Calculate Viscosity of Crude Oil by Redwood Viscometer

Izzet Niyazi Sulayman[1], Ali Hasan Abdulla[2], Abdulemeer Mahdi Abbas Ali[3]

[1,2,3]Kirkuk University, Iraq / College of Engineering - Petroleum Dept.

ABSTRACT

The viscosity plays a very important role in a variety of interesting engineering problems involving fluid flow in porous media and reservoir simulation. Generally oil viscosity can be obtained in two ways, either by carrying out experimental measurements or estimated by a proper model. Due to the high expenses, and time wasting, literature models were applied to measure viscosity of crude oils. Whenever laboratory data obtained were made to find a best-fit correlation due to the demand for mathematical equation of fluid flow for reservoir simulation. This study has been done based on data received from Iraqi's oil fields, consists of fifteen experimental points of oil viscosity at known temperature. In this work; several correlations have been presented in the literature [Beggs & Robinson (1975), Petrosky and farshad (1995), Egbogah-Jacks (1990), Glaso`s (1980), Beal`s (1946), Kartoatmdjo & Schmidt (1991), Labedi (1992)] used for predicting the viscosity of crude oil. Statistical analysis in terms of absolute deviation percent (% AD), and the absolute average deviations percent (% AAD) are used to subject the evaluation of the viscosity correlations. A correlation appeared to have the minimum average absolute error (2.477 %) is selected to be the best formula adopted in this study. This correlation has been developed for prediction of dead oil viscosity. Validity and accuracy of this correlation has been confirmed by comparing the obtained results of this correlation and other ones with experimental data for Iraqi oil samples. Checking the results of this correlation shows that the obtained results of Iraqi oil viscosities in this work are in agreement with experimental data compared with other correlations.

Keywords: fluid flow, viscositycorrelation, absolute deviation, absolute average deviations, dead oil viscosity, Iraqi oil viscosities.

INTRODUCTION

Crude oil viscosity is an important physical property that controls and influences the flow of oil through porous media and pipes. The viscosity, in general, is defined as the internal resistance of the fluid to flow. The oil viscosity is a strong function of the temperature, pressure, oil gravity, gas gravity, gas Solubility. Whenever possible, oil viscosity should be determined by laboratory measurement at reservoir temperature and pressure. The viscosity is usually reported is standard pvt analyses. If such laboratory data are available, engineers may refer to published correlations, which usually vary in complexity and accuracy depending upon the available data on the crude oil. Depending on the pressure, the viscosity of crude oils can be classified into three categories[1]: dead oil viscosity, µod, saturated oil viscosity, µob, and under saturated oil viscosity, µo.

Estimation of the oil viscosity at pressure equal to or blow the bubble point pressure is a two-step procedure: Firstly .calculate the viscosity of the oil without dissolved gas (dead oil) µod, at the reservoir temperature and the second step is adjust the dead oil viscosity to account for the effect of the gas solubility at the pressure of interest. At pressure greater than the bubble point pressure of the crude oil, another adjustment step, i.e.step3,should be made to the bubble point oil viscosity ,µob, to account for the compression and the degree of under-saturation in the reservoir. A brief description of several correlations that are widely used in estimating the oil viscosity in the above three steps is given below:

Models can be classified into three different categories:

1. Theoretical models
2. Semi-theoretical models
3. Empirical models

The theoretical models are mainly used for calculating viscosities of pure component and their mixtures Empirical models are mainly described in terms of correlations[2].Semi theoretical models for viscosity prediction have provided blend between theoretical and correlative models[3].Semi theoretical models are derived from theoretical framework, but involve parameters experimentally determined. Empirical methods include a wide variety of equation used throughout the industry involving constants calculated from experimental data. There are several empirical correlations used to calculate the oil viscosity based on frequently available hydrocarbon system parameter, such as temperature, pressure, oil gravity, gas gravity, and gas solubility.

Dead-oil viscosity correlation:

For empirical correlations, the dead oil viscosity is determined first. The dead oil is defined at atmospheric pressure and at any fixed system temperature without dissolved gas. This dead oil viscosity then is corrected for the system pressure condition. Normally dead oil viscosity is determined in the laboratory[4]. The dead oil viscosity correlations are:

Beal´s correlation:

From a total of 753 values for dead oil viscosity between 100-220ºF, Beal (1946) developed graphical correlation for determining the viscosity of the dead oil as a function of temperature and the API gravity of the crude [5]

$$\mu od= (0.32+\frac{1.8\times10{}^\wedge 7}{API^{4.53}})(\frac{360}{T+200}){}^\wedge a \qquad (1)$$

where,

$$a=10{}^\wedge(0.43+\frac{8.33}{API}) \qquad (2)$$

μod: Dead oil viscosity at 1 atm pressure and temperature, T in ºF

Beggs and Robinson correlation:

Beggs and Robinson (1975) developed an empirical correlation for determining the viscosity of crude oil[6]. It is based on 460 dead oil viscosity measurements and can be expressed as

$$\mu od= 10{}^\wedge(x-1) \qquad (3)$$

$$\text{where:-}\frac{10{}^\wedge(3.0324-0.02023^{o}API)}{T{}^\wedge 1.163} \qquad (4)$$

Glaso´s Correlation:

Glaso (1980) proposed a generalized mathematical relationship for computing the dead oil viscosity the relationship was developed from experimental measurements on 26 crude oil sample[7].the correlation has the following form:

$$\mu od=[3.141(10^{10})][(T-460)-{}^{3.444}][\log(API)]^{a}(5)$$

where,

$$a=10.313[\log\{T-460]-36.447 \qquad (6)$$

Kartoamodjo and Schmidt´s Correlation:

In its empirical form , this correlation [8] is a combination of the three correlation ; they are Beal's correlation [5] , standing´s correlation [9],and Beggs and Robinson´s correlation [6],it can be expressed as:

$$\mu od=(16\times10{}^\wedge 8)[T{}^\wedge(-2.8177)][\log API]{}^\wedge(5.756\log(T)-26.9718) \qquad (7)$$

MODIFIED KARTOATMODJO CORRELATION (MEDIUM OILS): [10]

$$\mu od=220.15\times10{}^\wedge 9\times T{}^\wedge(-3.556)[\log(API)]{}^\wedge(12.5428\times\log(T)-45.7874) \qquad (8)$$

EGBOGAH-JACKS CORRELATION: [11]

$$\mu od=10{}^\wedge 10{}^\wedge[-1.7095+(\frac{389.45}{API+131.5})+[-1.2943+(\frac{135.585}{API+131.5})]\times\log((T-32)\times\frac{5}{9}))] \qquad (9)$$

