

Effect of Characterization of C₇₊ and C₁₁₊ on the Prediction of PVT Properties of the Black Oil System

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ABSTRACT

Experimental data of PVT properties of some samples of black oil were obtained and matched with the prediction of equation of state. Effect of C₇₊ and C₁₁₊ on the saturation pressure, relative volume, density, vapour Z-factor and gas formation volume factor were determined. Splitting of C₇₊ and C₁₁₊ was also carried out. The effect of splitting of both types of heavy ends on the PVT properties mentioned above were also determined. It was found that characterized C₁₁₊ when used in equation of state gave better prediction of fluid properties than using C₇₊. It was found that splitting of C₇₊ into pseudo component gave better prediction of saturation pressure than C₁₁₊ into pseudo component. It was observed that when pseudocomponents of C₁₁₊ are used in equation of state gave more error in the prediction of saturation pressure, relative volume, density, gas Z-factor as compared to the C₇₊. It was also found that more the number of the pseudocomponent more will be error in the prediction of saturation pressure. Peng Robinson equation of state (PR EOS) was used to simulate constant composition expansion (CCE) and differential liberation (DL) experiments. It was observed that capability of PR EOS to simulate CCE experiment is better than the differential liberation experiment. The error analysis in the prediction of PVT properties mentioned above is also elaborated.

INTRODUCTION

Characterization of heavy ends has long been understood since 1935 when Watson gave the idea of the characterization factor. After that several attempts have been made to characterize the heavy ends. Most commonly used methods in the industry are Cavett, 1962; Standing, 1977; Robinson and Peng, 1978; and Ahmed et al. 1985. All these methods have a common feature which is the use of measurable physical

properties like boiling point, density and molecular weight of the C₇₊ fraction. These physical properties are used in different correlations to obtain critical properties of the heavy ends. Once the Heavy ends are characterized, equation of state (EOS) can be used to simulate the PVT properties of the fluid under study.

Due to the complex nature of the petroleum fluids, it is difficult to determine its composition completely. In the lab, usually hydrocarbon components above C₇ are lumped together as C₇₊ fraction. In some cases, PVT labs give compositional analysis upto C₁₁ or C₁₂ and components above are grouped as C₁₁₊ or C₁₂₊. To assign the properties to the heavy ends is known as characterization. The method of characterization of heavy ends greatly influence the prediction of the fluid's properties by equation of state (EOS) (Robinson and Peng, 1978; Ahmed, 1986; Ahmed, 1989; Pedersen et al. 1989; Khan, 1992; Khan, 1994). It is also the common practice in industry to split the heavy ends into pseudofraction or pseudocomponents for using in EOS. There is no clear information about the number of the pseudocomponents. The question is whether we need any splitting?. If splitting is performed, what will be the number of the pseudocomponents. Is there any difference in the use of C₇₊ or C₁₁₊ in the equation of state. These are the questions which need to be answered. In the following sections, an attempt is made to clarify some of the uncertainties mentioned above.

METHODOLOGY

Few samples of black oil were selected from different wells of Sono oil field and their PVT analysis were carried out by Core laboratories International Ltd, Abu Dhabi. All the samples were collected at bottom hole conditions. The experimental data of measured properties of the fluids like relative oil volume, gas formation volume factor, density and gas Z-factor were used as reference for the prediction of properties by PR EOS. Heavy ends C₇₊ and C₁₁₊ were characterized by Lee Kessler correlations (1975) and splitting of these heavy ends into pseudocomponents was carried out by using Whitson method (1983). For each property, C₇₊

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Table 1. Compositional analysis of sample 1.

