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APPLICATION OF THE THEORY OF SIMILARITY FOR PURPOSES  
OF GENERALIZING THE THERMAL-DIFFUSION FACTOR FOR  
MIXTURES OF MULTIATOMIC NONPOLAR GASES

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The thermal-diffusion factor of 14 nonpolar-gas mixtures has been generalized on the basis of similarity theory. The theoretical values of  $\alpha_{th}$  obtained on the basis of this generalized relationship are compared with the experimental data.

A great amount of experimental material on the thermal diffusion of mixtures containing multiatomic gases has recently been published in the literature. Nevertheless, the practical application of these data frequently encounters difficulties. Indeterminacy arises in the evaluation of the reliability of these experimental data, obtained by various authors for the corresponding ranges of average temperatures and concentrations, differing from one another by more than 10%. The various semiempirical methods of forecasting thermal-diffusion characteristics are complicated in their application, as for example [1, 2] those which are based on the utilization (in the calculations) of experimental data.

The thermal-diffusion results are presented in the literature, as a rule, in the form of a relationship between the thermal-diffusion factor  $\alpha_{th}$  and the average (characteristic) temperature  $T$  or the concentration  $x$ . In a number of cases, in the place of  $\alpha_{th}$  we are confronted with the values of  $\Delta c_1$  (or  $q$ ) as a function of  $T_1$  and  $T_2$  ( $T_1$  and  $T_2$  denote the temperatures of the vessels in the thermal-diffusion apparatus, in which case  $T_1 > T_2$ ).

Various methods exist for the averaging of the temperature [3], but the most widely used is the Brown formula [4], which determines the mean logarithmic temperature:

$$T = \frac{T_1 T_2}{T_1 - T_2} \ln \frac{T_1}{T_2} \quad (1)$$

Since in accordance with (1) various experimental conditions (i.e., various values of  $T_1$  and  $T_2$ ) may correspond to one and the same average temperature, we are interested in evaluating the changes in the quantity  $\alpha_{th}$  with a change in the values of  $T_1$  and  $T_2$ , but with the mean logarithmic temperature kept constant. The values of  $\alpha_{th}$  were studied in [5] for various temperature values in the upper and lower vessels of the thermal-diffusion apparatus. It was demonstrated (as an example, for the mixture He-N<sub>2</sub>) that with a fixed temperature  $T_2$  for the lower vessel on the order of 290-293 K and with a change in the temperature  $T_1$  in the upper vessel from 400 to 1010 K the quantity  $\alpha_{th}$  undergoes virtually no change.

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TABLE 1. Molecular Diameters of Solid Spheres, Calculated from the Viscosity Data for T = 273 K

Gas	$[\eta]_1 \cdot 10^7$ (N·sec)/m <sup>2</sup>	$\sigma$ , Å	Gas	$[\eta]_1 \cdot 10^7$ (N·sec)/m <sup>2</sup>	$\sigma$ , Å
He	186,0	2,18	H <sub>2</sub>	84,0	2,73
Ne	293,0	2,60	N <sub>2</sub>	166,3	3,75
Ar	212,7	3,64	O <sub>2</sub>	191,8	3,61
Kr	233,0	4,16	CH <sub>4</sub>	100,8	4,19
Xe	211,0	4,89	CO <sub>2</sub>	136,5	4,62

TABLE 2. Values of the Polynomial Coefficient

$$\ln(\alpha^{-1})_{\text{th.s.sp}} = \sum_{i=1}^n C_i (\ln T^*)^{i-1}$$

C <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>	C <sub>4</sub>
2,38257	-1,52495	0,330919	
2,38489	-1,53050	0,334716	-0,764609

TABLE 3. Values of the Polynomial Coefficient  $\alpha_{\text{th.s.sp}}^{-1} = a + bx_1$  for Various Gas Mixtures

