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Research Paper

A NEW TWO STAGES RECOMBINATION PROCESS FOR CRUDE OIL: SIMULATION AND EXPERIMENTAL APPROACH

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Many recombination techniques used in the literature are intended to reproduce the true saturation pressure of the reservoir at a given temperature, using gas from first stage separator and stock tank oil. A common procedure is to inject an excess amount of gas into the oil phase and then pressurize the system at constant temperature until obtaining a monophasic fluid. A differential liberation test is then performed at reservoir saturation pressure keeping the temperature constant so that the resulting liquid phase is taken to represent the reservoir live oil. Since composition of gas from the first stage separator is different to that of the reservoir, the resulting live has composition different in some extent to that of the monophasic fluid of the reservoir. In the first part of this paper, simulation results using compositional analysis data from two UAE live are presented. Simulation refers mainly to saturation pressure and flash calculations using a modified Peng-Robinson equation of state. In the second part of this paper a new and reliable method for recombination process of live oil is presented. This technique uses a two stage process where fresh gas from the first stage separator is injected in a PVT cell containing stock tank and the pressure increased until a monophasic system is obtained. Differential liberation is then performed reducing the pressure to reservoir saturation pressure at constant temperature. After removing the resulting gas phase, new fresh gas is injected and the differential liberation is again performed. Saturation pressure of the resulting liquid phase is then measured and compared to experimental and simulation results. Results show that the two stage recombination process produces a crude oil with composition and saturation pressure close to that of the reservoir.

Keywords: Recombination process, Live oil, Experiments, Thermodynamics modeling

INTRODUCTION

Obtaining representative reservoir fluid samples has become of increasing importance in the

development and exploitation of oil and gas condensate reservoirs. This is especially true of reservoirs where extensive computer simulations

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are used to scope out developmental strategies or where enhanced oil recovery options are investigated. Often times these decisions are based on properties measured on relatively small fluid volumes produced from the reservoir at one point in time. Therefore, it is imperative that the fluid samples used to make these decisions closely match the characteristic properties of the reservoir fluids at actual reservoir conditions. Representative fluid samples can usually be obtained from producing reservoirs at either surface or subsurface locations. Surface samples are removed at either the separator or at the wellhead, with the associated gas and liquid subsequently recombined in proportions to represent the actual reservoir fluid. Subsurface samples are removed from within the wellbore at actual reservoir conditions using bottom hole sampling tools and techniques. The suitability of the particular sampling technique will depend on a large number of factors which may include economic considerations such as the cost of sampling and associated loss of production, the type of surface facilities that are available, the fluid volumes that will be required and the type of reservoir and fluid to be sampled. Due to the difficulty and costs of bottom hole samples, a common way to obtain a live is to synthesize a reservoir fluids sample whose composition and bubble point is consistent with available PVT well data making these viable as representative of the reservoir oil. Thus, recombination is needed to reproduce as close as possible the reservoir fluid composition needed for both the PVT and core flooding tests. Equation of State modeling can be particularly useful to evaluate the quality of the surface samples and provide a method of recombining phases in order to predict overall phase behavior at reservoir conditions. In

instances where the entrainment of disassociated phases is suspected, the Equation of State can be a valuable tool to determine if the separator gas collected is representative of the evolved reservoir solution gas. In order to determine whether the separator gas and liquid could be used to recombine a representative sample of the in situ liquid an equation of state was used simulate the reservoir fluid. Based on the original compositional analysis of the bottom hole sample an EOS model can be tuned to fit the original bubble point pressure at reservoir conditions. Once the EOS had been tuned to match the original reservoir conditions, the oil is then partially depleted to current reservoir conditions and then flashed to the present separator conditions. In most cases, bottom hole sample are now available.

COMPOSITIONAL ANALYSIS COMPARISONS

Gas from first stage separator and stock tank oil whose compositions were performed by a commercial service provider were recombined at several molar ratio and the compositions of resulting monophasic fluid (RO) were compared of those of two UAE reservoir fluids called (B_1 and B_2). The compositional analysis of these samples are shown in Tables 1 and 2 The global composition of component i in the monophasic fluid is obtained through a global material balance as shown in Equation 1.

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

where β represents the vapor molar ratio, and y_i and x_i are the mole fractions of component i in the vapor and liquid phase, respectively. For B_1 and B_2 , the values of β , y_i , and x_i were obtained by flashing the monophasic fluid from well

condition to standard temperature (60°F) and pressure (14.696 psia). The resulting gas and liquid phase were then analyzed by chromatography. For the RO chart, the values of x_i and y_i were obtained by chromatographic analysis of stock tank oil and gas from the first stage separator, respectively. Results are shown in Figures 1 and 2. In these figures, the molar ratio of vapor phase (number of mol in vapor by the total number of mols) for the RO sample is varied in order to obtain a monophasic fluid with composition similar to those B₁ and B₂.

