# New Correlation for Predicting Undersaturated Oil Compressibility for Mishrif Reservoir in the Southern Iraqi Oil Fields

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## ABSTRACT

Reservoir fluids properties are very important in reservoir engineering computations such as material balance calculations, well testing analyses, reserve estimates, and numerical reservoir simulations. Isothermal oil compressibility is required in fluid flow problems, extension of fluid properties from values at the bubble point pressure to higher pressures of interest and in material balance calculations (Ramey, Spivey, and McCain). Isothermal oil compressibility is a measure of the fractional change in volume as pressure is changed at constant temperature (McCain).

The most accurate method for determining the Isothermal oil compressibility is a laboratory PVT analysis; however, the evaluation of exploratory wells often require an estimate of the fluid behavior prior to obtaining a representative reservoir sample. Also, experimental data is often unavailable. Empirical correlations are often used for these purposes.

This paper developed a new mathematical model for calculating undersaturated oil compressibility using 129 experimentally obtained data points from the PVT analyses of 52 bottom hole fluid samples from Mishrif reservoirs in the southern Iraqi oil fields. The new undersaturated oil compressibility correlation developed using Statistical Analysis System (SAS) by applying nonlinear multiple regression method. It was found that the new correlation estimates undersaturated oil compressibility of Mishrif reservoir crudes in the southern Iraqi oil fields much better than the published ones. The average absolute relative error for the developed correlation is 7.16%.

**Key words: Isothermal, compressibility, under-saturated, Bubble-Point, Mishrif**

# علاقة جديدة للتنبؤ بانظغاطية النفط الغير مشبع لمكمن المشرف في الحقول النفطية في جنوب العراق

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**الخلاصة**

خواص الموائع المكمنية مهمة جدا في حسابات هندسة النفط مثل حسابات توازن المادة، تحليلات فحص الابار، تخمينات الاحتياطي، ومحاكاة المكامن العددية. إنضغاطية النفطِ الثابتة الحرارةِ مطلوبةُ في مشاكلِ جريان المائع ،تهتم بتمديد خواص المائع مِنْ القِيَمِ في ضغط الفقاعةِ إلى الضغوطِ الأعلى وفي حساباتِ موازنة المادة. إنضغاطية النفطِ الثابتة الحرارةِ مقياس للتغييرِ الجزئيِ في الحجمِ مع تغير الضغط في درجةِ الحرارة الثابتةِ.

الطريقة الاكثر دقة لقياس إنضغاطية النفطِ الثابتة الحرارةِ هي تحليلات الضغط والحجم والحرارة المختبرية؛ على أية حال، تقييم الآبار الإستكشافية يتطلبِ تخمينَ سلوكِ المائع في أغلب الأحيان قبل الحُصُول على عيّنة مكمنية مثالية . أيضاً البيانات التجريبية غير متوفرةُ في أغلب الأحيان. لذلك فأن العلاقات التجريبية تَستعملُ غالباً لهذه الأغراض.

هذه الدراسة طوّرتْ نموذج رياضي جديد لحساب إنظغاطية النفط فوق نقطة الفقاعه بأستخدام 129 نقطة من بيانات مكتسبة بشكل تجريبي مِنْ تحليلاتِ الضغط والحجم والحرارة مِنْ 52 عينةِ مِنْ مكمن المشرف في حقولِ النفط العراقيةِ الجنوبية. العلاقة الجديدة لإنظغاطية النفط فوق نقطة الفقاعه طورت باستخدام Statistical Analysis System بواسطة تطبيق طريقة Nonlinear Multiple .Regression

لقد وجِدَ بأنهُ العلاقة الجديدة تُخمِن إنظغاطية النفط فوق نقطة الفقاعه لنفوط تكوين المشرف في الحقول النفطية الجنوبية العراقية افضل بكثير من تلكَ المنشورة. معدل نسبة الخطأ المطلقة للمعادلة المطورة هو 7.16 %.