Gas mixture	a	b	Gas mixture	a	b
He-CO <sub>2</sub>	2,09346	-1,54697	H <sub>2</sub> -O <sub>2</sub>	2,04766	-1,10773
He-N <sub>2</sub>	2,16051	-1,37085	H <sub>2</sub> -CO <sub>2</sub>	2,03917	-1,36282
Ne-CO <sub>2</sub>	3,23253	-1,90101	H <sub>2</sub> -N <sub>2</sub>	2,05718	-1,14260
Kr-N <sub>2</sub>	2,61592	-0,68741	H <sub>2</sub> -CH <sub>4</sub>	2,13556	-1,13420
Xe-N <sub>2</sub>	2,27396	-1,01169	N <sub>2</sub> -CO <sub>2</sub>	4,82204	-1,38781
Xe-CH <sub>4</sub>	2,09978	-0,88663	O <sub>2</sub> -CO <sub>2</sub>	6,20213	-1,94402
H <sub>2</sub> -Ar	2,03781	-1,12850	CH <sub>4</sub> -CO <sub>2</sub>	2,73532	-0,67117
H <sub>2</sub> -Xe	2,00554	-0,28284			

However, an increase in T<sub>2</sub> by 70 K (with the mean logarithmic temperature kept constant) leads to an increase in  $\alpha_{\text{th}}$  by approximately 5-6%.

Experimental determination of the thermal-diffusion characteristics of gas mixtures is laborious. Even in the slight change that occurs in the gas composition during the process of thermal diffusion (usually by no more than 7-10%), the measurement of this quantity involves practical difficulties. Therefore, depending on the method of the experiment (the type of installation, the method of determining the gas composition), as well as the form and composition of the gas mixture being investigated, the accuracy of determining these characteristics may be diverse. Usually, for gas mixtures (excluding mixtures of isotopes) the error in the results of the investigations into  $\alpha_{\text{th}}$ , estimated by the authors at a pressure close to the normal, ranges from  $\pm(1-10)\%$ . Consequently, within the limits of error of the thermal-diffusion experiment the mean logarithmic temperature may serve as a basis for comparison of the  $\alpha_{\text{th}}$  data measured by various authors.

The thermal-diffusion factor for mixtures of inert gases had been generalized on the basis of similarity theory in earlier works [6, 7]. The theoretical relationships for  $\alpha_{\text{th}}$ , obtained here, contained two correction factors n and k which were dependent on temperature and concentration. The complexity in determining these quantities over various temperature and concentration ranges limits the area in which these relationships can be employed.

In this paper we undertake a generalization of the  $\alpha_{\text{th}}$  factor for mixtures containing multiatomic nonpolar gases H<sub>2</sub>, N<sub>2</sub>, CO<sub>2</sub>, CH<sub>4</sub>. According to [8], the shape of the molecules of the above-enumerated gases does not differ significantly from the spherical. The coefficient of compressibility at the critical point for these gases is close to ~0.290, which is characteristic for monatomic gases. The values of the coefficients of compressibility for the mixtures made up of simple spherical and multiatomic nonpolar molecules, of course, approximate this quantity. The coefficient of compressibility for the mixture at the critical point (i.e., the pseudocritical value), according to [9], has been determined on the basis of the additive relationship from the values of the compressibility coefficient at the critical point of the components making up the mixture. However, the proximity of the

values for the compressibility coefficients in this case prove to be inadequate to determine groups of similar substances.

Using the method of least squares to process all of the above-cited values for the thermal-diffusion factors in their dependence on the cited temperature of the mixtures containing multiatomic nonpolar gases demonstrated that only the given  $\alpha_{th}$  of the mixtures for which the ratio  $\sigma_1/\sigma_2$  of the effective molecule collision diameters (subscript 1 pertains to the light component of the mixture) is less than unity fall out along a single curve. In this connection, the entire volume of data for the generalization was made up of existing data on the thermal-diffusion factor for 14 gas mixtures satisfying the condition  $\sigma_1/\sigma_2 < 1$ : He-N<sub>2</sub>, He-CO<sub>2</sub>, H<sub>2</sub>-Ar, H<sub>2</sub>-N<sub>2</sub>, H<sub>2</sub>-O<sub>2</sub>, H<sub>2</sub>-CH<sub>4</sub>, H<sub>2</sub>-CO<sub>2</sub>, N<sub>2</sub>-Kr, N<sub>2</sub>-Xe, Ne-CO<sub>2</sub>, N<sub>2</sub>-CO<sub>2</sub>, O<sub>2</sub>-CO<sub>2</sub>, CH<sub>4</sub>-CO<sub>2</sub>, Xe-CH<sub>4</sub>. As was done in [5], the values of  $\alpha_{th.s.sp}$  and  $\epsilon_{12}/k$  were taken as the reduction parameters for the variables  $\alpha_{th}$  and T. The collision diameters for the models of the solid spheres, which we needed to calculate  $\alpha_{th.s.sp}$ , were determined from the viscosity data [10, 11] obtained at 273 K (Table 1). The values of  $\epsilon_{12}/k$  were determined from the  $\epsilon/k$  for pure components [8] by means of the combination rules  $\epsilon_{12} = \epsilon_1\epsilon_2^{1/2}$  (k is the Boltzmann constant).

