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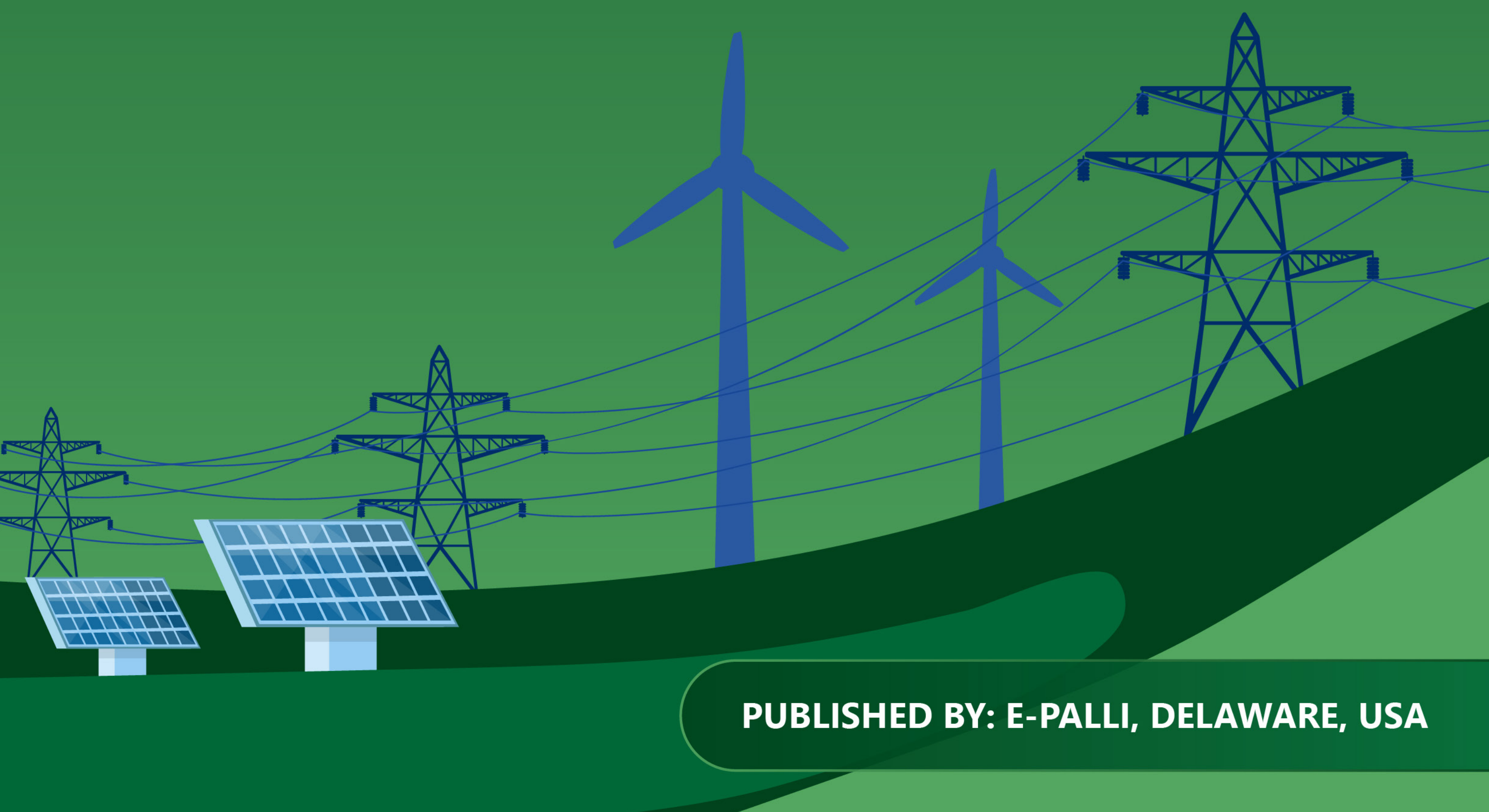

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Laboratory and Theoretical investigations of Petroleum Reservoir Fluid Properties

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ABSTRACT

Understanding the Pressure-Volume-Temperature (PVT) properties is very important to many kinds of petroleum determinations like calculations of reservoir fluid properties; expect the future performance, selection of enhanced oil recovery methods, and for production facilities design. Models for expecting reservoir fluid properties has been increased attention during last decade by knowing reservoir pressure and temperature, oil API gravity, and gas gravity. In general, PVT properties are obtained from laboratory experiments but in some cases In this study, complete PVT lab experiments were done and evaluated the most frequently used empirical black oil PVT correlations for application in the Middle East. Empirical PVT Correlations for the Middle East crude oil was compared as a function of commonly available PVT data. Correlations compared for: Bubble point pressure, solution gas oil ratio, oil formation volume factor, oil density, and oil viscosity. After evaluating the Empirical correlations, the crude sample was characterized using different EOS to arrive at one EOS model that accurately describes the PVT behavior of crude oil produced. The multi-sample characterization method is used to arrive at one consistent model for crude oil for the whole reservoir. The fluid sample is first analyzed for consistency to ensure that they are representative of oil produced, then it is used to obtain parameters for EOS model. The tuning procedure for the EOS is done systematically by matching the volumetric and phase behavior results with laboratory results. Results showed that some correlations give good results in PVT properties compared to the laboratory and can be used with Libyan oil, while some give a high percentage of error.

INTRODUCTION

The Pressure-Volume-Temperature (PVT) properties are very important to many kinds of petroleum determinations like calculations of reservoir fluid properties; expect the future performance, selection of enhanced oil recovery methods, and production facilities design. Models for expecting reservoir fluid properties has been increased attention during last decade by knowing reservoir pressure and temperature, oil API gravity, and gas gravity. In general, PVT properties are obtain from laboratory experiments but in some cases correlations are used whenever experimentally derived PVT data are not available and data from local regions are expected to give better approximation to estimated PVT values. Also, Equations of State, EOS, are increasingly being used to model fluid properties of crude oil and gas reservoirs. This technique offers the advantage of an improved fluid property prediction over conventional black oil models. Once the crude oil or condensate fluid system has been characterized, its PVT behavior under various conditions can easily be studied. This description is then used, within a compositional simulator, to study and choose among different scenarios.

PVT properties are obtained from laboratory experiments but in some cases

In this study, complete PVT lab experiments were done and evaluated the most frequently used empirical black oil PVT correlations for application in the Middle East. Empirical PVT Correlations for Middle East crude oil have been compared as a function of commonly available PVT data. Correlations have been compared for: Bubble point pressure, solution gas oil ratio, oil formation volume factor, oil density, and oil viscosity. After evaluating the Empirical correlations, the crude sample was characterized using different EOS to arrive at one EOS model that accurately describes the PVT behavior of crude oil produced.

