Available online atwww.uofk.edu
Proceedings Vol. 1 pp. 1-6
Annual Conference of Postgraduate Studies and Scientific Research
17-20 February 2012-10-17 Friendship
Hall, Khartoum

Prediction of PVT Properties of a Sudanese Crude Oil

(Block 3 and Block 7 as a Case Study)

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Abstract: Pressure, volume and temperature (PVT) data is extensively used in the design of oil production and transportation facilities. The purpose of this study is to predict PVT properties for a Sudanese crude oil at pressures above boiling point pressure using Equations of State (EOSs). Eight of the most widely known EOSs are used; namely Patel-Teja (PT), Peng-Robinson (PR), Modified Peng-Robenson (MPR), Schmidt-Wenzel (SW), Harmens-Knapp (HK), Van Der Waal (VDW), Soave- Redlich-Kwong (SRK) and Lawal-Lake-Silberberg (LLS). For the calculation of PVT from EOSs a computer code is written using MATLAB software. To validate the prediction procedure, experimental PVT is obtained from the Ministry of Petroleum, Sudan. It represents eight (8) crude oil samples compromising 112 data points of constant mass expansion (CME) test at pressure above the boiling point.

Keywords:EOSs, PVT, Sudanese Crude Oil.

1. INTRODUCTION

Three methods are available to calculate PVT data those methods are: Lab Test, Correlations and Equations of state. The first two methods have some limitations as will be illustrated bellow.

1.1Lab Test:

Such experimental data are not always available because of one or more of the following reasons:

- Reservoir samples collected are not reliable.
- PVT analyses are not available when data are needed.
- Obtaining an accurate PVT behavior of each reservoir fluid encountered will be costly and time-consuming.

1.2 Correlations:

These correlations are applicable only at a well-defined range of temperature and pressure. So they cannot be used for the Sudanese crude.
According to the above mentioned reasons I choose to use the Equation of state method as a calculation method for this thesis.

1.3 Equations of state:

An equation of state has been defined as an analytical expression relating the pressure to the volume and temperature. Equation of state (EOS) is used to describe the volumetric behavior, the vapor/liquid equilibra (VLE) and thermal properties of pure substances and mixtures.
The equation of state has to be expressed in the form of the defining equation for the particular reservoir properties it is describing. For the isothermal compressibility, the equation of state is expressed in volume and partially differentiated with respect to pressure at constant temperature. Also, since the evaluation of the isothermal compressibility involves the derivatives of the volumetric data, the possible deviation in these quantities is much greater than is encountered with the volumetric data only. [Olaoluwa, 2006]

1.4 History

Since the introduction of the equation of state by Van der Waals, many equation of state (EOS) having the form of Van der Waal's equation have been proposed. Two of the most common and popularly accepted EOS is the Redlich-

Kwong (RK EOS) and Peng Robinson (PR EOS). The Redlich-Kwong equation has been the most popular basis for developing new EOSs. Several modifications of the Redlich-Kwong equation have found acceptance, with Soave's modification (SRK EOS) being the simplest and the most widely used. Another trend has been to propose generalized three-, four-, and five – constant cubic equations that can be simplified into the PR EOS, RK EOS and other familiar forms. The Lawal-Lake-Siberberg (LLS EOS) is a four parameter EOS, which can be reduced to both the PR EOS and the RK EOS. [Kumar, 2004]

2.OBJECTIVE

The objective of this thesis is to predict PVT properties for a Sudanese crude oil at pressures above the boiling point pressure and at the reservoir temperature, and to assess the accuracy of the eight EOSs against the empirical data. Eight EOSs are used to predict these properties for eight data sheets represent the reservoir data of different wells from different petroleum fields.