As a result of processing all of the  $\alpha_{th}$  data for the above-enumerated 14 gas mixtures (a total of 200 points) by the method of least squares with the aid of the polynomial\*

$$\ln(\alpha_{th}^{*-1}) = \sum_{i=1}^n C_i (\ln T^*)^{i-1} \quad (2)$$

we obtain the following coefficients (Table 2).

Figure 1 shows the generalized temperature relationships of the thermal-diffusion factor in terms of the reference quantities (so as to avoid making any figure overly cumbersome, a portion of the data near the generalized curve has been omitted). The figure also shows a plot of the generalized curves (15, 16), obtained on the basis of the 2nd and 3rd degree polynomials. Because of the considerable differences in the behavior of the curves, so as to simplify the calculation of  $\alpha_{th}$  we used the second-degree polynomial.

We obtained the following expression from formula (2) to calculate the thermal-diffusion factors:

$$\alpha_{th} = \alpha_{th.s.sp} \cdot \exp \left[ \sum_{i=1}^n C_i (\ln T^*)^{i-1} \right], \quad (3)$$

where  $\alpha_{th.s.sp}$  is calculated on the basis of the relationships presented in [8].

Since the magnitude of the thermal-diffusion factor for the majority of gas mixtures is linearly dependent on concentration [12], by processing the calculated values of  $\alpha_{th.s.sp}^{-1}$  for the gas mixtures under consideration with the method of least squares we obtain the coefficient of the polynomial  $\alpha_{th.s.sp}^{-1} = a + bx_1$  (Table 3). Then, in place of (3), we can write

$$\alpha_{th} = \frac{(a + bx_1)^{-1}}{\exp [3.38257 - 1.52495 \ln T^* + 0.330919 (\ln T^*)^2]} \quad (4)$$

As an example, Figs. 2 and 3, as well as Table 4, show comparisons of the theoretical values of  $\alpha_{th}$ , obtained from the generalized relationship (4), with the experimental data of [13-38]. The figures also show the results of the Chapman-Enskog theory for the Lennard-Jones potential (12-6).

For the He-N<sub>2</sub> (Fig. 2a), the theoretical values of  $\alpha_{th}$  when T = 306 and 520 K (curves 6 and 7) differ little in magnitude, but we nevertheless observe an increase in these values with a rise in temperature. For the experimental data [18, 20, 21], we observe more readily that  $\alpha_{th}$  is independent of temperature (the divergence between these, on the average, does not exceed  $\pm(4-7)\%$ ). The data [19] for the case in which T = 253.4 K are elevated relative to the data [18] for concentrations of  $x_1 = 0.34$  by approximately 14%, and for  $x_1 = 0.531$

\*The formula of the polynomial has been chosen on the basis of the earlier-established functional relationship  $\ln(\alpha_{th}^{*-1}) = f(\ln(T^*))$ .

