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Developing New PVT Correlations for the Libyan Crude Oil Using Samples from Different Reservoirs

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Abstract: Five PVT correlation include bubble point pressure, solution gas oil ratio, oil formation volume factor, dead oil viscosity and oil density were used to analyze a total of 102 data sets from the Libyan crude oil reservoirs representing Sirte, Ghdames, Murzug and offshore Tripolitania basins, to find anew more accurate correlations. Linear & nonlinear regression and statistical software package (Excel, Minitab and Mat lab software) were applied on the above -mentioned crude samples. The application of multilinear regression and a statically software on the solution gas, oil ratio, temperature and API gravity, exhibit a direct proportional with the bubble point, where as in the case of gas gravity the correlation show inversely proportional with the bubble point. The relationships between the solution gas oil and other properties show that the distribution of the tested points in these investigations are located very closet the 45° trend line for the solution gas oil ratio, indicating that the correlations have a higher accuracy with our new developed PVT equations for the analyzed Libyan crude oil samples. The cross plots between measured vs. calculated oil formation factor, dead oil viscosity and oil density is play a very good reliable correlation compared with previous published correlations done by other researchers as well as in the statistical calculation, in addition the AARE and R^2 results were calculated for previous published correlation in different locations over the world. Based on the obtained results in this research, the proposed correlations are more accurate than all the other previous published correlations, exclusively for the Libyan crude oil.

Keywords: *PVT, Empirical Correlations, bubble point pressure, oil density ,Libya*

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1. Introduction

The Pressure volume temperature (PVT) correlations are very important tools in reservoir technology. These measurements are the basis for estimating the amount of oil in the crude reservoir, production capacity, and variations in produced gas/oil ratios during the reservoir's production life. PVT relations also area requirement for calculating the recovery efficiency of a reservoir, especially during the prospection phase, when only produced fluid properties are available from flowing tests, one can resort to empirically derived PVT relations (Glaso, 1980). The PVT parameters discussed here are based on a total of 102 samples collected from four different localities in the onshore and offshore the Libyan state, representative of Sirte, Ghdames, Murzug and Tripolitania basins (Fig.1).

Petroleum is a mixture of hydrocarbons, naturally occurrence, may be exist in solid, liquid or gaseous states, depending on the conditions of temperature and pressure to which it have subjected. Petroleum deposits vary widely in chemical composition depending on location that have entirely different physical and chemical properties, sulfur, nitrogen, oxygen, and helium are minor constituents in oils. The physical and chemical properties of crude oils are vary considerably and dependent on the concentration of the various types of hydrocarbons and of the minor constituents present in it (Jellah, 2018; El-Hoshoudy, and Desouky, 2019).

Ahmed (2007) stated that volumetric behavior of reservoir fluids must be determined as a function of pressure and temperature in order to make an engineer evaluate the production performanceofareservoircalculations,reservoirevaluation,numericalreservoirsimulation, design of development processes, design of EOR process, material balance calculations, log calibration, well test analysis, design of surface facilities etc.

Reservoir fluid analysis provides some of the key data for the petroleum engineer. The quality of the testing, therefore, is important to ensure realistic physical property values are used in the various design procedures.

The PVT properties are important parameters in reservoir engineering. However, these PVT properties are usually determined from laboratory tests, but in some cases where adequate samples can't be obtained or during exploration phase, when only produced fluid properties are available from flowing tests, one can rely on the empirical PVT correlations for predicting the physical fluid properties (Shlk M. et al. and Alkhaboli, 2016).

To provide calculations and physical property data for well flow and surface facility design, the PVT tests and subsequent reports gives the source of the reservoir fluids properties, that is necessary to describe the behavior of the reservoir over its development and production phase. The tests conducted should take into consideration that, the process going on both above and below the saturation pressure. Data of most these fluid properties were determined by laboratory experiments that performed on the tested samples of actual reservoir fluids, in the case of absence of experimentally measured properties of crude oils,

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it is necessary for the petroleum engineer to determine the properties from empirically derived correlations.

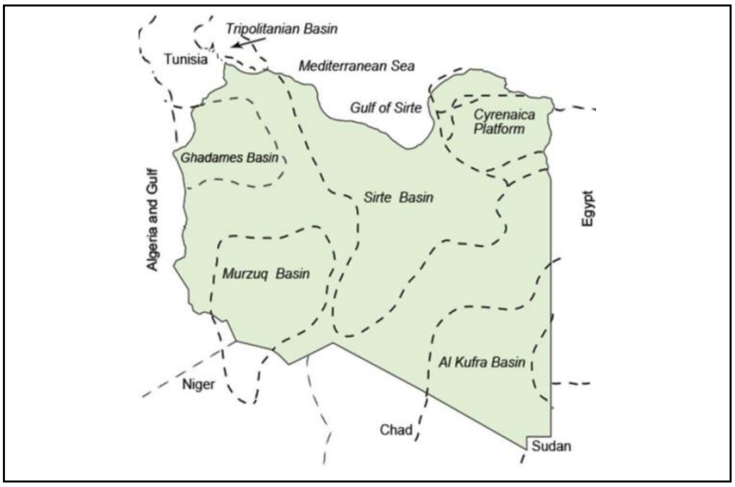

Fig. 1.Map of Libya showing the study areas (after BMI Research report (2018).

