Testing of viscosity correlations for crude oil samples

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الملخص

تعتبر لزوجة النفط الخام خاصية فيزيائية مهمة لأنها تؤثر على تدفق النفط عبر الوسائط المسامية، ويمكن بشكل عام الحصول على لزوجة النفط بطريقتين، إما عن طريق إجراء قياسات تجريبية أو تقديرها بواسطة نموذج مناسب. في هذا البحث استخدم الارتباط الدقيق في حساب لزوجة النفط في ظروف التشغيل المختلفة سواء للزيوت المشبعة أو تحت التشبع. تم اقتراح العديد من الارتباطات التجريبية لحساب النفط المشبع وغير المشبع، تم الحصول على البيانات المختبرية للعثور على أفضل ارتباط، ثم تأكيد الدقة من خلال مقارنة النتائج التي تم الحصول عليها من الارتباط والنتائج الأخرى مع التجارب لعينات الزيت.

Abstract

Oil viscosity is an important physical property that controls and influences the flow of oil through porous media .Generally oil viscosity can be obtained in two ways, either by carrying out experimental measurements or estimated by a proper model. In this paper use an accurate correlation in calculating the oil viscosity at various operating conditions either for dead saturated or under saturated oils. Several empirical correlations have been suggested for calculation of the dead,saturated,and undersaturated oil, whenever laboratory data obtained are made to find a best-fit correlation ,accuracy confirmed by comparing the obtained results of the correlation and other ones with experimental for oil samples.

Keywords: undersaturated oil, dead saturated oil viscosity factor

INTRODUCTION

Viscosity is defined as the internal resistance of the fluid to flow which is related to the internal resistance or friction and is there for related to the mobility of the fluid and is measured as the ratio of the shearing stress to the rate of shearing strain.

Dynamic viscosity

Is a measure of the internal resistance and is a tangential force per unit area required to move one horizontal plane with respect to the other at unit velocity when maintained a unit distance apart by the fluid.

Kinematic Viscosity

Is defined as the ratio of dynamic viscosity to density a quantity in which no force is involved and can be obtained by dividing the dynamic viscosity of a fluid with its mass density[1].

$$V = \mu / \rho$$

Where:

V = Kinematic Viscosity

μ = dynamic viscosity

ρ = density

* Types of fluid characterizations are:

1. Newtonian (true fluids) where the ratio of shear stress to shear rate or viscosity is constant ,e.g.water,oil,etc.
2. Non-Newtonian (plastic fluids) where the viscosity is not constant.

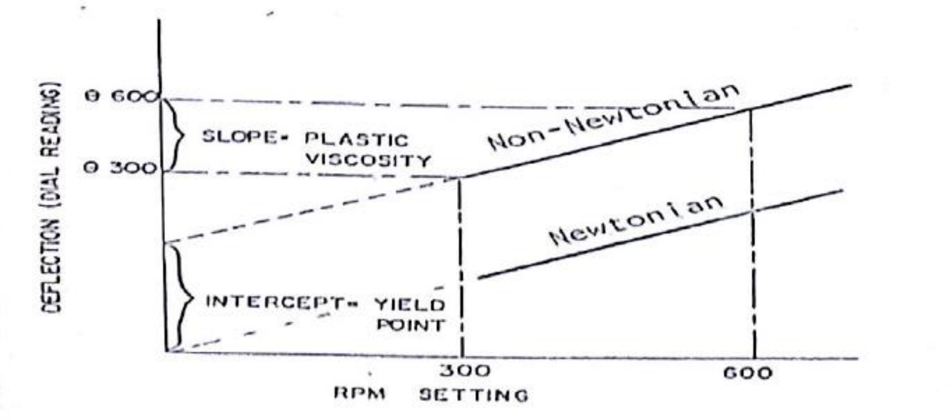


Fig (1) Types of fluid characterizations

The oil viscosity is a strong function of the temperature, pressure, oil gravity, gas gravity, and gas solubility. Whenever possible, oil viscosity should be determined by laboratory measurements at reservoir temperature and pressure. The viscosity is usually reported in standard PVT analyses. If such laboratory data are not available, engineers may refer to published correlations, which usually vary in complexity and accuracy depending upon the available data on the crude oil[2]. According to the pressure, the viscosity of crude oils can be classified

Into three categories:

• **Dead-Oil Viscosity μ_{od}**

The dead-oil viscosity is defined as the viscosity of crude oil at atmospheric pressure (no gas in solution) and system temperature.

