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Assessment of the Common PVT Correlations in Iraqi Oil Fields

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Abstract

Pressure volume temperature (PVT) analysis is the process of determining the fluid behaviors and properties of oil and gas samples from an existing well. Normally, PVT properties are experimentally measured in the laboratory. However, the absence of PVT measurement negatively impacts the application of many petroleum engineering calculations such as reserves estimation, material balance, reservoir simulation, production equipment design, and optimization of well performance.

In this work, we developed a program using VBA and MS EXCEL to compare between the collected measurements of PVT properties that were collected from 41 Iraqi oil cruds and the values obtained from the correlations. After the comparison process, we chose the correlation that have the close values to the PVT measurements that were collected previously.

This type of study, in which we compare the results of existing literature correlations to the measured value in a laboratory for a specific country or location, has been conducted in a number of countries, including Kuwait, the United Arab Emirates, and Egypt, but not in Iraq, which is where the value of this study lies.

A total of 92 correlations were involved in this study including, (19) Bubble point pressure, (10) gas-oil ratio, (20) oil FVF, (10) saturated Viscosity, (3) density at bubble point, (7) undersaturated oil compressibility, (12) dead viscosity, (3) undersaturated oil FVF, (8) undersaturated viscosity.

Over all, the best performance was obtained using the “Elsharkawy and Alikhan [1] “correlation for (Pb, Rs, Bo) , “Standing [2]” correlation for Density at bubble point , “Almehaideb [3]” for below bubble point viscosity , “Labedi [4]” for Dead viscosity, “Al-Marhoun [5]” for above bubble point oil FVF, “Standing [2]” for above bubble point oil compressibility, “Petrosky and Farshad [6]” for above bubble point viscosity, based on consistently low values of (AAPE) and (RMS) and cross plot.

Keywords: Upstream Oil & Gas, Correlation, Best Result, PVT, PVT Property.

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1. Introduction

Determination of the reservoir PVT properties is a key element in the oil field development process. These PVT properties can be measured in the laboratory using collected bottom-hole samples. It is well known that these measurements are rarely used in Iraqi oil fields. In order to get the actual value of the PVT properties, correlations are applied because it is easy, time- effective, and yield reasonably accurate results when applied at the original limitations.

In this study, the measurements were collected from various Iraqi fields, such as Buzurgan, Abo-Ammod, Garaph, Amarra and Kumeit. that raised a total of 41 well PVT data. We programed more than 93 correlations considering their limitations using VBA & MS Excel and compared the result from each correlation with the measured value from the laboratory. Finally, we applied a statistical method to determine the best correlation for each PVT property.

2. Data Analysis

To perform an unbiased evaluation, the data bank used in this study was obtained from different unpublished sources.

The collected data consist of reservoir temperature, oil gravity, solution gas oil ratio etc. within the range as shown in Table (1).

Table (1) Data range of PVT data

Laboratory measurement Parameters	Minimum	Mean	Maximum
At & Below Bubble point pressure			
Tank-Oil gravity (°API)	20	25.5	37.2
Bubble-point pressure, Pb (psia)	1112.3	2732	3854.8
Bubble-point oil FVF, Bob (bbl/STB)	1.2036	1.471	2.08
Gas oil ratio, Rs (SCF/STB)	0	385.249	1660.344
Reservoir temperature, T (°F)	90.8	215.5	283
Reservoir Pressure, P (psia)	14.7	3854.837	1350.9
Gas gravity, Yg	0.708	0.802	0.907
Oil Viscosity, μ (CP)	0.2255	1.223	9.8396
Above bubble point pressure			
Reservoir Pressure, P (psia)	1422.33	4266.99	6400.49
Oil Viscosity, μ (CP)	0.23	0.71	2.50
Oil Formation Volume factor, Bo (bbl/STB)	1.21	1.65	2.00

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3. Error Analysis

Two checking methods were attained to obtain the best correlation:

A. Statistical Criteria

- The average absolute percent relative error (AAPE):

$$\mathrm{AAPE} = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{Y_{measured} - Y_{calculated}}{Y_{measured}} * 100\right|$$

- Root mean square (RMS):

$$\mathrm{RMS} = \sqrt{\frac{\sum_{i=1}^{n}(Y_{measured} - Y_{calculated})^2}{n}}$$

- Nearest calculated Value to Measured value: using a custom Excel formula we compare the measured value at some point with the calculated value we obtain from the correlations at the same point and the function return the correlation that comes closest to the measured value.

B. Cross Plot Method*:*

In this technique, the estimated values are plotted versus the experimental values to create the cross plots. A (45^o, ±10%) straight line is drawn on the cross plot which passes through the points of the coincidence of experimental and calculated values. The closer plotted data points are to (45^o) line, the better the correlation.

4. Result And Discussion

***A.* Bubble Point pressure (Pb):**

We concluded from the result in Tables (2) , Figures (1) to (5), that the best correlation to obtain the best estimation of the bubble point pressure is "Elsharkawy and Alikhan [1]".

