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Viscosities of vegetable oils and fatty acids

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Viscosities of Vegetable Oils and Fatty Acids

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Data for viscosity as a function of temperature from 24 to 110°C (75 to 230°F) have been measured for a number of vegetable oils (crambe, rapeseed, corn, soybean, milkweed, coconut, lesquerella) and eight fatty acids in the range from C_9 to C_{22}. The viscosity measurements were performed according to ASTM test methods D 445 and D 446. Several correlations were fitted to the experimental data. Correlation constants for the best fit are presented. The range of temperature in which the correlations are valid is from 24°C (75°F), or the melting point of the substance, to 110°C (230°F). The correlation constants are valuable for designing or evaluating such chemical process equipment as heat exchangers, reactors, distillation columns, mixing vessels and process piping.

KEY WORDS: Fatty acids, vegetable oils, viscosity.

Liquid viscosity is important in the design of process equipment for the fatty acid industry. For example, it is an important parameter in estimating efficiency of distillation columns for separation of fatty acids. Liquid viscosity data are required in the design of heat transfer equipment. Process piping design and pressure drop determination also require viscosity data. Additionally, the viscosity of mixtures of fatty acids may be estimated from the viscosity of the individual fatty acid components.

The data were measured in glass capillary kinematic viscometers. Kinematic viscosity was calculated from the measured flow time. Applicable correlations were applied to the observed kinematic viscosities. Final results are reported in terms of dynamic viscosities. Correlation constants, based on the experimental data, are also presented. These correlation constants can easily be incorporated into computer-aided-process-design programs.

EXPERIMENTAL PROCEDURES

The experimental procedures were performed with Cannon-Fenske (Fisher Scientific, Pittsburgh, PA) glass capillary kinematic viscometers in a constant-temperature bath. A Precision Scientific constant-temperature bath with a Micro-set Thermoregulator (Chicago, IL), in accordance with ASTM D 445 (1), was used in the procedures for viscosity determinations. This assembly maintains a temperature uniformity of ±0.0033°C (±.005°F) throughout the range of 20 to 130°C (68 to 266°F), which exceeds the ASTM D 445 (1) requirements. Cannon-Fenske (reverse flow) viscometers, ASTM D 446 (2), were used for the measurements of the kinematic viscosities. Fisher Scientific ASTM D 445 (1) thermometers with subdivisions of 0.056°C (0.1°F) were used for monitoring bath temperature. Two viscosity tests were performed at one time, with two different viscometers. The procedures in the ASTM standard test methods D 445 and D 446 (1,2) for viscosity determinations were followed. Variations in viscosity as a function of temperature were measured.

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Please refer to the preceding paper in this issue (3) for the fatty acid composition and source or manufacturer of each vegetable oil, and for the purity and the manufacturers of the fatty acids used in the experimental procedures. The information was provided by the manufacturers.

RESULTS AND DISCUSSION

Kinematic viscosities, v, expressed in centistokes, were calculated from the measured flow time, t, and instrument constant, c, by means of the following equation

$$v = ct \qquad [1]$$

The values for c are provided by the viscometer manufacturer. Instrument constants may also be evaluated from the standard liquids. The viscometer constants were corrected for effects of temperature when the filling temperature is substantially different from room temperature. Corrections for gravitational constant, surface tension and kinetic energy are insignificant.

Dynamic viscosities, μ_L, expressed in centipoise, were calculated from the kinematic viscosities and the densities, ϱ, by means of the following equation

$$\mu_L = \varrho v \qquad [2]$$

Densities were measured at the same time as the viscosities, and are reported in the preceding paper in this issue (3). Final results for the dynamic viscosities for vegetable oils and fatty acids are tabulated in Tables 1 and 2, respectively. Available literature data (4,5) are presented for comparison.

The difference between successive test results by the same apparatus under constant operating conditions on identical test material never exceeded 0.35% of their mean. This is within the sensitivity limits imposed by ASTM test method D 445 (1).