The multi-sample characterization method is used to arrive at one consistent model for crude oil for the whole reservoir. The fluid sample is first analyzed for consistency to ensure that they are representative of oil produced, then it is used to obtain parameters for EOS model. The tuning procedure for the EOS is done systematically by matching the volumetric and phase behavior results with laboratory results.

Objectives

This study aims to achieve these goals:

1. Understanding the main PVT experiments for reservoir fluids and learn the importance of their design and results.
2. Using PVT analysis report to calculate oil physical properties, in this study
   - > Bubble Point Pressure, Pb
   - > Oil Formation Volume Factor, FVF, Bo
   - > Gas Oil Ratio, Rs
   - > Oil Density, ϱo
   - > Oil Viscosity, μo
3. Using most of the Empirical PVT correlations to determine the previous sample physical properties by

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designing Excel software.
4. Evaluation the Empirical PVT correlations by Comparison the results from the observation data from the lab experiments and the results getting from the correlations.
5. Understanding and training on Eclipse software just for PVTi software and understanding the function of different E.O.S.
6. Test Equation of State's ability to predict the PVT properties by matching the PVT lab data with different E.O.S.
7. Appreciate the need for E.O.S tuning, the role of experimental data and parameters used for tuning.
8. Developed new PVT correlations for one Libyan oil field just for:
   * Bubble Point Pressure, Pb

METHODOLOGY

In this study we select one Libyan crude oil which was heavy oil (Black oil) to do all routine lab PVT experiments For bottom hole sample the following sequence of PVT tests are proposed:
   * Select most representative sample
   * Flash to atmospheric conditions
   * Constant mass study (PV Relation)
   * Differential vaporization
   * Separation test
   * Viscosity determination
   * Calculations
   * Final report

The authors tried to develop new correlations for Libyan crude oil to estimate the following properties by using regression analysis by Data Fit software.
   * Bubble Point Pressure, Pb

Experimental PVT data were collected from different reservoirs in the Sirte basin area.
In this study, we use the PVTi software to simulate the Laboratory PVT data by using three scenarios:
Scenario 1: the component up to C_7+(with impurities N_2, CO_2, H_2S)
Scenario 2: Grouping component up to C_7+(N_2–C_1), (CO_2-C_2), (iC_4-nC_4), (iC_5-nC_5)
Scenario 3: all components up to C30+
We notes that the three scenarios need tuning
In this study, we choose three parameters for regression:
Regression 1: the change in binary interaction parameter (BIP)
Regression 2: the change in omega a parameter (Ωa)
Regression 3: the change in acentric factor parameter (ω)

RESULTS AND DISCUSSION

Authors developed new correlations for Libyan crude oil to estimate the following properties by using regression analysis by DataFit software.
   * Bubble Point Pressure, Pb

Experimental PVT data were collected from different reservoirs in the Sirte basin area.
   * Direct Flash of Bottom Hole Sample to Atmospheric Conditions

At Pr = 3000 Psia and Tr = 204 F^0

GOR, Scf/STB	Bo, bbl/STB	Gas Gravity	Oil Density, gm/cc	APIo
93	1.0965	0.8374	0.8930	26.95
PV Relation				
Bubble Point Pressure, Psia		660		

Table 1: Constant Mass Expansion

Pressure, Psia	Relative Volume, Vr/Vb	Y-Function
3000	0.9769	
2750	0.9795	
2686 Pr	0.9803	
2500	0.9821	
2250	0.9835	
2000	0.9852	
1750	0.9875	
1500	0.9900	
1250	0.9925	
1000	0.9950	
800	0.9973	
660 Pb	1.0000	
600	1.0329	3.04
500	1.1087	2.94

450	1.1613	2.89
400	1.2286	2.84
300	1.4375	2.74
200	1.8702	2.64
100	3.2021	2.54
85	3.6759	2.53

Table 2: Differential Liberation Test

P,Psia	Rs	RL	Bo	Den,gm/cc	Den.,Ib/cf	G.G	Z factor	Bg
3000			1.1175	0.8145	50.82			
2750			1.1205	0.8123	50.69			
2686 Pr			1.1214	0.8116	50.65			
2500			1.1235	0.8101	50.55			
2250			1.1251	0.8090	50.48			
2000			1.1270	0.8076	50.39			
1750			1.1297	0.8057	50.28			
1500			1.1325	0.8037	50.15			
1250			1.1354	0.8017	50.02			
1000			1.1382	0.7996	49.90			
800			1.1409	0.7978	49.78			
660 Pb	99	0	1.1440	0.7956	49.65			
450	80	20	1.1314	0.8016	50.02	0.7693	0.9651	0.04029
300	63	36	1.1169	0.8093	50.50	0.8051	0.9734	0.06095
200	50	50	1.1043	0.8163	50.94	0.8371	0.9802	0.09206
100	31	68	1.0915	0.8225	51.33	0.9118	0.9888	0.18574
15	0	99	1.0754	0.8283	51.69	1.0250	0.9981	1.24992

Table 3: Separator Test

Stage	**Psep , Psia**	**Tsep, Fo**	**GOR, Scf/STB**	**Bo, bbl/STB**
1	65	70	65	1.0710
2	**30**	**45**	**24**	**0.9922**

Table 4: Viscosity Test

Pressure, Psia	Oil Viscosity, cp
3000	5.250
2750	5.198
2686 Pr	5.184
2500	5.146
2250	5.104
2000	5.058
1750	5.028
1500	4.997
1250	4.975
1000	4.957
800	4.924

660 Pb	4.915
450	5.063
300	5.147
200	5.251
100	5.372
15	5.705

Empirical Correlations

Table 5: The most Empirical correlations used in this study

Property	B.P.P.	Bo	Rs	Viscosity
Correlations	Standing	Standing	Standing	Beal
	Vasquez & Beggs	Vasquez &Beggs	Vasquez &Beggs	Beggs& Robinson
	Glaso	Glaso	Al-Marhoun	Glaso
	Al-Marhoun	Al-Marhoun	Glaso	Chew &Connally
	Petrosky&Farshad	Petrosky&Farshad	Petrosky&Farshad	Vasquez &Beggs
	Dokla& Osman	Material Balance	Velarde	
	Mohsen Khazam	Schmidt	Hanafy	
	Valko&Mccain	Arps	De Ghetto	
	Omar&Todd			
	Al-shammasi			
	Macary&Elbatanoney			
	Mehran			

Bubble Point Pressure

The Experimental Pb = 660Psia

The next table show the comparison and the absolute error percentage between the experimental and the calculated Pb by using most of the Empirical correlations.