If API > 30

$$Pb = \left(\frac{Rs}{\gamma_g^{0.04439} API^{1.1394}\ 10^{(0.0008392\ T\ -\ 2.188)}}\right)^{1\ /\ 0.94776} \quad \text{... (4.1)}$$

Else if API <= 30

$$Pb = \left(\frac{Rs}{\gamma_g\ 10^{\left(0.4636\frac{API}{T} - 1.2179\right)}}\right)^{1\ /\ 1.18026} \quad \text{... (4.2)}$$

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Table (2) Statistical Analysis for Bubble Point Correlations

Correlation	AAPE	RMS	Number of Occurrences for nearest value	Number of Points within limit
Al-Marhoun [7]	27.271	742.555	1	31
Al-Marhoun [8]	32.068	912.391	0	30
Almehaideb [3]	19.602	714.977	2	8
Elam [9]	44.101	1230.091	0	41
Al-Shammasi [10]	33.669	918.432	0	41
Bolondarzadeh [11]	38.113	1031.782	0	41
Doklah and Osman [12]	17.761	628.570	0	3
Elsharkawy and Alikhan [1]	11.020	348.675	24	36
Dindoruk and Christman [13]	51.241	1347.416	0	39
Glaso [14]	62.706	1607.085	0	27
Hanafy [15]	22.183	638.421	3	40
Ikiensikimama and Ogboja [16]	253.980	6229.499	0	37
Khairy [17]	22.014	769.185	1	7
Standing [2]	43.034	1096.869	0	35
McCain [18]	44.101	1230.091	0	41
Vasquez and Beggs [19]	59.445	1632.018	1	41
Hanafy [20]	21.583	698.251	9	40
Petrosky and Farshad [21]	57.647	1496.860	0	34
Khamehchi and Ebrahimian [22]	88.465	2935.850	0	5

B. GAS-OIL Ratio (Rs):

We concluded from the result in Tables (3), Figures (6) to (8), that the best correlation to obtain the best estimation of Gas-Oil Ratio is "Elsharkawy and Alikhan [1]".

If API > 30

$$Rs = \gamma_g^{0.04439} \ P^{0.94776} \ API^{1.1394} \ 10^{(-2.188 + 0.0008392 * T)} \qquad \ldots (4.3)$$

Else if API <= 30

$$Rs = \gamma_g \ P^{1.18026} \ 10^{(-1.2179 + 0.4636 * (API / T))} \qquad \ldots . (4.4)$$

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Table (3) Statistical Analysis for Gas-Oil Ratio Correlations

Correlation	AAPE	RMS	number of occurrences for nearest value	Number of points within limit
Al-Marhoun [8]	54.363	208.147	9	327
Dindoruk and Christman [23]	43.017	295.215	0	274
Elsharkawy and Alikhan [1]	20.938	90.074	336	388
Glaso [14]	50.630	242.873	2	276
Khamehchi and Ebrahimian [22]	42.013	305.991	1	63
Hemmati and Kharrat [24]	34.397	161.947	19	376
Petrosky and Farshad [21]	41.222	301.514	0	171
Standing [25]	45.089	188.574	3	376
Vasquez and Beggs [19]	48.009	210.391	3	376
Omar faleh [26]	60.899	707.282	0	137

C. Saturated Oil Formation Volume Factor (Bo):

We concluded from the result in Tables (4), Figures (9) to (13), that the best correlation to obtain the best estimation of Oil FVF is "Elsharkawy and Alikhan [1]".

$$Bo = 1 + 4.0428 * 10^{-4}\ Rs + 6.3802 * 10^{-4} * (T - 60) +$$
$$7.8 * 10^{-7}\ Rs\ (T - 60) * \left({}^{Yg}/_{Yo}\right) \quad ... (4.5)$$

Table (4) Statistical Analysis for Oil FVF Correlations

Correlation	AAPE	RMS	Number of Occurrences for nearest value	Number of points within limit
Abdul-Majeed and Salman [27]	4.661	0.075	20	498
Al-Marhoun [7]	5.440	0.090	8	340
Al-Marhoun [8]	4.303	0.075	6	339
Al-Marhoun [5]	3.381	0.053	12	498
Almehaideb [3]	4.117	0.066	8	90
Al-Najjar [28]	2.127	0.040	33	355
Al-Shammasi [10]	2.985	0.048	24	455
Dindoruk and Christman [23]	5.598	0.082	3	380
Doklah and Osman [12]	2.283	0.039	6	29
Elam [9]	2.360	0.041	41	416

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Elsharkawy and Alikhan [1]	1.482	0.029	126	402
Farshad [29]	4.401	0.065	3	402
Glaso [14]	5.400	0.078	0	293
Khairy [17]	3.542	0.059	60	498
Macary and El-Batanoney [30]	6.477	0.105	10	125
Omar and Todd [31]	9.567	0.149	0	88
Petrosky [32]	3.647	0.055	9	307
Standing [2]	3.383	0.051	28	458
Vasquez and Beggs [19]	8.440	0.121	2	498
Omar Faleh [33]	2.267	0.044	99	498

D. Oil Density at bubble point (RHOB):

We concluded from the result in Tables (5), Figure (17), that the best correlation to obtain the best estimation of Oil Density at bubble point is "Standing [2]", even thought that "Ahmed [34]" have more number of occurrence we looked to who has the lowest RMS & AAPE value which is "Standing [2]".

