DEVELOPMENT OF A NEW CORRELATION TO PREDICT VISCOSITY OF PETROLEUM FRACTIONS

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Abstract

Knowledge of temperature dependence of liquid viscosity plays an important role in a variety of engineering problems in oil and gas transportation. In this work an experimental database was established, which consists of kinematic viscosity for several petroleum fractions in kerosene and gas oil ranges. A new correlation was developed to predict the effect of temperature on Kinematic Viscosity of petroleum fractions of a wide boiling range from 30 to 200^{o}C. This correlation is based on the correlation of viscosity of pure hydrocarbons that had been developed by Mehrotra (1995). Fitting parameters have been evaluated for 235 experimental data points from 31 true boiling point fractions of Libyan crude oils and for 144 data points Arab heavy, Arab medium, and Arab Berri crude oils. In addition, fitting parameters have also been evaluated for both Libyan and Arabian and other world crude-oil fractions. The proposed correlation fits the kinematic viscosity data with an overall average relative error of 2.7 % for the 33 Libyan crude oil fractions and 2.4 % for the 167 Arabian crude oils fractions, and 3.0 % for the 35 other world fractions.

Keywords: Kinematic viscosity, modeling, petroleum fraction, Libyan crude oil

Introduction

Most processes are based on the use of fluids as raw material, reagents, or heat transfer media. The behavior of a fluid in flow is very much related to two intrinsic properties of the fluid density and viscosity Gautam (2013), Watson et al. (1935). Therefore, viscosities of these fluids play a very important role in the processing of materials. The viscosity behavior of crude oils is qualitatively similar to that of pure liquids. Oils are known to become less viscous as temperature increases, but no theory has yet been formulated to predict precisely the variation in viscosity of liquids with temperature Eyring (1936).

Petroleum is a complex mixture consisting mainly of hydrocarbons and contains minor quantities of sulfur, nitrogen, oxygen, and metals. The physical and chemical characteristics of crude oils, and the yields and properties of products or fraction made from them, vary considerably and are dependent on the concentration of the various types of hydrocarbons and the minor constituents. Furthermore, analysis in terms of individual components is not practical, which makes the theoretical development of predictive procedures extremely difficult Ely et al. (1981), Mehrotra (1994), Beg et al. (1988).

Besides experimental investigation, different viscosity models were evaluated for prediction of heavy oil/solvent viscosity. It was recognized that Lederer model is the best one Amir H., et al. (2016). Furthermore, a numerous correlative and predictive methods have been proposed for studying the effect of temperature on the viscosity of petroleum fraction Eyring (1936), Amin et al. (1980), Beg et al. (1988), Mehrotra (1995), Mehrotra et al. (1996), ASTM (1997), Soltani et al. (2010) and Meyer et al. (2014). The most widely used approach in calculating petroleum product blends is the ASTM method [14], which is based on the additive quantity:

$$\log\log(v_b + 0.8) = \sum(X_i/100)\log\log(v_i + 0.8) \quad (1)$$

where:

v_b and v_i are the kinematic viscosities at a given temperature, of the blend and of the blend components, in cst, Xi is the percentage of the given components in the blend.

Recently, a generalized kinematic viscosity-temperature correlation for undefined petroleum fractions of all boiling ranges including 455 °C+ fraction have been developed by Amin et al. Amin et al. (1994), which based on Eyring's equation. The only characterization properties required for the estimation are API gravity, 50% boiling point and molecular weight.

Soltani et al. in (2010) reported a generalized equation based on modified Eyring's theory for predicting kinematic viscosity of petroleum fractions. The equation required only molecular weight and boiling point. They used two reference fluids for each range of molecular weights Soltani et al. (2010). Edreder, and Mezughi in 2014 established experimental database consists of density and kinematic viscosity of some distillated petroleum fractions in different boiling temperature ranges derived from Libyan crude oils at several temperature levels (30, 35, 40, 50 °C). Then, they modified and used McAllister to predict viscosities of these fractions Edreder et al. (2014). New empirical PVT correlations have been developed Recently by Khazam et. al (2016) for Libyan crudes with reliable degree of accuracy. These include; bubble point pressure, oil formation volume factor, stock tank oil molecular weight, oil viscosity, saturated oil viscosity and under-saturated oil viscosity Khazam et al. (2016).