MODIFIED EGBOGAH-JACKS CORRELATION (EXTRA-HEAVY OILS): [10]

$$\mu od=10{}^\wedge 10{}^\wedge[1.90296-0.012619\times API-0.61748\times\log(T)] \qquad (10)$$

MODIFIED EGBOGAH-JACKS CORRELATION (HEAVY OILS):[10]

$$\mu_{ob} = 10^{10[2.06492-0.0179*API-0.70226*\log(T)} \qquad (11)$$

LABEDI CORRELATION:[12]

$$\mu\ od=\frac{10\ 9.224}{API{}^\wedge(4.7013\ x\ T0.6739)} \qquad (12)$$

PETROSKY&FARSHAD CORRELATION:[13]

$$\mu_{ob}= 2.3511\ x\ 10^{7}\ x\ T^{-2.10255}\ x\ (\log\ (API))^{(4.59388\ x\ (\log T\ )\ -\ 22.82792\ )} \qquad (13)$$

CORRELATION FROM LITERATURE:

$$\mu_{ob} = \frac{10\ {}^\wedge(4.9563-0.00488T)}{API+\left(\frac{T}{30}-14.29\right)^{2.709}} \qquad (14)$$

$\mu_{ob}= 10^{(0.10231 \text{ x } API\text{^}(2) - 3.9464 \text{ x } API + 46.5037)} \text{ x } T^{(-0.04542 \text{ x } API\text{^}(2) + 1.70405 \text{ x } API - 19.18)}$ (15)
$\mu_{ob}= 10^{(-0.8021 \text{ x } API + 23.8765)} \text{ x } T^{(0.31458 \text{ x } API - 9.221592)}$ (16)

SATURATED CRUDE OIL VISCOSITY CORRELATIONS:

The reservoir oil viscosity depends on the solution-gas content. Oil viscosity decreases with rising pressure as the solution gas increases, up to the bubble point pressure. There are few empirical correlations to determine the viscosity of saturated or under saturated crude oil systems.

BEGGS AND ROBINSON CORRELATION:

This correlation is based on 2073 saturated oil viscosity measurements [6] .The empirical from of this equation is :
$\mu_{ob} = (10.715\,(Rs + 100)^{-0.515})\,\mu_{od}^{\,b}$ (17)
Where,
$b = 5.44\,(Rs + 150)^{(-0.338)}$ (18)
This correlation was developed from these ranges of data :
Pressure = 132 to 5.265 psia
Temperature = 70 to 295^{o} F
Oil gravity = 16 to 58^{o} API
And gas solubility = 20 to 2070 scf/STB

KARTOATMODJO AND SCHMIDT'S CORRELATION:

This correlation recommends the following correction of the dead-oil viscosity presented in equations bellow to determine the live-oil viscosity.[8]
$\mu_{ob} = -\,0.06821 + 0.9824\,F + 0.0004034\,F^2$ (19)
here :-
$F = (0.2001 + 0.8428 \text{ x } 10^{-0.000845Rs}) \text{ x } \mu_{ob}^{(0.43 + 0.5165y)}$ (20)
$Y = 10^{-0.0008Rs}$ (21)

CHEW &CONNALLY CORRELATION: [14]

$\mu_{ob} = a \text{ x } (\mu ob)^{b}$ (22)
Where :-
$a = 0.20 + 0.80 \text{ x } 10^{(-0.00081 \text{ x } Rs)}$ (23)
$b = 0.43 + 0.57 \text{ x } 10^{(-0.00072 \text{ x } Rs)}$ (24)

LABEDI CORRELATION: [12]

$$\boldsymbol{\mu_{ob}} = \frac{\mathbf{(102.344 - 0.03542xAPI)x\mu od0.6447}}{\mathbf{pb\text{^}(0.426)}} \quad (25)$$

KAHN ET AL CORRELATION:[15]

$$\mu ob = \frac{0.09 \text{ x}(\text{ SG gas })\text{^}(0.5)}{Rs \text{ x}\left(\frac{T+459.67}{459.67}\right) \text{ x } \left[1-\left(\frac{141.5}{API+131.5}\right)\right]} \qquad (26)$$

KARTOATMODJO CORRELATION:

$\mu_{ob} = -\,0.06821 + 0.9824 \text{ x } F + 0.0004034 \text{ x } F^2$(27)
Where :-
$F = [\,0.2001 + 0.8428 \text{ x } 10^{[-0.000845xRs]} \text{ x } \mu_{ob}\,[0.43 + 0.5165 \text{ x } 10^{(-0.00081 \text{ x } Rs)}$(28)

UNDER SATURATED OIL-VISCOSITY CORRELATIONS:

Above the bubble-point pressure , rising pressure increases the viscosity of oil because of its compressibility; that is when the pressure increases then the oil molecules become closer from each other and then the internal friction of oil increases, so the viscosity increases because it is a measure of the internal friction

KHAN'S CORRELATION:

From 1500 experimental viscosity data point on Saudi Arabian crude oil systems , the following equation was developed with a reported absolute average relative error of 2% .[15]
$\boldsymbol{\mu_{o} = \mu_{ob} X_{e}^{[9.6x10\text{^}(-5)(p-pb)]}}$ (29)

BEAL CORRELATION:[5]

$\mu o = \mu_{ob} + 0.001 \text{ x } (p - p_b) \text{ x } (0.024\,x\mu_{ob}^{1.6} + 0.038 \text{ x } \mu ob^{0.56})$ (30)

VASQUEZ AND BEGGS'S CORRELATION:

The following correlation was proposed to determine crude oil viscosity above the bubble point pressure using the viscosity at the bubble point pressure.[16]

$\mu o = \mu ob(\frac{p}{pb})^{m}$ (31)

Where,

$m= 2.6 \times p^{1.187} \times 10^{a}$ (32)

$a = - (3.9 \times 10^{-5}) \times p - 5$ (33)

This correlation is based on data in the following ranges :

Pressure = 141 to 9.515 Pisa
Gas solubility =90.3 to 2.199 scf/ STB
Viscosity = 0.1177 to 148 cp
Gas specific gravity = 0.511 to 1.351
Oil gravity = 15.3 to 59.5^{o} API

KARTOATMODJO AND SCHMIDT'S CORRELATION:

This correlation allow correlation the saturated crude oil viscosity at the bubble-point , μob ,based on equation for under saturated pressure, p. [8].