The aim of this paper is to develop new PVT correlations, exclusively for the Libyan crude oils, to upgrade data bank for all producing basins in Libya, and finally to test and compare reliability of the results obtained in this investigation with another published correlations done by another researchers around different geographic locations over the world.

2. Methodology

All the data under investigation was collected and filtered for the purpose of developing PVT correlations, The first step in the screening process was studying the relationship between the properties, (response & variables) individually, to make a reasonable regression for constructing a correlation.

The study of the relationship was based on including the plots that provided the most logical behavior of the data points distribution, Minitab diagnostic report was the first indicator for the model accuracy. Data points with large residual or unusual values were removed.

Five PVT correlations were developed using multiple regression with trial and error method, using various statistical and mathematical software packages (Minitab, matlab and Excel). Scatted plots were constructed in order to evaluate the relationships between variables to help in the process of formulations the correlations. Residual plots and 45^o degree plots were constructed in order to evaluate and visualize the models suggested compared to former studies aside with the statistical indicators

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A summary of data points used in this study for develop and testing PVT correlations is presented in Table 1.

Table1.Pointsused to develop and testing PVT correlations

PVT	N^O of points used to develop the correlation	N^O of points used to test the correlation
Bubble point pressure	102	20
Solution Gas Oil ratio	843	165
Formation volume factor	844	165
Dead oil viscosity	63	15
Oil density	96	20

In this paper, several statistical indicators have been used to seek a fair comparison. These indicators are(average percent relative error, average absolute percent relative error, standard deviation and correlation coefficient (R^2).

Finally, in our study, it has been proven that, when the previous correlations are applied on Libyan oil crude, it is associated with errors and as the accurate determination of the PVT properties is uncompromising. (Fig. 2) summarizes the steps taken to establish the correlation model.

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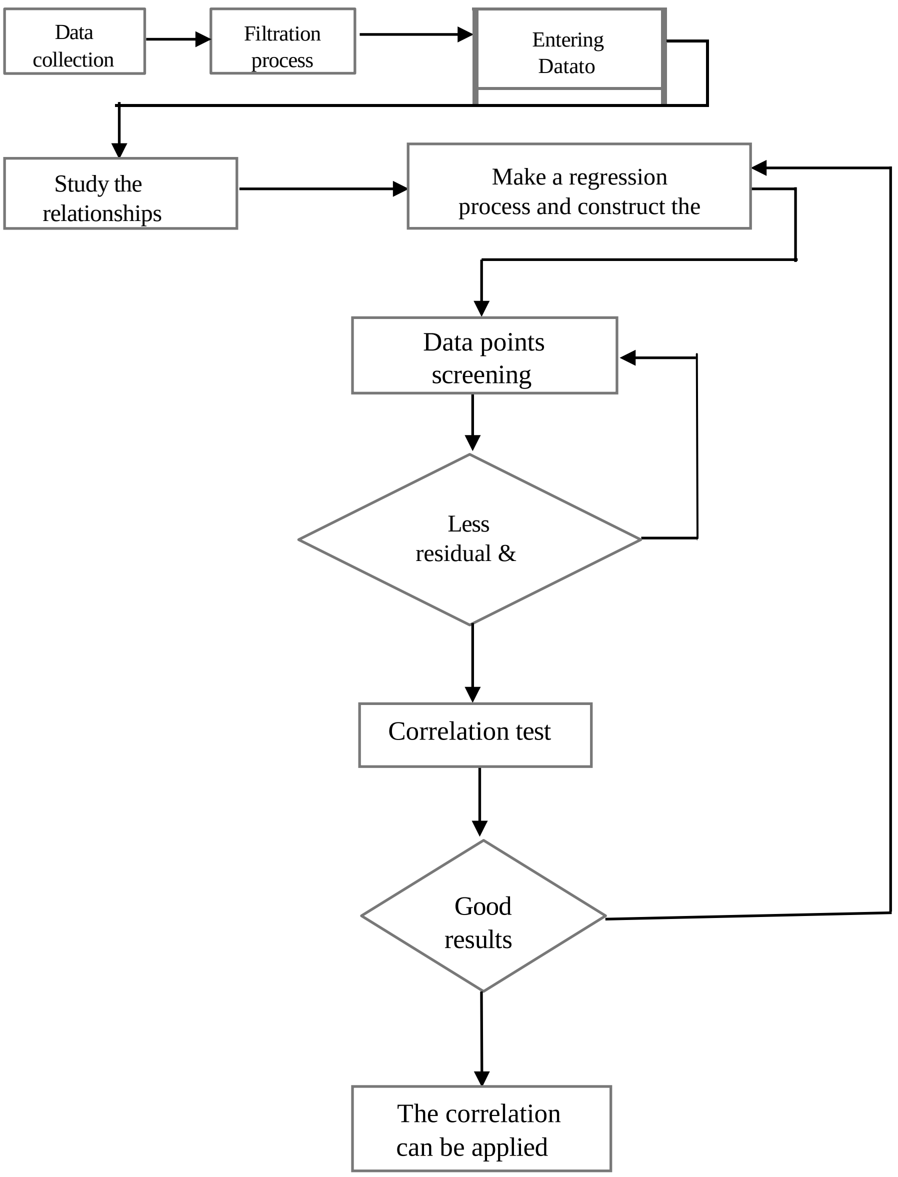

