TRANSFER CHARACTERISTICS OF MULTICOMPONENT COOLING AGENTS

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A method for calculating and predicting the coefficients of thermal conductivity and viscosity of pure substances and two- or multicomponent mixtures has been developed on the basis of the single-parameter law of the corresponding states.

Mixtures consisting of Freons, hydrocarbons, and inert gases constitute operating media which offer promise for the refrigeration and cryogenic technology. Such mixtures make it possible to produce cold at a lower temperature, reduce the power capacity of the equipment, and improve the exoenergic efficiency of low-temperature throttling cycles.

In order to calculate the heat exchange processes in such systems, it is necessary to have reliable information on the thermophysical characteristics of the mixtures. However, there are very few data in the literature concerning the characteristics of two- or multicomponent mixtures, in particular, the coefficients of thermal conductivity and viscosity. In connection with this, we have performed experimental investigations of the λ and η values for a number of Freon-based mixtures that offer promise for the cryogenic and refrigeration technology. A method for calculating the transfer coefficients was developed on the basis of the results obtained.

Table 1 provides information on the experimental investigations of the transfer characteristics. The thermal conductivity measurements were performed by using the stationary hot-wire method, while viscosity was measured by means of a capillary viscosimeter. Some of the experimental data on λ and η were published in [1-4]. Table 2 provides the coefficients of thermal conductivity and viscosity of the R12—R22 and R12—R22—R142 mixtures at the saturation curve.

The experimental results obtained, in combination with the most reliable literature data on the thermal conductivity and viscosity of hydrocarbons, Freons, and inert gases [5-9], were used in developing a method for calculating the transfer coefficients.

Processing of data on the viscosity and thermal conductivity for the state of a rarefied gas has shown that, in a wide temperature range ($0.5 < \tau < 3$), the data on λ and η are ade-

TABLE 1. Investigated Ranges of Parameters for the Transfer Characteristics of Cooling Agent Mixtures

Mixture	Thermal conductivity		Viscosity	
	T, K	P, MPa	T, K	P, MPa
R13—R14 (x_1=0,54)	100—300	0,1—20	—	—
R12—R22 (x_1=0,21)	216—416	0,1—20	223—443	0,1—20
R12—R22 (x_1=0,54)	217—425	0,1—20	224—433	0,1—20
R12—R22 (x_1=0,72)	215—406	0,1—20	223—434	0,1—20
R14—R22 (x_1=0,17)	—	—	245—403	0,1—20
R14—R22 (x_1=0,38)	290—340	0,1—20	—	—
R14—R22 (x_1=0,58)	270—310	0,1—15	—	—
R14—R22 (x_1=0,79)	240—280	0,1—15	—	—
R12—R22—R142 (x_1=0,24; x_2=0,24)	216—420	0,1—20	201—433	0,1—20
R22—R50—R740 (x_1=0,62; x_2=0,32)	280—377	0,5—11,2	302—373	0,2—5,9
R12—R22—R142—R744 (x_1=0,20; x_2=0,20; x_3=0,45)	215—411	0,1—20	224—433	0,1—20

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TABLE 2. Transfer Characteristics of Mixtures at the Saturation Curve

T, K	Thermal conductivity, 10^4 W/(m·deg K)				Viscosity, μPa·sec			
	R12—R22			R12—R22—R142	R12—R22			R12—R22—R142
	$x_1=0{,}21$	$x_1=0{,}54$	$x_1=0{,}72$	$x_1=0{,}24$; $x_2=0{,}24$	$x_1=0{,}21$	$x_1=0{,}54$	$x_1=0{,}72$	$x_1=0{,}24$; $x_2=0{,}24$
200	1188	1075	1043	1165	—	—	—	—
220	1103	996	967	1085	406	435	452	551
240	1017	917	891	1005	318	336	355	421
260	932	840	816	927	251	266	280	322
280	849	767	743	852	200	210	221	256
300	770	699	674	781	161	168	177	194
320	696	638	611	716	129	134	142	158
340	629	586	566	659	105	108	115	129

