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PVT Correlations for Trinidad Oil Offshore the South West Coast

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Abstract

Reservoir fluid properties such as bubble point pressure, oil formation volume factor and solution gas-oil ratio are used for the evaluation of reservoir performance and reserves estimation. Laboratory analyses of these properties are not always available and they are best estimated from correlations. The available correlations were developed for both worldwide applications or for specific regions since oil from different regions vary in compositions. In this study correlations by Standing, Vasquez and Beggs, Glaso, Al-Marhoun, Petrosky Farshad and Velarde *et al.* were tested to estimate the above mentioned PVT data for Trinidad oils offshore the Southwest Coast. A spread sheet was developed for the calculations and the data for the evaluations were taken from twelve PVT reports.

The results show that the Velarde *et al.* correlations gave the best estimate of the aforementioned PVT data for the twelve available PVT data sets. A comparison of the estimated and experimental PVT data show differences of less than ± 7.0% for bubble point pressures, less than ± 4.0% for oil formation volume factors and less than ± 10.0% for solution gas oil ratios. These results indicate that the Velarde *et al*. correlations can be used to obtain accurate estimation of the above PVT properties for Trinidad oils offshore the Southwest Coast for future reservoir engineering calculations. The Verlade *et al.* correlation was developed for worldwide application and its suitability to predict PVT data for a region should be tested prior to the development of new correlations.

Key words: PVT Correlations; Oil; Bubble-point pressure; Oil formation volume factor; Solution gas-oil ratio; Trinidad

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NOMENCLATURE

AAD	=	average absolute deviation
B_o	=	oil formation volume factor, rb/STB
B_{ob}	=	oil formation volume factor at the bubble point, rb/STB
c_o	=	oil compressibility, psi^{-1}
Est.	=	estimated
Expt.	=	experimental
PVT	=	pressure, volume, temperature
p	=	pressure, psia
T	=	temperature, °F
P_b	=	bubble point pressure, psia
R_s	=	solution gas-oil ratio, scf/STB
R_{sb}	=	solution gas-oil ratio at the bubble point, scf/STB
rb	=	reservoir barrels
scf	=	standard cubic feet
STB	=	stock tank barrels

Greek

γ_{API}	=	stock tank oil gravity, °API
γ_g	=	gas specific gravity
γ_o	=	stock tank oil gravity
γ_{STO}	=	stock tank oil specific gravity
ρ_a	=	apparent density of surface gas if it were a liquid, lbm/cuft
ρ_{oR}	=	reservoir oil density at reservoir conditions, lbm/cuft
ρ_{po}	=	pseudoliquid density at standard conditions (sc), lbm/cuft

INTRODUCTION

An accurate description of reservoir fluid properties such as bubble point pressure (P_b), oil formation volume factor (FVF), (B_o), and solution gas-oil ratio (R_s), is of extreme importance to Reservoir Engineers (Ahmed, 2006). These data are obtained experimentally from pressure – volume – temperature (PVT) analyses and are used to evaluate reservoir performance, reserves estimation and for designing production facilities (Ahmed, 2006). For oil reservoirs the analyses are conducted on samples taken when the reservoir pressure is above the bubble point (Bon *et al*., 2007). Laboratory analyses of these properties are not always available or reliable and could be very costly and time consuming (McCain, 1990). In many cases PVT studies are performed only on samples taken from exploratory wells and PVT properties for other wells in the field are estimated from empirically derived correlations (Ahmed, 2006).

The first concerted effort to develop correlations for estimating bubble point pressure, oil formation volume factor and solution gas-oil ratio using field measured data was started by Standing (1947) as follows:

$$P_b = 18.2[(R_{sb} / \gamma_g)^{0.83}(10^{\,0.00091\,T\,-\,.0125\,\gamma_{API}}) - 1.4] \qquad (1)$$

where: P_b = bubble point pressure, psia
R_{sb} = initial solution gas-oil ratio (from bubble point pressure and above), scf/STB
γ_g = gas specific gravity
γ_{API} = stock tank oil gravity, °API
T = reservoir temperature, °F

$$B_o = 0.9759 + 12X10^{-5}[R_s(\gamma_g / \gamma_o)^{0.5} + 1.25\,T]^{1.2} \qquad (2)$$

where: B_o = oil formation volume factor, rb/STB
R_s = solution gas-oil ratio, scf/STB
γ_g = gas specific gravity
γ_o = stock tank oil gravity
T = reservoir temperature, °F

Equation (1) when re-arranged can be used to determine solution gas oil ratios at pressures below the bubble point pressure.

