Egypt.J.Chem. **Vol. 63**, No. 5. pp. 1941 - 1954 (2020)

Egyptian Journal of Chemistry
http://ejchem.journals.ekb.eg/

Improvement Wilson Equation (K-Values) of Gas-liquid Equilibrium for Advancing Estimating Bubble Point Pressure

E.M. Mansour* and S.M. Desouky
Production Department, Egyptian Petroleum Research Institute, Cairo, Egypt

KNOWING the bubble point pressure of the oil reservoirs is a key factor for the petroleum engineers in order to optimize the development of the oil field starting from the discovery phase until the abandonment. Thus any considerable error in estimating the bubble point pressure will lead to errors in the production and reservoirs engineering calculations. More than six hundred Egyptian oil samples of PVT analysis were used to improve the Wilson equation (K-Values) for estimating bubble point pressure. None of the published bubble point pressure correlations is particularly accurate when applied to Egyptian crude oils. Experimental work was conducted in the PVT- Services Center of the Egyptian Petroleum Research Institute (EPRI). In this work, the K-values correlation proposed by Wilson equation was modified by adding new terms such as API, GOR, and heptanes plus-fraction (C_7^+) of compositional analysis of the reservoir fluid. Multiple non-linear regression analysis is used to calculate the new equation constant after adding the new terms. The statistical error analysis shows that the Correlation coefficient $(r^2,\%)$, the average percent relative error (ARE), the standard deviation $(S,\%)$ and the average absolute percent relative error $(AARE)$ of the modifying are 99.75 %, 1.77%, 8.08%, and 6.84 %, respectively. This correlation of K-factor can be applied not only to low and moderate pressure but also to higher pressures up to (4500 psi) by this modification. Evaluation among the bubble point pressure calculated from the modified Wilson equation and the literature published ones were done. Results confirm that the modified Wilson equation is more accurate one and it can be used for estimating the reservoir fluids characteristics in the absence of data measurement.

Keywords: Bubble point pressure correlations, Reservoir fluid, Multiple regressions, PVT tests, Gas liquid equilibrium.

Introduction

Pressure-Volume-Temperature (PVT) analysis is the general method used to simulate the volumetric behavior of reservoir fluids under the same condition [1-3]. PVT properties are critical to identifying the reservoir fluid type, estimate recovery amount, design production surface facilities, and perform reservoir simulation studies [3-6]. An essential PVT property is the bubble point pressure (saturation pressure) at reservoir temperature that required for reservoir studies **[7-10]**. The bubble point pressure of the crude oil is the pressure where the first gas bubble is liberated from the system, where at this point the change from one phase to two-phase can be clearly seen [11-13]**.** The bubble point pressure prediction can be done by experimental work or by computation method. In the absence of such experimental analysis, the bubble point pressure may be estimated by the equation of state, empirical correlations or K-values [14]. PVT computation methods are used for the following reasons: (i) insufficient sample volume (ii) cost reduction (iii), not representative samples (iv) unavailable lab measurements [15-17]. Most popular bubble point pressure correlations informed in the literature are involved in this paper as shown in Appendix A. Standing (1947) expressed his correlation in graphical and mathematical form. He expressed empirical correlation for bubble point pressure by correlating some of inputs parameters such as

---

*Corresponding author e-mail: emanmansour84@yahoo.com
Received 6/8/2019; Accepted 13/10/2019
DOI: 10.21608/ejchem.2019.15671.1951

GOR, gas density, API gravity, and temperature of the reservoir. 105 points of data from Californian oil fields were used in correlating Standing study. The bubble point correlation revealed 4.8% average error [18]. Borden-Razasa (1950) developed correlation based on data from wells extending from the Gulf Coast to the Rocky Mountains in the U.S.A. A total of 180 bottom hole samples and six recombined samples were used in developing this correlation. His correlation was expressed in a graphical form only. It revealed an average error of 1.84% [19]. Laster (1958) used 158 samples from South America, Canada, and U.S.A. to modify mathematical and graphical correlation forms [20]. Glaso (1980) developed his correlation based on the data of 45 samples from the North Sea. The North Sea oils are with paraffin cities equivalent to oils with UOP characterization factor of 11.9. The correlation showed (ARE) and $(S,\%)$ of 1.28% and 6.98% respectively [21]. Al-Marhoun (1988) expressed a correlation for bubble point pressure based on 160 points of data from Middle East fields. The (ARE) and $(S,\%)$ of this equation were determined to be 0.03% and 3.54% respectively [22]. Dokla-Osman (1992) was published a correlation based on 51 oil samples collected from fields of UAE. Dokla-Osman recommended usage of his correlation in UAE as it provides a good approximation of PVT properties comparing to other available correlations such as Glaso, Standing, and Al-Marhoun. The(ARE) and $(S,\%)$ of Dokla-Osman correlation were 0.45% and 10.35% respectively [23]. De Ghetto et al. (1994) published their correlation against an asset of 195 samples collected from the North Sea, the Persian Gulf, Africa, and the Mediterranean Basin. Around 3700 data points have been examined for this correlation. Oil samples with API range 6< API<56.8. The new bubble point correlation proposed by De Ghetto et al gave errors lower than 10% as compared with literature bubble point pressure correlations [24]. Almehaideb (1997) used 15 dissimilar reservoirs in the UAE to improve the bubble point pressure correlation. In addition to the commonly used four parameters in other correlations including reservoir temperature, oil gravity, gas gravity, and GOR .5.0% and 6.56% are $(ARE)$and$(S,\%)$ respectively of Almehaideb correlation. Taghizadeh &Asghari (2007) worked on PVT analysis of 55 samples collected from different fields in Iran (Iranian Offshore Oil Fields, Iranian Central Oil Fields, and Iranian Southern Oil Fields) to develop their correlation. The correlation model development was based on Al-Marhoun's correlation for predicting the bubble point pressure of Iran crude oils. Taghizadeh &Asghari correlation was obtained as a direct function of oil gravity, reservoir temperature, GOR and, gas gravity by applying linear regression analysis using Eview's software [26]. Ehsan Khamehchi1 (2009) correlated a mathematical model with 94 crude oil data, (r) index result was close unity for bubble point pressure correlation [27]. Macary-Batanon correlation (1992) was built by using 90 oil samples from the Gulf of Suez with an average error of 0.525%. However, they determined average errors of -30.32% and -7.5% for Standing and Glaso bubble point pressure correlations [28]. Hanfi (1998) expresses gas solubility in oil as a strong function of gas gravity, API and reservoir temperature. Consequently, improvement of empirical correlation between any fluid property and gas oil ratio should include the mentioned above parameters. For that reason, a simple correlation between bubble point pressure and GOR was developed by (r) index resulted in 0.90 [29-30]. Numerous investigators suggested different methods for estimating worthy K-values for crude oils to determine bubble point pressure. Eq (1)is a general method used to determine bubble point pressure[31].