Another correlation has been developed by Mehrotra for pure component Moharam (1995) and modified by Shanshool et. al. to represent the data for petroleum fractions Shanshool et al. (2001), as follows:

$$Log\ (\nu\ + 0.7)\ =\ 100(0.01T)\ b \tag{2}$$

$$b = -5.745 + 0.616\ln(ECN) - 40.468(ECN)^{-1.5}$$

$$ECN(Tb, API) = -1799.8195 - 0.0403386\ \mathrm{Tb} + 8.19416 * 10^{-5} Tb^2 - 352.52229\ (\mathrm{Tb/API})^{0.1}\ + 2158\ (\mathrm{Tb/API})^{0.02}) \tag{3}$$

Another expansion was made on Shanshool model's to get accurate data on effect of temperature on the viscosity of petroleum fraction Shanshool et al. (2001). This new approach was done by introducing molecular weight as a new parameter to have an equation for ECN as:

$$\mathrm{ECN}\ (\mathrm{Tb, API, MW}) =\ 127.80102\ +\ 0.2726758\ Tb\ - 33.939922\ (Tb/MW)\ + 0.47842702\ (Tb/API)\ - 1.1614052MW\ +\ .0014715009MW^2 \tag{4}$$

where:

Tb = 50% boiling point, K;
ECN=Effective carbon number;
ν =Kinematic viscosity, cSt;
MW= molecular weight

The characterization properties required for the previous correlation are API gravity, 50% boiling point and molecular weight. Thus, this correlation required the calculation of the MW which is not an easy procedure. Recently Khazam et. al. have used calculated stock-tank molecular weight (Mwt) in oil viscosity correlation based on the temperature and molecular weight parameters in which molecular weight is determined using the following equation:

$$\mathrm{Mwt} = \frac{6255.8}{(\mathrm{API} - 6.27)} \tag{5}$$

where:

Mwt= Calculated stock-tank molecular weight (lb/lbmol) and

API = Investigated oil gravity.

This equation have been used to estimate the molecular weight of the investigated oil fractions. Khazam et al. (2016).

To this end, the aim of this work is to obtain a generalized kinematic – temperature correlation for liquid petroleum fractions of a wide boiling range and to study viscosity measurements of petroleum fraction cuts with temperature. The correlations that will be developed are purely depending on the correlation of viscosity of pure hydrocarbons that had been developed by Mehrotra.

Experimental

Materials

Two Libyan crude oils were selected. The selected crude oils are, Hamada, and Sharara. The crude oils were distillated in the Azawiya Refinery laboratory to obtain the samples under investigation, these are: Kerosene range. The ASTM D2892 procedure for crude distillation was followed.

Density measurement

The densities of the petroleum fractions were obtained by Mettler/Paar DMA48 which is based on measuring the period of oscillator of a hollow vibrating U-shaped tube, which is filled with sample liquid. The precision and accuracy of the density measurements with accuracy of 1x 10^{-4}th g/cm^3, resolution 1x10^{-5}th and the calibration procedure has been done by dry air and double-distilled water, after completing the calibration procedure, xylene sample (density at 20 °C =0.867±0.005) was used to check the calibration period.

