Journal of Petroleum & Environmental Biotechnology

Saeed et al., J Pet Environ Biotechnol 2016, 7:6
DOI: 10.4172/2157-7463.1000305

Research Article Open Access

A Current Viscosity of Different Egyptian Crude Oils: Measurements and Modeling Over a Certain Range of Temperature and Pressure

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Abstract

Viscosity is an important characteristic of crude oil. The viscosity has significant effect for all events in the pipeline transportation of crude oil. The changing in viscosity of crude oil is depending on the temperature, pressure and chemical composition of the crude. In the determination process of crude oil viscosity operations, it is usual to use only temperature dependence of viscosity while the pressure is neglected. Therefore, the essential goal of this study is to obtain a model that can successfully calculate the viscosity in a wide range of temperatures and pressures. Moreover, at this study a mathematical model of changing the current viscosity of Egyptian crude oil with changing of temperature and pressure is determined. Different API gravities of 6 oil samples ranging from 13.4 to 40.4 are tested.

The current viscosity measured at the temperature and pressure ranges from 20 to 140°C and from 14.7 to 132.3 psi. These measurements are determined by using the quartz process viscometer apparatus. The comparison between the experimental data and the calculated values is indicated that the proposed model successfully calculate the experimental data with an average absolute percentage relative error of less than 3 and correlation coefficients of 0.991. It is noted that it's possible to predict a correlation for the dead crude oil viscosity using temperature and pressure change, because the pressure is important for the viscosity and cannot be neglected.

Keywords: Current viscosity; Viscometer apparatus; Crude oils; Mathematical; Correlation

Introduction

The viscosity is important for numerical simulations to determine the economics of the Enhanced Oil Recovery (EOR) projects and the success or failure of a given EOR schemes. The viscosity of crude oil depends on many factors; one of them is the source of chemical composition [1]. So, developing a model of viscosity to include different regions of the world seems to be a very impossible task [2]. Authors in that field are depending on viscosity measurements as interval readings, but this paper is depending on the current readings of viscosity to simulate the reality. So the aim of resent research is the determination of current Egyptian crude oil viscosity as a function of temperatures and pressures and creating mathematical model for this current viscosity with parameters directly indicate compositions which are more valuable and simple to use. In general, the viscosity is defined as the internal resistance of the fluid to flow. The crude oil viscosity is an important physical property that controls and influences the flow of oil through porous media and pipes [3]. Evaluation of viscosity of crude oil is an important for the design of various operations in the crude oil production field. Therefore, the viscosity of crude oil, pressure and temperature dependent, must be evaluated for both reservoir engineering and operation design.

The changing in viscosity with temperature and pressure change is usually predicted empirically. Despite of the importance of viscosity in engineering design, our understanding of such property is inferior to that of equilibrium properties. There are many difficulties in calculating viscosity measurements, especially for olive oil, which is a very important property that should be precisely evaluated for the reservoir simulation. Measuring the viscosity of dead oil is easier using empirical correlations at different temperatures other than the reservoir temperatures. These dead oil measurements are used in calculating live oil viscosity [4]. The difficult and high cost of viscosity measurements at reservoir conditions are the main reason for the weakness of such data. Beal developed a chart that described the viscosities of 655 dead oil samples, representing 492 oil fields around the world and covering viscosities ranging from 0.8 to 155 cP, °API gravities from 10.1 to 52.5 and temperatures from 38°C to 105°C. In addition, Kartoatmodjo and Schmidt [5] represented an empirical correlation to predict the viscosity of dead oil with 3588 data points from 661 dead oil samples that covered gravities ranging from 14.4 to 58.9 API, viscosities ranging from 0.5 to 682 cP, and temperatures ranging from 75°F to 320°F. Labedi [6] also presented the dead oil viscosity in the range of 0.66 to 4.79 cP and °API ranging from 32.2 to 48.0 as a function of API gravity and temperature in the range of 38 to 152°C using 91 data points.

