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Characterization of fluid properties and pseudo-fraction analysis for oils with low gas oil ratios

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Abstract

The Sadi reservoir is one of the largest and most important unconventional tight oil reservoirs in southern Iraq. However, it suffers from low production rates, necessitating many development strategies that require a correct and reliable characterization of reservoir fluid properties. Whilst these properties are originally obtained from laboratory experiments, measurement errors often occur despite rigorous workflows, which negatively affect the calculation of reservoir fluid properties. This study utilizes the fluid thermodynamics characterization program (PVTp) to generate a reliable model for determining the oil properties of Sadi reservoir. A methodology was developed to simulate fluid thermodynamic tests, including Differential Liberation (DL) and Constant Composition Expansion (CCE) tests. This was achieved through adjusting the Peng-Robinson Equation of State (PR-EOS) by splitting and lumping the C_{7+} plus fractions and calibrating the Ω parameters to match model results with experimental data using regression. Using the absolute average error (AAE) as a model performance benchmark, the model achieved an AAE of 1% for estimating the relative volume, 0% for estimating oil density, 0.41% for estimating oil formation volume factor, 4% for oil viscosity, and 5% for the gas oil ratio. These values represent the highest AAE recorded for this dataset and show good agreements within the acceptable limits. The PR-EOS model proves to be an accurate fluid characterization alternative that can be applied to similar field data, providing a valuable tool for reservoir management, improving performance, and reducing costs in the future.

Keywords: *Sadi Reservoir; PVT modeling; Equation of state; Splitting and Lumping; Regression.*

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1- Introduction

Reservoir fluids experimental analysis based on Pressure-Volume-Temperature (PVT) relation helps to improve reservoir productivity along well life. Many physical properties obtained from PVT analysis are critical for evaluation stages, such as to evaluate oil and gas reserves, design surface and subsurface equipment, and pipeline multiphase flow modeling. However, experimentally derived reservoir fluid properties are often unavailable or prohibitively expensive obtain. These laboratory experiments are performed as a function of pressure and constant temperature, the PVT modeling was developed using empirical correlations (equation of state) to represent the variation of reservoir fluid composition as a function of pressure and temperature. This variation is essential for improving oil recovery by obtaining accurate correlations. Some reservoirs are characterized by a significant variation in composition at the origin, or with the use of improvement methods, such as in situ combustion and injection methods, therefore the composition of the reservoir fluid changes in situ [1].

Artificial intelligence techniques have recently been used to determine reservoir fluids' PVT properties and validate the correlations generated for the PVT properties. Fuzzy logic techniques were used and a set of statistical error analyses to verify the accuracy and validity of the correlations generated for estimating reservoir properties, fuzzy logic predicted many reservoir fluid properties such as gas solubility, oil viscosity, and formation volume factor, these AI derived correlations properties were compared with accurately laboratory-measured samples to proving the model's validity [2]. An artificial neural network (ANN) model was also presented to predict bubble point pressure in Iraqi fields, one hundred four reservoir samples were used, and the reservoir temperature, solution gas oil ratio, oil density, and gas relative density were used as model inputs [3]. Despite the accuracy of these models, they are specific-to-specific reservoir samples. They are trained and developed based on the required vast data, which is sometimes difficult to obtain.

Common equation of state (EOS) models are developed to accurately describe the behavior of the PVT reservoir using many reservoir samples. Some models used the joint EOS adjusted in all reservoir parts, even for the surface equipment (separation equipment). In such studies, the data were initially checked to ensure the balance of materials and phases by balancing materials consistently to ensure data quality and identify outliers. Showed that one of the effective methods to develop an

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EOS model is the proper and accurate description of the heavy fractions that contain varying proportions of paraffin, naphthenic, and aromatic compounds, as well as the use of a sufficient number of components [4].

Fine-tuning of the EOS (Peng-Robinson Equation of State) model can be obtained by splitting the plus fractions $+C_7$ into pseudo-components characterised by mole fraction and molecular weight, the two-stage exponential splitting method was used, and then the pseudo-components were lumped into aggregated sets for fine-tuning the EOS model. The model was proven valid for predicting the specific gravity of oil, oil viscosity, and oil formation volume factor in the Qaiyarah oil field [5].

The regression technique generates a useful fluid properties correlation that can be compared with those obtained from laboratory experiments, such as the fixed-mount expansion test and the differential liberation test [6, 7]. Constant Composition Expansion (CCE) and Differential Liberation (DL) tests are essential tools for understanding the volumetric behavior, liquid-vapor equilibrium, and thermal properties of reservoir fluids [8]. The equation of state simulates these tests using specific hydrocarbon composition data, providing an efficient alternative to laboratory experiments [9].

This paper aims to build a model to predict the PVT properties of a specific important reservoir in Iraq (Sadi reservoir fluid) at different temperatures and pressures. Using the Peng-Robinson Equation of State to estimate minimum miscibility pressure values for Sadi and Tanomaa reservoirs, to obtain the best match for PVT properties between the computed and laboratory-measured values, the parameters of this equation have been adjusted by separating the plus component and the regression process, and by modifying (Pc, Tc) that affect the PR-EOS computation [10]. This study aims to provide a deeper understanding of oil modeling and its sensitivity to critical parameters through an acceptable agreement between experimental data related to the outputs of the operating system. Thus, the PVT properties of the oil in the selected reservoir can be predicted. The PVT model developed for oil reservoirs will be used as a fingerprint in the dynamic modeling of the reservoir under study.

