A Simple Multivariate Bubble Point Correlation for Deep Offshore Niger Delta Crude

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Abstract

In this study, a new linear bubble point correlation for deep offshore Niger Delta crude was developed using Excel. Using 129 data points characterizing crude from deep offshore Niger Delta fields, a simple multivariate model was developed by dividing the data points into modeling and validation data. With R2 of 0.999, the new model was found to satisfactorily predict the bubble point pressure of deep offshore Niger Delta crude samples. However, it was discovered that for crude samples with API density less than 50, the percentage error between predicted actual bubble points were less than 10%. While for crude samples with API gravity above 50, percentage error was above 10%, reaching up more than 60% in for some API gravities. Therefore, it was deduced that the developed model is applicable to deep offshore Niger Delta crude samples with API densities less than 50.

Keywords
Bubble point, solution gas oil ratio, API gravity, oil formation volume factor, reservoir temperature

1. Introduction

The bubble point pressure of a hydrocarbon system is defined as the highest pressure at which a bubble of gas is liberated from oil. This input property can be measured experimentally for a crude oil system by conducting a constant-composition expansion test. In the absence of the experimentally measured bubble point pressure, it is necessary for the engineer to make an estimate of this crude oil property from the readily available measured producing parameters (Moradi *et al*., 2010).

Knowledge of bubble point pressure is one of the important factors in the primary and subsequent developments of an oilfield. Bubble point pressure is required for material balance calculations, analysis of well performance, reservoir simulation and production engineering calculations. In addition, bubble point is an ingredient, either directly or indirectly, in every oil property correlation. Thus, an error in bubble point pressure will cause errors in estimates of all other oil properties. Which will propagate errors throughout all reservoir and production engineering calculations (Ikiensikimama and Ogboja, 2009).

Available bubble point correlations normally use data that are typically available in the field in different combinations. Hence, by considering a subset of variables that actually influence bubble points of hydrocarbon systems, the contributions of other important variables are usually lost. Also, by taking a clue from the seminal bubble point correlation work of Standing in 1947, most correlations developed since then have always been nonlinear in nature. Thereby, resulting in rigorous calculations that are usually confusing and time-consuming. In this study, a linear approach is taken to model bubble point, by considering as many variables as possible. These variables include bottom-hole pressure, bottom-hole temperature, bottom-hole density, bottom hole viscosity, oil formation volume factor, gas oil ratio, and API gravity.

2. Literature Review

Katz (1942) published a graphical correlation for predicting oil formation volume factor. Katz used U.S. mid-continent crude to develop his correlations. The correlation uses reservoir temperature, pressure, solution gas oil ratio, oil gravity and gas gravity. The correlations were presented only in graphical form. Katz correlations were hard to use because of the requirement to use graphs and calculations in combination.

Standing (1947) published his correlations for bubble point pressure and for oil formation volume factor. Standing correlations were based on laboratory experiments carried out on 105 samples from 22 different crude oils in California. The correlations treated the bubble point pressure and the oil formation volume factor as a function of the reservoir temperature, gas oil ratio, oil gravity and gas gravity. Standing correlations were the first to use these four parameters, commonly used after his work in developing correlations. These correlations are the most widely used correlations in the oil industry.

Lasater (1958) presented a new correlation model based on 158 samples from 137 reservoirs in Canada, U.S. and South America. His correlation was only for bubble point pressure. It is based on standard physical chemical equations of solutions. It utilizes Henry's law constant and the observation that the bubble point ratio at different temperatures is equal to the absolute temperatures ratio for hydrocarbon systems not close to the critical point. The correlation was presented in graphical form, and was used as a look-up chart. An advantage of Lasater correlation is the wide variety of data sources used to develop the correlation.

Cronquist (1972) presented a ratio correlation based on 80 data points from 30 Gulf Coast reservoirs. The correlation is useful for the analysis of depletion drive reservoirs when PVT analysis is not available. The method was presented in graphical form and requires an estimation of average reservoir properties.

Vazquez and Beggs (1976) published correlations for gas oil ratio and oil formation volume factor. They started categorizing oil mixtures into two categories, above 30 API gravity and below 30 API gravity. They also pointed out the strong dependence on gas gravity and developed a correlation to normalize the gas gravity measurement to a reference separation pressure of 100 psi. This eliminated its dependence on the separation conditions. More than 6000 data points from 600 laboratory measurements were used in developing the correlations.