Several correlations for predicting dead oil viscosity are available in the literature review and some of them are discussed in this study, the Beggs and Robinson [7] represented a model for temperatures ranging from 21 to 146°C and El sharkawy and Alikhan [8] also represented a model based on crude oil samples from the Middle East for temperatures ranging from 38°C to 150°C. Naseri et al. [9] provided model for temperatures ranging from 40 to 146°C. Many authors decided that, Beal and Beggs and Robinson equations are

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Received September 07, 2016; **Accepted** September 30, 2016; **Published** October 08, 2016

Citation: Saeed S, Aboul-Fotouh TM, Ashour I (2016) A Current Viscosity of Different Egyptian Crude Oils: Measurements and Modeling Over a Certain Range of Temperature and Pressure. J Pet Environ Biotechnol 7: 305. doi: 10.4172/2157-7463.1000305

Citation: Saeed S, Aboul-Fotouh TM, Ashour I (2016) A Current Viscosity of Different Egyptian Crude Oils: Measurements and Modeling Over a Certain Range of Temperature and Pressure. J Pet Environ Biotechnol 7: 305. doi: 10.4172/2157-7463.1000305

more accurate than previous efforts which might have been true for this viscosity range. However, large errors observed when this model applied outside of these temperatures, viscosity and API ranges. Darko Knežević et al. [10] developed a mathematical model of new correlation for the lubricating oil dynamic viscosity as a function of temperature and pressure. In this work viscosity of Egyptian crude oils with API ranges from 13.4 to 40.4 are measured experimentally over wide range of temperature and pressures and a mathematical model has been developed.

Experimental Study

The dynamic current viscosity, μ of dead crude oil for 6 samples in a temperature range from 20 to 140°C and pressure range from 14.7 to 132.3 psi is determined using a quartz process viscometer apparatus. The quartz processviscometer consists of two components, the electronic device for control and evaluation and the measuring head. The core of the quartz process viscometer is an oscillating quartz sensor that is subjected to dampening by the viscous properties of the surrounding liquid at the measuring head. The type of the sensor is SiO_2 of cylindrical shape with small dimensions. The quartz viscometer's microprocessor contains powerful extrapolation algorithm of the temperature dependent density of the liquid, resulting of a mathematical and physical analysis of the system [11]. Optionally the viscometer can be supplied with a high pressure sample container, which can be used to measure the viscosity of pressurized samples up to 100 bar (1450 psi) at a maximum temperature of 150°C (300°F) as shown in Figure 1. Moreover, the steps for how to use this apparatus are illustrated in Figure 2. These steps are expressed as the following:

1. The sample is filled into the pressure cell (1)

2. Inside the pressure cell a crude oil level of 100 ml is marked (10)

3. The formation of a vortex due to a stirrer with (200 r/m) found so recommended to fill in some more fluid (~103 ml).

4. The sensor head is screwed into the closure head from the below using a suitable copper gasket (3).

5. Before closing the unit, please place the O-ring seal (2) in the notch on the inner side.

6. A location bolt (4) shows the correct orientation of the flange lid; please make sure that the pin enters the corresponding bore (5).

7. After closing the unit, use the 8 screws (6) to close and fix the pressure cell.

8. To improve the temperature regulation, a customizedinsulation jacket (11) can be supplied.

Figure 1: The process viscometer apparatus in the laboratory.

Figure 2: Steps of measurements in the process viscometer apparatus.

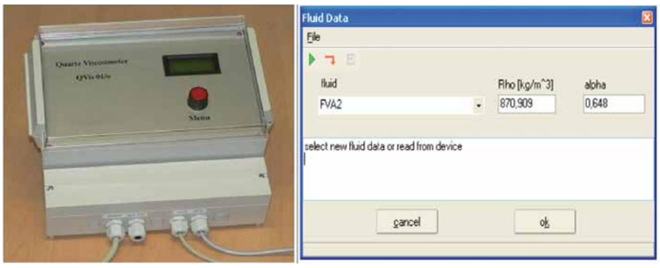

Figure 3: The control unit of the process viscometer apparatus.

9. The needle valve (7) is used to pressurize the unit. The pressure inside the unit is displayed on the pressure gauge (8).

