THERMAL CONDUCTIVITIES OF BENZENE AND TOLUENE VAPORS

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UDC 536.23

Experimental and averaged values are presented for thermal conductivities of benzene and toluene vapors over the temperature range 300-700°K at a pressure of ~1 bar.

Data on the thermal conductivity of materials in the vapor phase are necessary for calculation of heat-exchange processes in many areas of technology. Moreover, the experimental study of thermophysical properties of vapors plays an important role in the development of molecular-kinetic theory. In the present study the thermal conductivities of benzene and toluene in the vapor phase were measured by the hot-wire method.

The quartz measurement tube was enclosed in a quartz shield and installed in a thermostatically controlled chamber. The quartz shield was connected to the glass portions of the apparatus with a quartz-to-glass transition fitting. The liquid vapor source was poured into a glass flask at a temperature chosen to produce the necessary vapor pressure. To avoid vapor condensation the entire system from flask to thermostat chamber was heated by special electric heaters.

Measurement cell characteristics were as follows: internal diameter, D_i = 4.07 mm; external diameter, D_o = 5.69 mm; diameter of platinum heater located along tube axis, d_h = 0.157 mm; length of measurement section, l = 160 mm.

The resistance thermometer installed on the external surface of the measurement tube was made of high-purity type PL-I platinum wire with d = 0.1 mm and resistance ratio R_{100}/R_0 = 1.3923.

The coefficient of thermal conductivity was determined from the equation

TABLE 1. Experimental Data on Thermal Conductivity of Toluene Vapor

Q, W	$T_{wi}-T_{wa}$, °K	δT_{qu}, °K	ΔT_{gas}, °K	$\lambda' \cdot 10^3$, W/m·°K	$\delta\lambda_{rad} \cdot 10^3$, W/m·°K	$\delta\lambda_e \cdot 10^3$, W/m·°K	$\lambda \cdot 10^3$, W/m·°K	T_m, °K
0,1180	26,94	0,04	26,90	16,5	0,12	0,35	16,1	370,0
0,1260	22,18	0,04	22,14	21,4	0,12	0,35	20,9	418,7
0,1096	18,24	0,03	18,21	22,6	0,35	0,35	22,0	431,5
0,1090	18,02	0,03	17,99	22,8	0,35	0,35	22,2	433,9
0,1368	18,16	0,04	18,12	28,5	0,35	0,35	27,8	474,6
0,1401	18,06	0,04	18,02	29,3	0,35	0,23	28,7	485,3
0,0735	9,63	0,02	9,61	28,5	0,58	0,35	27,5	487,8
0,1444	17,06	0,04	17,02	32,0	0,47	0,35	30,8	511,6
0,1459	16,41	0,04	16,37	33,6	0,47	0,47	32,7	523,6
0,2280	23,40	0,07	23,33	36,9	1,2	0,47	35,2	549,1
0,2290	22,11	0,07	22,04	39,1	1,2	0,47	37,4	566,8
0,2290	21,88	0,07	21,81	39,5	1,2	0,47	37,9	569,0
0,2760	23,98	0,08	23,90	43,5	1,3	0,47	41,6	600,0
0,2775	23,46	0,08	23,38	44,7	1,4	0,47	42,8	599,9
0,2816	20,53	0,08	20,45	51,9	2,2	0,58	49,1	659,1
0,2811	20,70	0,08	20,62	51,4	2,2	0,58	48,6	659,9
0,2818	19,52	0,08	19,51	54,4	2,3	0,58	51,5	682,6

S. Ordzhonikidze Moscow Aviation Institute. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 31, No. 5, pp. 826-830, November, 1976. Original article submitted July 23, 1975.

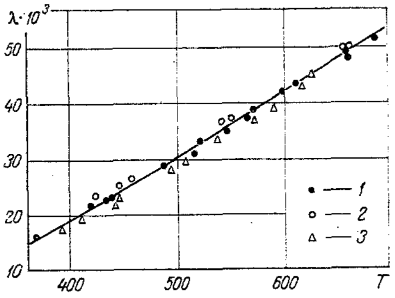

Fig. 1

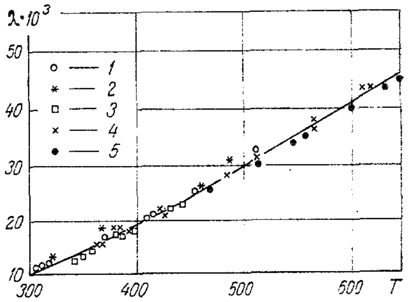

Fig. 2

Fig. 1. Thermal conductivity of toluene vapor versus temperature: 1) present study; 2) [2]; 3) [3]. λ·10³, W/m·°K; T, °K.