**كلمات رئيسية:تساوي الضغط،الانضغاطية،تحت الاشباع،نقطة الفقاعة،المشرف**

## INTRODUCTION

Reservoir fluid properties form one of the many bases in petroleum engineering calculations. The evaluation of oil and gas reserves, fluid flow through porous media, and multiphase flow in pipes, surface and subsurface equipment design, and production system optimization are strongly depending on reservoir fluid physical properties. Those properties may be measured experimentally in a PVT (pressure-volume-temperature) laboratory or they may be estimated by using empirical correlations.

The most accurate method for determining the behavior of these fluids is a laboratory PVT analysis; however, the evaluation of exploratory wells and the advanced design of equipment often require an estimate of the fluid behavior prior to obtaining a representative reservoir sample. Also, experimental data is often unavailable in reservoirs which do not warrant the cost of an in depth fluid study. Empirical correlations are often used for such purposes.

The isothermal oil compressibility at pressure above the bubble point is defined as the fractional change in volume of oil as pressure is changed at constant temperature (Ahmed). For crude oil system, the isothermal compressibility coefficient of the oil phase $C_o$ is defined, for pressure above the bubble-point, by one of the following equivalent expression (McCain):

$$C_O = -\frac{1}{V}\left(\frac{\partial V}{\partial P}\right)_T \qquad (1)$$

$$C_O = -\frac{1}{Bo}\left(\frac{\partial B_O}{\partial P}\right)_T \qquad (2)$$

$$C_O = \frac{1}{\rho_O}\left(\frac{\partial \rho_O}{\partial P}\right)_T \qquad (3)$$

Laboratory PVT analysis is used to acquire data that are used in the estimation of the isothermal compressibility from the equations given above. Values of the fluid properties including the isothermal compressibility are often required when laboratory PVT data are not available. Thus, there are a number of developed correlations for the estimation of the isothermal compressibility using readily available fluid properties.

This study has been developed new empirical correlation for calculating undersaturated oil compressibility using nonlinear regression method. The new correlation developed by using 129 data points collected from Mishrif reservoir in the southern Iraqi oil fields.

**LITERATURE REVIEW**

In the last decades, engineers realized the importance of developing and using empirical correlations for PVT properties. Studies carried out in this field resulted in the development of new correlations.

In 1980, Vasquez and Beggs developed a correlation for the isothermal oil compressibility correlated with the gas solubility Rs, reservoir temperature T, API gravity, gas specific gravity $\gamma_g$ and reservoir pressure. They used 4036 experimental data points and linear regression model to develop the new correlation.

In1985, Ahmed used 245 experimental data points to propose a mathematical expression for the isothermal oil compressibility using the gas solubility $R_S$ as the only correlation parameter**.**

In 1993 Petrosky and Farshad developed a new correlation for undersaturated isothermal oil compressibility using 304 data points obtained from the Gulf of Mexico crude oils. This new correlation introduces one additional fitting parameter to the model functional form used by Vasquez and Beggs in order to increase the accuracy of the correlation**.**

In 1994, De Ghetto et.al. evaluated the reliability of some isothermal oil compressibility correlations and came up with some modified correlations which they reported as being more accurate. They characterized the fluid samples used in their studies as extra heavy oil (API≤10), heavy oil (10< API≤22.3), medium oil (22.3< API≤31.1) and Light oil (API>31.1). They reported that the errors on the correlation were decreased by about five percent**.**

In 2001, Dindoruk and Christman proposed a new correlation for estimating undersaturated oil compressibility for the Gulf of Mexico. The proposed oil compressibility correlation predicts the oil compressibility values with an average absolute relative error of 6.21%.

In 2003, Al-Marhon presented a new mathematical model for calculating undersaturated oil compressibility using 3412 data points from 186 Middle East PVT reports. Al-Marhon reported an average absolute relative error of 5.46%**.**

In 2008, Al-Aboodi developed new correlation for oil compressibility for the south Iraqi oils using non-linear regression method. The average absolute relative error is 6.13%.

**DATA DESCRIPTION**

The data used in this study were obtained from Mishrif reservoir for several southern Iraqi oil fields. Table (1) presents the description of data utilized in this study with ranges of solution gas oil ratio at bubble point, reservoir temperature, gas relative density, API oil gravity, pressure above bubble point and undersaturated oil compressibility. A total of 129 data sets from 52 samples were collected and checked for accuracy.