10. For safety reasons an overpressure valve (9) is part of the unit. For the control unit:

At the lower border of the main window is the status line, which displays the settings of "the current measurement" (Figure 3):

- Given density.
- Given coefficient of thermal expansion
- Name of the fluid (if known).
- Number of measurements (or start temperature or measurement duration).
- Stop temperature.
- Temperature (or time) step.

According to the density extrapolation of the samples the process viscometer need to introduce thermal expansion factor (α) which calculated from the following equation (1):

$$\rho t = \rho 15 - (tf - t15) \quad (1)$$

Where:

ρt is the density of the fluid at final temperature in Kg/m^3,

$\rho 15$ is the density of the fluid at 15.5°C,

α is thermal expansion coefficient,

tf is the final temperature of the fluid,

t15 is the temperature of the fluid at 15.5°C.

Every crude oil gravity has certain (α) introduced in the beginning of process measurements. The measurements based on time step as you prefer (ex.: every 15 sec). Also magnetic stirrer is used in samples at 200 revolutions per minute (r/m) (current measurements). After recording the reading of runs from the apparatus, the Figures between the viscosities versus temperatures are plotted. Table 1 describes the data used with these runs. In addition, the chemical composition of the crude oil is related to (specific gravity and Watson characterization factor). And The Watson factor is related to the average boiling point and API gravity of the crude oil through the following relation [12]:

$Kw = (131.5 + API141.5)\ (T_b)1/3$

In the correlations which utilizing the Watson characterization factor, we follow the procedure of Twu [13] for the estimation of dead oil viscosity; which can be briefed as follows:

$\mu od = \gamma oT * vT$

γ_{oT} is the crude oil specific gravity at temperature T and is given by the following relation

$\gamma_{oT} = 0.999012(\gamma_{o\,60} VCF_T)$

γo 60 is the crude oil specific gravity at 60 °F.

VCF_T is the crude oil volume correction factor at 60 °F:

$VCF_T = e^{[-\propto 60\ \Delta(1+0.8\propto 60\ \Delta T)]}$

$\propto_{60}$ is the thermal expansion coefficient at 60 °F:

$$\alpha_{60} = \frac{K_0 + K_1\gamma_{060}}{\gamma_{0\,60}^2}$$

In the quartz process viscometer apparatus, the thermal expansion factor and the density in g/cm³ (specific gravity) of the crude oil at 60°F are essential input parameters for each run. Hence, the apparatus automatically apply this rule in its calculations for the current viscosity in experimental data. So, the composition is taking into consideration in the 5 recent model and the calculated parameters (constants) of the recent model are directly indicated the composition.

Results and Discussion

The new model

The experimental data of the dynamic current dead oil viscosity of 6 samples with different API values is measured with in the temperature range and pressure range of (20°C to 150°C), (14.7 to 132.3 Psi). The ASTM shows that dead oil viscosity is classified according to its standard API at 15.5°C which is the first parameter for any model, and the second parameter is the value of the measured temperature [14,15]. According to literature review, most of the previous models are based on, sometimes two parameters, the API and temperature to calculate the dead viscosity. In most cases, API parameter has no physical meaning [16] Therefore, another parameter is used with temperature, such as pressure. The objective is to create a model in the following formats to calculate the dead oil viscosity.

Variable	Range
API	13.4 to 40.4
Temperature (ºC)	20 to140
Pressure (psi)	14.7 to 132.3
Density (g/cm³)	808.8 to 975.6
Thermal expansion factor (α)	0.65 to 0.7
Revolution / minute (r/m)	200

Table 1: Description of data used with samples.

$$\mu_{od} \propto (T,) \quad (2)$$

Where: μ_{od} is the dead oil viscosity in cP,

T is the temperature in °C,

P is the pressure in psi.