Standing's (1947) set of correlations although developed for California oil, have been widely applied over the years to crude oil from different regions. Since then correlations were published (Valko & McCain, 2003) for worldwide applications and for specific geographical regions e. g. Glaso (1980) for North Sea oil, Al-Marhoun (1988) for Middle East oil, Petrosky and Farshad (1990) for Gulf of Mexico oil. The available correlations were developed to give improved estimations by adjustments of Standing's (1947) correlations and by introducing methods that improved the accuracy of the field measured data (gas specific gravity and initial solution gas oil ratio) required for the calculations (Vasquez & Beggs, 1980; McCain, 1990). However the suitability of these correlations should be tested with experimental PVT data before being applied. From an evaluation of correlations published over the last 50 years, Valko and McCain (2003) pointed out that geographical correlations are unnecessary and that a carefully prepared universal correlation is quite adequate.

Verlade *et al*. (1997) published a universal set of correlations and equations for the estimation of bubble point pressure, oil formation volume factor and solution gas-oil ratio that corrects for three major deficiencies of all published correlations. These deficiencies are:

(1) Calculation of solution gas oil ratio at the bubble point pressure requires a field derived bubble point pressure which is not always available.
(2) Calculated values of formation volume factors and solution gas-oil ratios do not match the concave up, point of inflection, concave down shapes evident in experimental data as pressures declines below the bubble point pressure.
(3) A material balance relationship with oil formation volume factor, solution gas-oil ratio and reservoir oil density.

The first attempt to test the suitability of PVT correlations for Trinidad oil reservoirs was conducted by Hosein (1984). His study was based on limited data for the on-land oil reservoirs. Reservoirs offshore the Southwest Coast of Trinidad has oil in place of about 2 billion barrels. From a limited data set of twelve PVT reports this study was conducted to determine a suitable set of correlations for estimating the PVT properties of this offshore oil which are needed for the development and production of these reservoirs.

1. DATA DESCRIPTION

The 12 laboratory PVT reports that were available for this study were generated by commercial laboratories outside of Trinidad. The API gravity (°API) ranges from 17.6° to 34.4°, gas specific gravity from 0.621 to 0.834, initial solution gas-oil ratio from 288 scf/STB to 1261scf/STB and reservoir temperature from from 140 °F to 216 °F. These represent the field measured data required for the calculations. The bubble point pressure (P_b) ranges from 2100 psia to 5600 psia and oil formation volume factor at the bubble point (B_{ob}), from 1.148 rb/STB to 1.549 rb/STB and are shown in Tables 1 and 2 respectively.

2. CORRELATIONS TESTING

Correlations for estimating bubble point pressure (P_b) and oil formation volume factor at the bubble point (B_{ob}), by Standing (1947), Vasquez and Beggs (1980), Glaso (1980), Al-Marhoun (1988), Petrosky and Farshad (1993) and Velarde *et al*. (1999) were first tested. Correlatios for the estimation of oil formation volume factor and solution gas-oil ratio at other depletion pressures where decided from the results obtained. An excel spreadsheet was developed to perform the calculations.

3. RESULTS AND DISCUSSION

3.1 Estimation of Bubble Point Pressure (P_b) and Oil Formation Volume Factor at Bubble Point Pressure (B_{ob})

Figures A1 to A6 in the Appendix show crossplots between the estimated bubble point pressures for each of the six correlations mentioned above and experimental bubble point pressures for the twelve Trinidad oil samples. Table 1 shows differences in percent (see Equation 3 below) between the estimated and experimental values for each of the six correlations. The correlation by Verlade *et al* (1999) gave differences less than ± 7.0 % for all twelve oil samples and also the lowest average absolute deviation (AAD) (see Equation 4 below) of 4.2 %. The other correlations gave higher differences and less accurate estimation for some of the samples.

$$\text{Difference (Diff. in \%)} = \frac{[y_{\text{Est.}} - y_{\text{Expt}}.]}{y_{\text{Expt}}.} \text{ X } 100 \quad (3)$$

Average Absolute Deviation (AAD in %) =

$$\frac{1}{n} \times \sum_{i=1}^{n} \left| \frac{y_{\text{Est.}} - y_{\text{Expt.}}}{y_{\text{Expt.}}} \right| \times 100 \quad (4)$$

Table 1
Comparisom of Experimental (Expt.) and Estimated (Est.) Bubble Point Pressures (P_b) from Correlations by: Standing (1947), Vasquez and Beggs (1980), Glaso (1980), Al-Marhoun (1988), Petrosky and Farshad (1993) and Velarde *et al.* (1999)

