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Evaluation of Viscosity Correlations for Niger Delta Gas Reservoirs

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Abstract-An accurate prediction of viscosity as a property of Natural gas is very important in the design and operation of fluid transportation, production, and processing. This paper presents the evaluation of gas viscosity correlations for the Niger Delta gas reservoirs. The correlations were evaluated using statistical analysis such as percentage mean relative error, percentage absolute error, standard deviation of the mean relative error and absolute error as well as the coefficient of correlation. These statistical parameters were combined into a single parameter called rank using Multiple Statistical Optimization Model (MULSON). The analysis was done using 319 data sets obtained from Niger Delta gas reservoirs. From the statistical analysis, Dempsey (1965) correlation ranked the best with the numerical value of 0.705 and also with the best performance plot. Charts of Viscosity against Pseudo Reduced Pressure and Temperature as well as Viscosity Ratio versus Pseudo Reduced Pressure and Temperature were developed based on Dempsey (1965) correlation for Niger Delta region. This work is valid for data range of $1.4 \geq T_r \geq 1.90$ and $0.2 \geq P_r \geq 10.80$.

Keywords- *viscosity, correlation, Rank, statistic*

I. INTRODUCTION

Natural gas as a global energy source has been gaining wider currency in recent years. The utilization of natural gas has become an interesting topic due to the significant increase of crude oil price and the growth of energy demand because of our lifestyle. Thus, natural gas is a promising energy alternative due to its availability and its similar property to petroleum. As the exploration of this resource continues, it is important to know the state of the reservoir. These reservoir fluid physical properties constitute an integral part of the data required for the comprehensive study of the reservoirs, accurate estimation of gas recovery and design of optimum production systems. The estimation of reserves and the design of the best depletion strategy are feasible only when realistic and reasonably accurate values of reservoir fluid properties are available. An accurate prediction of transport properties of natural gases is very important in the design and operation of fluid transportation, production, and processing. Viscosity is a fluid property that measures the resistance of a specific fluid; in this a hydrocarbon gas, to flow. Viscosity is an important property in the calculations related to fluid flow and estimation of other physical properties in liquid systems [1]. In the petroleum industry the unit used for the hydrocarbon gas viscosity is usually centipoises (cp), which is defined as g/100 sec-cm. Because of the difficulties of viscosity measurements in laboratory, this parameter can be estimated from empirical correlations with low deviation. Like all intensive properties, viscosity of a natural gas is completely described by the following function [2].

$$\mu_g = f\left(P, T, y\right) \tag{1}$$

Where μ_g is the viscosity of gas phase. The above relationship simply states that the viscosity is a function of pressure, temperature, and composition. Several well know correlations are used in petroleum industry to determine value of gas viscosity ([3]; [4]; [5]; [6])

[5] presented a semi empirical relationship for calculating the viscosity of natural gases. The authors expressed the gas viscosity in terms of the reservoir temperature, gas density, and the molecular weight of the gas. They reported 2% average absolute error (low pressures) and 4% average absolute error (high pressures) for hydrocarbon gases where the specific gravity is below 1.0. For gases of specific gravity above 1.0, their relation is purported to be “less accurate.” Their correlation can predict viscosity values with a standard deviation of 2.7% and a maximum deviation of 8.99%. The equation is also valid for 10< P< 8000 psia, 100 < T < 340 ^oF. and 0.9 < CO_2 < 3.2 mol.%.

[6] developed a New Correlation for calculating the Viscosity of Natural Gas under surface and reservoir condition. They obtained the correlation by the analysis of experimental pressure, volume and Temperature (PVT) Data of Gas associated with Nigerian Crude oil. He went further to compare equation formulated with experimental PVT viscosity and then tested the general validity of the new equation by using it to solve two problems for which solutions by the complex charts of [3] were available.

