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Study on Viscosity Correlations for Iraqi Crude Oils

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Abstract:

One of the important properties in identification of reservoir performance is viscosity which is defined as the resistance to internal friction of the molecules of the fluid, and friction created as a result of attraction forces between the fluid molecules which resist the fluid flow and restrict it. It is necessary for running simulation, or(building reservoir model)fluid flow through porous media and pipelines, well testing and design of production equipment.

The factors that affect the fluid viscosity are: -

- Gas Oil Ratio.
- Reservoir Pressure and Temperature.
- API-gravity.

There are empirical relationships for estimating viscosity above, at, and below the bubble point pressure. In this study, a new correlations are suggested by correlating the experimentally PVT data for Iraqi crude oils from North, Middle, and South oil fields. One hundred and eleven laboratory tests were used to formulate these new empirical correlations.

A final correlations (above, at, and below the bubble point) have been established by nonlinear regression technique, and the correlations were tested by statistical error analysis results. Good agreement was shown between the experimental viscosities and calculated viscosities using new correlations.

Introduction

Viscosity is defined as the measure of resistance to fluid flow that is necessary for reservoir studies. A lot of correlations for estimating crude oil viscosity for above, at, and below the bubble point are shown in table (1) as functions, year and geographical locations. These correlations are functions of measurable PVT properties (GOR, oil API gravity, gas gravity, reservoir pressure and temperature.

There are empirical equations for estimating viscosity above, at, and below the bubble point pressure.

Such as:

- The Beggs and Robinson [3,5] (1975) are generally applicable correlation equations for dead, gas- saturated and under saturated oil viscosity for North America.

- Labidi [2,3] (1982) correlation for Libya, Nigeria, and Angola oils to estimate oil viscosity for dead, gas- saturated and under saturated, and these equations are a functions of temperatures, oil gravity, and bubble point pressure.

- Khahn and Marhum[2,3,6](1987) correlations contain equations for estimating oil viscosity at, above and below the bubble point for Saudi Arabian oils; the correlation is a function of gas gravity, relative temperature, and gas oil ratio.

- The Petrosky and Farshad [1](1990) correlations contain equations for estimating oil viscosity above, at and below the bubble point for Gulf of Mexico oils.

- The Kartoatmodjo (1991) correlation as a function of oil gravity, temperature and gas oil ratio for estimating oil viscosity above, at, and below the bubble point for Mediterranean Basin and Africa [1].

In this study, New correlations are suggested by correlating the experimentally PVT data of Iraqi crude oils from North , Middle ,and South oil fields that were obtained for above, at, and below the bubble point pressure.

PVT Data

The PVT analyses of (111) bottom hole fluid sample (experimentally data) for Iraqi crude oils from North, Middle, and south oil fields to obtain the ranges of the data used are shown in table (2).

Viscosity Correlations

Crude oil viscosity can be classified into three regions:

-Oil viscosity at bubble point pressure

-Oil viscosity above the bubble point pressure

- Oil viscosity below the bubble point pressure (dead oil viscosity)

The viscosities are functions of readily measurable PVT properties as shown below :

$$\mu - f(Rs , T , \gamma_g , \gamma_o , Pb)$$

μ - Viscosity

Pb - Bubble Point pressure,

Rs - Solution Gas Oil Ratio,

γ_g - Dissolved Gas Gravity (air = 1),

γ_o- Stock – Tank Oil Gravity (water = 1),

T - Reservoir Temperature

The experimentally data (111) from PVT analyses of different Iraqi oil fields were used to determine viscosities (above, at, and below the bubble point) by using known world empirical equations as shown in the appendix.

The nonlinear regression technique has been used to develop the new viscosity correlations for three regimes as shown in these equations.