$\mu o =1.0008 * \mu_{ob}+ 0.001127(p-pb) * (-0.006517 * \mu_{ob}^{1.8148} +0.038 * \mu_{ob}^{1.59})$ (34)

VISCOSITY MESURMENT:

Viscosity measurements at different temperatures were performed by using Capillary viscometer. The selection of type and size of viscometer depend on the type and density of oil stocks. The Capillary tube viscometer was placed in a water bath type Koehler, which was capable of maintaining the temperature with in+o.1 ^{o}C of the selected temperature. The viscosity of all crudes was measured at five different temperature, 22, 30, 40, 50 and 60^{o}C. Kinematic viscosity was calculated from the measured flow time (t) and the viscometer calibration constant by the equation (35).

$$v = k * t \quad (35)$$

Where:

v : Is the kinematic viscosity in cst.
k : Is the calibration constant of the viscometer in cst/s.
t : Is the flow time in second.

EXPERIMENTAL PROCEDURE

1. A certain amount of each crude oil sample was poured in to a breaker then transferred to the viscometer.
2. The viscometer which containing the crude oil is inserted in the water bath at the required temperature.
3. The pump was used to raise the level of the crude oil to the starting mark on the left hand limp of the viscometer, another finger is used to close the other limp to avoid the flow of the crude oil due to air.
4. The finger is removed to allow his flow of crude oil down the capillary at that point, the time at which the crude oil flow down is taken and recorded.
5. This process is repeated for the various crude oils and at different temperature.
6. The viscosity then is obtained by multiplying the constant of the viscometer by the time obtained

Fig. (1): (Kinematic viscosity measurement apparatus & capillary viscometer) experimental DATA

Three Iraqi crude oil of different API gravities were selected for this study, as given in tables (1). Type (A) was kirkuk crude of (23.3)API^{o} gravity, type(B) was kirkuk crude of (29.3) API^{O} gravity and type (C) was jamboor crude of (37) API^{o} gravity.

Table (1): properties of Iraqi crude oils

Specification	Type A	Type B	Type C
Sp.gr.at 15.6C^{o}(60F^{O})	0.914	0.88	0.84
API^{O} gravity	23.3	29.3	37

Data have been provided from three reservoirs, tape A, type B, type C. Details of these data are listed in table (2,3).

Table (2): Experimental data of three oil sample viscosities

Temperature		Type (A) Kirkuk crude oil data		Type (B) Kirkuk crude oil data		Type (C) Kirkuk crude oil data	
Temp. C^{o}	Temp. F^{o}	Kinematic Viscosity (Cst)	Dynamic Viscosity (Cp)	Kinematic Viscosity (Cst)	DynamicVisc-osity (Cp)	Kinematic Viscosity (Cst)	Dynamic Viscosity (Cp)
22	71.6	67.6	61.7864	27.6	24.288	7.6	6.3992
30	86	45.3	41.4042	20.6	18.128	5.6	4.7152
40	104	29.3	26.7802	14.7	12.936	4.2	3.5364
50	122	19.98	18.26172	10.9	9.592	3.4	2.8628
60	140	14.4	13.1616	8.3	7.304	2.9	2.4418

The viscosities are measured in centistokes. To obtain the viscosity in centi-poise, the viscosity in centistokes is multiplied by the fluid density (g/cm^{3}).

VISCOSITY TEMPERATURE RELATIONSHIP

Plotting the experimental data yields Fig.(2) in which viscosity versus temperature has been drawn for the three samples. While Fig(3) shows how viscosity changes according to API gravity and Fig(4) we shows the relationship between dead oil viscosity against calculated oil viscosity.

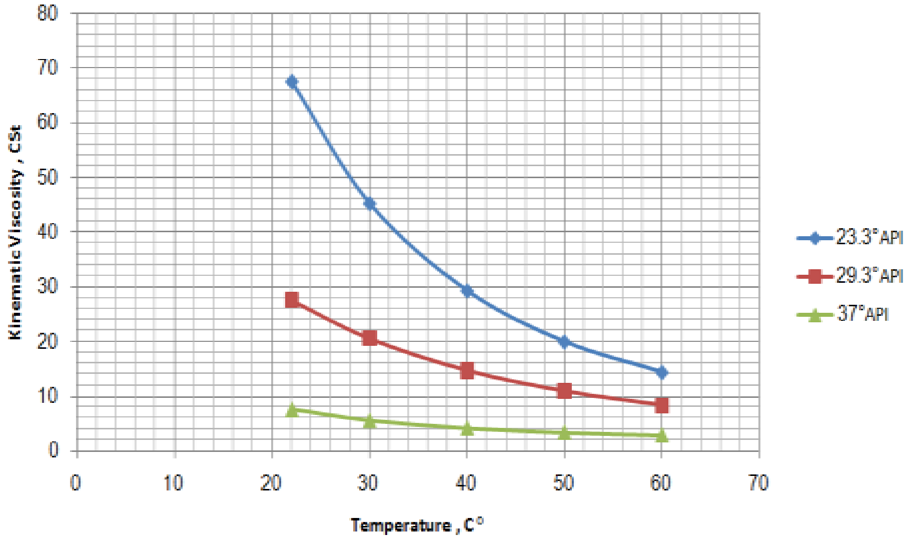
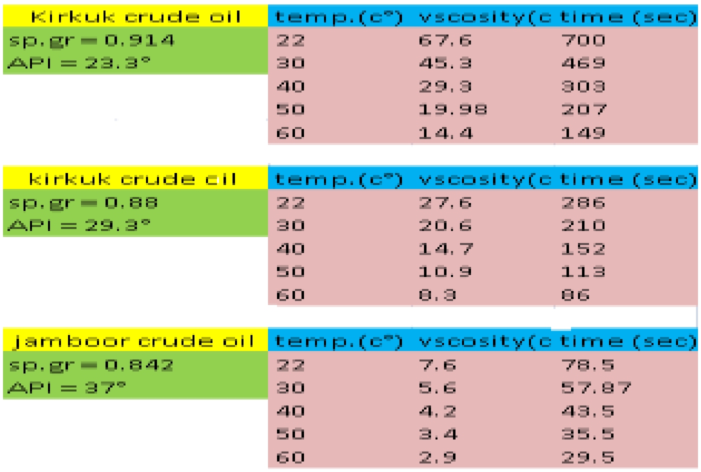


