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Short communication

A generalized viscosity correlation for undefined petroleum fractions

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Abstract

A single consistent correlation, based on Walther's equation, is described and used to estimate the kinematic viscosity–temperature behavior for undefined petroleum fractions. The correlation requires a minimum of experimental information, with a minimum number of correlation constants. When a single viscosity measurement is used as an input, the described correlation is shown to be more flexible and gives results comparable with those of previously published correlations. When the boiling point and the specific gravity are available as input, the correlation is shown to give better results than other published correlations. © 1999 Elsevier Science S.A. All rights reserved.

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1. Introduction

For the development, design, planning and operation of processes in the petroleum industry, an engineer has to deal with the so-called undefined mixtures such as petroleum fractions. The kinematic viscosities of these fractions are required in calculations involving mass transfer and fluid flow. Currently, there are increasing demands on the accuracy of viscosity prediction techniques for implementation in property prediction computer routines.

Considering the complex nature of petroleum fractions and the difficulty of even identifying the components present in such mixtures, developing a viscosity estimation correlation accounting for all the composition details is difficult. In process calculations, it is much easier to express the viscosity as a function of temperature with a simple analytical expression that is easy to use in computer applications.

Numerous estimation methods have been developed to represent the effect of the temperature on the viscosity of different crude oil fractions at atmospheric pressure. Most of these methods are empirical in nature since no fundamental theory exists for the transport properties of liquids.

Amin and Maddox [1] proposed a correlation based on the modification of Eyring's equation:

$$\nu = A\left[\exp\left(\frac{B}{T}\right)\right] \tag{1}$$

and related the coefficients A and B to 50% boiling point and to the Watson characterization factor (dependent on an average boiling point and the specific gravity).

Beg et al. [2] correlated the constants A and B of Eq. (1) with the specific gravity and mid-boiling point of undefined petroleum fractions over a boiling point range from 80°C to 400°C. Amin and Beg [3] proposed another Eyring-type correlation to predict the kinematic viscosities of heavy petroleum fractions (TBP 455°C + fractions of Arabian crude oils) with a boiling point range from 490°C to 550°C. Moharam et al. [4] combined the double logarithmic relationship of Wright [5] with the fact that the viscosity correlates well with the boiling temperature and the inverse of the absolute temperature, to develop a generalized empirical correlation to represent the kinematic viscosity–temperature behavior for the range 50–550°C:

$$\ln(\nu) = A \times \exp\left[\left(\frac{T_b}{T}\right) \times \gamma^B\right] + C \tag{2}$$

with

$$A = 1.0185,$$

$$B = \frac{T_b}{305.078} - 0.55526$$

and

$$C = -3.2421$$

where γ is the specific gravity, T_b and T are in K and ν is the kinematic viscosity of the fraction in mm^2/s.

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Dutt [6] proposed an Antoine-type correlation using the average boiling point only as an input. The equation has the form:

$$\ln(\nu) = A + B/(T + C) \tag{3}$$

where A is a constant and B and C are functions of the boiling temperature.

Based on Walther's equation [7], Mehrotra [8] proposed a correlation which has the form:

$$\log\log(\nu + 0.8) = a_1 + a_2 \log(T) \tag{4}$$

with

$$a_1 = 5.489 + 0.148(T_b)^{0.5}$$

and

$$a_2 = -3.7$$

Allan and Teja [9] proposed an approach that requires a single viscosity measurement to calculate the effective carbon number (ECN). They correlated the constants of the Antoine-type correlation to this effective carbon number. However, Gregory [10] showed that the method gives an incorrect viscosity–temperature trend for effective carbon numbers bigger than 22.

Puttagunta et al. [11] proposed a relatively more accurate correlation which requires a single viscosity measurement at 37.78°C and atmospheric pressure to make the prediction. The correlation has the form:

$$\ln(\nu) = \frac{b}{\left(1 + \dfrac{T - 37.78}{310.93}\right)^s} + c \tag{5}$$

where T is the temperature (°C), c is a constant, and b and s are functions of the kinematic viscosity at 37.78°C.

