ABSTRACT: Producing oil from deep offshore fields poses serious risk especially due to peculiar pressure and temperature regimes characterizing the fields. These variables affect the bubble point of the produced hydrocarbon in such fields. The significance of Bubble point pressure and gas solubility has led researchers to continually develop correlations to accurately predict these reservoir oil properties. In this work, measured bubble point pressure is first evaluated and a new correlation is established to estimate crude oil bubble point pressure for deep offshore region of West Africa. Nonlinear Multiple Regression analysis was utilized. The correlation applies to API crude oils ranging from 38 to 56. Comparison with other published ones of this new correlation indicates that it is much more precise than the others. The developed correlation's Average Absolute Percent Error (percentage) is 4.8 percent. The result is indicative of an agreement between the measured and estimated data.

KEYWORDS- bubble point, pressure, correlation, deep offshore, Nigeria

INTRODUCTION

So many questions have been asked in other anticipate the volumetric and phase behavior of the hydrocarbon fluid produced from the reservoir. Questions of: What kind of fluids will be produced? Will the crude solidify at the bottom temperature? For offshore fields Will the produced gas be reinjected, sold or flared?

This has been a concern for Reservoir and Production Engineers as to maximize hydrocarbon recovery cost effectively in the minimum amount of time

Laboratory analysis of reservoir oil sample is the best way to determine the reservoir’s bubble point pressure. Reservoir pressure-volume-temperature (PVT) analysis is carried out experimentally in the PVT laboratory by simulating the hydrocarbon fluid flow from the reservoir to the surface. During this process, the bubble point pressure is measured. The bubble-point pressure (Pb) is defined as the highest pressure at which a bubble of gas is first liberated from the oil. Bubble point pressure is a vital reservoir fluid property. A bubble test designates important information to the geologist about the expected recovery of the oil in a well. If the oil that will be recovered is undersaturated (containing very little dissolved gas), only a small percentage of the oil is recoverable without the use of some advanced recovery method. Determination of this property is used to evaluate the hydrocarbon behavior and also the probable technology for improved hydrocarbon recovery.
The experimentally obtained PVT properties can be time consuming, expensive and may not be accessible and readily available. Consequently, researchers have developed so many correlations to determine the bubble point pressure and other oil properties.

The aim of this study is to develop a bubble point pressure correlation for a deep-water offshore region using a nonlinear multiple regression analysis.

**LITERATURE REVIEW**

Several correlations for predicting bubble point pressure have been presented from different locations. Literature has revealed that the most commonly used empirical correlations are the Standing (1947), Lasata (1958), Glaso (1980), Vazques and Beggs (1980), and Al-Marhoun (1988) correlations for predicting bubble point pressure, dissolved gas and oil formation volume factor. The following correlations by a few researchers are summarized:

**Standing (1947)** developed correlations to determine the bubble point pressure and formation volume factor from solution gas oil ratio, oil density, gas relative density, and temperature. The correlation was developed from 105 data points of 22 HC mixtures from California Region.

\[
Pb = a1 \times \left[ \left( \frac{Rs}{Yg} \right)^{a2} \times \frac{10^{a3+T}}{10^{a4+API}} - a5 \right]
\]

Where \( a1 = 18.2, a2 = 0.83, a3 = 0.00091, a4 = 0.0125, a5 = 1.4 \)

**Lasata (1958)** used standard physical-chemical equations of solutions to develop correlations of \( Yg \) and \( Pb \) of 158 data points from Canada West Mid Continental U.S.A and South America.

\[
Pb = \frac{(pf)(T+459.67)}{Yg}, \quad Yg = \frac{Rs}{a1 \frac{Yg}{a2} \frac{Mo}{a1}}
\]

Where \( Mo = a3 - a4 * API + a5 * API^2 \)

\( pf = a6 - a4 * Yg + a5 * Yg^2 \)

\( a1 = 379.3, a2 = 350, a3 = 725.32143, a4 = 16.03333, a5 = 0.09524, a6 = 0.38418 \)

\( a7 = 1.20081, a8 = 9.64868 \)

**Glaso (1980)** Proposed a correlation for an empirical correlation for bubble point pressure from solution gas oil ratio values (Rs) as a function of pressure (P), temperature (T), specific gravity (\( Yg \)) and oil gravity (\( Yo \)). He developed correlation was obtained from 45 laboratory measurements from the North Sea region.