**Table 1- Range of data for the Mishrif crude oil used**

| Property | Minimum Value | Maximum value | Mean |
|---|---|---|---|
| P(psia) | 1104.7 | 3257.544 | 2335.19983 |
| GOR(SCF/STB) | 337.0123 | 757.5196 | 556.8827 |
| Absolute Temp. ($R^{\circ}$) | 619.47 | 699.75 | 653.707 |
| $\gamma g$(air=1) | 0.854722 | 1.183 | 0.967681 |
| Oil API Gravity | 18.5 | 29.3 | 23.8446532 |
| Co($psia^{-1}x10^{-6}$) | 5.3976 | 13.7898 | 8.17142 |

## CORRELATION DEVELOPMENT

The new correlation for the undersaturated oil compressibility was developed as a function of stock tank oil gravity (API), gas gravity ($\gamma_g$), absolute temperature (T), pressure above bubble point (P) and solution gas-oil ratio at bubble point (Rsb). The nonlinear multiple regression analysis was used for developing the new correlation using 129 data points. The best regression analysis results were obtained by using the following equation:

$$\mathbf{Co = C_1\, Rsb^{C2}\, (T-460)^{C3}\, \gamma g^{C4}\, API^{C5}\, P^{C6} + C_7\, (Rsb)^{X}} \quad (4)$$

Where:

$$\mathbf{X = C_8\, (T-460)^{C9}\, \gamma g^{C10}\, API^{C11}\, P^{C12}} \quad (5)$$

After testing many combinations, this new oil compressibility correlation shows best results. The regression coefficients used in Eqs.4 and 5 are presented in Table (2).

## STATISTICAL ERROR ANALYSIS

Statistical error analysis is performed to compare the performance and accuracy of the new correlation with other empirical correlations. Average absolute percent relative error, standard deviation and correlation coefficient were computed for each correlation.

Table (3) shows the statistical error analysis results of the new undersaturated oil compressibility correlation as compared with the other published correlations. In comparison with other known correlations the new undersaturated oil compressibility correlation gives lowest values of average absolute percent relative error (AAERR) and standard deviation (SD) of 7.16 percent and 8.8 percent respectively. A lower value of (AAERR) and (SD) indicate better accuracy of the correlation. The correlation coefficient is 0.89. This shows that the new correlation predicts better undersaturated oil compressibility for Mishrif reservoir crude oil in the southern Iraqi oil fields than any other known correlations.

The cross plot in Figure (1) shows acceptable agreement between the measured and the estimated undersaturated oil compressibility using the new correlation. The other correlation results are show in figures (2) through figure (7).

## CONCLUSIONS

1. A new empirical correlation for predicting undersaturated oil compressibility for Mishrif reservoir crude oil in the southern Iraqi oil fields has been developed using nonlinear multiple regression method.
2. The newly developed correlation outperforms the existing ones based on the low value of average absolute percent relative error and standard deviation.

**Table 2-** Regression Coefficients for the Proposed Undersaturated Oil Compressibility, $C_O$, Correlation

| Coefficient | Value | Coefficient | Value |
|---|---|---|---|
| $C_1$ | 1.726837 E-06 | $C_7$ | 6.82566523E-07 |
| $C_2$ | 31.631122612 | $C_8$ | 0.3166985628 |
| $C_3$ | -38.270904704 | $C_9$ | 0.43010271746 |
| $C_4$ | -15.586357515 | $C_{10}$ | -0.39150460567 |
| $C_5$ | -5.5528136321 | $C_{11}$ | 0.126861310815 |
| $C_6$ | 1.3384367465 | $C_{12}$ | -0.29853819248 |

