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Improved Dead Oil Viscosity Model

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Abstract

This research work developed two new dead oil viscosity correlations: a general correlation and typical Niger Delta crude correlation, with large data range. The dead oil viscosity, affects the accuracy of viscosity models, especially when used in engineering problems involving fluid flow in porous media and particularly reservoir simulation. An accurate estimate of its value is therefore a very necessary concern. The models were developed using Linear and Non-Linear Multiple regression analysis. Multiple statistical assessments were employed to evaluate the accuracy of these models. The models are solved using Matlab and Microsoft Excel to obtain the General Model correlation coefficient of 0.870 and that of Typical Niger Delta Crude coefficient of correlation was 0.94. The models also gave better performance plots compared to existing models.

Keywords: viscosity, fluid flow, crude oil, Niger delta, dead oil viscosity, reservoir

Introduction

Real-time access to accurate data plays a very important role in the entirety of the oil and gas business. The dead oil viscosity, which is crude oil with no gas in solution, is a pre-requisite parameter in evaluating saturated viscosity and undersaturated viscosity. The determination of viscosity is required for evaluation of the pressure drop resulting from flow through porous media, tubing or pipelines. It's also a necessary property for ascertaining well productivity (Ikiensikimama, 2009).

The most common method for obtaining the viscosity of crude oil that contains dissolved gas is first to estimate the viscosity of the dead oil and then correct this value for dissolved gas. Dead oil viscosity is the viscosity of crude oil at atmospheric pressure (no gas in solution) and system temperature. This dead oil viscosity (μ_{od}) depends on API gravity (γ_{API}) of the stock-tank oil and the Reservoir temperature (T) (Beal, 1946).

Most research works have focused on determining the Saturated and Undersaturated oil viscosities with little emphasis on dead oil viscosity. This affects the accuracy of such viscosity models, especially when used in engineering problems involving fluid flow in porous media and particularly reservoir simulation.

Therefore, this work aimed at developing two new correlations: a General and Typical Niger Delta Crude dead oil viscosity correlation.

Literature Review

From a total of 753 values for dead-oil viscosity at and above 100^{o}F, Beal (1946) developed a graphical correlation for determining the viscosity of dead oil as a function of temperature and the API gravity of the crude. Standing (1977) expressed the proposed graphical correlation in a mathematical relationship.

Beggs and Robinson (1975) also developed a dead oil viscosity empirical correlation from analyzing 460 dead-oil viscosity measurements.

Glaso (1980) proposed a generalized mathematical relationship for computing dead oil viscosity. The relationship was developed from experimental measurements on 26 crude oil samples. The data used ranged from 50-300^{o}F for the system temperature and 20-48^o for the API gravity of the crude.

Ikiensikimama (2009) developed a dead oil viscosity correlation with 246 data sets from 250 laboratory PVT reports from the Niger Delta. He also compared his correlation with existing correlations with same data set.

All these scientists used crude from different locations and of different characteristics. Each study claimed that the resulting correlations could be applicable to the different regions of the world, including Nigerian crude (Niger Delta crude). However, these correlations are of limited accuracy because of the variation in the geological, lithological and petrophysical conditions of the operating environment. It is also true that crude oil composition and characteristics vary from region to region.

Therefore, the technique for developing these correlations is very important in order to predict accurately with little error margin the desired reservoir fluid property.

PVT Data for the Study

The PVT analyses of 250 reservoir fluid samples from 250 laboratory PVT reports from the Niger Delta region were validated and used for this study. For the dead oil viscosity, 245 experimental data sets were collated and used for the General Dead oil viscosity model with API gravity ranging from 14.87°API to 53.23°API and reservoir temperature ranging from 122.3°F to 264°F. 227 of the experimental data sets were used for the Typical Niger Delta crude dead oil viscosity model with API ranging from 21.14°API to 53.23°API and reservoir temperature ranging from 127°F to 264°F. The ranges for the entire data used are shown in Table 1. The data sets collated were obtained from conventional PVT reports that derived the various fluid properties from differential liberation processes.

Model Development

The empirical dead oil viscosity correlation used the general relationship developed by Beal (1946),

$$\mu_{od} = f_{(\gamma_{API},T)}$$

A power law was developed with the necessary requirement for convergence

$$f_{(a,b,k)} = k\gamma_{API}{}^{a}T^{b} - \mu_{od}$$

Where k, a and b are constant.