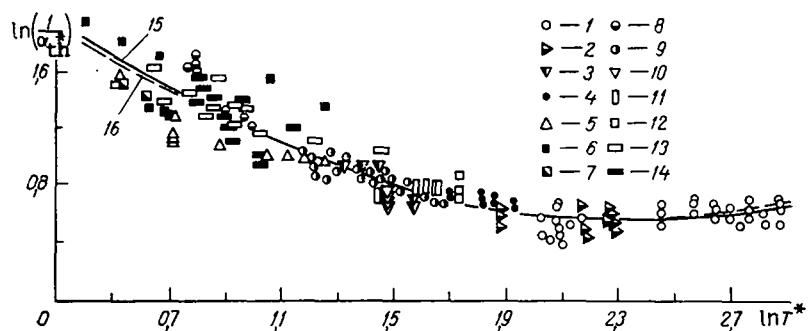


Fig. 1. The relationship between  $\ln(1/\alpha_{th}^*)$  and  $\ln T^*$  for 14 binary gas mixtures: 1) He-N<sub>2</sub>; 2) He-CO<sub>2</sub>; 3) H<sub>2</sub>-O<sub>2</sub>; 4) Ar-H<sub>2</sub>; 5) O<sub>2</sub>-CO<sub>2</sub>; 6) Kr-N<sub>2</sub>; 7) Xe-N<sub>2</sub>; 8) Xe-CH<sub>4</sub>; 9) H<sub>2</sub>-CO<sub>2</sub>; 10) Ne-CO<sub>2</sub>; 11) H<sub>2</sub>-CH<sub>4</sub>; 12) H<sub>2</sub>-N<sub>2</sub>; 13) CH<sub>4</sub>-CO<sub>2</sub>; 14) N<sub>2</sub>-CO<sub>2</sub>; 15, 16) generalized curves obtained from the 2nd and 3rd degree polynomials.

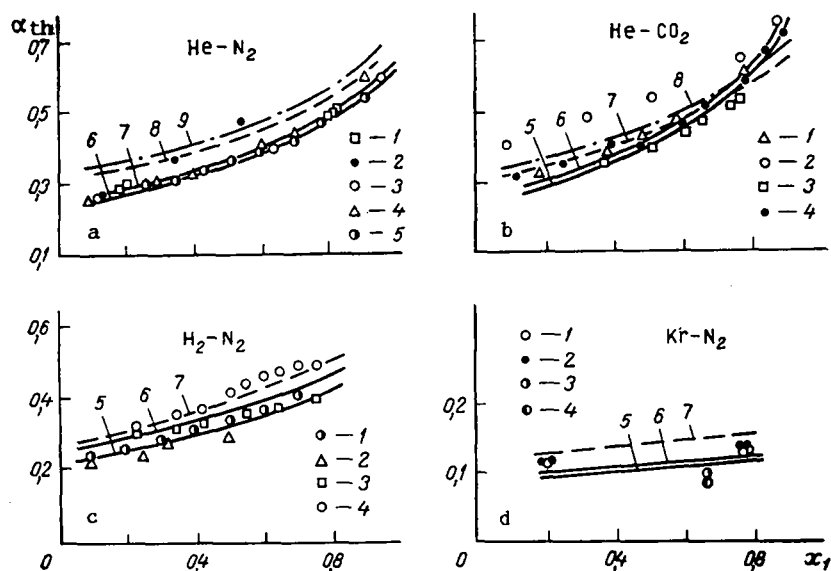


Fig. 2. Comparison of the theoretical values of  $\alpha_{th}$  with the experimental data and those calculated in accordance with the Chapman-Enskog theory which involves utilization of the Lennard-Jones potential (12-6) for various gas mixtures. The concentration relationship: a) He-N<sub>2</sub>; experimental data: 1) T = 253.9 K [18]; 2) 253.4 K [19]; 3, 5) 339 and 596 K [20]; 4) 306 K [21]; 6, 7) theoretical values of  $\alpha_{th}$  for T = 305 and 520 K; 8, 9) Chapman-Enskog theory for the same temperatures; b) He-CO<sub>2</sub>; experimental data: 1) T = 306 K [21]; 2) 341 K [22]; 3) 437 K [23]; 4) 413.6 K [28]; 5, 6) theoretical values of  $\alpha_{th}$  for T = 306 and 437 K; 7, 8) Chapman-Enskog theory for the same temperatures; c) H<sub>2</sub>-N<sub>2</sub>; experimental data: 1) T = 318.6 K [24]; 2) 318 K [11]; 3, 4) T < 596 K and T > 596 K, respectively [25]; 5, 6) theoretical values of  $\alpha_{th}$  for T = 318.6 and 596 K; 7) Chapman-Enskog theory for T = 318.6 K; d) Kr-N<sub>2</sub>; experimental data: 1, 2) [18] for T = 254.1 and 270.7 K; 3, 4) interpolated data [16] for the same temperatures; 5, 6) theoretical values of  $\alpha_{th}$  for T = 254 and 270 K; 7) Chapman-Enskog theory for T = 254 K.

