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ASSESSMENT OF BUBBLEPOINT OIL FORMATION VOLUME FACTOR EMPIRICAL PVT CORRELATIONS

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ABSTRACT

The oil formation volume factor (FVF) among other factors is the most important factor that enables the calculation of the amount of reserves in a particular reservoir. In this paper, the existing oil formation volume factor correlations were assessed for their performance using data from the Niger Delta Region. Two hundred and fifty PVT reports were validated for this study from various oil fields. Both quantitative and qualitative analytical methods were implemented through statistical parameters and performance plots respectively. From the general evaluation i.e. using the full range of the data, Hemmati and Kharrat (2007) correlation performed the best for the Niger Delta crude with percent mean absolute relative error (E_a) of 1.9055 and correlation coefficient (r) of 0.9897. From the oil API gravity ranges reliability analysis, it is clear that different correlations other than Hemmati and Kharrat (2007) would be more appropriate for API≤ 35.

KEYWORDS: Oil Formation Volume Factor, Bubblepoint, Empirical Correlation, PVT Correlation

1.0 INTRODUCTION

One of the fundamental problems that must be solved by the reservoir engineer is the prediction of the reservoir performance and well behavior. Well, reservoir rock and fluid data plus flow characteristics and reservoir geology and geometry are all utilised to determine the amount of reserves i.e. the initial-oil or gas in place. Various methods of production are then examined and evaluated and well and reservoir performances under various modes of operations are predicted. Financial calculations are carried out for different methods of production. All these information are used to determine the optimum development of a field documented as Field Development Plan (FDP).

If reservoir rock properties, flow characteristics and reservoir geology and geometry are precisely determined, then the only variable left is the fluid data i.e. the PVT data of the reservoir to accurately calculate the stock tank oil initial-in-place (STOIIP). In the absence of experimental PVT reports (data), correlations are used to enable the Exploration & Production industry make crucial decisions concerning the development of the field and the efficiency of the correlations to precisely approximate the PVT data matter most. However, the most important PVT parameter required for this purpose is the oil formation volume factor.

The purpose of this paper is to assess the performances of the existing oil formation volume factor models/correlations available in the literature as applied to a databank in the Niger Delta region. The fluid property and correlations examined are as shown on Table 1, not only in the range of input data defined by each author but in the PVT data range for this study as presented in Table 2.

Table 1: Fluid properties and correlations examined

Fluid property	*Published empirical correlations*
Bubblepoint Oil FVF * Local Correlations	Standing (1947), Vazquez and Beggs (1980), Glaso (1980), Obomanu and Okpobiri (1987)*, Udegbunam and Owolabi (1987)*, Al-Marhoun (1988), Abdul-Majeed and Salman (1988), Dokla and Osman (1992), Petrosky and Farshad (1993), Farshad et al. (1992), Al-Marhoun (1992), Omar and Todd (1993), Almehaideb (1997), Marcary and El-Batanony (1992), Kartoatmojo and Schmidt (1994), Al-Shammasi (2001), Dindoruk and Christman (2004), Hemmati and Kharrat (2007)

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Table 2: Data range for the study

Parameter	Minimum	Maximum
Tank-oil gravity (^{o}API)	14.87	53.23
Bubblepoint oil FVF, B_{ob} (rb/stb)	1.051	3.2705
Pressure above Bubblepoint, P_{ab} (psia)	115	8451
Bubblepoint pressure, P_b (psia)	67	6560
Pressure below bubblepoint, P_{bb} (psia)	25	6015
Bubblepoint solution GOR, R_{sb} (scf/stb)	19	2948.8
Solution GOR below bubblepoint, R_{sbb} (scf/stb)	2	3299
Reservoir temperature, T (^{o}F)	122.3	264
Average surface gas gravity (avg. γ_g)	0.564	1.294

