

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

Taha A. Burgan, Saleh F. Moammer, Ali A. Khair, Mahfoud Z. Aghnaya

Abstract— Five PVT correlations including 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 a new more accurate correlation. Linear & nonlinear regression and statistical software packages (Excel, Minitab, and Mat lab software) were applied to the above-mentioned crude samples. The application of multilinear regression and statically software on the solution gas, oil ratio, temperature, and API gravity, exhibit a direct proportionality with the bubble point, whereas in the case of gas gravity, the correlation shows inversely proportionality 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 close to the 45° trend line fourth solution gas oil ratio, indicating that the correlations have higher accuracy with our newly 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 play a very good reliable correlation compared with previously published correlations done by other researchers as well as in the statistical calculation, in addition, the AARE and R2 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 previously published correlations, exclusively for Libyan crude oil.

Index Terms— Bubble Point Pressure, Empirical Correlations, Libya, Oil Density, PVT.

I. 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 [1]. The PVT parameters discussed here are based on a total of 102 samples collected from four different localities in the onshore and offshore Libyan state, representative of Sirte, Ghdames, Murzug, and Tripolitania basins (Fig.1).

Petroleum is a mixture of hydrocarbons, naturally occurring, and may exist in solid, liquid, or gaseous states,

depending on the conditions of temperature and pressure to which it has been subjected. Petroleum deposits vary widely in chemical composition depending on location and 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 the minor constituents present in them [2],[3].

Ref. [4] stated that the volumetric behavior of reservoir fluids must be determined as a function of pressure and temperature to make an engineer evaluate the production performance of reservoir calculations, reservoir evaluation, numerical reservoir simulation, 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 the 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 [5].

To provide calculations and physical property data for well flow and surface facility design, the PVT tests and subsequent reports give the source of the reservoir fluids properties, which 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 of these fluid properties were determined by laboratory experiments that were performed on the tested samples of actual reservoir fluids, in the case of the absence of experimentally measured properties of crude oils, the petroleum engineer must determine the properties from empirically derived correlations.

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

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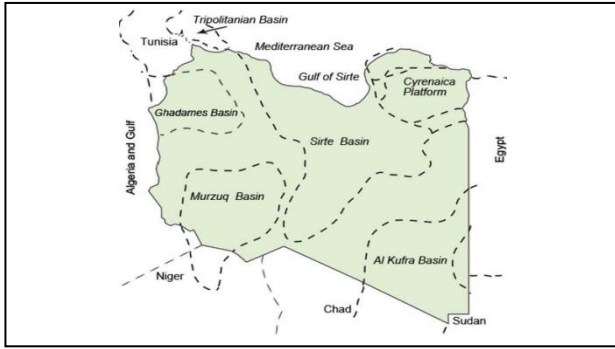


Fig. 1. Map of Libya showing the study areas [6].

II. METHOD

All the data under investigation was collected and filtered to develop 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, The 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).

Scatter plots were constructed to evaluate the relationships between variables to help in the process of formulation of the correlations. Residual plots and 45° degree plots were constructed to evaluate and visualize the models suggested compared to former studies aside from the statistical indicators.

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

TABLE1
POINTS USED TO DEVELOP AND TEST PVT CORRELATIONS

PVT	No of the points used to develop the correlation	No of the 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 to Libyan oil crude, it is associated with errors and the accurate determination of the PVT properties is uncompromising. Fig. 2 summarizes the steps taken to establish the correlation model.