Fig. (2): Dynamic viscosity Vs. Temperature

Table (3): properties of Iraqi crude oils VS. Temperature



Kirkuk crude oil	temp.(c°)	vscosity(c	time (sec)
sp.gr = 0.914	22	67.6	700
API = 23.3°	30	45.3	469
	40	29.3	303
	50	19.98	207
	60	14.4	149

kirkuk crude oil	temp.(c°)	vscosity(c	time (sec)
sp.gr = 0.88	22	27.6	286
API = 29.3°	30	20.6	210
	40	14.7	152
	50	10.9	113
	60	8.3	86

jamboor crude oil	temp.(c°)	vscosity(c	time (sec)
sp.gr = 0.842	22	7.6	78.5
API = 37°	30	5.6	57.87
	40	4.2	43.5
	50	3.4	35.5
	60	2.9	29.5

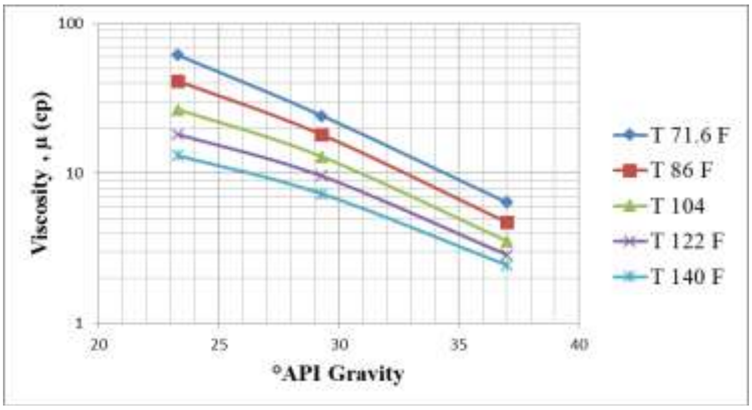


Fig. (3): Dynamic viscosity Vs. API gravity

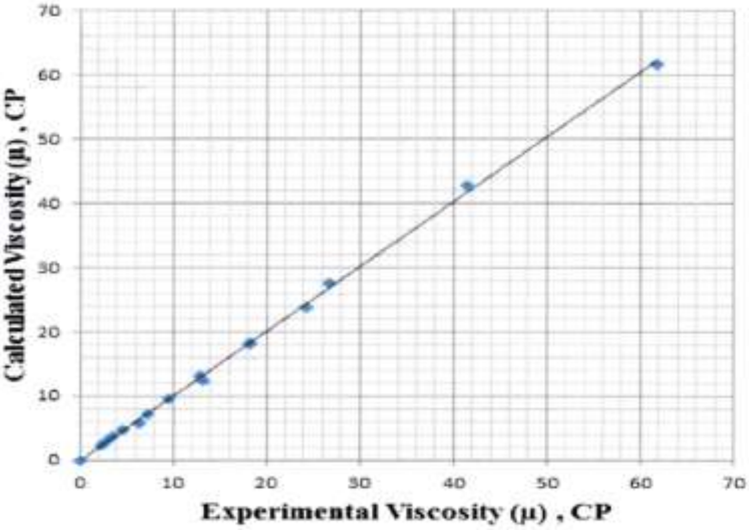


Fig. (4): dead oil viscosity are plotted against calculated oil viscosity

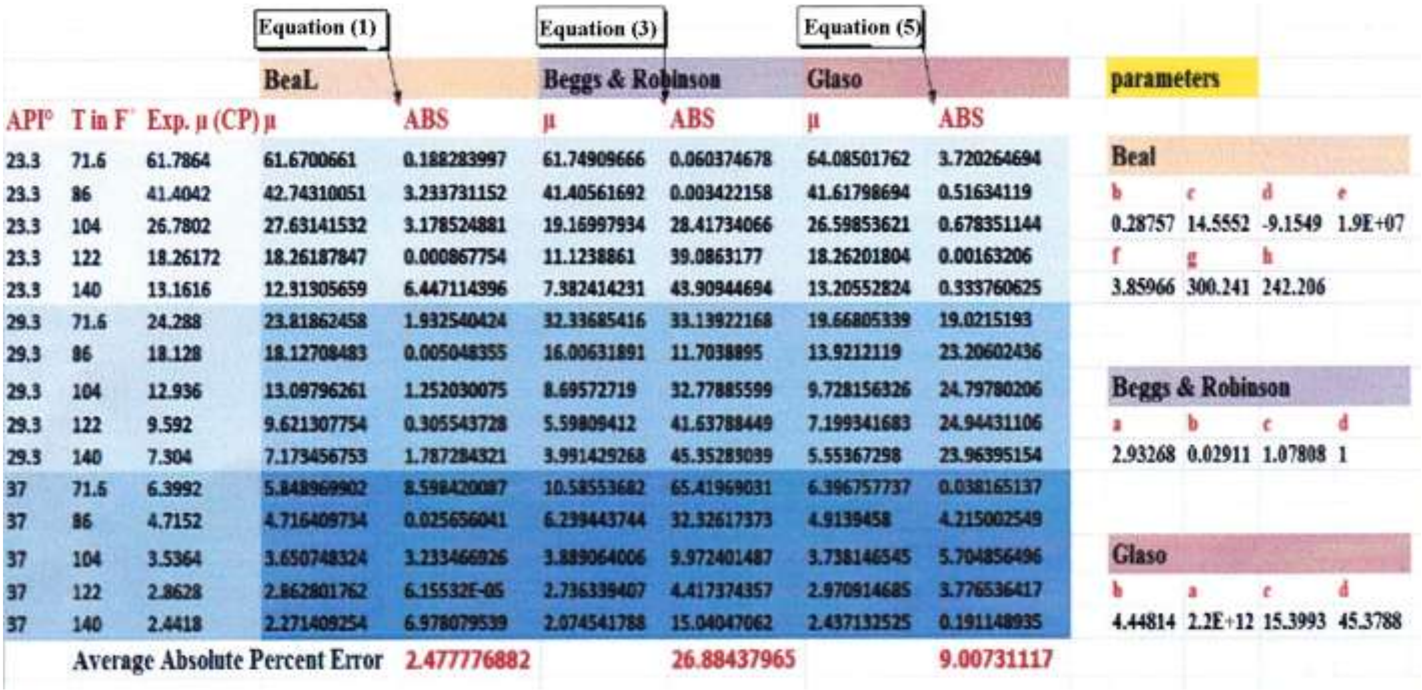
THE RESULTS

The most popular empirical models presently used in petroleum engineering calculations for predicting dead oil viscosity (gas-free crude or stock tank) are those developed by Beal, Beggs and Robinson, and Glaso. Beal's model was developed from crude oil data from California, Beggs and Robinson's model was developed from the crude oils of an unknown location, whereas Galso's model from crude oils in the North Sea. Recently, Labedi and Kartoatmodjo and Schmidt presented other empirical models for estimating dead crude oil viscosity for African crudes and using data bank respectively.

