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RECEIVED for review December 27, 1965. Accepted March 23, 1966. Research sponsored by the U. S. Atomic Energy Commission under contract with the Union Carbide Corp.

Surface Tension–Viscosity Relation for Liquids

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An empirical equation is proposed, $\gamma = A_{\text{exptl.}} B/\eta$, relating viscosity ($\eta$) to surface tension ($\gamma$) where A and B are dimensional constants. Experimental literature data for 33 liquid systems (organic and inorganic) are used to demonstrate the validity of the equation. Water, benzene, and toluene liquid systems are used to show that the constant B is a function of (Mk/R) where M is the molecular weight, k is the thermal conductivity, and R is the gas constant. The data suggest that this equation may be applicable over the entire liquid phase regime for any given substance.

SEVERAL relations have been postulated relating surface tension of a liquid in air to viscosity. In 1932, Silverman and Roseveare (*9*) postulated that

$$\gamma - \tfrac{1}{4} = \frac{A}{\eta} + B \qquad (1)$$

where A and B are empirical constants for a given substance. In 1953, Murkerjee (*5*) postulated that viscosity is related to surface tension by

$$\gamma = \mathrm{K}\eta^{n1/3} \qquad (2)$$

where K and n are empirical constants. In 1956, Sanyal and Mitra (*8*) postulated the following relations:

$$\text{Associated liquids: } T\log\eta - a\gamma^{5/6} = b \qquad (3)$$

$$\text{Nonassociated liquids: } T\log\eta - a\gamma = b \qquad (4)$$

where a and b are empirical constants. In 1962, Pratap and Narsimhan (*7*), suggested that surface tensions and viscosity are related by the following equation:

$$\frac{u_L \cdot \eta \cdot V^{2/3}}{(M \cdot T)^{1/2}} = 9.27_{\text{exptl.}} \frac{1.091 \cdot N^{1/3} \cdot \gamma \cdot V_m^{2/3}}{R \cdot T} \qquad (5)$$