Expt. P_b psia	Est. P_b Standing	Diff. %	Est. P_b Vasquez and Beggs	Diff. %	Est. P_b Glaso	Diff. %	Est. P_b Al-Marhoun	Diff. %	Est. P_b Petrosky and Farshad	Diff. %	Est. P_b Velarde *et al.*	Diff. %
2167	2127	1.9	2476	14.3	2856	31.8	2683	23.8	2488	14.8	2248	3.7
2272	2208	2.9	2338	2.9	2571	13.2	2010	-11.5	2368	4.2	2174	-4.3
2344	2227	5.2	2632	12.3	3190	36.1	3110	32.7	2541	8.4	2238	-4.5
2960	2786	6.2	3168	7.0	3429	15.8	2954	-0.2	3393	14.6	3038	2.6
3025	2474	22.3	2699	-10.8	2998	-0.9	2851	-5.8	3110	2.8	2888	-4.5
3105	3183	-2.5	3621	16.6	4018	29.4	3236	4.2	3461	11.5	2994	-3.6
3151	3129	0.7	3695	17.3	3950	25.4	3571	13.3	3752	19.1	3301	4.8
3348	3102	7.9	3647	8.9	4222	26.1	2891	-13.7	3419	2.1	3201	-4.4
3495	2885	21.2	3356	-4.0	3636	4.0	3024	-13.5	3481	-0.4	3436	-1.7
4750	3691	28.7	4255	-10.4	4353	-8.4	4684	-1.4	4561	-4.0	4452	-6.3
5091	4840	5.2	5706	12.1	5516	8.3	4503	-11.6	5349	5.1	4792	-5.9
5557	4827	15.1	5491	-1.2	5334	-4.0	6107	9.9	5755	3.6	5195	-4.7
AAD, %		10.2		11.2		18.6		13.4		8.9		4.2

Table 2
Comparisom of Experimental (Expt.) and Estimated (Est.) Oil Formation Volume Factor at Bubble Point (B_{ob}) from Correlations by: Standing (1947), Vasquez and Beggs (1980), Glaso (1980), Al-Marhoun (1988), Petrosky and Farshad (1993) and Velarde *et al.* (1999)

Expt. B_{ob} rb/STB	Est. B_{ob} Standing	Diff. %	Est. B_{ob} Vasquez and Beggs	Diff. %	Est. B_{ob} Glaso	Diff. %	Est. B_{ob} Al-Marhoun	Diff. %	Est. B_{ob} Petrosky and Farshad	Diff. %	Est. B_{ob} Velarde *et al.*	Diff. %
1.169	1.173	0.3	1.162	-0.6	1.146	-2.0	1.202	2.8	1.162	-0.6	1.155	-1.2
1.245	1.262	1.4	1.179	-5.3	1.222	-1.8	1.231	-1.2	1.251	0.5	1.236	-0.7
1.148	1.155	0.6	1.135	-1.2	1.125	-2.0	1.216	5.9	1.142	-0.6	1.142	-0.5
1.250	1.273	1.9	1.255	0.4	1.244	-0.5	1.220	-2.4	1.248	-0.1	1.241	-0.7
1.259	1.262	0.2	1.246	-1.0	1.233	-2.1	1.217	-3.3	1.243	-1.2	1.246	-1.0
1.257	1.281	1.9	1.220	-2.9	1.244	-1.1	1.271	1.1	1.256	-0.1	1.25	-0.6
1.251	1.265	1.1	1.253	0.2	1.235	-1.3	1.239	-1.0	1.235	-1.3	1.233	-1.4
1.204	1.232	2.3	1.193	-0.9	1.197	-0.6	1.163	-3.4	1.207	0.2	1.204	0.0
1.285	1.270	-1.1	1.260	-1.9	1.243	-3.3	1.221	-5.0	1.241	-3.4	1.269	-1.2
1.302	1.318	1.2	1.305	0.3	1.285	-1.3	1.291	-0.8	1.279	-1.8	1.285	-1.3
1.375	1.436	4.5	1.382	0.5	1.399	1.8	1.335	-2.9	1.279	0.3	1.389	1.0
1.549	1.646	6.2	1.589	2.6	1.609	3.9	1.587	2.5	1.545	-0.3	1.538	-0.7
AAD, %		1.9		1.5		1.8		2.7		0.9		0.9

Figures A7 to A12 in the Appendix show crossplots between the estimated oil formation volume factors at bubble point pressure for each of the six correlations and experimental oil formation volume factors at bubble point pressures for the twelve Trinidad oil samples. Table 2 shows differences in percent between the estimated and experimental values for each of the six correlations. The correlation by Verlade *et al*. (1999) gave differences less than ± 2.0 % for all twelve oil samples. The other correlations gave higher differences for some of the samples. The correlations by Verlade *et al*. (1999) and Petrosky and Farshad (1993) gave the lowest average absolute deviation (AAD) of 0.9 %.

