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Reservoir Fluids Model for a Middle Eastern Sandstone Reservoir

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Abstract

Knowledge of the properties of reservoir fluids are very important in petroleum reservoir engineering (e.g. estimation of reserves in an oil reservoir, well test inflow performance calculations, and numerical reservoir simulation). The process of obtaining accurate values for these physical properties for hydrocarbon is most important in different oil industries. The main resource to get these properties is laboratory measurements but in many cases these measurements not available, thus other methods can be used to estimate these properties. This paper concerns with the prediction of the phase behavior and physical properties for a Middle Eastern sandstone reservoir by using multiphase equilibrium and properties determination program. Soave-Redlich-Kwong Equation of State & Peng-Robinson's Equation of State and its modifications have been used to calculate the physical properties of reservoir fluid. To do so, each laboratory experiment was first simulated with the cubic Peng Robinson EOS without performing any regression and compared to the laboratory observations (PVT) as primarily results. Then splitting and lumping processes were used to tune or characterize the EOS so that it can reproduce the PVT experiments. The calculated PVT properties from these two steps are compared with the measured PVT data and the results show that the splitting and lumping processes given a good accuracy in predicting the PVT properties of the sandstone reservoir.

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1. Introduction

Reservoir fluid properties form one of the many bases in petroleum engineering calculations. The evaluation of oil and gas reserves, fluid flow through porous media, multiphase flow in pipe, surface and subsurface equipment design, and production system optimization are dependent strongly on reservoir fluid physical properties. Those properties may be measured experimentally in a PVT (pressure-volume-temperature) laboratory or they may be estimated by using empirical correlations. The most accurate method for determining the behavior of these fluids is a laboratory PVT analysis; however, the evaluation of exploratory wells and the advanced design of equipment often require an estimate of the fluid behavior prior to obtaining a representative reservoir sample. Also, experimental data is often unavailable in reservoirs which do not warrant the cost of an in-depth fluid study.

Reservoir engineering techniques are applied to improve the understanding of the reservoir performance and fluid properties. The process includes the calibration of an EOS to describe the phase behavior of the reservoir fluid; input data tables for PVT fluid properties and rock-saturation dependent properties such as relative permeability; the initialization of the simulation model to assess the volume of the original hydrocarbon in place; and the history match to test the validity of the simulation model and prepare the model to predict future reservoir performance.

Last six decades, engineers realized the importance of developing and using empirical correlations for PVT properties. Studies carried out in this field resulted in the development of new correlations and by an equation of state (EOS) express**.**

The earliest study of behavior of ideal gas as a function pressure (P), specific or molar volume (V) and the temperature (T) have been given by an equation of state (EOS) express by a simple form **(1):**

$$PV=RT \quad \ldots\ldots 1$$

The above equation depends on two major assumptions:

- The volume of the gas molecules is insignificant compared to both the volume of the container and distance between the molecules.
- There are no attractive or repulsive forces between the molecules or the walls of the container.

Van der Waals (1873) **(2)** attempted to eliminate these two assumptions in developing an empirical equation of state for real gases. The attempt to eliminate the first assumption, van der Waals pointed out that the gas molecules occupy a significant fraction of the volume at higher pressures and proposed that the volume of the molecules, denoted by the parameter *b*, be subtracted from the actual molar volume, *V*, in above equation, which will be giving:

$$P=RT/(V-b) \quad \ldots\ldots 2$$

Where the parameter (*b*) is known as the co-volume and considered to reflect the volume of molecules. The variable (*V*) represents the actual volume in (ft^3 per1mole) of gas. To eliminate the second assumption, van der Waals subtracted a corrective term, denoted by (a/V^2) from this equation to account for the attractive forces between molecules. In a mathematical form, van der Waals proposed the following expression:

$$P=\frac{RT}{V-b}-\frac{a}{V^2} \quad \ldots\ldots 3$$

Many attempts have been made to develop an equation of state for the real fluids.

Clausius (1880) (3) has modified the Van der Waals equation of state to improve the accuracy, in the following form:

$$P = \frac{RT}{(V-b)} - \frac{a}{TV^2} \quad \text{……………………………………………………………………...4}$$

Beattie and Bridgemen (1927) (4) presented an equation of state with five constants. The Beattie – Bridgemen equation of state is for a single component system and it is as follows:

$$P = \frac{RT}{V^2}\left[1 - \frac{c}{V^3 T^3}\right]\left(V + B_0\left\{1 - \frac{b}{V}\right\}\right) - \frac{A_0\left(1 - \frac{a}{V}\right)}{V^2} \quad \text{……………………………..……..5}$$

Where (A_0, B_0, a, b and c) are empirical constants defined for each pure gas.