Viscosity-temperature correlations. Liquid viscosities are sensitive to temperature, T. For most liquids at temperatures below the normal boiling point, the plot of ln μ vs. 1/T or ln μ vs. ln T is approximately linear. Therefore, most correlations are presented in this form. The Andrade equation (6) may be the simplest two-constant temperature-liquid viscosity function.

$$\ln \mu_L = A + \frac{B}{T} \qquad [3]$$

Alternatively, this may be represented by

$$\mu_L = Ae^{\frac{B}{T}} \qquad [4]$$

Equations 3 and 4 each require two data points. Perry (7) introduced a third constant for more accuracy.

$$\ln \mu_L = A + \frac{B}{(T + C)} \qquad [5]$$

Other modified versions of Equation 3, which introduce one or more constants to improve the fit to the

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TABLE 1

Viscosity of Vegetable Oils

Temperature °C (°F)	Viscosity (cP)						
	Crambe	Rapeseed	Corn	Soybean	Milkweed	Coconut	Lesquerella
23.9 (75.0)	86.7	78.8	52.3	54.3	56.3		275
37.8 (100.0)	48.7	44.9	30.8	31.8	32.7	28.0	121
48.9 (120.0)	33.0	30.3	22.7	23.3	23.8	19.8	69.8
60.0 (140.0)	23.4	21.4	15.7	16.1	16.4	13.3	43.5
82.2 (180.0)	13.2	12.1	9.28	9.51	9.60	7.55	20.4
100.0 (212.0)	9.06	8.41	6.57	6.73	6.79	5.22	12.7
110.0 (230.0)	7.55	7.15	5.60	5.71	5.71	4.36	10.2
Literature data		45.510		50.09		27.129	
Temp. °C (Ref.)		37.8 (4)		25 (5)		37.8 (4)	

TABLE 2

Viscosity of Fatty Acids

Temperature °C (°F)	Viscosity (cP)							
	Nonanoic 9:0	Capric 10:0	Lauric 12:0	Myristic 14:0	Palmitic 16:0	Stearic 18:0	Oleic 18:1	Erucic 22:1
23.9 (75.0)	7.25						29.0	
37.8 (100.0)	4.97	6.33					17.7	32.3
48.9 (120.0)	3.92	4.96	7.47				13.2	22.4
60.0 (140.0)	3.03	3.72	5.42	7.48			9.32	15.9
71.1 (160.0)	2.48	3.02	4.28	5.83	7.64		7.27	11.9
82.2 (180.0)	2.02	2.42	3.38	4.50	5.80	7.31	5.61	8.90
98.9 (210.0)	1.56	1.84	2.50	3.26	4.13	5.08	4.03	6.18
110.0 (230.0)	1.37	1.60	2.10	2.78	3.47	4.24	3.41	5.16
121.1 (250.0)						3.50		
Literature data	3.79	2.56	3.84	5.06	7.10	9.04	9.41	
Temp. °C (Ref. 4)	50	75	75	75	75	75	60	

TABLE 3

Correlations for the Vegetable Oil Viscosities (cP)

Vegetable oils	Constants			Equation no.	Data points n	Mean deviation (%) r	Temperature range °C
	A	B	C				
Crambe	−2.0277E + 00	9.2659E + 02	−1.5427E + 02	2	7	0.07	23.9–110.0
Rapeseed	−2.44621E + 01	6.21021E + 03	2.6671E − 02	4	7	0.07	23.9–110.0
Corn	−1.95604E + 01	5.22544E + 03	1.9943E − 02	4	7	1.32	23.9–110.0
Soybean	−2.00596E + 01	5.32374E + 03	2.0634E − 02	4	7	1.44	23.9–110.0
Milkweed	−2.03845E + 01	5.40303E + 03	2.0948E − 02	4	7	1.91	23.9–110.0
Coconut	1.0945E + 00	−2.25154E + 03	9.1778E + 05	3	6	1.65	37.8–110.0
Lesquerella	6.6123E + 00	−6.28877E + 03	1.7800E + 06	3	7	0.12	23.9–110.0