Fig. 2. A flow chart illustrates the research methodology

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3. Results and Discussions

Among different fluid properties, accuracy of bubble point pressure (P_b), oil formation volume factor (B_o), solution gas oil ratio (Ros), oil density correlation (ρ) and dead oil viscosity (μod) are very essential in reservoir engineering calculations. A accurate laboratory studies of PVT and phase-equilibrium behavior of reservoir fluids are necessary for characterizing these fluids and evaluating their volumetric performance at various pressure levels. There are many laboratory analyses that can be made on a reservoir fluid samples. The amount of data desired determines the number of tests performed in the laboratory.

In general, there are three types of laboratory tests used to measure the hydrocarbon reservoir samples; first is a primary test, which is simple, routine field (on-site) tests involving the measurements of the specific gravity and the gas-oil ratio of the produce hydrocarbon fluids. Second is laboratory tests, these tests are conducted by several laboratory tests to characterize the reservoir hydrocarbon fluid, they include compositional analysis of the system, Constant- composition expansion, differential liberation, separator tests, and constant-volume depletion. Third is special laboratory PVT tests**,** these types of tests are performed for very specific applications. If a reservoir is to be depleted under miscible gas injection or a gas-cycling scheme, the following tests may be performed as slim-tube test or/and swelling test.

Many investigators have used PVT laboratory test results, and field data to develop generalized correlations for estimating properties of reservoir fluids. The main properties that are determined from empirical correlations are the bubble point, gas solubility, volume factors, density and viscosity (Danesh 1998).

Based on a 102 analyzed samples, which determined under linear regression and statistical software package (Excel Minitab and Matlab). The details results and discussions are presented in the following points.

3.1 Bubble point pressure (P_b)

The bubble point pressure is the point of pressure at which the first few molecules leave the liquid and form small bubbles of gas. A multiple linear regression has been applied using Minitab software, to construct the bubble point pressure of the Libyan crudes by applying the following new developed equation: -

$$\boldsymbol{Pb = 21536 + (37.65 \times Rso) - (2187 \times \log(Rso)) - (230.4 \times \frac{API}{\gamma_g}) - (165.5 \times T) + \left(0.000882 \times Rso^2\right) + \left(0.3443 \times T^2\right) - \left(10.98 \times Rso \times \frac{API}{\gamma_g}\right) + (1.264 \times \log(Rso) \times T)}$$

Where:

R_{so} = Solution gas oil ratio (SCF/STB)
API = Stock-tank oil gravity from flash separation (API°)
γ_g = Average specific gravity of total surface gases from flash separation
T = Reservoir temperature, (°F)

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Applications of the above presented equation on the solution gas oil ratio, temperature and API gravity, the results show a direct proportional with the bubble point, whereas in the case of the gas gravity the equation display inversely proportional with the bubble point. It is also noticeable that, the equation include both square and logarithm functions, which they are based on the matrix plot approach used in the Minitab software, in order to ensure the optimum formula compared to linear behavior.

The statistical indicators of different published bubble point pressure (P_b) were correlated with the results calculated by the new developed P_b formula, for the analyzed Libyan crude oil samples. The P_b value of this study are considerablyhigher than the other values presented in (Table 2).However, the new P_b equation registered R^2 value of 0.87, which considered to be better prediction than overall the other former published correlations when compared with values from other places.

Table2. Statistical parameters for bubble point pressure (P_b).