2- Geological background

Sadi reservoir is located in Halfaya oil field, 35 km southeast of Amara in Iraq. Sadi reservoir consists of two layers: Sadi-A and Sadi-B. Sadi-A is an aquifer layer with a thickness of approximately 51 m, while Sadi-B contains crude oil and consists of three layers: Sadi-B1, Sadi-B2, and Sadi-B3. The Sadi-B3 layer is divided vertically into four layers: Sadi-B3-U1, Sadi-B3-U2, Sadi-B3-U3, and Sadi-B3-U4, based on the petrophysical properties of the rocks, their electrical properties, and their lithology. The thickness of Sadi-B1 layer ranges from approximately 28 m, the Sadi-B2 layer is approximately 30 m, and the Sadi-B3 layer is approximately 20 m thick, as shown in Fig. 1 [11]. According to lithology, Sadi reservoir is divided into Sadi-A, a soluble grey limestone rock, and Sadi-B1, mainly bioturbated wackestone. At the same time, Sadi-B2 comprises bioturbated packstone and pelagic foraminiferal chondrites, which are either dolomitised or pyrite cemented. Sadi-B3 has developed shale containing smectitic, pyrite, oolitic packstone, and skeletal intraclastic packstone; echinoderms, pebbles, oolitic, dark grain (pyritic), and chondrite can also be found in Sadi-B3 [12].

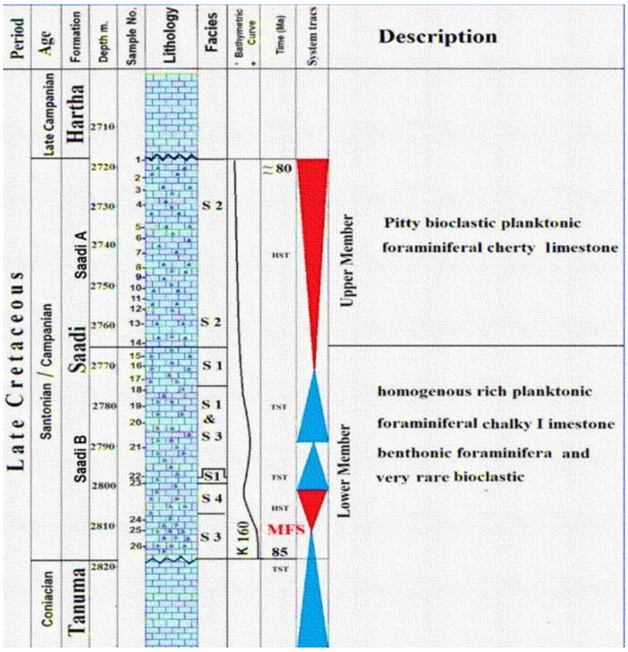

Fig. 1. Stratigraphic column of the Sadi Reservoir

3- PVT modeling

In reservoir fluid modeling especially for black oil model, it is necessary to use laboratory data such as the constant composition expansion experiment data that includes (oil density, relative volume (which expresses the total volume of the liquid relative to the volume of the liquid at saturation)). In addition, it is necessary to use differential liberation experiment data such as oil viscosity, oil formation volume factor, and gas oil ratio. Successful modeling requires careful handling of C7+ fraction data for molecular weight, density, and mole fraction, as well as reservoir data such as temperature and pressure at the initial conditions, pressure and temperature at the saturation conditions (which represents the appearance of the first gas bubble).

Limited phase behavior studies of oil Sadi reservoir have been available in the literature. Consequently, this study aims to build a model to predict the PVT properties of a specific important reservoir in Iraq (Sadi reservoir fluid) at different temperatures and pressures by tuning the Peng-Robinson equation of state (PR-EOS). The study objective is to obtain agreement between laboratory data and the equation of state outputs using regression analysis into the PVTp software.

Several black oil modeling scenarios will be followed in this study, including a splitting and lumping scenario for plus fractions C7+ and a regression to tune the equation of state.

3.1. Using EOS to generate PVT data

According to Eq. 1, Peng-Robinson equation of state (PR-EOS) is used in this study to estimate the hydrocarbon properties and phase behavior of Sadi reservoir fluids [13].

$$P = \frac{RT}{Vm-b} - \frac{a_c\,\alpha}{Vm(Vm+b)+b(Vm-b)} \tag{1}$$

Where:

$$a_c = 0.4572\frac{R^2 {T_c}^2}{P_c^2} \tag{2}$$

$$\alpha^{1/2} = 1 + m\left(1 - T_r^{1/2}\right) \tag{3}$$

$$m=0.37464+1.54226\omega - 0.26992\omega^2 \tag{4}$$

$$b = 0.07780\frac{RT_c}{P_c} \tag{5}$$

The molar volume in the Peng-Robinson equation of state (1) is replaced by (ZRT/P) and rewritten as Eq. 6.

$$Z^3 - (1-B)Z^2 + (A - 2B - 3B^2)Z - (AB - B^2 - B^3) = 0 \tag{6}$$

Where:

$$A=\frac{a_T p}{(RT)^2} \tag{7}$$

$$B=\frac{bp}{RT} \tag{8}$$

Eq. 6 produces three roots, the smallest value being the mole fraction of the liquid (Z_L) and the largest value being the mole fraction of the gas (Z_g).