Before creating the new current viscosity model, understanding the relationship. Between the input and output variables is important. Specifically, identifying which parameters are insignificant and can be eliminated from the final model and the parameters that are highly correlated with the output. Accordingly, the current dead oil viscosity (μod) is considered to be a function of temperature (T) and pressure (P). As shown in plotting the data yields Figure 4. It illustrates how viscosity changes according to temperature and pressure changes. As illustrated in Figure 4 the viscosity decreasing by increasing temperature and when measuring the viscosity at different pressures are observed that the value of viscosity increased by increasing the pressure at certain API. More addition, due to the samples of crude oils is prepared from different Egyptian company's fields so there is a difference in composition. Figure 5 illustrates the relationship between current viscosity and frequency (the frequency is a parameter given by the quartz viscometer apparatus) for every run at (0.3, 6.9 bar) and 200 r/m. Additionally, it shows decreasing in current viscosity with increasing the frequency of the fluid. Moreover, Reynolds Number is calculated at temperature intervals (50°C, 100°C, 150°C) from the following relation to know the type of flow [17].

$$N_{Re} = D\ N\ \rho\ /\mu \quad (3)$$

Where: D is the inside diameter of the crude cylinder in the quartz process viscometer.

N = The agitator speed (rph).

ρ = The density of the crude given by the apparatus.

μ= The viscosity of the crude given by the apparatus

The NRe >10,000 the flow is turbulent.

The validity of the new viscosity model

After testing many previous viscosity equations for all the experimental viscosity data for this study as a function of pressure and temperature, the results show that the following equation is set to be presented the data in this work and give us correlation coefficients (R2) up to 0.99 as follow:

$$\mu_{0d}(\mathrm{P,T}) = \mathrm{a}e^{\left[\frac{b}{(T-c)}\right]} e^{\left[P/(a_1+a_2T)\right]} \quad (4)$$

Where: μ_{od} is the dynamic viscosity in cp, T is the temperature in °C and P is the pressure in psi. (a, b, c, a1, a2) are constants (parameters directly indicate composition). The model can predict the current dead oil viscosity with an average percentage absolute relative error (AARE) of 3% and correlation coefficient (R2) of 0.991. The results are evaluated and tested using different techniques. One of the main challenges in this study is that most of the existing models in the literature are limited to certain ranges of temperature, API value. But this study represents the current viscosity at different ranges of temperatures and pressures with