Authors	Samples Origin	AARE (%)	AE%	AAD (%)	Max Dev.	Min Dev.	R^2
Standing (1947)	California	68	-47.87	472.03	2671.01	2.98	0.52
Vasquez and Beggs (1980)	world wide	78	-63.96	510.07	3111.72	2.52	0.51
Al-Marhoun (1988)	Middle east	66	-37.67	437.76	2905.16	16.61	0.45
Farshad , et al**.** (1996)	Colombia	78	-58.23	517.18	2525.88	1.40	0.39
Petrosky and Farshad (1993)	Gulf of Mexico	82	32.12	496.08	2509.83	6.24	0.63
Kartoatmodjo and Schmidt (1994)	World wide	76	-62.14	534.89	3509.09	6.43	0.51
Khazam (1995)	Libya	67	-50.75	420.00	1930.91	8.39	0.62
Velarde, et al., (1997)	Global literature	64	-37.86	434.06	2601.34	11.86	0.41
Hanafy et al., (1997)	Egypt	109	-90.35	749.48	6843.05	8.72	0.19
Alshammasi (1999)	World wide	282	-279.79	2097.41	12292.10	214.31	-0.47
Dindoruk and Christman (2001)	Gulf of Maxico	66	-39.24	442.62	2636.49	5.85	0.29
Khazam et al., (2016)	Libya	74	-58.83	415.74	2151.23	17.40	0.57
New developed correlation	Libya	**41**	**16.18**	**257.32**	**1399.02**	**1.69**	**0.87**

AARE%: Absolute average relative error; AE%: average error, AAD%: average standard deviation, R^2: correlation coefficient.

The average absolute relative error (AARE) presented by Khazam (1995) and Khazam et al. (2016) for the Libyan crude oil samples did not show a satisfactory results for the data tested in this study. On the other hand, the data exhibit higher absolute average relative error (AARE) when compared with the current averages, so none of the mentioned correlations showed a better performance in the other statistical indicators.

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The cross plot of laboratory measured and the calculated bubble point pressure (Fig.3), show a strong positive correlation, thus indicating that these correlation coefficient (R^2) values for the bubble point pressure (P_b) are of an excellent accuracy with the results obtained by the new developed correlation.

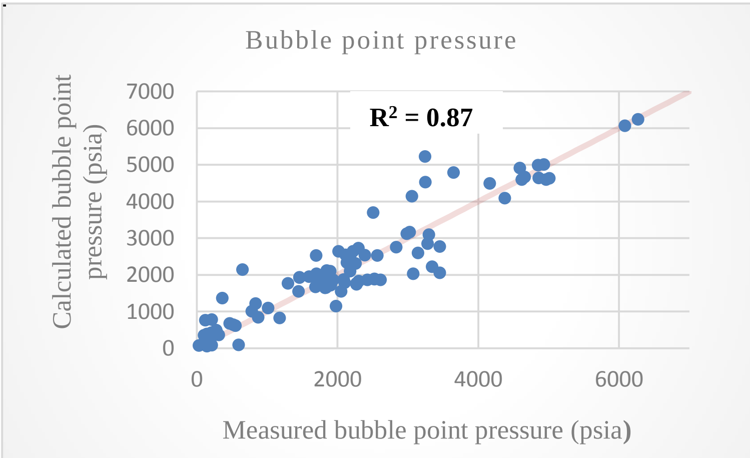

Fig. 3. Cross plot of the developed P_b correlation

3.2 Solution gas oil ratio (Rso)

The solution gas oil ratio is defined as the number of cubic feet (cubic meter) of at standard conditions, which will dissolve in one barrel (cubic meter) of stock tank oil when subjected to reservoir pressure and temperature. After analyzing the relationships between the solution gas oil ratio and the other properties, it turned out that, the R_{so} is a function of formation volume factor, temperature and pressure. By using the multiple linear regression of the Libyan crudes by applying the following new developed formula:-

$$\boldsymbol{Rso} = (\mathbf{1356.1} \times \boldsymbol{Bo}\ ) - (\mathbf{0.3689} \times \boldsymbol{T}) + (\mathbf{0.08835} \times \boldsymbol{P}) - \mathbf{1440.1}$$

Where:
B_o = Formation volume factor (BBL/STB)
T = Reservoir temperature (°F)
P = Reservoir pressure (Pisa)

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Table 3. Statistical parameters for solution gas oil ratio correlations (R_{so}).