3. STUDY

Equations of state are applied to multi-component systems by the use of mixing rules to calculate the constant terms of the EOS (a, b, β, α) that will represent the multi-component system. The mixture parameters used in the study are defined as,

$$a_m = \sum_i^n \sum_j^n x_i x_j (a_i a_j)^{0.5} \delta_{ij} \quad (1)$$

$$b_m = \left(\sum_i^n x_i b_{\cdot}^{1/3}\right)^3 \quad (2)$$

$$\alpha_m = \sum_i^n \sum_j^n x_i x_j (\alpha_i \alpha_j)^{0.5} \delta_{ij} \quad (3)$$

$$\beta_m = \sum_i^n \sum_j^n x_i x_j (\beta_i \beta_j)^{0.5} \delta_{ij} \quad (4)$$

The binary interaction parameter δ_{ij} is generally determined by minimizing the difference between predicted and experimental data. A binary interaction parameter should therefore be considered as a fitting parameter and not a rigorous physical term. The interaction parameters between hydrocarbon systems with little difference in size are generally considered to be unity, but values of the binary interaction parameters for non-hydrocarbon–hydrocarbon system may not be 1. [Olaoluwa,2006], For this study the binary interaction parameter is taken as unity, because the reservoir fluids used in the study does not have significant amount of non-hydrocarbons.

Characterization of Heavy Petroleum Fractionsto determine the properties of the heptane-plus (C7+), which account for the heavy component in the multi-component reservoir fluid system, we use a correlation proposed by Lawal-Tododo-Heinze.

The correlation expressed the critical pressure (Pc), critical temperature (Tc), acentric factor (ω), boiling point (Tb) and critical z-factor (zc) as a function of apparent molecular weight (M) and specific gravity (Sg) of the pseudo-component. [Olaoluwa,2006]

$$P_c = 3.1839 * 10^4 M^{-0.93426} S_g^{1.64074} T_b^{0.49447} C^{-2.39909} \quad (5)$$

$$T_c(R) = 66.3775 M^{0.12286} S_g^{0.47926} T_b^{0.41286} C^{-0.35734} \quad (6)$$

$$\omega = 4.54949 * 10^{-9} M^{0.02445} S_g^{-2.08511} T_b^{2.903798} C^{-1.54424} \quad (7)$$

$$T_b(R) = 108.7017 M^{0.4225} S_g^{0.4268} \quad (8)$$

$$z_c = \frac{0.293}{1+0.375\omega} \quad (9)$$

$$C = \frac{3.8501}{1.54057 - 0.02494\sqrt{M}} \quad (10)$$

4. MATERIAL

The data sheets for eight wells from block 3 and block 7 southern east Sudan are provided composition and reservoir temp together with specific volume data against pressure are also provided.