Table 6: Experimental and Calculated Pb

Correlation	Experimental Pb	Calculated Pb	Abs. Error %
Standing	660	615	6.8
Glaso	660	596	10.7
Vesquez	660	609	7.7
Marhoun	660	746	11.5
Petrosky	660	632	4.4
Dokla	660	539	18.3
Mohsen Khazam	660	797	20.8
Valko&Mccain	660	631	4.4
Omar&Todd	660	702	6.3
Al-shammasi	660	667	1.1
Macary&Elbatanoney	660	806	22
Mehran	660	652	1.2

Oil Formation Volume Factor

The Experimental Bo = 1.0965 bbl/STB

The next table show the comparison and the absolute error percentage between the experimental and the calculated Bo by using most of the Empirical correlations.

Table7: Experimental and Calculated Bo

Correlation	Experimental Bo	Calculated Bo	Abs. Error %
Standing	1.0965	1.1091	1.15
Glaso	1.0965	1.0802	1.5
Vesquez	1.0965	1.1189	2

Marhon	1.0965	1.1303	3
Petrosky	1.0965	1.0961	0.03
Material Balance	1.0965	1.0190	7
Schmidt	1.0965	1.1273	2.8
Arps	1.0965	1.0965	0

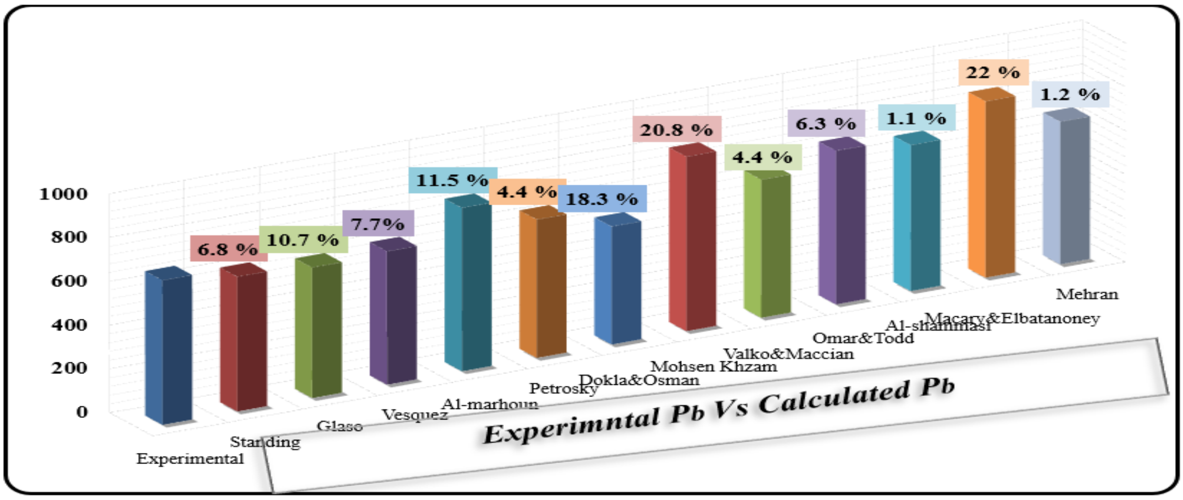

Figure 1: Shows the absolute deviation percentage of calculated Pb with the experimental one.

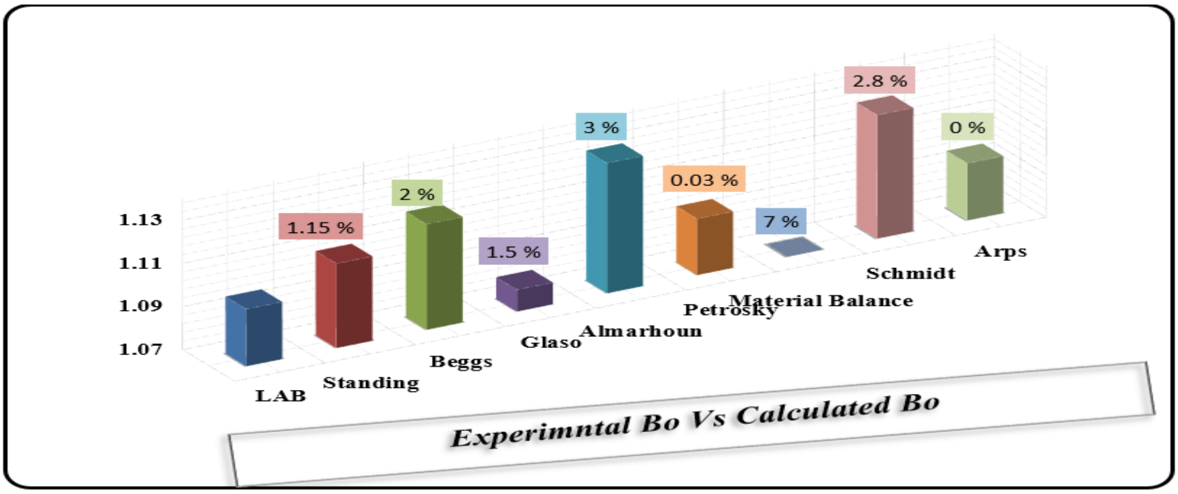

Figure 2: Shows the absolute deviation percentage of calculated Bo with the experimental one.

Gas Oil Ratio

The Experimental Rs = 93 Scf/STB

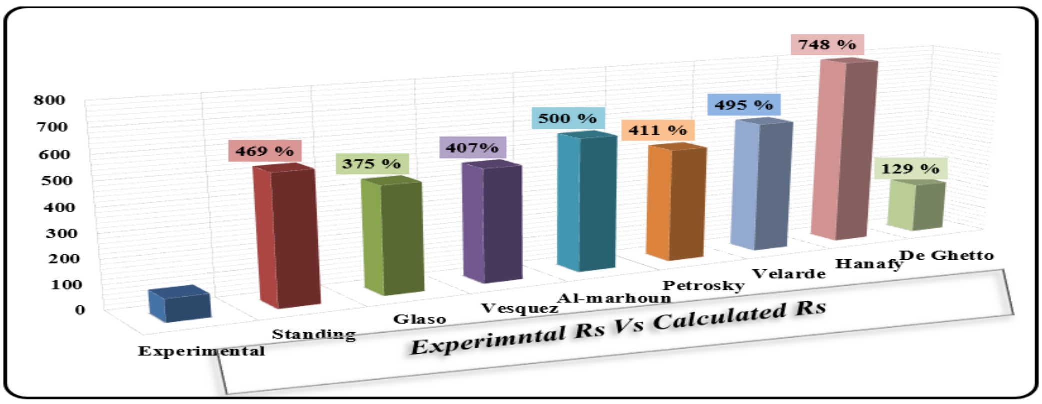

Figure 3: Shows the absolute deviation percentage of calculated Rs with the experimental one.