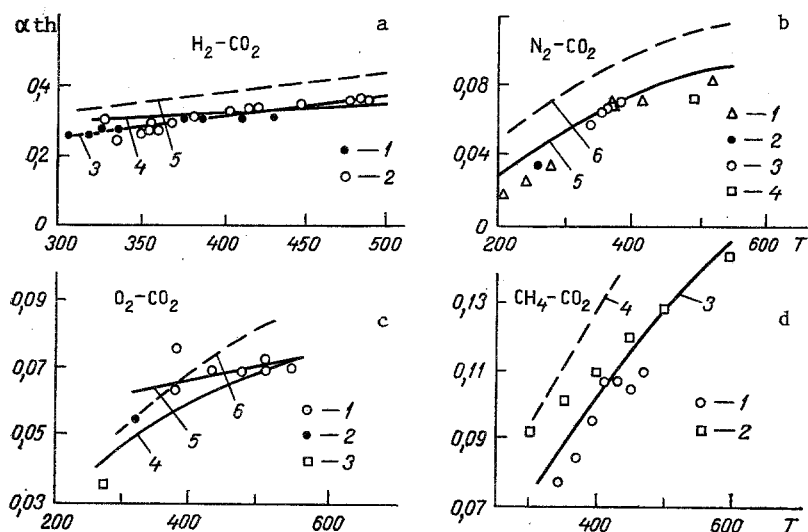


Fig. 3. Comparison of theoretical values of  $\alpha_{th}$  with experimental values and those calculated according to Chapman-Enskog theory involving the utilization of the Lennard-Jones potential (12-6) for various gas mixtures. Temperature relationships: a)  $H_2-CO_2$ ; experimental data ( $x_{H_2} = 0.543$ ): 1) [29] 2) [30]; 3) values of  $\alpha_{th}$  obtained on the basis of similarity theory [27]; 4) theoretical values of  $\alpha_{th}$  from formula (4); 5) Chapman-Enskog theory; b)  $N_2-CO_2$ ; experimental data ( $x_{N_2} = 0.5$ ): 1) [16] ( $x_{N_2} = 0.497$ ); 2) [21]; 3) [26]; 4) values of  $\alpha_{th}$  from similarity theory [27]; 5) theoretical values of  $\alpha_{th}$  from formula (4); 6) Chapman-Enskog theory; c)  $O_2-CO_2$ ; experimental data ( $x_{O_2} = 0.608$ ): 1) [14]; 2) processed data [13]; 3) interpolated data [15]; 4) theoretical values of  $\alpha_{th}$  from (4); 5) data obtained from similarity theory [27]; 6) Chapman-Enskog theory; d)  $CH_4-CO_2$ ; experimental data ( $x_{CH_4} = 0.5$ ): 1) [31]; 2) [32]; 3) theoretical values of  $\alpha_{th}$  from (4); 4) Chapman-Enskog theory. T, K.

~25%. The divergence between the experimental data and the theoretical [21, 20] when  $T = 306$  and  $596$  K, respectively, on the average does not exceed 4% (for the data of [21] with concentrations of He  $\sim 0.95$  the divergence of the theoretical data amounts to 14%).

For purposes of comparison against the theoretical data of  $\alpha_{th}$  for the He- $CO_2$  mixture we used the experimental results from [21-23, 28], derived at average temperatures of  $T = 306, 341.6,$  and  $437$  K (Fig. 2b). As we can see from the figure, on the basis of the experimental data it is difficult to draw a uniquely defined conclusion with regard to the extent to which  $\alpha_{th}$  is dependent on temperature. The data of [22], obtained for  $T = 341$  K ( $T_1 = 361.4; T_2 = 323.2$  K), exhibit higher values of  $\alpha_{th}$  (by approximately 16-20% in the concentration region  $x_1 = 0.1-0.7$ ) than the data from [23, 28] obtained for  $T = 413.6$  K ( $T_1 = 600, T_2 = 297$  K) and  $T = 437$  K ( $T_1 = 750-765, T_2 = 273$  K), respectively. The theoretical data are in agreement with the experimental data from [21, 23] within limits of  $\pm(1-12)\%$ .

For the  $H_2-N_2$  mixture (Fig. 2c) the agreement of the theoretical  $\alpha_{th}$  data with the experimental [11, 24] when  $T = 318$  K ranges from 0.5-5%, and in the case of the data from [25] when  $T < 596$  K in the range of  $\pm(1-13)\%$ . As regards the data from [25] in the case in which  $T > 596$  K, they are situated systematically higher than the experimental data (curve 5) obtained for the case in which  $T = 596$  K.