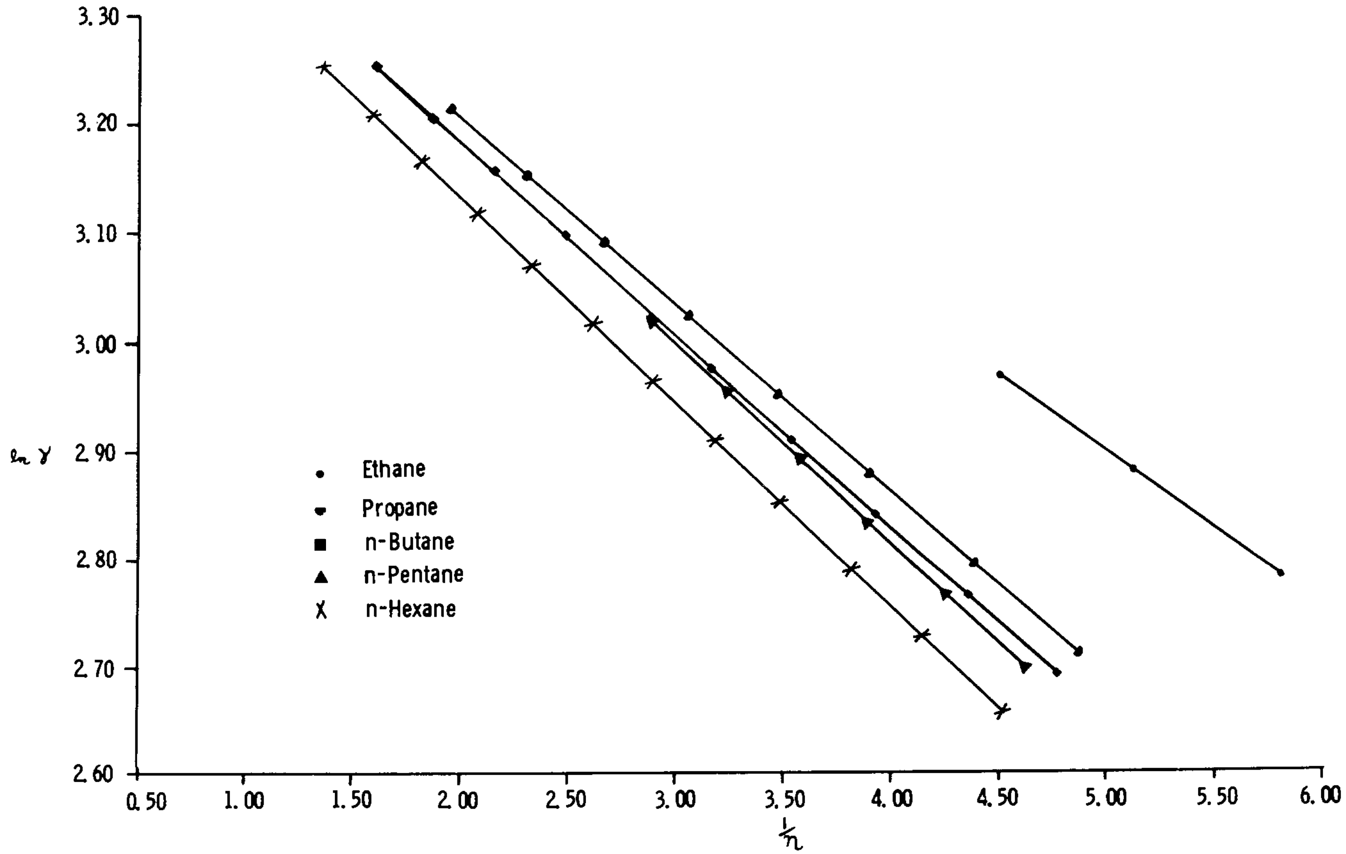

Figure 1. Least squares fit of experimental data for some members of the paraffin series

Table I. Curve Fit Data of $\gamma = A_{\text{exptl.}} B/\eta$

Substance	Slope	Intercept
Ethane	−0.1391	36.61
Propane	−0.1696	34.64
n-Butane	−0.1734	34.06
n-Pentane	−0.1865	35.45
n-Hexane	−0.1851	33.23
Benzene	−0.1916	38.87
Ethylbenzene	−0.1937	38.65
n-Propylbenzene	−0.2092	36.98
Aniline	−0.2505	45.46
Toluene	−0.1913	39.40
Phenol	−0.3119	41.63
Nitrobenzene	−0.2705	50.32
Iodobenzene	−0.2787	46.67
Bromobenzene	−0.2502	45.22
Chlorobenzene	−0.2216	43.80
o-Xylene	−0.1975	38.15
m-Xylene	−0.1936	39.17
p-Xylene	−0.1809	37.16
Acetone	−0.1871	42.19
Methyl propyl ketone	−0.1867	36.52
Dimethyl ketone	−0.1816	36.70
Water	−0.08366	79.10
Methyl alcohol	−0.1502	29.29
Ethyl alcohol	−0.1955	26.49
n-Propyl alcohol	−0.2691	26.93
n-Butyl alcohol	−0.2215	26.65

Table II. Curve Fit of Uranyl Solution Data Using $\gamma = A_{\text{exptl.}} B/\eta$

Constant Concentrations			
Solution	Concn., Moles/Liter	Slope	Intercept
Uranyl nitrate hexahydrate in water	0.23	−0.0917	79.58
Uranyl acetate dihydrate in water	0.024	−0.08803	78.27
Uranyl nitrate hexahydrate in methanol	0.1	−0.1568	29.33
Uranyl acetate dihydrate in methanol	0.07	−0.1570	29.80
Anhydrous uranyl acetate in methanol	0.024	−0.1479	29.57
Constant Temperature			
	T, ° C.	Slope	Intercept
Uranyl nitrate hexahydrate in water	0	−0.0558	78.58
	60	−0.03686	71.92
Uranyl nitrate hexahydrate in methanol	0	−0.1962	30.62
	60	−0.1290	27.31