From the above results, it was decided to continue testing the Verlade *et al.* (1999) equations and correlations (see Appendix A) for estimating oil formation volume factor and solution gas-oil ratio at other depletion pressures for the Trinidad samples. The ranges of the experimental data and number of data points tested are shown in Table 3.

3.2 Estimation of Oil Formation Volume Factor at Pressures above Bubble Point Pressure (B_o)

Oil formation volume factors at pressures above bubble point were estimated using the following equation which is obtained from the definition of the coefficient of isothermal compressibility of oil above bubble point (McCain, 1990):

$$B_o = B_{ob} \, EXP\,[c_o (P_b - P)] \tag{5}$$

where c_o = the coefficient of isothermal compressibility of oil or oil compressibility (psi^{-1})

P_b = bubble point pressure (psia) which was estimated by the Velarde *et al.* (1999) correlation

B_{ob} = oil FVF at bubble point pressure (psia) which was estimated by the Velarde *et al.* (1999) correlation

Figure 1 shows a crossplot between the estimated oil formation volume factors at pressures above bubble point and experimental oil formation volume factors at pressures above bubble point for the twelve Trinidad oil samples. The differences between the estimated and experimental values were less than ± 2.0 % for every pressure depletion step (118 data points) from reservoir pressure to bubble point pressure. The average absolute deviation was less than 1.0 % (Table 3).

Table 3
Ranges of Data and Average Absolute Deviation (AAD, %) Between Experimental and Estimated B_o and R_s

No. of Data Points	PVT Property	Min.	Max.	AAPD %
118	B_o above P_b (rb/STB)	1.131	1.548	0.8
133	B_o below P_b (rb/STB)	1.054	1.478	0.6
133	R_s at and below P_b (scf/STB)	31	1261	5

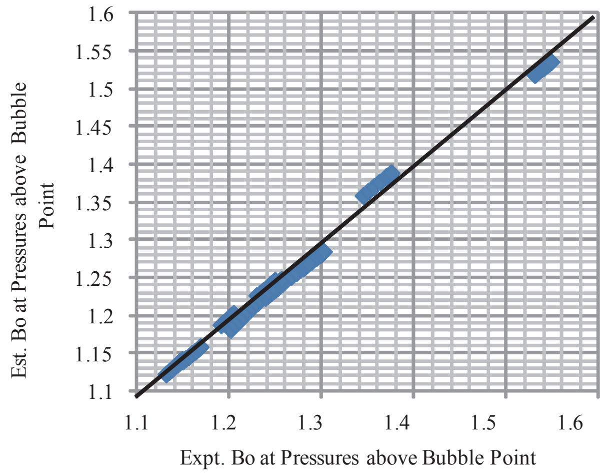

Figure 1
Crossplot for Oil FVF (B_{ob}) Above Bubble Point {$B_o = B_{ob}$ EXP[c_o (P_b-P)]}, (McCain, 1990)

3.3 Estimation of Oil Formation Volume Factors (B_o) and Solution Gas Oil Ratios (R_s) at Pressures below Bubble Point by Velarde *et al*.s' (1999) Correlations.

Figure 2 shows a crossplot between estimated oil formation volume factors at pressures below bubble point by Velarde *et al.* (1999) equation and experimental oil formation volume factors at pressures below bubble point for the twelve Trinidad oil samples. The differences between the estimated and experimental values were less than ± 4.0 % for every pressure depletion step (133 data points) below bubble point pressure. The average absolute deviation was less than 1.0 % (Table 3).

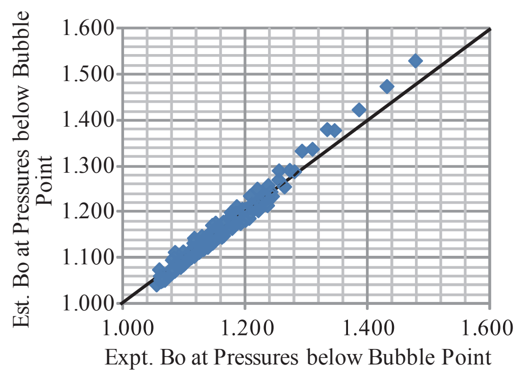

Figure 2
Crossplot for Oil FVF (B_{ob}) Below Bubble Point Velarde *et al*.s' (1999) Correlation

Figure 3 shows a crossplot between estimated solution gas-oil ratios at pressures below bubble point by Velarde *et al*. (1999) correlation and experimental solution gas-oil ratios at pressures below bubble point for the twelve Trinidad oil samples. The differences between the estimated and experimental values were less than ± 10.0 % for every pressure depletion step (133 data points) below the bubble point pressure. The average absolute deviation was less than 5.0 % (Table 3).