Viscosity measurement

The viscometer used herein was a Cannon-Fenske type for transparent liquids (size 50 ranging from 0.8 to 4.0 cSt), immersed in thermostatic bath using water as a medium, the temperature is controlled within 0.01 K. An electronic stopwatch with accuracy of 0.01 s is used to measure the efflux time. Kinematic Viscosities were obtained from the measured efflux time, t, and the equation:

$$\nu = C\,t \qquad (6)$$

Where ν = kinematic viscosity, mm^2/s, C = calibration constant of the viscometer (cSt/s) and t = measured flow time, s. The constant was determined by using calibration standards.

Results and Discussions

Kinematic viscosities of petroleum fractions for the investigated crude oils were measured at several temperatures. The results are presented in Tables 1. To get more generalized correlation, more data is required. TBP fractions of Arab heavy, Arab medium, Arab light and Arab Berri (extra light) crude oils Abu-Eishah (1999) with boiling ranges between 420.65 K and 825.93 K will be used. The properties of these oils are listed in Table 2.

Development of a New Correlation for Petroleum Fractions

The correlations that will be developed are purely dependent on the correlation of viscosity of pure hydrocarbons that had been developed by Mehrotra et al. (1996) of the following from:

$$ECN = f(Tb, API) \tag{7}$$

In order to find a functional relationship between viscosity of petroleum fraction and various other parameters, such as temperature, oil gravity (API) and true boiling point (TBP), multiple regression analysis is required. The new correlation based on modification of Shanshool correlation as follows: For each petroleum fraction cuts we have to find the best ECN, which gives the lowest AAD (average absolute deviation) between experimental kinematic viscosities and the corresponding calculated values over the available temperature range. A simple subroutine program is suitable to find the empirical ECN. To formulate these effective carbon numbers as a function of typical properties of petroleum fractions like API gravity and TBP. Using the program statistics, Cary (1990) in Regression analysis has been made to give function relationship between ECN, API, and TBP as follows:

$$ECN\ (Tb, API) = a + b(Tb^{c})(\frac{1}{API^{d}}) \tag{8}$$

where:

$a = 1.42$, $b = 3.4*10^{-4}$, $c = 2$, $d = 0.5$

For petroleum fractions, the ECN are related to the kinematic viscosity though:

$$Log\ (\nu\ + 0.7)\ =\ 100(0.01T)\ b$$

$$b = -5.745 + 0.616 \ln(ECN) - 40.468(ECN)^{-1.5}$$

The percent absolute average deviation (% AAD) is defined by:

$$\% AAD = \frac{1}{m} \sum_{i=1}^{n} \frac{|\upsilon^{\exp} - \upsilon^{cal}|}{\upsilon^{\exp}} \times 100 \tag{9}$$

Testing of the New Correlation

The new correlation based on modification of Shanshool, Shanshool et al. (2001) correlation for each petroleum fraction cuts we have to find the best ECN, which gives the lowest AAD (average absolute deviation) between experimental kinematic viscosities and the corresponding calculated values over the available temperature range.

The method is used to predict the viscosity of wide boiling temperature of kerosene and gas oil ranges derived from Libyan crude oils, and Arabian crude oils. Experimental kinematic viscosity data of the investigated liquid petroleum fractions with the corresponding calculated value from Eq.(3) and Eq (8) for some Libyan and Arab crude oils are summarized in Table (1) and (2). The characterization properties, 50% boiling points and specific densities, and the experimental kinematic viscosity data of the investigated liquid petroleum fractions are also listed in the same table.

The present generalized kinematic viscosity correlation as has been applied to more than 250 data points for 21 fractions derived from 7 crude oils. Evaluations of the prediction capability of the present correlation for a large range of boiling temperature comparing with pervious correlation (Eq 3) are given in Tables 1 and 2.