$$\Sigma K_iZ_i = 1 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

To perform the bubble point calculation, K-value has to be calculated. Prediction methods for K-values of crude oils have an enormous interest in petroleum and chemical industries as DePriester charts, Wilson equation, Whitson and Torp equation, McWilliams equation and Almehaideb et al. DePriester [31] presented K-value for light hydrocarbons as charts at pressure 6000 psi.

Wilson equation [32] proposed a simplified expression for K-value as shown Eq (2). This correlation of K-factor is applied to low and moderate pressure only.

$$K_i = \frac{p_{ci}}{p}\exp\left[5.37(1+\omega_i)\left(1-\frac{T_{ci}}{T}\right)\right] \qquad \ldots\ldots\ldots\ldots(2)$$

McWilliams [33] fitted K-value charts of DePriester to the following polynomial equation as shown in Eq (3).

$$\ln K = \frac{a_{T1}}{T^2} + \frac{a_{T2}}{T} + a_{T3} + a_{p1} \ln p + \frac{a_{p2}}{p^2} + \frac{a_{p3}}{p} \qquad \text{.......(3)}$$

Whitson and Torp equation [34] modified Wilson's equation by incorporating the convergence pressure to provide effects of the compositional at high pressures as seen in Eq (4).

$$K_i = \left(\frac{p_{ci}}{p_k}\right)^{A-1}\left(\frac{p_{ci}}{p}\right)\exp\left[5.37A(1+\omega_i)\left(1-\frac{T_{ci}}{T}\right)\right] \qquad \text{..........(4)}$$

Almehaideb et al [35] proposed K-value based on polynomial formula for the UAE only as Eq (5).

$$K_i^{\text{New}} = \left(\frac{p_{ci}}{p_k}\right)^{A-1}\left(\frac{p_{ci}}{p}\right)\exp[A \times K_i^*] \qquad \text{.......(5)}$$

K-values of Wilson equation, Whitson and Torp equation, DePriester charts, and polynomial equation are poorly compared with hydrocarbon and non-hydrocarbon components [36]. So in this study, we will focus on improving k-value based on the most common K-values equation for gas-liquid equilibrium calculations, presented by Wilson equation [32]. Also, an examination of existing bubble point pressure correlations with the improved Wilson equation using testing PVT data from different fields in Egypt.

Experimental Work

In order to develop predictive values of bubble point pressure, it was necessary to have many experimental PVT data coming from the different fields in Egypt either from the bottom-hole sample or recombined surface separator sample. 6600 data points of volatile and black oils PVT samples that have field data, primary test results, and constant mass expansion (CME) tests results are stored as a data bank for this study.

Measurement of Composition, Oil Gravity, and Gas/Oil Ratio.

Primary tests started with transferring a sample of reservoir fluid to laboratory PVT-Cell under reservoir condition. A sample portion was injected at reservoir conditions to make flash liberation at standard conditions (P=14.73 psia and T=60°F). Chromatography analyzer conducted for the stock tank oil and flashed gas. In addition, stock-tank oil gravity was measured by using density meter. Based on the solution gas/oil ratio and specific gravity measurement, the compositional analysis of a good stream was conducted [2].

Measurement of Bubble Point Pressures of Crude Oils:

Constant-mass expansion test was done by placing a crude oil sample in a visual PVT cell at a pressure more than the formation pressure and temperature of the reservoir as seen in (Figure 1) [30]. A stirrer was used to ensure gas-liquid equilibrium [23] agitates the cell regularly. At constant temperature, the volume of the total hydrocarbon inside the cell was reduced for different pressures as shown in (Figure 2) [12]. The bubble point pressure is conducted by pressure/volume relation curve or visually observed and also it can be recorded from the cell directly [8].

Results and Discussion

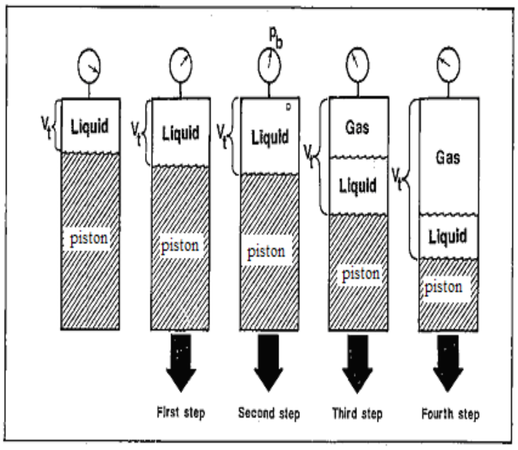
PVT Data Acquisition

Figure 3 shows a very big variation in each data set that include oil gravity, gas-oil ratio, C_7^+ mole% of the good stream, experimental bubble point pressure, reservoir temperature, reservoir pressure, molecular weight of flashed gas, oil specific gravity, gas specific gravity, oil formation volume factor and stock tank oil molecular. Table (1) shows statistical basic characteristic data of Egyptian crude Oils, which comprise the minimum, maximum and average of more than 600 oil samples. This table ensures the best selection of crude oil samples for improving Wilson equation.