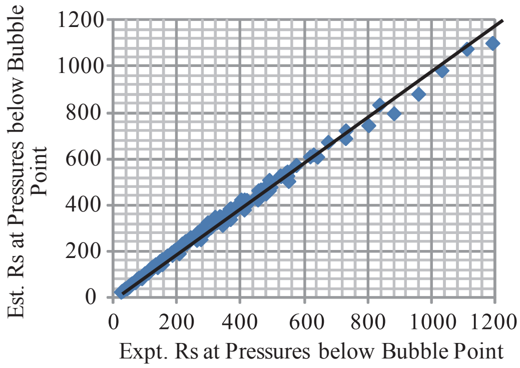

Figure 3
Crossplot for Sulution GOR Below Bubble Point Velarde *et al.*s' (1999) Correlation

CONCLUSIONS

The above results indicate that the Velarde *et al*. (1999) correlations can accurately estimate bubble point pressures, oil formation volume factors and solution gas-oil ratios for Trinidad oils offshore the Southwest Coast. The differences between the estimated and experimental data was less than ± 7.0 % for bubble point pressures, less than ± 4.0% for oil formation volume factors and less than ± 10.0% for solution gas oil ratios. These results indicate that the Velarde *et al.* (1999) correlations can be used to estimate the above PVT properties for Trinidad oil offshore the Southwest Coast for future reservoir engineering calculations. There is no need to obtain new correlations for these reservoir oils.

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REFERENCES

[1] Ahmed, T. (2006). R*eservoir Engineering Handbook*. Houston: Gulf Publishing Company.

[2] Al-Marhoun, M. A. (1988). PVT Correlations for Middle East Crude Oils. *Journal of Petroleum Technology*, *40*(5), 650-666.

[3] Bon, J., Sarma, H. K., Rodrigues, J. T., & Bon, J. G. (2007). Reservoir Fluid Sampling Revisited – A Practical Perspective. *SPE Reservoir Evaluation and Engineering*, *10*(6), 589-596

[4] Glaso, O. (1980). Generalized Pressure-Volume-Temperature Correlations. *Journal of Petroleum Technology*, *32*(5), 785-795.

[5] Hosein, R. (1984). *PVT Correlations for On-land Oil Reservoirs in Trinidad* (BSc. thesis). The University of The West Indies Library, St Augustine, Trinidad.

[6] McCain, W. D. (1990). *The Properties of Petroleum Fluids* (2nd ed.). Tulsa, Oklahoma: Penn Well Publishing Co.

[7] Petrosky, G. E. Jr., & Farshad, F. F. (1993). Pressure-Volume-Temperature Correlations for Gulf of Mexico Crude Oils. *Paper presented at SPE 68th Annual Technical Conference and Exhibition, Oct. 3-6, Houston, Texas.*

[8] Standing, M. B. (1947). A Pressure-Volume-Temperature Correlation for Mixtures of California Oils and Gases. *Drilling and Production Practice*, *API*: 275.

[9] Valko, P. P., & McCain, W. D. Jr. (2003). Reservoir Oil Bubblepoint Pressures Revisited: Solution Gas–Oil Ratios and Surface Gas Specific Gravities. *Journal of Petroleum Science and Engineering*, *37*(3-4), 153-169.

[10] Vasquez, M., & Beggs, H. D. (1980). Correlations for Fluid Physical Property Prediction. *Journal of Petroleum Technology*, *32*(6), 968 – 970.

[11] Velarde, J., Blasingame, T. A., & McCain, W. D. Jr. (1999). Correlation of Black Oil Properties at Pressures below Bubblepoint Pressure – A New Approach. *Journal of Canadian Petroleum Technology*, *36*(13), 1-6.