Table 1: Characterization properties and the correlation results of the kinematic viscosity for fractions from the petroleum fractions of Libyan crude oils

Tb (K)	API	T(K)	ν (mm/s^{-1}) Exp	From correlation (3)		Present correlation	
				ν (mm/s^{-1})	Dev (%)	ν (mm/s^{-1})	Dev (%)
Sharara							
506.21	43.27	333.15	1.239	1.384	11.703	1.299	4.850
506.21	43.27	343.15	1.093	1.19185	9.0436	1.123	2.760
506.21	43.27	353.15	0.982	1.04336	6.24846	0.987	0.492
506.21	43.27	363.15	0.88	0.92647	5.28118	0.879	-0.086
506.21	43.27	373.15	0.797	0.833	4.51676	0.793	-0.496
506.21	43.27	383.15	0.728	0.75722	4.01341	0.723	-0.680
506.21	43.27	393.15	0.671	0.69505	3.58411	0.666	-0.812
574.15	30	303.15	6.728	7.84616	16.61946	7.161	6.439
574.15	30	308.15	6.094	6.70752	10.06755	6.144	0.823
574.15	30	313.15	5.35	5.79553	8.32766	5.326	-0.439
574.15	30	343.15	2.743	2.86906	4.59561	2.678	-2.362
574.15	30	373.15	1.66	1.74384	5.05044	1.645	-0.881
Sarrir							
492.15	42	313	1.695	1.81047	6.81211	1.685	-0.562
492.15	42	323	1.564	1.50453	-3.80252	1.407	-10.009
492.15	42	343.15	1.09	1.10366	1.25346	1.041	-4.483
492.15	42	353	1.008	0.97251	-3.52089	0.921	-8.658
690	19	323	23	23.634	2.756	21.361	-7.126

690	19	373	5.655	5.905	4.414	5.489	-2.935
690	19	323	22	23.634	7.426	21.361	-2.905
Hamada							
504.54	43.62	333.15	1.21	1.355	11.983	1.272	5.141
504.54	43.62	343.15	1.07	1.168	9.198	1.101	2.932
504.54	43.62	353.15	0.956	1.024	7.122	0.969	1.345
504.54	43.62	363.15	0.861	0.910	5.736	0.864	0.373
504.54	43.62	373.15	0.777	0.819	5.456	0.780	0.426
504.54	43.62	383.15	0.717	0.746	3.987	0.712	-0.677
504.54	43.62	393.15	0.66	0.685	3.790	0.656	-0.585
Amal							
478.15	45	310.8	1.437	1.537	6.993	1.433	-0.251
478.15	45	323	1.169	1.244	6.398	1.166	-0.219
690	19	323	20.913	23.634	13.010	21.361	2.142
690	19	373	5.405	5.905	9.243	5.489	1.554

Table 2: The characterization properties and the correlation results of the kinematic viscosity for fractions from Arabian crude oils

Tb (K)	API	T(K)	ν (mm/s^{-1}) Exp	From correlation (3)		Present correlation	
				ν (mm/s^{-1})	Dev (%)	ν (mm/s^{-1})	Dev (%)
Arab Berri crude oil							
421.9	55.992	313	0.742	0.722	-2.677	0.683	-7.940
421.9	55.992	343	0.562	0.533	-5.179	0.511	-9.055
421.9	55.992	353	0.516	0.495	-4.144	0.476	-7.700
505.2	43.797	313	1.625	1.944	19.628	1.808	1.277
505.2	43.797	353	0.961	1.027	6.874	0.972	1.103
505.2	43.797	363	0.867	0.913	5.281	0.866	-0.065
574.7	36.393	373	1.374	1.473	7.213	1.392	1.330
574.7	36.393	383	1.217	1.298	6.673	1.231	1.110
574.7	36.393	393	1.094	1.158	5.805	1.100	0.555
574.7	36.393	403	1.007	1.043	3.553	0.994	-1.340
671.9	28.749	443	1.344	1.351	0.532	1.288	-4.146