The basic requirements for building a PVT model are that the temperature should be 190°F at a saturation pressure of 3078 Psia, the oil density and viscosity should be 729.7 g/m3 and 0.776 cp, respectively, at the saturation pressure, and the oil formation volume factor should be 1.396 bbl/STB at the saturation pressure. Recommended using there is the Average Absolut Error (AAE) value a metric used to evaluate the accuracy of a model by measuring the average proportion of errors between predicted and actual values. In that case, it should not exceed 5% for the oil viscosity, oil formation volume factor, and gas oil ratio. As for the oil density and relative volume, the AAE value should not exceed 1% from the laboratory data [14]. The required data for modeling PVT behavior are given in Table 1.

Table 1. Initial and saturation conditions, as well as the mole fraction of Sadi oil sample

Reservoir pressure at initial conditions (psia)	4846	**Reservoir pressure at saturation conditions (psia)**	3078
Reservoir temperature at initial conditions (°F)	190.4	**Reservoir temperature at saturation conditions (°F)**	190.4
Component	**Mole fraction**	**Component**	**Mole fraction**
N_2	0.554617	$i\text{-}C_4H_{10}$	0.907374
CO_2	0.174879	$n - C_4H_{12}$	2.96795
CH_4	40.1193	$i\text{-}C_5H_{12}$	1.50596
C_2H_6	8.95782	$n\text{-}C_5H_{12}$	1.80975
C_3H_8	5.33932	C_6H_{14}	3.27674
C_{7+}		34.3863	

3.2. Splitting for pseudo-components

The splitting process involves breaking the plus fraction C7+ into pseudo-components. The plus fractions C7+ represent a significant part of the matching process. Therefore, a method is used to split the C7+ into multiple pseudo-components, each characterized by molecular weight, mole fraction, and specific gravity. In this study, Whitson method, as given in Eq. 9, is used Whitson method to split the plus fractions C7+, this method uses a three-parameter probability function to generate a series of distributions for the plus fraction. The main parameters are (α), (β), and (ῃ). (α) The distribution factor represents, (β) represents the average molecular weight, and (ῃ) represents the initial molecular weight; the series is generated from distributions for the same fluid by varying the main parameter, (α) [15]. The PVTp software features a tool that helps users find the best combination of (α) values and the number of pseudo-components to match the fluids. The plus fraction C7+ in the reservoir sample under study was split into 28 pseudo-components, as shown in Table 2.

$$P(M) = \frac{(M-\eta)^{\alpha-1}exp\{-[(M-\eta)/\beta]\}}{\beta^\alpha \Gamma(\alpha)} \tag{9}$$

Where:

$$\beta = \frac{M_{C7+}-\eta}{\alpha} \tag{10}$$

$$\eta \approx \frac{110}{1-(1+4/\alpha^{0.7})} \tag{11}$$

3.3. Lumping for pseudo-components

The pseudo components lumping process is a time-saving method for simulating reservoir fluids. The pseudo components are clustered into smaller groups based on similar molecular weights [16,17]. The method indicated that the lumping process is essential for reducing simulation and processing time for reservoir fluids through phase behaviour calculations. Lumping allows for complex mixtures of components but with fewer clusters. The PVTp software has two lumping modes: automatic and manual. For the used oil sample in this study, the pseudocomponents were lumped into six groups, the process of lumping requires in which the critical properties (P_c, T_c, and ω) of the individual carbon number fractions are averaged to one set of the critical properties for the lumped pseudo-component or group, as shown in Table 3.

Table 2. Pseudo-components splitting of Sadi reservoir sample

Pseudo-Component	Composition (Mole fraction)	Pseudo-Component	Composition (Mole fraction)	Mole fraction	Composition (Mole fraction)
C_7	3.10686	C_{16}	1.40936	C_{25}	0.54375
C_8	3.21723	C_{17}	1.27623	C_{26}	0.496833
C_9	2.89267	C_{18}	1.15678	C_{27}	0.454245
C_{10}	2.60321	C_{19}	1.04944	C_{28}	0.415657
C_{11}	2.34483	C_{20}	0.952899	C_{29}	0.380665
C_{12}	2.11401	C_{21}	0.865994	C_{30}	0.348911
C_{13}	1.90763	C_{22}	0.787701	C_{31}	0.320066
C_{14}	1.72295	C_{23}	0.71711	C_{32}	0.293848
C_{15}	1.72295	C_{24}	0.653407	C_{33}	0.543875
C_{34}					0.200567

Table 3. Characteristics of the pseudo-components after lumping process of Sadi reservoir sample