$$\rho = \frac{0.0136\ Rs\ \gamma_g + 62.4\ \gamma_o}{0.972 + 0.000147\ (Rs * \left(\frac{\gamma_g}{\gamma_o}\right)^{0.5} + 1.25\ T)^{1.175}} \quad ...(4.6)$$

Table (5) Statistical Analysis for Oil Density at Bubble point Correlations

Correlation	AAPE	RMS	Number of occurrences for nearest value	Number of points within limit
Ahmed [34]	3.557	1.735	8	16
Hanafy [15]	4.136	2.320	7	16
Standing [2]	3.512	1.607	1	16

E. Saturated Oil Viscosity (μ):

We concluded from the result in Tables (6), Figures (14) to (16, that the best correlation to obtain the best estimation of Saturated Oil Viscosity is "Almehaideb [3]". Here we chose "Almehaideb [3]" although that "Beggs and Robinson [35]" have the lowest (AAPE) because of (1) the (AAPE) is a scale-sensitive metric, the result will take on extreme values when the denominator is small and the (AAPE) metric is a percentage however the (RMSE) is not (2) the number of occurrences for the nearest value for the first correlation is higher.

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$$\mu = \frac{6.59927 * 10^5}{Rs^{0.597627} \quad T^{0.941624} \quad \gamma_g^{0.555208} \quad API^{1.487449}} \quad \ldots (4.7)$$

Table (6) Statistical Analysis for Saturated oil Viscosity Correlations

correlation	AAPE	RMS	number of occurrences for nearest value	Number of points within limit
Al-Khafaji [36]	28.273	0.620	16	124
Almehaideb [3]	27.098	0.416	43	116
Beggs and Robinson [35]	24.354	0.492	16	124
Bergman [37]	28.857	0.585	2	124
Dindoruk and Christman [23]	42.843	0.487	10	115
Elsharkawy and Alikhan [1]	25.313	0.517	4	124
Khamehchi and Ebrahimian [22]	135.148	0.614	1	48
Petrosky and Farshad [6]	25.601	0.533	5	124
Standing [25]	49.130	0.808	15	124
Naseri [38]	38.474	0.880	12	124

F. **Dead Oil Viscosity (μ dead):**

We concluded from the result in Tables (7) and Figures (18) to (20), that the best correlation to obtain the best estimation of Dead Oil Viscosity is “Labedi [4]”. Here we chose “Labedi [4]”instead of “Al-Khafaji [36]” although Al-Khafaji has lower (AAPE) because the (AAPE) is a scale-sensitive metric, the result will take on extreme values when the denominator is small so it can’t be used for low volume data and the (AAPE) metric is a percentage however the (RMSE) is not.

$$\mathbf{A} = \boldsymbol{API}^{-2.92} \quad , \qquad \mathbf{B} = \boldsymbol{T}^{-2.0356} \qquad \ldots (5.8)$$

$$\boldsymbol{\mu_{dead}} = \mathbf{10}^{9.37} * \mathbf{A} * \mathbf{B} \quad \ldots (5.9)$$

Table (7) Statistical Analysis for Dead oil Viscosity Correlations

Correlation	AAPE	RMS	number of occurrences for nearest value	Number of points within limit
Al-Khafaji [36]	32.139	1.798	3	12
Beal [39]	43.768	1.904	0	11
Beggs and Robinson [35]	57.870	1.877	3	12
Dindoruk and Christman [23]	59.239	1.765	0	11

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Elsharkawy and Alikhan [40]	139.738	3.276	1	12
Glaso [14]	74.235	2.113	1	12
Hossain [41]	63.335	2.343	1	12
Labedi [4]	44.701	1.657	2	12
McCain [18]	133.300	3.026	0	12
Naseri [38]	44.489	1.763	1	12
Standing [2]	150.474	3.489	0	3
Petrosky and Farshad [6]	96.354	2.557	0	12

G. Undersaturated Oil FVF (Bo):

We concluded from the result in Table (8) and Figure (21), that the best correlation to obtain the best estimation of Undersaturated oil FVF is “Al-Marhoun [5]”.

A1= -1.3668 * 10 ^ -5 A3= 0.02408026

A2= -1.95682 * 10 ^ -8 A4= -9.26019 * 10 ^ -8

$$C = a1 * Rs + a2 * Rs^2 + a3 * \gamma_g + a4 * (T + 460)^2 \quad \dots (4.10)$$

$$Bo = Bo_{bubble} * \left(\frac{P}{P_{bubble}}\right)^C \quad \dots (4.11)$$

Table (8) Statistical Analysis for Undersaturated Oil FVF Correlations

correlation	AAPE	RMS	number of occurrences for nears value	Number of points within limit
Ahmed [42]	1.825	0.037	14	42
Al-Marhoun [5]	0.189	0.024	27	42
General equation [43]	2.636	0.053	1	42

H. Undersaturated Oil Compressibility (Co):

We concluded from the result in Table (9) and Figures (22), (23), that the best correlation to obtain the best estimation of Undersaturated Oil Compressibility is “Standing [2]”. Here we chose “Standing [2]” although “Petrosky and Farshad [21]” has the highest number of occurrences for the nearest value because the first correlation has the lowest value for both (AAPE) and (RMS).