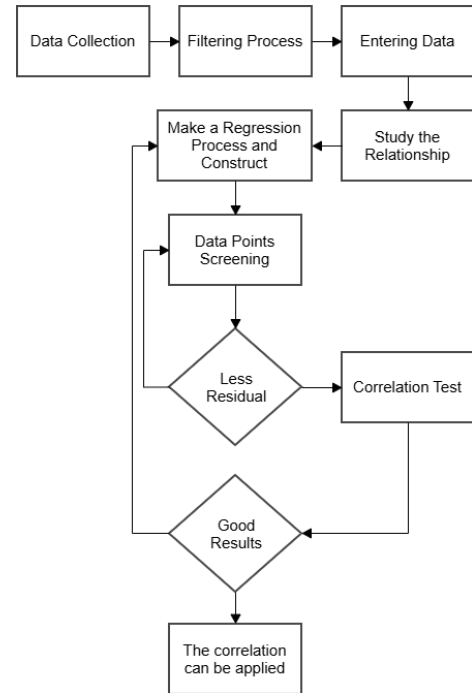


Fig. 2. A flow chart illustrates the research methodology

II. RESULTS AND DISCUSSION

Among different fluid properties, the accuracy of bubble point pressure (P_b), oil formation volume factor (B_o), solution gas-oil ratio (R_{os}), oil density correlation (ρ), and dead oil viscosity (μ_{od}) are very essential in reservoir engineering calculations. 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. Many laboratory analyses can be made on 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; the first is a primary test, which is a simple, routine field (on-site) test 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 slim-tube tests or/and swelling tests.

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 [7].

Based on 102 analyzed samples, which were determined under linear regression and statistical software package (Excel Minitab and Matlab). The details results and

discussions are presented in the following points.

A. 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 newly developed equation:

$$P_b = 21536 + (37.65 \times R_{so}) - (2187 \times \log(R_{so})) - (230.4 \times \frac{API}{\gamma_g}) - (165.5 \times T) + (0.000882 \times R_{so}^2) + (0.3443 \times T^2) - (10.98 \times R_{so} \times \frac{API}{\gamma_g}) + (1.264 \times \log(R_{so}) \times T) \dots\dots\dots (1)$$

Where:

R_{so} = Solution gas oil ratio (SCF/STB)

API = Stock-tank oil gravity from flash separation (APIo)

γ_g = Average specific gravity of total surface gases from flash separation

T = Reservoir temperature, (°F)

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 displays inversely proportional with the bubble point. It is also noticeable that the equation includes both square and logarithm functions, which are based on the matrix plot approach used in the Minitab software, 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 newly developed P_b formula, for the analyzed Libyan crude oil samples. The P_b value of this study is considerably higher than the other values presented in (Table 2). However, the new P_b equation registered an R^2 value of 0.87, which is considered to be a better prediction than overall the other former published correlations when compared with values from other places.

TABLE 2

STATISTICAL PARAMETERS FOR BUBBLE POINT PRESSURE (P_b)

Authors	Samples Origin	AARE (%)	AE%	AAD (%)	Max Dev.	Min Dev.	R^2
Standing [10]	California	68	-47.87	472.03	2671.01	2.98	0.52
Vasquez and Beggs [11]	worldwide	78	-63.96	510.07	3111.72	2.52	0.51
Al-Marhoun [12]	Middle east	66	-37.67	437.76	2905.16	16.61	0.45
Farshad, et al. [28]	Colombia	78	-58.23	517.18	2525.88	1.40	0.39
Petrosky and Farshad [13]	Gulf of Mexico	82	32.12	496.08	2509.83	6.24	0.63
Kartoatmodjo and Schmidt [14]	World wide	76	-62.14	534.89	3509.09	6.43	0.51
Khazam [8]	Libya	67	-50.75	420.00	1930.91	8.39	0.62
Velarde, et al. [38]	Global literature	64	-37.86	434.06	2601.34	11.86	0.41
Hanafy et al., [15]	Egypt	109	-90.35	749.48	6843.05	8.72	0.19
Al-Shammasi [17]	World wide	282	-279.79	2097.41	12292.10	214.31	-0.47
Dindoruk and Christman [18]	Gulf of Mexico	66	-39.24	442.62	2636.49	5.85	0.29
Khazam et al. [9]	Libya	74	-58.83	415.74	2151.23	17.40	0.57
Newly developed correlation	Libya	41	16.18	257.32	1399.02	1.69	0.87

The average absolute relative error (AARE) presented by Ref. [8],[9] for the Libyan crude oil samples did not show 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.