For obtaining the monophasic fluid of the RO sample, two molar ratio (β) of vapor phases are used. Figures 1 and 2 show the comparison of monophasic fluid composition of the three samples

A comparison of these Figures shows that the compositions of monophasic fluid (RO) does not satisfy the reservoir fluid compositions represented by B1 and B2, especially for the methane composition (Figure) 1 and for the C₂ to C₆ composition (Figure 2).

To evaluate the effect of composition change using this technique, we perform simulations of PVT properties of the different samples. Simulations task refer mainly to use a modified Peng Robinson equation of state to perform saturation pressure and flash calculations.

The modified Peng-Robinson Equation

The value of Z_c of hydrocarbons from the PR (Peng-Robinson) EOS ($Z_c=0.307$) is a significant improvement over that others cubic equation of state (RK, SRK), and consequently, the PR equation predicts the liquid density significantly better. However experimental values of Z_c for hydrocarbon are less than 0.29.

A third parameter, usually referred as c or volume shift parameter, was then introduced through the following relation (McCain, 1990):

$$v^{(3)} = v^{(2)} - \sum_{i=1}^{nc} x_i c_i \quad \dots(2)$$

where $v^{(3)}$ is the corrected third parameter volume and $v^{(2)}$ is the volume predicted by the two parameter equation. The shift in volume leads to reduction of Z factor. The values of c_i are commonly calculated comparing the observed liquid molar volume at standard condition of temperature (T_{st}) and pressure (P_{st}) with that obtained by the three parameter EOS at the same

Figure 1: Comparative Compositional Analysis of B₁ and RO. The Molar Ratio of the Vapor Phase is Fixed at 0.54 for RO

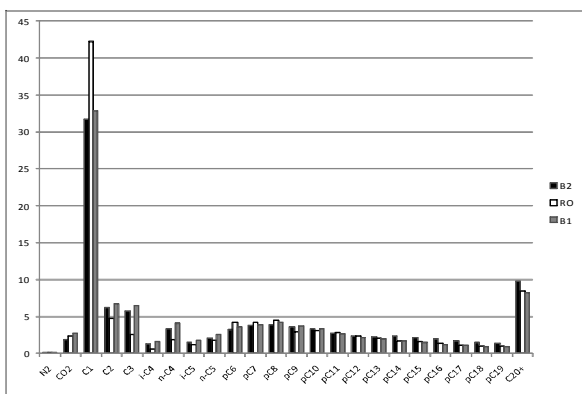


Figure 2: Comparative Compositional Analysis of B₂ and Recombined Oil. The Molar Ratio of the Vapor Phase is Fixed at 0.42 for Project

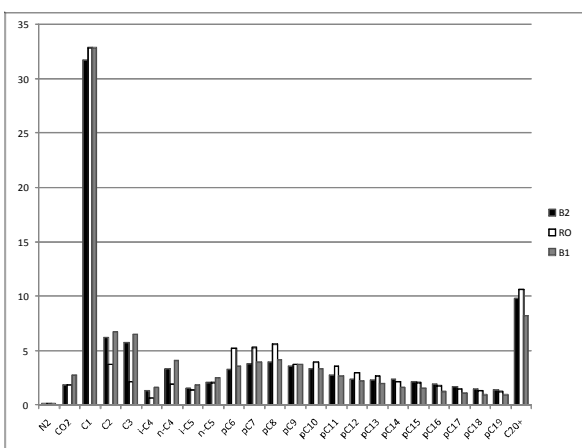


Table 1: Compositional Analysis of Sample B₁			
Compound	Liquid (mol%)	Gas (mol%)	Monophasic fluid (mol %)
N ₂	0.00	0.18	0.10
CO ₂	0.03	4.86	2.74
C ₁	0.08	58.58	32.86
C ₂	0.25	11.73	6.68
C ₃	1.05	10.72	6.47
i-C ₄	0.57	2.39	1.59
n-C ₄	2.06	5.62	4.05
i-C ₅	1.73	1.88	1.81
n-C ₅	2.90	2.24	2.53
pC ₆	6.56	1.27	3.60
pC ₇	8.42	0.43	3.94
pC ₈	9.33	0.09	4.15
pC ₉	8.49	0.01	3.74
pC ₁₀	7.61	0.00	3.35
pC ₁₁	6.13	0.00	2.70
pC ₁₂	5.00	0.00	2.20
pC ₁₃	4.50	0.00	1.98
pC ₁₄	3.74	0.00	1.64
pC ₁₅	3.41	0.00	1.50
pC ₁₆	2.79	0.00	1.23
pC ₁₇	2.42	0.00	1.06
pC ₁₈	2.15	0.00	0.95
pC ₁₉	2.04	0.00	0.90
C ₂₀₊	18.75	0.00	8.24
Molar ratio of vapor (β)		0.56	