All of these models have expressed dead oil viscosity as a function of both oil API gravity and reservoir temperature (T). When these correlations were applied to data collected considerable errors and scatter were observed. The error percentage for all published dead crude oil models are measured. The average relative error (ARE), absolute average relative error (AARE) are defined as below:

$$\mathrm{ARE}=\frac{1}{\mathrm{N}}\sum_{\mathrm{i}=1}^{\mathrm{N}}\left(\frac{\mathrm{X}_{\mathrm{expermental(i)}}-\mathrm{X}_{\mathrm{calculated(i)}}}{\mathrm{X}_{\mathrm{expermantal(i)}}}\right)\times 100 \qquad (36)$$

Where i is the sample number and N is the total number of samples which is three. Twenty four correlations were used in this work, to estimate the viscosity of dead oil, some of these correlation are shown below Fig (5, 6, 7, 8):



			Equation (1)		Equation (3)		Equation (5)	
			BeaL		Beggs & Robinson		Glaso	
API°	T in F°	Exp. μ (CP)	μ	ABS	μ	ABS	μ	ABS
23.3	71.6	61.7864	61.6700661	0.188283997	61.74909666	0.060374678	64.08501762	3.720264694
23.3	86	41.4042	42.74310051	3.233731152	41.40561692	0.003422158	41.61798694	0.51634119
23.3	104	26.7802	27.63141532	3.178524881	19.16997934	28.41734066	26.59853621	0.678351144
23.3	122	18.26172	18.26187847	0.000867754	11.1238861	39.0863177	18.26201804	0.00163206
23.3	140	13.1616	12.31305659	6.447114396	7.382414231	43.90944694	13.20552824	0.333760625
29.3	71.6	24.288	23.81862458	1.932540424	32.33685416	33.13922168	19.66805339	19.0215193
29.3	86	18.128	18.12708483	0.005048355	16.00631891	11.7038895	13.9212119	23.20602436
29.3	104	12.936	13.09796261	1.252030075	8.69572719	32.77885599	9.728156326	24.79780206
29.3	122	9.592	9.621307754	0.305543728	5.59809412	41.63788449	7.199341683	24.94431106
29.3	140	7.304	7.173456753	1.787284321	3.991429268	45.35283039	5.55367298	23.96395154
37	71.6	6.3992	5.848969902	8.598420087	10.58553682	65.41969031	6.396757737	0.038165137
37	86	4.7152	4.716409734	0.025656041	6.239443744	32.32617373	4.9139458	4.215002549
37	104	3.5364	3.650748324	3.233466926	3.889064006	9.972401487	3.738146545	5.704856496
37	122	2.8628	2.862801762	6.15532E-05	2.736339407	4.417374357	2.970914685	3.776536417
37	140	2.4418	2.271409254	6.978079539	2.074541788	15.04047062	2.437132525	0.191148935
	Average Absolute Percent Error			2.477776882		26.88437965		9.00731117