[3] developed graphical correlations for estimating the viscosity of natural gas as a function of temperature, pressure, and gas gravity. The computational procedure of applying the proposed correlations by Calculating the pseudo-critical

pressure, pseudo-critical temperature, and apparent molecular weight from the specific gravity or the composition of the natural gas. Corrections to these pseudocritical properties for the presence of the non-hydrocarbon gases (CO_2, N_2, and H_2S) should be made if they are present in concentrations greater than 5 mole percent. He then obtained the viscosity of the natural gas at one atmosphere and the temperature of interest.

[4] Modified [3] correlation and provided the above equation that allows computation of the corrected atmospheric viscosity without having to use a chart. The value of gas viscosity at atmospheric conditions is adjusted to reservoir conditions by obtaining a value of gas viscosity ratio from either of the charts of viscosity ratio against pseudo-reduced pressure or Viscosity ratio vs. pseudo-reduced temperature. [7] Updated [6] correlation to provide more accurate method for predicting the viscosity of pure component and light natural gas mixtures.

[8] Developed a viscosity prediction model for natural gases at high pressures and high temperatures. In his work, he showed that commercial gas viscosity measurement devices currently available suffer from a variety of problems and do not give reliable or repeatable results. However, at the extremely high pressures encountered in high pressure and high temperature reservoirs, the natural gases consist mainly of methane as the hydrocarbon constituent and some non-hydrocarbon impurities. Available viscosity values of methane were used in the development of a correlation for predicting the viscosities of naturally occurring petroleum gases at high pressures and high temperatures. [9] studied the state of the art – Natural Gases Viscosity under Reservoir Condition. In their work, they designed a spreadsheet program for calculating gas viscosity and using different gas viscosity correlations includes micros for solving z-factor. By this, they were able to eliminate many errors and save time by using the new charts and the spreadsheet program. Therefore, this paper aims at using Niger delta viscosity data to evaluate the applicability of existing models in estimating natural gas physical properties with the aid of an excel template and to develop a Viscosity chart with the best ranked model.

II. IIMETHODOLOGY

A. Data Description

The PVT analyses of 198 reservoir fluid samples from the Niger Delta region were considered for this study. The Data sets collated were obtained from conventional PVT reports that derived the various fluid properties. In the report, the reservoir fluid analysis for flashed liquid, flashed gas and recombination of reservoir fluid were considered for the various components for the validation of the data.

The various PVT reports were validated and the valid ones with depletion study were used to determine the effect depletion has on viscosity of the gas. The validation checks are aimed at establishing the consistency of the measured data and are unlikely to detect non-representative sample [10]. The ranges of the data gotten from PVT reports used for this study are presented in Table 1.

TABLE I. DATA RANGE FOR THE STUDY

Parameter	Minimum	Maximum	Mean
Reservoir Temperature (oR)	151.00	274.60	198.76
Reservoir Pressure (Psia)	130.00	7115	2615.77
Specific gravity	0.6056	1.1457	0.7356
Reduced Temperature	1.400	1.870	1.700
Reduced Pressure	0.200	10.80	3.87
Experimental Viscosity (Cp)	0.0112	0.0342	0.01883
Predicted Viscosity (Cp)	0.01023	0.0339	0.01835

B. Quantitative and Qualitative Screening

To compare the performance and accuracy of the new model to other empirical correlations, two forms of analyses were performed which are quantitative and qualitative screening. For quantitative screening method, statistical error analysis was used. The statistical parameters used for the assessment were percent mean relative error (E_r), percent mean absolute error (E_a), percent standard deviation relative (S_r), percent standard deviation absolute (S_a) and correlation coefficient (R).