$$\mathbf{A = 4.347 * 10^{-3} * (P - P_{bubble}) - 79.1 + \rho_{bubble}} \quad \dots (5.12)$$

$$\mathbf{B = 7.141 * 10^{-4} * (P - P_{bubble}) - 12.938} \quad \dots (5.13)$$

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$$\mathbf{Co = 10^{-6} * e^{A/B}} \quad ...(5.14)$$

Table (9) Statistical Analysis for Undersaturated Oil Compressibility Correlations

Correlation	AAPE	RMS	number of occurrences for nearest value	Number of points within limit
Ahmed [34]	78.519	1.14626E-05	1	13
Almehaideb [3]	out of limit	out of limit	-	-
Elsharkawy and Alikhan [1]	13.934	3.16476E-06	4	13
McCain [18]	16.041	2.6232E-06	0	13
Petrosky and Farshad [21]	10.955	2.27562E-06	5	13
Standing [2]	10.857	2.03417E-06	3	13
Vasquez and Beggs [19]	25.927	3.80648E-06	0	13

I. **Undersaturated Oil Viscosity (μ):**

We concluded from the result in Tables (10) and Figures (24), (25), that the best correlation to obtain the best estimation of Undersaturated Oil Viscosity is "Petrosky and Farshad [6]". Here we chose "Petrosky and Farshad [6]" instead of "Almehaideb [3]" because of the big difference in (AAPE) and (RMS) value for both correlations.

$$A = -1.0146 + 1.3322 * \log \mu_{bubble} - 0.4876 * \log(\mu_{bubble})^2 - 1.15036 * \log(\mu_{bubble})^3$$

$$\mu = \mu_{bubble} + 1.3449 * 10^{-3} * (P - P_{bubble}) * 10^{A} \quad ...(4.15)$$

Table (10) Statistical Analysis for Undersaturated Oil Viscosity Correlations

correlation	AAPE	RMS	number of occurrences for nearest value	Number of points within limit
Almehaideb [3]	4.059	0.069	14	42

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Beal [39]	5.527	0.112	5	42
Beggs and Robinson [35]	4.127	0.113	10	42
Dindoruk and Christman [23]	12.748	0.199	0	42
Elsharkawy and Alikhan [40]	11.305	0.182	0	42
Kartoatmodjo and Schmidt [44]	13.783	0.235	0	42
Petrosky and Farshad [6]	2.963	0.030	13	42
Vasquez and Beggs [19]	4.127	0.113	0	42

5. Conclusion

To summarize the result of this work, for Iraqi oil field the following correlations gives the best estimations of the PVT properties and as follow:

Bauble point Pressure (Pb)	Elsharkawy and Alikhan [1]
Gas-Oil Ratio (Rs)	Elsharkawy and Alikhan [1]
Saturated Oil FVF (Bo)	Elsharkawy and Alikhan [1]
Oil Density at Bubble point (ρ)	Standing [2]
Saturated Oil Viscosity (μ)	Almehaideb [3]
Dead Viscosity (μ dead)	Labedi [4]
Undersaturated Oil FVF (Bo)	Al-Marhoun [5]
Undersaturated Compressibility (Co)	Standing [2]
Undersaturated Viscosity (μ)	Petrosky and Farshad [6]

We found through this study that it’s not necessary to develop new correlation for some properties such as (Bo, Co, RHOB) both saturated and undersaturated. However, for properties such as (Viscosity both saturated and undersaturated, Dead Viscosity, Rs) there is a significant need to develop new correlations that provide a good estimation for these properties of Iraqi oil fields because the current correlations provide inaccurate results compare with measured value for the property.

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Tabel (11) Limitation of correlations for each PVT property

Correlation	Property	T (F°)		Rs (SCF/STB)		API		γ_g		P(psia)	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Elsharkawy and Alikhan [1]	P_{bubble}	130	250	39	1586	19.9	42.76	0.663	1.268	-	-
Elsharkawy and Alikhan [1]	Rs	130	250	-	-	19.9	42.76	0.663	1.268	302	4375
Elsharkawy and Alikhan [1]	Bo	130	250	39	1586	19.9	42.76	0.663	1.268	-	-
standing [2]	ρ_{bubble}	-	-	-	-	-	-	-	-	-	-
Almehaideb [3]	μ	-	-	128	3871	-	-	-	-	-	-
Labedi [4]	μ_{dead}	100	306	-	-	32.2	48	-	-	-	-
Al-Marhoun [5]	Under. Bo	75	240	1	3113	-	-	0.657	1.588	25	4475
standing [2]	Under. Co	-	-	-	-	-	-	-	-	-	-
Petrosky and Farshad [6]	Under. μ	-	-	-	-	-	-	-	-	-	-