Fig. 2. Thermal conductivity of benzene vapor versus temperature: 1) present study; 2) [5]; 3) [6, 7]; 4) [3]; 5) [8].

TABLE 2. Experimental Data on Thermal Conductivity of Benzene Vapor

Q, W	$T_{wi} - T_{wa}$, °K	δT_{qu}, °K	ΔT_{gas}, °K	λ′, W/m·°K	$\delta\lambda_{rad}$, W/m·°K	$\delta\lambda_e$, W/m·°K	λ, W/m·°K	T_m, °K
0,0607	20,33	0,02	20,31	0,0113	—	0,00023	0,0110	304,1
0,0549	18,01	0,02	17,99	0,0115	—	0,00023	0,0113	304,9
0,0941	29,11	0,03	29,08	0,0121	—	0,00023	0,0118	313,9
0,0685	14,47	0,02	14,45	0,0176	0,00012	0,00023	0,0172	372,9
0,1175	21,22	0,04	21,18	0,0209	0,00012	0,00035	0,0204	406,4
0,1174	21,14	0,04	21,10	0,0209	0,00012	0,00035	0,0205	407,9
0,1241	17,68	0,04	17,64	0,0265	0,00047	0,00035	0,0257	453,6
0,1239	17,69	0,04	17,65	0,0256	0,00047	0,00035	0,0256	454,4
0,2432	27,37	0,07	47,30	0,0335	0,00080	0,00047	0,0322	510,3

$$\lambda = \frac{Q \ln \dfrac{D_{\mathrm{i}}}{d_{\mathrm{h}}}}{2\pi l \Delta T_{\mathrm{gas}}}. \tag{1}$$

The following corrections were considered in performing the experiments: 1) heat transfer by radiation; 2) temperature change across measurement cell wall; 3) heat loss from ends of heater.

Convective heat transfer was eliminated by an appropriate choice of measurement cell dimensions and temperature gradient within the material studied. In all experiments GrPr < 1000, a sufficient criterion for absence of convection in the measurement cell.

To clarify the effect of temperature discontinuity at the wire–gas boundary, studies were performed at various vapor pressures. Results revealed that a change in pressure from 80 to 640 mm Hg at the highest experimental temperatures had no effect on the values of λ. Thus, in experiments in this pressure range the correction for temperature change may be neglected.

The operation of the apparatus was checked by use of a thoroughly studied substance – air. The results obtained agreed within 1% with currently accepted values of the thermal conductivity for air [1].

1. The thermal conductivity of toluene vapor (C_7H_8) was measured over the temperature interval 370-682°K. Chemically pure grade toluene was used in the experiments. Results are presented in Table 1. 2. The thermal conductivity of benzene vapor (C_6H_6) was measured over the temperature interval 304-510°K. Chemically pure benzene was used. Results are presented in Table 2. Comparison of the results of different authors is of interest.

Experimental data on the thermal conductivity of toluene vapor at pressure P ~ 1 bar are offered by Akhundov and Gasanova [2] for the temperature range 398-673°K, and by Kostrovskii and Prostov [3] for the range 396-623°K. Both studies used the hot-wire method. A comparison of the experimental results is presented in Fig. 1.

TABLE 3. Recommended Data for Thermal Conductivity of Toluene Vapor

T, °K	$\lambda \cdot 10^3$, W/m·°K	T, °K	$\lambda \cdot 10^3$, W/m·°K	T, °K	$\lambda \cdot 10^3$, W/m·°K
380	16,5	500	30,2	620	44,0
400	18,7	520	32,5	640	46,4
420	21,0	540	34,8	660	48,8
440	23,3	560	37,1	680	51,1
460	25,6	580	39,4	700	53,6
480	27,9	600	41,7		

TABLE 4. Recommended Data for Thermal Conductivity of Benzene Vapor

T, °K	$\lambda \cdot 10^3$, W/m·°K	T, °K	$\lambda \cdot 10^3$, W/m·°K	T, °K	$\lambda \cdot 10^3$, W/m·°K
320	11,9	440	23,8	560	36,6
340	13,7	460	25,9	580	38,8
360	15,7	480	28,0	600	41,0
380	17,7	500	30,2	620	43,2
400	19,7	520	32,2	640	45,5
420	21,7	540	34,4	660	47,8

The disagreement between these studies at P = 1 bar comprises 7% at T = 400°K and 4.5% at T = 600°K. The results of [2] are higher than those of the present study. Maximum disagreement is 4%. The results of [3] are lower than the data presently obtained. Maximum disagreement is 3.8%.