For correlation comparison, a new approach of combining all the statistical parameters mentioned above (E_r, E_a, S_r, S_a and R) into a single comparable parameter called Rank was used [10]. The use of multiple combinations of statistical parameters in selecting the best correlation can be modeled as a constraint optimization problem with the function formulated as;

$$\mathbf{Min}\ Z_i = \sum_{j=1}^{m} S_{i,j} q_{1,j} \tag{2}$$

Subject to

$$\sum_{i=1}^{n} S_{i,j} \tag{3}$$

with

$$0 \leq S_{ij} \leq 1 \tag{4}$$

Where $S_{i,j}$ is the strength of the statistical parameter j of correlation i and q_{ij}, the statistical parameter j corresponding to correlation i. j=E_r, E_a, ….R^1 ,where R^1 = (1-R) and Z_i is the rank, RK (or weight) of the desired correlation. The optimization model outlined in equations 3 to 5 was adopted in a sensitivity analysis to obtain acceptable parameter strengths. The final acceptable parameter strengths so obtained for the quantitative screening are 0.4 for E_a, 0.2 for R, 0.15 for S_a, 0.15 for S_r, and 0.1 for E_r. Finally, equation 3 was used for the ranking. The correlation with the lowest rank was selected as the best correlation for that fluid property. It is necessary to mention that minimum values were expected to be best for all other statistical parameters adopted in this study except R, where a maximum value of 1 was expected. Since the optimization model (Equations 3 to 5) is of the minimizing sense a minimum value corresponding to R must be used. This minimum value was obtained in the form (1-R). This means the correlation that has the highest correlation coefficient (R) would have the minimum value in the form (1-R). In this form the parameter strength was also implemented to 1-R as a multiplier. Ranking of correlations was therefore made after the correlations had been evaluated against the available database.

For qualitative screening, performance plots were used. The performance plot is a graph of the predicted versus measured properties with a 45^o reference line to readily ascertain the correlation's fitness and accuracy. A perfect correlation would plot as a straight line with a slope of 45^o.

III. RESULTS AND DISCUSSION

A. *Correlation Evaluation*

The results of the evaluation of the four of the most widely used viscosity correlations as applied to Natural gas are presented. The correlations evaluated are: ([4]; [5]; [7]; [6]).

The results of the assessment as presented in Table 2 gave statistical accuracies for all the natural gas viscosity correlations examined. From the analysis [4] ranked the best with numerical value of 0.705 and [7] ranked the lowest with the value of 41.8941.

TABLE II. STATISTICAL PARAMETER FOR THE FOUR CORRELATION EVALUATED

CORRELATIONS	ARE%	AAE %	SDr	SDa	R	Rank (Rk)
Londono *et al* (2002)	78.9605	83.9668	0.4686	0.4686	0.6315	41.8941
Lee et al. (1966)	6.3074	8.7215	0.0557	0.0557	0.9668	4.1425
Ohirhian (2008)	-4.1147	5.4739	0.0536	0.0468	0.9797	0.8085
Dempsey (1965)	-2.2963	2.3285	0.0072	0.0072	0.9949	0.705

As a confirmatory test, the use of Cross plots were also considered. These are plots of experimental values of Natural gas viscosity against those estimated by the correlations as shown in Figures 1 to 4. A perfect correlation is that plot that gives a straight line with a slope of 45^o. Figure 4 gave an almost perfect slope of 45^o. [4] correlation gave the best cross plot.

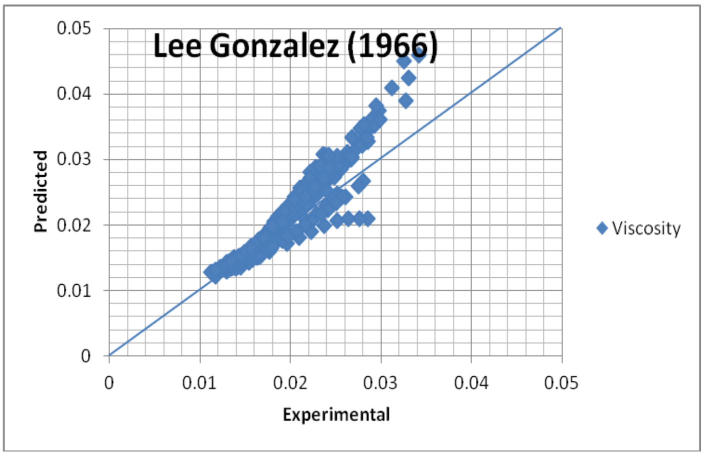

Figure 1. Cross plot of Experimental against Predicted Using [5] Correlation.