For the Kr- $N_2$  mixture (Fig. 2d) the theoretical values of  $\alpha_{th}$  seemingly occupy an intermediate position relative to the experimental data [18] for  $T = 254.1$  and  $270.7$  K and [16] (interpolated for these same temperatures). The divergence between the experimental data falls within the limits of 8-24%.

The theoretical results for  $\alpha_{th}$ , obtained by the molecular-kinetic Chapman-Enskog theory for the Lennard-Jones potential with a force constant, as recommended in [8], and shown in Fig. 2, are essentially elevated in comparison with the experimental data.

TABLE 4. Comparison of Theoretical Values of  $\alpha_{th}$  with the Experimental Data Obtained by Various Authors

Gas mixture	$x_1$ (light-component concentration)	$T_1, K$	$T_2, K$	$T, K$	$\alpha_{th.e}$	$\alpha_{th.c}$	$\frac{\alpha_{th.e}-\alpha_{th.c}}{\alpha_{th.c}} \times 100, \%$	Literature source for experimental data		
H <sub>2</sub> -O <sub>2</sub>	0,2	374,1	273,6	318,6	0,280	0,248	+11	[24]		
	0,4				0,315	0,280	+11			
	0,6				0,360	0,325	+9,7			
	0,75	294	90	153	0,410	0,370	+9,8	[35]		
	0,482				0,186	0,186	0			
	0,631				0,218	0,209	+4,1			
	0,737				0,232	0,229	+1,3			
	0,846				0,240	0,254	-5,8			
	0,298	290	153	207,1	0,204	0,209	-2,5	[36]		
					187	231	0,229		0,226	+1,3
	199				238,8	0,230	0,230		0	
	242				264,6	0,231	0,246		-6,5	
H <sub>2</sub> -Ar	0,156	293	498	377,5	0,262	0,257	+1,3	[20]		
					694	437,3	0,272		0,271	+0,4
					795	464,2	0,277		0,275	+0,7
	0,309	293	498	377,5	0,282	0,284	-0,7	[20]		
					694	437,3	0,287		0,298	-3,8
					795	464,2	0,291		0,303	-4,1
	0,544	293	498	377,5	0,321	0,337	-5,0	[20]		
					694	437,3	0,338		0,354	-4,7
					795	464,2	0,342		0,359	-5,0
					0,759	293	498		377,5	0,381
694	437,3	0,391	0,426	-8,9						
795	464,2	0,397	0,433	-9,0						
H <sub>2</sub> -CH <sub>4</sub>	0,3147	297	500	381	0,264	0,260	+1,5	[37]		
	0,4495				0,288	0,284	+1,4			
	0,4986				0,299	0,294	+1,7			
	0,5881				0,305	0,315	-3,3			
	0,5				299	523	390		0,286	0,297
	372	537	444	0,292				0,312	-6,8	
H <sub>2</sub> -Xe	0,2	362	324	342	0,197	0,208	-5,6	[24]		
	0,4				0,232	0,250	-7,8			
	0,6				0,277	0,312	-12,6			
Ne-CO <sub>2</sub>	0,176	362	324	342	0,173	0,149	+13,9	[22]		
							+0,017			
	0,570				0,229	0,201	+12,0			
							+0,010			
	0,710				0,241	0,229	+5,0			
Xe-N <sub>2</sub>	0,837				+0,013			[18]		
					0,290	0,269	+7,2			
							+0,010			
	0,185						0,107		0,095	+11,2
Xe-CH <sub>4</sub>	0,815				0,134	0,131	+2,2	[33]		
	0,2				0,122	0,114	+6,6			
	0,8				0,153	0,147	+3,9			
	0,5				0,164	0,173	-5,5			
					+0,010			[34]		
					479,9	0,171	0,179		-4,7	
						+0,014				
					502,0	0,187	0,186		+0,5	
						+0,016				
	0,82					300,0	0,121		0,132	-9,1
	0,79						0,119		0,130	-9,2
0,21			0,092	0,095	-3,3					
0,19			0,091	0,094	-3,3					

Figure 3 shows the relationships between temperature and  $\alpha_{th}$  for mixtures of CO<sub>2</sub> with H<sub>2</sub>, N<sub>2</sub>, O<sub>2</sub>, and CH<sub>4</sub>.