671.9	28.749	453	1.225	1.233	0.618	1.177	-3.887
671.9	28.749	463	1.118	1.132	1.247	1.083	-3.118
671.9	28.749	473	1.031	1.046	1.442	1.002	-2.770
Arab medium crude oil							
421.9	50.796	313	0.766	0.788	2.913	0.744	-2.875
505.2	43.278	363	0.881	0.922	4.631	0.875	-0.697
505.2	43.278	373	0.797	0.829	4.014	0.789	-0.970
505.2	43.278	383	0.728	0.754	3.536	0.720	-1.130
505.2	43.278	393	0.671	0.692	3.132	0.663	-1.238
505.2	43.278	403	0.619	0.641	3.529	0.615	-0.593
505.2	43.278	443	0.466	0.505	8.383	0.489	5.038
505.2	43.278	453	0.435	0.483	10.923	0.469	7.716
574.7	35.481	313	3.969	4.694	35.321	4.325	6.663
574.7	35.481	353	1.797	2.028	12.875	1.904	5.956
671.9	25.670	413	1.992	2.058	3.320	1.948	-2.224
671.9	25.670	423	1.768	1.824	3.166	1.730	-2.144
671.9	25.670	433	1.58	1.632	3.284	1.551	-1.822
671.9	25.670	443	1.42	1.472	3.697	1.402	-1.234
671.9	25.670	453	1.279	1.339	4.679	1.278	-0.113
671.9	25.670	463	1.165	1.226	5.212	1.172	0.573
671.9	25.670	473	1.066	1.129	5.928	1.081	1.425
Arab heavy crude oil							
421.9	55.967	313	0.753	0.722	-4.061	0.683	-9.250
421.9	55.967	343	0.568	0.533	-6.153	0.511	-9.990
421.9	55.967	353	0.525	0.495	-5.762	0.476	-9.259
505.2	43.127	313	1.704	1.978	16.109	1.840	7.981
505.2	43.127	343	1.111	1.189	7.035	1.121	0.868
505.2	43.127	353	0.994	1.041	4.733	0.985	-0.941
574.7	34.775	413	0.918	0.980	6.760	0.936	1.910
574.7	34.775	423	0.842	0.897	6.533	0.858	1.918
574.7	34.775	433	0.772	0.827	7.144	0.793	2.718
574.7	34.775	443	0.712	0.768	7.851	0.738	3.602

574.7	34.775	453	0.656	0.717	9.337	0.690	5.230
671.9	25.426	313	19.136	18.292	-4.409	16.561	-13.454
671.9	25.426	343	7.27	7.267	-0.045	6.708	-7.726
671.9	25.426	443	1.438	1.483	3.153	1.413	-1.761
671.9	25.426	453	1.293	1.348	4.279	1.286	-0.503
671.9	25.426	463	1.179	1.234	4.672	1.180	0.047
671.9	25.426	473	1.078	1.137	5.437	1.088	0.946

As seen from the results, the proposed correlation has been found to fit all fractions (the low boiling, medium boiling, and high boiling) of the different types of the Libyan crude oil. Also, the proposed correlation fits all the fractions of the different typed of Arabian crude oil with almost the same accuracy. The predicted values at several temperature levels were tested by using the experimental viscosities. The value of overall percentage AAD of the predictive capability of the present correlation is investigated in this study and is summarized in Figure 1. The overall AAD% for Libyan crude oils is 2.44 %, for and Arabian crude is 2.8 % respectively.