Bendict, Webb and Rubin (BWR) (1940) (5) proposed another equation of state with eight constants in the following form:

$$P = \frac{RT}{V} + \frac{B_o RT - A_o - \left(\frac{C_o}{T^2}\right)}{V^2} + \frac{bRT - a}{V^3} + \frac{a\alpha}{V^6} + \frac{c}{T^2 V^3}\left(1 + \frac{\gamma}{V^2}\right)\exp\left(\frac{-\gamma}{V^2}\right) \quad \text{……………..………..6}$$

This equation may be considered a modification of Beattie – Bridgemen equation of state. Where (A_0, B_0, C_0, a, b, and c) are empirical constants defined for lighter hydrocarbon. Many investigators have attempted to generalize this equation of state. Among them Starling and Han (6) have accomplished the most well-known and successful generalization of the (BWR) equation of state by extended it to 11 constants.

2. Methodology

2.1. PVT model

In this paper, WinProp simulator, the multiphase equilibrium and properties determination program(7) , has been adopted to develop APVT model for predicting the reservoir fluid properties for selected sandstone reservoir in a middle eastern oil field . This simulator uses two equation of state for prediction of different reservoir fluid properties these are; Soave-Redlich-Kwong Equation of State & Peng-Robinson's Equation of State and its modifications.

WinProp is CMG's equation of state multiphase equilibrium property package featuring fluid characterization, lumping of components, matching of laboratory data through regression, simulation of multiple contact processes, phase diagram construction, solids precipitation, and more. Laboratory experiments considered in WinProp include recombination of separator oil and gas, compressibility measurements, constant composition expansion, differential liberation, separator test and constant volume depletion.

WinProp can be used to analyze the phase behavior of reservoir gas and oil systems, and to generate component properties for CMG's compositional simulator GEM**.** WinProp contains a graphical interface which allow to prepare data, run the phase property calculation engine, view the output with an editor, and create plots with Excel.

2.2. Fluid Properties and Equation-of-State Characterization

The crude of the selected sandstone reservoir is a light oil with a stock tank gravity of 30.5°API and an initial GOR of 809.94 scf/stb. Bubble point pressure is 2804 psi and initial reservoir pressure is 6059.77 psi at a reference depth of 3750 m and 235.94 °F. Table (1) shows the fluid composition.

Table 1. Original Reservoir fluid composition in

Component	**Mole fraction**
Co_2	0.0043
N_2	0.0064
C_1	0.3292
C_2	0.0866
C_3	0.0440
ic_4	0.0160
nc_4	0.0580
ic_5	0.0140
nc_5	0.0218
C_{6+}	0.4197
SUM	1.0000

Where:

C_{6+} Molecular weight:	210
C_{6+} Density @ 60 °F, g/cm^3:	0.8814

An essential part of a compositional reservoir simulation of a miscible EOR method is the prediction of the complex phase equilibria during EOR processes. The objective of the fluid study was to tune an EOS that would reproduce the observed fluid behavior and production characteristics seen in field operations and to predict the CO_2, natural gas/oil phase behavior in the compositional simulation. Cubic EOS have found widespread acceptance as tools that permit the convenient and flexible calculation of the phase behavior of reservoir fluids.

They facilitate calculations of the complex behavior associated with rich condensates, volatile oils and gas injection processes[(8)].

In this paper many equations of state have been tested such as Peng Robinson, Soave-redlich-kwong and its modification to obtain the best match for PVT properties. However, the Peng Robinson EOS was chosen to generate the EOS model because it gives the best agreement for measurement data and bubble point pressure for the selected reservoir. The viscosity model considered to match the oil viscosity of the reservoir fluid was the Pedersen Corresponding States model, which is a predictive model for gas or liquid viscosity.

In this paper, PVT laboratory sample data of the sandstone formation has been used in the tuning of the EOS. These data includes differential liberation (DL) experiments and constant composition- expansion (CCE). Table (2) lists the experiments and the measured parameters imported to the developed PVT model.

Table 2. PVT Experimental Data

Reservoir Fluid Composition	Mole fractions, C6+ density and molecular Weight (Table 4.1)
Constant Composition Expansion	Relative volumes, saturation pressure, oil Density, oil compressibility and oil viscosity
Differential Liberation	GOR, relative oil volume, gas *Z* factor, oil SG, gas SG, gas FVF

3. Results and Discussion

3.1. Preliminary Results by the Basic EOS.

Each laboratory experiment was first simulated with the cubic Peng Robinson EOS without performing any regression and compared to the laboratory observations (PVT). The preliminary results after the simulation were good, demonstrating that the behavior of the fluid was being reproduced with a basic (not yet tuned) EOS; however, some experiments were not fully matched. This was a clear indication that the parameters of the EOS should be adjusted in order to reproduce the behavior of the reservoir fluid.