The cross plot of laboratory-measured and the

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

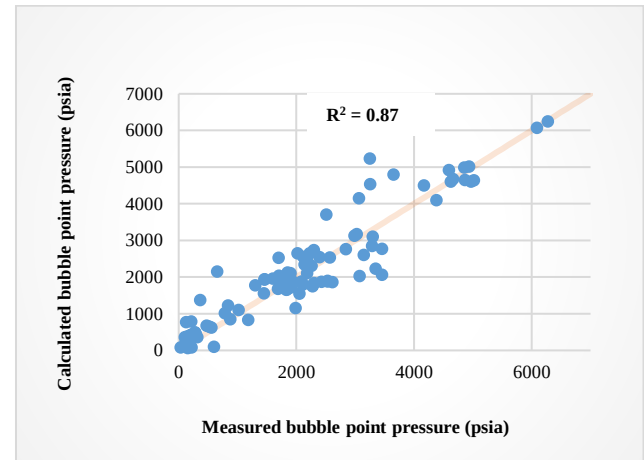


Fig. 3. Cross plot of the developed P_b correlation

B. Solution gas oil ratio (R_{so})

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 newly developed formula:

$$R_{so} = (1356.1 \times B_o) - (0.3689 \times T) + (0.08835 \times P) - 1440.1 \dots\dots\dots (2)$$

Where:

B_o = Formation volume factor (BBL/STB)

T = Reservoir temperature (°F)

P = Reservoir pressure (Pisa)

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 [10]	California	50.36	7.87	137.68	1763.83	0.10	0.42
Vasquez and Beggs [11]	worldwide	49.71	18.05	138.90	1851.44	0.08	0.29
Al-Marhoun [12]	Middle east	61.94	1.05	183.82	4070.27	0.32	0.29
Petrosky and Farshad [13]	Gulf of Mexico	111.00	-101.70	189.91	2872.90	0.16	0.71
Kartoatmodjo and Schmidt [14]	World wide	48.07	15.84	131.72	1847.53	0.31	0.24
Hanafy et al. [15]	Egypt	60.66	21.34	158.14	2135.14	0.08	0.19
Levitan and Murtha [16]	Global literature	49.43	15.34	136.446	1841.68	0.02	- 1.08
Al-Shammasi [17]	World wide	54.75	-47.77	91.3801	834.10	0.08	0.85
Dindoruk and Christman [18]	Gulf of Mexico	85.74	73.48	310.1674	2432.51	2.23	- 82.83
Hemati and Kharrat [19]	Iran	53.33	1.12	144.3713	1746.57	0.25	0.44
Mazandarani and Asghari [20]	Iran	50.44	8.96	137.1051	1790.84	0.42	0.40
Khamechi and Ebrahimian [21]	Middle East	47.36	19.15	133.21	2033.17	0.19	- 0.14
Jarrahian et al. [22]	Global literature	313.33	-307.51	1029.3815	11309.13	1.68	- 0.60
Khazam et al. [9]	Libya	54.29	21.82	164.478	2311.37	0.04	0.35
Newly developed correlation	Libya	26.32	- 3.77	26.5151	540.68	0.05	0.97

The newly developed formula (Solution gas oil ratio (R_{so}), shows high accuracy correlations as compared with the other average data presented in (Table 3), only except those data presented by Ref. [17] which show a satisfactory result in R² 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 Table 3 did not show a good performance in (AARE) as well as in the results obtained by the newly 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), illustrates a strong positive correlation, indicating that the correlation coefficient (R²) values for the solution gas-oil ratio (R_{so}) have a high accuracy with the results obtained by the newly developed correlation.