- **Oil Viscosity Correlation At Bubble Point Pressure :**

$$\mu = -0.06203 + 0.9833 \times F + 0.0003668 \times F^{2} \ldots\ldots\ldots\ldots\ldots(1)$$

Where:

$$F = \left\{0.2001 + 0.8428 \times 10^{(-0.000845 \times Rs)}\right\} \times \mu od \left\{0.43 + 0.5165 \times 10^{(-0.00081 \times Rs)}\right\}$$

- **Oil Viscosity Above The Bubble Point Pressure:**

$$\mu o = 0.863782 \times (1.00081 \times \mu_{ob} + 0.001127 \times (P - Pb) \times (-0.006517 \times \mu_{ob}^{1.8148} + 0.038 \times \mu_{ob}^{1.590}) \ldots\ldots\ldots(2).$$

Where:

μob :Oil viscosity at bubble point pressure

- **Oil viscosity below the bubble point**

$$\mu_{od} = 0.6049 \times (16 \times 10^{8} \times T^{(-2.8177)} \left[\log(API)\right]^{(5.7526 \times \log(T) - 26.9718)}) \ldots\ldots\ldots\ldots(3)$$

Where :

T - is temperature (in ^{o}F)

API - Gravity of Oil @ 60 ^{o} F

Then comparing these correlations by statistical error analysis

Comparison of Correlation by Statistical Analysis

The average percent relative error, average absolute percent relative error, minimum / maximum absolute percent relative error, standard deviation, correlation coefficient and Tan θ have been computed as shown below. The correlations empirical equations (Kartomtmodjo, Petrosky & Farshad, Begg & Robinson, Kahn & Marhuon and Labedi) and new correlations (above ,at, and below the bubble point) with the experimental viscosity are shown in tables (3-5) and figures (1-3).

Statistical Error Analysis Results	Viscosity above Pb	Viscosity @ Pb	Viscosity of Dead Oil
Standard Deviation	19.91	19.36	34.24
Correlation Coefficients(r)	0.957	0.979	0.868
Tan θ	1.0	1	1

Conclusions

1 -The non linear regression technique has been used to develop new viscosity correlations for Iraqi crude oil above, at, and below the bubble point pressure.

2 - Comparison the known world empirical equations (Kartomtmodjo, Petrosky & Farshad , Begg & Robinson , Kahn & Marhuon and Labedi) with experimental viscosities and correlation tested by statistical error analysis are shown below:

Statistical Error Analysis Results	Viscosity above Pb	Viscosity @ Pb	Viscosity of Dead Oil
Standard Deviation	19.91	19.36	34.24
Correlation Coefficients(r)	0.957	0.979	0.868
Tan θ	1.0	1	1

3- The new correlation has been made by non linear regression technique and tested by statistical error analysis

4 – This study showed that Kartomtmodjocorrelation was more applicable to determine viscosity world for Iraqi oil after this new correlation.

Nomenclature

Pb -Bubble –Point Pressure (psia)

P -Reservoir Pressure (psia)

Rs - Solution Gas Oil Ratio (SCF/STB)

γo - Oil Relative Density (water=1)

γg - Gas Relative Density (air =1)

API - Gravity of Oil @ 60 ^{o} F

μ_{ob}- Oil Viscosity @ Bubble Point (CP)

μ_{od}- Dead Oil Viscosity (CP)

Er -Average Percent Relative Error

Ei - Percent Relative Error

AARE - Average Absolute Relative Error

Emax - Maximum Absolute Relative Error

Emin -Minimum Absolute Relative Error

r - Correlation Coefficient

n - Number of Independent Variables

n_d- Number of data points

exp - Experimental

Ext - Estimated from Correlation

T - Temperature (in ^{o}F)

Ə r - Relative Temperature = (T+459.69)/459.69) (T in ^{o}F)

Statistical Error Analysis Equations

1- Average Percent Relative Error (Er)

$$Er = \frac{1}{n} \Sigma Ei$$

Where Ei =Relative deviation %

$$Ei = \{(Xest - X\exp)/ X\exp\} \times 100$$

2- Average Absolute Percent Relative Error (Ea)

$$Ea = \frac{1}{n} \sum |Ei|$$

3- Minimum/Maximum Absolute Relative Error

$$E_{nim} = \min|Ei|$$
$$E_{\max} = \max|Ei|$$

4- Standard deviation

$$S = \left[1/(n_d - n - 1) \right] \sum Ei^2$$

5-Correlation Coefficient (r):

$$r = 1 - \left\{ \sum (Xest - X\exp)^2 / \sum (X\exp - Y)^2 \right\}$$

Where

$$Y = \frac{1}{n} \sum X\exp$$

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Table (1)Viscosity Correlations with Geographic Locations