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Figures

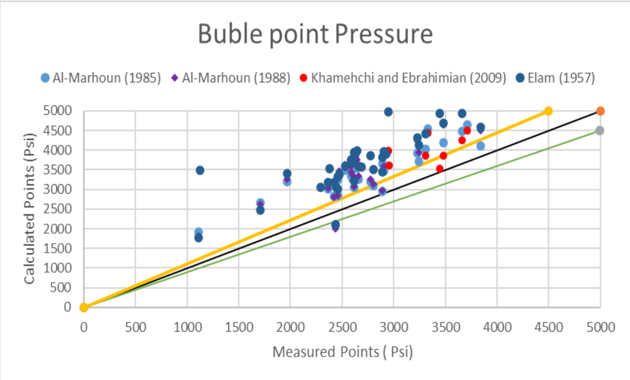

Fig. (1): Cross Plot for Bubble point Correlations

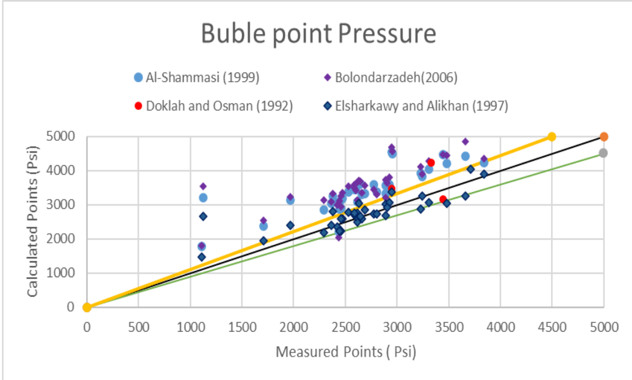

Fig. (2): Cross Plot for Bubble point Correlations

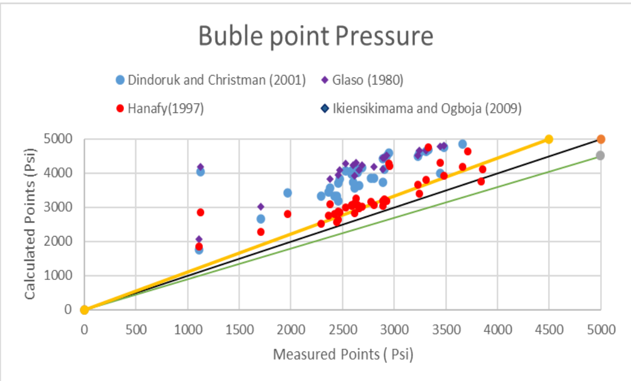

Fig. (3): Cross Plot for Bubble point Correlations

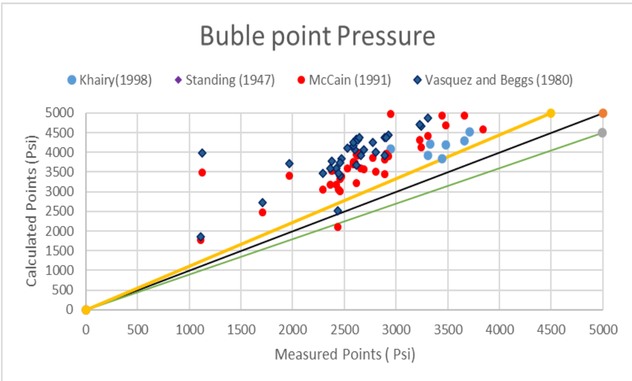

Fig. (4): Cross Plot for Bubble point Correlations

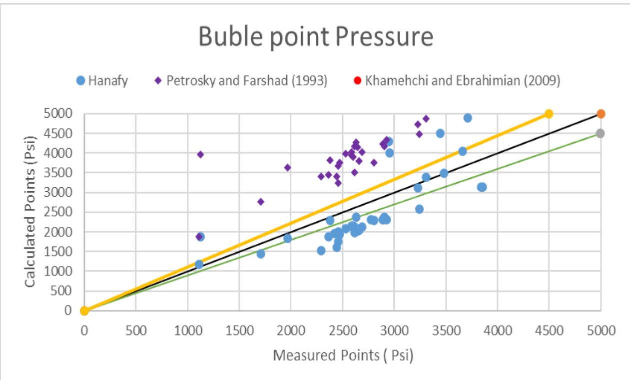

Fig. (5): Cross Plot for Bubble point Correlations

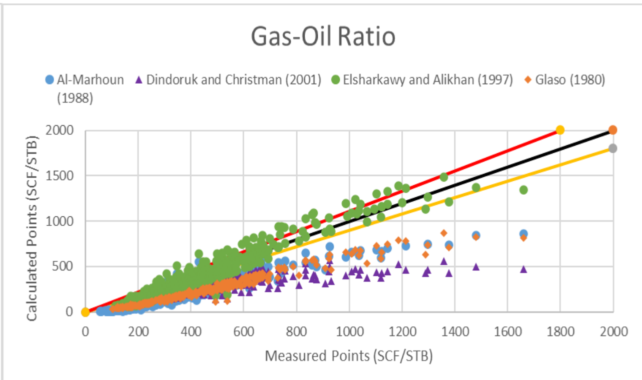

Fig. (6): Cross Plot for Gas oil Ratio Correlations

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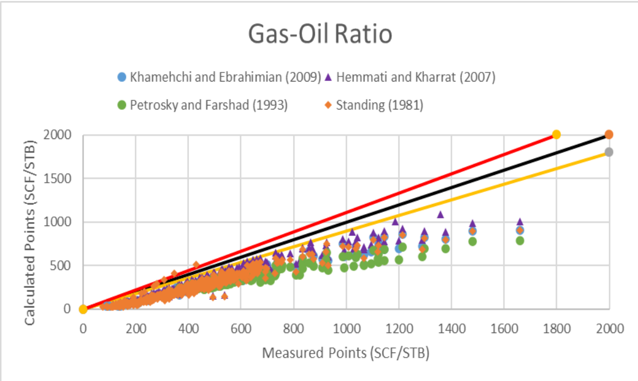