Glaso (1978) developed correlations for bubble point pressure, formation volume factor, gas oil ratio, and oil viscosity for North Sea hydrocarbon mixtures. Glaso6 correlations main feature is that they account for paraffinicity by correcting the flash stock tank oil gravity to an equivalent corrected value using reservoir temperature and oil viscosity. They also account for the presence of non-hydrocarbons on saturation pressure by using correction factors for the presence of CO_2, N_2, and H_2S in the total surface gases. A total of 45 oil samples, most of which came from the North Sea region, were used in the development of these correlations.

Al-Marhoun (1988) published new correlations for estimating bubble point pressure and oil formation volume factor for the Middle East oils. 160 data sets from 69 Middle Eastern reservoirs were available for the correlation development. Al-Marhoun correlations were the first to be developed for Middle East reservoirs.

Obomanu and Okpobori (1987) presented new correlations for predicting gas oil ratio and oil formation volume factor for Nigerian crude oils. They used 503 data points from 100 Nigerian reservoirs in the Niger Delta Basin. They used Al-Marhoun bubble point pressure correlation model form and modified Standing oil formation volume factor correlation model form. In addition, they developed new correlation coefficients for Nigerian crude oils. The oil formation volume factor correlation divided the crude oils into two ranges according to oil gravity. In 1988, Abdul-Majeed and Salman published an oil formation volume factor correlation based on 420 data sets from unpublished sources. The form of the correlation is AlMarhoun oil formation volume factor correlation with new calculated coefficients. Al-Fattah and Al-Marhoun reported that 259 data sets used by Abdul-Majeed and Salman are from Vazquez's M.S. thesis. 256 data sets were found as reported by Al-Fattah and Al-Marhoun.

Asgapur, Mc Lauchlin, Wong and Cheun (1989) published a new set of correlations for different geological reservoirs for western Canadian gases and crude oils. Correlations for bubble point pressure, solution gas oil ratio at and below the bubble point pressure, and oil formation volume factor at and below the bubble point pressure were developed for four geological reservoirs. The new approach of developing correlations for a specific geologic time was justified by the different behavior of western Canadian reservoirs. Very little detail was presented concerning the crude oil differences. The new correlations used Al-Marhoun bubble point pressure correlation form and developed a new form for oil formation volume factor. The new approach resulted in less average error than Standing, Lasater and Vazquez and Beggs correlations for all the geologic reservoirs studied.

Labedi (1990) published new correlations for oil formation volume factor, oil density and fluid compressibility for African crude oils. Labedi's correlations eliminate the need for gas gravity and total gas oil ratio by using the separator pressure and temperature. 97 data sets from Libya, 28 sets from Nigeria, and 4 sets from Angola were available for the study. The correlations substitute the gas gravity and total gas oil ratio, which are very unlikely to be measured in the field, with separation gas oil ratio, temperature, and pressure as these are reported in field tests.

Dokla and Osman (1992) published a new set of correlations for estimating bubble point pressure and oil formation volume factor for UAE crudes. They used 51 data sets to calculate new coefficients for Al-Marhoun (1988) Middle East correlations. Al-Yousef and Al-Marhoun pointed out that the Dokla and Osman bubble point pressure correlation performance found contradicting physical laws, as the bubble point pressure is decreasing with temperature and insensitive to oil gravity changes. The data used in calculating the coefficients were insufficient to obtain an empirical correlation.

Al-Marhoun (1992) published a second correlation for oil formation volume factor. The correlation was developed with 11728 experimentally obtained formation volume factors at, above, and below bubble point pressure. The data set represents samples from more than 700 reservoirs from all over the world, mostly from Middle East and North America.

Farshad, Leblance, Garber, and Osorio (1992) produced a new set of correlations for bubble point pressure, solution gas oil ratio and the oil formation volume factor. They used the number of surface separator stages as a criterion for developing the correlations. The main feature of the new correlation is that it uses separator gas gravity and solution gas oil ratio instead of the totals, and corrects them for separation temperature and pressure. Reservoir samples from 98 Colombian reservoirs were available for the study. The new correlations used Standing and Glaso correlations forms and calculated new coefficients for them. The correlations for single stage separation process are considered for this study. The proposed correlations based on corrected separator data are more realistic since the stock tank gas gravity and solution gas oil ratio are seldom measured in the field.

Macary and El-Batanoney (1992) presented new correlations for bubble point pressure, oil formation volume factor and solution gas oil ratio. 90 data sets from 30 independent reservoirs in the Gulf of Suez were used to develop the correlations. The new correlations were tested against other Egyptian data of Saleh, Maggoub and Asaad, and showed improvement over published correlations.