The statistical accuracy between measured and preliminary results of Constant composition Expansion and Differential Liberation data are shown in Tables (3) and (4) respectively. Figures (1) and (2) show the preliminary match of the experiments by the basic EOS.

Table 3. Statistical Parameter for preliminary results of CCE test (Before splitting and lumping)

Property	AAERR %	SD %
Oil density, (lbm/ft^3)	4.407	0.432
Relative Volume (ROV)	2.40	1.75
Oil compressibility (1/Psia)	19.73	0.405
Oil Viscosity (cp)	5.483	5.447

Table 4. Statistical parameter for preliminary results of Differential Liberation test (Before splitting and lumping)

Property	AAERR %	SD %
Oil Formation Volume Factor (rb/stb)	5.564	1.74
Gas Formation Volume Factor (rcf/scf)	5.097	2.382
Gas Compressibility Factor	1.286	0.633
Gas-Oil Ratio (scf/stb)	7.547	10.19
Oil Specific Gravity	3.37	0.78
Gas Specific Gravity	4.944	6.39

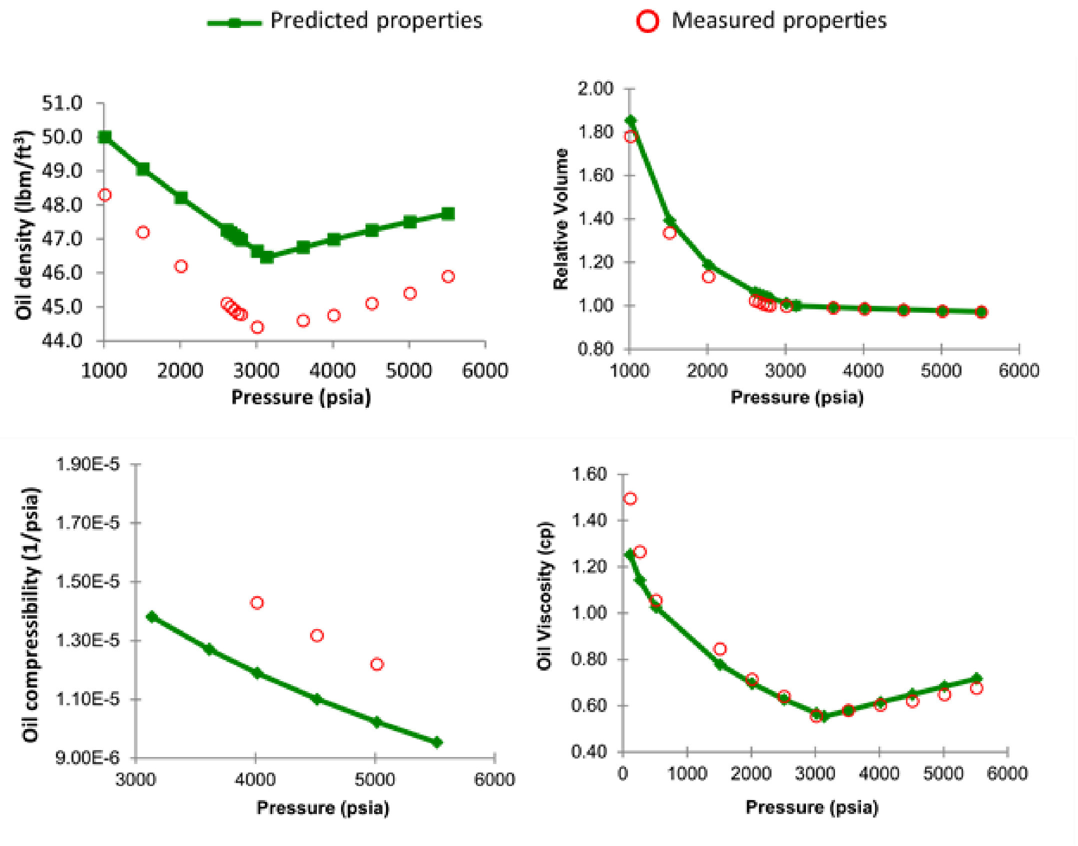

Fig. 1: Measured and predicted properties of CCE test using the basic EOS.