Components	Mole %	Density (g/cc)	Mol.Wt
N2	1.56		
CO2	1.35		
CH4	16.61		
C2H6	4.13		
C3H8	5.19		
IC4H10	1.90		
NC4H10	3.53		
IC5H12	2.11		
NC5H12	2.68		
C6H14	4.54		
C7H16 (C7+)	6.96 (56.40)	0.834	176
C8H18	9.67		
C9H20	5.10		
C10H22	4.17		
C11H24	2.96		
C12+	27.54	0.873	232.3

and C₁₁₊ were used as characterized heavy ends in EOS. The predicted properties were matched with the experimental values. These characterized pseudocomponents were used simultaneously in the equation of state to predict the properties mentioned above and matched with the experimental results. In each case, error in percent for each property was calculated. The same procedure was applied in the C₁₁₊ fraction and error in percent was calculated in the prediction of each property. In the following sections, the effects of C₇₊ and C₁₁₊ as single fraction and their pseudocomponents on the different properties measured in PVT lab during differential experiments are described. The composition of fluids used in the study are shown in Tables 1, 2, and 3. Eclipse Version 92 is used for the simulation of the PVT properties of the fluid by 3-Parameter Peng and Robinson (1976) EOS. The equation is given in appendix. The interaction coefficients were not used in the prediction. These coefficients are not constant and vary from component to component in different fluids. Therefore, for error analysis, it is wise to use the existing equation without adjustment of any parameter. The predictions of the fluids 1, 2, 3 are performed at three different reservoir temperatures; 235°F, 255°F, 182°F respectively

EFFECT ON BUBBLE POINT PRESSURE

Bubble point pressure marks the boundary between saturated and under saturated reservoir, hence it becomes essential to measure this pressure in the lab. On the other hand, by incorporating composition of fluid in equation of state (EOS), this pressure can be predicted. The reliability of the prediction mainly depends on the composition of the fluids and particularly description of the heavy ends in EOS. The other factor is the temperature at which the prediction is being performed with respect to the critical temperature of the system (Khan et al. 1992). In this study, bubble point pressures of three different samples at three different temperatures were predicted and matched with the experimental values. The prediction is performed by using C₇₊ and C₁₁₊ as single characterized fractions and their pseudocomponents as well. The difference in the prediction of bubble point pressure by using different number of pseudocomponents are determined in terms of error %. It was found that by using C₇₊ as a single fraction, predicted bubble point pressure was higher than the experimental values. The maximum deviation from the experimental values in three samples was 12 to 28 psi. When two pseudocomponents are used, the deviation in the prediction reduces and matches with experimental values. By increasing the number of pseudocomponents C₇₊ after two, more error in the prediction of bubble point pressure was noticed. By incorporating C₁₁₊ as a single fraction, the prediction of bubble point pressure is less than the experimental values with maximum difference of 7 to 49 psi. By splitting the C₁₁₊ fraction into 2,3,4,5,6 pseudocomponents, more deviation in the predicted bubble point pressure was observed from the experimental values. The error in percentage increases by increasing the number of pseudocomponents. It shows that by splitting the heavy ends (C₁₁₊), no improvement in the prediction of bubble point pressure can be achieved. The effect of using both types of heavy ends and their pseudocomponents on the prediction of bubble point pressure of three samples is demonstrated in Figure 1(a,b,c).

EFFECT ON RELATIVE OIL VOLUME

Relative oil volume is another property of the reservoir fluid measured in the PVT lab. It is considered as equivalent to the oil formation volume factor. It is ratio of oil volume at certain pressure and reservoir temperature to the residual oil volume, measured in the differential

Table 2. Compositional analysis of sample 2.

Components	Mole %	Density (g/cc)	Mol.Wt
CO ₂	1.22		
N ₂	1.47		
CH ₄	16.79		
C ₂ H ₆	4.19		
C ₃ H ₈	5.22		
IC ₄ H ₁₀	2.39		
NC ₄ H ₁₀	4.14		
IC ₅ H ₁₂	2.25		
NC ₅ H ₁₂	3.15		
C ₆ H ₁₄	4.78		
C ₇ H ₁₆ (C ₇₊)	7.57 (54.4)	0.8329	188
C ₈ H ₁₈	11.05		
C ₉ H ₂₀	4.65		
C ₁₀ H ₂₂	4.92		
C ₁₁₊	26.21	0.876	270