Modification of Wilson equation (K-values):

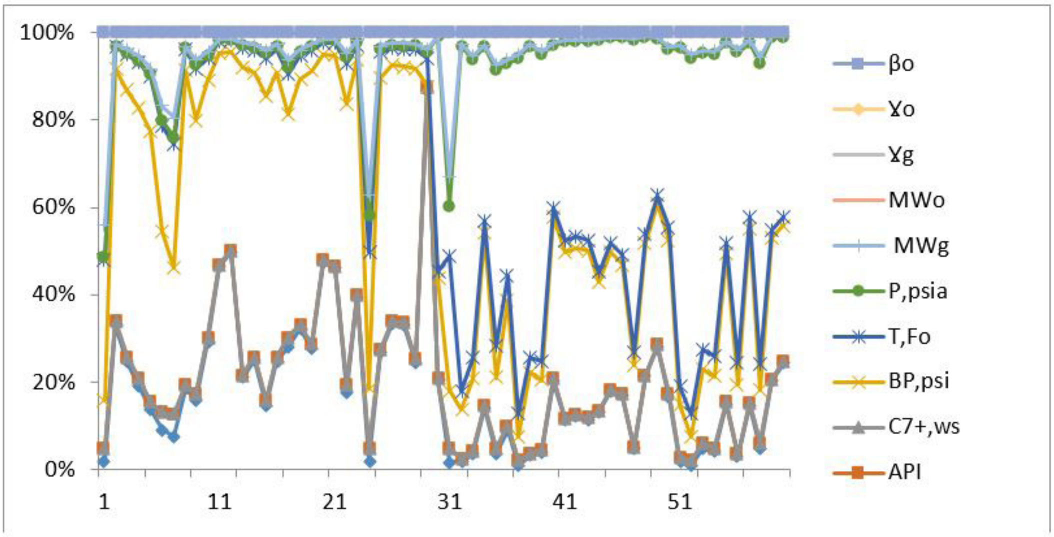
Although the Wilson equation (K-values) is not accurate and has certain solution techniques for gas-liquid equilibrium calculations, we used it as the initial trier values of K-factors. There are some steps to improvement Wilson equation (k-values). The first step: the modifying depends on data collected from field like the reservoir temperature (T_{res}) and data from experimental work like well stream compositional analysis and many other assumptions of pressure. The second step: the modifying applied to the constant value that equal 5.37 in the Wilson equation, which changed to be empirical correlation [15]. The development of the correlation depends on the selection of the parameters that are anticipated to influence the bubble point pressure behavior. The relations between these parameters on the

Figure(1): Visual PVT cell lab



Figure(2): Constant-Mass Expansion

Figure (3): shows variation in the selection of PVT experimental crude oils samples.



individual and the combined basis of the BP were examined [3]. The best parameters were selected in building up the correlation and the least ones were omitted. This leads to building a correlation based on API, gas-oil ratio and heptanes plus-fraction by using non-linear multiple regression analysis. The development of the correlation occurred by using a regression analysis that depends on the variable's nature of them. The regression analysis concept depends on fitting the independent variables to predict one dependent variable [16]. Non-linear multiple regression analysis explains the relations between the dependent variables and independent variables [37]. Therefore, by applying multiple regression analysis, we estimated that

C= a1+ a2 ln(GOR) + a3 ln(API) +a4 ln(C7+) …………………………….(6)

Where a1, a2, a3 and a4 are coefficients that determined by the regression analysis.

a_1 = 5.08008 & a_2= 0.052 & a_3= -0.265 & a_4= 0.033

Then replacement of the constant equals 5.37 in Wilson equation with the developed empirical correlation presented in Eq (6) to improving in Wilson equation (K-values) that shown in Eq (7).

$$K_j = \frac{EXP[C\ (1 + \omega_j)\ (1 - 1/T_{rj})]}{P_{rj}} \qquad \text{……………(7)}$$

Accordingly, K-values change by changing the sample, not due to either reservoir pressure or reservoir temperature but also due to constant values that affected by parameters such as API, the gas/oil ratio (R_s), and heptanes plus-fraction of compositional analysis of the reservoir. After developing K-values, we can substitute Eq (6) into Eq (7) then calculate Σ KZ with many assumed pressures and apply trial and error until Σ KZ equals one. Figure (4) shows the determination using this assumed pressure value [6]. Also, this modification of K-factor correlation can be applied not only to low and moderate pressure but to high pressure up to (4500 psi). A comparison of the calculation of bubble point pressure from the new model with the results of the bubble point pressure from popular correlations occurs. Therefore, we checked this accuracy by statistical error analysis and graphical error analysis. Firstly, the accuracy of each empirical correlation was occurred by applying the statistical error analysis. The statistical errors analysis comprise the (ARE), $(AARE)$, $(E_{\min})$, $(E_{\max})$, $(S,\%)$ and $(r^2,\%)$ were computed for each empirical correlation and new modeling. In the worldwide: Table (2) reports the statistical errors analysis of the several empirical correlations in the worldwide by applying them on Egyptian crude oils (black &volatile oils).

Standing (1947) correlation gives the lowest $(S,\%)$ of 27.81 and highest $(r^2,\%)$ of 88.29. This shows that the Standing (1947) correlation is the best bubble point correlation for predicting bubble point pressure of Egyptian crude oils. In the Middle East: Dokla-Osman(1992) correlation presented well results as compared with other correlations examined in the Middle East. Table (3) showed least (ARE) of -10.14 and the best $(r^2,\%)$ of 88.83. Therefore, Dokla-Osman (1992) correlation is the best for predicting of bubble point pressure for Egyptian black & volatile oils. In another hand, Ehsan Khamehchil (2009) has the lowest accuracy of $(r^2,\%)$ applying it to Egyptian crude oils.

In Egypt: In this instance, Macary-Batanon (1992) correlation has the least error for data used as compared with Hanfi (1980) correlation as seen in tables (4). Macary-Batanon (1992) has the best $(r^2,\%)$ of -23.53 for Egyptian oil reservoirs.