Table (1). Analysis of samples composition in mole %

com	A1	A2	A3	A5	A6	B3	B4	B5
N2	0.16	0.33	0.2	0.18	0.43	0.25	0.21	0.21
CO2	4.88	5.04	2	1.26	2.48	8.7	4.52	11.1
H2S	0	0	0	0	0	0	0	0
C1	1.23	1.33	1.69	1.44	2.53	1.75	1.31	3.37
C2	0.14	0.14	0.27	0.27	0.36	0.16	0.06	0.6
C3	0.12	0.11	0.25	0.31	0.24	0.11	0.05	0.42
iC4	0.04	0.03	0.12	0.13	0.06	0.02	0.02	0.1
nC4	0.06	0.06	0.27	0.33	0.09	0.04	0.03	0.24
iC5	0.03	0.02	0.22	0.23	0.04	0.01	0.01	0.1
nC5	0.04	0.03	0.37	0.41	0.04	0.02	0.02	0.18
C5 neo-Pentane	0	0	0	0	0	0	0	0
C6	0.05	0.05	1.04	1.08	0.04	0.02	0.03	0.54
Me-Cyclo-pentane	0	0	0.21	0.21	0	0	0	0.1
Benzene	0	0	0.04	0.06	0	0	0	0.02
Cyclo-hexane	0	0	0.13	0.15	0	0	0	0.07
C7	0.03	0.04	1.67	1.69	0.02	0.02	0.02	0.83
Me-Cyclo-hexane	0	0	0.53	0.51	0	0	0	0.23
Toluene	0	0	0.05	0.05	0	0	0	0.03
C8	2.42	2.34	2.8	2.81	2.13	0.44	2.26	1.4
Ethyl-benzene	0	0	0.15	0.14	0	0	0	0.13
Ortho-xylene	0	0	0.06	0.07	0	0	0	0.03
C9	4.25	4.11	3.8	3.96	4.36	3.25	4.36	2.17
C10	4.58	4.35	4.55	4.29	4.54	3.67	3.88	2.34
C11	4.13	4.2	4.43	4.48	4.45	3.15	3.95	2.63
C12	4.62	4.48	4.4	4.49	5	3.86	3.87	2.79
C13	4.67	4.71	4.55	4.71	4.87	3.6	3.89	3.27
C14	4.05	4.01	4.29	4.33	3.74	3.13	3.76	3.32
C15	4.67	4.68	4.32	4.48	4.72	4.12	4.07	3.6
C16	3.9	3.9	3.74	3.79	3.83	3.48	3.82	3.27
C17	3.25	3.28	3.42	3.46	3.39	3.45	3.78	3.21
C18 s	3.45	3.47	3.37	3.44	3.49	3.27	3.43	3.31
C19	3.29	3.29	3.16	3.21	2.96	3.15	3	2.94
C20	3.15	3.15	2.85	2.91	3.54	2.68	3.03	2.54
C21	2.97	2.97	2.72	2.79	2.54	2.74	2.82	2.51
C22	2.84	2.82	2.63	2.69	2.87	2.71	2.69	2.38
C23	2.57	2.57	2.6	2.66	2.6	2.65	2.83	2.45
C24	2.76	2.74	2.53	2.57	2.74	2.86	2.81	2.34
C25	2.65	2.63	2.54	2.59	2.52	2.76	2.59	2.49
C26	2.28	2.31	2.42	2.48	2.49	2.71	2.82	2.41
C27	2.7	2.68	2.36	2.42	2.47	3	2.9	2.56
C28	2.6	2.6	2.11	2.17	2.26	2.89	2.77	2.24
C29	2.15	2.15	2.02	2.12	2.3	2.85	2.68	2.32
C30	2.08	2.08	1.87	1.91	1.98	2.64	2.26	2.05
C31	1.68	1.69	1.69	1.76	1.83	2.2	2.01	1.96
C32	1.62	1.64	1.43	1.48	1.4	1.91	1.65	1.63
C33	1.34	1.34	1.23	1.27	1.27	1.55	1.41	1.39
C34	1.15	1.15	1.04	1.06	1.12	1.35	1.22	1.16
C35	1.11	1.11	0.95	0.96	0.9	1.15	1.14	1.06
C36+	10.29	10.37	10.6	9.8	11.36	11.68	12.02	13.5