All authors estimate the measurement accuracy to be 2%.

Using the present data together with that of [2] and [3], average values were obtained for the coefficient of thermal conductivity of toluene vapor over the temperature range 380-700°K at P ~ 1 bar. The recommended data are presented in Table 3.

The maximum deviation of the data in [2] from the average curve is 4%, with a mean deviation of 3%. The experimental data of [3] have a maximum deviation of 3.8% with an average of 2.7%. The results of the present study show a mean deviation of 2%.

It should be noted that the data on the thermal conductivity of toluene vapor obtained earlier in [4] for the temperature range 309-700°K are low in value at high temperatures. This is apparently the consequence of the presence of high-molecular-weight impurities in the toluene.

Experimental data on thermal conductivity of benzene vapor at P ~ 1 bar are available in [5] for temperatures of 273-485°K, in [6] for 348-436°K, in [7] at 339 and 358°K, in [8] at 394-667°K, and in [3] at 364-616°K. A comparison of the data from these studies is presented in Fig. 2. As is evident from the figure, the results of [3, 6-8] and the present study agree well with each other. Mean deviation is 2-2.8%. An exception is the data of Moser [5], which are higher than the other results by 5-7%.

Using the present results and those available in the literature, Table 4 presents averaged values of thermal conductivity for benzene vapor at P ~1 bar over the temperature range 320-660°K. The error of the recommended thermal conductivity values for toluene (Table 3) is ± 3% and for benzene (Table 4), ± 2.5%.

NOTATION

Q	is the heat flux from heated platinum wire;
T_{wi}	is the wire temperature;
T_{wa}	is the wall temperature;
δT_{qu}	is the temperature change across wall of quartz tube;
ΔT_{gas}	is the temperature difference in gas layer;
λ'	is the coefficient of thermal conductivity without consideration of heat loss from ends and radiation;
$\delta\lambda_{rad}$	is the correction for radiation;
$\delta\lambda_e$	is the correction for heat loss from ends of measurement filament;
λ	is the coefficient of thermal conductivity;
T_m	is the mean temperature.

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DIFFUSION IN A POROUS SYSTEM IN CROSSED ELECTRIC AND MAGNETIC FIELDS

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UDC 532.72:(537.27+538.6)

Diffusion in crossed electric and magnetic fields is considered; measurements are reported on accelerated diffusion in the extraction of low-molecular-weight fractions (hemicelluloses) from cellulose and of copper salts from viscose fiber.

Extraction from capillary systems into surrounding liquids is an important general process in mass transfer; examples are elimination of copper salts from viscose fiber by washing the fiber with sulfuric acid [1] and extraction of low-molecular-weight fractions (hemicelluloses) from cellulose with caustic soda during mercerizing [2, 3].

Considerable interest attaches to the use of various fields, including electromagnetic ones, in liquids to accelerate diffusion in such systems; in particular, crossed electric and magnetic fields may be employed. Here we consider the rates of diffusion processes under such conditions and present some measurements.

The external-diffusion rate is controlled by the hydrodynamic conditions around the dispersed phase, and that rate may be increased by efficient mixing [4, 5], as well as by mechanical oscillation (ultrasound, vibration, etc.) [6], and by magnetic [7] or electric [8-10] fields.

It has been shown [8-10] that an electric field in a conducting liquid produces a flow of the liquid near a local solid, liquid, or gaseous inclusion because the magnetic field arising from the current interacts with the liquid. More vigorous flows arise near such particles in crossed electric and magnetic fields [11-14]. Also, flows arise in a very narrow range within the boundary and ordinary diffusion layers because the electric double layer at the interface interacts with the crossed fields [15]. One naturally expects that all these various flows will substantially accelerate mass transfer, and as a result one will obtain conditions close to ideal mixing in the external-diffusion region.

The current density in the liquid, and the distribution between and within the particles, may be dependent on the effective conductivities of both media. Methods of estimating effective conductivity for porous systems have been surveyed [16], and it has been shown that the value is dependent on the conductivity of the skeleton in a particle and on that of the liquid within the porous structure, as well as on the structure of the skeleton. The case where σ_{ef} for the particles is related to σ_l for the liquid by ($\sigma_l \le \sigma_{ef}$) is of only theoretical interest, since the converse applies in nearly all practical cases. As a result, the current density within the particles is nearly always substantially less than that in the liquid ($j_l \gg j_p$). If the system is in a uniform external magnetic field, the density of the electromagnetic forces f acting on the liquid phase outside a particle is substantially

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Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 31, No. 5, pp. 831-838, November, 1976. Original article submitted October 28, 1975.