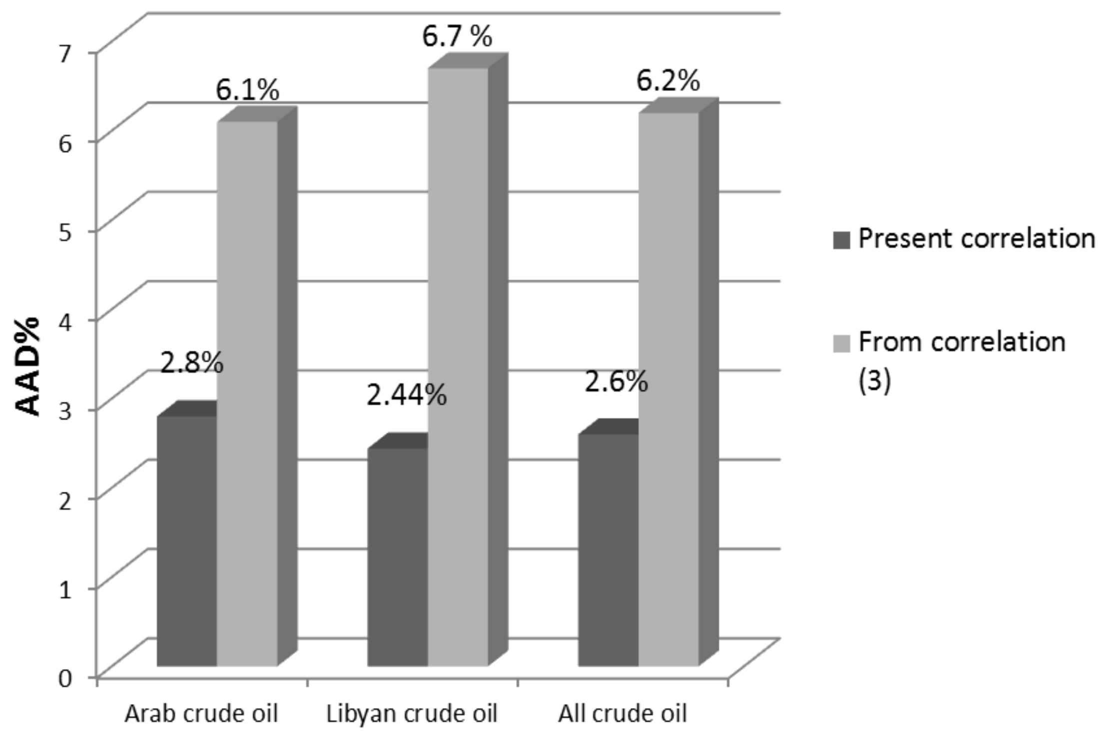

Figure 1: Summary of the results of previews correlation and present correlation for viscosity using experimental data.

Overall percentage AAD of the predictive capability of Eq (3) tested using experimental data for Libyan and Arabian crude oil is also shown in Figure 1. The overall AAD % for Libyan crude oils is 6.7%, and for Arabian crude is 6.2% respectively. In general, ghe analysis shows that the present correlation fit the experimental data consisting of 235 viscosity measurements for the 33 fractions of Libyan crudes and 167 Arabic crude oil fractions, and the 35 other world fractions with an overall absolute error of 2.5%, as compared with the overall absolute error of 8.7% given by previous correlation. Although relatively wide range of crudes and temperatures the AAD % in general shows low value. This low value of AAD%, in fact, indicates a very good agreement between the results obtained experimental and by using the new correlation.

Conclusions

A generalized kinematic viscosity - temperature correlation has been developed for liquid petroleum fractions in boiling range of 360-825.93 K, based on modified form of a pure hydrocarbon correlation. It requires the knowledge of only two characterizing properties of the fractions, i.e. API gravity and 50 % boiling point for kinematic viscosity predictions. The results showed that the equation could predict values as good as those from experimental measurements. Fitting parameters have also been evaluated for both Libyan crude oils and other Arabian crude oils and world crude oils. The present correlation fits the kinematic viscosity data with an overall average relative error of 2.7 % for the 33 Libyan crude oil fractions and 2.4 % for the 167 Arabic crude oil fractions, and 3.0 % for the 35 other world fractions. The fitting correlation when used for all available experimental data gives an overall average error of only 2.5 %. The results obtained from the correlation have been validated using only the experimental data gathered in our laboratory for both Libyan and Arabian crude-oil fractions, however, further experimental work is currently carried out on other crude oil fractions in order to achieved more validate to our correlation.

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