Correlations name	Samples Origin	AARE (%)	AE (%)	AAD (%)	Max Dev.	Min Dev.	R^2
Standing (1947)	California	50.36	7.87	137.68	1763.83	0.10	0.42
Vasquez and Beggs (1980)	world wide	49.71	18.05	138.90	1851.44	0.08	0.29
Al-Marhoun (1988)	Middle east	61.94	1.05	183.82	4070.27	0.32	0.29
Petrosky and Farshad (1993)	Gulf of Mexico	111.00	-101.70	189.91	2872.90	0.16	0.71
Kartoatmodjo and Schmidt(1994)	World wide	48.07	15.84	131.72	1847.53	0.31	0.24
Hanafy et al.,(1997)	Egypt	60.66	21.34	158.14	2135.14	0.08	0.19
Levitan and Murtha (1999)	Global literature	49.43	15.34	136.446	1841.68	0.02	- 1.08
Al-Shammasi (1999)	World wide	54.75	-47.77	91.3801	834.10	0.08	0.85
Dindoruk and Christman (2001)	Gulf of Mexico	85.74	73.48	310.1674	2432.51	2.23	- 82.83
Hemati and Kharrat (2007)	Iran	53.33	1.12	144.3713	1746.57	0.25	0.44
Mazandarani and Asghari (2007)	Iran	50.44	8.96	137.1051	1790.84	0.42	0.40
Khamechi and Ebrahimian,.(2009)	Middle East	47.36	19.15	133.21	2033.17	0.19	- 0.14
Jarrahian et al. (2015)	Global literature	313.33	-307.51	1029.3815	11309.13	1.68	- 0.60
Khazam et al.(2016)	Libya	54.29	21.82	164.478	2311.37	0.04	0.35
New developed correlation	**Libya**	**26.32**	**- 3.77**	**26.5151**	**540.68**	**0.05**	**0.97**

AARE% Absolute average relative error; AE%:average error AAD%: average standard deviation, R^2: correlation coefficient

The new developed formula (Solution gas oil ratio (Rso), show high accuracy correlations as compared with the other average data presented in (Table 3), only except those data presented by Al-Shammasi (1999) which show a satisfactory result in R^2 and the average standard deviation (AAD) values, but from the other side the absolute average relative error (AARE) his results falls behind many correlations. it can be noticed that the data presented in the Table 3 did not show a good performance in (AARE) as well as in the results obtained by the new developed equations, which illustrated high accuracy numbers when compared with other published correlations,

The cross plot of the measured and calculated gas solubility (Fig. 4), illustrate a strong positive correlation, indicating that the correlation coefficient (R^2) values for the solution gas oil ratio (Rso) have a high accuracy with the results obtained by the new developed correlation.

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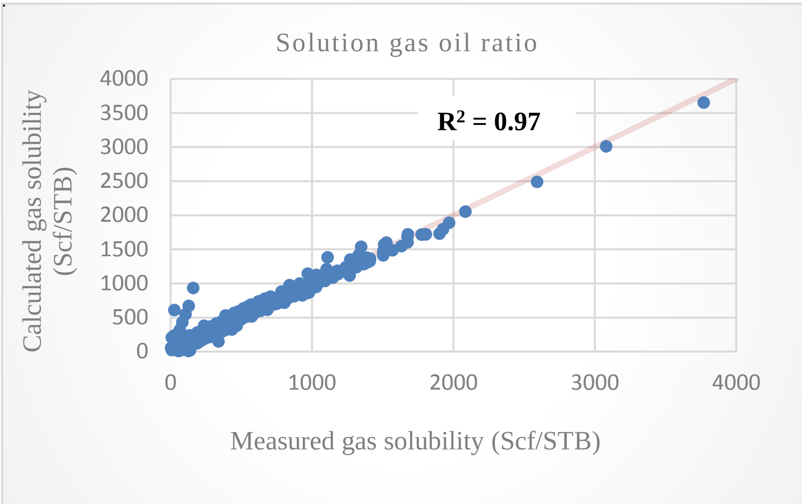

Fig. 4. Cross plot for the developed R_{so} correlation

3.3 Oil formation volume correlation(Bo)

The oil formation volume factor is a volume in barrels measured with cubic meters, occupied in the reservoir, at the prevailing pressure and temperature. performing multiple linear regression using Minitab after adjusting all variables. The best regression results wear obtained by using the following oil formation volume factor equation:-

$$Bo = (0.8875) + (0.004107 \times API) + (0.00059 \times Rso) + (0.1532 \times \gamma g) - (0.000449 \times T)$$

Where:

API : Stock-tank oil gravity from flash separation (API^{o})

R_{so} : Solution Gas Oil Ratio (SCF/STB)
γ_g : Average specific gravity of total surface gases from flash separation
T : Reservoir temperature, (°F)

The above equation shows that the regression process of the oil formation factor (Bo) is a function of API, R_{so}, Y_g and reservoir temperature (T).

The statistical indicators of different published oil formation volume correlation (Bo) and the new developed formula (Bo) for the Libyan crude oils (Table 4), display a correlation coefficient (R^2) value of 94.45, which obviously too close to the accurate prediction.

The results emphasis that the formula of the developing new oil formation volume factor have higher performance than previous developed models and empirical correlations, therefore the new developed correlation can be adopted to evaluate (Bo) for the crude oils.

