Viscosity and Density of the Ternary Liquid System Acetone–Benzene–Ethylene Dichloride

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Kinematic viscosities and densities have been measured experimentally in the liquid system acetone–benzene–ethylene dichloride. Viscosities were obtained between 25° and 55° C. and densities between 25° and 45° C. The data include the three binary systems associated with the ternary one.

PROPERTIES of acetone, benzene, ethylene dichloride, and their mixtures have been quite thoroughly studied. The following data are available in the literature: surface tensions of the pure liquid components at their normal boiling points (*9*, *18*, *20*); thermal conductivities of the pure liquid components at various temperatures (*17*) and of the acetone-benzene binary system (*7*); heat capacities of the pure components at various temperatures including both the vapor phase (*12*, *16*) and the liquid phase (*12*, *20*); latent heats of vaporization of the pure components (*12*, *16*, *20*), of the acetone-benzene binary system (*19*), and of the benzene-ethylene dichloride binary system (*22*). In addition, there are vapor pressures of the pure components (*6*, *16*); refractive indices of the binary and ternary liquid systems (*5*); viscosities of the pure vapor components (*10*); and vapor-liquid equilibria in the binary and ternary systems (*3*). The equilibrium data for the acetone-benzene system are corrected in reference (*4*).

The pure components and their mixtures are easily handled, and modest temperatures are associated with operation at normal atmospheric pressure. In addition, lines of constant density and constant refractive index are almost perpendicular on triangular composition coordinates, so the ternary system is quite simple to analyze experimentally.

The system acetone-benzene-ethylene dichloride is therefore, well suited for the study of transport phenomena, especially when vapor-liquid phase changes are of primary interest. Two important properties of the binary and ternary liquid mixtures must be established—namely, the viscosity and the density. The present work seeks to furnish firm values of these liquid-phase properties over a useful range of temperatures and the complete range of compositions.

EXPERIMENTAL PROCEDURE

Kinematic viscosities were measured by means of a modified Cannon-Fenske viscometer. An overflow reservoir, as described by Pospekhov (*13*), was used to provide a constant filling level. The viscometer was calibrated by fitting data obtained with distilled and deionized water to the correlation of Bingham (*1*). Constant temperatures were maintained by means of a Fisher bath with a mercury control capable of holding the bath within a variation of 0.03° C. Temperature measurements were made by means of an Eimer and Amend precision thermometer. Viscosities were measured at 25°, 35°, 45°, and 55° C.

Densities were determined by means of a 25-ml. pycnometer in association with an analytical balance and the previously mentioned constant temperature bath. The precision of measurement was 0.5 mg. Data were obtained at 25°, 35°, and 45° C. on the same liquids whose viscosities were measured.

MATERIALS

The benzene was of analytical reagent grade (Mallinckrodt), and chromatography showed only trace impurities with an estimated total concentration of 0.03%. The acetone (Fisher Certified Reagent) showed only a trace water peak of 0.02% on the chromatograph. The ethylene dichloride (Matheson, Coleman and Bell practical grade) showed two impurities which passed through the chromatograph prior to the ethylene dichloride. Total impurities were estimated to be about 0.03%.

TREATMENT OF DATA

Kinematic Viscosity. Methods of accounting for the effects of temperature (*8*, *11*) and composition (*8*, *11*, *14*, *15*) on the viscosities of liquids have been proposed previously and are available in the literature. The present work indicates that the influence of temperature on the viscosities of the pure components can be expressed quite satisfactorily by means of the equation

$$\ln \nu_i = A_i + B_i/T \qquad (1)$$

Consequently, the viscosities at an operating temperature T and a reference temperature T_0 are related through the expression

$$\frac{(\nu_i)_T}{\exp\left[B_i\left(\frac{1}{T}-\frac{1}{T_0}\right)\right]} = (\nu_i)_{T_0} \qquad (2)$$

The left-hand side of this equation is a suitable kinematic viscosity parameter, independent of temperature.