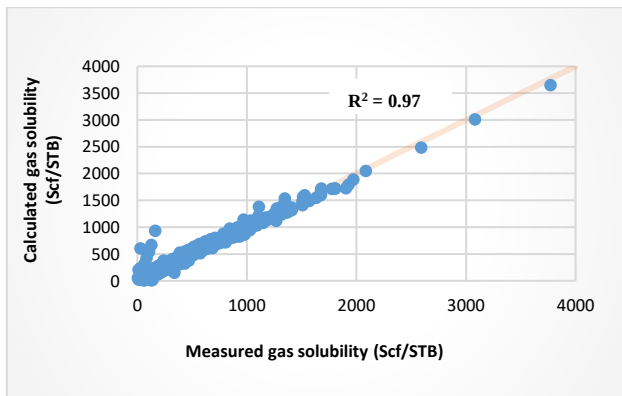


Fig. 4. Cross plot for the developed R_{so} correlation

C. 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 were obtained by using the following oil formation volume factor equation:

$$Bo = (0.8875) + (0.004107 \times API) + (0.00059 \times R_{so}) + (0.1532 \times \gamma_g) - (0.000449 \times T) \dots\dots\dots (3)$$

Where:

API: Stock-tank oil gravity from flash separation (API°)

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 newly developed formula (Bo) for the Libyan crude oils (Table 4), display a correlation coefficient (R²) value of 94.45, which is too close to the accurate prediction.

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

The evaluated numbers presented in Table 4 show the developed correlation almost has the best results in AARE, ARE, (R²) compared to the other correlation, but it falls behind Ref. [11] and Ref. [23] in the maximum standard deviation.

The cross plot of the measured and the calculated oil formation volume (Fig. 5), illustrates an excellent positive correlation, this shows that the correlation coefficient (R²) values for the oil formation volume (Bo) have high accuracy with the results obtained by the newly developed correlation in the most of statistical indicators.

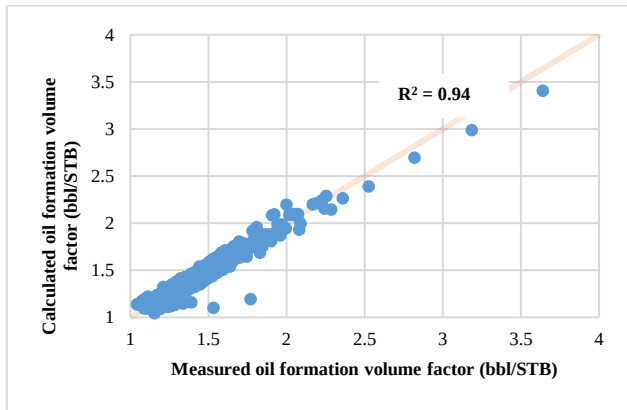


Fig. 5. Cross plot for the developed Bo correlation

D. Oil density correlation (ρ)

The oil density is defined as the weight per unit volume of the oil at reservoir conditions, its calculation is based on temperature and oil formation volume factor. The oil density correlation has developed using an online regression. Its 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:-

$$\rho = 49.96 + (0.01545 * T) - (0.6996 * Bo) + 1.538 \quad (4)$$

Where:

T = Reservoir temperature, (°F)

Bo = Formation volume factor (BBL/STB)

