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DEPENDENCE OF THE TRANSPORT PROPERTIES OF LIQUIDS ON THE SOUND VELOCITY AND DENSITY

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UDC 532.14+534

Linear relations expressing the transport properties of liquids as a function of the sound velocity and the density are derived according to the Shirokov dimensionless group, Rao's rule, and the author's formula $\eta = m + n\lambda$.

The dimensionless group of Shirokov [1] is known to qualitatively consolidate four thermophysical properties of liquids in the form

$$\frac{\eta u^2}{T\lambda} = 1. \tag{1}$$

According to Rao's rule [2, 3], the sound velocity in a liquid is proportional to the third power of the density of the medium:

$$u \approx \rho^3. \tag{2}$$

According to our data [4], the transport properties of liquids along the isotherms are linked by a linear relation:

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TABLE 1. Values of the Coefficients in Eqs. (5), (7), (9), and (11), Computed for Water by the Least-Squares Method: $\left[a_1, \frac{(\mathrm{km/sec})^2}{\mathrm{W/m \cdot ^\circ C}}; b_1, \frac{1}{\mathrm{W/m \cdot ^\circ C}}\right]$; $\left[a_2, \frac{(\mathrm{g/cm^3})^6}{\mathrm{W/m \cdot ^\circ C}}; b_2, \frac{1}{\mathrm{W/m \cdot ^\circ C}}\right]$; $\left[a_3, \frac{1}{\mathrm{Pa \cdot sec}}; b_3, \frac{1}{(\mathrm{Pa \cdot sec})(\mathrm{km/sec})^2}\right]$; $\left[a_4, \frac{1}{\mathrm{Pa \cdot sec}}; b_4, \frac{1}{(\mathrm{Pa \cdot sec})(\mathrm{g/cm^3})^6}\right]$

t, °C	a_1	b_1	a_2	b_2	a_3	b_3	a_4	b_4
0	1,40344	1,04899	0,57000	1,18660	0,000389	0,0000903	0,000424	0,0001425
50	1,30071	1,01706	0,48000	1,05000	0,002135	—0,0001275	0,002096	—0,0002842
100	1,37746	0,90711	0,41255	0,95072	0,004537	—0,0004200	0,004573	—0,0013343
150	1,25841	0,89035	0,33159	0,91754	0,007106	—0,0007700	0,007215	—0,0029527
200	1,01816	0,94866	0,24004	0,95184	0,009588	—0,0012311	0,009476	—0,0049832
250	0,77500	1,05555	0,16028	1,03716	0,012111	—0,0020428	0,011955	—0,0094321
300	0,62909	1,15193	0,09971	1,15599	—	—	—	—
350	0,57587	1,21288	0,05881	1,29936	—	—	—	—

$$\eta = m + n\lambda. \tag{3}$$

From relations (1)-(3) we can deduce four equations expressing the transport properties of liquids as a function of the sound velocity and the density. Replacing η in Eq. (1) by expression (3), we obtain

$$\frac{u^2}{\lambda} = a_1 + b_1 u^2, \tag{4}$$

i.e., the ratio u^2/λ along the isotherms depends linearly on the sound velocity squared, and

$$\lambda = \frac{u^2}{a_1 + b_1 u^2}. \tag{5}$$

Making use of Rao's rule (2), we can write expression (4) in the form

$$\frac{\rho^6}{\lambda} = a_2 + b_2 \rho^6, \tag{6}$$

i.e., the ratio ρ^6/λ along the isotherms depends linearly on the sixth power of the density of the liquid, and

$$\lambda = \frac{\rho^6}{a_2 + b_2 \rho^6}. \tag{7}$$

Replacing the value of λ in relation (1) by expression (3), we obtain

$$\frac{1}{\eta} = a_3 + b_3 u^2, \tag{8}$$

i.e., the reciprocal of the dynamic viscosity coefficient along the isotherms depends linearly on the sound velocity squared, and

$$\eta = \frac{1}{a_3 + b_3 u^2}. \tag{9}$$

Making use of Rao's rule (2), we can write expression (8) in the form

$$\frac{1}{\eta} = a_4 + b_4 \rho^6, \tag{10}$$

i.e., the reciprocal of the dynamic viscosity coefficient along the isotherms depends linearly on the sixth power of the density of the liquid, and

$$\eta = \frac{1}{a_4 + b_4 \rho^6}. \tag{11}$$

In expressions (4)-(10) a_1, b_1; a_2, b_2; a_3, b_3; a_4, b_4 denote temperature-dependent characteristic coefficients of a given liquid.

We have determined the values of these coefficients for water by the method of least squares in accordance with expressions (4), (6), (8), and (10), using existing data on u [5], λ [6], η [7], and ρ [8]; they are summarized in Table 1 and plotted graphically in Fig. 1.

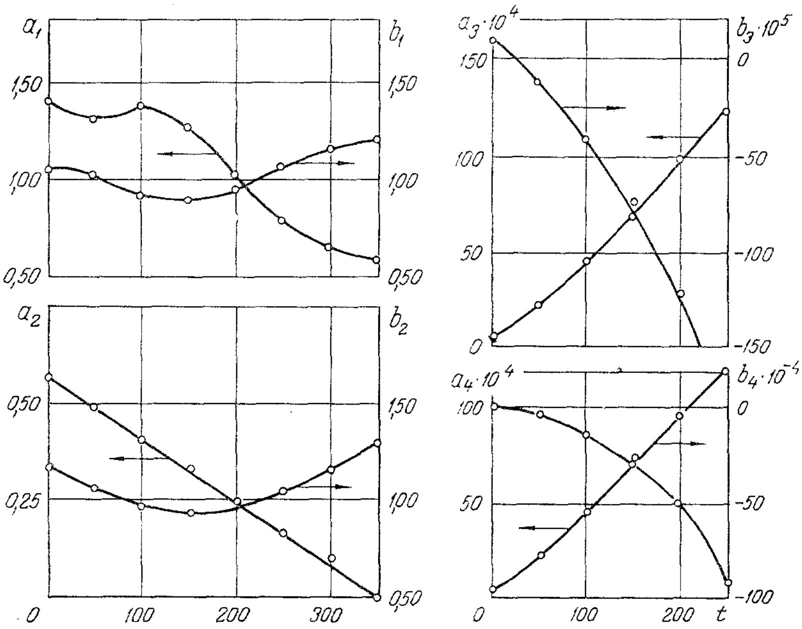

Fig. 1. Curves of the coefficients $a_1 = f(t)$, $b_1 = \varphi(t)$; $a_2 = f(t)$, $b_2 = \varphi(t)$ in Eqs. (4)-(7) and $a_3 = f(t)$, $b_3 = \varphi(t)$; $a_4 = f(t)$, $b_4 = \varphi(t)$ in Eqs. (8)-(11) for water.

A check has shown that the proposed expressions (5) and (7) describe the thermal conductivity within the temperature limits 0-350°C and at pressures p_s up to 100 MPa with maximum deviations of 1.5-2% from the recommended data [6]. These deviations refer mainly to the saturated liquid.

In the indicated temperature and pressure ranges expressions (9) and (11) describe the dynamic viscosity coefficient within the tolerances set forth for η in [7].

It must be supposed that the given expressions will also be applicable to other liquids.

NOTATION

T, absolute temperature; η, dynamic viscosity coefficient; u, sound velocity in the liquid; λ, thermal conductivity; ρ, density; a, b, temperature-dependent characteristic coefficients of a given liquid.

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