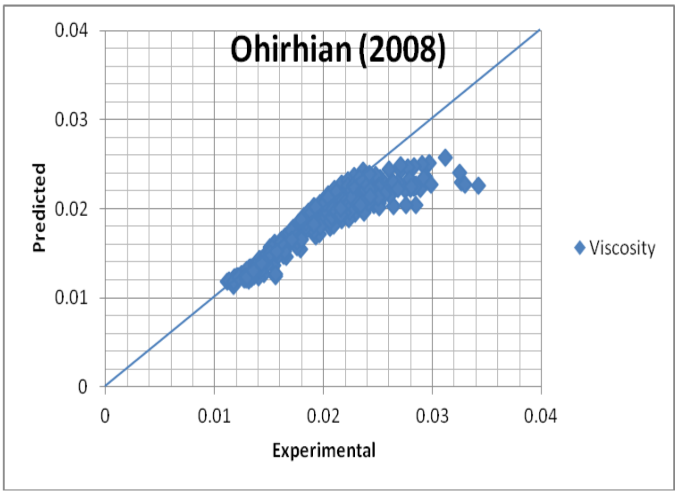

Figure 2. Cross plot of Experimental against Predicted Using [6] Correlation.

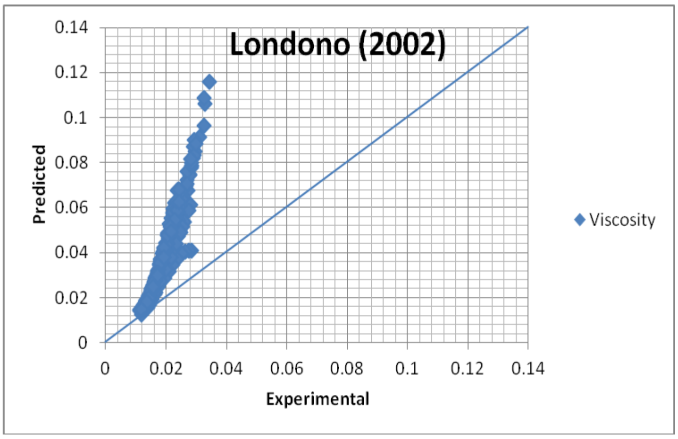

Figure 3. Cross plot of Experimental against Predicted Using [7] Correlation.

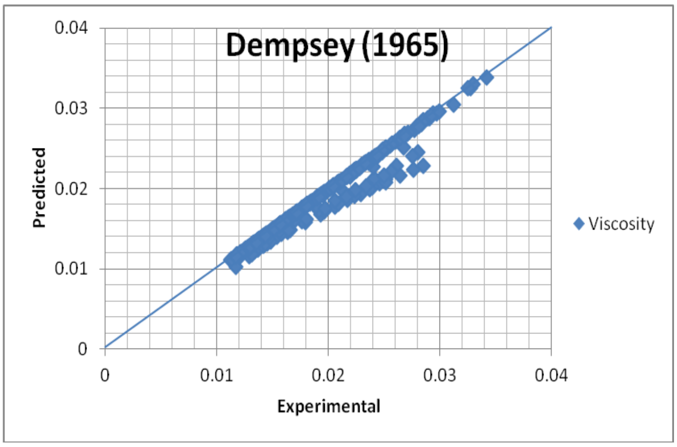

Figure 4. Cross plot of Experimental against Predicted Using [4] Correlation.