Psudo-components	Mole fractions	Molecular weight	Specific gravity	Critical temperature (°F)	Critical pressure (psig)	Boiling temperature (°F)	Acentric factor
C7::C8	6.32409	128.525	0.814123	662.241	411.152649	304.045	0.33599
C9::C10	5.49587	160.328	0.854311	793.552	336.2677	429.61	0.443126
C11::C13	6.36648	199.123	0.885867	913.386	275.898651	553.246	0.562306
C14::C16	4.68974	245.122	0.92026	1051.68	219.234085	703.962	0.723786
C17::C20	4.43536	295.933	0.946137	1151.58	188.849182	814.615	0.850006
C21::C34	7.07476	399.862	0.982621	1280.58	162.046417	955.025	1.01161

3.4. Regression analysis

The equation of state does not respect the fundamental law of conservation of mass. Due to its poor adherence to material balance, the results are incorrect, particularly between the well and the separator. While the EOS equation of state produces all PVT properties, its failure to adhere to the law of conservation of mass makes the results unreliable regarding liquid dropout and gas oil ratios. There are many regression models each differs according to the characteristics used in the matching. The regression process may be applied to the original (All Component T_{cs} P_{cs} AF_s etc.) or Global Ω_a, Ω_b plus Pseudo T_{cs} P_{cs} AF_s., Individual Ω_a, Ω_b plus Pseudo T_{cs} P_{cs} AF_s., T_{cs} P_{cs} AF_s with Multiplier on Each Property., T_{cs} P_{cs} AF_s with Shift/Multiplier on Each Property). After many attempts, the regression with individual Ω_a, Ω_b plus pseudo T_{cs} P_{cs} AF_s has been proven to match the properties of PVT fluids except for viscosity. The Peng-Robinson equation of state includes Ω_a through the a(T) equation, a constant of 0.45724, and Ω_b through Eq. 5, a constant of 0.0778. These constants were originally derived experimentally, but in this regression model, they are used as variables in the matching process (since modifying these parameters (Ω_a, Ω_b) is related to modifying the critical properties, as they are directly related according to Eq. (2, 5) for each component, as shown in Table 4. This model does not change the measured properties of methane because methane has a critical temperature T_c lower than the reservoir temperature, causing sharp changes in the parameters (Ω_a, Ω_b)) near the critical point, and the application of the correlation beyond the critical point is questionable [18].

3.4.1. Viscosity regression model

Several regression models are mentioned in literature for estimating fluids viscosity, such as (Lohrens Bray Clark [19], Pedersen et al. [20], Zhou et al. [21], and Little and Kennedy [22]). In the current studied sample and after many attempts to reach good agreement between measured and calculated viscosity, the Lohrens Bray Clark (LBC) model proved to match the viscosity data of the studied oil sample. The LBC model calculations based on many important parameters such as the composition, specific gravity and critical volume (Vc). This regression is performed separately because the necessary volume is not included elsewhere in the EOS models. The LBC model is a modification proposed by Jossi method which is based on a fourth-order polynomial equation in reduced density, as shown in Eq. 12 [23].

$$[(\mu - \mu^0)\xi + 10^{-4}]^{1/4} = a_1 + a_2\rho_r + a_3\rho_r^2 + a_4\rho_r^3 + a_5\rho_r^4 \qquad (12)$$

$$\mu^0 = \sum_{i=1}^{N} Z_i\, \mu_i\, MW_i^{1/2} / \sum_{i=1}^{N} Z_i MW_i^{1/2} \qquad (13)$$

$$\xi = 5.35\left(\frac{T_{PC}}{M^3 P_{PC}^4}\right) \qquad (14)$$

$$\rho_{pr} = \frac{\rho}{\rho_{PC}} = (\rho/\ MW)\ V_{PC} \quad (15)$$

Where:

a_1=0.1023 $a_2 = 0.023364$ $a_3 = 0.05833$ $a_4 = -0.040758$ $a_5 = 0.0093324$

Table 4. Regression parameters after lumping processes

Psudo components	**Critical temperature (°F)**	**Critical pressure (psig)**	**Acentric factor**	Ω_a	Ω_b
N_2	-233.104004	477.32608	0.0390000008	0.475512058	0.0580031835
CO_2	87.6920013	1058.25891	0.238999993	0.205197379	0.0758341998
CH_4	-116.517998	658.380798	0.0109999999	0.451408982	0.0781798214
C_2H_6	89.7979965	693.651184	0.0989999995	0.402867109	0.0872896537
C_3H_8	206.005997	602.682983	0.152999997	0.480287135	0.0752015039
i-C_4H_{10}	274.694	514.359985	0.182999998	0.494311005	0.0710409656
n-C_4H_{12}	305.294006	535.963135	0.199000001	0.480613887	0.0708741397
i-C_5H_{12}	369.806	468.361511	0.226999998	0.440814644	0.0818146095
n-C_5H_{12}	385.59201	474.827759	0.250999987	0.442709327	0.0810940713
C_6H_{14}	454.100006	425.008331	0.298999995	0.450703859	0.0793858618
C7::C8	662.240906	411.152649	0.335990459	0.462395161	0.077358976
C9::C10	793.552002	336.2677	0.44312647	0.434652269	0.0788758546
C11::C13	913.385986	275.898651	0.562305987	0.437728375	0.0788317993
C14::C16	1051.67883	219.234085	0.723785996	0.436843067	0.0789130032
C17::C20	1151.58008	188.849182	0.850006044	0.439423829	0.0787839293
C21::C34	1280.58447	162.046417	1.01160944	0.448219806	0.0783052668