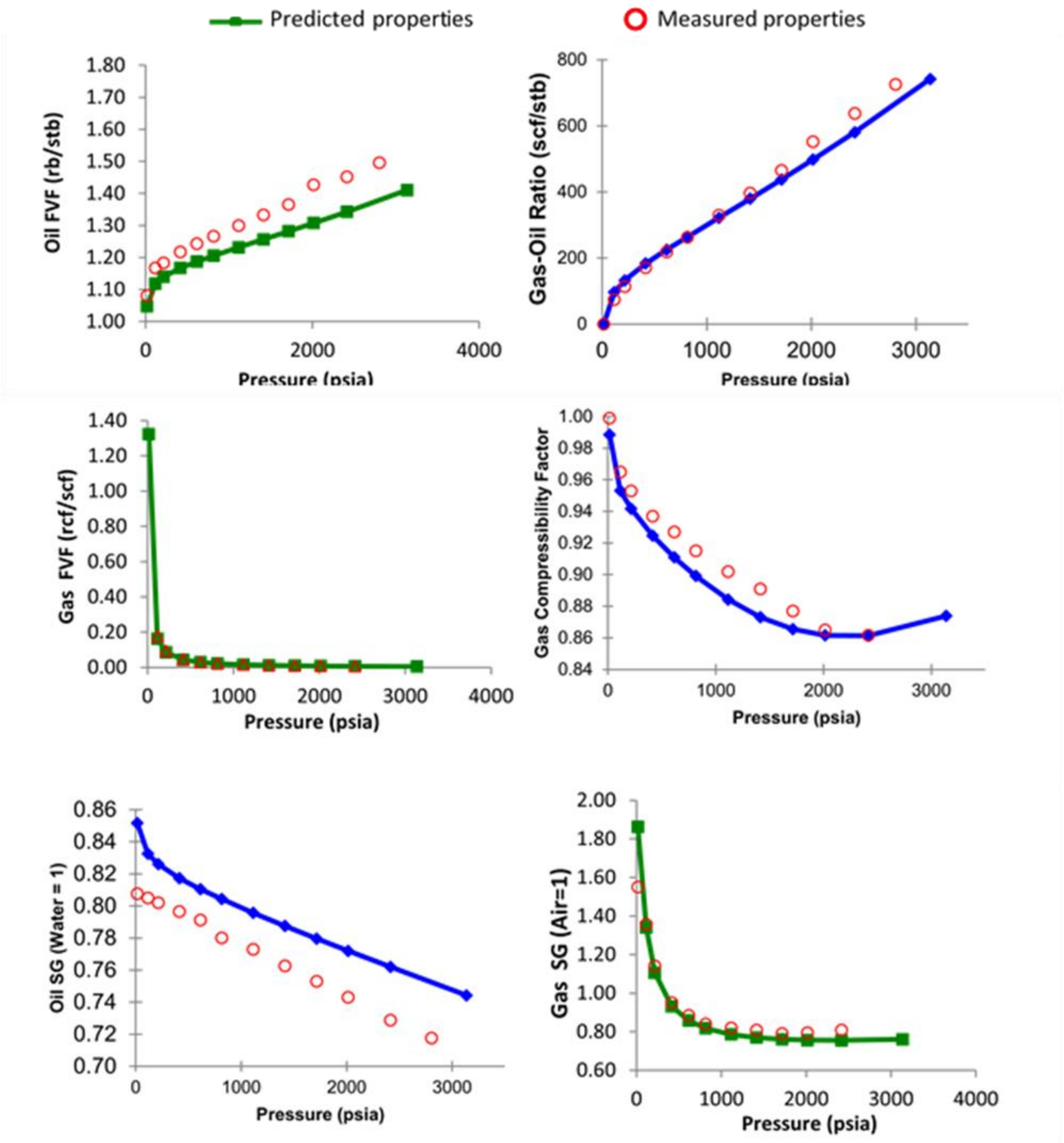

Fig. 2: Measured and Calculated properties of Differential Liberation test using the basic EOS.

3.2. Final PVT model with Splitting and Lumping Processes

Splitting and lumping processes were used to tune or characterize the EOS so that it is able to reproduce the PVT experiments. This was a multistep process that started by the splitting the heavy component as proposed by Whitson(10). Whitson's method uses a six-parameter (2 stage- exponential) to characterize the molar distribution (mole fraction/molecular weight relation) and physical properties of petroleum fractions such as hexanes-plus (C_{6+}). This method is used to enhance the EOS predictions. In this study several methods to splitting of C_{6+} have been tried such as seven, nine and ten pseudo component to achieve good match between measured and calculated data, but it has been found splitting of C_{6+} into the six pseudo components gave accurate match between the data. The heavy component (C_{6+}) was split into six pseudo components based on its relative mole fraction. The pseudo components were identified as (C_6-C_9), (C_{10}-C_{12}), (C_{13}-C_{16}), (C_{17}-C_{20}), (C_{21}-C_{24}) and C_{25+}. Table (5) shows the new components after splitting. By splitting the heavy component (C_{6+}), the total number of components of the reservoir fluid had increased from 10 to 15 components. This 15-component mixture was used to tune the EOS by regressions to match the observations.

