RELATION BETWEEN TRANSFER PROPERTIES OF FLUIDS

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It has been established that there is a linear relation between the thermal conductivity and the dynamic viscosity of fluids under isothermal conditions.

Theoretical and experimental studies made within recent years have established several important relations as that, for example, constant-viscosity lines must be straight lines in the T, $1/\beta_T$ system of coordinates [1].

The authors here have established [2, 3] that the equation of state and the transfer properties of normal water, heavy water, and five aromatic hydrocarbons (benzene, toluene, and o-, m-, p-xylenes) can be represented as follows:

for normal and heavy water

$$pv/RT = 1 + \frac{B}{v} + \frac{E}{v^4}, \tag{1}$$

$$\lambda/\lambda_s' = 1 + \frac{B_\lambda}{v} + \frac{E_\lambda}{v^4}, \tag{2}$$

$$\eta/\eta_s' = 1 + \frac{B_\eta}{v} + \frac{E_\eta}{v^4}, \tag{3}$$

where coefficients B, E, B_λ, E_λ, B_η, E_η depend on the temperature only; and λ_s', η_s' denote, respectively, the thermal conductivity and the dynamic viscosity along the lower-limit line;

for the five aromatic hydrocarbons

$$pv/RT = 1 + \frac{B}{v} + \frac{H}{v^7}, \tag{1'}$$

$$\lambda/\lambda_s' = 1 + \frac{B_\lambda}{v} + \frac{H_\lambda}{v^7}, \tag{2'}$$

$$\eta/\eta_s' = 1 + B_\eta/v + H_\eta/v^7. \tag{3'}$$

Moreover, the coefficients of these equations must be related as follows:

for normal and heavy water

$$-(B/E)_{p,v,T} = \rho_0^3, \tag{4}$$

$$-(B/E)_\lambda = -(B/E)_\eta = \rho_s^3; \tag{5}$$

for the five aromatic hydrocarbons

$$-(B/H)_{p,v,T} = \rho_0^6, \tag{4'}$$

$$-(B/H)_\lambda = -(B/H)_\eta = \rho_s^6, \tag{5'}$$

where $\rho_s = 1/v_s$ is the density of the fluid on the saturation line, while $\rho_0 = 1/v_0$ is the density of the fluid in its $pv/RT = 1$ state existing on every isotherm.

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TABLE 1. Values of Coefficients m(t) (W/m · deg) and n(t) (W · m/N · sec · deg) in Eq. (9) for Normal Water and Toluene

t, °C	For water		For toluene	
	$m(t)$	$n(t)$	$m(t)$	$n(t)$
0	1,5318	— 545,04	—	—
10	3,9401	—2580,71	—	—
20	6,7768	—6163,64	—	—
30	45,2517	—56000,00	—	—
40	—7,9683	13204,55	—	—
50	—3,2200	7102,23	0,0771	107,92
75	—	—	0,0690	140,65
100	—0,2314	3269,97	0,0611	177,97
125	—	—	0,0562	210,04
150	0,1484	2971,87	0,0528	239,13
175	—	—	0,0513	261,44
200	0,1876	3567,62	0,0517	274,21
225	—	—	0,0527	283,25
250	0,0812	5017,68	0,0523	305,49
275	—	—	0,0507	341,67
300	—0,1831	8073,64	—	—
350	—0,1394	8182,13	—	—

Taking into account (5) and (5'), we can rewrite formulas (2), (2') and (3), (3') as:

for normal and heavy water

$$(\lambda/\lambda_s' - 1)/\rho \cdot E_\lambda = -\rho_s^3 + \rho^3, \tag{6}$$

$$(\eta/\eta_s' - 1)/\rho \cdot E_\eta = -\rho_s^3 + \rho^3; \tag{7}$$

for the five aromatic hydrocarbons

$$(\lambda/\lambda_s' - 1)/\rho \cdot H_\lambda = -\rho_s^6 + \rho^6, \tag{6'}$$

$$(\eta/\eta_s' - 1)/\rho \cdot H_\eta = -\rho_s^6 + \rho^6. \tag{7'}$$

Equating the left-hand sides of (6) and (7), as well as of (6') and (7'), we obtain the following relation between the transfer properties:

for normal and heavy water

$$\frac{\lambda/\lambda_s' - 1}{E_\lambda} = \frac{\eta/\eta_s' - 1}{E_\eta}, \tag{8}$$

for the five aromatic hydrocarbons

$$\frac{\lambda/\lambda_s' - 1}{H_\lambda} = \frac{\eta/\eta_s' - 1}{H_\eta}. \tag{8'}$$

Furthermore, considering relations (5) and (5'), we obtain a single relation between the transfer properties for all the fluids here:

$$\lambda = \lambda_s' \left(1 - \frac{B_\lambda}{B_\eta}\right) + \frac{\lambda_s'}{\eta_s'} \cdot \frac{B_\lambda}{B_\eta} \eta$$

or

$$\lambda = m(t) + n(t)\,\eta, \tag{9}$$

where

$$m(t) = \lambda_s' \left(1 - \frac{B_\lambda}{B_\eta}\right); \tag{10}$$

$$n(t) = \frac{\lambda_s'}{\eta_s'} \cdot \frac{B_\lambda}{B_\eta}. \tag{11}$$

The coefficients m(t) and n(t) in Eq. (9) can be calculated either according to (10) and (11) or from test data on λ and η by the method of least squares [9].