4- Results and discussion

The EOS model is based on the principle of thermodynamics. Adjusting it with high accuracy can predict reservoir behavior and important reservoir fluid properties. Upon completion of the regression process for the Peng–Robinson Equation of State (PR-EOS) parameters, the model was systematically prepared for subsequent evaluation and performance forecasting. A rigorous regression of the critical properties and acentric factors was conducted to ensure high fidelity in the results. Following this refinement, the model strongly correlated with the experimental data, particularly concerning the bubble-point pressure, oil formation volume factor, oil viscosity, oil density, gas oil ratio, and relative volume at pressures exceeding the bubble-point pressure. The regression analysis for each property is illustrated in the following sections in details.

4.1. Bubble-point pressure

This pressure represents the pressure at which the first gas bubble appears in a liquid at a given temperature. It is also called the saturation pressure. A red fit line represents the Peng-Robinson equation of state model prediction for saturation pressure, passing through or near the green cross (X), representing the saturation pressure measured during laboratory experiments. To ensure that the phase behavior model is valid for predicting fluid behavior under actual reservoir conditions, the line of fit for the Peng-Robinson equation of state model must match the green cross (X), representing the bubble-point pressure from laboratory experiments, as shown in Fig. 2.

4.2. Constant composition expansion (CCE)

In PVT analysis, CCE is a crucial test that evaluates how a reservoir fluid sample responds to changing pressure levels while keeping its composition constant. This test is necessary to comprehend the fluid's physical characteristics in real reservoir conditions, including liquid viscosity and relative volume or the fluid's volume about its initial state.

The main objective of CCE in PVT Analysis is to determine fluid behavior, bubble point pressure identification, and liquid density and relative volume measurement. The CCE test thoroughly explains how the fluid transitions from a liquid phase to a two-phase (liquid and gas) system, enabling better reservoir management. In this work, a good agreement with experimental data was obtained with grouping (lumping). Therefore, CCE is essential for accurately characterizing the fluid dynamics of the reservoir and optimizing production strategies because it captures the physical characteristics of reservoir fluids under pressure conditions that are similar to actual reservoir states [24, 25].

Fig. 3 illustrates the inverse relationship between relative volume and pressure. The relative volume decreases with increasing pressure. This decrease is particularly significant when the pressure is below the saturation pressure. This is because the liquid occupies a large volume due to its ability to expand due to the presence of gas in the two-phase region. Above saturation pressure, the relative volume stabilizes as the pressure increases. The liquid transforms into a single phase due to gas compressing, reducing the relative volume.

The PR-EOS model (red line) closely follows the laboratory data: relative volume decreases rapidly when the pressure is below 2000 psi and begins to stabilize after the saturation pressure (3063 psi). The AEE% is 1%, indicating the reliability of the PR-EOS model in predicting fluid behavior across the reservoir pressure range.

Considering Fig. 4, which shows the relationship between the density of liquid and the pressure gradient, when the pressure is above the saturation pressure, the density of the liquid gradually decreases with the decrease in pressure. This is due to the expansion of the gas inside the liquid in the form of bubbles without starting to be released. After the pressure of the bubble point, the gas bubbles begin to release, increasing the liquid's density. A represented AEE% of 0% means an excellent match between the laboratory data and the PR-EOS model data, which makes the PR-EOS model reliable for predicting the fluid density for Sadi reservoir sample.

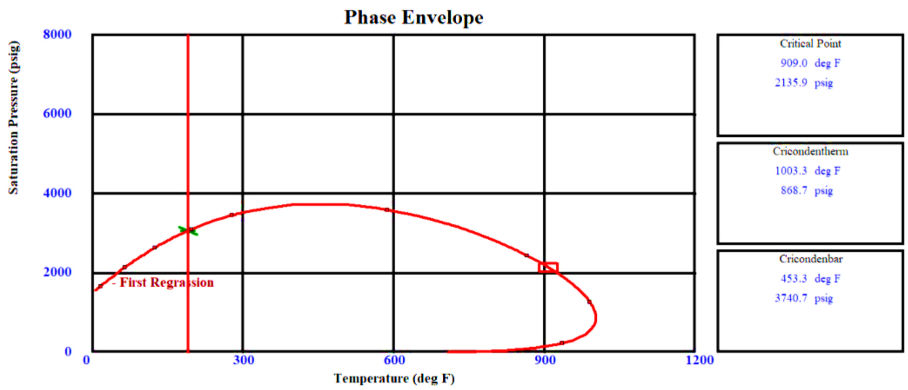

Fig. 2. Phase envelope for oil sample from Sadi reservoir; the green cross (X) represents the saturation pressure data from the laboratory, and the red fitting line represents the predicted PR-EOS model for saturation pressure data