AAERR =Average Absolute Percent Relative Error.
API = American Petroleum Institute.
Bob =OFVF at bubble point, RB/STB
Co = Isothermal Oil Compressibility, $psia^{-1}$
$E_i$ = Relative deviation, %.
$E_r$ = Average percent relative error, %.
$E_a$ = Average absolute percent relative error%.
FVF = Formation Volume Factor
GOR = Gas-Oil Ratio, SCF/STB.
P = Pressure above bubble point, psia
Pb = Bubble point pressure, psia.
$P_{sep}$ = Separator pressure, psia.
R = Coefficient of Correlation, %.
Rsb = Solution GOR at bubble point SCF/STB
T = Reservoir temperature, R, F.
V=Volume, $m^3$, $cm^3$, $ft^3$.
$\gamma_g$ = Gas specific gravity (air=1)
$\gamma_o$ = Oil specific gravity
$\gamma_{API}$ = Oil API gravity.
$\gamma_{gs}$ = Gas specific gravity at separator pressure
$\gamma_{ob}$= Oil specific gravity at bubble point
PVT = Pressure-Volume-Temperature
SAS = Statistical Analysis System
SD =Standard Deviation

## REFERENCES

Ahmed, T.: "Compositional Modeling of Tyler and Mission Canyon Formation Oils with Co2 and Lean Gases," final report submitted to Montanans on a New Track Science (MONTS) (Montana National Science Foundation Gran Program), 1985-1988.

Ahmed, T. H., Hydrocarbon Phase Behavior, Gulf Publishing Company, Vol. 7, (1989). Page106.

Al-Marhoun, M.A.: "Evolution of Mathematical Models of PVT Properties for Middle East and Canadian Crude Oils," paper SPE SA03 Presented at the 2003 SPE Technical Symposium of Saudi Arabia section held in Dhahran, Saudi Arabia, 7-9 June 2003.

De Ghetto, G., Paone, F. and Villa, M.: "Reliability Analysis on PVT Correlation," Paper SPE 28904 presented at the 1994 European Petroleum Conference, London, 25-27 October.

Dindoruk B., Peter G. Christman: "PVT Properties and Viscosity Correlations for Gulf of Mexico Oils," paper SPE 71633 presented at 2001 SPE Annual Technical Conference and Exhibition, New Orleans, Louisiana, 30 September-3Octobor.

McCain, W. D., Jr., "The Properties of Petroleum Fluids," Penn Well Books, 2nd Edition,(1990).

JPT. (June 1980), p. 968-970.

Petrosky, G.E. and F.F. Farshad.: "Pressure-Volume-Temperature correlation for Gulf of Mexico , " SPE paper # 26644, 1993, P.395-406.

Ramey, H. J.: “Rapid Methods for Estimating Reservoir Compressibilites,” paper SPE 772, JPT, 447, April (1964).

Spivey, J. P, P.P. and McCain, W. D.: “Applications of the Coefficient of the Isothermal Compressibility to Various Reservoir Situations with New Correlation for Each Situation,” paper SPE 96415 presented at the 2005 Annual Technical Conference and Exhibition, Dallas, Texas, October 9-12.

R. R. Al-Aboodi.: “PVT Correlations for Selected Iraqi Oil Fields,” MS Thesis, University of Baghdad,April(2008)

Vasquez, M.E. and Beggs, H.D.: “Correlation for Fluid Physical property Prediction,” Journal of Petroleum Technology,

**Table 3- Comparison of statistical accuracy of undersaturated oil compressibility, $C_o$, correlations**

| **Correlation** | **AAERR %** | **SD %** | **R** |
|---|---|---|---|
| Present study | 7.166692 | 8.80621 | 0.894 |
| De Ghetto& Villa | 17.796 | 14.6716 | 0.811 |
| Al-Marhoun | 19.0595 | 13.358 | 0.828 |
| Vasquez& Beegs | 19.82 | 12.982 | 0.855 |
| Petrosky& Farshad | 24.2564 | 13.5746 | 0.821 |
| Dindoruk& Chirsman | 29.6411 | 19.682 | 0.537 |
| Ahmed | 80.0932 | 36.98 | 0.195 |