TABLE 4

Correlations for the Fatty Acid Viscosities (cP)

| Fatty acids	Carbon	Constants			Equation no.	Data points n	Mean deviation (%) r	Temperature range °C
		A	B	C				
Nonanoic	9:0	−1.28399E + 01	3.44593E + 03	1.0839E − 02	4	8	0.81	23.9–110.0
Capric	10:0	−2.6280E + 00	7.1762E + 02	−1.5129E + 02	2	7	1.17	37.8–110.0
Lauric	12:0	−2.5030E + 00	7.0888E + 02	−1.6475E + 02	2	6	0.55	48.9–110.0
Myristic	14:0	6.1590E − 01	−1.94571E + 03	8.0399E + 05	3	5	0.88	60.0–110.0
Palmitic	16:0	−3.43507E + 01	7.86679E + 03	3.9312E − 02	4	4	0.10	71.1–110.0
Stearic	18:0	2.6780E + 00	−3.43749E + 03	1.1344E + 06	3	4	0.60	82.2–121.1
Oleic	18:1	−1.64441E + 01	4.55414E + 03	1.5075E − 02	4	8	1.22	23.9–110.0
Erucic	22:1	−1.82905E + 01	5.10332E + 03	1.7229E − 02	4	7	0.70	37.8–110.0
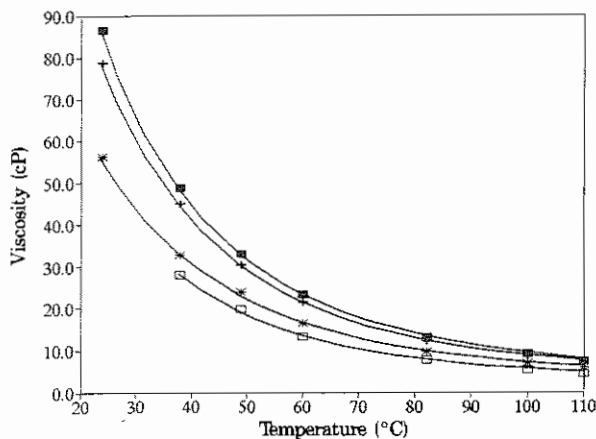
FIG. 1. Viscosity *vs.* temperature for vegetable oils. The lines are correlation derivatives and the points are experimental data. (■), Crambe; (+), rapeseed; (*), milkweed; and (□), coconut.
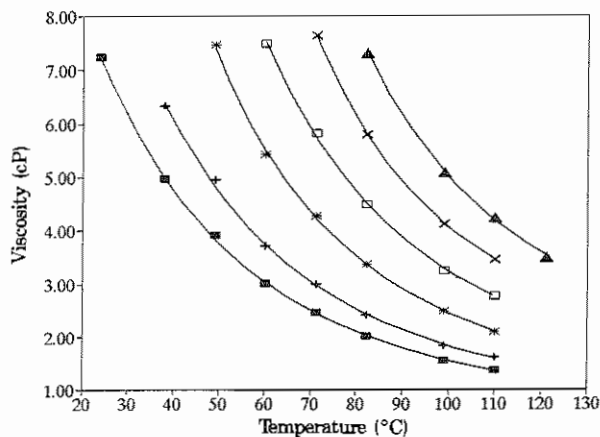

FIG. 2. Viscosity *vs.* temperature for fatty acids. The lines are correlation derivatives and the points are experimental data. (■), Nonanoic acid; (+), capric acid; (*), lauric acid; (□), myristic acid; (X), palmitic acid; and (▲), stearic acid.

experimental data, also have been used. The general forms of such correlations with higher-order terms are:

$$\ln \mu_L = A + \frac{B}{T} + \frac{C}{T^2} + \frac{D}{T^3} \cdots \qquad [6]$$

and

$$\ln \mu_L = A + \frac{B}{T} + CT + \frac{D}{T^2} \cdots \qquad [7]$$

In Equations 3–7, temperature is in °K. For most liquids, D and higher-order terms are insignificant. Truncation after the second term in Equations 6 and 7 or elimination of C in Equation 5 results in the Andrade equation, Equation 3.

The results of regression analysis for dynamic viscosies are tabulated in Tables 3 and 4. The equation number for the given coefficients correspond to Equations 5–7. Equations 6 and 7 were truncated after the third term. The table also gives, for each substance, the range of temerature over which the correlation is valid, the number of data points, and percent mean deviation for the correlations. For all data the mean deviation is less than 2.0%. Figures 1 and 2 show the experimental and predicted viscosities from the correlations for vegetable oils (crambe, rapeseed, milkweed, coconut) and for saturated fatty acids (nonanoic, capric, lauric, myristic, palmitic, stearic), respectively. In these figures, lines represent the fitted correlations compared to the experimental points.

ACKNOWLEDGMENT

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