2.0 Literature

Over five decades, several empirical correlations/models have been proposed for determining oil formation volume factor property of crude oils. Most of these correlations/models refer to Ostermann et al. (1983), Saleh et al. (1987), Sutton and Farshad (1990), Bergen and Niko (1999), De Ghetto et al. (1994), Al-Shammasi (2001) and Hemmati and Kharrat (2007). As more correlations are developed, researchers evaluate the previously published correlations with the new ones. Others carry out studies to select the most accurate correlation for a particular reservoir or geographic area (Al-Shammasi, 2001). Ostermann et al. (1983) evaluated published correlations based on eight Alaskan fluid samples and indicated that Standing (1947) correlation for oil formation volume factor showed least error for Alaskan crudes. The samples they used were characterized by high nitrogen (N_2) and carbon dioxide (CO_2) contents. They concluded that it is necessary to evaluate the applicability of existing PVT correlations before using them with confidence. Saleh et al. (1987) published an evaluation of empirical correlations for Egyptian oils and Standing (1947) model showed the best result for oil formation volume factor.

Sutton and Farshad (1990) published an evaluation of Gulf of Mexico crude oils. They used 285 data sets for gas-saturated oil and 134 data sets for undersaturated oil representing different crude oils and natural gas systems. They concluded that Glaso (1980) correlation oil formation volume factor performed the best for most of the data studied. McCain (1991) published an evaluation of all reservoir properties correlations based on a large global database. For oil formation volume factor at and below bubble point pressure, the author recommended Standing (1947) correlation with estimation accuracy of 5.0% when used with total solution gas oil ratio but pointed out the dependence of estimated accuracy on the source of the data.

Petrosky and Farshad (1993) published a new correlation based on Gulf of Mexico crude with much lower absolute relative error for all correlations than what was reported in the literature. Petrosky and Farshad (1993) stated that Al-Marhoun (1988) correlation model for oil formation volume factor showed best performance out of the published models. Elsharkawy et al. (1994) published a study for evaluating PVT correlations for Kuwaiti crude oils. The study used 44 sample analyses for the evaluation. Al-Marhoun (1988) oil formation volume factor correlation model performed the best with an average absolute error of 2.72%.

Mahmood and Al-Marhoun (1996) presented an evaluation of PVT correlations for Pakistani crude oils. They used 166 data sets from 22 different crude samples for the evaluation. Al-Marhoun (1993) oil formation volume factor correlation gave the best results with an average absolute error of 1.23%.

Hanafy et al. (1997) published an evaluation for the most accurate correlation to apply to Egyptian crude oils. Although the reported average absolute error for Macary and El-Batanoney (1992) correlations were not the minimum, the study did recommend these correlations for bubble point pressure and oil formation volume factor.

3.0 Data Analysis

The data used were obtained from conventional PVT reports that derive the various fluid properties through differential liberation process from different oil fields in the Niger Delta. The reports were validated using material balance and Campbell plots (Campbell, 1988). Two hundred and fifty data sets were used for the analysis.

Two forms of analysis were adopted: quantitative analysis through statistical error analysis and qualitative analysis through performance plots (known as cross plots). To compare the performances of the empirical correlations, statistical error analysis is performed. The statistical parameters used for comparison are (see Tables 3 & 4):

Percent Mean Relative Error: It is an indication of the relative deviation from the experimental data, defined by:

$$\% \ MRE = E_r = \frac{1}{n}\sum_{i}^{n} E_i \qquad (1)$$

where E_i is the relative deviation of an estimated (predicted) value from an experimental value and is defined as:

$$E_i = \left[\frac{(X)_{exp} - (X)_{est}}{(X)_{exp}}\right] x\,100 \quad i = 1, 2, ...n \qquad (2)$$

where $(X)_{exp}$ and $(X)_{est}$ represent the experimental and estimated values, respectively for any fluid property. The lower the value of E_r, the more equally distributed is the error between positive and negative values.