experiment. When characterized single C₇₊ and C₁₁₊ fractions are used in the EOS, the predicted relative oil volume deviated from the experimental values with the maximum error of about 23 to 20 % respectively in three samples. When pseudocomponents of C₁₁₊ were used, the error % ranged from 10 to 20 % and it remained nearly same in respective sample. Generally, error % increases from higher pressure to low pressure and the predicted values are always higher than the experimental values. By using C₇₊ as single characterized fraction, 10 to 23 % error was calculated which is slightly higher than the previous case (C₁₁₊). By splitting C₇₊ into pseudocomponents, slight improvement was observed in the prediction. In this case the error % in the prediction of relative oil volume reduces with the number of the pseudocomponent. The effect of pseudocomponents on the prediction of relative oil volume is shown in Figure 2(a,b,c). In using C₇₊ fractions, the prediction of relative oil volume is always less than the experimental values. Generally the magnitude of error after using three pseudocomponents of both types of heavy ends (C₇₊ & C₁₁₊) is nearly same as demonstrated in Figure 2(a,b,c). It shows that more than two pseudocomponents have no significant contribution in the prediction of relative oil volume.

Table 3. Compositional analysis of sample 3.

Components	Mole %	Density (g/cc)	Mol.Wt
CO ₂	1.62		
N ₂	1.24		
CH ₄	16.61		
C ₂ H ₆	4.33		
C ₃ H ₈	5.01		
IC ₄ H ₁₀	2.37		
NC ₄ H ₁₀	3.99		
IC ₅ H ₁₂	2.85		
NC ₅ H ₁₂	2.70		
C ₆ H ₁₄	5.05		
C ₇ H ₁₆ (C ₇₊)	8.21 (54.23)	0.8310	182
C ₈ H ₁₈	10.77		
C ₉ H ₂₀	6.09		
C ₁₀ H ₂₂	5.01		
C ₁₁₊	24.15	0.8795	271

EFFECT ON Z-FACTOR

In differential liberation experiments, Z-factor of gas is determined at series of pressures. The EOS can be utilized for the determination of Z-factor. As this is compositional dependent property, by describing composition of the fluid in different ways in EOS, prediction of Z-factor can be different. In this study, effects of using different characterized heavy ends on the prediction of Z-factor were determined. By using C₇₊ as single fraction, error % in the prediction of Z factor range from 0.6 to 2.5 % in three samples. When pseudocomponents (2, 4, 6) of C₇₊ fraction are used, error % increases from 0.6 to 3 %. When C₁₁₊ as single characterized fraction was used in EOS, the error in the prediction was from 1.4 to 3.5 %. As a result of using pseudocomponents of C₁₁₊ fraction, slight increase in the error was observed. It was noticed that error % increases as one moves from high pressure to low pressure. It was found that use of C₇₊ fraction results in better prediction of Z-factor than C₁₁₊ fraction. On the other hand by use of C₁₁₊ fraction and its pseudocomponents in EOS, change in error % in prediction of Z-factor is nearly same from high to low pressure. The effect of different characterized fractions on the Z-factor is illustrated in Figure 3 (a, b, c).

EFFECT ON DENSITY OF LIQUID

In PVT labs usually density of the liquid phase is measured at various pressures during differential liberation experiments. Equation of state can be used for the prediction of density of liquid. Although density prediction by the EOS is not considered as more reliable (Ahmed 1986), never the less quick estimation can be obtained by the EOS and can be matched with experimental values. The reliability in the prediction of density of liquid can only be achieved when prediction and its error analysis is performed. Its prediction is also influenced by description of fluid in the EOS.

