Considerations for the dew point calculation in rich natural gas

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ABSTRACT

Hydrocarbon Dew Point (HCDP) in natural gas processing is a key quality parameter and a critical consideration for pipeline operations. In the present paper, a comparison between equations of state approaches is presented by estimating HCDP in rich natural gas using different approaches, i.e. PR, SRK or GERG-2004 EoS. Further, a parameter comparison is performed discussing the impact on the accuracy of estimating HCDP in natural gas using the selected approaches. The following parameters are compared: binary interaction coefficients, C_{7+} characterization methods, critical properties for single-carbon number groups and mixing rules. A set of considerations is presented in order to guide users to choose the most accurate right method for calculating HCDP in natural gas.

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1. Introduction

Hydrocarbon dew point (HCDP) in natural gas is an important quality parameter written into tariffs from producers through transmission and distribution companies to final-end users.

HCDP is the temperature at which hydrocarbons condensates first begin to form when natural gas is cooled at a constant pressure. In many cases, avoiding formation of liquids in natural gas is of critical importance. For instance, in gas pipeline transmission the presence of liquid hydrocarbons in combination with traces of water leads to the formation of hydrates, which can cause a considerable damage to compressors and pipelines. Therefore, the accuracy of the HCDP estimation is of high importance for the operator in order to ensure a high integrity of their facilities and to provide best quality product.

There are different methods for HCDP measurement:

- Manual, visual technique with chilled mirror dew point meter: it is the simplest and most widely applied method of HCDP measurement. These instruments are used for periodic spot check measurements.
- Equation of state (EoS) calculation from extended gas chromatography (GC) analysis: GC commonly provides a composition analysis to C_{6+} hydrocarbons. The use of EoS to calculate the HCDP requires an extended analysis of individual heavy-end components present in the natural gas, since the variation in C_{10} and higher components has a significant effect on the HCDP.
- Automatic, optical condensation dew point meter: These instruments function on the principal of direct measurement of the temperature at which hydrocarbon liquids start to form on a chilled surface exposed to the gas sample to be measured.

HCDP measurement methods have strengths and weaknesses. Thus, they provide a direct, highly sensitive and repeatable measurement and no specialized training or skill requirements for operation and maintenance. The main disadvantage of these methods is the high initial investment. On the other hand, using EoS allows identifying components contribution and provides a theoretical phase envelope curve. However, this indirect method of determining HCDP relays on the correct application of the EoS being used.

The present paper provides guidelines to choose the EoS/correlation and associated parameters to calculate the HCDP in rich natural gas.

2. State-of-art review of HCDP calculation in rich natural gas

According to Kidnay et al. (2006), the rich and lean terms in natural gas refer to amount of recoverable hydrocarbons present. A lean gas will usually be 1 gal of hydrocarbons per mole (GPM) of natural gas; whereas a rich gas may contain 3 or more GPM. Typical

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ranges of C_{7+} molecular weights and volume fractions for rich gases are taken from Nasrifar and Bolland, 2005 and Elsharkawy (2001) works, being 106–253 and 0–0.19, respectively.

A state-of-art review of the main EOS and correlations for the determination of HCDP in rich natural gas is given in Section 2.1. Additionally, associated binary interaction coefficients, C_{7+} characterization methods and mixing rules are presented in Sections 2.2–2.4, respectively.

2.1. Equations of state (EOS) and empirical correlations

Cubic equations of state are usually used to predict natural gas dew points. Alternatively, some correlations have been developed for specific purposes, such as per HCDP in gas condensate. A literature review of the use of different primary EoS and empirical correlations for HCDP calculation in natural gas is presented in Sections 2.1.1–2.1.4.

2.1.1. Equations of state

Two different approaches of EoS have been used for HCDP estimation: Cubic equations of state (such as Soave-Redlich-Kwong and Peng-Robinson) and an equation based on a multi-fluid approximation explicit in the reduced Helmholtz Energy (GERG-2004).