Percent Mean Absolute Relative Error: This parameter is to measure the mean value of the absolute relative deviation of the measured value for the experimental data. The value of the percent mean absolute relative error is expressed in percent. The parameter can be defined as:

$$\% \ MAR = E_a = \frac{1}{n}\sum_{i=1}^{N} |\, E_i \,| \qquad (3)$$

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

Standard Deviation: The standard deviation of the mean relative error (E_r) is defined in equation 4 and is a measure of the percent relative spread or dispersion of the data distribution:

$$\% \ SDR = S_r = \sqrt{\sum_{i=1}^{n}\left[\left(E_i - \left(\left(\overline{X} - (X)_{est}\right)/(X)_{exp}\right)_i x100\right)\right]^2 / n-1} \qquad (4)$$

A lower value of standard deviation means a smaller degree of scatteredness. The standard deviation of the E_a that is S_a is also used to measure the percent relative absolute spread or dispersion of the data distribution. 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.

The Correlation Coefficient: It represents the degree of success in reducing the standard deviation by regression analysis, defined by:

$$R = \sqrt{1 - \sum_{i=1}^{n}\left[(X)_{exp} - (X)_{ext}\right]_i^2 / \sum_{i=1}^{n}\left[(X)_{exp} - \overline{X}\right]_i^2} \qquad (5)$$

where $$\overline{X} = \frac{1}{n}\sum_{i=1}^{n}\left[(X)_{exp}\right]_i \qquad (6)$$

The value of the correlation coefficient varies from 0 to 1.0. The coefficient of zero indicates no relationship between the experimental and the predicted values while a 1.0 coefficient indicates a perfect positive relationship.

The performance plot (cross plot) is a graph of the predicted versus measured properties with a reference 45^o line to readily ascertain the correlations fitness and accuracy. A perfect correlation would plot as a straight line with a slope of 45^o (see Figures 1 through 9).

4.0 RESULTS AND DISCUSSION

The assessment of the different oil formation volume factor correlations were implemented with the correlations listed in Table 1. In arriving at the calculated results, measured quantities were used as input into the correlations. It is necessary to note that in the evaluation of the various correlations, that average gas gravity is used for the correlation evaluations. The best and some other relevant performance plots for each of the cases considered are included in this paper.. As stated by Al-Marhoun (2003), the most important indicator of the accuracy of an empirical correlation/model is the mean absolute relative error (E_a). In this study therefore, the mean absolute relative error is being used as the screening criterion.

4.1 General Correlation Assessment

A total of nineteen correlations are available for the bubblepoint oil FVF assessment. The results of the assessment as presented in Table 3 give statistical accuracies for all the bubblepoint oil FVF correlations examined. From the table, Hemmati and Kharrat (2007) correlation (see Fig. 1) of the Iranian crude ranked best with E_a of 1.9055 and correlation coefficient (R) of 0.9897 while Dokla and Osman (1992) correlation (see Fig. 2) of the United Arab Emirate (UAE) crude is the worst with E_a of 50.3400 for the entire data set used. Obomanu and Okpobiri (1987) and Udegbunam and Owolabi (1987) are two oil FVF correlations developed for the Niger Delta: these correlations took the 15th and 18th position on the ranking list (see Table 3 and Figs. 3 & 4). Their performances are not very impressive compared to other correlations in terms of statistical measures and performance plots. This trend is expected since these correlations were developed for black oils and the data used for this study covered the black-volatile oil range. However, the very poor performance (i.e. the collapsed) of Udegbunam and Owolabi (1987) correlation for the bubblepoint oil FVF is attributed to the fact that the data set (i.e. the fluid properties) used for the development of this correlation is not representative of the Niger Delta region as it is with the Dokla and Osman (1992) correlation of the UAE crude.