Several regressions were carried out during the process of tuning the EOS. The first regression was performed on all the experiments against the critical pressure of the pseudo components, C_{6+}(C_6 to C_{25}). The results provided very good predictions with little error when compared against PVT data.

In general, the regression parameters were basically the C_{6+} (C_6 to C_{25+}) pseudo components critical pressure (P_c), critical temperature (T_c), a centric factor (ω) and binary interaction coefficients (δ). The shift parameters of the C_{6+}(C_6 to C_{25+}) pseudo components were also regressed together, so that changes within the C_{6+} fraction were consistent.

Table 5. Reservoir Fluid Composition in Mole Fractions (After Splitting Process)

Component	**Mole Fraction**
CO_2	0.0043
N_2	0.0064
C_1	0.3292
C_2	0.0866
C_3	0.0440
iC_4	0.0160
nC_4	0.0580
iC_5	0.0140
nC_5	0.0218
C_6-C_9	0.0143
C_{10}-C_{12}	0.0743
C_{13}-C_{16}	0.0690
C_{17}-C_{20}	0.0450
C_{21}-C_{24}	0.0299
C_{25+}	0.1860
Sum	1.0000

After a satisfactory match of all the experimental data, the next step was to group the 15- component EOS into a reduced pseudo component EOS acceptable for a compositional simulation. Doing this reduction minimized the computational time constraint and the numerical complexity of the reserviorcomositional simulation.

The lumping process consisted of forming new pseudo components from existing components. Then regressions were performed to fine-tune the newly formed pseudo component EOS properties. This process was repeated a number of times to select the best grouping at each stage in the pseudoization process.

Since various combinations of grouped components are possible, the criteria for grouping were selecting components with similar properties and molecular weight and having as few components as necessary to match the PVT experiments.

A series of grouping exercises were performed. First, a 11-component EOS model was obtained after grouping (N_2 , C_1), (C_2 , C_3), (i-C_4,n-C_4) and (i-C_5,n-C_5), leaving the remaining components ungrouped.

The regression parameters to tune the EOS were the critical properties of the newly formed pseudocomponents. After performing these regressions, the PVT properties of the 6-component EOS model matched the 15-component EOS model almost exactly.

From the 11-component EOS model, another grouping was conducted. The C_{6+} pseudo components, C_{6+} (C_6 to C_{25+}), were grouped into a single fraction (C_{6+}). With this grouping a 6-component EOS model was obtained. The 6 component EOS model contained the following components: (CO_2); (N_2, C_1); (C_2, C_3); (i-C_4,n-C_4); (C_5-C_6), and (C_{6+}). Table (6) shows the new components and their mole fractions after lumping process.

Table 6. Reservoir Fluid Composition (After Lumping Process)

Component	Mole fraction
CO_2	0.0043
C_1,N_2	0.3356
C_2,C_3	0.1306
IC_4,NC_4	0.0740
IC_5,NC_5	0.0358
C_{6+}	0.0419
sum	1.0000

Regression was performed again, and the 6-component EOS model predicted PVT properties very similar to the 11-component EOS model. This EOS was accepted for use in reservoir compositional simulation.
Table (7) summarizes the best regression parameters of EOS for the sandstone reservoir fluid after splitting and lamping processes. The statistical accuracy between measured and final results of Constant Composition Expansion and Differential Liberation data are shown in Tables (8) and (9) respectively. Figures (11) through (20) show the comparison of results of selected experiments. As can be seen, the results provided avery good match with the measured values for all parameters.

Table 7. Best Regression Parameters and Critical Properties for the sandstone Reservoir Fluid after Splitting and Lumping Processes

Component	P_C (atm)	T_C (k)	Acentric factor	Molecular Weight	V_C (1/mol)	Omega A	Omega B
CO_2	49.015406	305.35393	0.1040077	44.000	0.14526213	0.45723553	0.77796074
C1,N_2	45.184018	189.31279	8.6105E-03	16.271	0.98815854	0.45723553	0.77796074
C_2,C_3	46.048727	328.71939	0.11619296	34.795	0.16588395	0.45723553	0.77796074
IC_4,NC_4	37.169308	421.42768	0.18932432	58.124	0.25672275	0.45723553	0.77796074
IC_5,NC_5	33.341333	465.4842	0.24161453	72.151	0.3047816	0.45723553	0.77796074
$C6_+$	21.536638	729.70913	0.5278152	210.000	0.6817638	0.45723553	0.77796074