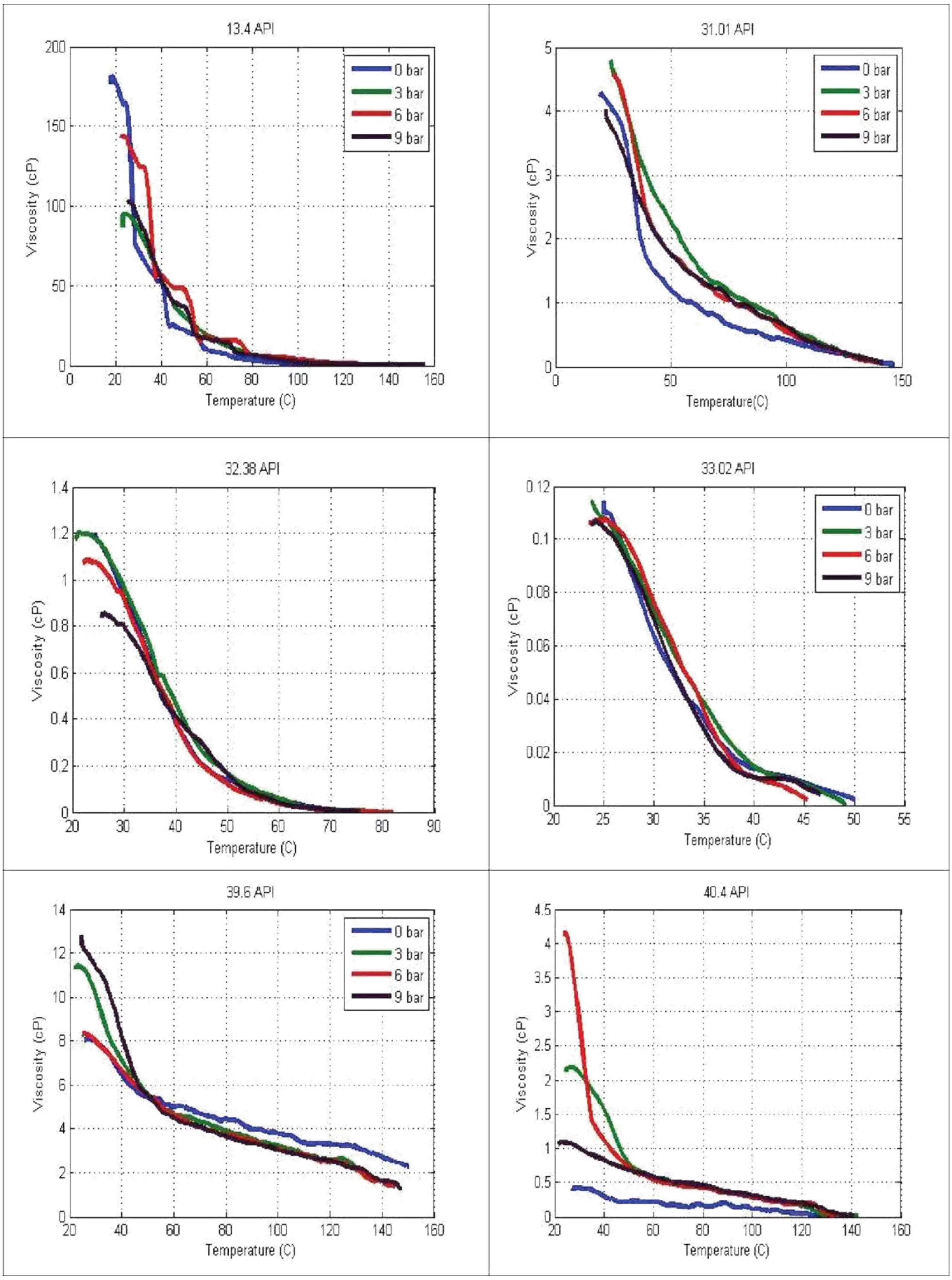

Figure 4: Experimental data of different Egyptian crude oil samples viscosities.

constant parameters which directly indicate composition.

Table 2 indicates the values of (a, b, c, a1, a2) related to each run of the data set. To check the ability of the new current viscosity model to indicate all experimental data, cross plots are used. The values are in a good agreement, with the average percentage absolute relative error and standard division comparing with previous models as indicated in Table 3. Table 4 indicates the evaluation of the new model for prediction of the current dead oil viscosity. In addition, the absolute percentage average relative error (AARE%) and the standard percentage deviation (SD%) tests are performed between the calculated and the measured

