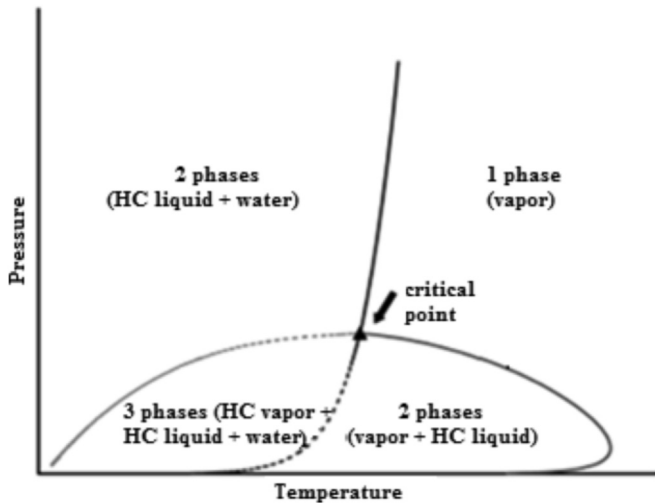


Fig. 1. Phase diagram of the system “reservoir gas condensate mixture – water” [3].

condensate fields development uses the EoS and Huron–Vidal (HV) mixing rule [16,17]. This method is included in the specialized PVT-simulators and is based on the joint application of EoS and activity coefficients.

2. Brine accounting in the modeling of phase equilibrium

The use of cubic EoS with classical mixing rule is based on the assumption of the random distribution of molecules in each phase. This assumption is not applicable for water or alcohol dissolved in HC phase, because their molecules have a polar structure. Traditionally, the activity coefficients (for example, UNIQUAC [14] or UNIFAC [15]) based models are used to describe such systems. Since these models work only at low pressures they are not applied for modeling the vapor–liquid equilibrium (VLE) at reservoir condition. Hence the various methods based on the EoS (Soreide and Whitson [6], Huron and Vidal [16], Kabadi and Danner [18] and others [19,20]) have been developed to describe the interaction between water molecules and other components of reservoir systems in a wide range of temperature and pressure.

3. Three-parameter Peng–Robinson equation of state

The method of phase behavior calculation based on the cubic three-parameter Peng–Robinson (PR) EoS [21,22], appears to be convenient and widely used. PR EoS has the following form:

$$p = \frac{RT}{v-b} - \frac{a}{v(v+b) + b(v-b)} \quad (1)$$

$$a = 0.45724 \frac{T_c^2 R^2}{p_c} \alpha, \text{ where } \alpha = \left[1 + m \left(1 - \sqrt{\frac{T}{T_c}} \right) \right]^2, \quad b = 0.0778 \frac{RT_c}{p_c}, \quad \bar{v} = v - c, \quad c = sb \quad (2)$$

$$\text{If } \omega \leq 0.49, \text{ then } m = 0.37464 + 1.54226\omega - 0.26992\omega^2 \quad (3)$$

$$\text{If } \omega > 0.49, \text{ then } m = 0.3796 + 1.485\omega - 0.1644\omega^2 + 0.01667\omega^3 \quad (4)$$

Critical pressure p_c , critical temperature T_c , acentric factor ω and shift–parameter s for light HC components (C_1 – C_5) and non-HC components (N_2 , H_2S , CO_2) are uniquely determined on the basis of experimental data, while for heavier HC fractions – by means of various correlations [22–24].

The main reason for the third parameter (c) input in the PR EoS is achievement of a higher accuracy of the density of the phases calculation at the given thermobaric conditions. It should be noted that accounting of parameter c of EoS does not affect the phase equilibrium calculation [2] because the correction to the molar volume is introduced after solving the problem of VLE and determining of a components mole fractions in phases. Therefore, c parameter is not used at the EoS solution, calculation of fugacity and equilibrium phases composition.

A more convenient form of the EoS (1) is written by means of Z-factor. Since $Z = pv/RT$ by definition, the PR EoS (1) can be written as follows:

$$Z^3 - (1-B)Z^2 + (A-3B^2-2B)Z - (AB-B^2-B^3) = 0, \quad (5)$$

$$A = \alpha \frac{p}{(RT)^2}, \quad B = b \frac{p}{RT} \quad (6)$$

We proceed to the multicomponent systems, since all natural HC systems consist of a variety of both HC and non-HC components. For multicomponent systems, parameter A is usually calculated by using the classical mixing rule, and B , c by using the linear one (additivity rule):

$$A = \sum_{i=1}^N \sum_{j=1}^N z_i z_j \sqrt{A_i A_j} (1 - k_{ij}), \quad B = \sum_{i=1}^N z_i B_i, \quad c = \sum_{i=1}^N z_i s_i b_i \quad (7)$$

A_i and B_i are calculated by Formulas (6), while a_i and b_i by Formulas (2) for each component, respectively.

Binary interaction parameters (BIP) k_{ij} are defined by correlations [25] or analytically [2] using experimental data.

The expression for the fugacity calculation of i -th mixture component has the following form for PR EoS and classical mixing rule:

$$\ln(\varphi_i) = \ln\left(\frac{f_i}{z_i p}\right) = \frac{B_i}{B}(Z-1) - \ln(Z-B) + \frac{A}{2\sqrt{2}B} \left(\frac{B_i}{B} - \frac{2}{A} \sum_{j=1}^N z_j A_{ij} \right) \ln \left[\frac{z + (1 + \sqrt{2})B}{z - (1 - \sqrt{2})B} \right] \quad (8)$$

where $A_{ij} = (1 - k_{ij}) \sqrt{A_i A_j}$.

With the use of the methods for determining the systems stability at the given thermobaric conditions [2,6,26], as well as algorithms of VLE calculation [2,6,27], we can estimate whether the system is homogeneous or heterogeneous state and determine the composition and PVT-properties of the coexisting phases.

4. Huron–Vidal mixing rule

Huron and Vidal have offered the method of phase equilibrium calculation in water containing systems [16], which is suitable for modeling VLE in gas condensate deposits reservoir engineering. They have combined methods of phase equilibria modeling based on the application of EoS and activity coefficients.

Huron and Vidal proposed the calculation of Gibbs free energy on the basis of non-random two-liquid (NRTL) model and with the use of cubic EoS in a certain way:

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