TABLE 4

STATISTICAL PARAMETERS FOR OIL FORMATION VOLUME Bo

Authors	Samples Origin	AARE (%)	AE (%)	AAD (%)	Max Dev.	Min Dev.	R ²
Standing [10]	California	3.95	2.71	0.04	0.43	0.0001	0.89
Vasquez and Beggs [11]	World wide	9.92	-8.72	0.10	0.32	0.00	0.38
Glazo [1]	Global literature	5.45	5.05	0.05	0.45	0.00	0.82
AlMarhoun [12]	Middle east	3.86	2.24	0.04	0.41	0.00	0.85
Abdul-Majeed and Salman [24]	worldwide	3.74	-0.99	0.04	0.40	0.00	0.91
Dokla and Osman [25]	U.A.E	4.28	0.26	0.04	0.98	0.00	0.88
Marcary and El-Batanoney [26]	Gulf of Suez	6.08	-4.58	0.06	1.18	0.00	0.82
Omar and Todd [23]	Malaysia	4.66	-2.62	0.05	0.38	0.00	0.90
Kartoatmodjo and Schmidt [14]	World wide	4.31	3.18	0.04	0.42	0.00	0.83
Petrosky and Farshad [13]	Gulf of Mexico Texas Louisiana	3.71	1.52	0.04	0.43	0.00	0.89
Khazam [8]	Libya	6.23	5.38	0.07	0.52	0.00	0.53
De Ghetto et al. [27]	Mediterranean Basin, Africa, and the Persian Gulf	11.08	11.08	0.11	0.63	0.02	0.04
Farshad, et al. [28]	Colombia	4.22	3.27	0.04	0.43	0.00	0.87
Al-Mehaideb [29]	U.A.E	4.68	2.73	0.05	0.46	0.00	0.66
Hanafy et al. [15]	Egypt	3.54	1.05	0.04	0.42	0.00	0.92
Al-Shammasi [17]	World wide	3.91	2.36	0.04	0.42	0.00	0.86
Elksharkawy and Alikhan [30]	Middle East	4.14	1.15	0.04	0.41	0.00	0.83
Khazam et al. [9]	Libya	13.51	-9.40	0.15	1.69	0.00	0.60
Newly developed correlation	Libya	2.92	-0.13	0.03	0.41	0.00	0.94

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 Ref. [15] correlation in all the statistical indicators, and it falls behind values presented by Ref. [10] correlation coefficient R².

TABLE 5

STATISTICAL PARAMETERS FOR OIL DENSITY CORRELATIONS (ρ)

Authors	Samples Origin	AARE (%)	AE%	AAD (%)	Max. Dev.	Min. Dev.	R ²
Standing [10]	California	16.14	16.14	5.91	16.21	1.67	0.83
Hanafy et al. [15]	Egypt	11.84	11.14	4.33	12.13	0.01	-0.03
Newly developed correlation	Libya	1.48	-0.04	0.54	2.75	0.00	0.45

The cross plot of the measured vs. calculated oil density of the Libyan crude oil samples (Fig. 6) shows that the results obtained by the newly developed oil density equation (ρ) have a positive correlation coefficient, which is considered to be the best prediction than the other former published correlations when compared with values of other places.

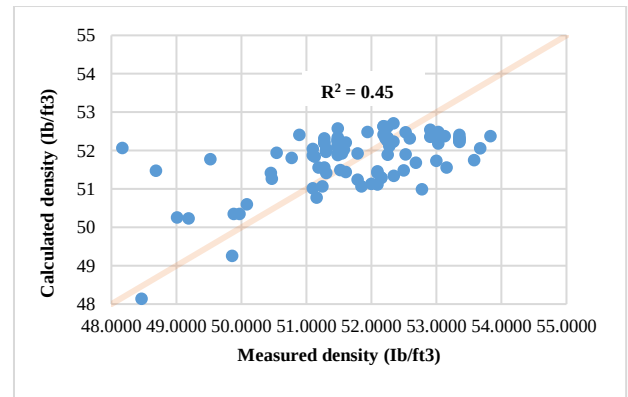


Fig. 6. Cross plot for the developed ρ correlation

E. 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 the laboratory over the entire range of pressure (from above bubble point to atmospheric pressure) at reservoir temperature in a 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 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 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:

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

..... (5)

Where:

API: Stock-tank oi gravity from flash separation (APIo)

T: Reservoir temperature, (°F)

The μ_{od} correlation shows 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.

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 (Table 6). The newly developed formula mentioned above for the Libyan crudes μ_{od} has recorded values of 34.29%, 0.37%, and 0.75 for AAAR, AAD, and R2 respectively. These values provide better knowledge of the reliability of the discovered new μ_{od} correlation comprised of many published correlations demonstrated by other researchers.