Oil Density

The Experimental ϱo = 0.8930 gm/cc, 55.723 Ib/cf

The next table show the comparison and the absolute error percentage between the experimental and the calculatedϱo by using most of the Empirical correlations.

Table 8: Experimental and Calculated ϱo

Correlation	Experimental ϱo	Calculated ϱo	Abs. Error %
Standing	55.723	51.015	8.45
Petrosky&Farshad	55.723	61.415	10.21
Vesquez&Beggs	55.723	51.006	8.47
Material Balance	55.723	51.785	7.07

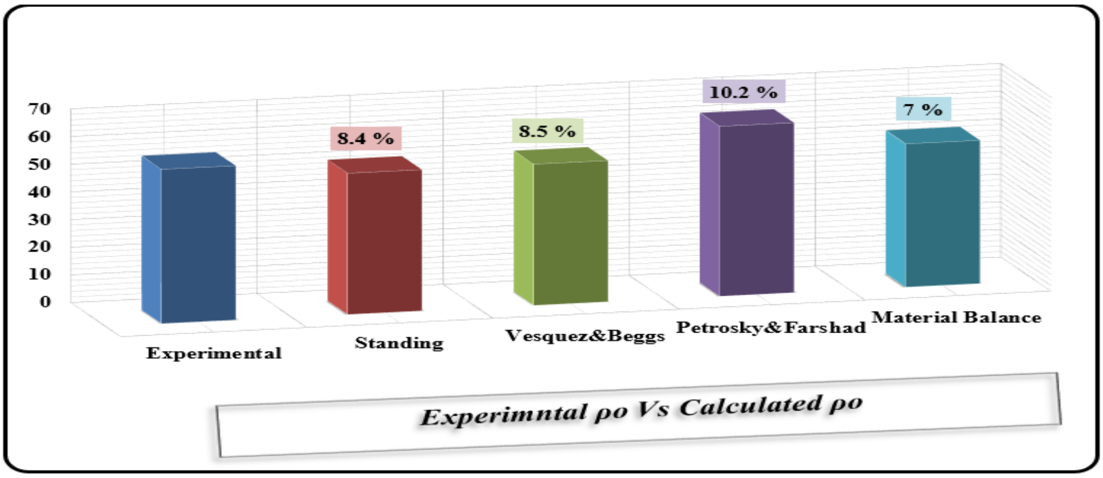

Figure 4: Shows the absolute deviation percentage of calculated ϱo with the experimental one.

Oil Viscosity

Experimental dead oil viscosity =5.705cp

Experimental bubble point (saturated) oil viscosity = 4.915 cp

Experimental under saturated oil viscosity at reservoir P=2686 psia& T =204 F^0 =5.184cp

To evaluate the Empirical correlations for estimating the oil viscosity we have to determine the viscosityby correlations in three faces which are at dead oil, saturated oil, and under saturated oil viscosity and compare them with the lab results.

Table 9: Experimental and Calculated Oil Viscosites

Dead Oil Viscosity			
Correlation	Experimental μod	Calculated μod	Abs. Error %
Beal's	5.705	3.334	41.5
Beggs	5.705	3.291	42.3
Glaso	5.705	3.793	33.5
Saturated Oil Viscosity			
Correlation	Experimental μob	Calculated μob	Abs. Error %
Chew	4.915	4.059	17.4
Beggs	4.915	3.129	36.3
Under-Saturated Oil Viscosity			
Correlation	Experimental μo	Calculated μo	Abs. Error %
Beggs	5.184	6.885	32.8

Equation of State

Simulation of PVT lab data by E.O.S (PVTisoftware):

In this study, we use the PVTi software to simulate the Laboratory PVT data by using three scenarios:

Scenario 1: the component up to C_7+(with impurities N_2, CO_2, H_2S)

Scenario 2: Grouping component up to C_7+(N_2–C_1), (CO_2-C_2), (iC_4-nC_4), (iC_5-nC_5)

Scenario 3: all components up to C30+

We notes that the three scenarios need tuning

In this study, we choose three parameters for regression:

Regression 1: the change in binary interaction parameter (BIP)

Regression2: the change in omega a parameter (Ωa)

Regression3: the change in acentric factor parameter (ω)

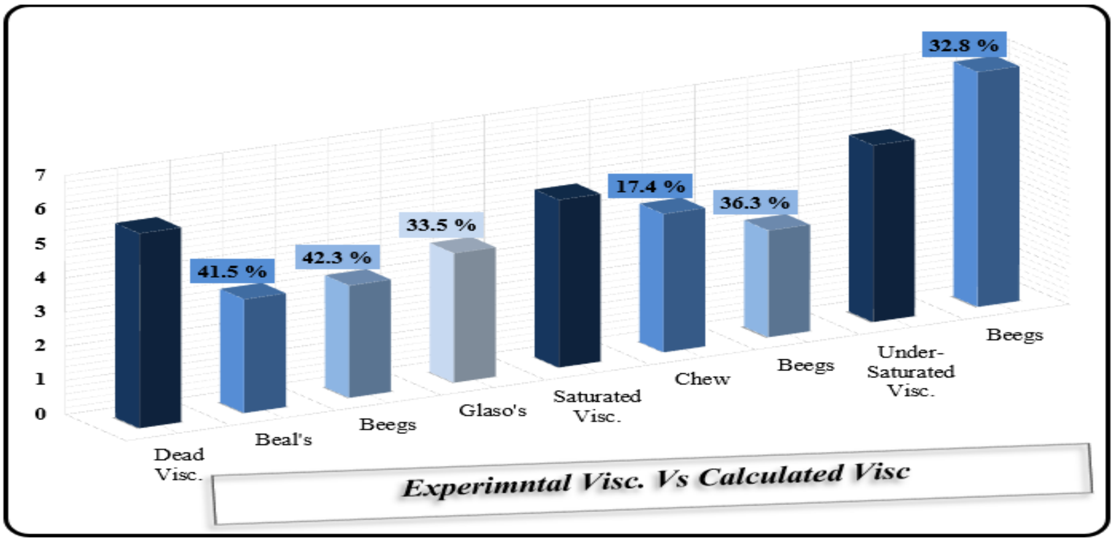

Figure 5: Shows the absolute deviation percentage of calculated viscosities with the experimental one.