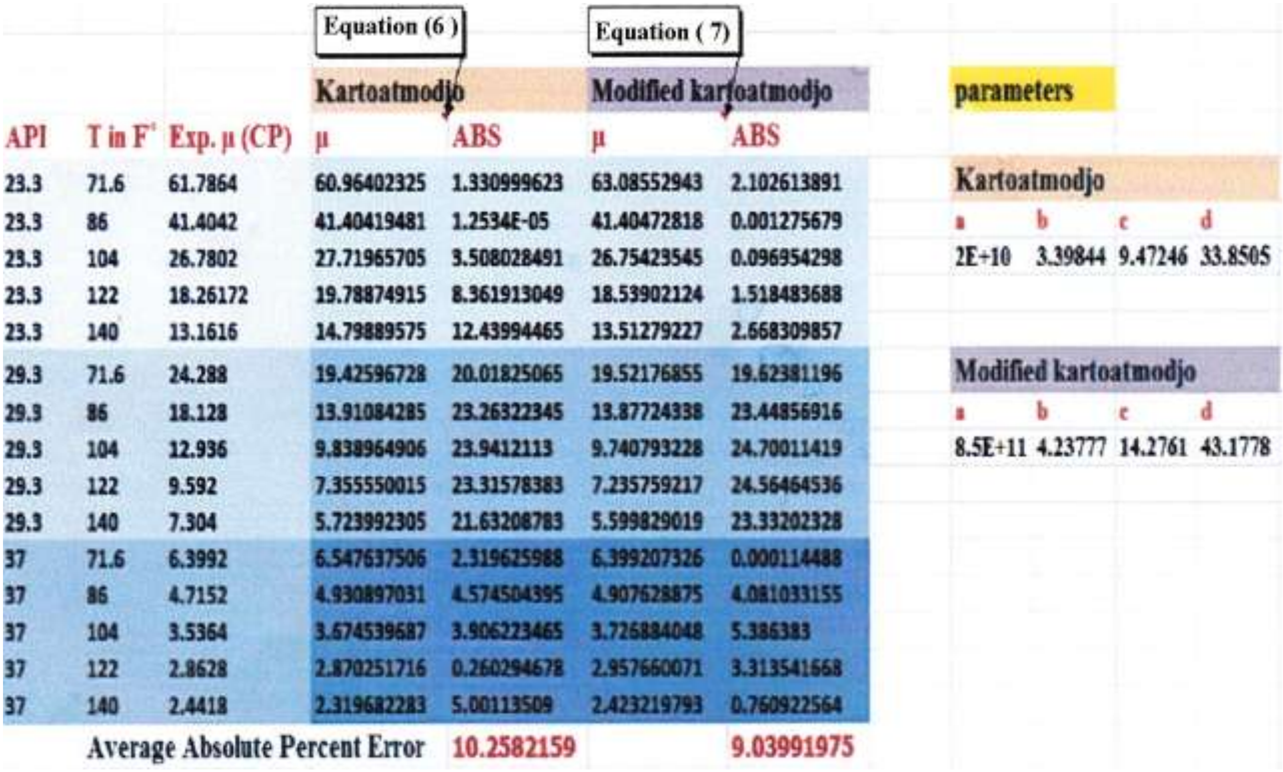
parameters

Beal			
b	c	d	e
0.28757	14.5552	-9.1549	1.9E+07
f	g	h	
3.85966	300.241	242.206	

Beggs & Robinson			
a	b	c	d
2.93268	0.02911	1.07808	1

Glaso			
b	a	c	d
4.44814	2.2E+12	15.3993	45.3788

Fig (5): Beal & Robinson and Glaso correlations



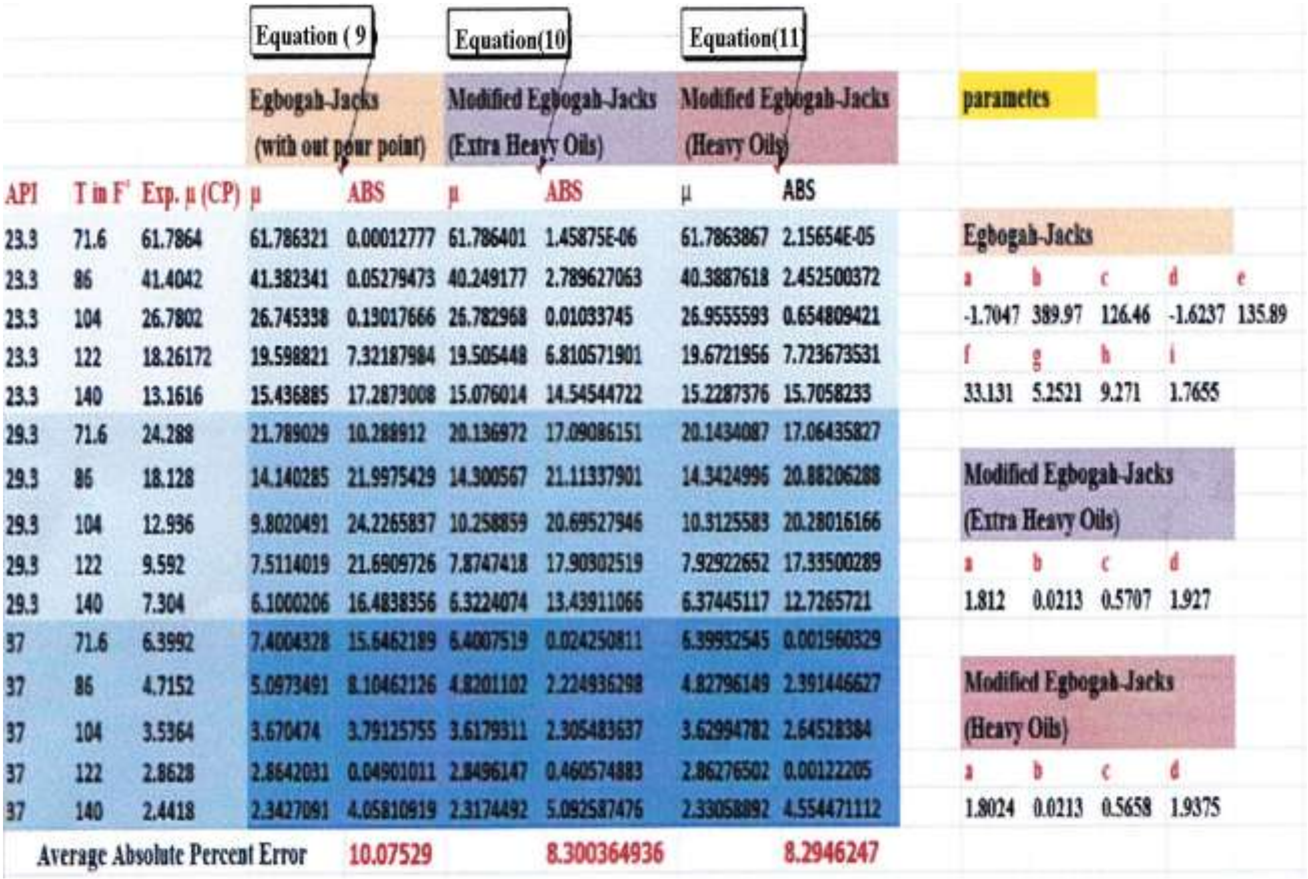
			Equation (6)		Equation (7)	
			Kartoatmodjo		Modified kartoatmodjo	
API	T in F°	Exp. μ (CP)	μ	ABS	μ	ABS
23.3	71.6	61.7864	60.96402325	1.330999623	63.08552943	2.102613891
23.3	86	41.4042	41.40419481	1.2534E-05	41.40472818	0.001275679
23.3	104	26.7802	27.71965705	3.508028491	26.75423545	0.096954298
23.3	122	18.26172	19.78874915	8.361913049	18.53902124	1.518483688
23.3	140	13.1616	14.79889575	12.43994465	13.51279227	2.668309857
29.3	71.6	24.288	19.42596728	20.01825065	19.52176855	19.62381196
29.3	86	18.128	13.91084285	23.26322345	13.87724338	23.44856916
29.3	104	12.936	9.838964906	23.9412113	9.740793228	24.70011419
29.3	122	9.592	7.355550015	23.31578383	7.235759217	24.56464536
29.3	140	7.304	5.723992305	21.63208783	5.599829019	23.33202328
37	71.6	6.3992	6.547637506	2.319625988	6.399207326	0.000114488
37	86	4.7152	4.930897031	4.574504395	4.907628875	4.081033155
37	104	3.5364	3.674539687	3.906223465	3.726884048	5.386383
37	122	2.8628	2.870251716	0.260294678	2.957660071	3.313541668
37	140	2.4418	2.319682283	5.00113509	2.423219793	0.760922564
	Average Absolute Percent Error			10.2582159		9.03991975