\[
Pb = 10^{a1+a2*(log(G)-a3*(log(G))^2}
\]
Where $G = \left( \frac{Rs}{Yg} \right)^{a4} + T^{a5} \times API^{a6}$

$a1 = 1.7669$, $a2 = 1.7447$, $a3 = 0.30218$, $a4 = 0.816$, $a5 = 0.172$, $a6 = -0.989$

**Vasquez and Beggs (1980)** carried out a Worldwide crude oil system study of 5008 data points.

$$Pb = \left[ (a1 \times \frac{Rs}{Yg}) \times 10^{-a3 \times \frac{API}{460 + T}} \right]^{\frac{1}{a2}}$$

$$Ygs = Yg \times (1 + 5.915 \times 10^{-5} \times T_{sep} \times API \times \log\left(\frac{P_{sep}}{114.7}\right))$$

If API <= 30 => $a1 = 27.64$, $a2 = 1.0937$, $a3 = 11.172$

If API > 30 => $a1 = 56.06$, $a2 = 1.187$, $a3 = 10.393$

**McCain (1991)** also carried out a Worldwide crude oil system study of 100 pressure data points.

$$Pb = a1 \times (C_{pb} - a2)$$

$$C_{pb} = \left( \frac{Rs}{Yg} \right)^{a3} \times 10^{(a4 \times T + a5 \times API)}$$

Where $a1 = 18.2$, $a2 = 1.4$, $a3 = 0.83$, $a4 = 0.00091$, $a5 = 0.0125$

**Al Marhoun (1988)** developed a correlation for estimating bubble point pressure from the Middle Eastern crude oil system. The data was generated from 160 experimental pressure data.

$$Pb = a1 \times Rs^{a2} \times Yg^{a3} \times Yo^{a4} \times (T + 460)^{a5}$$

Where $a1 = 5.38088e-3$, $a2 = 0.715082$, $a3 = -1.877840$, $a4 = 3.143700$, $a5 = 1.326570$

**McCain (1991)** carried out a Worldwide crude oil system study of 100 pressure data.

$$Pb = a1 \times (C_{pb} - a2)$$

$$C_{pb} = \left( \frac{Rs}{Yg} \right)^{a3} \times 10^{(a4 \times T + a5 \times API)}$$

Where $a1 = 18.2$, $a2 = 1.4$, $a3 = 0.83$, $a4 = 0.00091$, $a5 = 0.0125$

**Petrosky and Farshad (1993)** carried out a PVT analysis on 81 laboratory data from Gulf of Mexico crude oil system. They developed a gas solubility correlation using a nonlinear regression software.
\[ P_b = a_1 \left[ \left( \frac{R_s^{a_2}}{Y_g^{a_3}} \right) \times 10^x - a_4 \right] \]
\[ x = a_5 \times T^{a_6} - a_7 \times \text{API}^{a_8} \]

\[ a_1 = 112.727, \ a_2 = 0.5774, \ a_3 = 0.8439, \ a_4 = 12.340, \ a_5 = 4.561 \times 10^{-5}, \ a_6 = 1.3911, \ a_7 = 7.916 \times 10^{-4} \]

**Al-Shammasi (1999)** published a neural network model for oil formation volume factor consisting of two hidden layers, five nodes in the first layer and three in the second layer. The model used 1161 Worldwide data sets.

\[ P_b = Y_o^{a_1} \left( \text{Exp}(a_2 \times Y_g \times Y_o) \right) \times (R_s \times T + 460) \times Y_g^{a_3} \]

Where \( a_1 = 5.527215, \ a_2 = -1.841408, \ a_3 = 0.783716 \)

**Ikiensikimama & Ogboja (2009)** Performed a correlation on 250 data sets of a Niger Delta crude sample.

\[ Y_g = \frac{R_s}{\frac{a_1 \times \text{API}}{a_1 + (a_2 \times Y_o)}} \]

\[ \left( a_3 - a_4 \times \text{API} \right)^{a_5} \]

\[ P_b^* = a_6 + a_7 \times Q + a_8 \times Q^{a_9} \]

\[ a_1 = 336.0064009, \ a_2 = 6.7063984, \ a_4 = 0.677706662, \ a_3 = 47.57094772 \]
\[ a_5 = 1.530935619, \ a_7 = -2.316548789, \ a_6 = 0.243181338, \ a_8 = 10.60657909 \]
\[ a_9 = 1.518030465, \ a_{10} = 635.4152349 \]