APPENDIX A

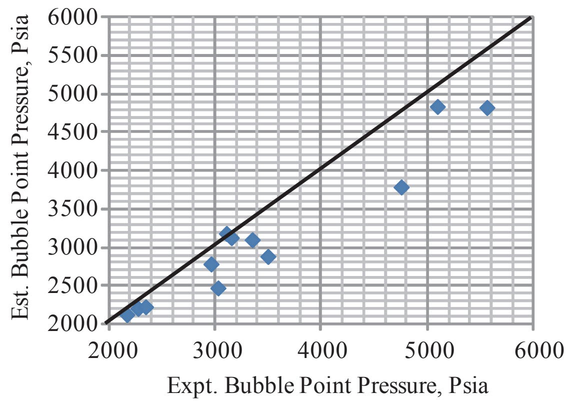

Figure A1
Crossplot for Bubble Point Pressure – Standing's (1947) Correlation

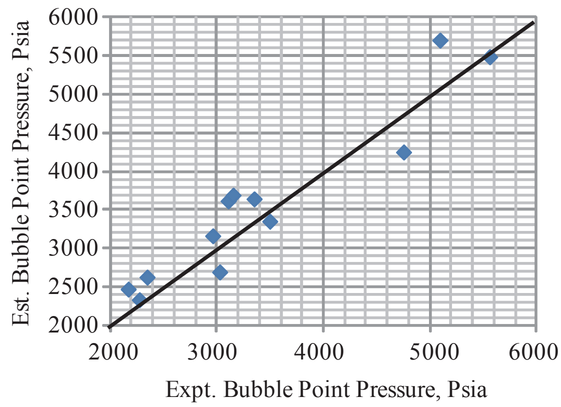

Figure A2
Crossplot for Bubble Point Pressure – Vasquez and Beggs' (1980) Correlation

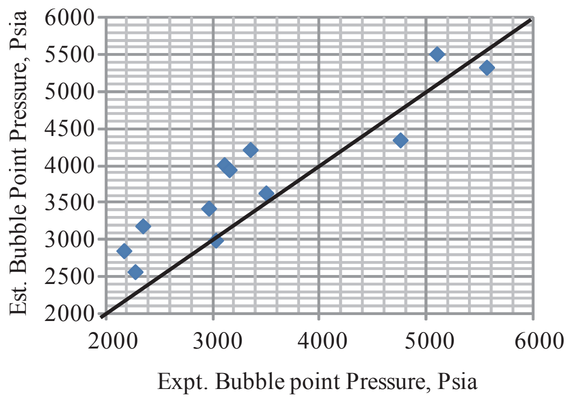

Figure A3
Crossplot for Bubble Point Pressure – Glaso's (1980) Correlation

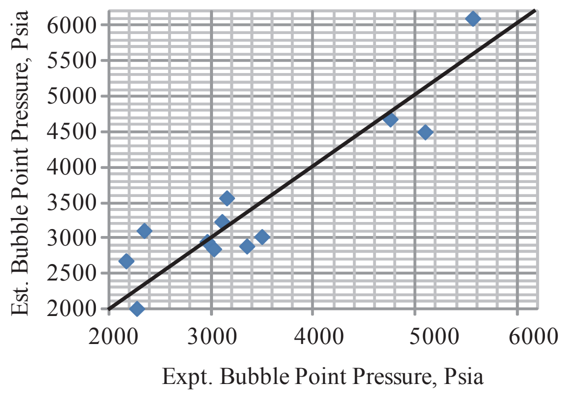

Figure A4
Crossplot for Bubble Point Pressure – Al-Marhoun's (1988) Correlation

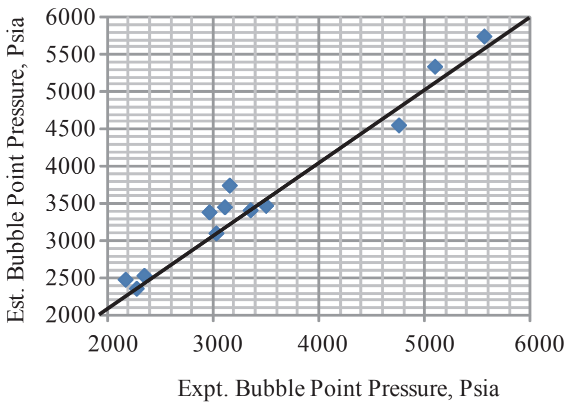

Figure A5
Crossplot for Bubble Point Pressure – Petrosky and Farshad's (1993) Correlation

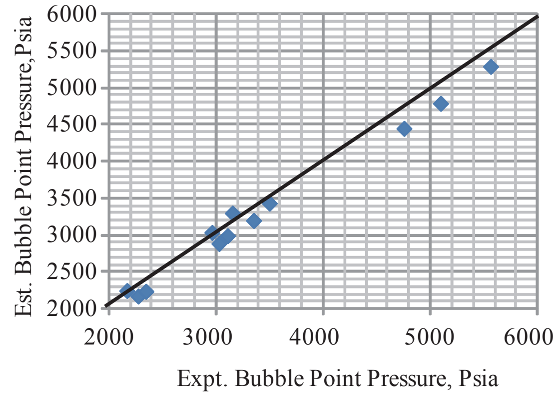

Figure A6
Crossplot for Bubble Point Pressure – Velarde *et al.*s' (1999) Correlation