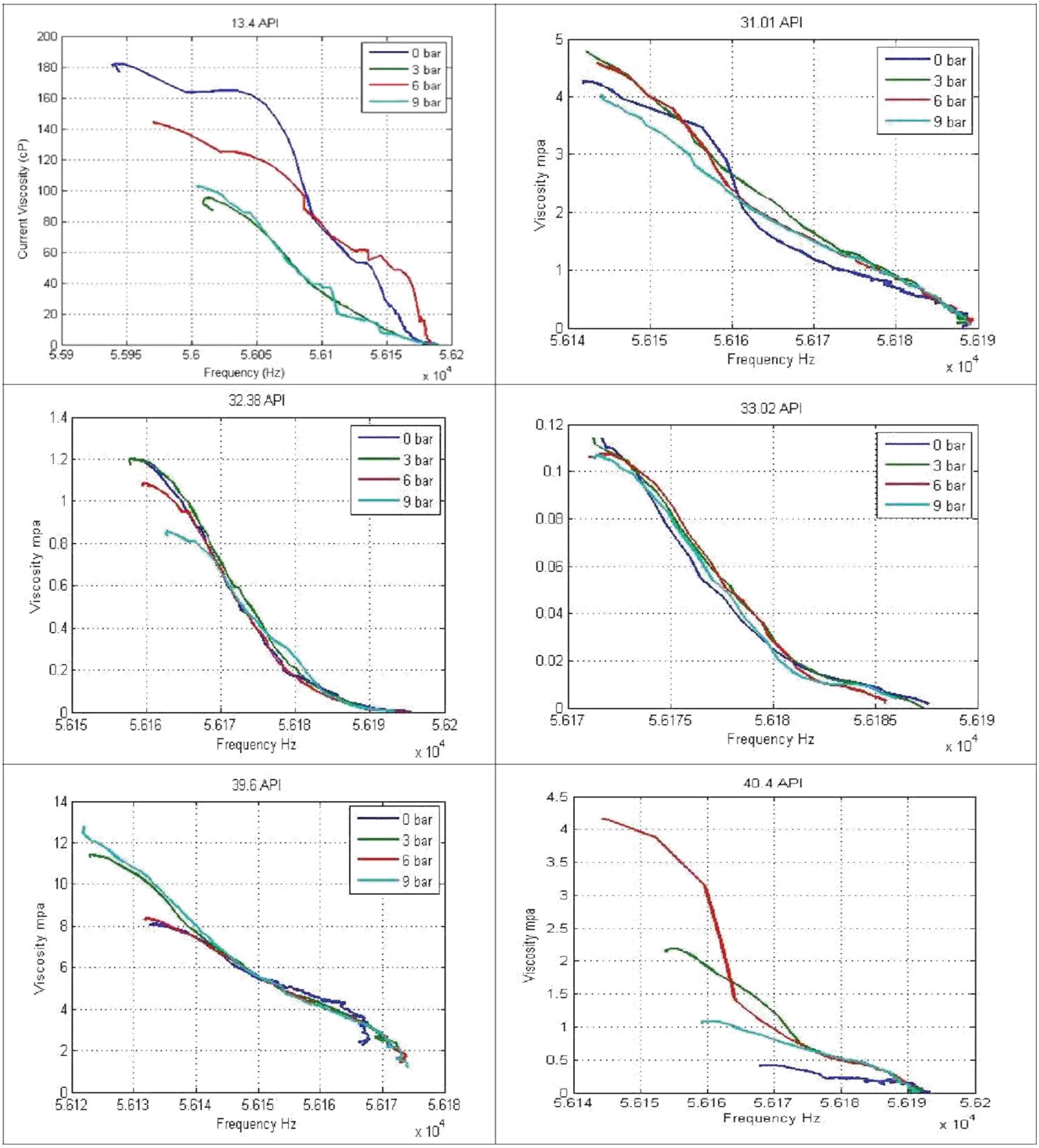

Figure 5: Experimental data of different Egyptian crude oil samples viscosities.

results by the following expressions:

$$AARE\% = \left|\frac{(measured - calculated)}{measured}\right| * 100 \quad (5)$$

$$SD = \frac{1}{1-N}\sqrt{\sum_{i=1}^{N}\left(\left|\frac{measured - calculated}{measured}\right| - AARE\right)2} \quad (6)$$

Where: *i* is the sample number and *N* is the total number of samples.

The new model shows the lowest average percentage absolute

Parameters (directly indicate composition)	Values of parameters at different pressures (Psi)				°API
	14.7	44.1	88.2	132.2	
a	1.007	0.000212	6.475	2.717	13.4
b	-20.38	4.405	102.7	115.7	
c	-1.897	-0.6139	-9.704	-5.272	
a1	1.469	-10.28	-2241	-4769	
a2	0.04793	1.491	239	483.6	
a	0.9112	0.9423	0.0293	1.006	39.6
b	0.142	3.759	0.0085	-4349	
c	-376.3	-1105	26.11	0.7489	
a1	5.301	11.57	14.35	0.4612	
a2	0.0538	0.2569	0.0488	0.24	
a	0.3132	0.0043	0.0017	0.00603	31.01
b	65.56	-0.00346	-0.001	302.1	
c	-5.811	26.1	25.45	-139.7	
a1	-7.439	5.511	9.61	24.52	
a2	5.435	0.0324	0.0583	0.1663	
a	0.00017	0.0044	511.6	4.585	33.02
b	0.7921	26.34	161.8	1395	
c	0.6613	57.57	63.64	239.4	
a1	0.8194	9.282	-17.72	-10.79	
a2	0.0576	0.0796	-0.121	2.401	
a	1.08E-06	0.00323	0.0704	3.34E-06	40.4
b	-0.0124	-2.86	125.6	0.00297	
c	26.97	19.82	-6.978	21.67	
a1	1.078	4.876	625	9.934	
a2	0.002261	0.05478	22.28	0.0183	
a	0.05061	0.07867	0.0368	1.21E-07	32.38
b	-34.77	-89.97	-86.09	-28.9	
c	4.174	2.507	8.988	13.2	
a1	-0.1303	-0.208	-2.118	5.831	
a2	0.1268	0.2811	0.4903	0.05881	