Table 8. Statistical Accuracy for Final Results for CCE test (After Splitting and Lumping)

Property	AAERR %	SD %
Oil density, (lbm/ft3)	0.21	0.213
Relative Volume (ROV)	0.574	0.66
Oil compressibility (1/pisa)	1.535	0.7
Oil Viscosity (cp)	2.356	3.103

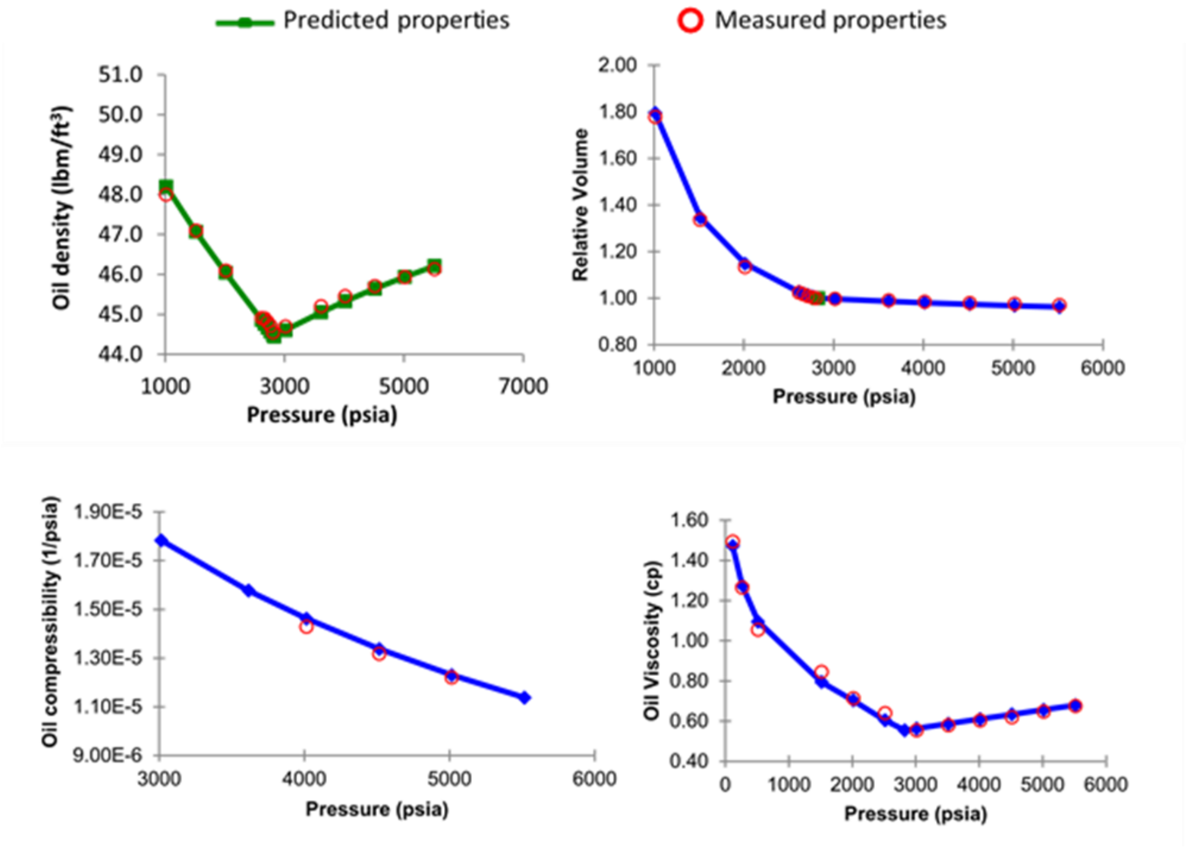

Fig.3: Comparison between the Predicted and Observed properties of CCE test after Splitting and Lumping Processes

Table 9. Statistical Accuracy for Final Results of Differential Liberation Test (after Splitting and Lumping)

Property	AAERR %	SD %
Oil Formation Volume Factor (rb/stb)	1.362	0.747
Gas Formation Volume Factor (rcf/scf)	4.68	1.623
Gas Compressibility Factor	0.865	0.721
Gas-Oil Ratio (scf/stb)	2.954	4.245
Oil Specific Gravity	0.851	1.08
Gas Specific Gravity	3.294	5.218