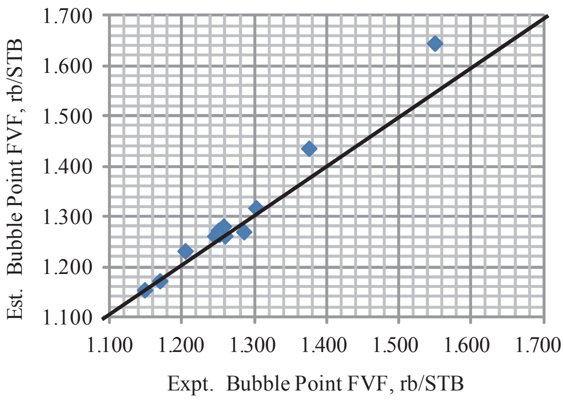

Figure A7
Crossplot for Bubble Point Oil FVF (B_{ob}) – Standing's (1947) Correlation

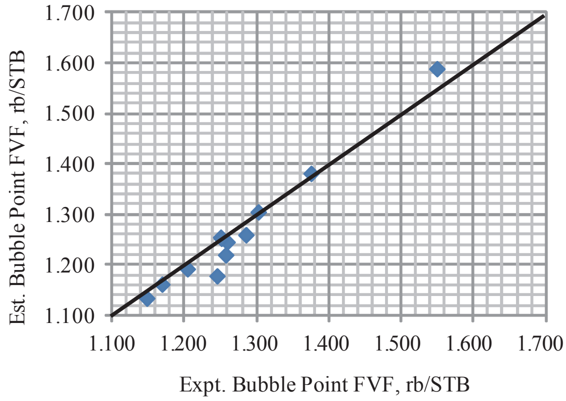

Figure A8
Crossplot for Bubble Point Oil FVF (B_{ob}) –Vasquez and Beggs' (1980) Correlation

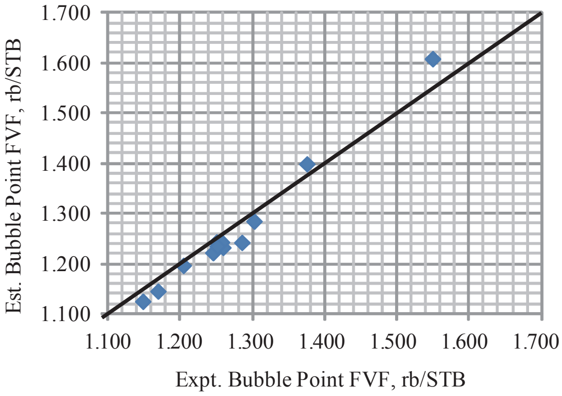

Figure A9
Crossplot for Bubble Point Oil FVF (B_{ob}) – Glaso's (1980) Correlation

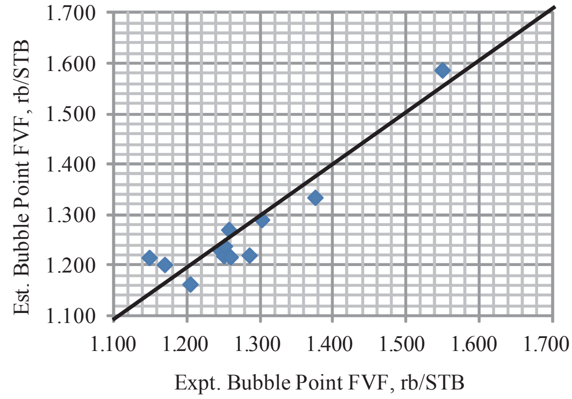

Figure A10
Crossplot for Bubble Point Oil FVF (B_{ob}) – Al-Marhoun's (1988) Correlation

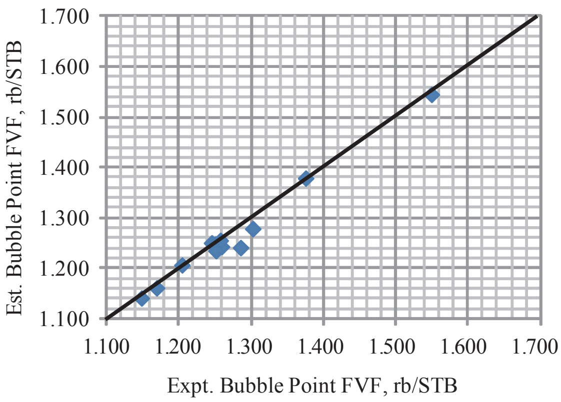

Figure A11
Crossplot for Bubble Point Oil FVF (B_{ob}) – Petrosky and Farshad's (1993) Correlation