parameters

Kartoatmodjo			
a	b	c	d
2E+10	3.39844	9.47246	33.8505

Modified kartoatmodjo			
a	b	c	d
8.5E+11	4.23777	14.2761	43.1778

Fig (6): Kartoamodjo and MODIFIED KARTOATMODJO Correlation



			Equation (9)		Equation(10)		Equation(11)	
			Egbogah-Jacks (with out pour point)		Modified Egbogah-Jacks (Extra Heavy Oils)		Modified Egbogah-Jacks (Heavy Oils)	
API	T in F'	Exp. µ (CP)	µ	ABS	µ	ABS	µ	ABS
23.3	71.6	61.7864	61.786321	0.00012777	61.786401	1.45875E-06	61.7863867	2.15654E-05
23.3	86	41.4042	41.382341	0.05279473	40.249177	2.789627063	40.3887618	2.452500372
23.3	104	26.7802	26.745338	0.13017666	26.782968	0.01033745	26.9555593	0.654809421
23.3	122	18.26172	19.598821	7.32187984	19.505448	6.810571901	19.6721956	7.723673531
23.3	140	13.1616	15.436885	17.2873008	15.076014	14.54544722	15.2287376	15.7058233
29.3	71.6	24.288	21.789029	10.288912	20.136972	17.09086151	20.1434087	17.06435827
29.3	86	18.128	14.140285	21.9975429	14.300567	21.11337901	14.3424996	20.88206288
29.3	104	12.936	9.8020491	24.2265837	10.258859	20.69527946	10.3125583	20.28016166
29.3	122	9.592	7.5114019	21.6909726	7.8747418	17.90302519	7.92922652	17.33500289
29.3	140	7.304	6.1000206	16.4838356	6.3224074	13.43911066	6.37445117	12.7265721
37	71.6	6.3992	7.4004328	15.6462189	6.4007519	0.024250811	6.39932545	0.001960329
37	86	4.7152	5.0973491	8.10462126	4.8201102	2.224936298	4.82796149	2.391446627
37	104	3.5364	3.670474	3.79125755	3.6179311	2.305483637	3.62994782	2.64528384
37	122	2.8628	2.8642031	0.04901011	2.8496147	0.460574883	2.86276502	0.00122205
37	140	2.4418	2.3427091	4.05810919	2.3174492	5.092587476	2.33058892	4.554471112
Average Absolute Percent Error				10.07529		8.300364936		8.2946247

parametes

Egbogah-Jacks

a	b	c	d	e
-1.7047	389.97	126.46	-1.6237	135.89
f	g	h	i	
33.131	5.2521	9.271	1.7655	

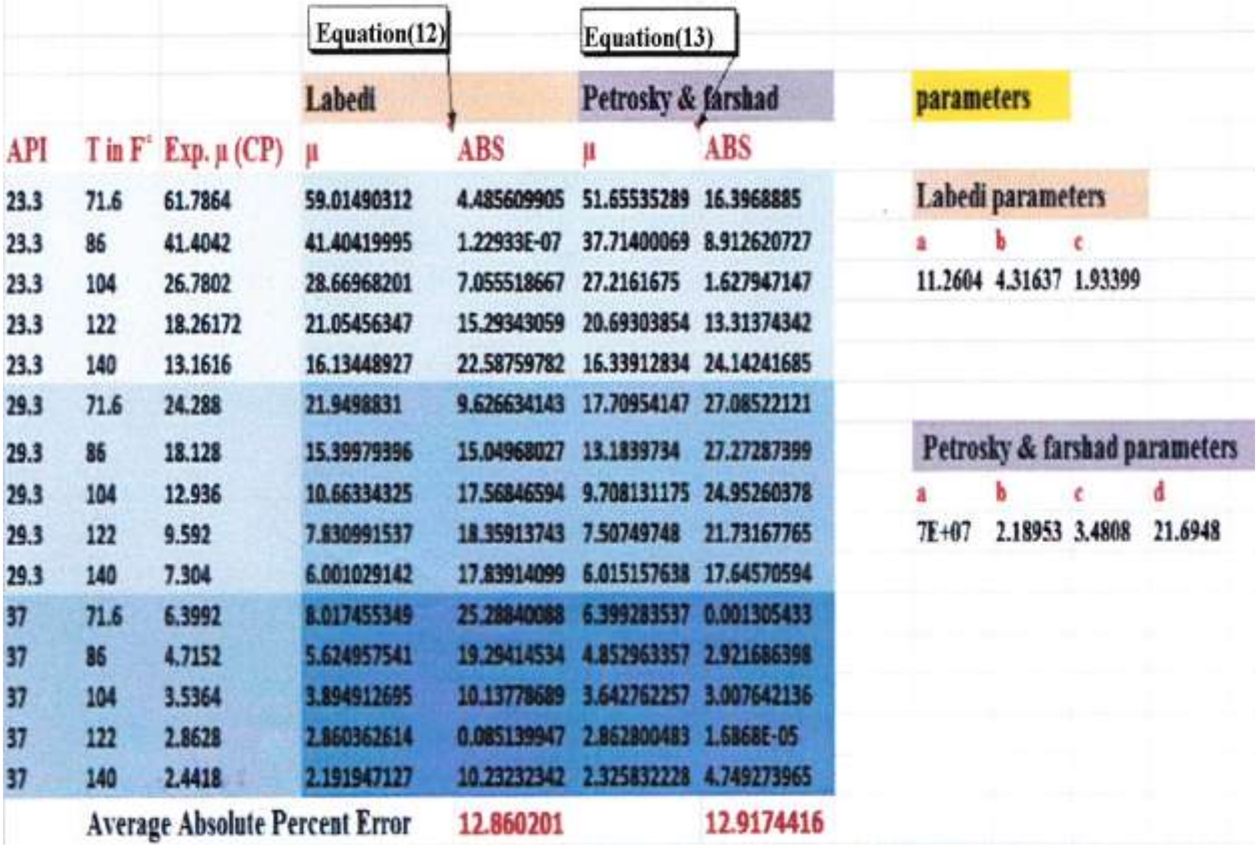
Modified Egbogah-Jacks (Extra Heavy Oils)

a	b	c	d
1.812	0.0213	0.5707	1.927

Modified Egbogah-Jacks (Heavy Oils)

a	b	c	d
1.8024	0.0213	0.5658	1.9375

Fig (7): Egbogah- Jacks & Modified Egbogah-jacks and Modified Egbogah-Jacks correlation