Next, we Linearize using Taylor series expansion,

$$f_{(a,b,k)} = k_o\gamma_{API}^{a_o}T^{b_o} - \mu_{od} + (a-a_o)\frac{\partial f}{\partial a}\bigg|_{a_o,b_o,k_o} + \frac{(a-a_o)^2}{2}\frac{\partial^2 f}{\partial a^2}\bigg|_{a_o,b_o,k_o} + (b-b_o)\frac{\partial f}{\partial b}\bigg|_{a_o,b_o,k_o} + \frac{(b-b_o)^2}{2}\frac{\partial^2 f}{\partial b^2}\bigg|_{a_o,b_o,k_o} + (k-k_o)\frac{\partial f}{\partial k}\bigg|_{a_o,b_o,k_o} + (k-k_o)\frac{\partial^2 f}{\partial k^2}\bigg|_{a_o,b_o,k_o} \cong 0$$

Further simplification,

$$\mu_{od} = k_o\gamma_{API}^{a_o}T^{b_o}\left[1 + \frac{(a-a_o)^2}{2}\left(\frac{2}{(a-a_o)} + ln\gamma_{API}\right)ln\gamma_{API} + \frac{(b-b_o)^2}{2}\left(\frac{2}{(b-b_o)} + lnT\right) + \frac{k-k_o}{k_o}\right]$$

The above model was used to determine the dead oil viscosity correlations for General and typical Niger delta dead oil prediction.

After series of iterations, the best convergence for the least square parameters was obtained using curve fitting tool in MATLAB (see Figure 1 and 2).

Therefore, the new dead oil viscosity correlations are stated below.

$$\mu_{od} = X_1(1 + X_2 ln\gamma_{API} + X_3 lnT)$$

For General Crude Analysis,

$$X_1 = \frac{47209999.96}{\gamma_{API}^{3.185}T^{0.176}}$$

$$X_2 = 0.045454028(ln\gamma_{API} - 6.644518272)$$

$$X_3 = 0.014721569(lnT - 11.67542323)$$

For Typical Niger Delta Crude Analysis,

$$X_1 = \frac{52270000T^{0.7327}}{\gamma_{API}^{4.655}}$$

$$X_2 = 0.049288568(ln\gamma_{API} - 6.369426752)$$

$$X_3 = 0.015379637(lnT - 11.40250855)$$

Quantitative Analysis

Multiple statistical parameters were adopted to ascertain the accuracy of the empirical models (see Table 3). The method and equations adopted here were obtained from Ikiensikimama (2009). The parameters analyzed include:

Percent Mean Relative Error (E_r): This measures the relative deviation from the experimental data, defined by,

$$E_r = \frac{1}{n}\sum_{i}^{n} E_i$$

Where E_i is the relative deviation of an estimated value from an experimental value

$$E_i = \left[\frac{(\mu_{od})_{exp} - (\mu_{od})_{est}}{(\mu_{od})_{exp}}\right] \times 100$$

$$i = 1,2, \ldots n$$

Percent Mean Absolute Relative Error (E_a): It measures the relative absolute deviation from the experimental values, defined by:

$$E_a = \frac{1}{n}\sum_{i=1}^{n} |E_i|$$

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

$$r = \sqrt{1 - \sum_{i=1}^{n}\left[(\mu_{od})_{exp} - (\mu_{od})_{ext}\right]_i^2 \Big/ \sum_{i=1}^{n}\left[(\mu_{od})_{exp} - \bar{\mu}_{od}\right]_i^2}$$

$$\bar{\mu}_{od} = \frac{1}{n}\sum_{i=1}^{n}\left[(P_{od})_{exp}\right]_i$$

Qualitative Analysis

Performance plot (cross plot) of the Predicted vs. Measured properties with a reference line of 45^o was used to ascertain the correlations fitness and accuracy. A perfect correlation would plot as a straight line with a 45^o slope. (see Figure 3 and Figure 4).

Results and Discussion

Calculations of the various PVT properties were made with the aforementioned statistical parameters and the results compared with Oyedeko and Ulaeto (2011), Ikiensikimama (2009), Beal (1946), Glaso (1980), Egboga and Jack (1990), Kartoatmodjo and Schmidt (1991), Petrosky and Farshad (1995), Beggs and Robinson (1975). (see Table 2 and Table 3).