TABLE 3. Initial Data and Errors in Description of the Transfer Characteristics

Substance	$\eta_{0,cr}$, μPa·sec	$\lambda_{0,cr}\cdot 10^4$ W/(m·deg K)	$\Delta\eta_{\omega=1}$, μPa·sec	$\Delta\lambda_{\omega=1}$, 10^4 W/(m·deg K)	ρ_{cr}, kg/m³	A	S_{η_0},%	S_{λ_0},%	S_{η},%	S_{λ},%
Argon	12,35	96	16,12	186	531	4,00	0,9	0,5	1,6	1,0
Krypton	18,44	69	24,02	134	909	4,00	0,7	0,4	1,0	1,9
Xenon	22,70	54	30,37	103	1115	4,10	0,7	0,4	1,2	1,1
Neon	7,20	111	9,66	219	483	3,80	1,3	1,6	1,7	2,0
Nitrogen	8,60	117	10,43	220	313	3,57	1,0	4,2	2,9	3,4
Methane	7,42	206	7,89	305	162	3,95	0,5	2,6	3,0	5,2
Ethane	9,50	222	12,79	228	203	2,89	0,4	1,7	2,3	3,3
Propane	9,90	269	13,08	210	217	2,39	0,9	1,9	5,4	1,5
Freon R12	16,10	144	24,30	175	558	2,19	1,3	2,3	5,7	2,8
Freon R13	14,65	124	20,88	195	580	2,20	1,8	1,2	4,7	4,5
Freon R14	13,60	107	19,03	205	630	2,19	1,2	2,7	5,3	2,1
Freon R21	16,35	168	25,26	218	530	1,97	0,2	2,1	2,0	3,2
Freon R22	15,70	152	22,31	225	518	1,91	0,4	1,5	2,6	4,7
Freon R23	14,80	133	18,16	300	525	1,77	1,4	0,7	3,5	1,9
Freon R142	14,56	186	24,55	280	435	1,79	1,9	1,3	4,2	5,0
R12—R22 ($x_1=0{,}21$)	15,91	150	26,53	235	532	1,97	0,5	0,5	5,1	2,0
R12—R22 ($x_1=0{,}54$)	15,81	147	25,94	220	542	2,06	0,5	1,0	4,5	4,2
R12—R22 ($x_1=0{,}72$)	15,79	146	26,54	210	549	2,12	0,7	0,9	3,6	5,0
R12—R22—R142 ($x_1=0{,}24$ $x_2=0{,}24$)	15,20	169	26,20	225	485	1,91	0,1	1,3	3,7	3,5
R50—R22—R740 ($x_1=0{,}32$ $x_2=0{,}62$)	15,43	262	7,87	125	405	2,69	0,3	0,6	1,0	1,2

quately described by the equation

$$K^* = \sum_{i=1}^{2} a_i \tau^i, \tag{1}$$

where K* is the reduced viscosity coefficient $\eta^* = \eta/\eta_{0,cr}$ or the thermal conductivity coefficient $\lambda^* = (\lambda_0/C_{V_0})/(\lambda_{0,cr}/C_{V_0,cr})$ [10].

Equation (1) with the coefficients $a_1 = 1.082$ and $a_2 = -0.082$ describes the experimental data on the viscosity of 20 processed media with a root-mean-square error of 1.0%. For thermal conductivity, $a_1 = 1.067$ and $a_2 = -0.067$; the root-mean-square error is equal to 1.9%. Table 3 provides the $\eta_{0,cr}$ values, along with the root-mean-square errors for each of the substances used in the processing, that are necessary for calculation based on Eq. (1).

In processing data on the transfer coefficients in the range for solid gases and liquids, we used the specifics of the behavior of the excess viscosity $\Delta\eta = \eta - \eta_0$ and thermal conduc-

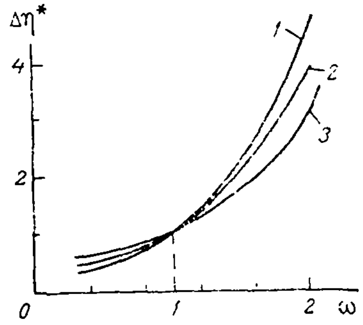

Fig. 1

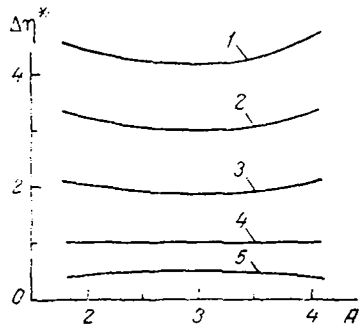

Fig. 2

Fig. 1. Dependence of $\Delta\eta^*$ on ω: 1) xenon (A = 4.10); 2) ethane (A = 2.39); 3) Freon R23 (A = 1.77).

Fig. 2. Dependence of $\Delta\eta^*$ on A: 1) ω = 2.0; 2) 1.75; 3) 1.5; 4) 1; 5) 0.5.