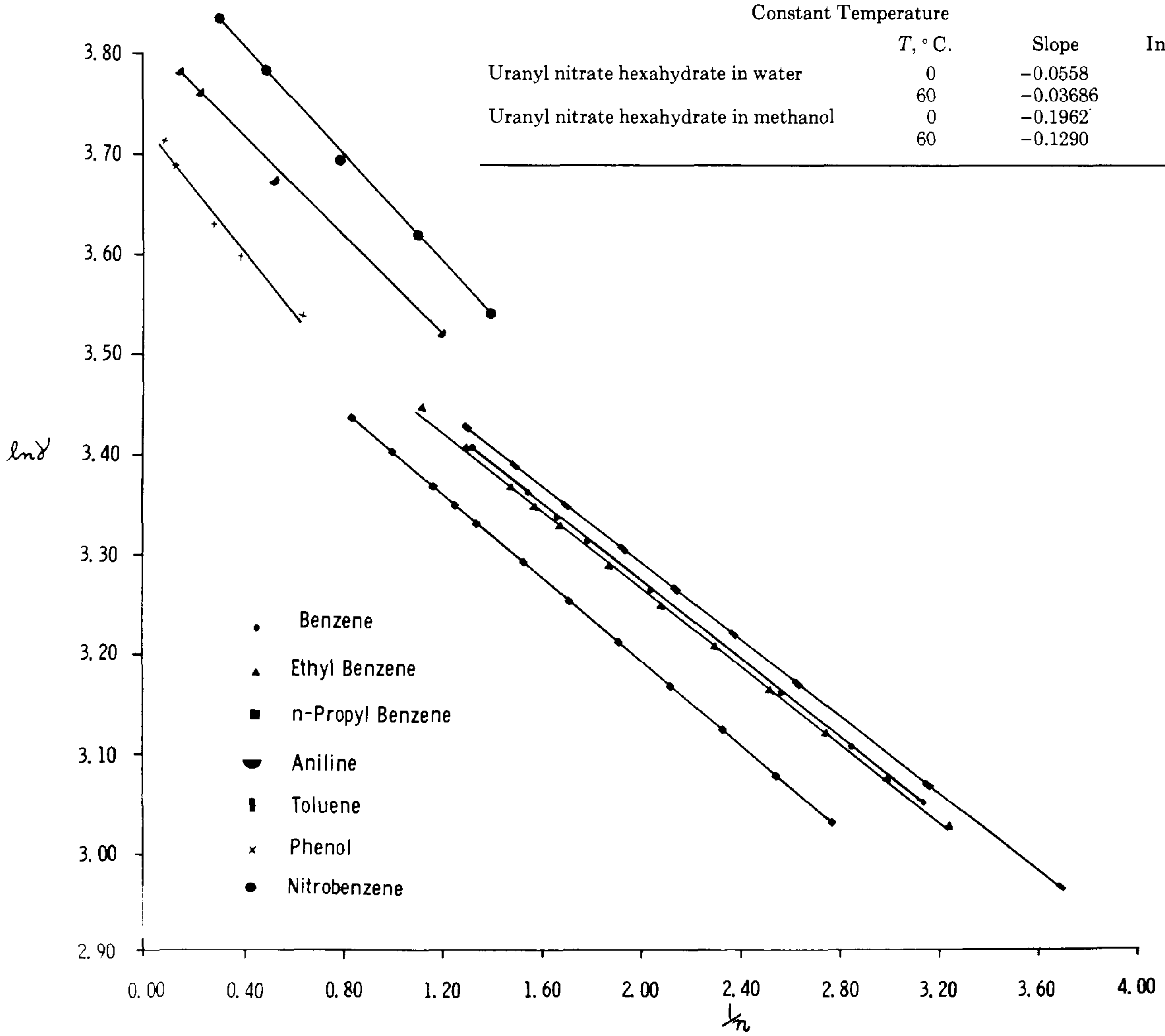

Figure 2. Least squares fit of experimental data for some members of the aromatic series

This equation was based on the free volume concept of Eyring as applied to transport properties. However, they showed this relation to be valid from 0° to 50° C. for the liquid systems they investigated.