RESULTS

All Scenarios before regression

Bubble point pressure, Original equations (before Regression)

Table 10: Pb before regression

Equation	Pb lab	C7+	ADD%	C7+ with grouping	ADD%	C30+	ADD%
PR3	660	403	39	361	45	375	43.2
SRK3	660	395	40	346	47.6	359	45.6
RK	660	267	59.5	246	62.7	252	61.8
ZJ	660	398	39.6	355	46	389	41
SW	660	403	39	361	45	375	43.2

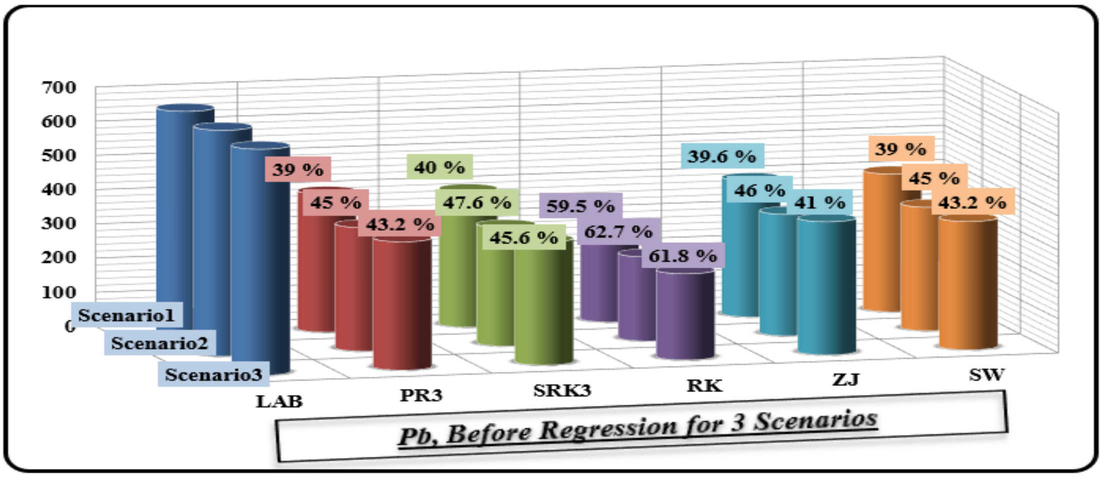

Figure 6: Pb before regression

Oil Formation Volume Factor, Original equations (before Regression)

Table 11: Bo before regression

Equation	Bo lab	C7+	ADD%	C7+ with grouping	ADD%	C30+	ADD%
PR3	1.0965	1.1151	1.7	1.1172	1.9	1.1622	6
SRK3	1.0965	1.1223	2.3	1.1242	2.5	1.1747	7.1
RK	1.0965	1.1791	7.5	1.1819	7.8	1.3758	25.4
ZJ	1.0965	1.1474	4.6	1.1493	4.8	1.2009	9.5
SW	1.0965	1.1181	1.9	1.1202	2.2	1.1571	5.5

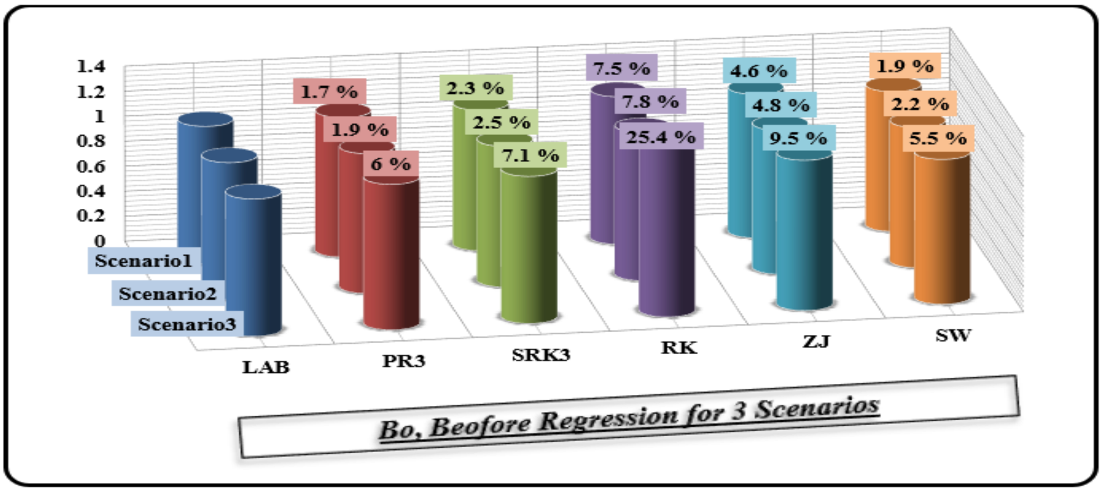

Figure 7: Bo before regression

Gas Oil Ratio, Original equations (before Regression):

Table 12: Rs before regression

Equation	Rs lab	C7+	ADD%	C7+ with grouping	ADD%	C30+	ADD%
PR3	93	81.9	12	81.7	12.2	82.2	11.6
SRK3	93	84.4	9.2	84.2	9.5	83.5	10.2
RK	93	74.3	20	74	20.4	72.5	22
ZJ	93	85.6	7.9	85.6	7.9	85.5	8
SW	93	82.3	11.5	82.1	11.7	77.6	16.5

