Journal of Petroleum Science and Engineering 149 (2017) 161–170

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

journal homepage: www.elsevier.com/locate/petrol

Linking fluid composition to black-oil properties

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ARTICLE INFO

Keywords:
Black-oil properties
Flash calculations
Reservoir fluid composition
Swollen mixtures

ABSTRACT

Field development studies require, among many other things, reliable estimates of fluid properties. In cases where experimental data is unavailable or incomplete, it is necessary to predict fluid properties using correlations, based on input variables such as temperature, API, saturation pressure, gas gravity, and flash GOR. However, there are situations when even these input variables are not known, and where the only information is the initial reservoir fluid composition.

The scope of the present work is to develop a predictive method which links the reservoir fluid composition to the input variables needed for the black-oil property correlations. The method is based on analysis of several experimental data sets comprising in total several hundred fluid compositions with associated black-oil properties as well as on isothermal flash calculations on 500,000 synthetic, but realistic, fluid compositions spanning a large range in compositional space. The aim of this work is therefore not to develop new correlations for oil compressibility, formation volume factors, viscosities etc. Rather, the contribution should be regarded as a novel way to incorporate reservoir fluid compositional information into an already existing framework for predicting fluid properties used for field development studies.

Results from the study show that it is possible to predict API, flash gas gravity, flash GOR and saturation pressure with reasonable accuracy for a large range of reservoir fluid compositions as long as the molecular weight of the plus fraction is known. The work sheds more light on the quantitative influence of individual component mole fractions on fluid properties.

1. Introduction

Accurate representation of fluid phase behavior can have a crucial impact on field development, regardless of the type of recovery process. The input parameters required to perform a black-oil reservoir simulation study consists of tabular data of phase properties versus pressure and can be provided by a number of laboratories around the world. However, it is not uncommon to be in a situation where a complete data set needed to conduct the study is not available, for a number of reasons:

1) The data was never measured
2) The data has been lost
3) The data quality is dubious, either due to sampling conditions or due to errors introduced during the laboratory experiments
4) The data set is incomplete
5) Reservoir fluid compositional data have been inferred from a downhole fluid analyzer and no further experiments have yet been performed

Many researchers in the past have developed correlations to predict fluid properties such as oil compressibility, formation volume factor, and fluid viscosity as well as gas phase properties. For details on some of the many industry-accepted methods, see Refs. Abdul-Majeed et al. (1990), Al-Khafaji et al. (1987), Al-Marhoun (2003), Aziz et al. (1972), Beal (1946), Beggs and Robinson (1975), Bennison (1998), Bergman (1992, 2000), Bergman and Sutton (2007), Chew and Connally (1959), De Ghetto et al. (1994), Egbogah and Ng (1990), Elsharkawy and Alikhan (1999), Fitzgerald (1994), Glasø (1980), Hall and Yarborough (1973), Kartoatmodjo and Schmidt (1994), Katz and Firoozabadi (1978), Kaye (1985), Labedi (1992), Lee et al. (1966), Naseri et al. (2005), Orbey and Sandler (1993), Petrosky and Farshad (1993, 1995), Riazi and Daubert (1980), Standing and Katz (1942), Standing (1981, 2000), Twu (1985) and Vazquez and Beggs (1980). These correlations are very useful, but are typically applicable only to the reservoir fluids on which the correlation parameters were tuned. Whitson and Brulé (2000) describe attempts made to include compositional effects of non-hydrocarbon components; however these models are correction factors to existing correlations and do not consider the entire reservoir fluid composition.

Common for all these correlations is that they require a number of black-oil input parameters, in addition to the reservoir temperature.

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http://dx.doi.org/10.1016/j.petrol.2016.10.035
Received 18 July 2016; Received in revised form 12 October 2016; Accepted 17 October 2016
Available online 20 October 2016

Situations may arise when one or several of these parameters are not available, and where laboratory or field measurements cannot be carried out within a reasonable time frame.

It is of course also possible to apply an equation-of-state (EOS) to predict fluid properties; however, it is generally acknowledged that EOS models require tuning to experimental data. Also, there may be circumstances where an EOS model is not readily available.

In this work, a framework is proposed to predict all the black-oil input parameters based on knowledge of the reservoir fluid composition and the molecular weight of the plus fraction. The framework is based on analysis of phase behavior data from a large, fluid database, supported by EOS-based calculations on a very large set of synthetically generated fluid compositions. The following sections will shed more light on the quantitative influence of individual component mole fractions on fluid properties.