Fig. (7): Cross Plot for Gas oil Ratio Correlations

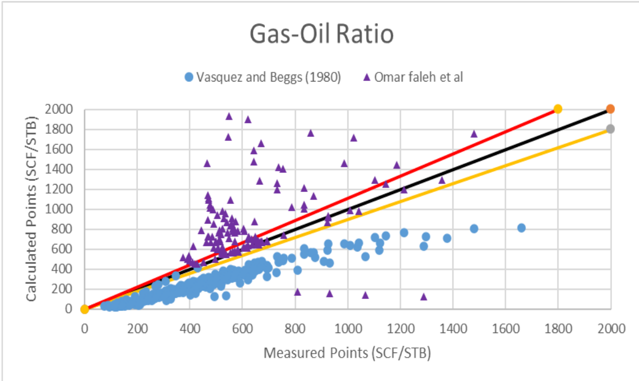

Fig. (8): Cross Plot for Gas oil Ratio Correlations

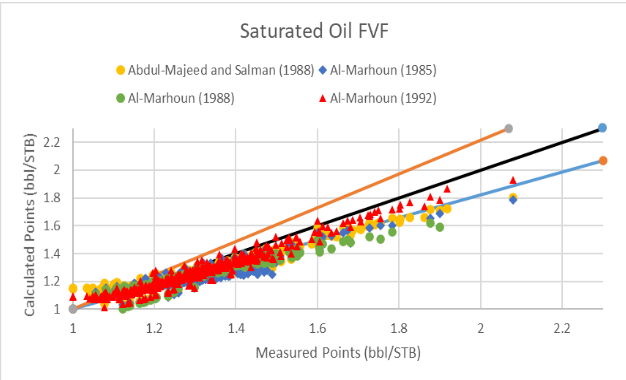

Fig. (9): Cross Plot for Oil FVF Correlations

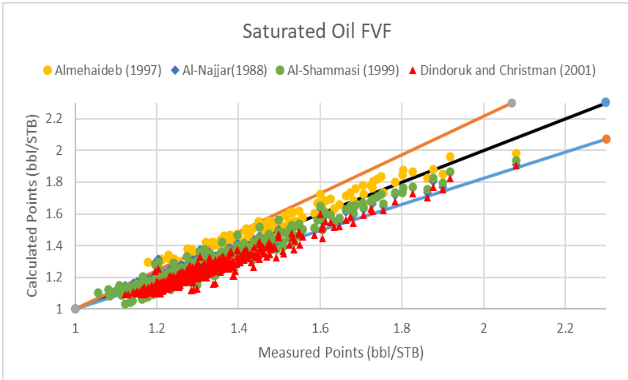

Fig. (10): Cross Plot for Oil FVF Correlations

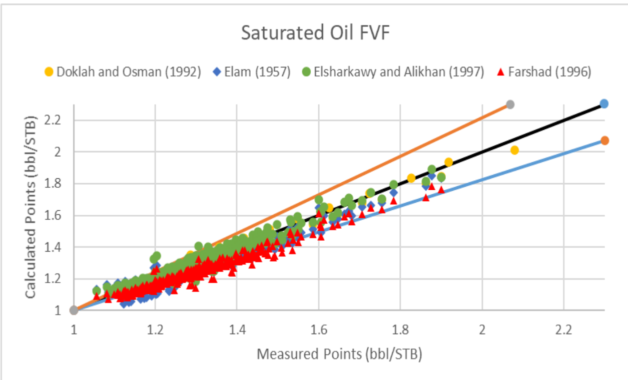

Fig. (11): Cross Plot for Oil FVF Correlations

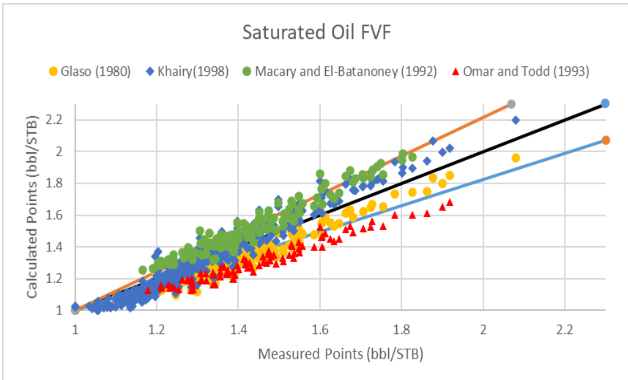

Fig. (12): Cross Plot for Oil FVF Correlations

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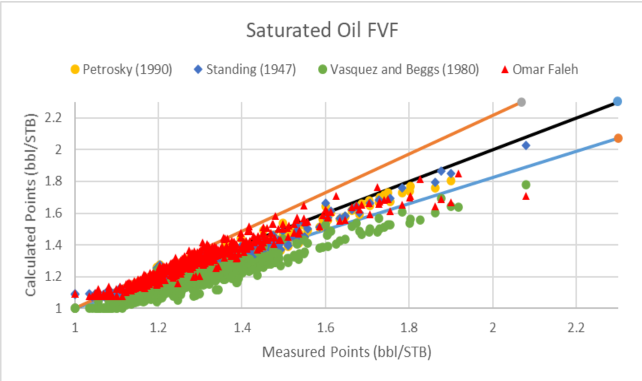