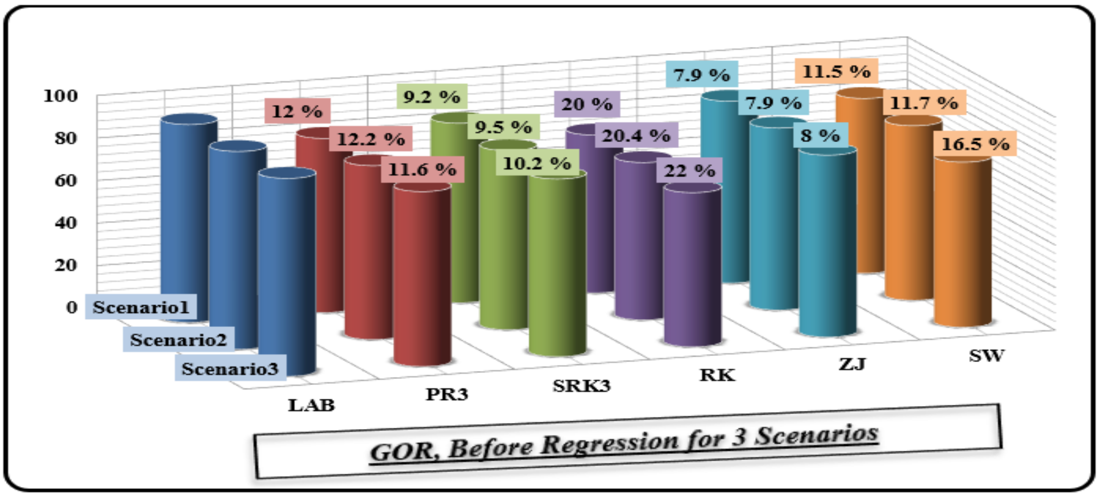

Figure 8: Rs before regression

Oil Density, Original equations (before Regression)

Table 13: ϱo before regression

Equation	ϱo lab	C7+	ADD%	C7+ with grouping	ADD%	C30+	ADD%
PR3	0.8930	0.7779	13	0.7775	12.9	0.7785	12.8
SRK3	0.8930	0.7812	12.5	0.7809	12.6	0.7801	12.6
RK	0.8930	0.6400	28.3	0.6398	28.4	0.6025	32.5
ZJ	0.8930	0.7793	12.7	0.7792	12.7	0.7800	12.6
SW	0.8930	0.7817	12.4	0.7814	12.5	0.7347	17.7

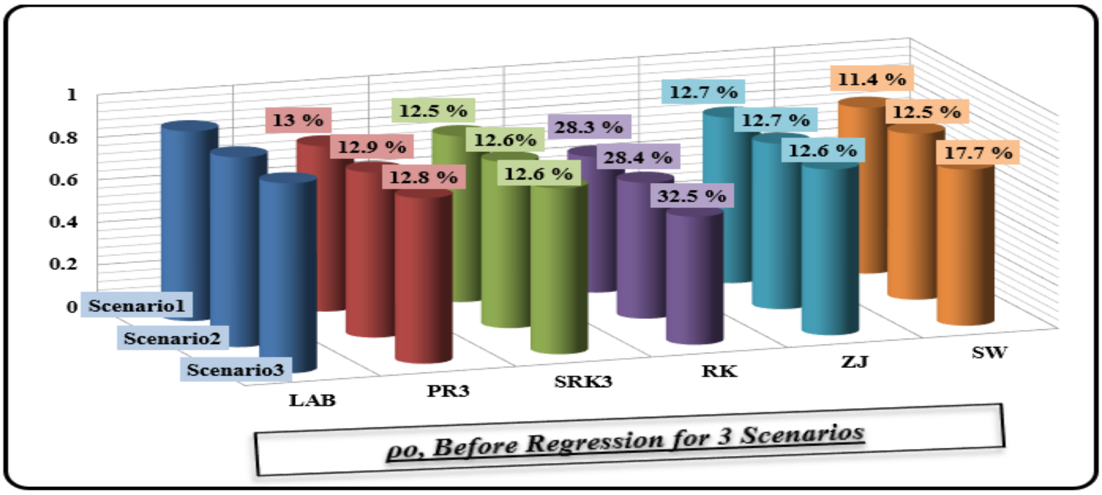

Figure 9: ρo before regression

Oil Viscosities, Original equations (before Regression)

Table 14: Viscositiesbefore regression

Dead Oil Viscosity							
Equation	**µod lab**	**C7+**	**ADD%**	**C7+ with grouping**	**ADD%**	**C30+**	**ADD%**
PR3	5.705	4.121	27.7	4.122	27.7	3.656	35.9
SRK3	5.705	3.834	32.7	3.833	32.8	3.322	41.7
RK	5.705	1.084	80.9	1.084	81	0.812	85.7
ZJ	5.705	3.420	40	3.423	40	3.284	42.4
SW	5.705	4.398	22.9	4.400	22.9	2.420	57.5
Saturated Oil Viscosity							
Equation	µob lab	C7+	ADD%	C7+ with grouping	ADD%	C30+	ADD%
PR3	4.915	3.674	25.3	3.667	25.3	3.192	35
SRK3	4.915	3.463	29.5	3.458	29.6	2.951	39.9
RK	4.915	1.072	78.2	1.071	78.2	0.833	83
ZJ	4.915	3.111	36.7	3.112	36.7	2.914	40.7
SW	4.915	3.829	22	3.822	22.2	2.204	55.1
Under-Saturated Viscosity							
Equation	µo lab	C7+	ADD%	C7+ with grouping	ADD%	C30+	ADD%
PR3	5.184	4.583	11.6	4.574	11.8	4.074	21.4
SRK3	5.184	4.617	10.9	4.609	11	4.057	21.7
RK	5.184	1.326	74.4	1.325	74.4	1.002	80.6
ZJ	5.184	3.827	26.2	3.828	26.6	3.599	30.5
SW	5.184	4.693	9.5	4.683	9.7	2.632	49.2

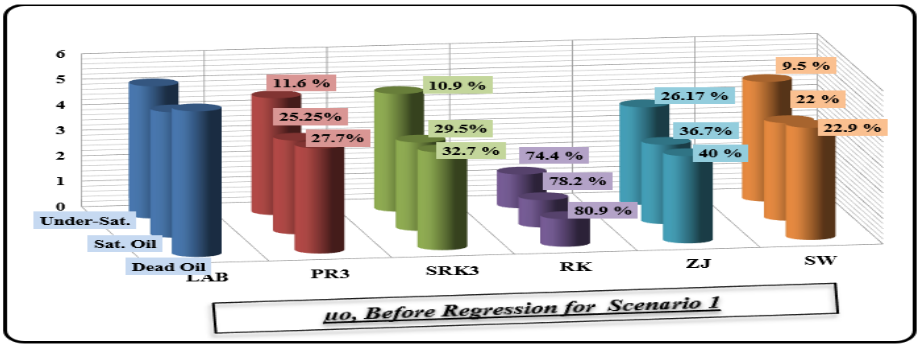

Figure 10: Viscositiesbefore regression

After Regression

Next tables show every property with three regressions for all scenarios:

Regression 1, the change in Binary Interaction Parameter (BIP)

Regression 2,the change in Omega a Parameter (Ωa)

Regression 3, the change in Acentric Factor Parameter (ω)