Table 2: The values of modeling parameters at different pressure and API.

References	Average absolute relative error % (AARE %)	Standard deviation% (SD %)
Beal	31.6	37.3
Beggs and Robinson	21.2	28.0
Glaso	27.4	31.9
Labedi	29.7	42.6
Kartoatmodjo and Shmidt	33.1	37.25
Ibrahim Ashour	19.2	25.8
Osama Alomair	8	203.7

Table 3: Average absolute relative error and standard deviation of previous model.

relative error and standard percentage deviations relative to the others. Figure 6 shows the behavior of a new model according to the experimental and calculated values. The new model provides the best prediction without any scattering between the experimental data and the calculated one, thus the new model presents high value of correlation coefficient. Figure 6 consists of plots for 6 samples at (13.4, 31.01, 32.38, 33.02, 39.6, 40.4) API.

Conclusion

Although, crude oils of different compositions can have the same °API gravity, significant errors may be introduced when the viscosities of crude oils are estimated from general viscosity trends and the API gravity. The new current dead oil viscosity model is a function of temperature T and pressure P with constant parameters that directly indicate composition which are more valuable and simple to use. Impossible to find any similarity between this study and previous one because all measurements are current viscosity, the crude oil is in continues motion in the apparatus at 200 revolutions per minute (r/m). The temperature is increased automatically up to 150°C and the reading is taken automatic with time step as the user prefer. The pressure range used is chosen to unique the pressure inside the pipe line which the fluid (crude oil) is transferred across. So, this process is simulated to the reality. The validity of the agreement between the experimental current dead oil viscosity data and the predicted values indicates that the new model successfully represents the experimental data with an average percentage absolute relative error less than 3% and correlation coefficients ranging from 0.99 to 0.94 at different temperatures and pressures. From the statistical analysis, the new model is present as one of the best models by comparing it with other models published in the literature. The new model shows it is easy to use different temperatures

API	Pressure (psi)	Average Absolute Relative Error (AARE%)	(Standard Deviation) SD %	R2
13.4	14.7	0.056	0.00452	0.9739
	44.1	0.144	0.937	0.9186
	88.2	0.1756	0.474	0.8867
	132.3	0.1037	0.856	0.918
31.01	14.7	0.0792	0.0023	0.886
	44.1	0.03	0.0388	0.9862
	88.2	0.0078	0.00569	0.9881
	132.3	0.0199	0.0302	0.9798
32.38	14.7	0.0772	0.3135	0.9138
	44.1	0.116	0.4587	0.8327
	88.2	0.1377	0.177	0.9007
	132.3	0.0826	0.5554	0.991
33.02	14.7	0.0557	0.725	0.9784
	44.1	0.3047	4.36	0.9285
	88.2	0.0787	1.127	0.9665
	132.3	0.1876	2.502	0.9207
39.6	14.7	8.12E-05	0.00019	0.9787
	44.1	4.95E-05	1.95E-05	0.9897
	88.2	0.00068	0.000652	0.9879
	132.3	0.00632	0.00998	0.9844
40.4	14.7	0.00451	0.00134	0.9304
	44.1	0.00804	0.00763	0.9876
	88.2	0.0413	0.0213	0.9744
	132.3	0.0315	0.0917	0.9522

Table 4: Accuracy of Egyptian crude oil model for estimating viscosity of recent study.