2. Development of the new modeling framework

2.1. Data sources

In this study, establishment of a link between reservoir fluid composition and black-oil input parameters is based on analysis of phase behavior data coming from a number of sources:

1) Several hundred proprietary data sets from many different countries and with a large spread in fluid compositions; see Table 1. Only data from bottom-hole samples flashed to standard conditions are used in the analysis. The data will be referred to in some of the figures as Data Set 1 and Swelling Data Set 1.
2) Public-domain data sets such as the experimental data published by Jaubert et al. (2002). This data will be referred to in some of the figures as Data Set 2 and Swelling Data Set 2.
3) A large set of synthetic, but realistic, fluid compositions. Each major component up to C_6 is allowed to attain specific values as given in Table 2. Combinations yielding a sum larger than unity are discarded. For the remaining cases, the C_{7+} mole fraction is then back calculated so that the mole fractions sum to 100%. This approach results in generation of approximately 500,000 valid component combinations.

2.2. EOS-based phase behavior calculations

For each synthetic fluid component, an isothermal flash calculation is performed using the volume-shifted Peng-Robinson EOS (Ref. Peng and Robinson (1976)). Pure-component properties as well as default binary interaction coefficients are taken from Pedersen and Christensen (2007). The flash calculations are performed at ambient pressure and temperature and pose no problem for a simple and straightforward successive substitution algorithm involving solution of the Rachford-Rice equation (Ref. Rachford and Rice (1952)). Results from the flash algorithm include the vapor mole fraction as well as equilibrium K-values, defined as vapor phase composition divided by liquid phase composition for each component. Binary interaction coefficients are listed in Table 4.

Table 1
Range of component compositions in data sets.

	N_2	H_2S	CO_2	C_1	C_2	C_3	i-C_4	n-C_4
Min (%)	0.00	0.01	0.01	0.06	0.03	0.05	0.01	0.01
Max (%)	14.44	41.90	94.51	98.50	13.00	10.56	4.25	8.27
Avg (%)	0.91	4.20	3.78	52.09	5.72	4.35	1.10	2.24

Table 2
Combinations of nine component mole fractions used for generation of 500,000 synthetic data sets. The C_{7+} mole fraction is constrained to ensure that all mole fractions sum to 100%. Combinations where the sum of mole fractions exceeds 100% are discarded.

N_2	H_2S	CO_2	C_1	C_2	C_3	C_4	C_5	C_6
0.1	0.1	0.1	1	0.1	0.1	0.1	0.1	0.1
1	1	1	5	1	1	1	1	1
5	5	5	20	5	5	5	5	5
20	20	20	50	10	10	10	10	10
50	50	50	75	20	20			
		75	90					

2.3. Data analysis

The starting point for the analysis is the reservoir fluid composition, z, at single-phase conditions. Whether it is biased by mud contamination does not matter for the time being. When the reservoir fluid is flashed to ambient pressure and temperature conditions in the two-phase region, the composition of the equilibrium gas and equilibrium liquid is denoted x and y, respectively. x, y, z are related to each other via the vapor mole fraction, β, as follows:

$$z_i = \beta y_i + (1-\beta)x_i \quad (1)$$

The equilibrium composition of liquid and vapor, x and y, are calculated by introducing the equilibrium K-factors:

$$K_i = \frac{y_i}{x_i} \quad (2)$$

After some rearrangement, x and y compositions can be calculated as follows:

$$x_i = \frac{z_i}{1+\beta(K_i-1)} \quad (3)$$

$$y_i = K_i x_i \quad (4)$$

Eqs. (1)–(4) require knowledge of the vapor mole fraction, β, which is treated in the next section.

In all subsequent discussion, measured data come from proprietary data sources and the calculated data are generated from the workflow proposed in this paper based on reservoir fluid compositions from the proprietary data.

2.3.1. Step 1. Correlating the vapor mole fraction, β

The first step, which is one of the novel aspects of this paper, involves estimation of β based on z. It is reasonable to expect that the most volatile components, typically nitrogen and methane, may have

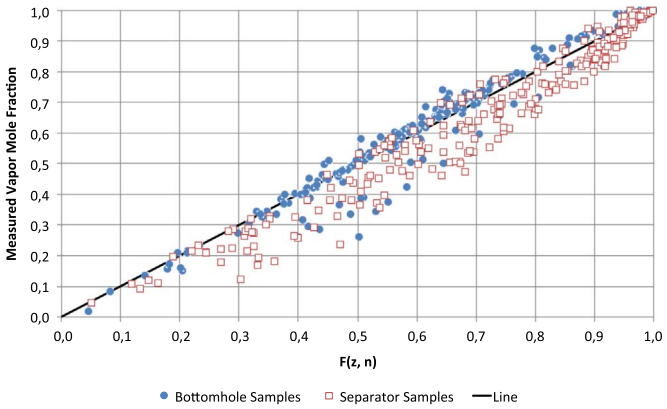

Fig. 1. Correlated and measured vapor mole fraction for bottom-hole samples. F(z, n) represents the composition-dependent function used to predict the vapor mole fraction and is defined in Eq. (6). Separator samples have been included only for visual purposes and have not been used in the data analysis.