Viscosity Correlations	Year	Functions	Geographic Locations
Kartoatmodjo	1991	API Oil Gravity Temperature (°F) GOR=Total Gas-Oil Ratio (SCF/STB)	Mediterranean Basin, Africa
Petrosky & Farshad	1990	API , Temp.(°F) GOR=Total Gas-Oil Ratio (SCF/STB)	Gulf of Mexico
Beggs & Robinson	1975	Temp.(°F) GOR=Total Gas-Oil Ratio (SCF/STB)	North America
Kahn & Marhuon	1987	γ_g = Gas Relative θ = Relative Temperature (°F) GOR =Total Gas-Oil Ratio (SCF/STB)	Saudi Arabia
Labidi	1982	Temperature (°F) API Oil Gravity Bubble Point Pressure (Psia)	Libya , Nigeria , Angola

Table(2) Range of Bubble Point Pressure, Solution GOR, and Viscosity @ BP of PVT Data (Experiment)

No. of Points	*PVT Property*	*Minimum*	*Maximum*
111	Bubble Point Pressure (Psia)	415	4253
111	Solution GOR (SCF/STB)	169.012	1452.601
111	Viscosity (CP) @Pb	0.21	273.51
111	Temperature (^{o} F)	104	250
111	Stock tank oil gravity , ^{o} API	14.74	37.4
111	Gas Gravity (air =1)	0.6743	1.9687

Table (3) ***Summary of Statistical Measures for Viscosity Above Bubble Point Pressure Correlations***

Parametters	This Study	Kartomtmodjo	Petrosky & Farshad	Begg& Robinson	Kahn & Marhuon	Labedi
Average Relative Error %	-3.99	4.866	102.653	-28.42	-1.121	326.778
Average Absolute Relative Error %	17.185	18.35	103.731	31.733	63.196	327.6
Minimum Absolute Average Relative Error %	0.151	0.088	1.052	0.228	4.44	45.71
Maximum Absolute Average Relative Error %	34.92	47.675	407.839	78.655	384.383	734.18
Standard Deviation %	19.91	22.629	133.897	37.67	87.18	371.448
Correlation Coefficient	0.957	0.944	0.75	0.323	-2.503	0.276
Tan (ə)	1.0	1.1	1.15	0.39	0.26	4

Table (4) ***Summary of Statistical Measures for Viscosity at Bubble Point Pressure Correlations***

Parametters	This Study (1a)	Kartomtmodjo (2a)	Petrosky & Farshad (3a)	Begg& Robinson (4a)	Kahn & Marhuon (5a)	Labedi (6a)
Average Relative Error %	-3.45	6.17	78.678	59.688	124.152	-326.379
Average Absolute Relative Error %	16.43	17.737	79.136	104.078	124.163	327.146
Minimum Absolute Average Relative Error %	0.046	0.698	0.154	0.193	0.631	0..131
Maximum Absolute Average Relative Error %	35.204	45.47	367.85	778.774	629.29	6.987
Standard Deviation %	19.36	21.855	98.94	191.256	162.04	370.575
Correlation Coefficient	0.979	0.934	0.818	-0.267	-3.014	-23.097
Tan (ə)	1	1.1	1.178	0.428	3.258	4.177