Bubble point pressure, (After Regression1)

Table 15: Pb After regression

Equation	Pb lab	C7+	ADD%	C7+ with grouping	ADD%	C30+	ADD%
PR3	660	551	16.5	522	21	380	42.4
SRK3	660	657	0.45	610	7.5	426	35.5
RK	660	403	39	387	41.4	278	57.9
ZJ	660	660	0	654	0.9	453	31.4
SW	660	551	16.5	522	21	380	42.4

Bubble point pressure, (After Regression2)

Table 16: Pb After regression 2

Equation	Pb lab	C7+	ADD%	C7+ with grouping	ADD%	C30+	ADD%
PR3	660	660	0	235	3.8	382	42.12
SRK3	660	660.18	0.02	660.07	0	428	35.15
RK	660	478	27.5	424	35.7	278	57.88
ZJ	660	660.3	0.04	660.02	0	454	31.21
SW	660						

Bubble point pressure, (After Regression 3)

Table 17: Pb After regression 3

Equation	Pb lab	C7+	ADD%	C7+ with grouping	ADD%	C30+	ADD%
PR3	660	473	28	419	36.5	379	42.6
SRK3	660	550	17	467	29.2	425	35.6
RK	660	294	55.5	268	59.4	275	58.3
ZJ	660	452	31.5	401	39.2	447	32.3
SW	660	473	28.3	419	36.5	379	42.6

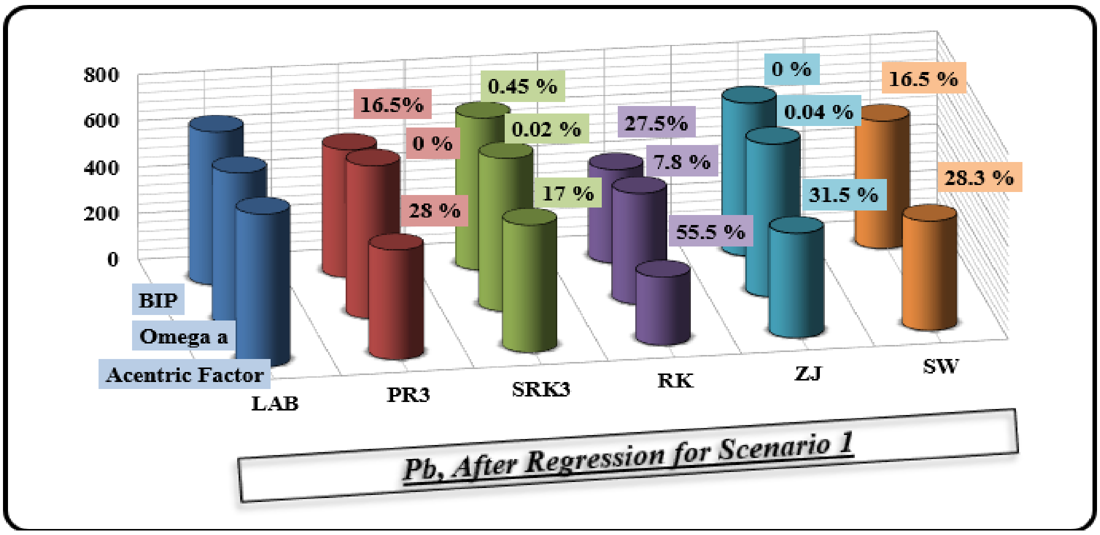

Figure 11: Pb After regression 1

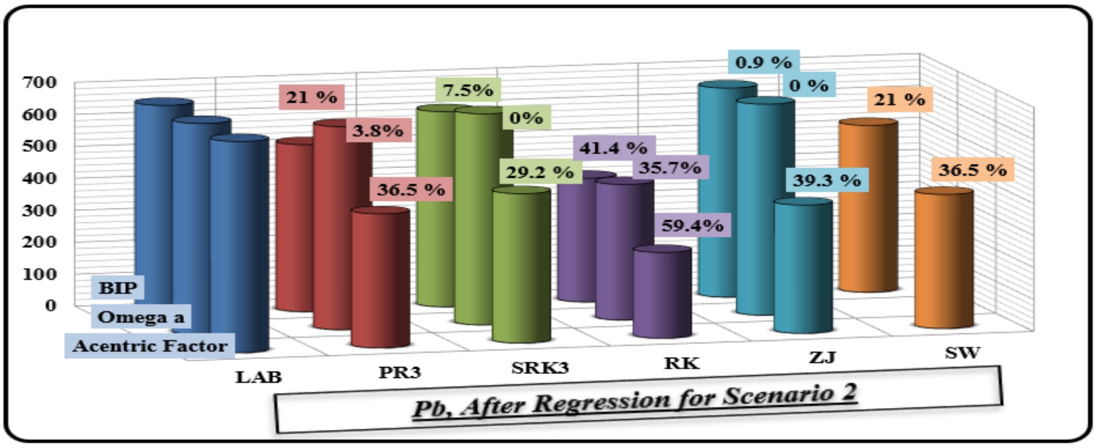

Figure 12: Pb After regression 2

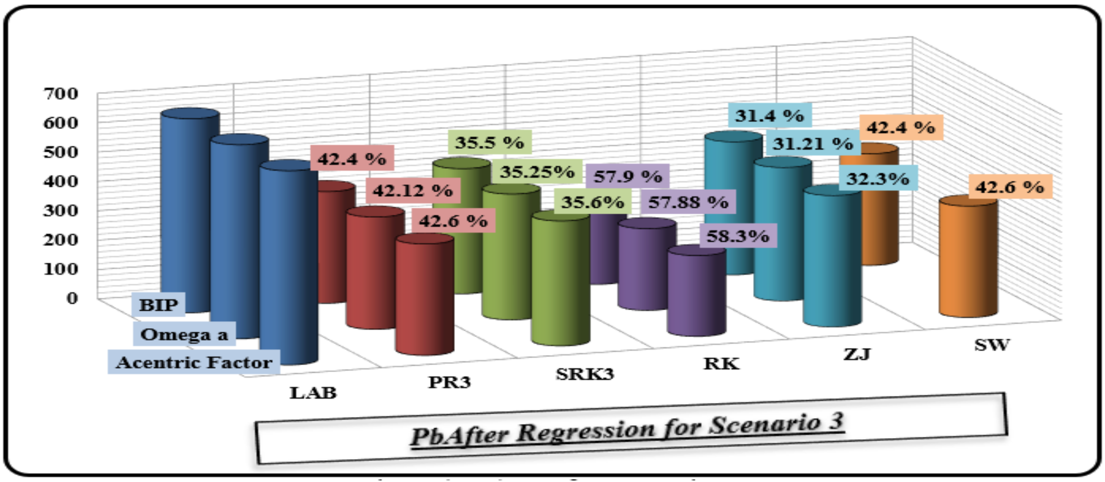

Figure 13: Pb After regression 3

Correlations Development

> Bubble Point Pressure, Pb

The bubble point pressure is function of (Rs, ɣg, API, T), so the regression analysis will be according to these parameters.