General Dead Oil Viscosity Model

A correlation coefficient of 0.87 was obtained with $E_r = -9.60\ and\ E_a = 34.23$ for the General Analysis. The result indicated the best model for this study.

Typical Niger Delta Crude

A correlation coefficient of 0.944 was obtained with $E_r = -11.79\ and\ E_a = 23.81$ for the General Analysis. The result indicated the best model for this study. Ikiensikimama (2009) also used crude oil samples from different regions of the Niger delta. This accounts for the slightly better result for the $E_r = 11.21\ and\ E_a = 23.17$. However, This Study obtained a better correlation coefficient of 0.944 as compared to 0.936 by Ikiensikimama.

Conclusion

The paper presented the development of two new dead oil viscosity correlations: for General crude oil and Typical Niger Delta crude oil. The equations were developed starting with a representative Power Series, linearized using Taylor series and convergence determined using the curved fitting tool in MATLAB. Both quantitative and qualitative assessments were used to handle the comparison between the developed correlations and the best existing correlations. The new correlation performed better than existing dead oil viscosity correlation for the Niger Delta.

Acknowledgment

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Nomenclature

a,b,k coefficient in correlation equations

$(\mu_{od})_{exp}$ measured dead oil viscosity

$(\mu_{od})_{est}$ predicted dead oil viscosity

$\bar{\mu}_{od}$ mean dead oil viscosity

n number of experiments

E_a Percent Mean Absolute Error

E_r Percent Mean Relative Error

T Reservoir Temperature

Abbreviations

API American Petroleum Institute

DOV Dead Oil Viscosity

PVT Pressure-Volume-Temperature

References

1. Beal, C. (1946): "The Viscosity of Air, Water, Natural Gas, Crude oil and Its Associated Gases at Oil Field Temperature and Pressures," Oil and Gas Property Evaluation and Reserve Estimates, Reprint Series, SPE, Richardson, TX, 3, 114-27
2. Beggs, H. D. and Robinson, J. R. (1975): "Estimating the Viscosity of Crude Oil Systems," JPT (Sept.) 1140-41.
3. Dindoruk, B., and Christman, P. G. (2004): "PVT Properties and Viscosity Correlations for Gulf of Mexico Oils," SPE Reservoir Engineering, (Dec.), pp 427 – 437.
4. Glaso, O. (1980): "Generalized Pressure-Volume Temperature Correlations" JPT, May, 785-795.
5. Egbogah, E. O and Jack, T. Ng (1990): "An Improved Temperature-Viscosity Correlation for crude oil systems," Journal of Petroleum Science and Engineering. 5, 197-200.
6. Ikiensikimama S. S and Ogboja O. (2009): "Evaluation of Empirically Derived Oil Viscosity Correlations for the Niger Delta Crude" Journal of Petroleum Science and Engineering, 69, 214 - 218.
7. Ikiensikimama, S. S. (2009): "Reservoir Fluid Property Correlations", pp 1-86
8. Kartoatmodjo, Trijana and Schmidt, Zelimie (1991): "New Correlations for Crude Oil Physical Properties," SPE paper 23556 (Unsolicited)
9. Kreyszig (2006): "Advanced Engineering Mathematics", 9th Edition
10. Oyedeko K. F. and Ulaeto U. W. (2011): "Predicting the Dead Oil Viscosity of Reservoir Fluids: A Case Study of the Niger Delta", Journal of Energy Technology and Policy, Vol.3, No. 13, 2013.
11. Palm, W. J. (1998) Introduction to Matlab 6 for Engineers, McGraw-Hill Publishing Co. Inc., New York.
12. Petrosky, J. and Farshad, F. (1995): "Viscosity Correlation for the Gulf of Mexico Oils." Paper SPE 29468 prepared at the 1995 SPE Production Operations Symposium held in Oklahoma City, OK, U.S.A., April 2 – 4.
13. Standing, M. B. (1977): "Volumetric and Phase Behavior of Oil Field Hydrocarbon Systems", Dallas: Society of Petroleum Engineers, pp. 125-126.