Table (2). Analysis of samples composition in wt %

com	A1	A2	A3	A5	A6	B3	B4	B5
N2	0.02	0.03	0.02	0.01	0.04	0.02	0.02	0.02
CO2	0.74	0.76	0.26	0.16	0.37	1.26	0.66	1.38
H2S	0	0	0	0	0	0	0	0
C1	0.07	0.07	0.08	0.07	0.14	0.09	0.07	0.15
C2	0.01	0.01	0.02	0.02	0.04	0.02	0.01	0.05
C3	0.02	0.02	0.03	0.04	0.04	0.02	0.01	0.05
iC4	0.01	0.01	0.02	0.02	0.01	0	0	0.02
nC4	0.01	0.01	0.05	0.05	0.02	0.01	0.01	0.04
iC5	0.01	0.01	0.05	0.05	0.01	0	0	0.02
nC5	0.01	0.01	0.08	0.08	0.01	0	0	0.04
C5 neo-Pentane	0	0	0	0	0	0	0	0
C6	0.01	0.01	0.26	0.26	0.01	0.01	0.01	0.13
Me-Cyclo-pentane	0	0	0.05	0.05	0	0	0	0.02
Benzene	0	0	0.01	0.01	0	0	0	0
Cyclo-hexane	0	0	0.03	0.04	0	0	0	0.02
C7	0.01	0.01	0.49	0.48	0.01	0.01	0.01	0.24
Me-Cyclo-hexane	0	0	0.15	0.14	0	0	0	0.07
Toluene	0	0	0.01	0.01	0	0	0	0.01
C8	0.89	0.86	0.94	0.91	0.78	0.15	0.8	0.45
Ethyl-benzene	0	0	0.05	0.04	0	0	0	0.04
Ortho-xylene	0	0	0.02	0.02	0	0	0	0.01
C9	1.77	1.71	1.42	1.43	1.79	1.29	1.74	0.79
C10	2.11	2	1.89	1.72	2.07	1.62	1.72	0.94
C11	2.09	2.12	1.9	1.86	2.23	1.52	1.92	1.09
C12	2.55	2.48	2.07	2.04	2.74	2.05	2.06	1.27
C13	2.81	2.83	2.33	2.32	2.9	2.07	2.25	1.62
C14	2.64	2.62	2.38		2.42	1.96	2.36	1.79
C15	3.3	3.31	2.6	2.6	3.31	2.79	2.77	2.1
C16	2.97	2.97	2.42	2.38	2.9	2.54	2.8	2.06
C17	2.64	2.67	2.37	2.32	2.73	2.69	2.96	2.15
C18 s	2.97	2.99	2.47	2.44	2.98	2.7	2.85	2.35
C19	2.97	2.97	2.43	2.38	2.65	2.73	2.61	2.19
C20	2.97	2.97	2.29	2.26	3.31	2.43	2.75	1.98
C21	2.97	2.97	2.32	2.29	2.52	2.63	2.71	2.07
C22	2.97	2.95	2.34	2.32	2.98	2.73	2.71	2.05
C23	2.81	2.81	2.41	2.39	2.81	2.77	2.97	2.2
C24	3.14	3.12	2.44	2.4	3.09	3.12	3.08	2.19
C25	3.14	3.11	2.56	2.52	2.96	3.14	2.95	2.43
C26	2.81	2.84	2.54	2.52	3.05	3.2	3.35	2.45
C27	3.47	3.44	2.58	2.56	3.14	3.7	3.59	2.72
C28	3.47	3.47	2.39	2.37	2.98	3.7	3.56	2.46
C29	2.97	2.97	2.37	2.41	3.14	3.78	3.56	2.64
C30	2.97	2.97	2.27	2.25	2.8	3.61	3.11	2.42
C31	2.48	2.5	2.12	2.13	2.67	3.12	2.86	2.39
C32	2.48	2.5	1.85	1.85	2.11	2.79	2.42	2.05
C33	2.11	2.1	1.64	1.64	1.97	2.34	2.14	1.8
C34	1.86	1.86	1.44	1.42	1.79	2.09	1.9	1.55
C35	1.86	1.86	1.34	1.32	1.49	1.85	1.84	1.46
C36+	24.89	25.08	38.1	38.96	26.99	27.45	26.86	43.95

5. METHODS

A computer algorithm was written to solve for volume of oil above boiling point pressure using MATLAB software. The procedure for calculating the volume is stated below.

- Calculate Zc Pc Tc and acentric factor for heavy petroleum compounds C36+ and C20+ starting from molecular weight for these compounds in the reservoir.
- Read in the temperature T (R), pressure p (psia) , universal gas constant R (psia cu ft/lb mole/R), critical temperature , critical pressure and acentric factor for all components in the mixture (C1 through C36+)
- Calculate the EOS parameter "a" and "b" for the multi-component system (C1 through C36+) using kays mixing rule.
- Determine the coefficient of the cubic equation.
- Determine the roots of the equation .If there are three real roots; the smallest root corresponds to the root of the multi-component oil system.
- Calculate the volume from the compressibility factor.
- Repeat these calculations for different pressures.
- Repeat these calculations for different EOSs.
- Repeat these calculations for different mixtures.