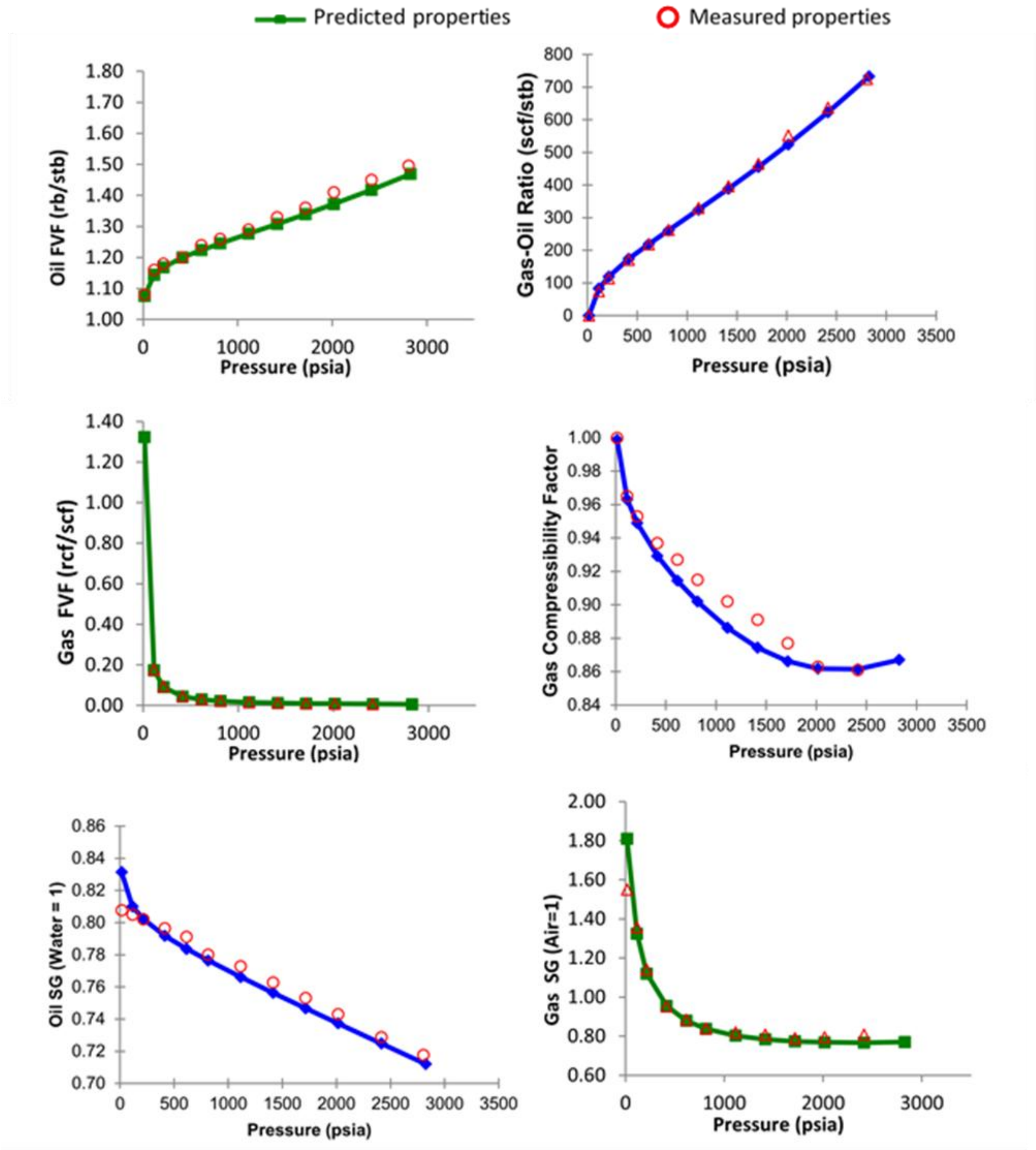

Fig.4: Comparison between the Predicted and Observed properties of Differential Liberation test after Splitting and Lumping Processes

In addition, the developed model shows a great accuracy for estimation bubble point pressure for the tested sandstone reservoir. The predicted bubble point pressure by the simulator after regression analysis is also compared with the measured one. Table (10) shows acceptable agreement between the estimated and measured bubble point pressure with absolute relative error (0.03%) compared with absolute relative error of 7.46% for the before regression estimation.

Table 10: Average Percentage Error between Measured and Calculated Bubble Point Pressure

Calculation method	Measured Bubble Point pressure (psia)	Calculated Bubble Point Pressure (psia)	AERR %
Before Regression	2804.7	3014	7.46
After Regression	2804.7	2804	0.03

3.2. Phase Behavior Diagram

The other main purpose of this work is to predict the behavior of the reservoir fluid at different conditions of pressure and temperature. The effect of the two reservoir parameters (pressure and temperature) with the behavior reservoir fluid is performed using phase behavior diagram interpretations.