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Table 4 Statistical parameters for oil formation volume B_o

Authors	Samples Origin	AARE (%)	AE (%)	AAD (%)	Max Dev.	Min Dev.	R^2
Standing (1947)	California	3.95	2.71	0.04	0.43	0.0001	0.89
Vasquez and Beggs (1980)	World wide	9.92	-8.72	0.10	0.32	0.00	0.38
Glaso (1980)	Global literature	5.45	5.05	0.05	0.45	0.00	0.82
AlMarhoun (1988)	Middle east	3.86	2.24	0.04	0.41	0.00	0.85
Abdul-Majeed and Salman (1988)	worldwide	3.74	-0.99	0.04	0.40	0.00	0.91
Dokla and Osman (1992)	U.A.E	4.28	0.26	0.04	0.98	0.00	0.88
Marcary and El-Batanoney (1993)	Gulf of Suez	6.08	-4.58	0.06	1.18	0.00	0.82
Omar and Todd (1993)	Malaysia	4.66	-2.62	0.05	0.38	0.00	0.90
Kartoatmodjo and Schmidt (1994)	World wide	4.31	3.18	0.04	0.42	0.00	0.83
Petrosky and Farshad (1995)	Gulf of Mexico Texas Louisiana	3.71	1.52	0.04	0.43	0.00	0.89
Khazam (1995)	Libya	6.23	5.38	0.07	0.52	0.00	0.53
De Ghetto et al., (1995)	Mediterranean Basin, Africa, and the Persian Gulf	11.08	11.08	0.11	0.63	0.02	0.04
Farshad , et al. (1996)	Colombia	4.22	3.27	0.04	0.43	0.00	0.87
Almed haideb (1997)	U.A.E	4.68	2.73	0.05	0.46	0.00	0.66
Hanafy et al., (1997)	Egypt	3.54	1.05	0.04	0.42	0.00	0.92
Al-Shammasi (1999)	World wide	3.91	2.36	0.04	0.42	0.00	0.86
Elksharkawy and Alikhan (1999)	Middle East	4.14	1.15	0.04	0.41	0.00	0.83
Khazam et al. (2016)	Libya	13.51	-9.40	0.15	1.69	0.00	0.60
New developed correlation	**Libya**	**2.92**	**-0.13**	**0.03**	**0.41**	**0.00**	**0.94**

AARE%: Absolute average relative error; AE%: average error AAD%: average standard deviation, R^2: correlation coefficient

The evaluated numbers presented in Table (4) show the developed correlation almost has the best results in AARE, ARE , (R^2) comparing to the other correlation, but it falls behind Vasquez and Beggs (1980) and Omar and Todd(1993) in the maximum standard deviation.

The cross plot of the measured and the calculated oil formation volume (Fig.5), illustrate an excellent positive correlation, this tell that the correlation coefficient (R^2) values for the oil formation volume (Bo) have a high accuracy with the results obtained by the new developed correlation in the most of statistical indicators.

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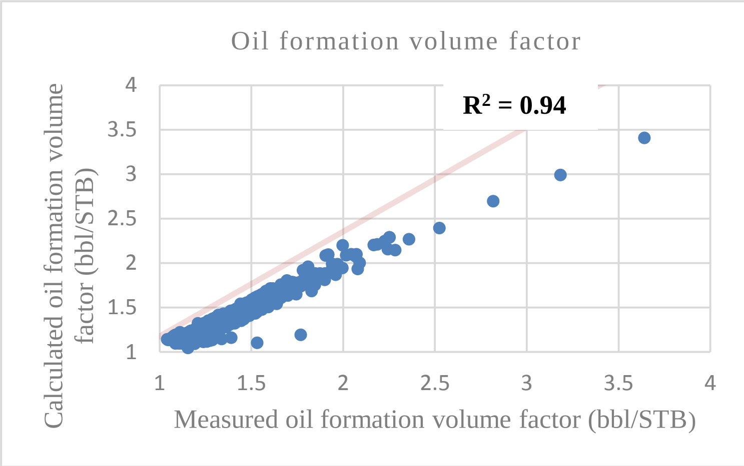

Fig. 5. Cross plot for the developed B_o correlation

3.4 Oil density correlation (ρ)

The oil density is defined as the weight per unit volume of the oil at reservoir conditions, its calculation based on temperature and oil formation volume factor. The oil density correlation has developed using an online regression. It is results show a direct proportion with the linear variation of reservoir temperature, and nonlinear variation of the formation volume factor. The regression process in this research is given by the following formula:-

$$\rho = 49.96 + (0.01545 * T) - (0.6996 * Bo^{1.538})$$

Where:

T = Reservoir temperature, (°F)
B_o = Formation volume factor (BBL/STB)

Data presented in (Table 5) represent the statistical analysis of oil density correlations **(ρ)** for the Libyan crude oil. The value of this study shows that the developed density correlation passes the values presented by Hanafy et al.,(1997) correlation in all the statistical indicators, and it falls behind values presented by Standing (1947) correlation coefficient R^2.