**Moradi (2010)** Performed a multiple regression analysis of bubble point pressure on 1801 data sets from the Middle East.

\[ P_b^* = a_1 \times \text{LOG(\text{API}) \times \left( \frac{141.5}{Y_o} - 131.5 \right)^a_1} \times \left( \text{EXP}(a_3 \times Y_g \times Y_o) \right) \times (R_s \times (T + 460) \times Y_g)^{a_4} \]

\[ P_b = a_5 \times P_b^* + a_6 \times P_b^{*2} + a_7 \times P_b^{*3} \]

**Moussa et al. (2017)** Developed a model by utilizing a novel comprehensive approach using hybrid Self-adaptive Differential Evolution and Artificial Neural Network (SaDE-ANN) that could be used as a robust and effective model to predict \( P_b \) and \( R_s \) of crude oils based only on oil and gas gravities in addition to the reservoir temperature.
Developing the Bubble Point Pressure Correlation

Data Analysis
For this work, a total of 176 data sets originated from a Deep-Offshore region were collected to confirm the accuracy of this work. The Data used consists of reservoir temperature, oil gravity, solution gas oil ratio, and average gas gravity for bubble point pressure. Microsoft Excel solver application was utilized for the regression equations.

Table 1: Data Range

<table>
<thead>
<tr>
<th>PVT Parameter</th>
<th>Min.</th>
<th>Max.</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>BHP. (Psi)</td>
<td>4520.375</td>
<td>5358.965</td>
<td>6109.43</td>
</tr>
<tr>
<td>Rs (scuft/Bbl)</td>
<td>1137.629</td>
<td>5540.787</td>
<td>15909.06</td>
</tr>
<tr>
<td>API</td>
<td>38.13</td>
<td>49.6183</td>
<td>55.85</td>
</tr>
<tr>
<td>T (°F)</td>
<td>159.038</td>
<td>193.35561</td>
<td>215.054</td>
</tr>
<tr>
<td>( \Upsilon_g )</td>
<td>0.5804026</td>
<td>1.98943</td>
<td>1.864004</td>
</tr>
</tbody>
</table>

The generalized relationship utilized for this empirical bubble point pressure correlation is developed by Standings

\[ P_b = f(Rs, \bar{\Upsilon}_g, Yo, T) \] …………………………………………………………………………………………………………………..Eq. 1

The nonlinear multiple regression analysis was used to develop the following relation:

\[ P_b = a_1 (Yo^{a_2} \cdot \Upsilon_g^{a_3} \cdot T^{a_4} \cdot Rs^{a_5}) \] …………………………………………………………………………………………………………………..Eq. 2

Table 2: Bubble point pressure Coefficients

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( a_1 )</td>
<td>67.3506</td>
</tr>
<tr>
<td>( a_2 )</td>
<td>2.313833</td>
</tr>
<tr>
<td>( a_3 )</td>
<td>1.066621</td>
</tr>
<tr>
<td>( a_4 )</td>
<td>0.682024</td>
</tr>
<tr>
<td>( a_5 )</td>
<td>0.070147</td>
</tr>
<tr>
<td>( \bar{\Upsilon}_g )</td>
<td>1.864004</td>
</tr>
</tbody>
</table>

The Average Absolute Percent Error (AAPE) is measured as 4.8%. This indicates that there is a strong agreement between the experimental and estimated value.

\[ E_a = \left( \frac{1}{n_d} \right) \sum_{i=1}^{n_d} |E_i| \times 100 \]
Figure 1: Cross plot of Bubble Point Pressure

Figure 2: API Distribution Chart
Figure 3: Effect of temperature on bubble point pressure at different Rs, gas and oil API gravity.

CONCLUSION

The accuracy of bubble point prediction is important to the petroleum engineers to characterize the oil reservoir and to account for oil in place. The result generated from this correlation was analyzed statistically and the Average Absolute Percent Error (AAPE) gotten is 4.8%. The correlation developed is an empirical correlation for Deep-Offshores region.

References


Standing, M.B." Volumetric and Phase Behaviour of Oil Field Hydrocarbon Systems" SPE, Dallas, TX, (1951).