Fig. (13): Cross Plot for Oil FVF Correlations

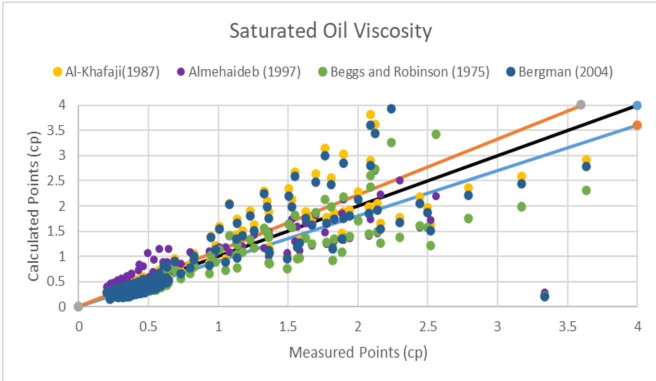

Fig. (14): Cross Plot for Saturated Oil Viscosity Correlations

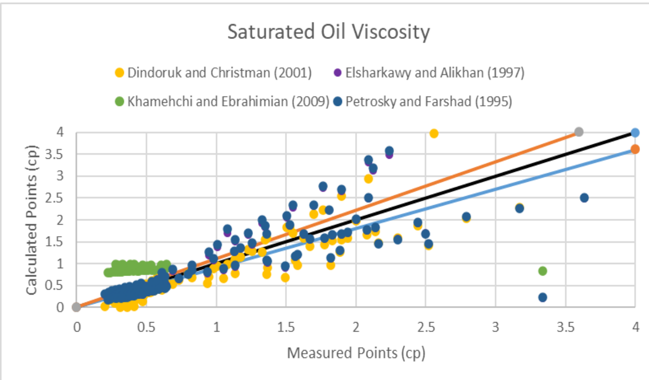

Fig. (15): Cross Plot for Saturated Oil Viscosity Correlations

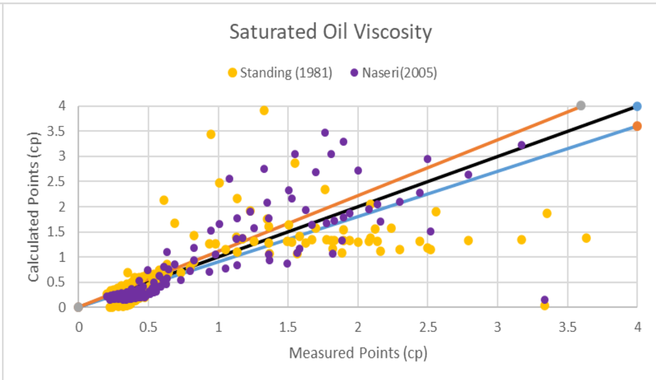

Fig. (16): Cross Plot for Saturated Oil Viscosity Correlations

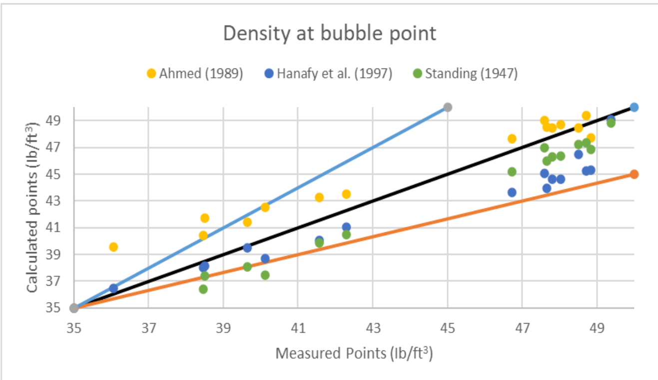

Fig. (17): Cross Plot for Density at bubble point Correlations

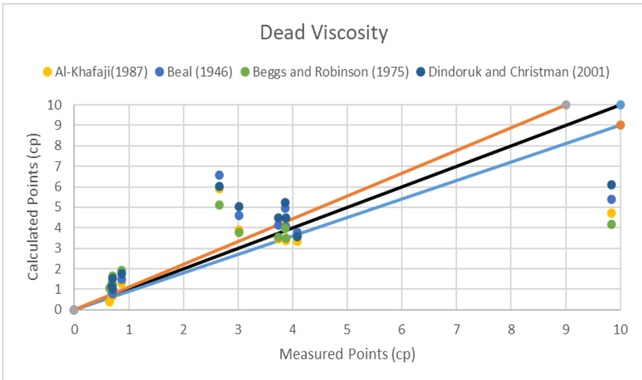

Fig. (18): Cross Plot for Dead Viscosity Correlations

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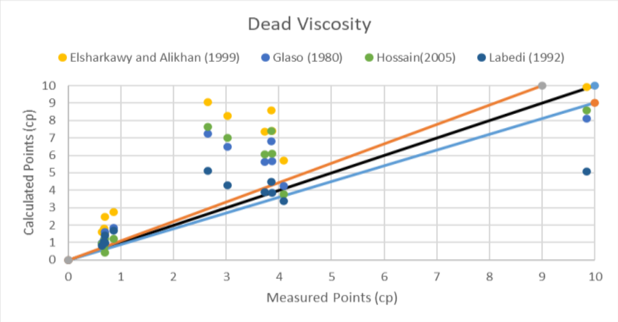