Table 5. Statistical parameters for oil density correlations (ρ)

Authors	Samples Origin	AARE (%)	AE%	AAD (%)	Max. Dev.	Min. Dev.	R^2
Standing (1947)	California	16.14	16.14	5.91	16.21	1.67	0.83
Hanafy et al., (1997)	Egypt	11.84	11.14	4.33	12.13	0.01	- 0.03
New developed correlation	Libya	**1.48**	**- 0.04**	**0.54**	**2.75**	**0.00**	**0.45**

AARE%: Absolute average relative error; AE%: average error AAD%: average standard deviation, R^2: correlation coefficient

The cross plot of the measured vs. calculated oil density of the Libyan crude oil samples (Fig. 6) show that the results obtained by the new developed oil density equation (ρ) have a

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positive correlation coefficient, which considered to be the best prediction than the other former published correlations when compared with values of other places.

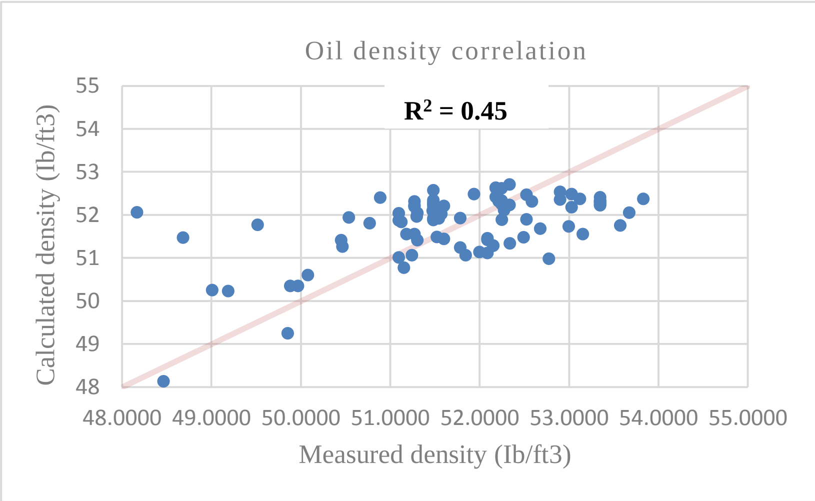

Fig. 6 Cross plot for the developed ρ correlation

3.5 Dead oil viscosity correlation (μ_{od})

The dead oil viscosity is defined as the viscosity of crude at the atmospheric pressure and the system temperature, (the viscosity of oil after removal of solution gas).It is well published that the viscosity is a measure of the resistance of fluid to flow and the viscosity of crude oil is measured in laboratory over the entire range of pressure (from above bubble point to atmospheric pressure) at reservoir temperature in unit of centipoises (cp). The viscosity of dead oil depends on the API and reservoir temperature (T) as correlating parameters. the dead oil viscosity is important in most applications related to the petroleum engineering.

Several forms of correlations were tested by using the conventional method, no formula gives a good statistical result or satisfying relationship between the response and variables. Therefore, to reach into the aimed results, the same form of correlation with different empirical parameters and non-linear regression was performed by using mat lab, the best regression analysis results were obtained by using the following dead oil viscosity equation: -

$$\mu od = \frac{1.218^{9}}{9.487 \times (T^{1.039} \times API^{3.431})}$$

Where:
API : Stock-tank oil gravity from flash separation (API^o)
T : Reservoir temperature, (°F)

The μ_{od} correlation show that, the dead oil viscosity is inversely proportional with the variation of temperature and the API gravity to the power of the constants (1.039, 3.431) respectively.

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The absolute average relative errors AARE for the dead oil viscosity and the other statistical indicators of different published μ_{od} correlations are established in the (Table 6). The new developed formula mention above for the Libyan crudes μ_{od} have recorded values of 34.29 %, 0.37 % and 0.75 for AAAR, AAD, and R^2 respectively. These values providing better knowledge of reliability of the discovered new μ_{od} correlation in comprising with many published correlation demonstrated by other researches.