To account for the influence of composition on the viscosities of mixtures in the manner proposed by previous investigators (*9*, *11*, *14*), it can be assumed that

$$\ln (\nu)_T = \sum_1^N x_i \ln (\nu_i)_T \qquad (3)$$

Combination of Equations 1 and 3 immediately yields the final expression

$$\frac{(\nu)_T}{\exp\left[B_m\left(\frac{1}{T}-\frac{1}{T_0}\right)\right]} = (\nu)_{T_0} \qquad (4)$$

where

$$B_m = \sum_1^N (B_i x_i) \qquad (5)$$

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Table I. Precision of Experimental Kinematic Viscosities (Comparison with Figure 1)

Binary *A-B*	
No. of points measured	30
95% Confidence interval on $(\nu)_{T_0}$[a]	±0.011
Approx. % of $(\nu)_{T_0}$ (av.)	±2.2
Binary *A-E*	
No. of points measured	38
95% Confidence interval on $(\nu)_{T_0}$	±0.009
Approx. % of $(\nu)_{T_0}$ (av.)	±1.9
Binary *B-E*	
No. of points measured	40
95% Confidence interval on $(\nu)_{T_0}$	±0.015
Approx. % of $(\nu)_{T_0}$ (av.)	±2.3

	$x_B/(x_B + x_E)$			
Ternary *A-B-E*	0.274	0.493	0.732	Over-all
No. of points measured	27	28	28	83
95% Confidence interval on $(\nu)_{T_0}$	±0.010	±0.006	±0.010	±0.009
Approx. % of $(\nu)_{T_0}$ (av.)	±2.1	±1.2	±2.0	±1.8

[a] Confidence intervals are expressed in centistokes.

Since $(\nu)_{T_0}$ is a function of composition alone, a set of experiments must be performed at the reference temperature T_0 to establish the effect of composition. Once this is accomplished, however, the parameter which is the left-hand side of Equation 4 should adequately include any effect of temperature, within the validity of the original assumptions set forth in Equations 1 and 3.

Density or Molal Volume. One means of correlating the densities of mixtures is to follow a procedure similar to that used in correlating the kinematic viscosities. Another method (*2*, *21*) which proves to be more satisfactory in the present case, is to deal instead with the molal volume V of the ternary mixture in terms of the molal volumes V_A, V_B, V_E, of the pure components and the interaction coefficients C_{AB}, C_{EA}, and C_{BE}. Their relationship is taken to be

$$V = x_A V_A + x_B V_B + x_E V_E + C_{AB} x_A x_B + C_{EA} x_E x_A + C_{BE} x_B x_E \quad (6)$$

The values of the coefficients can of course be determined from experimental data on the corresponding binary solutions. The direct connection between molal volume and density is obvious.

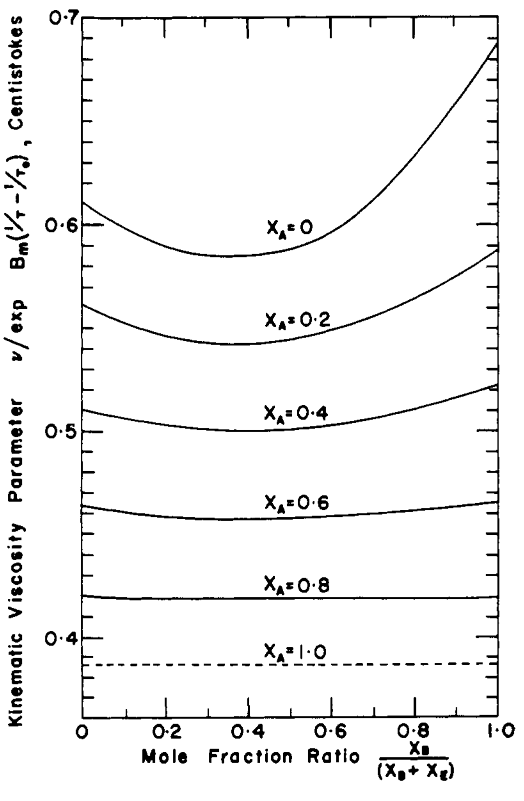

Figure 1. Viscosities of ternary liquid system, acetone (*A*)–benzene (*B*)–ethylene dichloride (*E*) at temperatures between 25° and 55° C.

ν = kinematic viscosity, centistokes
T = temperature, ° K.
T_0 = 298° K. (25° C.)