This behavior is represented by developing the (P-T) diagram for reservoir fluid that provides the state of the reservoir fluid at any pressure and temperature which is of great importance for the analysis of many future reservoir processes.

For X-Y phase envelopes, the variable to be used on the X-axis (independent variable) and the Y-axis (dependent variable) must be selected. The choices are temperature and composition for the X-axis and Pressure or temperature for the Y-axis. For a Pressure-Temperature (P-T) diagram one should select temperature as the independent variable and pressure as the dependent variable. Figure (3) shows the P-T diagram for sandstone reservoir fluid predicted by the developed PVT model.

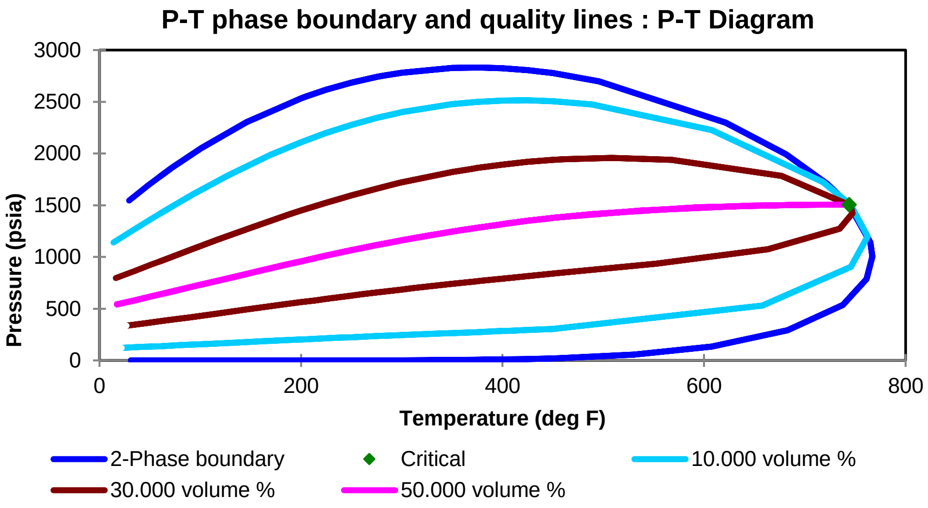

Fig. 5: Phase Behavior Diagram of the tested sandstone Reservoir

4. Conclusions

1. The developed model can be used to describe the behavior of the reservoir fluid properties.
2. Soave-Redlich-Kwong Equation of State & Peng-Robinson's Equation of State and its modifications are used for the prediction of PVT properties for Middle Eastern Sandstone Reservoir
3. Splitting and lumping processes were used to tune or characterize the EOS so that it is able to reproduce the PVT experiments.
4. The results which obtained after Splitting and lumping processes is better than these which obtained without Splitting and lumping processes.
5. Calculations of phase behavior performance based on this equation of state can be used in engineering studies and may reduce the amount of extensive laboratory

Nomenclature

a, b, c	Constant in various equations of state (dimensionless)	
A, B, m	Parameter in various equations of state(dimensionless)	
B_o	Oil formation volume factor, (bbl/stb)	
B_g	Gas formation volume factor, (scf/stb)	
n	Number of moles	lb.mole
P	Pressure	psi
P_b	bubble point Pressure	psia
P_c	Critical Pressure	Psia
R	Gas Constant	(psia.ft^3)/(lb.mole.^{o}R)
SD	Standard Deviation	(dimensionless)
S.G	specific gravity	(dimensionless)
T	Temperature	^{o}F
V	Volume	ft^3

Greek Symbols

α	Equation of state parameter	(dimensionless)
γ	Specific gravity (dimensionless)	
Δ	Indicates difference (dimensionless)	
μ_o, μ_g	viscosity of oil and gas, cp	
ρ	Density	lb/ft^3
(δ_{ij})	Interaction coefficients between different Components	(dimensionless)
ω	Acentric factor	(dimensionless)
Φ	Fugacity coefficient (dimensionless)	
Ω	Equation of state parameter	(dimensionless)

Abbreviations

AAERR	Average Absolute Relative Error
bbl	Barrel
CMG	Computer Modeling Group

EOR	Enhance Oil Recovery
EOS	Equation of state
Exp	Experimental
ft	feet
FVF	Formation Volume Factor
PR	Peng-Robinson
PVT	Pressure, Volume, Temperature
scf	standard cubic foot
SD	standard Deviation
stb	Stock tank barrel
SRK	Soave-Redlich-Kwong

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