Appendix

1. Beal (1946) (USA)

$$\mu_{od} = \left[0.32 + \left(\frac{1.8x10^7}{API^{4.53}}\right)\right]\left(\frac{360}{T+200}\right)^a$$

$$a = 10^{\left[0.43+\left(\frac{8.33}{API}\right)\right]}$$

2. Beggs and Robinson (1975) (UNKNOWN)

$$\mu_{od} = 10^X - 1$$

where $X = YT^{1.163}$, $Y = 10^Z$ and $Z = 3.0324 - 0.020023API$

3. Glaso (1980) (NORTH SEA)

$$\mu_{od} = (3.14x10^{10})\ T^{-3.444}\ (logAPI)[^{10.313(logT) - 36.447]}$$

4. Kartoatmodjo and Schmidt (1994) (DATA BANK)

$$\mu_{od} = 16.0x10^8 T^{-2.8177}\ (log(API))^{5.7620(log(T)) - 26.9718}$$

5. Petrosky and Farshad (1995) (GULF OF MEXICO)

$$\mu_{od} = 2.3511\ x\ 10^7 .\ T^{-2.10255} .\ [log\ API]^X$$

where $X = 4.59388log(T) - 22.82792$

6. Hossain (2005)

$$\mu_{od} = 10^{(-0.71523API\ +\ 22.13766)}T^{(0.269024API\ -\ 8.268047)}$$

7. Egbogah and Jack (1990) (AFRICA)

$$\mu_{od} = 10^d - 1$$

Where

$$d = 10^{[1.8653 - 0.02508API - 0.5644\log(T)]}$$

8. Ikiensikimama (2009) (NIGERIA)

$$\mu_{od} = 10^d - 1$$

$$d = 10^{[X_1 - X_2\gamma_{API} - X_3\log(T)]}$$

Where X1=2.09301856111249; X2=0.0350734724360959; X3=0.606384327643813;

X4=0.698084943686395

9. Labedi (1992) (AFRICA)

$$\mu_{od} = \frac{10^{9.224}}{API^{4.7018}T^{0.6789}}$$

10. Naseri (2005) (Middle East)

$$\mu_{od} = 10^{11.2699 - 4.298\log(\gamma_{API}) - 2.052\log T}$$

11. Oyedeko & Ulaeto (2011) (NIGERIA)

$$\mu_{od} = 10^{7.4173}.\gamma_{API}^{-2.9986}.T^{-1.1226}$$

Table 1: Entire Data Range for The Study		
Parameter	Minimum	Maximum
Tank-oil gravity (^{o}API)	14.87	53.23
Bubblepoint oil FVF (rb/stb)	1.051	3.2705
Bubblepoint pressure (psia)	67	6560
Pressure below bubblepoint (psia)	25	6015
Bubblepoint solution GOR (scf/stb)	19.0	2948.8
Reservoir temperature (^{o}F)	122.3	264.0
Average surface gas gravity (avg.γ_g)	0.564	1.294
Undersaturated oil viscosity (cp)	0.137	181.040
Bubblepoint viscosity (cp)	0.132	82.660
Dead oil viscosity (cp)	0.580	167.630

Table 2: Statistical Accuracy For General Dead Oil Viscosity Data			
Author	E_r	E_a	**r**
This Study	-9.60	34.24	0.870
Oyedeko & Ulaeto (2011)	-6.678	25.554	0.804
Ikiensikimama (2009)	7.297	26.374	0.864
Beal (1947)	-32.279	57.499	0.860
Glaso (1980)	-27.487	47.910	0.864
Egbogah & Jack (1990)	-46.722	50.556	0.8350
Kartoatmodjo & Schmidt (1991)	-24.046	53.289	0.865
Petrosky & Farshad (1995)	-27.207	41.110	0.860
Dindoruk & Christman (2004)	-20.057	37.854	0.860
Beggs & Robinson (1975)	-44.866	50.045	0.825

Table 3: Statistical Accuracy for Typical Niger DeltaCrude Dead Oil Viscosity			
Author	E_r	E_a	**r**
This Study	-11.790	21.634	0.944
Oyedeko & Ulaeto (2011)	-6.659	21.535	0.919
Ikiensikimama (2009)	11.215	23.172	0.936
Beal (1947)	-21.636	48.840	0.943
Glaso (1980)	-18.445	40.277	0.941
Egbogah & Jack (1990)	-42.708	47.368	0.935
Kartoatmodjo & Schmidt (1991)	-13.623	45.004	0.941
Petrosky & Farshad (1995)	-21.241	34.662	0.934
Beggs & Robinson (1975)	-44.162	48.617	0.933