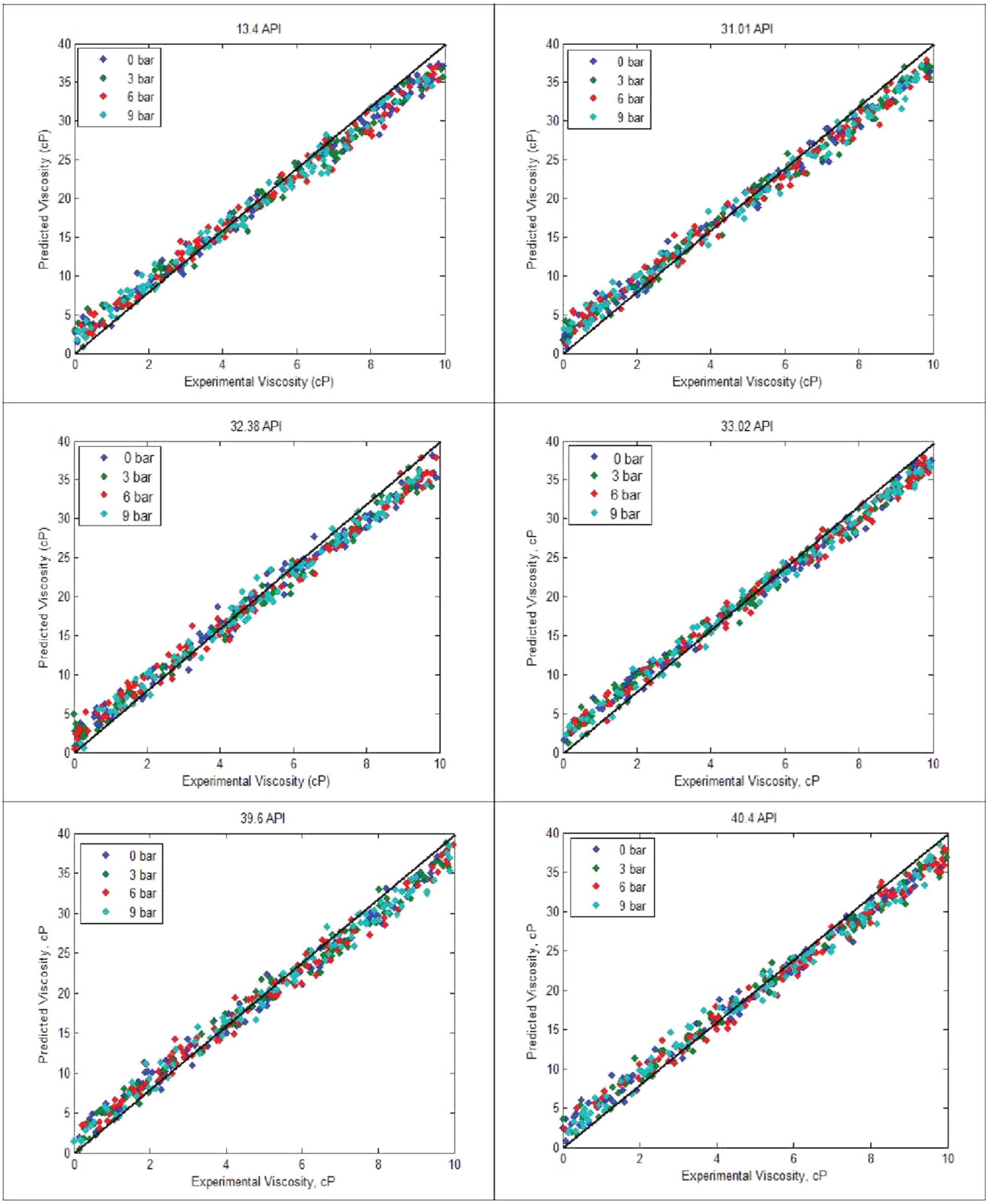

Figure 6: Deviation of experimental current viscosity data from predictive values using the new model.

and pressures to predict current viscosity, provide best accuracy over a wide range of oil gravities, and could be used to predict better outcomes in future works.

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