TABLE 6
STATISTICAL PARAMETERS FOR DEAD OIL VISCOSITY CORRELATIONS (μ_{od})

Authors	Samples Origin	AARE (%)	AE (%)	AAD (%)	Max Dev.	Min Dev.	R2
Beal [31]	California	41.90	42.73	0.67	2.11	0.00	-8.08
Beggs and Robinson [32]	Global literature	41.41	14.56	0.59	2.59	0.00	-3.11
Glaso [1]	Global literature	39.44	36.97	0.63	1.97	0.00	-9.89
Ng and Egbogh [33]	Canada	34.98	11.20	0.50	1.62	0.00	-2.67
Kaye [34]	California	36.82	31.44	0.58	1.86	0.01	-5.01
Labedi [35]	Africa	38.25	-1.63	0.49	1.44	0.01	-0.45
Labedi [36]	Libya	42.48	29.06	0.64	2.26	0.00	-5.01
Kartoatmodjo and Schmidt [14]	Worldwide	49.03	42.85	0.89	2.06	0.03	- 28.43
De Ghetto et al. [27]	Mediterranean Basin, Africa, and the Persian Gulf	69.46	68.37	1.20	2.53	0.13	- 591.29
Oyedeko and Ulaeto [37]	-	40.11	28.79	0.75	1.86	0.02	- 24.21
Dindoruk and Christman [18]	Gulf of Mexico	44.41	39.98	0.84	2.00	0.00	- 39.46
Elsharkawy and Gharbi [30]	Worldwide	97.79	94.84	1.32	2.73	0.17	- 67.05
Bergman [39]	USA	35.18	21.80	0.55	1.79	0.01	-5.37
Hossain and Sarica [40]	Worldwide	80.11	80.11	1.28	2.42	0.17	- 68.30
Ikiensikimama et al. [41]	Niger Delta	60.13	60.13	1.04	2.20	0.10	- 81.61
Naseri et al. [42]	Iran	64.06	62.52	0.93	2.31	0.16	- 28.88
Newly developed correlation	Libya	34.29	-6.45	0.37	1.60	0.00	0.75

The cross plot of the measured and calculated dead oil viscosity of the samples from the Libyan crude oil (Fig.7) exhibits a very good positive correlation coefficient R2, suggesting that the results obtained by the newly 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 Fig. 7.

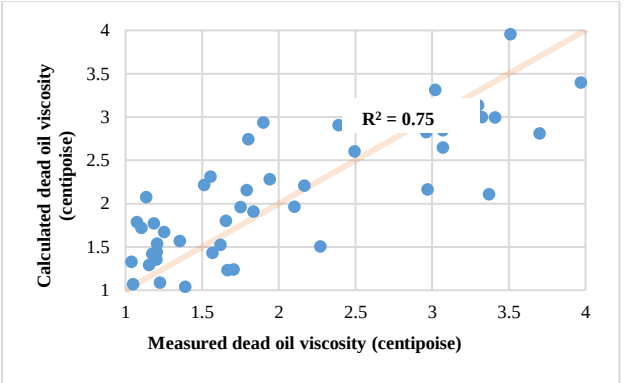


Fig. 7 Cross plot of the developed μ_{od} correlation

V. CONCLUSION

The investigation of five PVT correlations including 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, Ghdamas, Murzug, and offshore Tripolitania basins, were developed 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 packages, The accuracy of the models was examined and their performance was compared with available correlations and computer-based models. in addition, four major statistical indicators, R2, ARE, AARE, and MSD were used for the comparison process. Cross plot of the laboratory measured vs. calculated (bubble point pressure (Pb), solution gas-oil ratio (Rs), oil viscosity (μ), oil

density (ρ), and formation volume factor (Bo)) display strong positive correlation coefficient values, R2 indicating that the parameters obtained by the new Five developed equations have higher performance than previously developed models and empirical correlations. Finally, the statistical indicators of the newly developed equations in this paper are considered to be very reliable and more accurate compared with the other published correlations for Libyan crude oils.

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