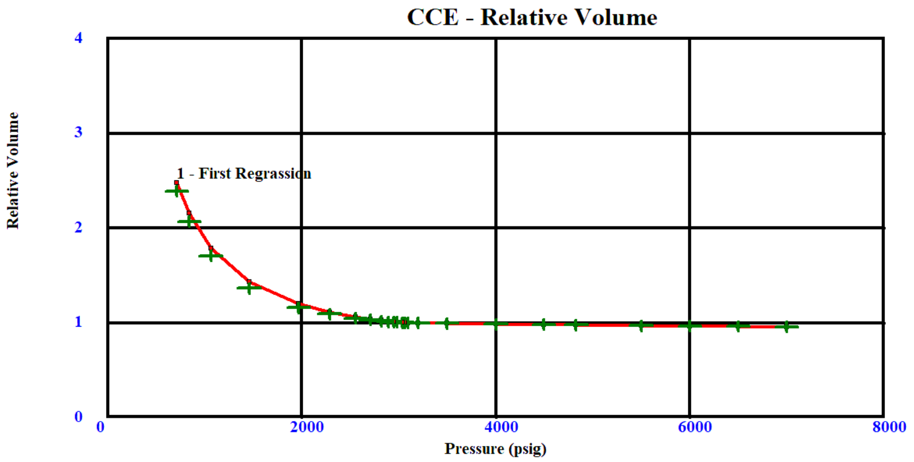

Fig. 3. The relationship between the relative volume and pressure (psig) of an oil sample from Sadi reservoir; The positive trend line represents the laboratory-relative volume data, and the red trend line represents the predicted relative volume data from the PR-EOS model

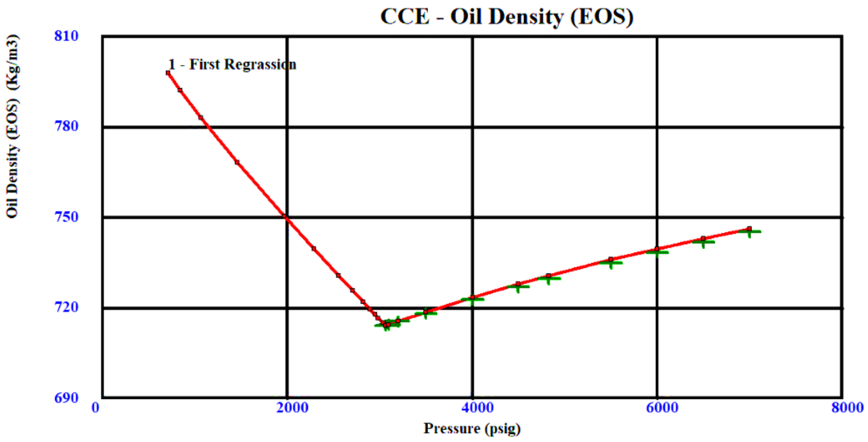

Fig. 4. The relationship between the liquid density (Kg/m3) and pressure (psig) of an oil sample from Sadi reservoir; The positive trend line represents laboratory oil density data, and the red trend line represents predicted oil density data from the PR-EOS model

4.3. Differential liberation (DL) experiment

It is a standard volumetric differential liberation experiment performed in the laboratory, also called a differential evaporation experiment [26]. This experiment simulates the gas-liquid separation process within a hydrocarbon system when the pressure is below the bubble point pressure. The gas dissolved in the oil is separated and released after the gas saturation reaches the critical gas saturation [27].

Fig. 5 illustrates the relationship between the gas-oil ratio (GOR) and pressure gradient. At high pressures, gas tends to be retained in the oil phase, and at saturation pressure, gas bubbles begin to escape, gradually reducing the GOR. At low pressures, the experimental data show higher values than the PR-EOS model data, indicating that the fluid sample releases gas more readily under low-pressure conditions than the values predicted by PR-EOS model. At high-pressures (above saturation pressure), the data show a slight discrepancy due to differences in fluid behavior under laboratory test conditions. The AEE% between the PR-EOS model and the laboratory data is 5%, the maximum acceptable discrepancy.

Fig. 6 shows the oil formation volume factor (Bo) as a function of pressure. Bo is the fluid volume under reservoir conditions relative to the volume under standard conditions. As the pressure decreases from the initial pressure, the oil expands due to the increased dissolved gas content without being released until it reaches the saturation pressure, where gas bubbles begin to be released, reducing the volume of the oil. This is because the laboratory oil sample retains more gas at these pressures. Despite this, the AEE% between the laboratory data and the PR-EOS data is 0.41%, which is an excellent percentage indicating a good match.

Fig. 7 shows the relationship of oil viscosity to pressure. Viscosity starts to decrease gradually with decreasing pressure due to the expansion of the oil as the dissolved gas begins to increase without being released. After reaching the saturation pressure, gas bubbles start to be released, increasing the oil's density. Although the laboratory data shows a slight decrease compared to the PR-EOS model at high pressures, the AEE% between them represents 4%, a good percentage.