• **Saturated-Oil Viscosity μ_{ob}**

The saturated (bubble-point)-oil viscosity is defined as the viscosity of the crude oil at the bubble-point pressure and reservoir temperature.

• **Undersaturated-Oil Viscosity μ**

The undersaturated-oil viscosity is defined as the viscosity of the crude oil at a pressure above the bubble-point and reservoir temperature. Estimation of the oil viscosity at pressures equal to or below the bubble-point pressure is a two-step procedure:

Step 1. Calculate the viscosity of the oil without dissolved gas (dead oil), mob, at the reservoir temperature.

Step 2. Adjust the dead-oil viscosity to account for the effect of the gas solubility at the pressure of interest.

At pressures greater than the bubble-point pressure of the crude oil, another adjustment step, i.e. Step 3, should be made to the bubble-point oil viscosity, mob, to account for the compression and the degree of undersaturation in the reservoir.

Crude oil types

Crude oil is different from field to another in appearance, and viscosity They range in color, odor, and in the properties they contain, crudes are roughly classified into three groups , according to the nature of the hydrocarbon they contain:

- Paraffin-Base crude oils

These contain higher molecular weight paraffin which is solid at related temperature, but little or no asphalile matter, they can produce high-grade lubricating oils.

- Asphaltie-Base crude oils

Contain large proportions of asphalite matter, and little or no paraffin. Some are predominantly naphthenic so yield lubricating oil that is more sensitive to temperature changes than the paraffin-base crudes.

- Mixed-Base crude oils

The gray area between the two types above .Both paraffin's and naphthenic are present, as well as aromatic hydrocarbons, most crude fit this category.

- Heavy crude oil :

Is any type of crude oil which does not flow easily. It is referred to as heavy because its density or specific gravity is higher than that of light crude oil. Heavy crude oil has been defined as any liquid petroleum with API gravity blew 10.0 °API[3-4].

Methods for estimating the viscosity:

The chosen methods are well known, accepted as potentially promising methods. They are categorized as semi-theoretical or empirical and further distinguished as predictive or correlative.

❖ Semi-theoretical methods:

Semi-theoretical are derived from a theoretical framework, but involve parameters experimentially determined.

❖ Empirical methods

Empirical methods include a wide variety of equations used throughout the industry involving constants calculated from experimental data.

Viscosity of crude oil types:

According to the pressure, the viscosity of crude oils can be classified into three categories:

1. Dead oil viscosity correlation,μ_{od}:

The dead-oil viscosity is defined the viscosity of crude oil at atmospheric pressure (no gas in solution) and system temperature. [5].

Viscosity correlations of the Dead oil:

- **The Beggs-Robinson correlation**

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

Where:

$$x = 1.0^{(3.0324-0.02023*°API)} \times T^{-1.163}$$

- **Labedi correlation :**

$$\mu_{od} = 10^{9.224} / (API^{4.7013} * T^{0.6739})$$

- **Petrosky and farshad correlation**

$$\mu_{od} = 2.3511*10^{7}*T^{-2.10255} * (\log API)^{(4.59388*(\log T) - 22.82792)}$$

- **Naseri correlation :**

$$\mu_{od} = 10^{(11.2699 - 4.2699 x \log(API) - 2.052 x \log(T))}$$

- **Kaye correlation :**

$$\mu_{od} = 10^{(T-0.65x10(2.305-0.03354xAPI)} - 1$$

- **Hossain correlation :**

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

Viscosity correlation for saturated oil:

The chew-connally correlation:

$$\mu_{ob} = (10)^{a}(\mu_{od})b$$

where:

$$a = Rs[2.2(10^{-7})Rs - 7.4(10^{-4})]$$

$$b = 0.68/10^{c} + 0.25/10^{d} + 0.062/10^{e}$$

$$c = 8.62(10^{-5})Rs$$

$$d = 1.1(10^{-3})Rs$$

$e = 3.47(10^{-3})Rs$[6,7,8].

2. Saturated oil viscosity correlation, μ_{od};

The saturated (bubble-point)-oil viscosity is defined as the viscosity of the crude oil at the bubble-point pressure and reservoir temperature.