The above relations apply only to restricted temperature ranges and therefore are of limited utility in predicting data for experimental and engineering purposes. The following relation,

$$\gamma = A_{\text{exptl.}} B/\eta \qquad (6)$$

where A and B are dimensional constants (for a given substance), seems more appropriate to fulfill these aims. It seems to apply over the entire liquid phase regime. This equation was tested by a least squares fit of the experimental data published in the literature (*1, 3-5, 10*) with the aid of a digital computer. Tables I and II depict the results of the data that were used. In all cases tested, the correlation is exceedingly precise. The general equation for this first degree polynomial is

$$\ln \gamma = \frac{B}{\eta} + \ln A \qquad (7)$$

where B is the slope and $\ln A$ is the intercept of the curve. The values of A (noted as Intercept) and B (noted as Slope) are listed in the tables for each substance. There seems to be a trend among the slopes for a given family. The slope seems to be directly proportional to the molecular weight of the given substance. Figures 1 and 2 illustrate the above postulate for the paraffins and the aromatics. The intercept may be indicative of the surface tension of the substance's solid phase since $A = \gamma$ when the viscosity approaches infinity. This has not been tested because of the lack of data.

Another form of Equation 6 is

$$\gamma = A'_{\text{exptl.}} C \frac{Mk}{R\eta} \qquad (8)$$

where C is a nondimensional constant. Table III and Figure 3 demonstrate the validity of this relation to the pure water, benzene, and toluene systems. The constant, C, appears now to be related to a rheochor concept such as has been postulated by Friend and Hargreaves (*2*).

Since Table II furnishes evidence to suggest that Equation 6 is applicable to solutions as well as pure liquids regardless of whether temperature or concentration is kept