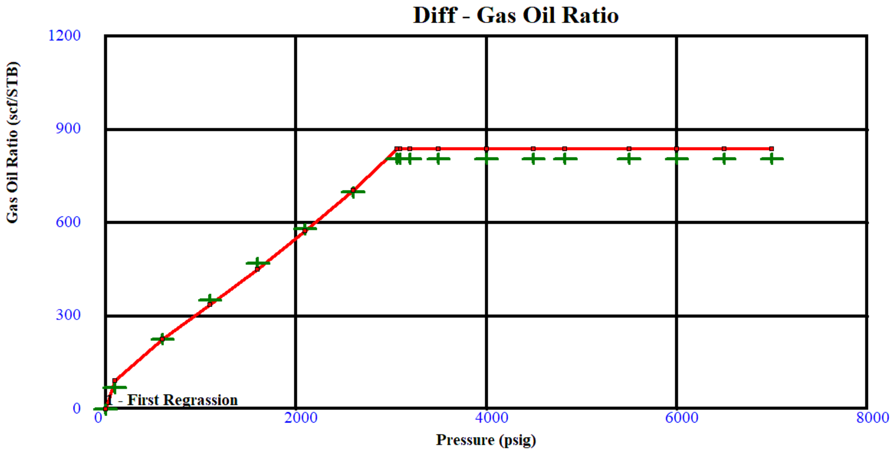

Fig. 5. The relationship between gas oil ratio (Scf/STB) and pressure (psig) of an oil sample from Sadi reservoir; The positive trend line represents the laboratory gas-oil ratio data, and the red trend line represents the predicted gas-oil ratio data from the PR-EOS model

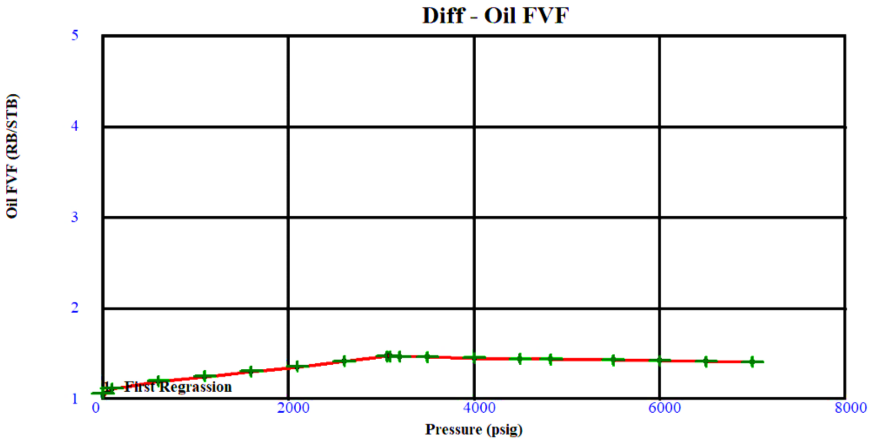

Fig. 6. The relationship between oil formation volume factor (RB/STB) and pressure (psig) of an oil sample from Sadi reservoir; The positive trend line represents the laboratory-tested oil formation volume factor data, and the red trend line represents the predicted oil formation volume factor data from the PR-EOS model

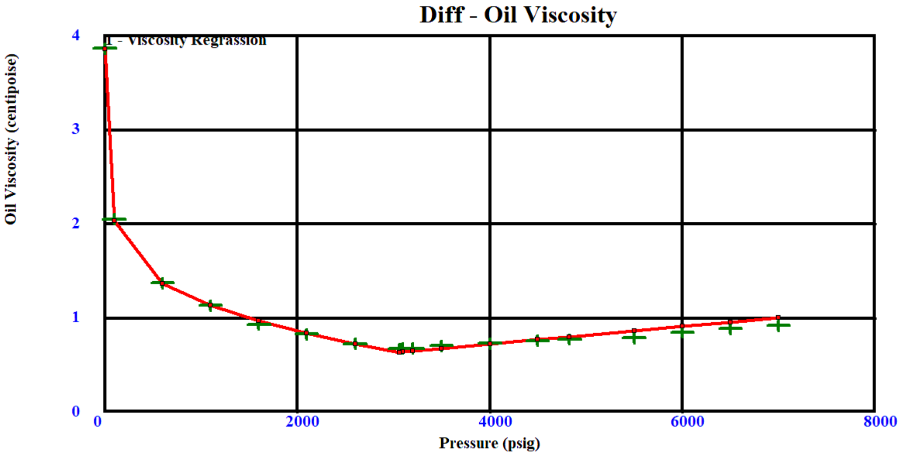

Fig. 7. The relationship between the oil viscosity (cp) and pressure (psig) of oil sample from Sadi reservoir; The positive trend line represents laboratory oil viscosity data, and the red trend line represents predicted oil viscosity data from the PR-EOS model

5- Conclusion

A PVT model was developed to predict the physical properties of Sadi reservoir crude oil. The model's validity was demonstrated by the significantly lower mean absolute average error between measured data and PR-EOS output, which was less than 5% for all calculated properties.

PR-EOS model was modified by using splitting and lumping process for the plus fractions C7+ to describe the reservoir fluid into six lumps, making it more suitable for simulating compositional fluids. A regression process was also used to Ω_a and Ω_b obtain values for each component, achieving an acceptable fit.

