Graphical Viscosity Correlation for Hydrocarbons

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A number of graphical viscosity correlations have been published in the literature (*1, 5* to *7, 12, 13, 16, 22, 35, 36, 42*). The limit of their applicability was difficult to define because of the scarcity of accurate experimental data at that time. The authors and their associates at the Institute of Gas Technology conducted a series of experiments to provide viscosity data for hydrocarbons (*12, 16* to *20, 24, 25, 27* to *31, 37, 38*) and presented several correlations (*19, 20, 31, 39*) in equation form.

Experimental viscosity data were compared with the values obtained from the graphical correlations in the literature. It was found that those correlations are either limited in range and/or inadequate in accuracy. The authors used the data for methane (*4, 6, 8, 12, 14, 22, 23*), ethane (*4, 10, 21, 37, 41*), propane (*4, 6, 9, 22, 37, 38, 40, 41*), *n*-butane (*11, 18, 34, 41*), *i*-butane (*24*), *n*-pentane (*1, 26, 29, 33*), *n*-hexane (*2*), *n*-heptane (*3*), *n*-octane (*3*), *n* decane (*28*), ethylene (*14*), nitrogen (*4, 32*), methane-propane mixtures (*6, 22*), methane-carbon dioxide mixtures (*15*), and four natural gases (*30*) to construct a graphical correlation. This graph can be used to predict the viscosity of pure components and multicomponent mixtures; it is accurate to ±5%.

CORRELATION

Carr (*12*), Shimotake, and Thodos (*35*), and Uyehara and Watson (*42*) showed that reduced properties can be used to advantage in correlating viscosity data. Starling and Ellington (*39*) and Gonzalez (*23*) showed that the introduction of molecular weight improves the generalization of corrtlation. Using these ideas as a guide, the authors plotted $\mu/(\Sigma X_i\sqrt{M_i})^{1/2}$ vs. T_r on semilog paper for all the systems mentioned above. The result is presented in Figure 1 as a function of the reduced pressure P_r. A cross plot is presented in Figure 2.

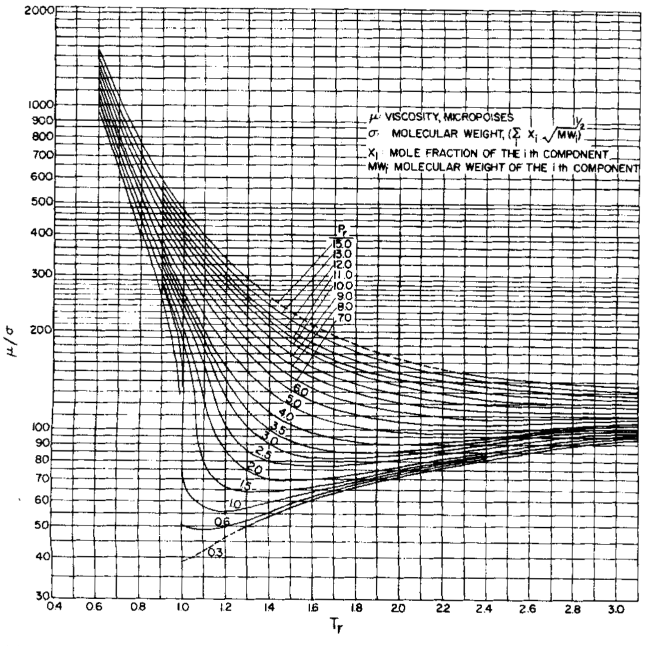

Fig. 1. Viscosity of hydrocarbon systems as a function of reduced pressure.

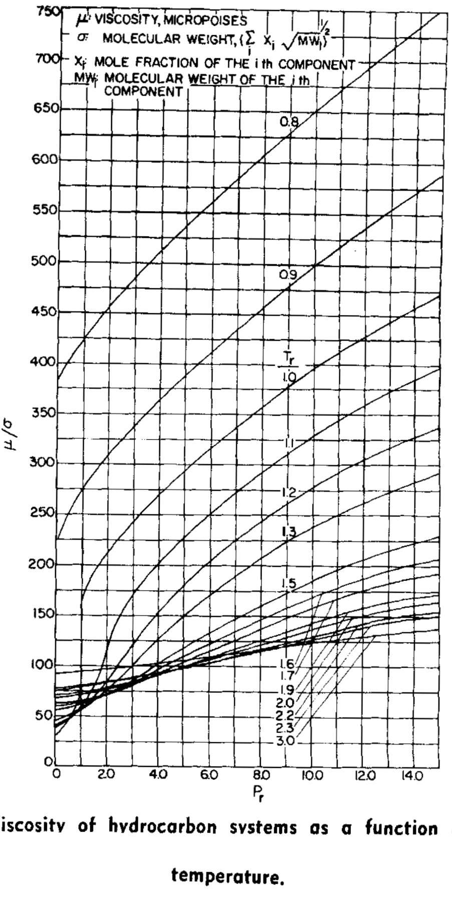

Fig. 2. Viscosity of hydrocarbon systems as a function of reduced temperature.

This correlation was tested with methane-*n*-butane mixtures (*17*), (maximum deviation 4%), four natural gases, (maximum deviation 5%), and neo-pentane (*25*), (maximum deviation 10%), for temperatures from 100° to 460°F. and pressures from 14.7 to 10,000 lb./sq. in. abs. The average deviation from experimental data was less than ±5%. In general, this correlation is at its best at high temperatures and low pressures and at its worst at low temperatures and high pressures. The compositions of natural gases are presented in Table 1. The first four gases were used in constructing the charts, and the last four gases were used to test the correlation. Table 2 presents a comparison which was tested with the eight natural gases presented in Table 1. Other graphical correlations which apply only to specific cases are not included in this paper.