Although empirical correlations of Standing (1947) and Dokla-Osman (1992) give the maximum improvement in the errors as compared with the other correlations in the world wide& the Middle East and Egypt, they still give high errors by applying the on Egyptian (Black &Volatile) oils. It is clear from these tables (2-4) that the new technique has better accuracy for the crude oil samples. In comparison with other correlations, the current study gives the lowest value of $(AARE)$ 6.84 %, (ARE) of 1.77 %, $(S,\%)$ of 8.08% and $(r^2,\%)$ of 99.75 %, which is near to unity. This work expresses a worthy agreement between experimental work and the current study to estimate bubble point pressure. Secondary, the graphical error analysis that includes cross plots & graphical plot, was used to determine the accuracy of each empirical correlation and the improvement of the Wilson equation (K-values). Cross plots of experimental versus the calculated bubble point pressure using a modified Wilson equation are existing form (Figure 5A) till (Figure 5L). Most of the data points in all empirical correlations that published in the literature fall not near to 45^0 lines and this is shown in (Figure 5-A) through (Figure 5-K). But in the current study, Most of the data points exist close to 45^0 lines,

TABLE (1): Egyptian crudes Oils Data ranges

PVT property	Maximum value	Minimum value	Average
$P_{res},_{Psi}$	7300.0	574.4	3685.7
T_{res},°F	298.0	104.5	212.3
$C_{7}^{+}{}_{w}$	0.93175	0.09067	0.44211
MW_g	55.7	17.9	28.13
MW_o	231.7	107.3	158.0
γ_g	1.92203	0.61953	0.97137
γ_o	0.9955	0.7676	0.8539
$Bb._{Psi}$	4800	43.5	2046.0
GOR , $_{SCF/STB}$	4910.5	9.9	1324.8
Bo, $_{Res.\ Bbl/bbl}$	4.5362	1.02282	1.6941
API_{sto}	52.8	10.7	34.9

TABLE (2) The Statistical accuracy of bubble point pressure using worldwide published correlation.

Correlation	$ARE_{,\%}$	$AREE_{,\%}$	E_{max}	E_{min}	S,%	r^2,%
Standing	-13.63	23.437	90.47	1.0369	27.81	88.29
Laster	-346.6	347.2	9195.3	0.0358	1177.5	28.50
Glaso	-26.93	35. 35	173.76	2.77	39.40	59.38

TABLE (3) The Statistical accuracy of bubble point pressure by applying some correlation in the Middle East.

Correlation	$ARE_{,\%}$	$AREE_{,\%}$	E_{max}	E_{min}	S,%	r^2,%
Al-Marhoun	-18.52	26.47	424.53	0.0094	56.75	82.61
Dokla-Osman	-10.14	28.57	99. 80	1.1149	32.16	88.83
De Ghetto et al	-40.78	43.16	192.43	0.2999	32.83	75.40
Almehaideb	-75.36	87.53	338.91	4.100	85.29	56.30
Taghizadeh&Asghari	-48.82	49.01	235.68	2.1700	52.09	80.83
Ehsan Khamehchi1	-27.23	31.73	79.32	0.3312	24.30	22.77

TABLE (4) The Statistical accuracy of bubble point pressure by applying some correlation in Egypt.

Correlation	$ARE_{,\%}$	$AREE_{,\%}$	E_{max}	E_{min}	S,%	r^2,%
Macary-Batanon	-31.02	31.09	99.49	1.3169	23.53	62.03
Hanfi	-26.72	33.76	226.41	0.4475	60.88	46.36
This Study	1.77	6.84	15.54	0.0250	8.08	99.75

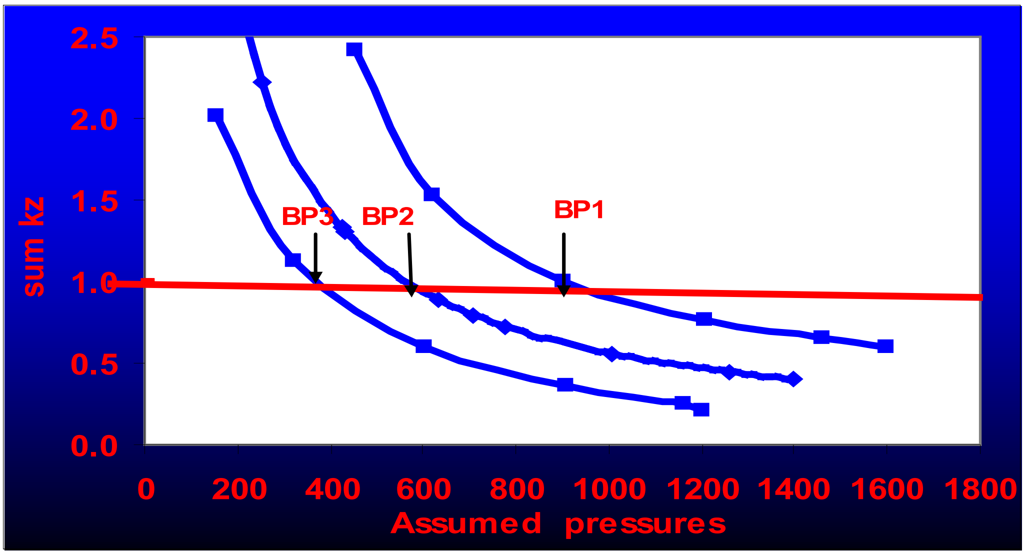
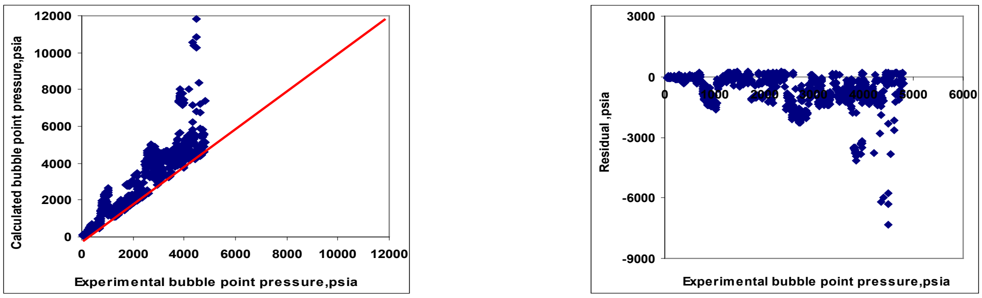
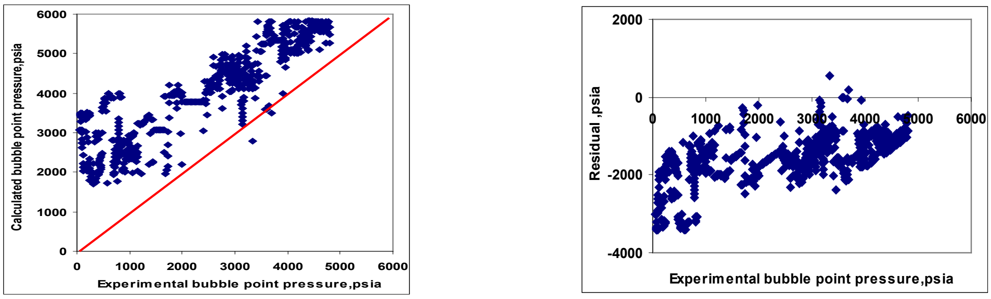