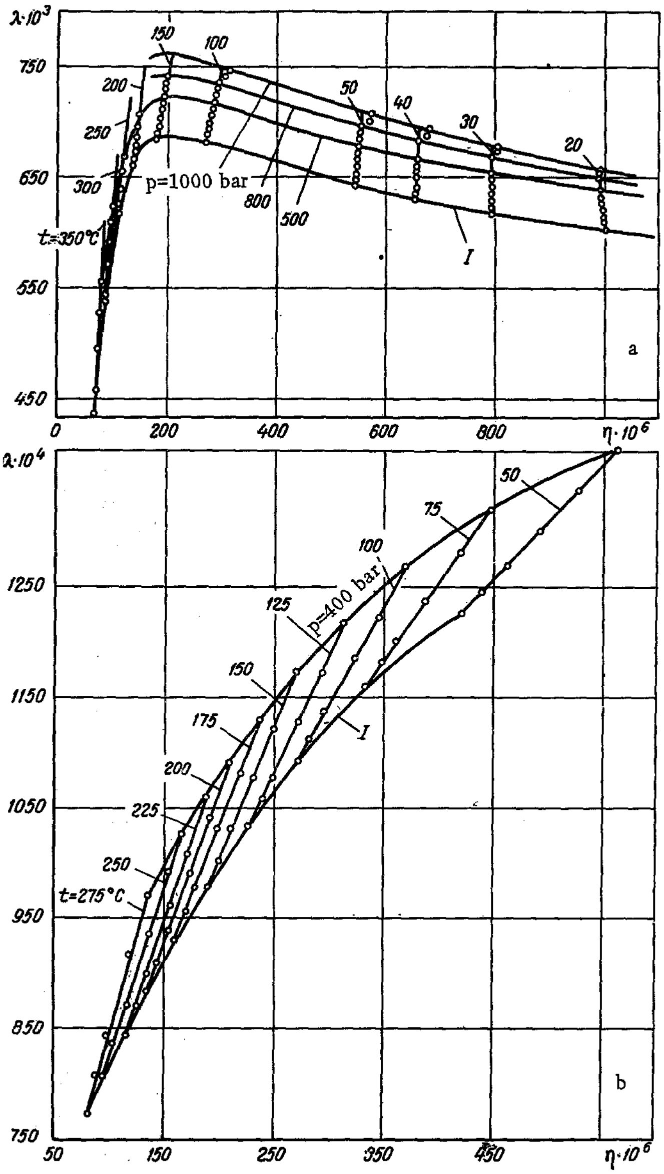

Fig. 1. Lines of constant temperature (t = const): a) for water in λ, η coordinates, according to International Condensed Tables [4] and test data in [7, 8, 9]; b) for toluene in λ, η coordinates, according to test data in [5, 6]; λ (W/m·deg); η (N·sec/m²); I) represents state of saturation.

It is to be noted that the second method of determining m(t) and n(t) offers the advantage of not requiring the additional coefficients B_λ and B_η, which would also have to be determined from test data on λ and η by the method of least squares according to Eqs. (2) and (3):

$$(\lambda/\lambda'_s - 1)\, v = B_\lambda + E_\lambda \frac{1}{v^3},$$

$$(\eta/\eta'_s - 1)\, v = B_\eta + E_\eta \frac{1}{v^3}$$

Values of coefficients m(t) and n(t) in Eq. (9), calculated for water and toluene by the method of least squares, are given in Table 1 based on International Condensed Tables [4] and test data in [5, 6].

The validity of Eq. (9) is confirmed by the linearity of the isotherms in λ, η coordinates (Fig. 1): for water under pressures up to 500 bars, on the basis of International Condensed Tables [4], for toluene under pressures up to 400 bars, on the basis of test data in [5, 6].

The availability of some test data on λ and η for water under pressures above 500 bars has allowed us to study the feasibility of extrapolating Eq. (9) to higher pressures.

We have found that up to 800 bars the values of η according to [4] and the test values of λ according to [7] fit rather well on isotherms which have been plotted up to 500 bars, while at $p = 900$ and 1000 bars the test values for η [8, 9] and λ [7] deviate by about 1.2% at 30°C, about 3% at 40°C, about 3% at 50°C, and about 2.7% at 100°C.

Thus, we find that the linear equation (9) describes, within test accuracy, the relation between λ and η for normal water over the 0-350°C temperature range under pressures up to $p_s = 1000$ bars and for toluene over the 50-250°C temperature range under pressures up to $p_s = 400$ bars.

In conclusion, we note that the relation between λ and η established here for normal water and toluene will be valid for other fluids as well, but this must still be verified experimentally.

NOTATION

T	is the absolute temperature;
β_T	is the compressibility;
p	is the absolute pressure;
v	is the specific volume;
R	is the gas constant;
λ	is the thermal conductivity;
η	is the dynamic viscosity;
λ'_s, η'_s	are the thermal conductivity and the dynamic viscosity at the lower-limit line;
B, E, H, B_λ, E_λ, H_λ, B_η, E_η, H_η	are the coefficients which depend on the temperature only;
ρ_s	is the density of a fluid at the lower-limit line;
ρ_0	is the density of a fluid in its $pv/RT = 1$ state existing on every isotherm;
$m(t)$	is the free term in the linear relation $\lambda = f(\eta)$, a function of the temperature only;
$n(t)$	is the coefficient in the linear relation $\lambda = f(\eta)$, a function of the temperature only;
$m_1(t)$	is the free term in the linear relation $\eta = \varphi(\lambda)$, a function of the temperature only;
$n_1(t)$	is the coefficient in the linear relation $\eta = \varphi(\lambda)$, a function of the temperature only.

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