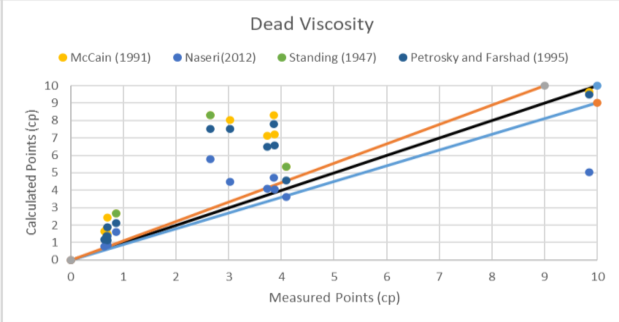
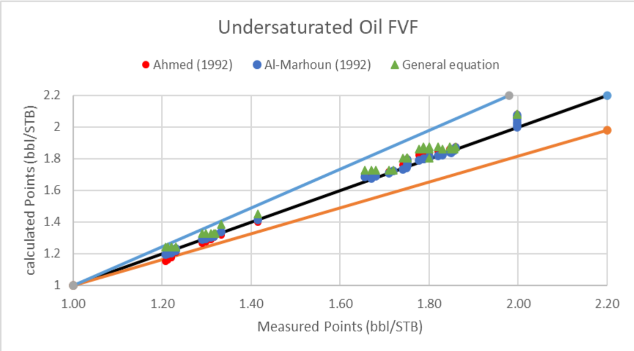


Fig. (19): Cross Plot for Dead Viscosity Correlations

Fig. (20): Cross Plot for Dead Viscosity Correlations



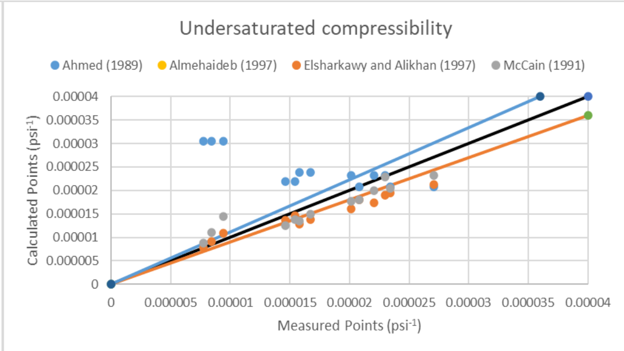
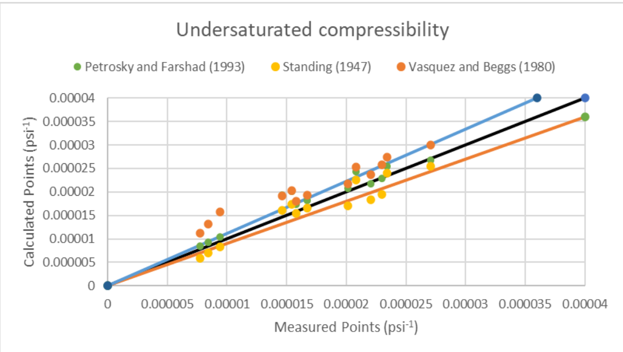


Fig. (21): Cross Plot for Undersaturated Oil FVF Correlations

Fig. (22): Cross Plot for Undersaturated Oil Compressibility Correlations



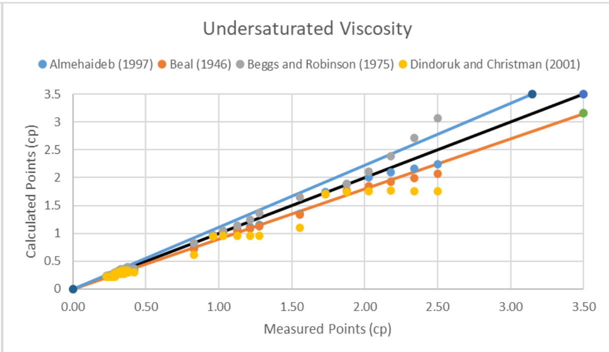


Fig. (23): Cross Plot for Undersaturated Oil Compressibility Correlations

Fig. (24): Cross Plot for Undersaturated Oil Viscosity Correlations

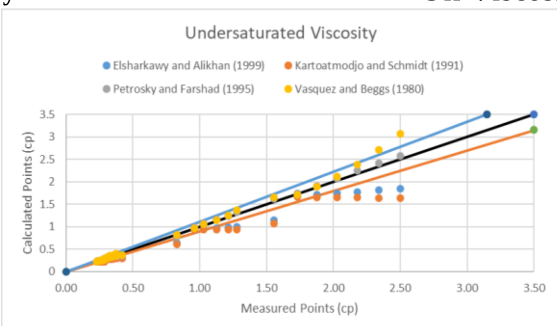


Fig. (25): Cross Plot for Undersaturated Oil Viscosity Correlations

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