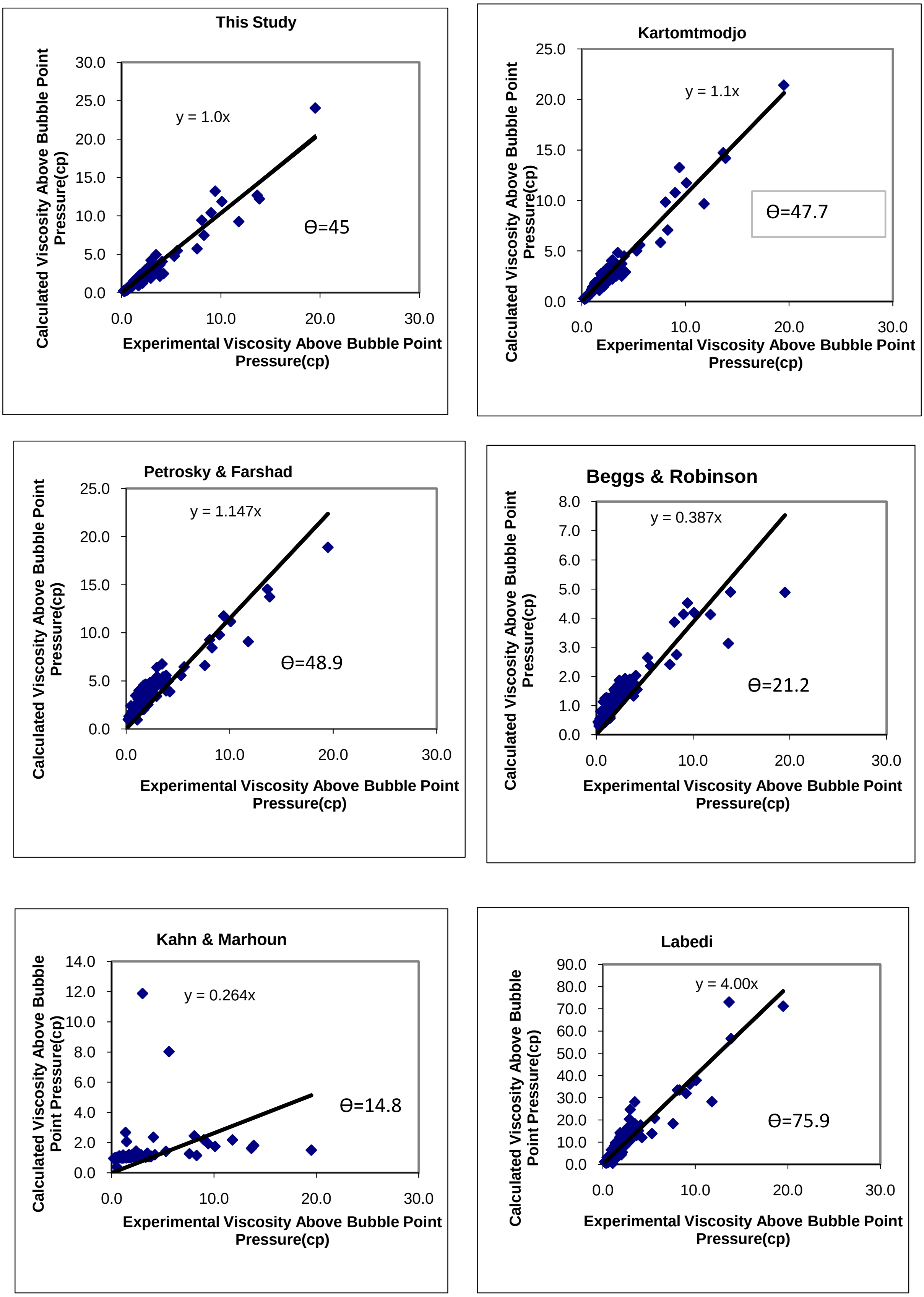

Fig (1)

Comparison of Viscosity(cp) @ Bubble Point by Correlation From This Study,Kartomtmodjo, Petrosky & Farshad Begg& Robinson , Kahn & Marhuon,Labedi