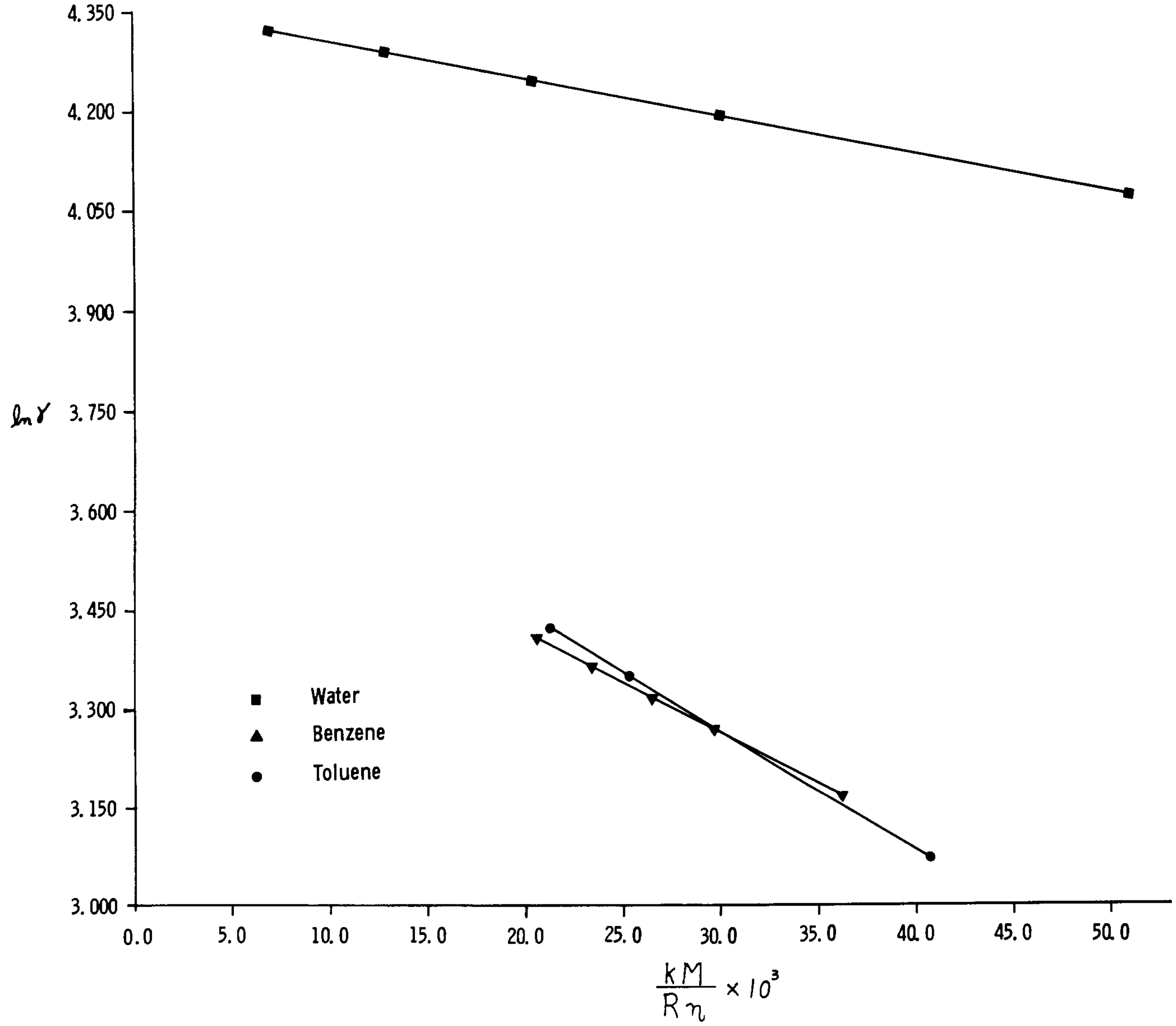

Figure 3. Least squares fit of $\gamma = A'_{\text{exptl.}} C \frac{Mk}{R\eta}$

Table III. Curve Fit Data Using $\gamma = A'_{\text{exptl.}} C[(Mk)/(R\eta)]$

Substance	Slope	Intercept
Water	−5.619	78.30
Benzene	−15.33	41.34
Toluene	−18.05	44.97

constant, perhaps the dimensional constant, B, in Equation 6 can be rationalized by the expression

$$B = \frac{EDR}{C_p V_m} \tag{9}$$

Then Equation 6 becomes

$$\gamma = A''_{\text{exptl.}} \frac{EDR}{C_p V_m \eta} \tag{10}$$

where E is a nondimensional constant for a given substance. If $A' = A''$, then

$$k = \frac{FDR^2 \rho}{C_p M^2} \tag{11}$$

where F is a nondimensional constant. Although Equations 9 through 11 have not been tested owing to the paucity of data, they have been proposed in the hopes that data are available to either validate or disprove the above hypothesis.

ACKNOWLEDGMENT

The author thanks Margarita Miller of the Frank J. Seiler Computer Center for the formulation of the computer program and the compilation of the data.

NOMENCLATURE

C_p = heat capacity, cal./gram ° K.
D = diffusion coefficient, cm.^{2}/sec.
k = thermal conductivity, cal./sec. cm.^{2} (° K./cm.)
M = molecular weight, gram/mole.
N = Avogadro's number
R = gas constant, 1.986 cal./mole ° K.
T = temperature, ° C.
u_L = velocity of sound in liquid, cm./sec.
V = volume, cm.^{3}
V_m = molar volume, cm.^{3}/mole
γ = surface tension of a liquid in air, dynes/cm.
η = viscosity, gram/cm.-sec. (centipoise)
ρ = density, gram/cm.^{3}

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RECEIVED for review January 27, 1966. Accepted April 22, 1966. Presented before the Colorado-Wyoming Academy of Science on April 22, 1966 at the Air Force Academy, Colo.