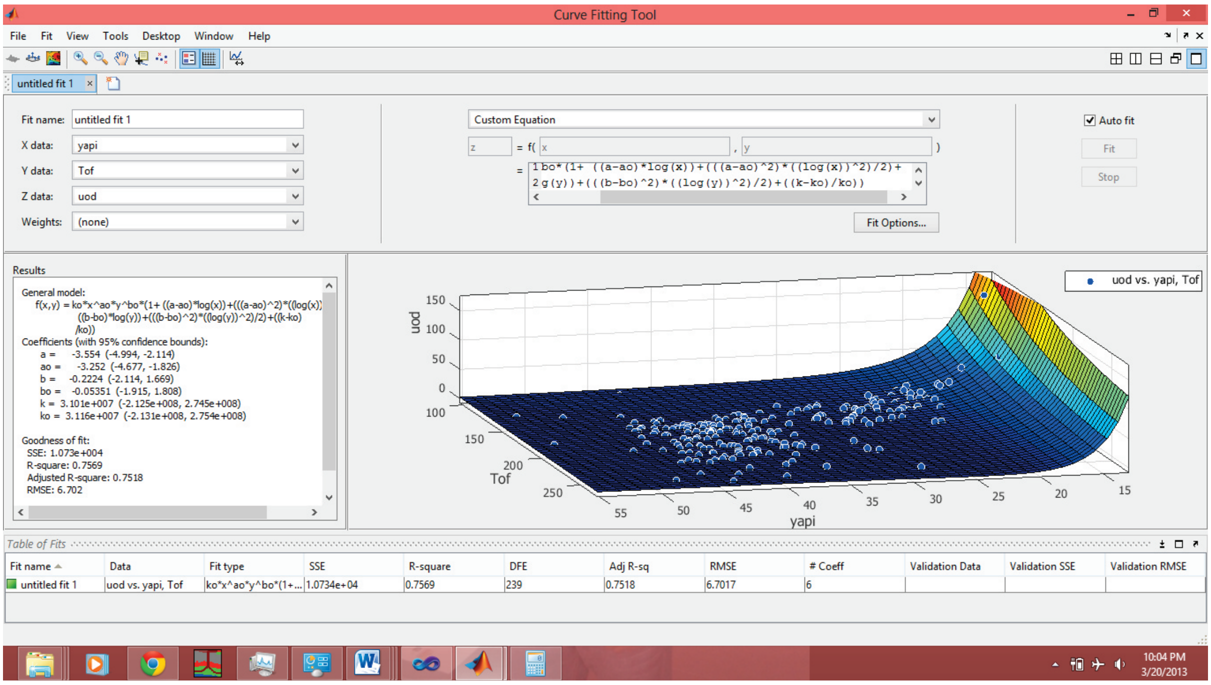

Figure 1: MATLAB Simulation for new General Dead Oil Viscosity

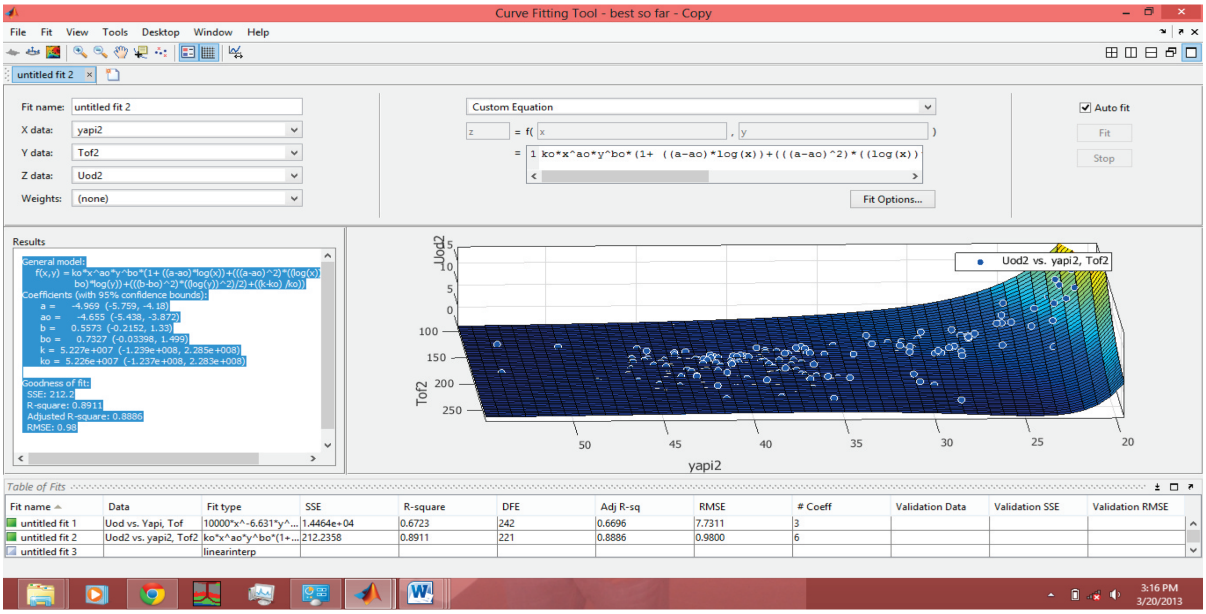

Figure 2: MATLAB Simulation for new Typical Niger Delta Crude Dead Oil Viscosity Correlation