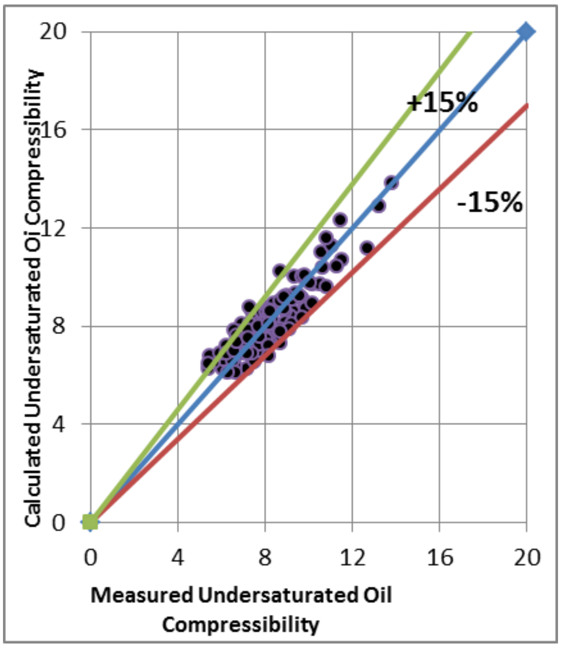


**Fig. 1** Cross plot for oil compressibility, psia$^{-1}$ × $10^{-6}$ (proposed correlation)

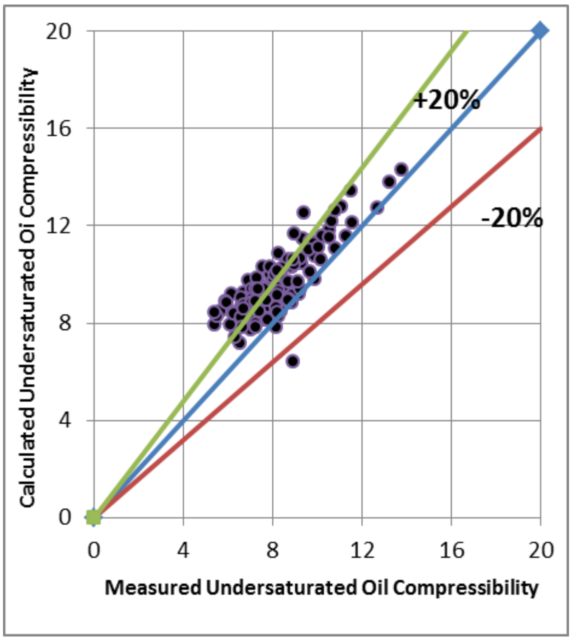


**Fig. 3** Cross plot for oil compressibility, psia$^{-1}$ × $10^{-6}$(Al-Marhoun's Correlation)

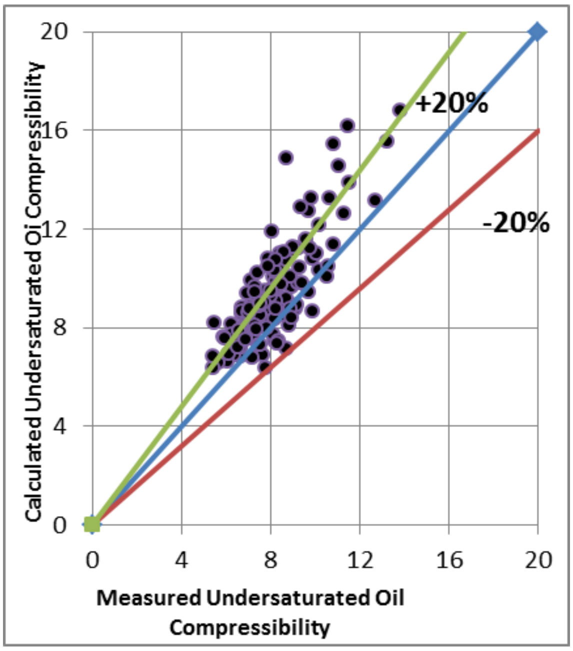


**Fig. 2** Cross plot for oil compressibility, psia$^{-1}$ × $10^{-6}$ (De Ghetto and Villa's Correlation)

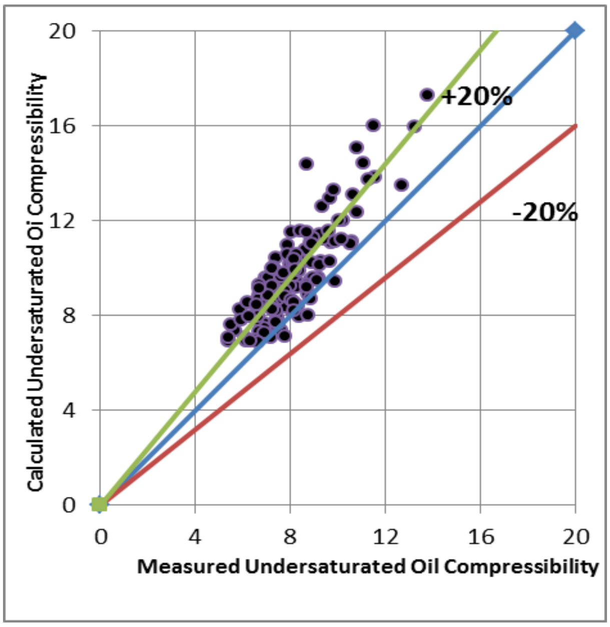


**Fig. 4** Cross plot for oil compressibility, psia$^{-1}$ × $10^{-6}$ (Vasquez and Beggs's Correlation)

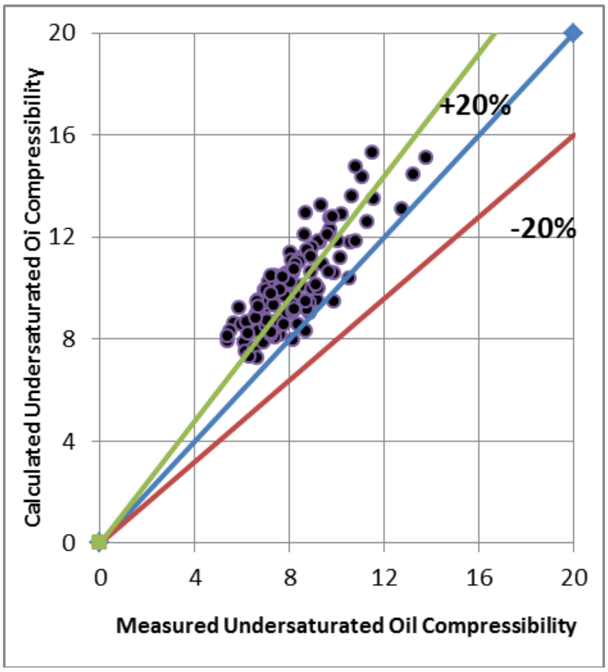


**Fig. 5** Cross plot for oil compressibility, psia$^{-1}$ × $10^{-6}$ (Petrosky and Farshad's Correlation)

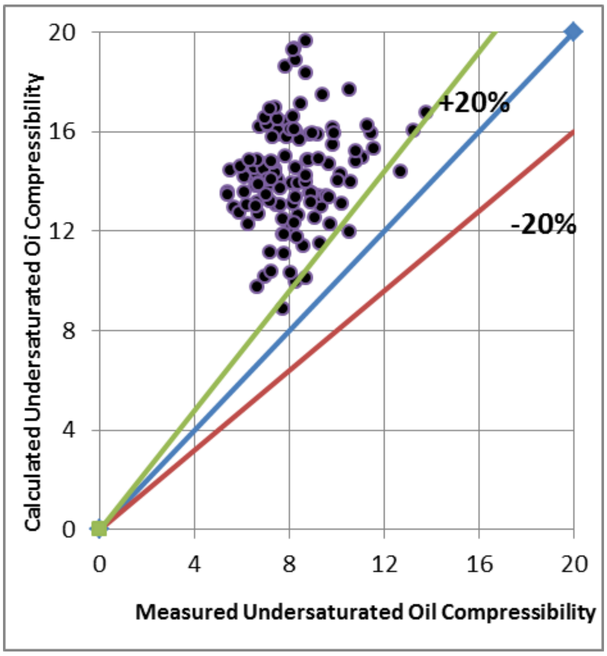


**Fig.7** Cross plot for oil compressibility, psia$^{-1}$ × $10^{-6}$ (Ahmed's Correlation)

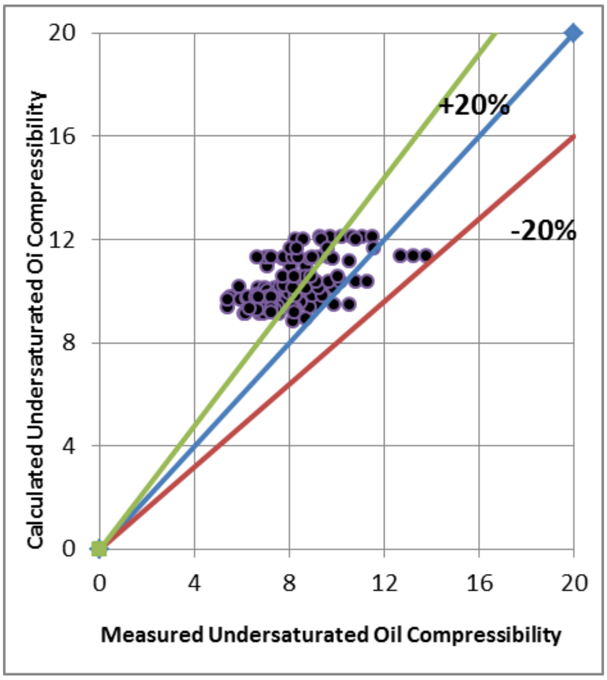