Table 3: Statistical Accuracy of Bubblepoint Oil FVF

Author (s)	E_r	E_a	S_r	S_a	R
Hannati and Kharrat (2007)	-0.0066	1.9055	2.9035	2.1874	0.9897
Kartoatmodjo and Schmidt (1994)	0.3064	1.9469	3.093	2.4198	0.9855
Al-Shammasi (2001) - (4p)	0.2014	1.9488	3.0797	2.39	0.9856
Petrosky and Farshad (1993)	-0.0617	2.0967	3.003	2.1466	0.9885
Al-Marhoun (1988)	1.1984	2.1552	3.2407	2.6982	0.981
Glaso (1980)	0.8779	2.5252	3.307	2.3039	0.9867
Dindoruk and Christman (2004)	0.7502	2.5424	4.4506	3.7261	0.9719
Omar and Todd (1993)	-1.0471	2.6515	3.7387	2.8319	0.982
Standing (1947)	-2.1183	3.1411	3.7548	2.9493	0.9778
Al-Marhoun (1992)	3.7118	3.8046	3.4835	3.3815	0.9634
Al-Shammasi (2001) - (3p)	-2.2231	4.0496	4.404	2.8092	0.9717
Abdul-Majeed and Salman (1988)	2.0299	4.0679	7.4763	6.5892	0.8694
Almehaideb (1997)	1.4301	4.6525	5.9994	4.039	0.9451
Vazquez and Beggs (1980)	4.8718	5.1725	5.3178	5.0245	0.9209
Obomamu and Okpobiri (1987)	0.9458	7.1476	8.9001	5.368	0.9442
Macary and El-Batanoney (1992)	-11.9908	12.1478	5.8558	5.5213	0.7901
Farshad et al (1992)	29.9971	29.9971	15.6848	15.6848	
Udegbunam and Owolabi (1987)	30.7416	30.7416	15.5754	15.5754	
Dokla and Osman (1992)	50.34	50.34	14.5101	14.5101	

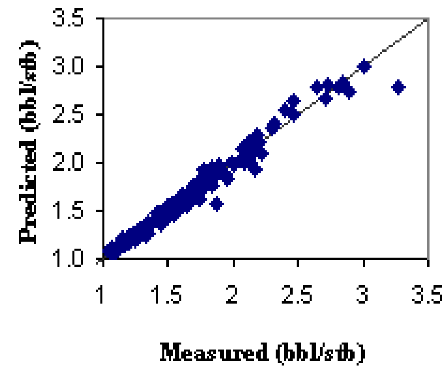

Fig. 1: Performance plot for bubblepoint oil FVF (Hemmati and Kharrat (2007))

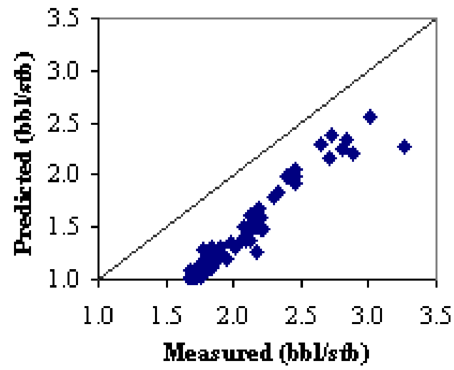

Fig. 2: Performance plot for bubblepoint oil FVF (Dokla and Osman (1992))

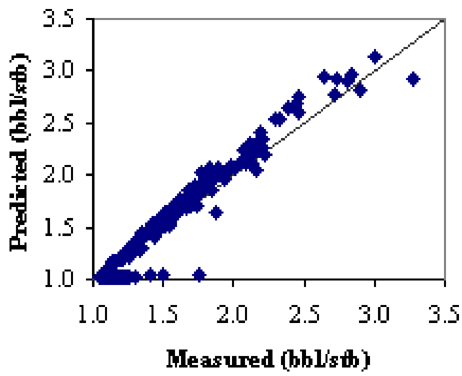

Fig. 3: Performance plot for bubblepoint oil FVF (Obomamu and Okpobiri (1987))