When characterized C₇₊ fraction was used in the EOS, the predicted values were higher than the experimental values with the error in the range of 5 to 8 % in three samples. By using two pseudocomponents of the C₇₊ fraction, error % in the prediction was reduced slightly. By using more than two pseudocomponents, no significant change in the prediction of density was observed. This shows that more than two pseudocomponents of C₇₊ fraction do not improve the prediction of density. By incorporating characterized C₁₁₊ as single fraction, the deviation of prediction from the experimental values was about 1.5 to 4.5 %. But by using its pseudocomponents the error increases from 1.5 to 3 % in one sample as shown in Figure 4(b). In other samples, no significant improvement in the prediction of density of liquid was noticed by using pseudocomponents of C₁₁₊ fraction. The effect of pseudocomponents of both types of heavy ends (C₇₊, C₁₁₊) are shown in Figure 4(a,b,c). The Figure 4 demonstrates that two pseudocomponents of both types of heavy ends when used in EOS, prediction of density is identical. The error % increases from high pressure to low pressure. This means that prediction of density at high pressure is more reliable than at low pressure. Generally it is seen that prediction of density at series of pressure is higher than the experimental data in differential liberation experiments.

The prediction of gas formation volume factor by describing heavy ends as C₇₊ and C₁₁₊ in differential liberation experiment at various pressure steps fully matched with the experimentally measured values as demonstrated in Figure 5.

In flash liberation experiments, the prediction of relative oil volumes using both heavy ends C₇₊ and C₁₁₊ fraction completely matched with the experimental values as shown in Figure 6.

CONCLUSIONS

Followings are the conclusions from the above study:

1. Bubble point pressure of black oil system can be predicted by EOS with certain degree of confidence either by using C₇₊ or C₁₁₊ as a characterized single fraction.

2. Two pseudocomponents of both heavy ends give nearly same prediction of bubble point pressure. More the pseudocomponents after two, more will be error in the prediction of bubble point pressure.

3. Error in the prediction of relative oil volume is nearly same using either by C₇₊ or C₁₁₊ characterized fractions. Splitting of the heavy ends into pseudocomponents slightly improves the prediction of relative oil volume.

4. Prediction of Z-factor is better by using C₇₊ fraction than C₁₁₊ fraction. More pseudocomponents result in more error in the prediction.

5. Prediction of density by using C₇₊ fraction is higher while by using C₁₁₊ fraction, prediction is less than the measured values. Use of two pseudocomponents of C₇₊ resulted improvement in the prediction of density. After two pseudocomponents, no significant change was observed.

6. Generally, it was observed that two pseudocomponents of heavy ends seem to be enough for the prediction of PVT properties of black oil system.

7. Prediction of gas formation factor in differential experiments agreed very well with measured values. Similarly, prediction of relative oil volume in Flash liberation experiments completely matched with measured values.

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APPENDIX

The modified 3 parameter PR EOS can be expressed as:

$$P = \frac{RT}{v+c-b} - \frac{a}{(v+c)^2 + 2b(v+c) - b^2} \quad (1)$$

$$a = 0.45724 R^2 T_c^2 / P_c \quad (2)$$

$$b = 0.07780 R T_c / P_c \quad (3)$$

$$c = 0.07780 R T_c / P_c \quad (4)$$

The parameters a, b, c are calculated for the individual components and for mixture as well. For mixture they are defined as below.

$$a_m = \sum_i \sum_j x_i x_j a_{ij} \quad (5)$$

$$b_m = \sum_i x_i b_i \quad (6)$$

$$c_m = \sum_i x_i c_i \quad (7)$$

In equation (5) a_{ij} is an empirically determined binary interaction coefficients characterizing the binary formed by component i and component j while m refers to the mixture.

NOMENCLATURE

- A, a = EOS parameters
- B, b = EOS parameters
- a_i & b_i = EOS parameters for calculating properties of component i
- a_m & b_m = EOS parameters for calculating the properties of mixture.
- P = pressure
- v = molar volume
- R = gas constant
- T = temperature
- P_c = critical pressure
- T_c = critical temperature.
- i, j = components
- x = mole fraction