			Equation(12)		Equation(13)	
			Labedi		Petrosky & farshad	
API	T in F'	Exp. µ (CP)	µ	ABS	µ	ABS
23.3	71.6	61.7864	59.01490312	4.485609905	51.65535289	16.3968885
23.3	86	41.4042	41.40419995	1.22933E-07	37.71400069	8.912620727
23.3	104	26.7802	28.66968201	7.055518667	27.2161675	1.627947147
23.3	122	18.26172	21.05456347	15.29343059	20.69303854	13.31374342
23.3	140	13.1616	16.13448927	22.58759782	16.33912834	24.14241685
29.3	71.6	24.288	21.9498831	9.626634143	17.70954147	27.08522121
29.3	86	18.128	15.39979396	15.04968027	13.1839734	27.27287399
29.3	104	12.936	10.66334325	17.56846594	9.708131175	24.95260378
29.3	122	9.592	7.830991537	18.35913743	7.50749748	21.73167765
29.3	140	7.304	6.001029142	17.83914099	6.015157638	17.64570594
37	71.6	6.3992	8.017455349	25.28840088	6.399283537	0.001305433
37	86	4.7152	5.624957541	19.29414534	4.852963357	2.921686398
37	104	3.5364	3.894912695	10.13778689	3.642762257	3.007642136
37	122	2.8628	2.860362614	0.085139947	2.862800483	1.6868E-05
37	140	2.4418	2.191947127	10.23232342	2.325832228	4.749273965
Average Absolute Percent Error				12.860201		12.9174416

parameters

Labedi parameters

a	b	c
11.2604	4.31637	1.93399

Petrosky & farshad parameters

a	b	c	d
7E+07	2.18953	3.4808	21.6948

Fig(8): Labedi & Petrosky-Farshad correlation

CONCLUSIONS

In This work ten correlations were used to estimate the viscosity of dead oil and define the effect of change of temperature on dead oil viscosity. The accuracy of each correlation for dead oil viscosity calculation was checked with experimental data. All the dead oil correlations were modified through introducing tuning parameters to improve their accuracy for Iraqi dead oil. The performance of the tuned correlations was found to better predict the data where the APE and AAPE decreases. The selected formula was Beal's correlation because it has minimum AAE (2.477 %). By the comparison of experimental values of viscosity with predicted ones, it is obvious that the new correlation provides results in good agreement with experimental values. Input parameters for this correlation are oil API gravity, reservoir temperature and pressure, which are easily measured in oil fields.

NOMENCLATURE

Symbols	Description	Units
T	Temperature	°F
API	Gravity of oil at 60°F	°API
P	Reservoir Pressure	psia
P_b	Bubble-point pressure	psia
f_w	Fractional flow of water	
fo	Fractional flow of oil	
a	Constant of equation	
b	Constant of equation	
e	Constant of equation	
f	Constant of equation	
μ	Dynamic viscosity	cp
ν	Kinematic viscosity	cst
μ_o	Under saturated oil viscosity	cp
μ_{ob}	Bubble point oil viscosity	cp
μ_{od}	Dead oil viscosity	cp
$\mu_{inj.}$	injected fluid viscosity	cp
μ_o	oil viscosity	cp
pb	Bubble point	
inj.	Injected fluid	
o	Oil	
w	water	
od	Dead oil	
D	Displacing phase	
d	Displaced phase	
ARE	Average relative error	
AARE	Absolute average relative error	

REFERENCES

[1] Ahmed, T., "Equations of State and PVT Analysis: Applications for Improved Reservoir Modeling", Gulf Publishing Company, Houston, Texas, (2007).

[2] Andrade, E. N., ―Theory of Viscosity of Liquids.‖, Philosophical Magazine, vol. 17, pp. 497-511, 1934; ibid, vol. 17, pp. 698-732, (1934).

[3] ASTM, Annual Book of ASTM Standards, Part 23, ASTM, Philadelphia, PA, (1981).

[4] Brill, J. B., Mukherjee, H., "Multiphase Flow in Wells", first printing, Henry L. Doherty, memorial fund of AIME, Richardson, Texas, (1999).

[5] Beal, C. "The Viscosity of Air, Water, Natural Gas, Crude Oils and Its Associated Gases at Oil Field Temperatures and Pressures", Trans., AIME 165, 94, (1946)

[6] Beggs, H. D., Robinson, J. R.: Estimating the Viscosity of Crude Oil Systems, J. Pet. Sci., pp 1140-1141, September (1975).

[7] Glaso, Generalized Pressure-Volume-Temperature Correlations, pp785-795 JPT, May (1980)

[8] Kartoatmodjo, T. and Schmidt, Z.: "New Correlations for Crude Oil Physical Properties", paper SPE 23556, Richardson, Texas (June 1991).

[9] Standing, M.B.: Volumetric and Phase Behavior of Oil Field Hydrocarbon Systems, ninth edition, SPE, Richardson, Texas (1981).

[10] [10] G De Ghetto, F Paone and M Villa, Pressure-Volume-Temperature Correlations for Heavy and Extra Heavy Oils, SPE 30316, International Heavy Oil Symposium, Calgary, Canada, 19-21 June 1995.

[11] E O Egbogah and J T Ng, An Improved Temperature-Viscosity Correlation for Crude Oil Systems, Journal of Petroleum Science and Engineering, 5, pp197-200, (1990)
[12] Labedi, R: Improved correlation for prediction the viscosity of light crudes. J. Pet. Sci. Eng. 8, p. 221 – 234, (1992).
[13] G E Petrosky and F FFarshad, Viscosity Correlations for Gulf of Mexico Crude Oils, SPE 29468, Production Operations Symposium, Oklahoma City, Oklahoma, 2-4 April (1995).
[14] J Chew and CH ConnallyJr, Viscosity Correlations for Gas Saturated Crude Oils, Trans AIME, 216, pp23-25, (1959).
[15] Khan, S., et al. "Viscosity Correlations for Saudi Arabia Oils", SPE Paper 15720. Dallas: Society of Petroleum Engineers, (1987).
[16] Vasquez, M. and Beggs, H.D.: "Correlations for Fluid Physical Property Prediction", JPT 968; Trans., AIME, 269, June (1980).

AUTHORS:

IZZET NIYAZI SULAYMAN

B.Sc. University of AL-Nahrain–Baghdad-Iraq/ Chem. Eng. – 1997
MsD. University of AL-Nahrain–Baghdad-Iraq/ Chem. Eng. – 2000
PhD. University of AL-Nahrain–Baghdad-Iraq/ Chem. Eng. –2007
Specialist: Fluid flow
Assistant Prof. in College of Engineering / Kirkuk University

ABDULEMEER MAHDI ABBAS ALI

B.Sc. University of Mines and Metallurgy – Titova Mitrovica – Yug. / 1989
MsD. University of Tuzla – Bih / 2012
Specialist: Geology of Mines
Assistant Lecturer in College of Engineering / Kirkuk University

ALI HASAN ABDULLA

B.Sc. University of Technology–Baghdad / Chem. Eng. – 2006
MsD. Azerbaijan State Oil Academy (Baku) / Azerbaijan – 2010
Specialist: Refinery of Petroleum and Gas
Assistant Lecturer in College of Engineering / Kirkuk University