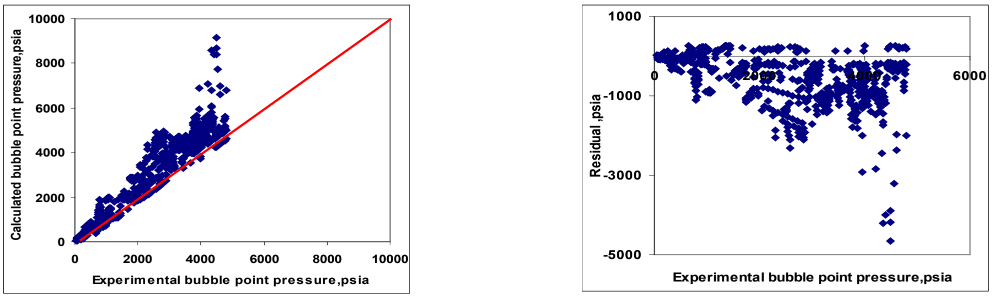
Figure (4): Assumed pressures versus Σ KZ.



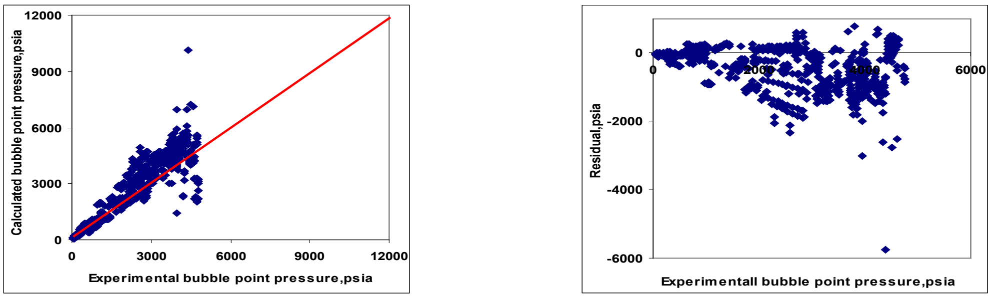
(Figure 5-A) Cross plot and residual plot of Bp [Standing].



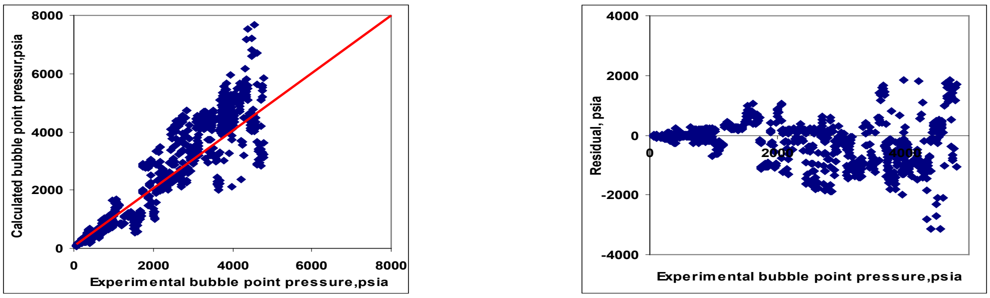
(Figure 5-B) Cross plot and residual plot of Bp [Laster].



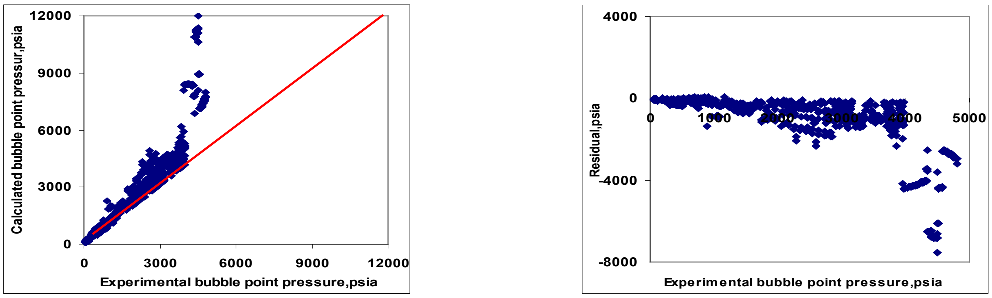
(Figure 5-C) Cross plot and residual plot of Bp [Glaso].



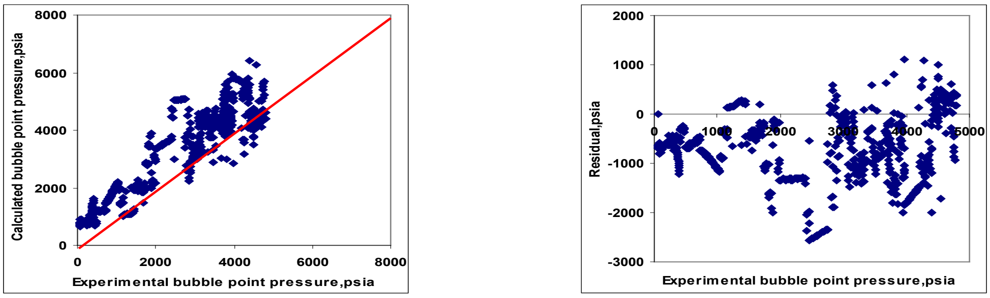
(Figure 5-D) Cross plot and residual plot of Bp [Al-Marhoun].