There are no unknowns in the volume equation .The universal gas constant R and the reservoir temperatures T are known. The EOS parameters "a" and "b" can be calculated using the critical properties and the mixing rules.

6. RESULTS

Table (3). Summary of Grand AAPD

Sample	PR	PT	SRK	MPR	SW	HK	LLS	VDW
A1	146%	11%	62%	153%	26%	41%	159%	58%
A2	65%	9%	68%	67%	22%	42%	111%	59%
A3	361%	20%	5%	375%	64%	93%	331%	96%
A5	365%	27%	118%	381%	69%	104%	338%	97%
A6	83%	2%	81%	88%	33%	56%	141%	54%
B3	274%	4%	76%	208%	79%	34%	80%	42%
B4	148%	8%	100%	163%	45%	37%	173%	58%
B5	67%	9%	75%	69%	29%	47%	121%	63%
AAPD	189%	11%	73%	188%	46%	57%	182%	66%

Table (4). Summary of Max AAPD

Sample	PR	PT	SRK	MPR	SW	HK	LLS	VDW
A1	685%	14%	99%	693%	52%	76%	502%	128%
A2	219%	12%	98%	244%	40%	47%	217%	79%
A3	1371%	35%	19%	1396%	103%	117%	1051%	240%
A5	1402%	62%	146%	1432%	111%	120%	1058%	257%
A6	352%	4%	90%	376%	55%	63%	293%	76%
B3	1225%	8%	100%	1125%	99%	47%	100%	58%
B4	458%	13%	119%	507%	75%	40%	353%	89%
B5	201%	11%	85%	233%	46%	55%	213%	83%
AAPD	739%	20%	95%	751%	73%	71%	473%	126%

Table (5). Summary of Min AAPD

Sample	PR	PT	SRK	MPR	SW	HK	LLS	VDW
A1	1%	10%	17%	16%	15%	33%	87%	7%
A2	2%	9%	67%	4%	14%	38%	85%	15%
A3	23%	14%	0%	16%	29%	32%	113%	12%
A5	15%	20%	3%	20%	41%	48%	132%	13%
A6	3%	0%	57%	2%	26%	51%	107%	11%
B3	13%	1%	93%	10%	99%	39%	99%	48%
B4	8%	4%	41%	23%	17%	33%	87%	3%
B5	7%	6%	70%	10%	16%	40%	80%	17%
AAPD	9%	8%	44%	13%	32%	39%	99%	16%

7. DISCUSIONS

All selected EOSs had shown a large deviation against the experimental volume. This deviation is due to C36+ and C20+ components .Since these components have a large weight in the reservoir although there is no laboratory analysis for the critical properties and acentric factor, all these properties had been estimated from the available equations in literature which may not be very accurate estimations.

The results of three parameter equations are much better than two and four parameter equations, PT & SW gave good results for high pressures rather than law pressures, PT gave grand AAPD of 11% and it is the only equation among the three parameter equations that did not used a, b and c coefficients as a function of the acentric factor.

8. CONCLUSION

EOS calculation technique is introduced for predicting of liquid volume for Sudanese reservoir from different wells. The behaviour of eight equations has been examined using a developed program inside MATLAB soft ware.PT equation of state had shown good capability to predict the volume for all different wells in pressures above boiling point pressure. All other equations of state had shown poor predictability against Sudanese reservoir.

9. RECEMMENDATIONS

The research was conducted using empirical and lab data ,in order to obtain a reliable results it is recommended to obtain all the data from the lab test specially for petroleum compounds C36+and C20+,and to conduct further studies on the modifications of PT equation of state**.**

ACKNOWLEDGEMENT

I deeply want to thank two persons how were behind this thesis my colleague Skeina Adam for her useful advices and my beloved sister Aisha for her great assistance.

I also want to thank Dr.AliRabah for his close supervision and assistance on data collection.

My thanks extend to Dr.TajalasfiaaMr.Taha and Mr.Norani for their assistance in MATLAB program.

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