Table 6. Statistical parameters for dead oil viscosity correlations (μ_{od})

Authors	Samples Origin	AARE (%)	AE (%)	AAD (%)	Max Dev.	Min Dev.	R2
Beal (1946)	California	41.90	42.73	0.67	2.11	0.00	-8.08
Beggs and Robinson (1975)	Global literature	41.41	14.56	0.59	2.59	0.00	-3.11
Glaso(1980)	Global literature	39.44	36.97	0.63	1.97	0.00	-9.89
Ng and Egbogh (1983)	Canada	34.98	11.20	0.50	1.62	0.00	-2.67
Kaye (1985)	California	36.82	31.44	0.58	1.86	0.01	-5.01
Labedi (1990)	Africa	38.25	-1.63	0.49	1.44	0.01	-0.45
Labedi (1992)	Libya	42.48	29.06	0.64	2.26	0.00	-5.01
Kartoatmodjo and Schmidt (1994)	Worldwide	49.03	42.85	0.89	2.06	0.03	- 28.43
De Ghetto et al. (1995)	Mediterranean Basin, Africa, and the Persian Gulf	69.46	68.37	1.20	2.53	0.13	- 591.29
Oyedeko and ulaeto (2001)	-	40.11	28.79	0.75	1.86	0.02	- 24.21
Dindoruk and Christman (2001)	Gulfof Maxico	44.41	39.98	0.84	2.00	0.00	- 39.46
Elsharkawy and Gharbi (2001)	Worldwide	97.79	94.84	1.32	2.73	0.17	- 67.05
Bergman (2004)	USA	35.18	21.80	0.55	1.79	0.01	-5.37
Hossain and Sarica.(2005)	Worldwide	80.11	80.11	1.28	2.42	0.17	- 68.30
Ikiensikimama et al., (2008)	Niger Delta	60.13	60.13	1.04	2.20	0.10	- 81.61
Naseri et al.(2012)	Iran	64.06	62.52	0.93	2.31	0.16	- 28.88
New developed correlation	**Libya**	**34.29**	**-6.45**	**0.37**	**1.60**	**0.00**	**0.75**

AARE%: Absolute average relative error; AE%:average error AAD%: average standard deviation, R^2: correlation coefficient

The cross plot of the measured and calculated dead oil viscosity of the samples from the Libyan crude oil (Fig.7) exhibit a very good positive correlation coefficient R^2, suggesting that the results obtained by the new developed dead oil viscosity formula (μ_{od}) are the best prediction than the other mentioned formulas when compared with the values of other places. However, the tested data for the new equation correlations are all laying within the trend of measured data, and no indication of abnormal or odd values prediction as shown in below Figure.

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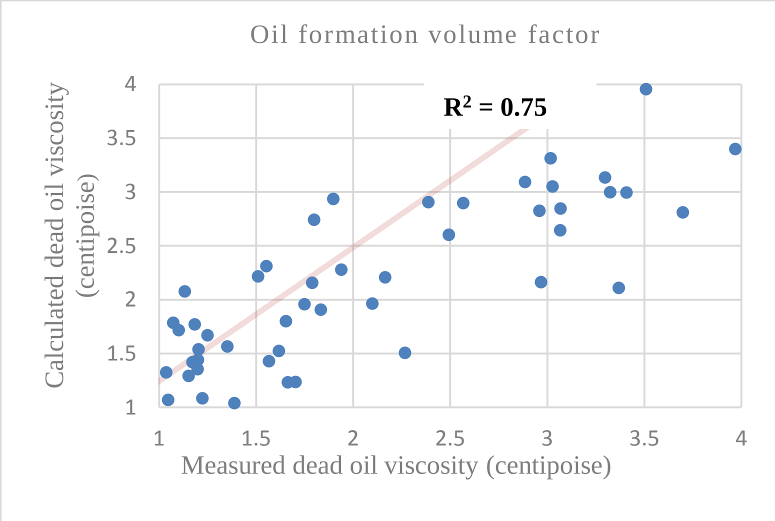

Fig. 7 Cross plot of the developed μ_{od} correlation

4. Conclusion

The investigation of five PVT correlations include bubble point pressure, solution gas oil ratio, Oil Formation Volume Factor, dead oil viscosity and oil density performed on the Libyan crude oil, representing Sirte, Ghdames, Murzug and offshore Tripolitania basins, were developed in order to determine PVT properties of 102 analyzed samples.

Minitab and Matlab software were used to establish the models for each property based on multiple linear & non-linear regressions and statistical software package, The accuracy of the models was examined and its performance was compared with available correlations and computer-based models. in addition four major different statistical indicators, R^2, ARE, AARE and MSD were used for the comparing process.

Cross plot of the laboratory measured vs. calculated (bubble point pressure (P_b) , solution gas oil ratio (R_s), oil viscosity (μ), oil density (ρ) and formation volume factor (B_o)) display strong positive correlation coefficient values, R^2 indicating that the parameters obtained by the new Five developed equations have higher performance than previous developed models and empirical correlations.

Finally, The statistical indicators of the new developed equations in this paper considered to be very reliable and more accurate comparing with the other published correlations for the Libyan crude oils.

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