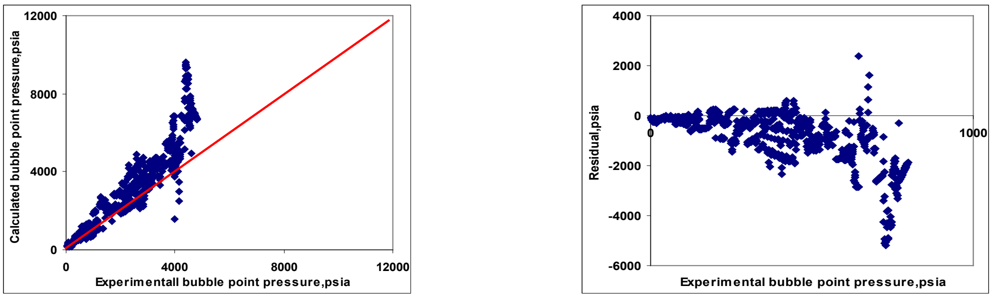
(Figure 5-E)Cross plot and residual plot of Bp [Dokla-Osman].



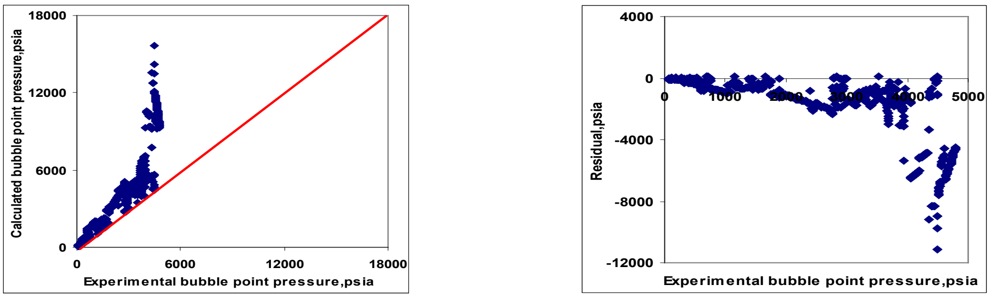
(Figure 5-F)Cross plot and residual plot of Bp [De Ghetto].



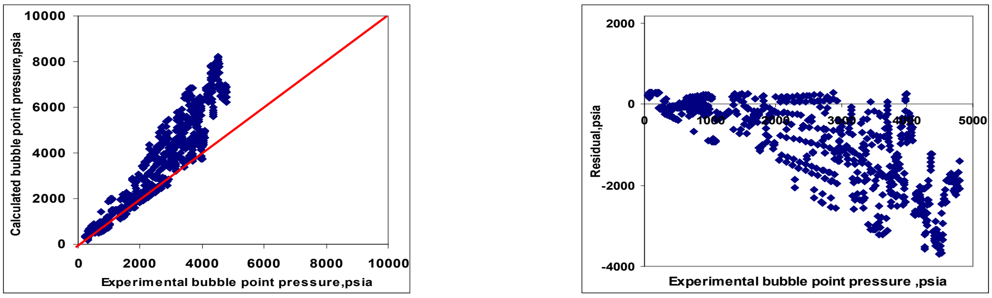
(Figure 5-G) Cross plot and residual plot of Bp [[Almehaideb]



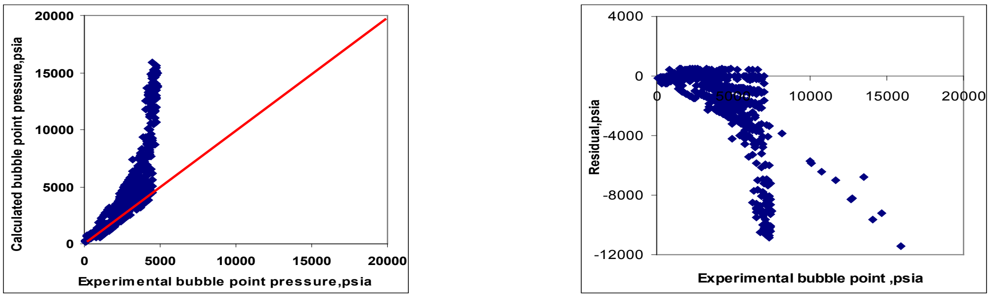
(Figure 5-H) Cross plot and residual plot of Bp [Taghizadeh&Asghari]



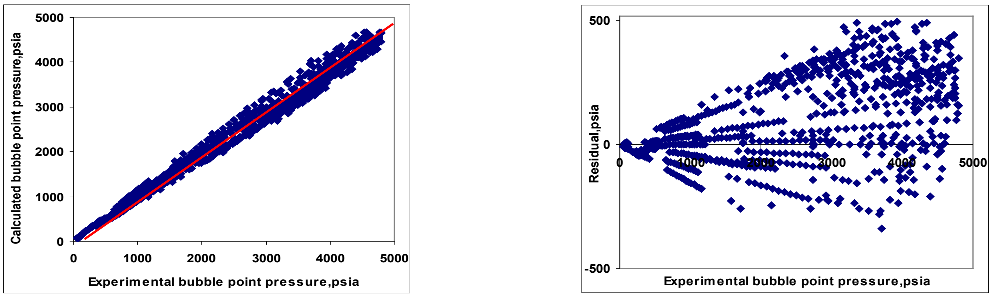
(Figure 5-I) Cross plot and residual plot of Bp [Ehsan Khamehchi]



(Figure 5-J) Cross plot and residual plot of Bp [Macary-Batanon]



(Figure 5-K) Cross plot and residual plot of Bp [Hanfi]



(Figure 5-L) Cross plot and residual plot of Bp [Current study] and this is shown in (Figure 5-L) which ensures the accuracy of improved Wilson equation (K-values). A graphical plot of residual (the difference between experimental and calculated bubble points pressure) and experimental bubble point pressure in (Figure 5-A) through (Figure 5-L). The current study demonstrated a uniform distribution of errors with most of the data points falling within a ± 500 psi residual line and this is shown in figure 18. This shows that the current study predicts better bubble point pressure for Egyptian crude oils by using Wilson equation (K-values) than any other known correlations.