Table 2: Compositional Analysis of Sample B₂			
Compound	Liquid (mol%)	Gas (mol%)	Monophasic fluid (mol %)
N ₂	0	0.23	0.12
CO ₂	0.01	3.58	1.86
C ₁	0.06	61.09	31.69

Table 2 (Cont.)			
Compound	Liquid (mol%)	Gas (mol%)	Monophasic fluid (mol %)
C ₂	0.15	11.80	6.19
C ₃	0.6	10.54	5.75
i-C ₄	0.37	2.24	1.34
n-C ₄	1.38	5.23	3.37
i-C ₅	1.36	1.65	1.51
n-C ₅	2.27	1.92	2.09
pC ₆	5.51	1.14	3.25
pC ₇	7.31	0.46	3.76
pC ₈	8.08	0.11	3.95
pC ₉	7.42	0.01	3.58
pC ₁₀	6.96	0.00	3.35
pC ₁₁	5.73	0.00	2.76
pC ₁₂	4.92	0.00	2.37
pC ₁₃	4.77	0.00	2.3
pC ₁₄	4.94	0.00	2.38
pC ₁₅	4.42	0.00	2.13
pC ₁₆	4.01	0.00	1.93
pC ₁₇	3.49	0.00	1.68
pC ₁₈	3.05	0.00	1.47
pC ₁₉	2.81	0.00	1.35
C ₂₀₊	20.38	0.00	9.82
Molar ratio of vapor (β)		0.52	

conditions. The difference determines the c_i for component i .

$$c_i = v^{EOS}(P_{st}, T_{st}) - v^{OBS}(P_{st}, T_{st}) \quad \dots(3)$$

The shift parameter are usually defined as a ratio

$$s_i = \frac{c_i}{b_i} \quad \dots(4)$$

where b_i is the EOS parameter for the pure component as defined above.

The volume shift correction has no effect on the isofugacity condition and thus the other predicted values like the saturation pressure and K values still unchanged.

Application of EOS in fluid mixtures requires a mixing rule to obtain the mixture parameters from the pure components ones. For

Table 3: Compositional Analysis of Sample RO

Compound	Liquid (mol%)	Gas (mol%)
C ₃	0.50	4.32
i-C ₄	0.54	0.76
n-C ₄	2.11	1.65
i-C ₅	2.09	0.47
n-C ₅	3.21	0.53
pC ₆	8.72	0.42
pC ₇	9.02	0.09
pC ₈	9.65	0.02
pC ₉	6.41	0.01
pC ₁₀	6.78	0.00
pC ₁₁	6.10	0.00
pC ₁₂	5.06	0.00
pC ₁₃	4.55	0.00
pC ₁₄	3.71	0.00
pC ₁₅	3.50	0.00
pC ₁₆	2.97	0.00
pC ₁₇	2.45	0.00
pC ₁₈	2.22	0.00
pC ₁₉	2.10	0.00
C ₂₀₊	18.29	0.00

hydrocarbon system the van der Waals mixing rules are commonly used

$$a = \sum_{i=1}^n \sum_{j=1}^n x_i x_j a_{ij} \quad \dots(5)$$

$$a_{ij} = \left[(a_i a_j)^{0.5} \right] (1 - k_{ij}) \quad \dots(6)$$

$$b = \sum_{i=1}^{nc} x_i b_i \quad \dots(7)$$

The k_{ij} are usually referred as Binary Interaction

Parameters (BIC) and are usually calculated tuning the EOS with experimental K values. For hydrocarbon systems the BIC are commonly set to zero, except for interaction between non hydrocarbon and hydrocarbon and between light and heavy hydrocarbon.