B. *Viscosity Chart Development*

From the validated database, a viscosity chart was developed as shown in Fig.s 5 to 8. In the computation of the natural gas viscosity with [11] and the revised [4] equations, an excel program was developed for easy analysis and to eliminate possible errors during calculation at any pressure and temperature values. The natural gas viscosity was calculated at one atmospheric pressure and impurities corrected using the [11] expression and finally for any pressure value by using the revised [4] equation.

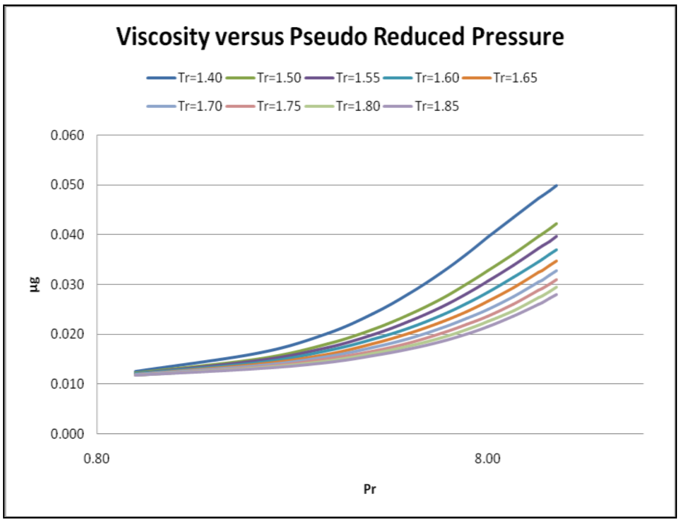

Figure 5. Viscosity versus Pseudo Reduced Pressure for Niger Delta region

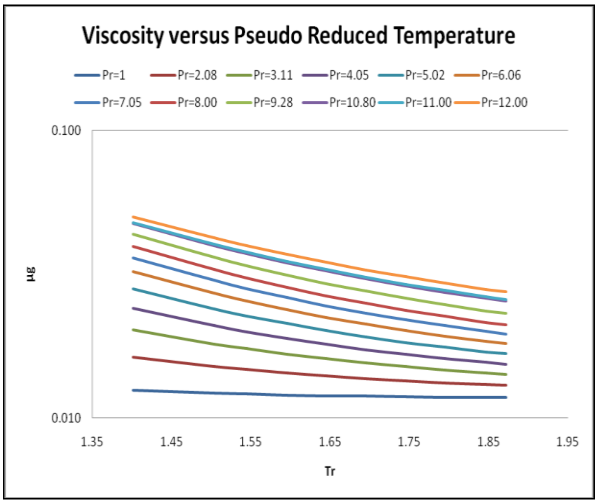

Figure 6. Viscosity versus Pseudo Reduced Temperature for Niger Delta Region.