EXPERIMENTAL RESULTS

The experimental constants B_i for the pure components acetone, benzene, and ethylene dichloride are, 785, 1189, and 984, respectively. The constants B_m for the binary and ternary mixtures are evaluated by inserting these values into Equation 5.

The kinematic viscosity parameter designated in Equation 4 is shown in Figure 1. No definite trend with temperature could be distinguished in the value of the parameter at a particular composition. Therefore, the average data for the binary solutions at all four temperature levels were used to establish the limits of the graph. The ternary data were first obtained at constant ratios of the mole fraction of benzene to the combined mole fractions of benzene and ethylene dichloride, that is, $x_B/(x_B + x_E)$. The data for all four temperature levels were again averaged, and the variation with acetone concentration was determined. These results were then cross-plotted in the interest of clarity. They are presented in Figure 1 as a family of lines at even increments of the mole fraction of acetone in the mixture. Since the vertical boundaries and the $x_A = 0$ line represent the binary mixtures, the graph is a composite of the data and the three pure components, the three binary mixtures and the ternary mixture are all included. Figure 1 is therefore a general working graph for the system at hand.

The precision of the experimental binary and ternary kinematic viscosities is shown in Table I. Comparison is made with the average and smoothed values of the viscosity parameter $(\nu)_{T_0}$ on which Figure 1 is based. The 95% confidence interval on $(\nu)_{T_0}$, expressed in centistokes, is reported along with the approximate percentage variation in $(\nu)_{T_0}$ on the average. The total number of experimental points is also specified.

The molal volumes of the pure components, and the values of the interaction coefficients are presented in Table II. The molal volumes of the binary and ternary solutions can be computed from these by means of Equation 6 at the three temperature levels investigated. The precision of the experimental data can be referred to the computed volumes.

Table II. Molal Volumes of Pure Components and Interaction Coefficients for Mixtures

	25° C.	35° C.	45° C.
V_A, cc./g. mole	73.9	75.2	76.3
V_B, cc./g. mole	89.6	90.6	91.7
V_E, cc./g. mole	79.5	80.4	81.3
C_{AB}, cc./(g. mole)(x^2)	1.3	−1.1	0.1
C_{EA}, cc./(g. mole)(x^2)	0.6	−0.9	−0.1
C_{BE}, cc./(g. mole)(x^2)	0.3	−0.2	0.9

Table III. Precision of Experimental Density Measurements (Comparison with Equation 6)

	25° C.	35° C.	45° C.
Binary *A*-*B*			
No. of points measured	7	7	7
95% Confidence interval on *V*[a]	±0.2	±0.3	±0.4
Approx. % of *V* (av.)	±0.2	±0.4	±0.5
Binary *A*-*E*			
No. of points measured	7	6	7
95% Confidence interval on *V*	±0.4	±0.3	±0.2
Approx. % of *V* (av.)	±0.5	±0.4	±0.2
Binary *B*-*E*			
No. of points measured	7	6	6
95% Confidence interval on *V*	±0.3	±0.3	±0.3
Approx. % of *V* (av.)	±0.4	±0.3	±0.3
Ternary *A*-*B*-*E*			
No. of points measured	18	18	18
95% Confidence interval on *V*	±0.2	±0.4	±0.2
Approx. % of *V* (av.)	±0.2	±0.5	±0.2

[a] Confidence intervals are expressed in cc./g. mole.

The 95% confidence interval on V, expressed in cubic centimeters per gram mole, the approximate percentage variation in V on the average, and the number of experimental points are all summarized in Table III.

The reference temperature T_0 is taken to be 298° K. (25° C.) in all cases. The choice can be made arbitrarily, of course, and 298° K. is simply a convenient reference, consistent with the base states of other properties reported in the literature.

NOMENCLATURE

A = constant in Equation 1, dimensionless
B = constant in Equation 1, °K.
C = constants in Equation 6, cc. per gram
N = number of components in the mixture, dimensionless
T = absolute temperature, °K.
V = molal volume, cc. per gram mole
x = mole fraction, dimensionless

Greek Letters

ν = kinematic viscosity, centistokes

Subscripts

A = refers to acetone
B = refers to benzene
E = refers to ethylene dichloride
i = refers to pure component i
m = refers to mixture
T = refers to temperature of mixture or component
T_0 = refers to reference temperature T_0

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