TABLE 4. Coefficients of Equation (2)

Coefficients	Viscosity	Thermal conductivity
a_{10}	$-4,8128 \cdot 10^{-1}$	$3,5226 \cdot 10^{-1}$
a_{11}	$1,9620 \cdot 10^{-1}$	$1,5079 \cdot 10^{-1}$
a_{12}	$-2,7626 \cdot 10^{-2}$	$-1,9206 \cdot 10^{-2}$
a_{20}	$2,6128 \cdot 10^{0}$	$1,0453 \cdot 10^{0}$
a_{21}	$-6,6374 \cdot 10^{-2}$	$-2,4163 \cdot 10^{-1}$
a_{22}	$-9,1717 \cdot 10^{-3}$	$1,8637 \cdot 10^{-2}$
a_{30}	$-1,4605 \cdot 10^{0}$	$-4,0608 \cdot 10^{-1}$
a_{31}	$-2,6812 \cdot 10^{-1}$	$-1,0966 \cdot 10^{-3}$
a_{32}	$5,8195 \cdot 10^{-2}$	$1,9599 \cdot 10^{-2}$
a_{40}	$5,5297 \cdot 10^{-1}$	$7,6196 \cdot 10^{-2}$

tivity $\Delta\lambda = \lambda - \lambda_0$, which are single-valued functions of the density in a wide range of state parameters up to $\omega \leq 2$ (we did not consider the behavior of the characteristics near the critical point). The dependences of $\Delta\eta^* = \Delta\eta/\Delta\eta_{\omega=1}$ on ω given in Fig. 1, which are plotted for xenon, propane, and Freon R23, indicate that, in order to generalize these data, it is necessary to introduce a factor accounting for the specific characteristics of the various individual substances and mixtures. In accordance with [11], the determining parameter A = 100 π for τ = 0.625 at the saturated vapor pressure curve, proposed by L. P. Filippov, is used as this factor. The A values for the substances included in the processing are given in Table 3. It should be noted that the determining parameter A varies in a very wide range (from 1.8 to 4.1), which made it possible to account for its effect on the transfer characteristics with a sufficiently high degree of accuracy. As an example, Fig. 2 represents isochoric sections of the $\Delta\eta^*(A)$ set.

As a result of processing the data files on η and λ, each of which included approximately 400 experimental points in the ranges ω = 0.5...2 and A = 1.8...4.1, we obtained the equations

$$\Delta K^* = \sum_{i=1}^{n} \sum_{j=0}^{m} a_{ij} \omega^i A^j. \tag{2}$$

The coefficients of Eq. (2) for the viscosity and thermal conductivity are given in Table 4. The values of $\Delta\eta_{\omega=1}$, $\Delta\lambda_{\omega=1}$, and ρ_{cr} necessary for calculations based on Eq. (2) and the root-mean-square errors for each of the substances included in the processing are given in Table 3. The over-all root-mean-square error for all the processed substances was equal to 3.6% with respect to viscosity and 3.5% with respect to thermal conductivity.

The proposed method makes it possible to determine with respect to a single experimental point the viscosity and thermal conductivity of hydrocarbons, Freons, inert gases, and their mixtures in a wide range of parameters of state.

NOTATION

η, dynamic viscosity coefficient; λ, thermal conductivity coefficient; T, temperature; p, pressure; ρ, density; T_{cr}, p_{cr}, and ρ_{cr}, critical temperature, pressure, and density, respectively; $\tau = T/T_{cr}$, $\pi = p/p_{cr}$, and $\omega = \rho/\rho_{cr}$, reduced temperature, pressure, and density, respectively; η_0 and λ_0, coefficients of viscosity and thermal conductivity for the rarefied gas state, respectively; $\eta_{0,cr}$ and $\lambda_{0,cr}$, coefficients of viscosity and thermal conductivity for the rarefied gas state at T_{cr}, respectively; C_{V_0}, ideal-gas isochoric specific heat; $C_{V_0,cr}$, ideal-gas isochoric specific heat at T_{cr}; $\Delta\eta_{\omega=1}$ and $\Delta\lambda_{\omega=1}$, excess coefficients of viscosity and thermal conductivity for $\omega = 1$, respectively; A, Filippov's determining parameter; K*, reduced excess coefficient of viscosity or thermal conductivity ($\Delta\eta^*$, $\Delta\lambda^*$); S, root-mean-square error; a, coefficient; x, mole fraction.

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