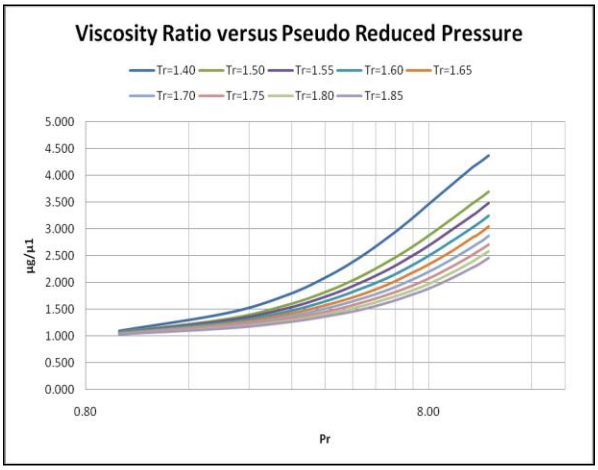

Figure 7. Viscosity Ratio versus Pseudo Reduced Pressure for Niger Delta region

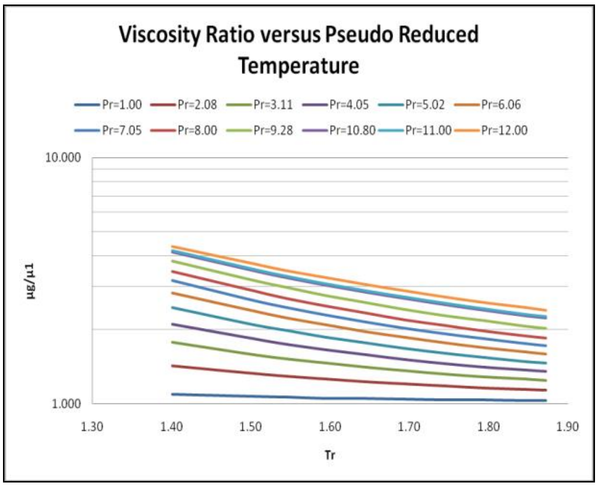

Figure 8. Viscosity Ratio versus Pseudo Temperature Niger for Delta region

C. *Viscosity Chart Evaluation*

This process involves entering the values of Reservoir pressure, Reservoir temperature and compositions in the overshadow cells, the critical temperature and pressure, and corrected critical temperature and pressure for impurities, reduced temperature and pressure are calculated.

By the help of this program, the natural gas viscosity at reservoir conditions can be calculated directly without going through the rigour of reading charts. These charts are compared with the conventional [3] viscosity chart to ascertain the reliability of the Niger Delta viscosity chart by using it to solve problems from standard textbooks and it proved impressive.

IV. CONCLUSION

The evaluation results of gas viscosity shows that [4] was the best correlation with mean relative error of -2.2963, absolute error of 2.3285, relative standard deviation of 2.52, absolute standard deviation of 0.0072, relative standard deviation of 0.0072, regression coefficient of 0.9949 and rank of 0.705 and had the best performance plot. [4], is therefore gas viscosity correlation recommended for Niger Delta region in the absence correlation developed for the region. Also, a viscosity chart was also developed for the Niger Delta from available gas database from the region. A plot of viscosity versus pseudo reduced pressure or pseudo reduced temperature yield a chart that mimics the conventional [3] chart and can be used for Niger Delta region. The chart is valid for data range of $1.4 \geq T_r \geq 1.90$ and $0.2 \geq P_r \geq 10.80$. Validating the developed viscosity chart with the [3] chart, showed that as long as the pseudo reduced properties lie within the range of the values plotted, the Niger Delta viscosity chart can be used reliably in place of the [3].

NOMENCLATURE

A = Sum of mole fraction of H_2S and CO_2
ARE = Average relative error, %
AAE = Average Absolute error, %
E_i = Relative deviation of estimated values from measured value, %
E_r = Relative Error,%
P = Pressure, Psia
P_c = Critical pressure, Psia
P_{ci} = individual critical pressure, psia
P_{pc}= Pseudo critical pressure, Psia
P'_c = corrected pseudo critical pressure, psia
P_{pr} =Pseudo reduced pressure, psia
R = Correlation Coefficient
Rk = Rank
SD = Standard deviation
SDa = Standard deviation of absolute error
SDr = Standard deviation of relative error
T= Temperature, ^oR
T_c = Critical temperature, ^oR
T_{ci} = Individual critical temperature, ^oR
T_{pr}= Pseudo reduced temperature
T'_c = Corrected pseudo critical temperature, ^oR
T_r= Reduced Temperature, ^oR
X_{est} = estimated value
X_{exp} = experimental value
y = Mole fraction
y_i = individual mole fraction
y_{CO2} = mole fraction of carbondioxide (CO_2)
y_{H2S} = Mole fraction of hydrogen sulphide (H_2S)
y_{N2} = Mole fraction of Nitrogen (N_2)
μ_1 = viscosity of the gas at atmospheric pressure and reservoir temperature, cp
μ_g = Gas Viscosity, cp
γ_g = Specific gravity of gas (air=1)
ε = Pseudo critical temperature adjustment parameter ^oR

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