An alternative method for evaluating BIC was proposed by Cheuh and Prauznitz (1968):

$$k_{ij} = A \left[1 - \left(\frac{2(v_{ci} v_{cj})^{1/6}}{v_{ci}^{1/s} v_{cj}^{1/s}} \right)^B \right] \quad \dots(8)$$

where v_{ci} is the critical molar volume of the component i. The value of B is commonly fixed to 6 and the coefficient A is adjusted to match measured saturation pressure of the mixture. In this work BIC were calculated by tuning the PR equation to K-values from the differential liberation tests reported for sample B₁ and B₂, and using the Cheuh-Prausnitz Equation for HC-HC binary interaction coefficients. The phase behavior package, PVTi, from Schlumberger which includes the Peng-Robinson EOS with its modifications as described above, was used. At this stage, and prior to the experimental runs, these represent the most accurate descriptions available of the reservoir fluid. It is expected that, based on the experimental results, further tuning of the EOS will be possible, and especially to the CO₂-hydrocarbon binary interaction coefficients (HC-CO₂ BIC).

EOS Tuning

Experimental saturation pressure value of B1 is used to tune the EOS. For this purpose the B parameter in Equation 8 is chosen as regression variable instead the critical pressure of C₂₀₊ fraction. Since correlations for critical pressure are in general less accurate than correlation for

Table 4: Saturation Pressure Data

Sample	Vapor Molar Ratio	Temperature (K)	Saturation Pressure (MPa)		
			Experiment	PR 1	PR2
B ₁	0.56	398	16,40	14.34	16.40
B ₂	0.52	386	15.70	13.35	15.83
RO	0.42	398	15.97	13.37	15.96
RO	0.42	386	15.72	13.01	15.68
RO	0.46	398	18.10	15.12	18.07
RO	0.46	386	17.82	14.73	17.78

critical temperature, the critical pressure of the heavy fraction is commonly used as regression variable for many crude oil properties calculations. The main limitation of using critical pressure of the C₂₀₊ fraction still on the fact that this procedure is poor for extrapolation to other samples, in contrast to the B parameter in Equation 11.

The EOS tuned using B1 sample is then used to predict saturation pressure of sample B₂. Finally the saturation pressure of the two RO samples showed in Figure 1 and 2 and referred as RO1 and RO2, are predicted using the same approach. Results are shown in Table 3.

In Table 4 PR1 and PR2 refer respectively to the PR EOS without tuning the BIC to saturation pressure data and the PR EOS after tuning

From Table 4 one can see that the use of the modified Peng Robinson equation of state with BIC calculated from the Chueh-Prausnitz equation leads to satisfactory saturation pressure calculations. In a next stage flash simulations were done in sample B1 and B2 using the modified Peng-Robinson. For this purpose the monophasic fluid is flashed to standard conditions (288 K and 0.1 MPa). The resulting phase compositions are then compared to experimental data as showed in Figure 3 to 7.

From Figures 3 to 6 one can see that the modified Peng Robinson EOS can describe satisfactorily the liquid and vapor compositions resulting from flash of samples B₁ and B₂. To obtain a recombined oil similar to that of the reservoir, the stock tank oil is combined with gas from a the first stage separator using gas molar