From this brief survey of the methods available in the literature, as shown in Table 1, it is apparent that the methods may be categorized, with regard to the input information required, into two groups. The first contains the methods that require physical property data such as boiling point (and specific gravity) to perform the estimation. The methods in this group are completely predictive and easy to use especially when the required input parameters are available as characterizing parameters for the liquids included. However, their accuracy is not as good since the boiling point (and the specific gravity) do not accurately represent the nature or the composition of the fluid under study. In addition, in some cases, it may be inconvenient to measure these physical parameters. The second group includes the methods that require one or two viscosity measurements. With the availability of a PVT analysis, it is possible to measure values of the liquid viscosity. These methods are accurate and require no physical property input data. However, they are not predictive and it is essential that considerable attention be paid to the reference measurements as the accuracy of the estimation depends entirely on these measurements.

The objective of this work is to describe a single consistent correlation that is capable of the estimation of the viscosity of undefined petroleum fractions using a minimum of experimental information as available to the user with a minimum number of correlation constants.

Table 1
Input property requirements for the liquid viscosity estimation method of undefined petroleum fractions

Type	Method	Input data
Methods require physical properties as input parameters	Amin and Maddox [1]	Tb, γ
	Beg et al. [2]	Tb, γ
	Amin and Beg [3]	Tb, γ
	Moharam et al. [4]	Tb, γ
	Dutt [6]	Tb
	Mehrotra [8]	Tb
Methods require a single viscosity measurement as input parameter	Allan and Teja [9]	ν_o
	Puttagunta et al. [11]	$\nu_{37.78}$

2. Viscosity–temperature correlation

As previously stated, Walther's equation [7] was the base of the work of Mehrotra [8]. In his work, the value of the parameter a_2 of Eq. (4) was set equal to −3.7. The parameter a_1 was expressed in terms of the average boiling point. In the present work, it was observed that the estimation of parameter a_1 from the boiling point alone is responsible for the deviation associated with the application of Eq. (4). Consequently, trials were made to eliminate this parameter or to improve its estimation depending on the available input information.

- In case a single viscosity measurement is available as input parameter, the parameter a_1 of Eq. (4) can be eliminated and the viscosity can be estimated using the following correlation

  $$\ln\ln(\nu + 0.8) = \ln\ln(\nu_0 + 0.8) + a_2 \ln(T/T_0) \tag{6}$$

  where ν_0 is the single viscosity measurement (mm^2/s) at temperature T_0 (K) and $a_2 = -3.7$.
- In case the specific gravity is available, together with the average boiling point, the proposed correlation has the form:

  $$\ln\ln(\nu + 0.8) = a_1 + a_2 \ln(T) \tag{7}$$

  with

  $$a_1 = 4.3414 \times (T_b \times \gamma)^{0.2} + 6.6913$$

  and

  $$a_2 = -3.7$$

  where T_b is the mid-boiling point in (K), γ is the specific gravity and ν is the kinematic viscosity in (mm^2/s).

The values of the constants included in Eq. (7) were determined for the studied undefined fractions using the Solver method (Excel 5.0, Microsoft).

- In case the average boiling point is the only available input parameter, the equation of Mehrotra [8] is sufficient for the viscosity estimation. The correlation takes the form

$$\ln\ln(\nu + 0.8) = a_1 + a_2 \ln(T) \quad (8)$$

with

$$a_1 = 0.3408 \times T_b^{0.5} + 13.4729$$

and

$$a_2 = -3.7$$

3. Results and discussion

Although a considerable quantity of viscosity data for petroleum fractions is available in the literature, few references report the kinematic viscosity with the corresponding mid-boiling point and specific gravity.

For predictions based on a single viscosity measurement, Eq. (6) was applied to predict the kinematic viscosity of 478 data points of 65 undefined petroleum fractions from 14 worldwide crude oils. The data we obtained from Beg et al. [2], Puttagunta et al. [11] and Miadonye et al. [12]. A comparison of Eq. (6) with Eq. (5) proposed by Puttagunta et al. [11] is shown in Table 2. The prediction was based on the viscosity at 37.78°C to have the comparison on the same basis. The viscosities at 37.78°C were either experimental or obtained from a curve fit. It is observed that Eq. (6) is superior to Eq. (5) in the following:

1. Eq. (6) contains two constants in comparison with four constants for Eq. (5).
2. Eq. (6) is based on a single viscosity measurement at any temperature and not on a specific temperature (37.78°C for Eq. (5)).
3. The availability of the viscosity measurement at any temperature does not necessitate a trial and error solution as required for Eq. (5).
4. Eq. (6) gives a comparable or better results as that of Eq. (5) since Eq. (6) gives 1.49% AAD against 1.59 for Eq. (5).