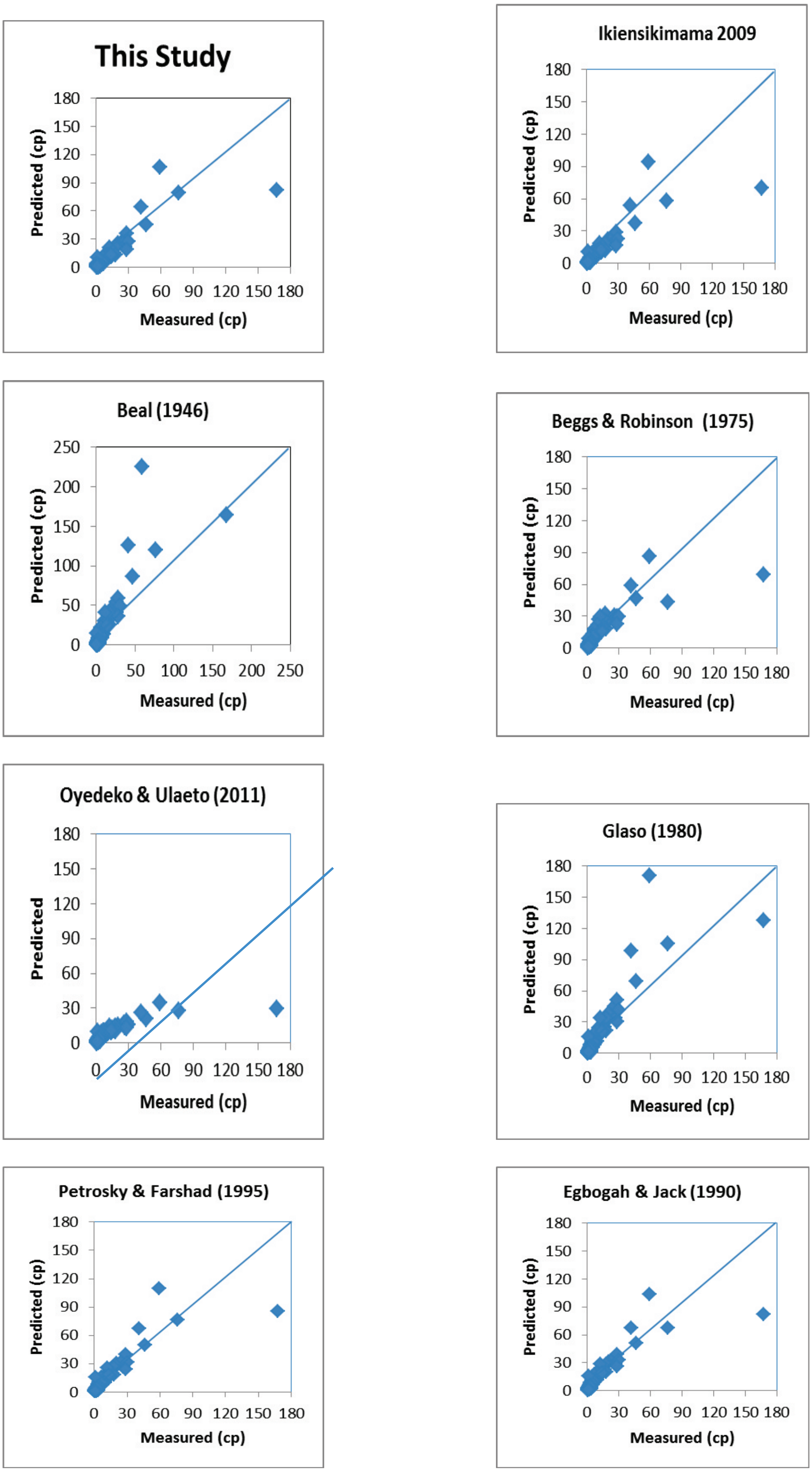

Figure 3: Performance Plots for General Dead