2.1.1.1. Cubic equations of state.
According to Nasrifar and Bolland, 2005 specifically the Soave-Redlich-Kwong (SRK) and Peng-Robinson (PR) EoS are often recommended for HCDP calculation in natural gas. Both equations share the same form:

$$P = \frac{RT}{v - b} - \frac{a_c \alpha^2}{(v - b_1)(v - b_2)} \tag{1}$$

Where α for SRK and PR are defined as:

$$\alpha_{PR} = 1 + \left(0.37464 + 1.5422\omega - 0.26992\omega^2\right)\left(1 - \sqrt{T/T_c}\right) \tag{2}$$

$$\alpha_{SRK} = 1 + \left(0.480 + 1.547\omega - 0.176\omega^2\right)\left(1 - \sqrt{T/T_c}\right) \tag{3}$$

The attractive force parameter a_c and the repulsive force parameter b (co-volume) in Eq. (1) are a function of the critical properties and the acentric factor ω. The corresponding parameters of Eqs. (1)–(3) are summarized in Table 1.

In Table 1, T_c and P_c denote the critical temperature and pressure, respectively.

In multi-component mixtures, the attraction and repulsive force parameters a_c and b are modified by including the interactions between dissimilar molecules or binary interaction parameters. The source data for the attractive and repulsive force parameters a_c and b and the acentric factor parameter ω do not reveal uncertain information for these EoS, according to George (2007). However, the binary interaction parameters are valid in specific ranges of pressures and temperatures.

Table 1
Parameters for the Peng-Robinson and Soave-Redlich-Kwong EoS.

Equation	α_c	b	b_1	b_2
Peng-Robinson	$\frac{0.45724R^2T_c^2}{P_c}$	$\frac{0.07780RT_c}{P_c}$	$-b(1 + \sqrt{2})$	$-b(1 - \sqrt{2})$
Soave-Redlich-Kwong	$\frac{0.42748R^2T_c^2}{P_c}$	$\frac{0.08664RT_c}{P_c}$	$-b$	0

For the determination of the rich natural gas dew point, Nasrifar and Bolland, 2005 recommend the Patel and Teja EoS. In the Patel and Teja EoS, a third constant "c" into the van der Waals equation's attraction term is included. The equation allows the adjustment of the critical compressibility factor, improving the saturation property predictions for polar fluids:

$$P = \frac{RT}{v - b} - \frac{a_c(T)}{v(v + b)(v - b)c} \tag{4}$$

Zheng and Guo, 1997 demonstrated the accuracy of the Patel and Teja EoS to predict the phase behaviour of gas condensate by calculating the critical properties of the SCN-components with the Lee–Kesler correlations and by splitting the plus-fraction (pseudocomponent C_{7+}) with a gamma distribution function.

George (2007) evaluated the accuracy of several C_{7+} characterization methods and the use of SRK, PR and GERG-2004 EoS (refer to Section 2.1.1.2). As a result of his study, for the cases of richer gases and higher pressures, characterizations using lower carbon numbers can be used with SRK to predict accurate dew points. An adaptation of the Gaussian characterization method was recommended to describe the hydrocarbon distribution beyond hexane.

Haghtalab et al. (2011) presented a modified PR EoS (named PRM in this study) by including a new alpha function and a temperature dependent function for co-volume. The results obtained by using this equation shows that it can be successfully applied for calculating the vapour–liquid equilibrium of synthetic natural gas, mixtures and gas condensates. The formulation of the alpha and beta function and co-volume are the followings:

$$a = 0.45724\left(\frac{R^2T_c^2}{P_c}\right)\alpha(T) \tag{5}$$

$$b = 0.07780\left(\frac{RT_c}{P_c}\right)\beta(T) \tag{6}$$

$$\alpha(T) = \exp\left(1 - n^{\ln T_r}\right) \tag{7}$$

$$\beta(T) = 1 + m(1 - T_r) \tag{8}$$

Where:

$$n = 1.7309 + 1.6571\omega + 0.1554\omega^2 \tag{9}$$

$$m = 0.2476 - 0.8857\omega + 0.1900\omega^2 \tag{10}$$

By incorporating this new alpha function and the temperature dependant co-volume, this modified Peng-Robinson EoS allows accurately predicting the vapour–liquid equilibrium of the gas condensate mixtures.

In all previous works, simple mixing rules (Van der Waals) for the EoS are used.

2.1.1.2. GERG.
Kunz et al. (2007) developed the GERG EoS which is based on a multi-fluid approximation explicit in the reduced Helmholtz Energy. The Helmholtz Energy is a thermodynamic property dependant on gas composition, density and temperature; other fluid properties can be derived from the Helmholtz Energy using thermodynamic principles. The range of applicability of this EoS is shown in Table 2.