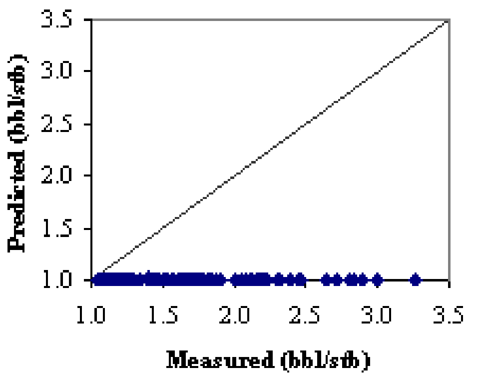

Fig. 4: Performance plot for bubblepoint oil FVF (Udegbunam and Owolabi (1987))

4.2 Oil API Gravity Reliability Analysis

The API gravity reliability analysis is used to assess the reliability of grouping correlations accuracy according to oil gravity. Particularly, since the density of oil is a fundamental characteristic as it reflects the chemical composition of crudes on which all the fluid main properties depend. For this reason, the reliability of each correlation was tested for each group in the different classes (groups). The results obtained for each group (class) are believed to be very significant as it is plausible that samples belonging to the same group are physically and chemically more comparable than samples from different groupings (De Ghetto et al., 1994).

Depending on their API gravity, crude species have been classified as light, blend, medium or heavy. The light crude has API gravity above 35°, the blend is between 26° and 35°, medium is between 21° and 26° while the heavy has API gravity less than or equal to 21°. For the purpose of this study, the light crude API gravity range has been further subdivided into two groups: light, between 35° and 45°, and very light 45° and above.

Table 4: Statistical accuracy of API reliability analysis for bubblepoint oil formation volume factor

	Dataset	Author (s)	E_r	E_a	S_r	S_a	r
API ≤ 21	18	Al-Shammasi (2001) -4p	-0.0124	0.9178	1.3872	1.0162	0.9823
21 > API≤ 26	40	Omar and Todd (1993)	-0.0288	1.0321	1.3954	0.9248	0.9436
26 > API ≤ 35	45	Al-Marhoun (1988)	-0.2587	1.2133	1.5618	1.0011	0.9913
35 > API≤ 45	132	Hemmati and Kharrat (2007)	0.6199	2.36	3.4982	2.6481	0.9793
API >45	15	Hemmati and Kharrat (2007)	-0.1593	2.7257	3.44	1.975	0.9884

The bubblepoint oil formation volume factor API reliability analysis statistical accuracies and number of data sets used are shown on Table 4 while the corresponding performance plots are as presented in Figs. 5 through 9. For the various groupings: Al - Shammasi (2001) – (4p), Omar and Todd (1993) and Al-Marhoun (1988) correlations performed best in the API gravity ranges of API ≤ 21, 21 > API≤ 26 and 26 > API ≤ 35 respectively while for the other groups Hemmati and Kharrat (2007) correlation performed best.

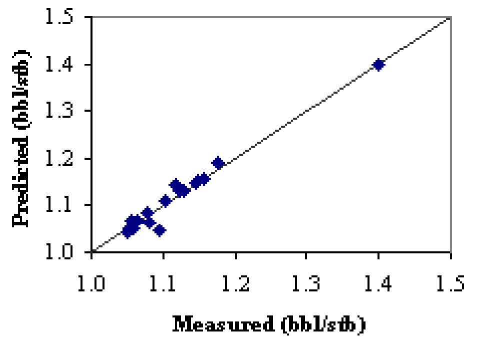

Fig. 5: Performance plot for bubblepoint oil FVF (API ≤ 21) (Al- Shammasi (2001)-4p)