Omar and Todd (1993), based on similar work to Standing oil formation volume factor correlation model, calculated a modified set of correlation coefficients. Omar and Todd also developed a bubble point pressure correlation that uses the oil formation volume factor in addition to oil gravity, gas gravity, solution gas oil ratio, and reservoir temperature.The new correlation was based on 93 data sets from Malaysian oil reservoirs. An estimated oil formation volume factor from the developed correlation can be used for bubble point prediction if it is not measured.

Petrosky and Farshad (1993) developed new correlations for Gulf of Mexico crudes. Standing correlations for bubble point pressure, solution gas oil ratio, and oil formation volume factor were taken as a basis for developing the new correlation coefficients. Vazquez and Beggs oil compressibility correlation model was used as a basis for oil compressibility correlation. The approach that Petrosky and Farshad applied to develop the correlations was to give the original correlation model maximum flexibility through nonlinear regression to achieve the best empirical relation the model can achieve through the available data set. The maximum flexibility allows each variable to have a multiplier and exponent. The original model fixes multipliers and exponents of some of the variables to one. Ninety data sets from Gulf of Mexico were used in developing these correlations.

Kartoatmodjo and Schmidt (1994) used a global data bank to develop new correlations for all PVT properties. Standing correlation models were taken as basis for bubble point pressure and solution gas oil ratio correlations. Vazquez and Beggs oil formation volume factor correlation was considered the basis for oil formation volume factor correlation.

Data from 740 different crude oil samples gathered from all over the world provided 5392 data sets for the correlation development.

Almehaideb (1997) published a new set of correlations for UAE crudes. He used 62 data sets from UAE reservoirs to develop the new correlations. Correlations developed are for bubble point pressure, oil formation volume factor, oil viscosity, and oil compressibility. The bubble point pressure correlation like Omar and Todd uses the oil formation volume factor as input in addition to oil gravity, gas gravity, solution gas oil ratio, and reservoir temperature. Improvement over published correlations was achieved with these correlations.
Al-shammasi (1999) presented a new correlation for bubble point pressure based on global data with improvement in performance over published correlations. He also presented new neural network models and compared their performance to numerical correlations. His evaluation examined the performance of correlations with original published coefficients and with coefficients calculated based on global data, data from a specific geographical location, and data for a limited oil gravity range. The evaluation of each coefficient class included geographical and oil gravity grouping analysis. The results showed that the classification of correlation models as most accurate for a specific geographical area is invalid to be used for these two fluid properties.
Ikiensikimama and Ogboja (2009) developed a new bubble point pressure correlation based on data from the Niger Delta. They utilized both quantitative and qualitative assessments to evaluate the correlation which compared most to the best existing bubble point pressure correlation for Niger Delta crude. Their new correlation outperformed the best existing correlation, which is Lasater correlation, by the statistical parameters used with a rank of 7.3 and better performance plot.

3. Model Development

In this study, it is believed that bubble point pressure of a hydrocarbon system is a function of its bottom-hole pressure, bottom-hole temperature, bottom-hole density, bottom-hole viscosity, oil formation volume factor, gas oil ratio, and API gravity. Mathematically,

$$P_b = f\,(P, T, \gamma, \mu, B_o, \gamma_{API}) \qquad (1)$$

The data used for development of the model was gotten from crude samples of oil fields in deep offshore Niger Delta. Table 1 shows the range of the data used for the study. A total of 129 data points comprising of depth, bottom hole pressure, bottom hole temperature, bottom hole density, bottom hole viscosity, oil formation volume factor, gas oil ratio, and API gravity was used inputted in an Excel. The whole data points were divided into modeling and validation data. Then, a simple linear model relating bubble point pressure and the aforementioned variables was generated.

Table1: Range of data used for the study

	Minimum	Maximum	Mean
API gravity	38.130	55.8500	49.96217
B_o (m^3/m^3)	202.62	2833.52	1088.438
B_o (m^3/m^3)	1.5670	10.8510	4.567000
Viscosity BHVisco. (mPas)	0.0360	0.41500	0.080078
BHD (kg/m^3)	288.30	648.100	420.4258
BHT (°C)	70.760	96.3600	86.46430
BHP (bar)	311.75	411.190	352.9866
BPP (bar)	266.60	365.900	330.7209

Precisely, the data was divided into two (2), with the top half used for model development and the second half used for validation. The model is presented in equation 2 below:

$$P_b = B_o 9.9175 + R_s 0.04519 + \gamma_{API} 13.2615 + P1.6511 + T6.277258 + \rho 0.66625 + \mu 296.3783 - 1829.30$$
(2)

4. Results and Discussion

Table 2 shows the regression statistic for the developed model. The coefficient of determination of the data set used was found to 0.998856.