Conclusions

The following conclusions can be drawn from this evaluation study.

1. Most popular bubble point pressure correlations reported in the petroleum literature which are a function of reservoir temperature, gas gravity, oil gravity, and gas/oil ratio have not a good correlation performance for Egyptian oils.

2. PVT experimental data were correlated very well with the proposed correlations to calculate a new constant in Wilson equation (K-Values)

3. Improved Wilson equation (K-Values) with the new constant represents a good correlation that fits for Egyptian oils.

4. It`s found that the improved k-value correlation is applied to high pressure, up to about (4500 psi) not only for low and moderate pressure.

5. This model also covers a wide range of variables than the previously published ones.

Notation:

(ARE):	Average percent relative error%.
$(AARE)$:	Average absolute percent relative error%.
$(r^2,\%)$:	Correlation coefficient
$(S,\%)$:	Stander deviation
API :	American Petroleum Institute, degree.
Bo :	Oil formation volume factor at bubble point pressure, bbl/STB.
Bp :	Bubble point, psia
$C_{7}^{+}{}_{w}$:	Heptan plus of well stream mole%
E_{max}:	Maximum absolute percent error.
E_{min}:	minimum absolute percent error
γ_g :	Gas gravity
γ_o :	Oil gravity
GOR :	Gas oil ratio, SCF/STB
K :	K-value
MW_g :	The molecular weight of flashed gas.
MW_o :	The molecular weight of stock tank oil.
P :	Pressure, psi.
P_{res} :	Reservoir pressure, psia.
P_r :	reduced pressure, $p_{assumed}/p_c$
T :	Temperature, °F.
T_{res} :	Reservoir temperature, °F.
T_r :	reduced temperature
W :	Centric factor, T_{res}/T_c

Appendix

A. The PVT correlations evaluated in this study have given below.

correlation	Author
Standing	**$Bp = 18.2 [(R_s/\gamma_g)^{0.83}.10^a – 1.4]$** **Where :a = 0.00091(T) - 0.0125 *API*** **The correlation was also expressed in a graphical form**
Borden-Razasa	**expressed in a graphical from only**
Laster	**$Bp = (P_f)(T+460)/\gamma_g$** **where : $P_f = P_b. \gamma_g / (7+460)$**
Glaso	**$Log(Bp) = 1.767+1.745\log(P_b^*). -0.30218[\log(Bp^*)]$^2.** **Where $Bp^* = (R_s/\gamma_g)^{0.816}. (T^{0.172}/API^{0.989})$**
Al-Marhoun	**$Bp = 0.00538088 (R_s)^{0.715082.} (\gamma g)^{-1.87784}. (\gamma o)^{3.1437}. (T+460)^{1.32657}$**
Macary-Batanon	**$Bp = 204.257 K [(R_s)^{0.51} – 4.7927]$** **Where: K= Exp(0.00077 *T*- 0.0097 *API*- 0.4003γg**
Dokla-Osman	**$Bp = 0.8364*10^4. (\gamma g)^{-1.0105}. (\gamma o)^{0.108}. (T+460)^{-0.953}. R_s^{0.724}$**
De Ghetto et al	**$Bp = 21.7429[(R_s / \gamma g)^{0.7646}(10^{0.00119T} /10^{0.0101}API)$**
Almehaideb	**$Bp = 620.592+6.23087(R_s\gamma o / \gamma g^{0.8439}6o^{1.38559})+2.89868$**
Hanfi	**$Bp = 3.205 R_{si} +157.27$**
Taghizadeh&Asghari	**$Bp =1.09373\times10 R\gamma_g{}^{0.5502}\gamma_o{}^{-1.71956} (T+ 460)^{2.0967}$**
Ehsan Khamehchi	**$Bp =107.93R^{0.9129}\gamma_g{}^{-0.666}\gamma T^{0.2122} API^{1.08}$**

References

1. Karen Schou Pedersen Peter L. Christensen (2007): "Phase Behavior of Petroleum Reservoir Fluids",P. 41, Taylor & Francis Group,USA.

2. Mansour, E.M. , Farag, A.B., El-Dars, F.S., Desouky, S.M., Batanoni, M.H. and M.R. Mahmoud, (2013): " Predicting PVT properties of Egyptian crude oils by a modified Soave–Redlich–Kowng equation of state ", Egyptian Journal of Petroleum, Vol. 22,(137–148).

3. Mansour, E.M., Desouky, S.M., El Aily, M., Helmi, M.E. (2018): "The Effect of Asphaltene Content on Predicting Heavy Dead Oils Viscosity: Experimental and Modeling Study", Fuel 212, 405–411.

4. Cobenas, R.H., SPE, I.T.B.A. and Crotti, M.A., SPE, Inlab S.A., (1999): "Volatile Oil. Determination of Reservoir Fluid Composition From a Non-Representative Fluid Sample" Society of Petroleum Engineers 21–23 April.

5. Al-Marhoun,M.A., (2004) :" Evaluation of empirically derived PVT properties forMiddle East crude oils " Journal of Petroleum Science and Engineering 42, 209– 221.

6. Nagi,J., Kiong,T.S., Ahmed, S.K. and Nagi,F., (2009):" Prediction of PVT Properties In Crude Oil SystemsUsing Support Vector Machines" Proceedings of ICEE 3rd International Conference on Energy and Environment 7-8 December, Malacca, Malaysia.

7. Mansour, E. M., Al- Sabagh A.M., Desouky, S.M., Mahmoud, M.R., and Zawawy, F.M., (2016): "Experimental Approach of Minimum Miscibility Pressure for CO2 Miscible Flooding: Application to Egyptian Oil Fields", International Journal of New Technology and Research (IJNTR), Vol-.2, (105-112).