Viscosity correlation for saturated oil

- **The Beggs-Robinson Correlation**

The $\mu_{ob} = a(\mu_{od})^{b}$

where:

$a = 10.715(R_s + 100)^{-0.515}$

$b = 5.44(R_s + 100)^{-0.338}$

- **The Labedi Correlation:**

$\mu_{ob} = (10^{2.344-0.03542xAPI}) \times (\mu od^{0.6447}) / (Pd^{0.426})$

- **The Kartoatmodjo and Schmidt correlation :**

$\mu_{ob} = -0.6821 + 0.9824 \times F + 0.0004034 \times F^2$

where

$F = (0.20001 + 0.8428 \times (10^{-0.000945xRs}) \times \mu_{od}(0.43+0.5165 \times 10^{-0.00081xRs}))$

- **The modified kartoaimodjo correlation:**

$\mu_{ob} = 0.0132 + 0.9821xF - 0.005215x F^2$

where:

$F = (0.2038 + 0.8591 \times (10^{-0.000945xRs}) \times \mu_{od}(0.385+0.5664 \times 10^{-0.00081xRs}))$

- **Elsharkawy & Alikhan correlation:**

$\mu ob = a(\mu_{od})^b$

Where:

$a = 1241.932(Rs + 641.026)^{-1.1240}$

$b = 1768.841(Rs + 1180)^{-1.06622}$ [9,10,11].

3. Under saturated oil viscosity correlation, $\mu_{o:}$

The under saturated oil viscosity is defined as the viscosity of the crude oil at a pressure above the bubble-point and reservoir temperature. Under saturated oil viscosity correlation, which usually use saturated crude oil. These correlations are:

- **Beal correlation:**

$\mu_o = \mu_{ob} + 0.001 \times (p - pb)(0.024\,\mu_{ob}^{1.6} + 0.038\,\mu_{ob}^{0.56})$

- **Vasques & Beggs correlation**

$\mu_o = \mu_{ob}\,(p/pb)^m$

Where

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

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

- **Khan & Ali correlation:**

$\mu_o = \mu_{ob} \times Exp\,(9.6x10^{-5}(p-pb))$

- **Labedi correlation:**

$\mu_o = \mu_{ob} - M\,(1 - (p/pb))$

where

$M = (10^{-2.488} \times \mu od^{0.9036} \times pb^{0.6151}) / 10^{0.01976 \times API}$

- **Kartoatmodjo & Schmidt correlation:**

$\mu_o = 1.00081\,\mu_{ob} + 0.001127(p - pb) \times (-0.006517\mu_{ob}^{1.8148} + 0.038\mu_{ob}^{1.590}$

- **Elsharkawy & Alikhan correlation:**

$\mu_o = \mu_{ob} + 10^{-2.0771}(p - pb) \times (\mu_{ob}^{1.1279} + \mu_{ob}^{-0.40712} \times pb^{-0.7941}$

where:

μo = viscosity of the undersaturated oil at reservoir pressure and temperature,cp

μob = viscosity of the saturated oil at the bubble –point pressure,cp

μod = viscosity of the dead oil at 14.7 psia and reservoir temperature ,cp

p = Reservoir pressure, psi

Pb = Bubble point pressure ,psi[5].

Experiments of viscosity:

The viscosity of hydrocarbon mixtures and petroleum reservoir fluids is commonly measured by either the rolling ball viscometer or the capillary tube viscometer.

Table(1) Experimental data of samples oil

Sample #	API	T (°F)	Rs (SCF/STB)	Pb (psi)	P (psi)	μod,cp (EXP)	μob,cp (EXP)	μo,cp (EXP)
1	38	131	173	375	3015	2.57	1.43	1.82
2	39	161	521	1400	5000	1.94	0.69	0.82
3	42	167	138	340	3015	1.62	0.73	0.93
4	49	170	930	1655	5015	0.63	0.49	0.57
5	48	174	800	1560	5015	0.86	0.43	0.50
6	47	176	1762	2445	5000	0.81	0.29	0.44
7	37	184	1382	3302	4509	1.65	0.28	0.45
8	43	200	119	287	3015	1.00	0.76	0.87
9	36	210	90	495	3015	2.16	1.07	1.42
10	39	250	1738	5935	7015	3.14	0.55	0.59
11	37	258	1216	2805	5615	0.85	0.41	0.47
12	41	262	536	1525	5015	1.97	0.53	0.63
13	38	263	864	3130	5515	1.04	0.38	0.51
14	30	270	649	3002	5206	1.37	0.66	0.73
15	42	285	904	3240	4515	0.69	0.40	0.45