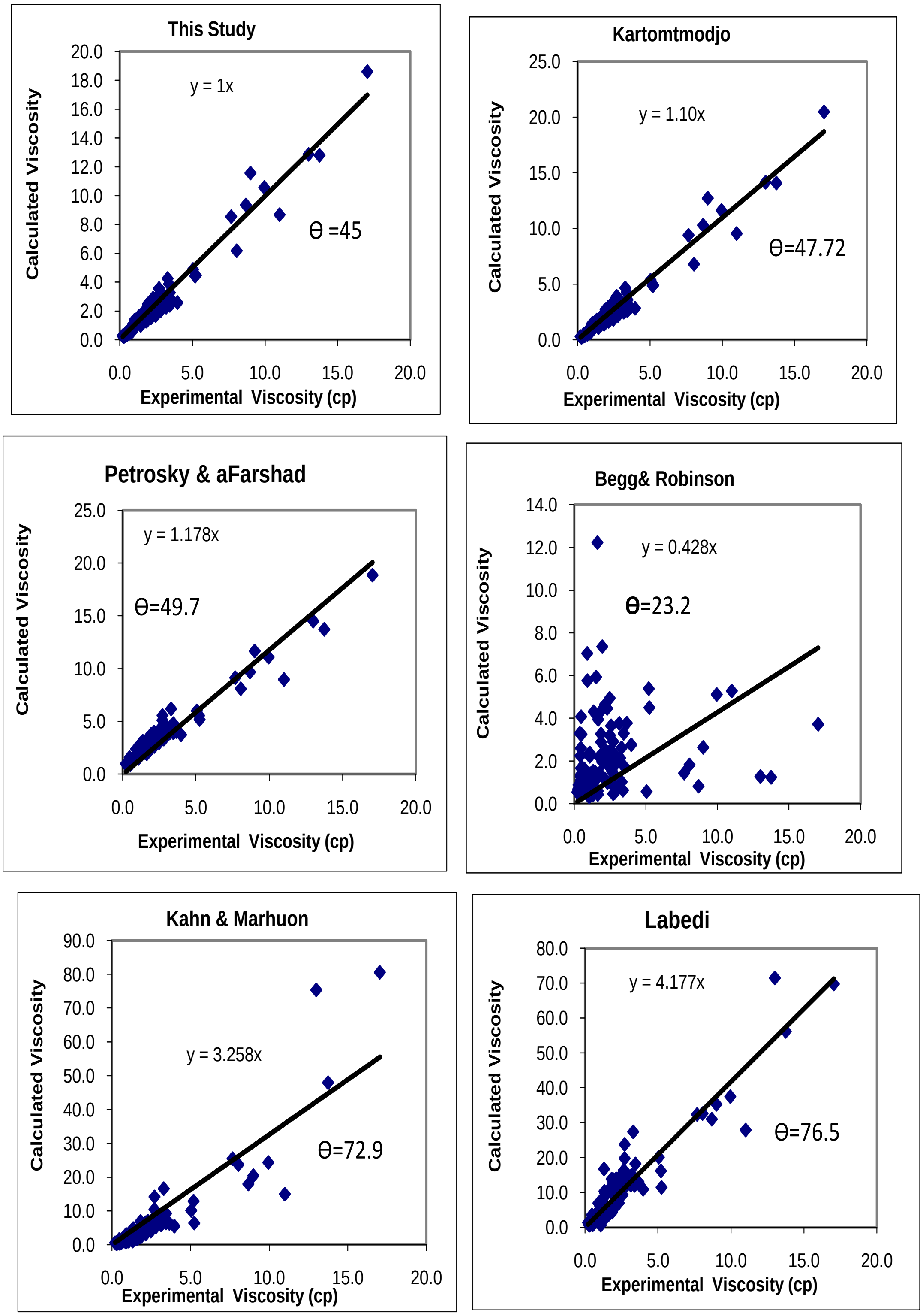

Fig (2)

Comparsion of Viscosity(cp) Above Bubble Point by Correlation From This Study,Kartomtmodjo, Petrosky & Farshad Begg& Robinson , Kahn & Marhuon,Labedi