**Fig. 6** Cross plot for oil compressibility, psia$^{-1}$ × $10^{-6}$ (Dindoruk and Chirstman's Correlation)

## APPENDIX A-DEFINITIONS OF STATISTICAL PARAMETERS

There are four main statistical parameters that being considered in this study. These parameters help to evaluate the accuracy of predicted fluid properties obtained from the black oil correlations.

## AVERAGE PERCENT RELATIVE ERROR (AERR)

This is an indication of the relative deviation in percent of the estimated values from the experimental values and is given as:

$$\boldsymbol{E_r} = \left(\frac{1}{n_d}\right) \sum_{i=1}^{n_d} \boldsymbol{E_i} \qquad (A_1)$$

$\boldsymbol{E_i}$ is the relative deviation in percent of an estimated value from an experimental value and is defined by:

$$E_i = \left(\frac{x_{est} - x_{exp}}{x_{est}}\right)_i \times 100, \quad (A_2)$$

Where: $x_{est}$ and $x_{est}$ represent the estimated and experimental values, respectively.

**Average Absolute Percent Relative Error (AAERR)**

This parameter is to measure the average value of the absolute relative deviation of the measured value from the experimental data. The value o f AAERR is expressed in percent. The parameter can be defined as:

$$E_a = \left(\frac{1}{n_d}\right) \sum_{i=1}^{n_d} |E_i| \qquad (A_3)$$

and indicated the relative absolute deviation in percent from the experimental values. A lower value of AAERR implies better agreement between the estimated and experimental values.

**STANDARD DEVIATION (SD)**

Standard deviation, SD, of the estimated values with respect to the experimental values can be calculated using the following equation:

$$SD = \left[\left(\frac{1}{n_d - 1}\right) \sum_{i=1}^{n_d} (E_i - E_r)^2\right]^{0.5} \quad (A_4)$$

The accuracy of the correlation is determined by the value of the standard deviation, where a smaller value indicates higher accuracy. The value of the standard deviation is usually expressed in percent.