For mixtures containing up to 80 mole % of carbon dioxide, the correction chart (Figure 3) should be used with Figures 1 or 2. This correction chart predicts the viscosity of methane-carbon dioxide mixtures (*15*) with a deviation of less than ±2%.

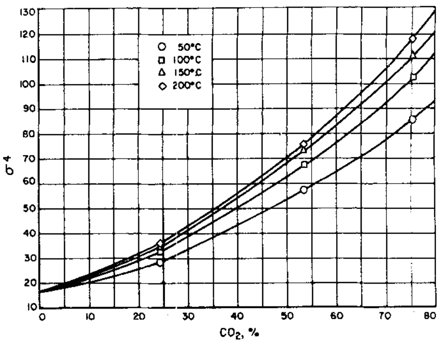

Fig. 3. Correction chart for mixtures containing carbon dioxide.

TABLE 1. COMPOSITIONS OF NATURAL GAS SAMPLES

Natural gas sample No.	1	2	3	4	5	6	7	8
He	—	—	—	—	0.05	—	—	—
CO_2	3.20	1.40	0.90	1.70	0.64	0.80	0.23	0.17
N_2	—	1.40	4.80	0.55	0.67	0.13	0.21	4.40
C_1	86.30	71.70	80.70	91.50	80.90	95.20	97.88	93.70
C_2	6.80	14.00	8.70	3.10	9.90	2.00	0.95	0.90
C_3	2.40	8.30	2.90	1.40	4.60	0.99	0.42	0.44
i-C_4	0.43	0.77	—	0.67	0.67	0.37	—	0.04
n-C_4	0.48	1.90	1.70	0.50	1.35	0.28	0.23	0.17
C_5	0.22	0.39	0.13	0.28	0.60	0.11	0.09	0.09
C_6	0.10	0.09	0.06	0.26	0.39	0.07	0.06	0.06
C_{7+}	0.04	0.01	0.03	0.08	0.11	0.03	0.03	0.02

TABLE 2. COMPARISON OF GRAPHICAL CORRELATIONS FOR PREDICTING THE VISCOSITY OF NATURAL GASES

Author(s)	Correlation parameters	Range		Maximum deviation	Remarks
		Temp., °F.	Press, lb./sq.in.abs.		
Beal (*5*)	Gas gravity	60° to 300°	400 to 5,000	19%	Beal also presented correlations for air, water, crude oil, and solubility. This table only presents the comparison of natural gas viscosity.
Bicher and Katz (*6*)	MW, P, T	0° to 400°	400 to 10,000	19%	Bicher and Katz are the first authors to present a graphical correlation for natural gases.
Bromley and Wilke (*7*)	$\mu^*, \frac{kT}{\epsilon}, \Phi$, etc.	up to 2,000°	14.7	4%	Bromley and Wilke's correlation works well for pure components and some nonhydrocarbons at low pressure.
Carr (*12*)	μ^*, Tr, Pr	Tr from 1 to 3	Pr from 1 to 60	8%	This correlation does not cover all the range indicated in the range column.
Carr, Kobayashi, and Burrows (*13*)	μ^*, Tr, Pr	Same as above		8%	Principle is the same as reference *12*.
Comings, Mayland, and Egly (*14*)	Tr, Pr, μ^*				For pure gases only.
This paper	MW, Pr, Tr	40° to 460°F.	14.7 to 10,000	5%	See conclusion section of this paper.
Smith and Brown (*36*)	MW, Tr, Pr	Tr from 0.65 to 1.5	Pr from 0 to 10	15%	This correlation works well for pure components and some binary paraffins.
Uyehara and Watson (*42*)	$\mu r, \mu c, Tr, Pr$	Tr from 0.5 to 10	Pr from 0.1 to 30	18%	This correlation works well for pure components and some nonhydrocarbons.

CONCLUSION

The correlation presented here can be applied to the following systems for temperatures from 40° to 460°F. and pressures from 14.7 to 10,000 lb./sq. in. abs.:

1. Pure paraffins from methane to *n*-decane, *i*-butane, *neo*-pentane, nitrogen, and ethylene.
2. Mixtures of hydrocarbons from methane to *n*-butane.
3. Natural gases containing up to 10 mole % of nitrogen.
4. Natural gases containing up to 10 mole % of carbon dioxide.
5. Critical-region viscosities for pure hydrocarbons from methane to *n*-pentane.

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NOTATION

M_i = molecular weight of component i
MW = molecular weight
P_{cm} = $\Sigma X_i P_{ci}$ = critical pressure of mixture
P_r = reduced pressure = P/P_c
T_{cm} = $\Sigma X_i T_{ci}$ = critical temperature of mixture
T_r = reduced temperature = T/T_c
X = mole fraction
X_i = mole fraction of component i

Greek Letters

$\frac{\epsilon}{k}$ = an effective temperature
Φ = function of molecular weight
μ = viscosity, micropoises
μ^* = viscosity at 1 atm.
μ_c = critical viscosity
μ_r = reduced viscosity
σ = modified molecular weight = $(\underset{i}{\Sigma} X_i\sqrt{MW_i})^{1/2}$

Subscripts

i = index for component
m = mixture

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