For predictions based on physical properties, Eq. (7) was applied to predict the kinematic viscosity of 316 data points of 45 undefined petroleum fractions from 13 crude oils for which the mid-boiling point and the specific gravity are available. Comparison of the prediction capabilities of

Table 2
Viscosity estimation from a single viscosity measurement

Crude oil	Ref.	No. of data points	% AAD	
			Puttagunta et al. [11]	Eq. (6)
Arab Berri	11	52[a]	2.88	1.41
Arab Medium	11	52[a]	2.89	1.55
Arab Heavy	11	52[a]	2.52	1.88
Boscan	2	8	1.5	1.68
California	12	59[a]	0.99	1.48
Iranian Export	2	11	0.72	0.25
Iranian Export	2	11	0.72	0.25
Light Valley	2	7	2.23	2.29
Midway special	2	8	3.52	3.7
Minas (Sumatra)	2	13	1.51	1.29
Oklahoma	12	65[a]	0.71	1.2
Pennsylvania	12	59[a]	0.88	1.44
Stabilized Arabian	2	8	0.95	0.16
Texas	12	25[a]	1.13	1.15
Wyoming	12	59[a]	0.89	1.58
Overall		478	1.59	1.47

[a]Values of $\nu_{37.78}$ are obtained by curve fit.

Table 3
Comparison of the results of Eq. (7) with the results of the presviously published correlations

Crude oil	No. of data points	% AAD					
		Amin-Madox [1]	Beg et al. [2]	Dutt [6]	Moharam et al. [4]	Mehrotra [8]	Eq. (7)
Arab Berri	52	63.89	8.11	3.74	3.68	2.81	1.16
Arab Heavy	52	52.74	6.62	6.61	4.84	3.73	1.42
Arab Medium	52	58.15	6.09	5.21	5.11	1.44	1.64
Boscan	8	13.42	8.10	18.13	4.75	19.00	3.70
California	27	24.49	8.53	10.09	3.07	8.55	3.34
Iranian Export	11	6.04	3.95	4.96	5.87	4.54	4.19
Light Valley	7	15.18	2.18	9.63	9.40	10.90	8.03
Midway special	8	22.88	9.22	15.79	9.45	14.65	9.59
Minas (Sumatra)	13	31.95	5.33	2.79	9.90	3.62	2.84
Oklahoma	26	14.24	7.30	5.46	3.67	5.43	2.66
Pennsylvania	261	1.09	11.54	4.76	11.02	5.05	8.00
Stabilized Arabian	8	7.71	2.19	3.02	4.88	4.73	3.35
Wyoming	26	15.90	9.66	7.46	6.35	6.91	4.04
Overall	316	37.22	7.40	6.31	5.54	5.00	3.05

Eq. (7) with several earlier correlations is shown in Table 3. Eq. (7) gives an overall average absolute deviation of 3.05% in comparison with the methods of Amin–Maddox [1], Beg et al. [2], Dutt [6], Moharam [4] and Mehrotra [8] that give 37.22, 7.4, 6.31, 5.54, and 5.0, respectively as percentage average absolute deviations.

Although it was expected that Eq. (7) will provide more accurate results than Eq. (4) proposed by Mehrotra [8], since the former uses more input information, the significant improvement in % AAD justify the effort to introduce the specific gravity as a correlating parameter especially when it is readily available, with the mid-boiling point, to characterize the undefined petroleum fractions.

4. Conclusion

A single consistent correlation, based on Walter's equation, was described to estimate the kinematic viscosity of undefined petroleum fractions with a minimum number of correlation constants. A single viscosity measurement, the mid-boiling point temperature or the specific gravity together with the mid-boiling point can be used as input information for the same equation to give accurate predictions. The described correlation is simple, flexible and gives comparable or better results when compared with the previously published correlations.

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