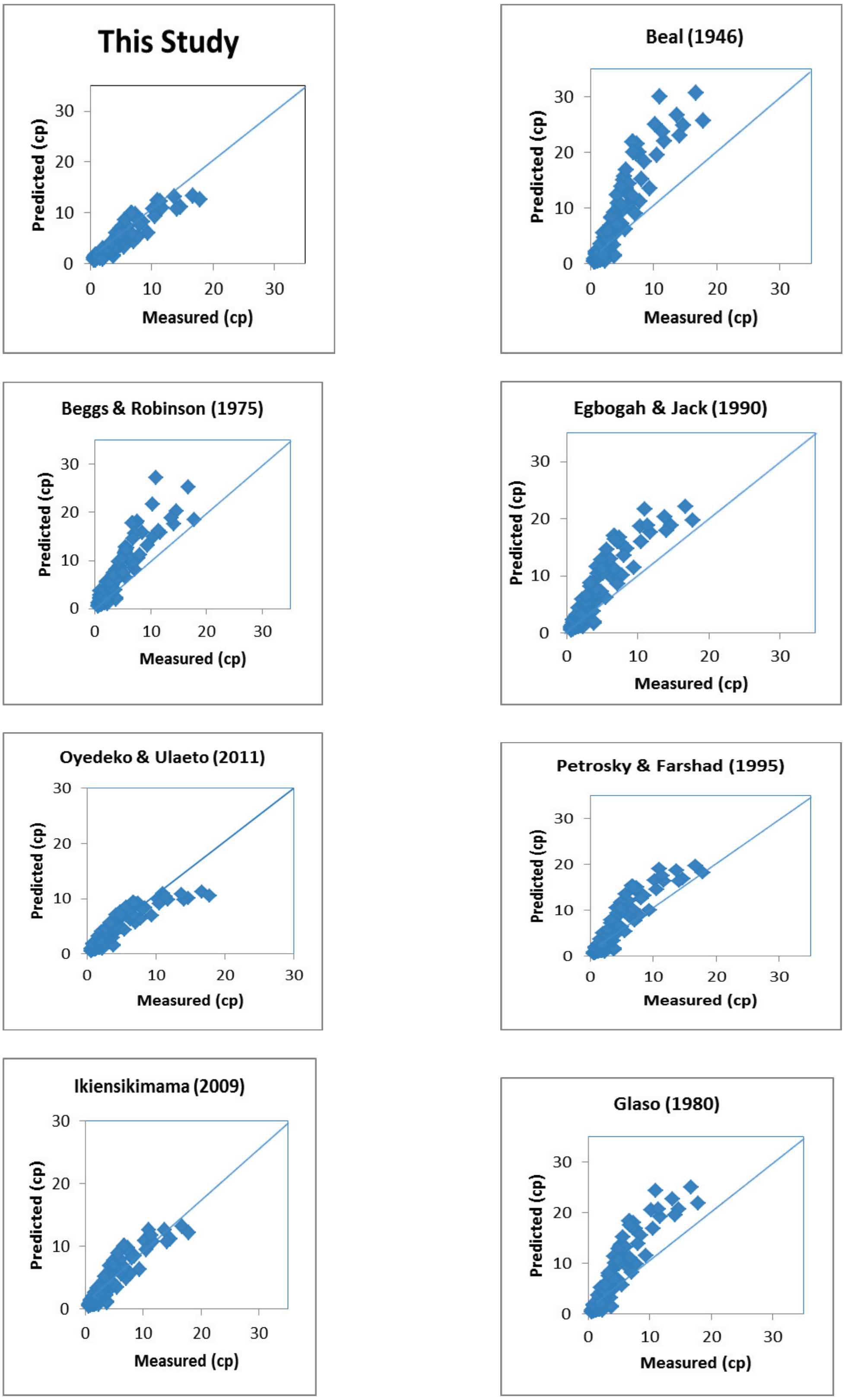

Figure 4: Performance Plots for Typical Niger Delta Crude Dead Oil