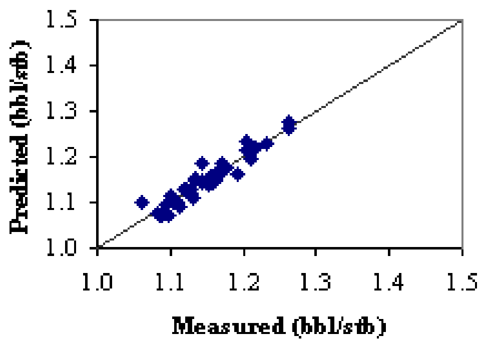

Fig. 6: Performance plot for bubblepoint oil FVF (21 > API≤ 26) (Omar and Todd (1993))

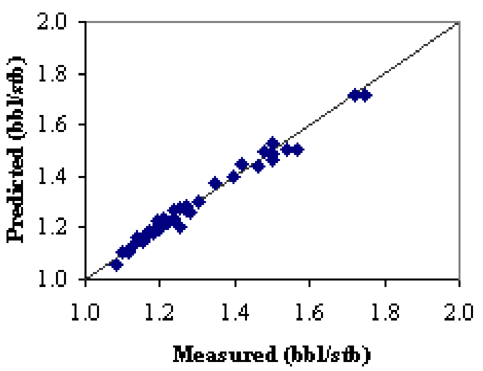

Fig. 7: Perfromance plot for bubblepoint oil FVF (26 > API ≤ 35) (Al-Marhoun (1988))

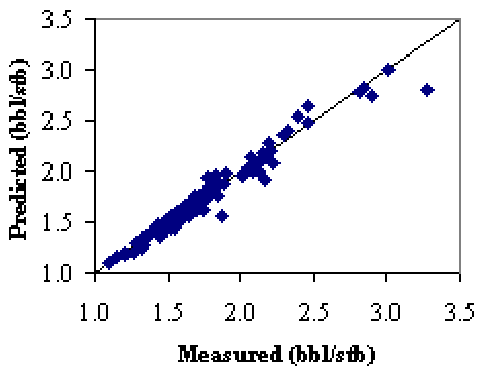

Fig. 8: Performance plot for bubblepoint oil FVF (35 > API≤ 45) (Hemmati and Kharrat (2007))

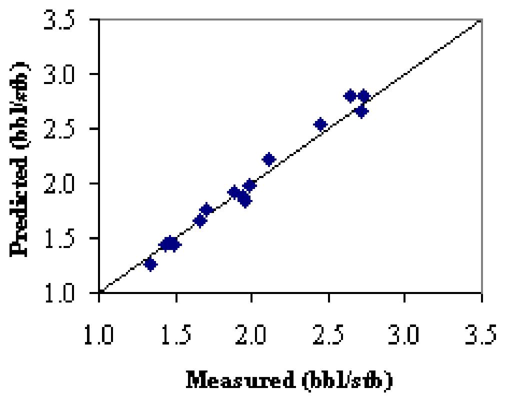

Fig. 9: Performance plot for bubblepoint oil FVF (API >445) (Hemmati and Kharrat (2007))

5.0 CONCLUSIONS

The performances of the existing oil formation volume factor correlations were assessed for the Niger Delta crude for 250 data sets obtained from different oil fields in the region. Both statistical and performance plots analyses were made. From the analysis Hemmati and Kharrat (2007) correlation of the Iranian crude is the best for the region among 18 other correlations examined worldwide with percent mean absolute relative error (E_a) of 1.9055 and correlation coefficient (r) of 0.9897. For oil API gravity ranges reliability analysis, the following correlations are recommended: Heavy oils (API≤ 21), Al-Shammasi (2001)-4p; Medium (21 API ≤ 26), Omar and Todd (1993); Blend (26 > API ≤ 35), Al-Marhoun (1988); Light (35 API ≤ 45), Hemmati and Kharrat (2007); and Very Light oils (API >45), Hemmati and Kharrat (2007). Therefore, these correlations are recommended for oil formation volume factor prediction for the Niger Delta crude in the absence of new or improved correlations.

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