The data were used in DataFit software is shown in Table.

Table 18: Pb After regression 3

Rs, Scf/STB	ɣg	API	T, F	Exp. Pb	Cal. Pb	Error%
93	0.8374	26.95	204	660	1020	-54.58
188	0.9347	33.9	117	655	604	7.71
535	1.074	38.8	234	1892	1670	11.72
1382	0.9808	36.51	184	3317	3333	-0.48
1366	0.9534	37.41	184	3255	3290	-1.07
1155	0.9531	38.86	172	2716	2754	-1.41
755	1.0012	39.87	170	2120	1854	12.57
88	1.0979	36.91	143	335	355	-6.01
133	0.9236	42.33	186	505	590	-16.87
368	0.9447	35.25	235	1865	1476	20.86
521	1.5472	48.66	192	944	971	-2.87
39	1.07	34.76	188	180	523	-190.45
56	1.1769	34.13	127	145	248	-71.10
245	1.407	39.85	145	535	470	12.12
320	0.9319	35.4	235	1705	1377	19.23
104	1.108	35.58	145	498	427	14.30

475	1.0482	38.1	239	1920	1597	16.84
314	1.2369	50.07	239	740	861	-16.39
1139	0.9343	43.91	300	2930	3178	-8.45
127	1.1242	32.6	195	600	768	-28.07
695	1.085	40.45	201	1700	1811	-6.55
851	1.0359	34.68	216	2570	2378	7.46
1323	0.97	40.02	263	3250	3480	-7.09

All the Fit information is attached in appendix B.
The Equation ID from the regression analysis is: a*x1+b*x2+c*x3+d*x4+e
Where, the Model Definition will be:
Pb = a*Rs+ b*ɣg + c*API + d*T + e

Where:
a = 2.106, b = -485.0232, c = -25.4528, d = 4.5037, e = 997.6735
The R^2= 0.9626 (96.26 %)

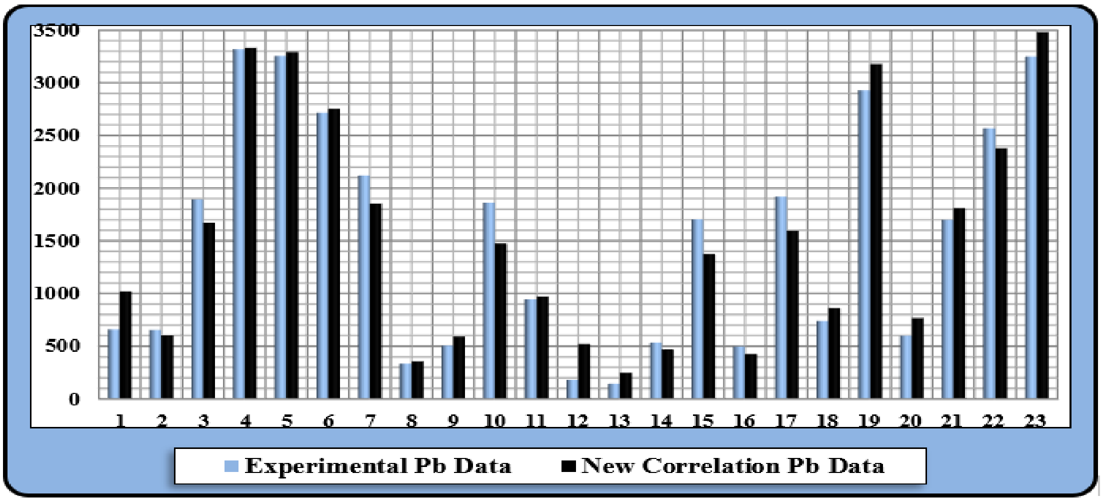

Figure 13: Experimental Pb Vs New correlation Pb

The range data of new correlations
Pb is function of (Rs, API, s.g, and T)

Property	Rs, Scf/STB	ɣg	API	T, F
Minimum	93	0.8374	26.95	117
Maximum	1382	1.2369	50.07	300
RK	93	74.3	20	22
ZJ	93	85.6	7.9	8
SW	93	82.3	11.5	16.5

CONCLUSIONS

Based on the results of this study, the following conclusions are obtained: Complete PVT lab studies have been done for one Libyan oil sample to compare the properties with the Empirical correlations for Middle East crude oil and the results show that there is a clear difference; The quality of the data is of vital importance for a reasonable tuning effort; Average absolute error is an important indicator of the accuracy of an empirical model; it is used in this study as a comparative criterion for testing the accuracy of correlations; Empirical correlations for Middle East crude oil have been compared for bubble point pressure, the solution gas-oil-ratio, oil formation volume factor, oil density, and oil viscosity; The PVT correlations can be placed in the following order with respect to their accuracy:

> For bubble point pressure, some correlations gives good result like Al-shammasi, Mehran, and Petrosky&Farashad while others gives high percentage of error like Dokla&Osman and Al Marhoun.

> For oil formation volume factor, all the correlations gives acceptable results accept the Material balance give about 7% Average error.

Characterization the experimental data by PVTi software show that:

> When we use the original Equation of State to predict the previous PVT properties, we have got unsatisfactory results.

> All the E.O.S needs tuning.

> In three scenarios that used in this study, the best one is the component up to C7+ without grouping.

The new correlations for bubble point pressure and oil formation volume factor give good results and can be used with Libyan crude oil in the same area.

RECOMMENDATIONS

The main recommendations we can get from this study are:

> Before using the Empirical correlations in reservoir calculations, we must make sure that they can be used for estimating the same PVT parameters for all types of oil and gas mixture with properties falling within the range

of data for each correlation.

> To be more accurate we should compare the results that obtained from the correlations with the data of the experimental work in PVT lab.

> With Libyan crude oil we advice to modify a new correlations that special for Libyan oil like Mohsen Khazam.

> When use any simulator to get PVT properties, we have to choose the best scenario that give the best result.

> About the new correlations for Libyan crude oil we use just 23 samples which not enough so that this work should be continue with more samples in the same area.

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