For the H<sub>2</sub>-CO<sub>2</sub> mixture, as we can see from Fig. 3a, the theoretical values of  $\alpha_{th}$  are in rather good agreement with the experimental data [29, 30] for concentrations of  $x_1 = 0.543$ , as well as with the data of [27] (curve 4), obtained on the basis of the theory of similarity. The Chapman-Enskog theory, in comparison with the experimental data and those calculated on the basis of relationship (4), yields values of  $\alpha_{th}$  elevated by approximately 15-20%.

For the N<sub>2</sub>-CO<sub>2</sub> mixture the theoretical values of  $\alpha_{th}$  (curve 5, Fig. 3b), obtained for an equimolar concentration, are elevated with respect to the experimental data [16, 26] by 1-8% in the temperature range from 340 to 540 K. With a drop in temperature, this divergence increases to 13% for the data of [21] (referred to atmospheric pressure) and 25-30% for the data from [16].

The data in [27], obtained by means of the similarity theory, demonstrate the slight change in  $\alpha_{th}$  with temperature, unlike the case of the data in [16, 26] and those calculated on the basis of relationship (4) (curve 5).

Approximately this kind of divergence is noted in the behavior of the theoretical data [27] and those obtained from relationship (4) for the  $O_2$ - $CO_2$  mixture ( $x_1 = 0.608$ , Fig. 3c). Apparently, this can be explained by the fact that in [27], in calculating  $\alpha_{th}$ , use was made of the results from [14] to serve as the reference data. The data in [15] were derived at a pressure of 0.03 MPa, and the experimental points shown in the figure therefore exhibit a somewhat reduced  $\alpha_{th}$  value. The Chapman-Enskog theory shows a more pronounced relationship between  $\alpha_{th}$  and temperature than do the experimental data and those calculated on the basis of relationship (4). Figure 3d shows the theoretical values of  $\alpha_{th}$  for a  $CH_4$ - $CO_2$  mixture in comparison with the experimental data from [31, 32], where the divergence between the data amounts approximately to 20%. As was to be expected, the theoretical values of  $\alpha_{th}$  occupy an intermediate position: in the temperature range 300-400 K they lie above the experimental data [31] by 8-4%, while with an increase in temperature they agree with the data of [32] within limits of  $\pm(0.2-6)\%$ . The Chapman-Enskog theory yields an elevated result with increasing temperature relative to the experimental data.

Table 4 also shows results from a comparison of theoretical and experimental  $\alpha_{th}$  data for a number of gas mixtures. As we can see, the agreement of the experimental and theoretical  $\alpha_{th}$  values in the majority of cases is satisfactory, with the divergence falling within the limits of error of the thermal-diffusion experiment, i.e.,  $\pm(2-10)\%$ .

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#### A RECUPERATOR WITH A MAGNETORHEOLOGICAL COOLANT

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We have evaluated the effectiveness of a "tube-within-a-tube"-type recuperator with the coolant based on a magnetorheological suspension, and we have performed the calculations.

It had earlier been established [1] that when a weakly concentrated magnetorheological suspension (MRS) of noncolloidal particles of a ferromagnetic carbonyl iron is involved in turbulent flow through a tube, and acted upon by a uniform magnetic field oriented perpendicular to the mean-velocity vector, significant intensification of heat transfer to the wall of the tube occurs, as well as an increase in the hydraulic resistance that is a function of the magnitude of field strength. The derived empirical relationships linking the heat-transfer coefficient and the coefficient of hydraulic resistance to the flow parameters of the MRS in the field are of the following form:

$$\alpha_H = \alpha_0(1 + 7.5Al'), \quad \xi_H = \xi_0(1 + 13.5Al'). \quad (1)$$

Here  $Al' = \mu_0 H^2 \varphi / \rho w^2$  is the modified Alfvén number [2]. Formulas (1) are valid for the interval  $0 \leq Al' \leq 1.2$ , which corresponds to the range of variations  $0 \leq H \leq 3.2 \cdot 10^5$  A/m;  $1$  m/sec  $\leq w \leq 2.4$  m/sec;  $0 \leq \varphi \leq 0.01$ .

Application of the observed effect offers the possibility of developing special heat exchangers with capabilities impossible in traditional equipment or, at least, difficult to achieve, and namely, the operational control of the basic working characteristics (the temperature difference in the heat carriers, the output of heat) without altering the flow rate of the heat carrier through a regulated increase in the heat-transfer coefficient.

Below we present the results from an estimate of the efficiency of a recuperator with a magnetorheological heat coolant (MRC). In this case, the basis for the comparison was pro-

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