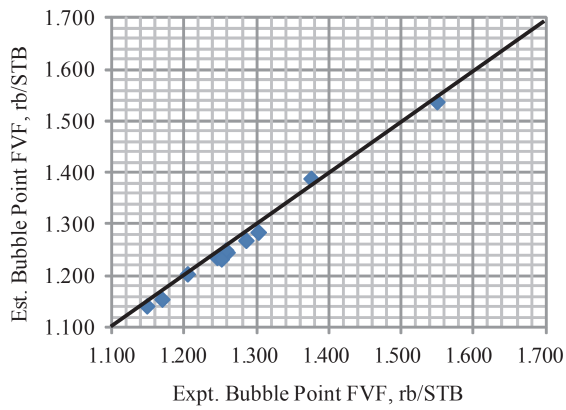

Figure A12
Crossplot for Bubble Point Oil FVF (B_{ob}) – Velarde *et al.*s' (1999) Correlation

Correlations and Equations recommended by Velarde *et al.* (1999) for the Estimation of Solution Gas-Oil Ratio, Oil Formation Volume Factor and Bubble Point Pressure.

Solution gas-oil ratio, $R_s = R_{sr}\ R_{sb}$ (A1)

where $R_{sr} = a_1\, p_r^{a_2} + (1-a_1) p_r^{a_3}$ (A2)

and $a_1 = A_0 \gamma_g^{A_1} \gamma_{API}^{A_2} T^{A_3} P_b^{A_4}$ (A3)

$a_2 = B_0 \gamma_g^{B_1} \gamma_{API}^{B_2} T^{B_3} P_b^{B_4}$ (A4)

$a_3 = B_0 \gamma_g^{C_1} \gamma_{API}^{C_2} T^{C_3} P_b^{C_4}$ (A5)

Reduced gas-oil ratio, $R_{sr} = R_s / R_{sb}$ (A6)

Reduced pressure, $P_r = p / p_b$ (A7)

Table A1
Regression Coefficients for the Solution Gas-Oil Ratio Correlation by Velarde *et al*. (1999)

Coefficients for Equation (A3)	Coefficients for Equation (A4)	Coefficients Equation for (A5)
$A_0 = 9.73 \times 10^{-7}$	$B_1 = 0.022339$	$C_1 = 0.725167$
$A_1 = 1.672608$	$B_1 = -1.004750$	$C_1 = -1.485480$
$A_2 = 0.929870$	$B_2 = 0.337711$	$C_2 = -0.164741$
$A_3 = 0.247235$	$B_3 = 0.132795$	$C_3 = -0.091330$
$A_4 = 1.056052$	$B_4 = 0.302065$	$C_4 = 0.047094$

Oil Formation Volume Factor,

$B_0 = (\rho_{STO} + 0.01357 R_s \gamma_g) / \rho_{oR}$ (A8)

$\rho_{po} = (R_s\, \gamma_{gs} + 4600 \gamma_{STO}) / (73.71 + R_s \gamma_{gs} / \rho_a)$ (A9)

where $\rho_a = -49.8930 + 85.0149 \gamma_{gs} - 3.70373 \gamma_{gs} \rho_{po} + 0.047982 \gamma_{gs} \rho_{po}^2 + 2.98914 \rho_{po} - 0.035689 \rho_{po}^2$ (A10)

Note: Eqs. (A8) and (A9) require an iterative solution. A first trial value of pseudo liquid density ρ_{po} for this iterative calculation is obtained by:

$\rho_{po} = 52.8 - 0.01 R_{sb}$ (A11)

ρ_{po} is adjusted from standard conditions to reservoir pressure and temperature to obtain the density of the reservoir oil at reservoir consitions, ρ_{oR} as follows:

$\rho_{po}(p, Tsc) = \rho_{po} + [0.167 + 16.181(10^{-0.0425\, \rho_{po}})]\, (p/1000) - 0.01[0.299 + 263(10^{-0.0603\, \rho_{po}})]\, (p / 1000)^2$ (A12)

$\rho_{oR}(p, T) = \rho_{po}(p, Tsc) - [0.0032 + 1.505(\rho_{po}(p, Tsc))^{-0.951}](T - 60)^{0.938} - [0.0216 - 0.0233(10^{-0.0161\, \rho_{po(p, Tsc)}})](T - 60)^{0.475}$ (A13)

Bubble Point Pressure,

$p_b = 1091.47[R_{sb}^{-0.081465}\, \gamma_{gs}^{-0.161488} 10^{X} - 0.740152]^{5.354891}$ (A14)

where $X = (0.013098\, T^{0.282372}) - (8.2 \times 10^{-6}\, API^{2.176124})$ (A15)