**CORRELATION COEFFICIENT(R)**

The purpose of performing correlation coefficient calculation is to describe the extent of the association between two variables namely experimental and calculated values obtained from the correlation. The value of the correlation coefficient varies from zero to (1.0). A coefficient of zero indicates no relationship between experimental and calculated values. A (1.0) coefficient indicates a perfect positive relationship. The correlation coefficient can be calculated using the following equation:

$$R = \left[1 - \left(\frac{\sum_{i=1}^{n_d} ((x_{est} - x_{exp})_i)^2}{\sum_{i=1}^{n_d} ((x_{exp} - \bar{x})_i)^2}\right)\right]^{0.5} \quad (A_5)$$

Where: $\bar{X}$ is the average value of the experimental PVT parameter, which can be calculated using the following equation:

$$\bar{x} = \left(\frac{1}{n_d}\right) \sum_{i=1}^{n_d} (x_{exp})_i \qquad (A_6)$$

**APPENDIX B- PVT CORRELATIONS USED FOR COMPARISON:**

1. **<u>Vasquez and Beggs (1980)</u>**

$$Co = \frac{-C_1 + 5R_{sb} + C_2(T - 460) - C_3\, \gamma_{gs} + C_4\, {}^{\circ}API}{10^5\, P} \qquad (B_1)$$

Where:

$C_1 = -1433$ $C_2 = 17.2$ $C_3 = 1180$ $C_4 = 12.61$

2. **<u>Ahmed (1985)</u>**

$$Co = \left[\frac{C_1 + C_2\left[R_s\left(\frac{\gamma_g}{\gamma_o}\right)^{0.5} + 1.25(T - 460)\right]^{1.175}}{C_4\gamma_o + C_5\, R_s\gamma_g}\right] e^{(C_3 P)} \qquad (B_2)$$

Where:

**$c_1$=1.026638 $c_2$=0.0001553 $c_3$=-0.0001847272**

**$c_4$=62400 $c_5$=13.6**

3. Petrosky and Farshad (1993)

$$C_O = 1.0705 \times 10^{-7} R_{sb}^{0.69357} \gamma_g^{0.1885} \times API^{0.3272} T^{0.6729} P^{-0.5906} \quad (B_3)$$

**4. Dindoruk and Christman (2010)**

$$C_0 = (C_1 + C_2 A + C_3 A^2) 10^{-6} \quad (B_4)$$

Where:

$C_1$= 4.487462368 $C_2$= 0.00519704

$C_3$= 0.00001258

$$A = \frac{\left[\frac{R_s^{a_1} \gamma_g^{a_2}}{\gamma_o^{a_3}} + a_4 (T-60)^{a_5} - a_6 R_s\right]^{a_7}}{\left[a_8 + (T-60) \frac{2 R_s^{a_9}}{\gamma_g^{a_{10}}}\right]^2} \quad (B_5)$$

**$a_1$=0.980922372 $a_2$=0.021003077**

**$a_3$=0.338486128 $a_4$=20.00006358**

**$a_5$=0.300001059 $a_6$=0.876813622**

**$a_7$=1.759732076 $a_8$=2.749114986**

**$a_9$=-1.713572145 $a_{10}$=9.999932841**

5. Al-Marhon (2003)

$$\ln C_O = -14.1042 + \frac{2.7314}{\gamma_{ob}} + \frac{-56.0605 \times 10^{-6} (P - P_b)}{\gamma_{ob}^3} + \frac{-580.8778}{(T+460)} \quad \ldots\ldots B_6$$

**6. Al-Aboodi**

7. (2008)

$$C_O = \frac{B_{ob}^X \, 10^Y (B_{ob}^{B_4} \; T^{B_5})}{10 P^{A_0} \; R_{sb}^{B_2}} \quad (B_7)$$

Where:

$$X = A_1 . R_{sb}^{A_2} . P^{A_3} . API^{A_4} . T^{A_5} \quad (B_8)$$

$$Y = B_0 . B_{ob}^{B_1} . API^{B_3} \quad (B_9)$$

| coefficient | $A_0$ | $A_1$ | $A_2$ |
|---|---|---|---|
| value | -0.05044 | 0.018044 | 0.919168 |
| coefficient | $A_3$ | $A_4$ | $A_5$ |
| value | -0.34903 | 0.2228 | 0.288464 |
| coefficient | $B_0$ | $B_1$ | $B_2$ |
| value | -0.0382 | -30.7513 | -0.32422 |
| coefficient | $B_3$ | $B_4$ | $B_5$ |
| value | 3.197813 | -6.82528 | 0.790544 |