Results and Discussion

- **Calculation of Dead oil viscosity correlation**

Using the correlation to estimate the viscosity of dead oil, and calculate average relative Error (ARE %) and absolute average relative Error (AARE %)

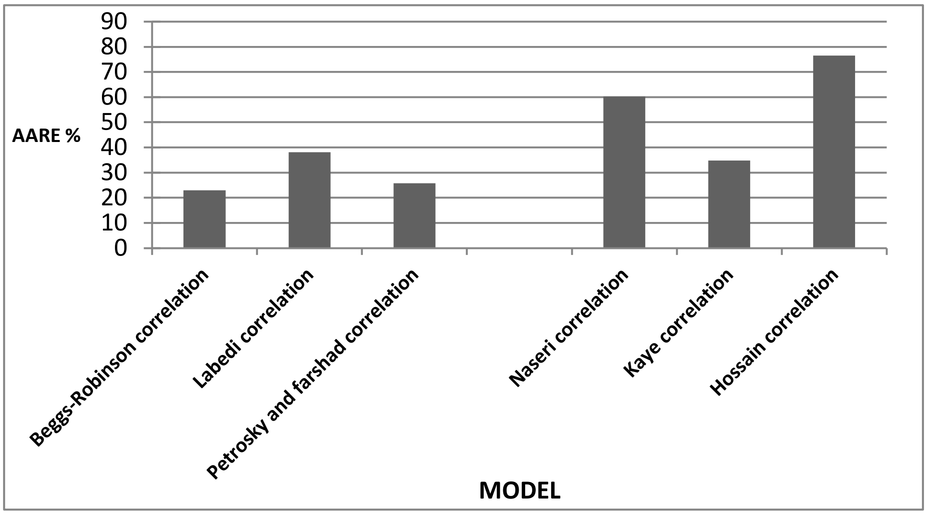
$$ARE\ (\%) = 1/N\ \Sigma^{N}_{i=1} [\ (X_{Experiment} - X_{calculation})]\ /\ X_{Experiment}\quad x\ 100$$

$$AARE\ (\%) = 1/N\ \Sigma^{N}_{i=1} [\ (X_{Experiment} - X_{calculation})]\ /\ X_{Experiment}\quad x\ 100$$

$i = 1,2,3 \ldots\ldots N$

Table(2) Values of average relative error and absolute average relative error of dead oil

MODEL	ARE%	AARE%
Beggs-Robinson correlation	2.97	23.03
Labedi correlation	14.18	38.15
Petrosky and farshad correlation	18.92	25.81
Naseri correlation	60.17	60.17
Kaye correlation	23.56	34.86
Hossain correlation	75.27	76.51



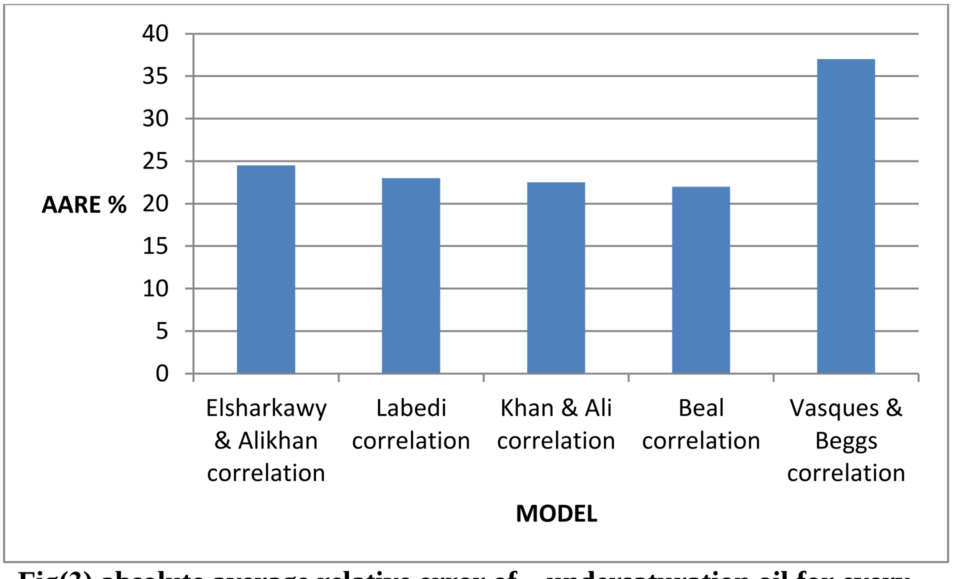
Fig(2) absolute average relative error of dead oil for every model