Table 2: Regression Statistics

Regression Statistics	
Multiple R	0.999428
R Square	0.998856
Adjusted R Square	0.998713
Standard Error	0.857696
Observations	64

The regression results are further summarized in the summary shown in Table 3.

Table 3: Regression results summary

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-1829.30	154.265	-11.8582	6.66E-17	-2138.33	-1520.27
B_o (m^3/m^3)	9.917502	10.36442	0.956879	0.342741	-10.8449	30.67994
R_s (Sm^3/m^3)	0.045193	0.040868	1.105816	0.273534	-0.03668	0.127062
API gravity	13.26153	1.38476	9.576768	2.14E-13	10.48752	16.03553
BHP (bar)	1.651094	0.075015	22.01027	3.03E-29	1.500821	1.801366
BHT (°C)	6.277258	0.453266	13.84895	9.87E-20	5.369257	7.185258
BHD (kg/m^3)	0.666252	0.071689	9.293649	6.07E-13	0.522642	0.809862
BHVisco (mPas)	296.3783	22.02831	13.45442	3.45E-19	252.2502	340.5063

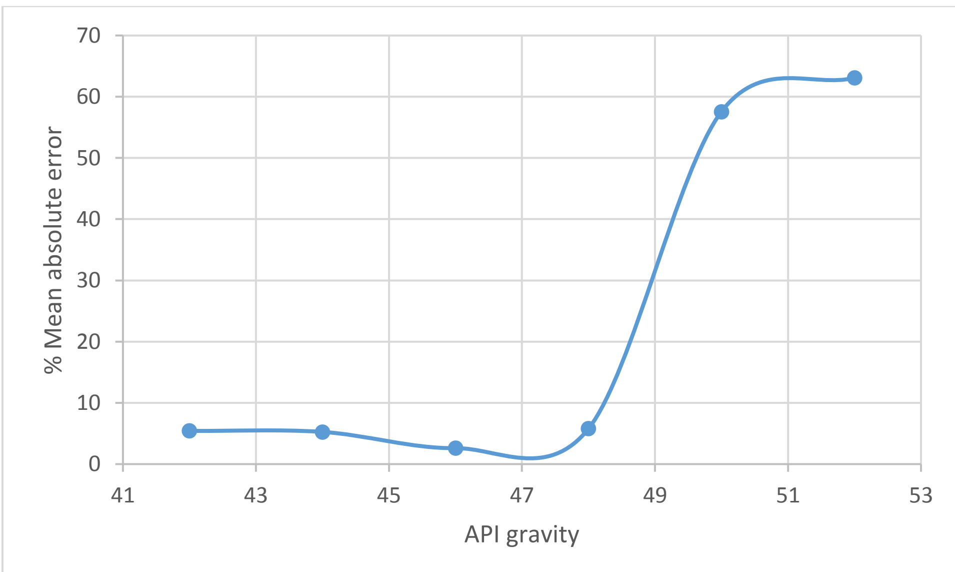

Figure 1: Errors of bubble point prediction grouped by API gravity

From Tables 2 and 3, it can be seen that with an R^2 of 0.999, it is obvious that the developed model gave good predictions compared to bubble point values from the group of data points used for modelling. Also, from Figure 1, judging from the percentage mean absolute error, it can be seen that prediction accuracy of the developed model in comparison to validation data initially increased as API gravity was increasing. This is evident in the gradually decreasing percentage mean absolute error from API gravity of 42 up to 47. Then, as API gravity increased from 50 upwards, the percentage mean absolute error, increased beyond 10% up to 60%. Therefore, it can be deduced that developed model is applicable to deep offshore Niger Delta crude samples with API densities less than 50.

5. Conclusion

From this study, bubble point pressure correlation has been developed for a Niger Delta field. This correlation can be used in calculating bubble point pressure using available data gathered from field. This can be used in defining this important parameter in the absence of experimental value in calculating material balance, analysis of well performance, reservoir simulation and production engineering calculations.
The developed model is applicable to deep offshore Niger Delta crude. The model is a linear multivariate model which can predict bubble point pressure satisfactorily for crude oil samples with API gravity of less than 50, which is typically the kind of crude oil found in this region.

6. References

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