The data used to develop the PVT model were obtained from a constant composition expansion (CCE) experiment (relative volume, oil density) and a differential liberation (DL) experiment (gas oil ratio, oil viscosity, and oil formation volume factor). The success of the obtained calculated properties was tested by matching the physical properties of Sadi reservoir fluid using PR-EOS with laboratory data. The AAE value for the relative volume was 1%, for the oil density 0%, for the oil formation volume factor 0.41%, for the oil viscosity 4%, and for the gas oil ratio 5%. This represents the highest absolute mean error recorded for the data, yet it represents the highest AAE value within the acceptable limit. Based on these results, it was concluded that the PR-EOS model modification will be maintained to estimate the parameters of a similar model in the field under study. However, it is recommended to compare the results of this work with other models such as the Soave Redlich - Kwong equation of state to open new horizons on PVT modeling of Sadi reservoir fluid.

Nomenclature

Symbol	Description	Unit
a_c,b	Constant in Equations of State	dimensionless
A, B	Parameter in Equation of State	dimensionless
Bo	Oil formation volume factor	bbl/STB
GOR	Gas oil ratio	Scf/STB
MW	Molecular weight	Ib/Ib mole
m	Parameter in Equation of State	dimensionless
Pc	Critical pressure	psia
Ppc	Pseudocritical pressure	psia
R	Gas constant	$\text{psia}.\frac{f^3}{\text{Ib}}.\text{mole}.°$
T	Temperature	°F
Tc	Critical temperature	°F
Tpc	Pseudocritical temperature	°F
Tr	Reduced temperature	dimensionless
Vm	Volume of liquid	ft^3
Vpc	Pseudocritical volume	ft^3
Zi	More weight of the component	dimensionless

Greek system

Symbol	Description	Unit
α	Nondimensional temperature-depended	dimensionless
μ_i	Individual component viscosity	cp
ρ	density	$\frac{\text{Ibm}}{ft^3}$
ρ_{pc}	Pseudocritical density	$\frac{\text{Ibm}}{ft^3}$
ρ_{pr}	Pseudoreduced density	dimensionless
ω	Acentric factor	dimensionless
ξ	Viscosity reduction factor of the component	cp^{-1}
$\Omega, \Omega_a, \Omega_a$	Parameter in Equation of State	dimensionless
Γ	Gamma function	dimensionless
α	Alpha parameter	dimensionless
β	Beta parameter	dimensionless
η	Eta parameter	dimensionless

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توصيف خصائص السوائل وتحليل الكسر الزائف للزيوت ذات نسبة الغاز المنخفضة

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الخلاصة

يُعتبر مكمن السعدي من أكبر وأهم مكامن النفط الصخري الغير التقليدية في جنوب العراق. إلا أنه يعاني من انخفاض معدلات الإنتاج، مما يتطلب العديد من استراتيجيات التطوير التي تتطلب توصيفًا دقيقًا وموثوقًا لخصائص سوائل المكمن. في الأصل، يتم الحصول على هذه الخصائص من التجارب المعملية، وعلى الرغم من دقة سير العمل التجريبي، إلا أن الأخطاء الكبيرة في دقة القياسات غالبًا ما تحدث، مما يؤثر سلبًا على حساب خصائص سوائل المكمن. تهدف هذه الدراسة إلى استخدام برنامج (PVTp) لتوصيف الديناميكا الحرارية للسوائل لإنشاء نموذج موثوق يمكن استخدامه للحصول على خصائص نفط مكمن السعدي. تم تطوير منهجية لمحاكاة اختبارات الديناميكا الحرارية للسوائل، بما في ذلك اختبارات التحرير التفاضلي (DL) و تمدد التركيب الثابت (CCE). يمكن تحقيق ذلك من خلال تعديل معادلة الحالة بينج–روبنسون (PR-EOS) عن طريق تقسيم وتجميع الكسور الموجبة +C7، ومعايرة Ω لمطابقة نتائج النموذج مع البيانات التجريبية باستخدام عملية الانحدار للبيانات. يستخدم نموذج معادلة الحالة بينج–روبنسون متوسط الخطأ المطلق (AAE) كمعيار لأداء النموذج. حقق النموذج قيمه متوسط خطأ مطلق (AAE) قدره ١٪ لتقدير الحجم النسبي، و٠٪ لتقدير كثافة النفط، و٠.٤١٪ لتقدير عامل حجم تكوين النفط، و٤٪ لتقدير لزوجة النفط، و٥٪ لتقدير نسبة الغاز إلى الزيت. يُعد هذا أعلى قيمه متوسط خطأ مطلق (AAE) مُسجل للبيانات، ولكنه يُمثل أعلى قيمة ضمن الحد المقبول. أثبت نموذج PR-EOS أنه بديل دقيق لتوصيف السوائل، ويمكن تطبيقه على بيانات حقلية مماثلة، مما يوفر أداة قيّمة لإدارة المكامن، وتحسين الأداء، وخفض التكاليف مستقبلًا.

الكلمات الدالة: مكمن السعدي، معادلة الحالة، نمذجة الضغط والحجم والحرارة، التقسيم والتجميع، الانحدار.