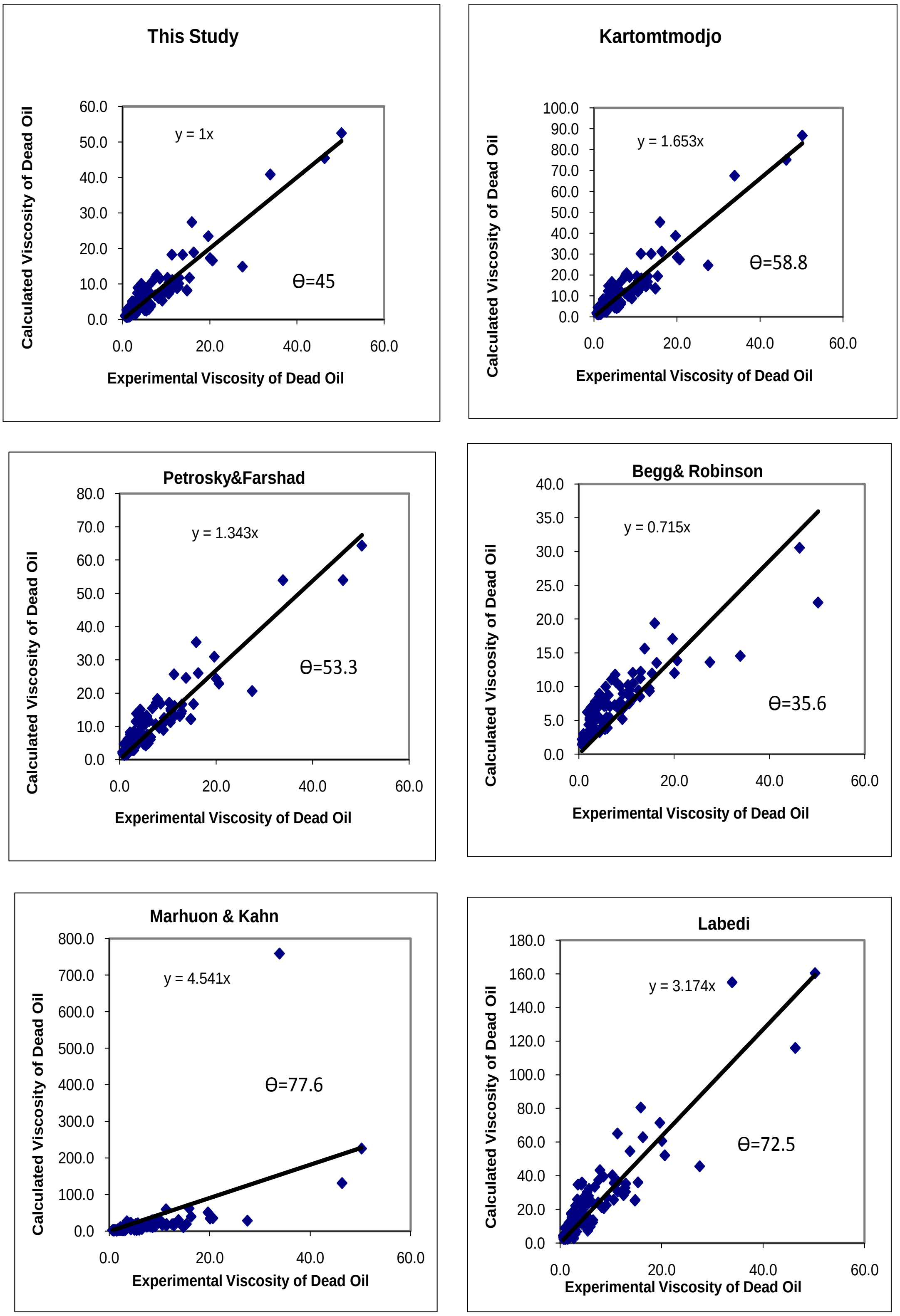

Fig (3)

Comparsion of Viscosity(cp) of Dead Oil &Deviation in Percent of Estimated by Correlation From This Study,Kartomtmodjo

Appendix

A – Viscosity @ Bubble Point Oil Correlations

Kartomtmodjo for Mediterranean Basin, Africa (1991)

$$\mu = -0.06821 + 0.9824 \times F + 0.0004034 \times F^{2} \quad \ldots\ldots\ldots\ldots$$

Where

$$F = \left\{0.2001 + 0.8428 \times 10^{(-0.000845 x Rs)}\right\} \times \mu od \left\{0.43 + 0.5165 \times 10^{(-0.00081 x Rs)}\right\}$$