8. Tarek Ahmed,(2007) : "Equations of State and PVT Analysis", 3rd ed., P. 32, Gulf Publishing Company, Houston, Texas.

9. Danesh,A., (1998): "Pvt and Phase Behaviour of Petroleum Reservoir Fluids" Handbook,P. 22, Elsevier Science & Technology Books.

10. Mansour, E.M. , Farag, A.B., El-Dars, F.S., Desouky, S.M., Batanoni, M.H. and M.R. Mahmoud, (2012): " Modification proposed for SRK equation of state", Journal of oil&gas, 110 (6),(78 – 91).

11. Elsharkawy, A.M., (2003) : "An empirical model for estimating the saturation pressures of crude oils", Journal of Petroleum Science and Engineering (38) 57– 77.

12. Mansour, E. M., Al- Sabagh A.M., Desouky, S.M., Mahmoud, M.R., and Zawawy, F.M., (2019): "A laboratory investigation of carbon dioxide-enhanced oil recovery by focusing on CO_2-oil physical properties ", Egyptian Journal of Petroleum, 28(1),(21 – 26).

13. Ahmedzeki,N.S., Ridha, I.M., Ali, Y.M., and AbidAlwahab, Z.T., (2012):" Development of PVT Correlation for Iraqi Crude Oils Using Artificial Neural Network " Iraqi Journal of Chemical and Petroleum Engineering Vol.13 No.3 September, 9- 16.

14. Osman, E. A., Abdel-Wahhab, O. A., Al-Marhoun, M. A., (2001):"Prediction of Oil Properties using Neural Networks" ,SPE Paper 68233, Presented at the SPE Middle East Oil Show Conference, Bahrain, March, 17-20.

15. Mansour, E. M., Al- Sabagh A.M., Desouky, S.M., Mahmoud, M.R., and Zawawy, F.M., (2018): "A new estimating method of minimum miscibility pressure as a key parameter in designing CO_2 gas injection process ", Egyptian Journal of Petroleum, 27, (801 – 810).

16. El Aily, M., Desouky, S.M., Mansour, E. M., M., Helmi, M.E. (2019): ""Modeling viscosity of moderate and light dead oils in the presence of complex aromatic structure ", Journal of Petroleum Science and Engineering, 173, 426–433.

17. Omid, S., Jamshid, M., Mehdi, S., Farouq, Z., (2012): "" Optimization of Formation Volume Factor and Solution Gas-Oil Ratio Correlations for Southern Iranian Oil fields Using Genetic Algorithm ", Journal of American Science, 8, 1s.

18. Standing, M.B., (1947): "A Pressure - Volume - Temperature Correlation for Mixtures of California Oils and Gases," Drilling and Production Practice, API, 275-287.

19. Borden, G.Jr., and Rzasa, M.J.,(1950):"Correlation of Bottom Hole Sample Data," Trans., AIME, Pet. Trans., T.P. 2931, 189, 345-348.

20. H.Lasater, J.A.,(1958): "Bubble-point Pressure Correlation," Trans. AIME , 213, 379-381.

21. Glaso,O, J.A.,(1980): "Generalized Pressure–volume–temperature correlations," JPT. MAY , 785-795.

22. Marhoun, M.A., (1988): "PVT Correlation for Middle East Crude Oils," JPT, 650-665.

23. Osman, E. A., Abdel-Wahhab, O. A. and Al-Marhoun, M. A., (2001): "Prediction of Oil PVT Properties Using Neural Networks", Paper SPE 68233 presented at the 12th SPE Middle East Oil Show &Conference.

24. De Ghetto, G., Paone, F., and Villa, M., (1994):"Reliability Analysis on PVT Correlations," SPE paper 28904, Presented at the SPE European Petroleum Conference held in London, U.K., October, 25-27.

25. Almehaideb, R.A., (1997) : " Improved PVT Correlations for UAE Crude Oils, " Paper SPE 37691 Presented at the 10th SPE Middle East Oil Show Held in Manama, Bahrain, March 15-18.

26. Taghizadeh, M. M. and Asghari,S.M., (2007): " Correlations for predicting solution gas-oil ratio, bubble point pressure and oil formation volume factor at bubble point of Iran crude oils," European Congress of Chemical Engineering (ECCE-6) Copenhagen, September (16-20).

27. Ehsan, K., , Fariborza, R., Hanieh, R. and Amir,E., (2009): " Novel empirical correlations for estimation of bubble point pressure, saturated viscosity and gas solubility of crude oils,pet sci,86-90.

28. Macary, S.M. and El-Batanoney, M.H., (1992): "Derivation of PVT Correlations for the Gulf of Suez Crude Oils," EGPC llth. Petroleum Exploration and Production Conference.

29. Hanafy, H.H., Macary, S.M., El-Nady, Y.M, Bayomi, A.A., and El-Batanony, M.H., (1997) : " A New Approach for Predicting the Crude Oil Properties," paper SPE 37439, presented at the 1997 SPE Production Operations Symposium, Oklahoma City, Oklahoma, March 9-11.

30. Ahmed,T., (2010):" Reservoir Engineering Handbook", 4th ed., P. 1, Gulf Professional Publications, USA.

31. DePriester CL. Chem Engng Prog Symp Ser 1953;49(7):1.

32. Wilson, G., (1968). : "A modified Redlich-Kwong equation of state applicable to general physical data calculations," Paper No15C, 65th AIChE National meeting.

33. McWillims,M.L.,:(1973):" An Equation to relate k-factors to pressure and temperature " chem. Engineering, 8, (25),138.

34. Whitson, C. H. and. Torp, S. B., (1983): "Evaluating Constant-Volume Depletion Data" Journal of Petroleum Technology, 2 P (616-620).

35. Almehaideb, R.A., I. Ashour, K.A. El-Fattah, (2003): "Improved *K*-value correlation for UAE crude oil components at high pressures using PVT laboratory data," Fuel 82, (1057–1065).

36. Mccain, W.D., (1994): "The Properties of petroleum fluids Handbook", 2nd ed., P. 148, PennWell publishing company, USA.

37. 37-Maason, R.,L. and Gunst, R.F. and Hess, J.L.,:(2003):" Statistical Design and Analysis of Experiments" John Wiley & Sons Inc.