- **Calculation of undersaturation oil viscosity correlation**

Table(3) Values of average relative error and absolute average relative error of undersaturation oil

MODEL	ARE%	AARE%
Kartoatmodjo & Schmidt	19	25

correlation		
Elsharkawy & Alikhan correlation	8.5	24.5
Labedi correlation	11	23
Khan & Ali correlation	3.5	22.5
Beal correlation	11.5	22
Vasques & Beggs correlation	14	37



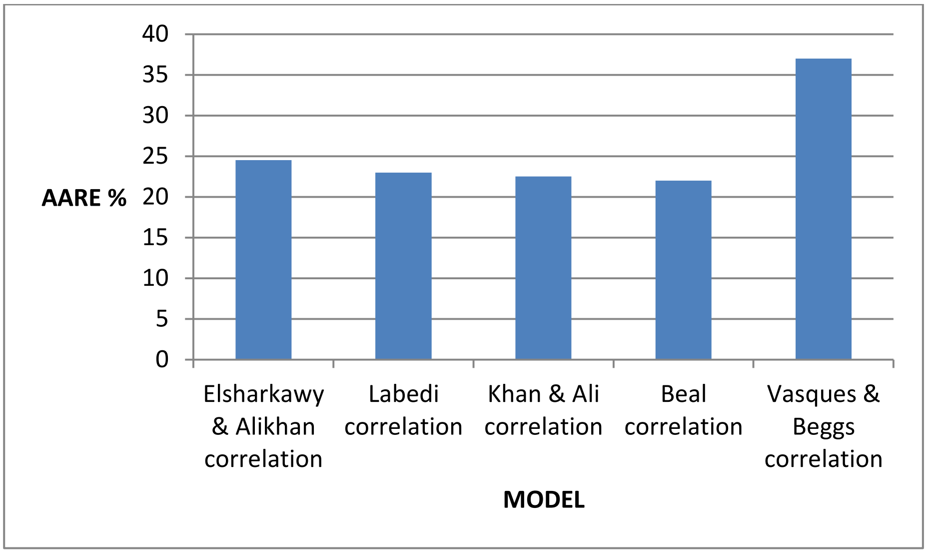
Fig(3) absolute average relative error of undersaturation oil for every model

- **Calculation of undersaturation oil viscosity correlation**

Table(4) Values of average relative error and absolute average relative error of undersaturation oil

MODEL	ARE%	AARE%
Kartoatmodjo & Schmidt correlation	19	25
Elsharkawy & Alikhan correlation	8.5	24.5
Labedi correlation	11	23
Khan & Ali correlation	3.5	22.5

Beal correlation	11.5	22
Vasques & Beggs correlation	14	37



Fig(4) average relative error and absolute average relative error of undersaturation oil for every model

Conclusion

Most common method for calculating viscosity of crude oil is the viscosity correlations.

In this work the following conclusion have been obtained during the investigation

- Bergman and Beggs & Robinson ,are the best correlations, and most accurate for Dead Oil Viscosity, due to the less error percent. It is not preferred to Naseri and Hossain correlations; because of it is high proportion of error.
- Modified Kartoatmodjo and Elsharkawy & Alikhan correlation are the best and accurate for saturation oil viscosities, also it is not for favor to use Labedi, and the Kartoatmodjo & Schmidt correlation.
- Beal's and Khan & Ali correlation are preferred to get accurate results for of the Undersaturated oil, and it is not recommended to apply

Kartoatmodjo & Schmidt , and Vasques & Beggs correlation due to the high proportion of error.

- The best estimate of the dead, saturated, and undersaturated oil viscosity for Libyan crude oil exmined in this study was found to be provided by Bergman, modified Kartoatmodjo, Beal's correlations for each type respectively.

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