Petrosky &Farshad for Gulf of Mexico (1990)

$$\mu = a \times (\mu_{od})^{b} \ldots\ldots\ldots\ldots\ldots (5a)$$

Where

$$a = 0.1651 + 0.6165 x 10^{(-0.60866 x 10^{-4} x Rs)}$$

$$b = 0.5131 + 0.5109 \times 10^{(-1.1831 x 10^{-3} \times Rs)}$$

Begg & Robinson for North America (1975)

$$\mu = a \times (\mu_{od})^{b} \ldots\ldots\ldots\ldots\ldots (6a)$$

Where

$$a = 10.715 \times (Rs + 100)^{-0.515}$$

$$b = 5.44 \times (Rs + 150)^{-0.338}$$

S.A.Khan , M.A. Al-Marhoun for Saudi Arabia (1987)

$$\mu = \frac{0.09\sqrt{\delta g}}{\sqrt[3]{Rs}\,\theta r^{4.5} (1 - \delta o)^{3}} \ldots\ldots\ldots\ldots (7a)$$

Labedi for Libya , Nigeria , Angola (1982)

$$\mu_{ob} = \left(10^{2.344 - 0.03542 x API}\right) \times \mu_{od}^{0.6447} \Big/ Pb^{0.426} \ldots\ldots\ldots\ldots\ldots (8a)$$

B - Viscosity Above Bubble Point Oil Correlations

Kartomtmodjo (2b) for Mediterranean Basin, Africa (1991)

(4b).........

$$\mu o = 1.00081 x \mu_{ob} + 0.001127 \times (P - Pb) \times (-0.006517 \times \mu_{ob}^{1.8148} + 0.038 \times \mu_{ob}^{1.590}$$

Petrosky &Farshad for Gulf of Mexico (1990)

$$\mu o = \mu_{ob} + 1.3449 x 10^{-3} x (P - Pb) x 10^{a} ....(5b)$$

Where

$$a = -1.0146 + 1.3322 x \log(\mu_{ob}) - 0.4876 x [\log(\mu_{ob})]^{2} - 1.15036 x [\log(\mu_{ob})]^{3}$$

Begg & Robinson for North America (1975)

$$\mu = \mu_{ob} \left[P/Pb \right]^{X} ....(6b)$$

$$X = C1 P^{C_2} EXP(C_3 + C_4 P)$$

$C_1 = 2.6$, $C_2 = 1.187$, $C_3 = -11.513$, $C_4 = -8.98x10^{-5}$

S.A.Khan , M.A. Al-Marhoun for Saudi Arabia (1987)

$$\mu o = \mu_{ob} \left(P/Pb \right)^{-0.14} e^{-2.5x10^{-4}(P-Pb)} ....(7b)$$

Labedi for Libya , Nigeria , Angola (1982)

$$\mu = \mu_{ob} + \left[\frac{10^{-2.488} \times \mu_{od}^{0..9036} \times Pb^{0.6151}}{10^{0.0197 \times API}} \right] \times \left(\frac{P}{Pb} - 1 \right) ....(8b)$$

C – Viscosity of Dead Oil Correlations

Kartomtmodjo for Mediterranean Basin, Africa (1991)

(4c)........ $\mu_{od} = 16x10^{8}\, xT^{(-2.8177)}\left[\log(API)\right]^{(5.7526x\log(T)-26.9718)}$

Petrosky &Farshad for Gulf of Mexico (1990)

$$\mu_{od} = 2.3511x10^{7} \times T^{-2.10255} \times (\log API)^{(4.59388x(\log T)-22.82792)} \ldots\ldots\ldots..(5c)$$

Begg& Robinson for North America (1975)

$$\mu_{od} = 10^{X} - 1 \ldots\ldots\ldots..(6c)$$

Where

$$X = 10^{(3.0324-0.02023xAPI)} \times T^{-1.163}$$

S.A.Khan , M.A. Al-Marhoun for Saudi Arabia (1987)

$$\mu_{b} = \mu_{ob}(P/Pb)^{-0.14} e^{-2.5x10^{-4}(P-Pb)} \ldots\ldots\ldots..(7c)$$

Labedi for Libya , Nigeria , Angola (1982)

$$\mu_{od} = \frac{10^{9.224}}{API^{4.7013} \times T^{0.6739}} \ldots\ldots\ldots..(8c)$$