Figure 3: Flash Simulation Result for the B₁ Liquid Phase

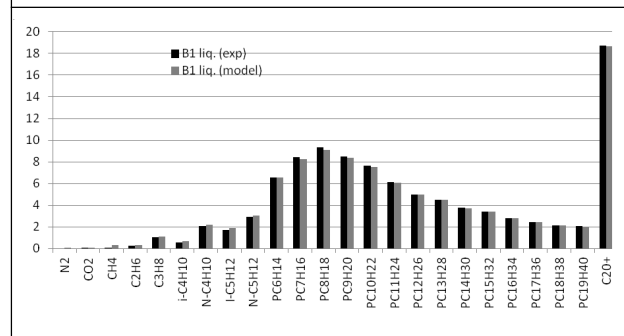
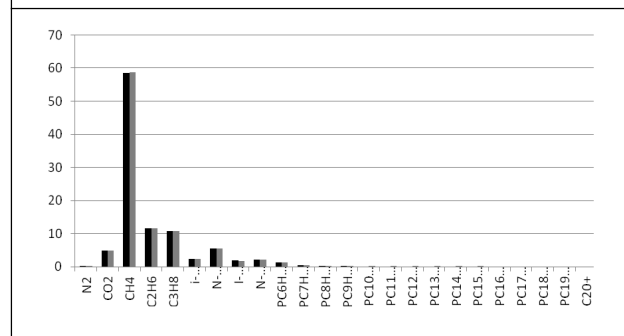
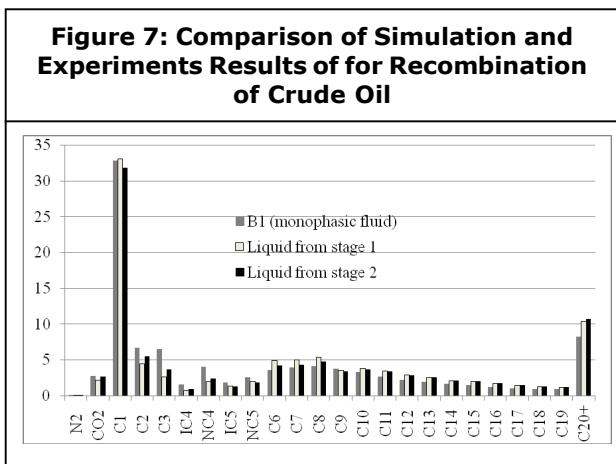
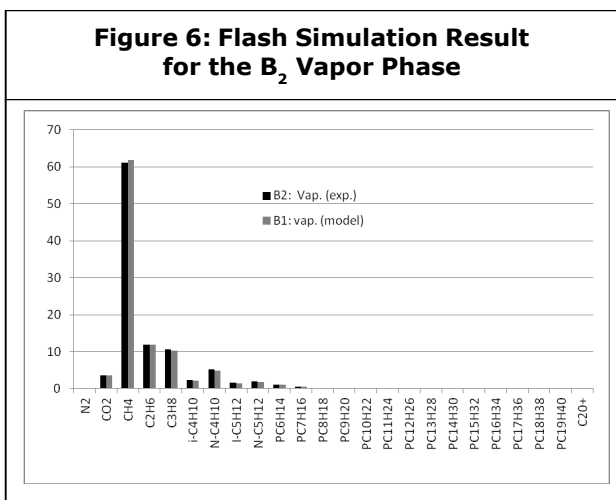
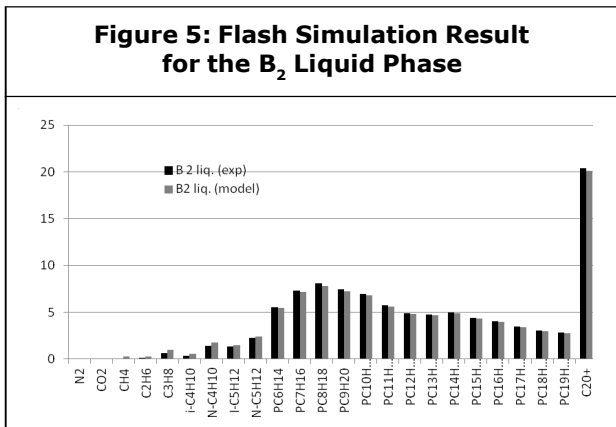


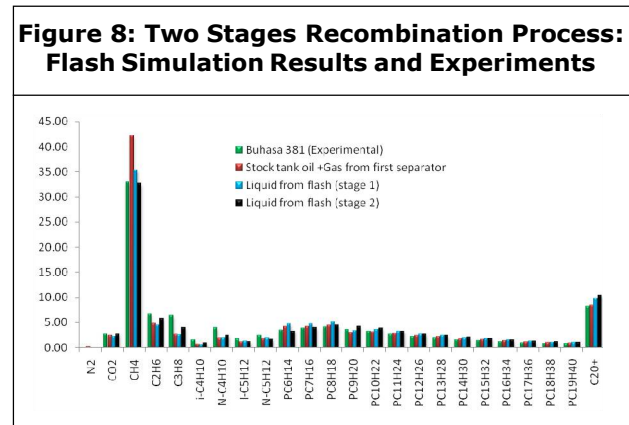
Figure 4: Flash Simulation Result for the B₁ Vapor Phase





ratio equal to 0.54. The resulting fluid is pressurized to obtain a monophasic fluid phase and then flashed to 1,64 MPa bar at constant temperature. A differential liberation is then performed to remove the gas phase. The liquid phase is then combined with gas from the first

stage separator using the same molar ration and a differential liberation test is taken to represent the reservoir fluid. To check the accuracy of this method, flash calculations are performed using the same scheme described above. Results are presented in Figure 8.



CONCLUSION

A suitable two stages recombination process was carried out in this work. Results shows that the modified Peng Robinson EOS with the Chueh-Prausnitz equation for binary interaction parameter present a good performance in correlating saturation pressure and flash data of crude oil. Thus this process represents a significant improvement in relation to the commonly used process and is less costly than the bottom hole sampling technique.

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