Liquid Thermal Conductivity Measurements

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New absolute thermal conductivity determinations for analytical reagent and British Pharmacopoeia quality benzene, ethyl bromide, ethyl iodide, toluene, and trichloroethylene have been made in the temperature interval 15° to 80° C. at normal atmospheric pressure. The results are believed accurate to ± 2% and are compared with the existing data.

THERMAL conductivity is an important thermo-physical property, and its values are needed in almost all heat transfer calculations, especially when dealing with the convective heat transfer of fluids. Accurate measurements of this property are unfortunately difficult to obtain especially for fluids; the majority of data being scanty and of doubtful accuracy. In some cases, divergencies in reported data exceed 40% which is outside the usual engineering tolerance utilized in design calculations.

In preparation for thermal conductivity measurements on water/steam (*20*) the apparatus described in reference (*19*) was constructed and tested with satisfactory results on several liquids and gases. New measurements are reported here for Analytical Reagent (A. R.) and British Pharmacopoeia (B.P. designates chemicals that have passed the British Pharmacopoeia standard tests) quality benzene, ethyl bromide, ethyl iodide, toluene, and trichloroethylene in the temperature interval 15° to 80° C. The accuracy of the results can be expected to be within ±2%.

APPARATUS AND PROCEDURE

An absolute steady state radial heat flow apparatus employing guard heaters was used. The test fluid filled a 0.5-mm. gap between concentric cylinders of brass (inner cylinder) and borosiliate glass (outer cylinder). The measurement of the power dissipated in the inner cylinder by means of a central electric heater, and the evaluation of the temperature difference across the fluid annulus allowed determinations of the thermal conductivity, λ, to be made. Complete details of the apparatus, measurement technique, errors, corrections, and reduction of experimental observations have been previously reported (*19*).

RESULTS AND ANALYSIS OF RESULTS

The experimental results obtained are presented in Figure 1. In the cases of ethyl bromide and toluene, the previous results (*19*) were considered insufficient for satisfactory analysis, and further measurements have been made as shown for these fluids.

Although a satisfactory relationship between the thermal conductivity and temperature will not be a linear relationship, many authors (*8, 14, 23*) have utilized this type of correlation over the limited range of their experimental data. The analysis of the present data resulted in a linear relationship of the form, $\lambda = A + Bt$; where the λ is the thermal conductivity at any temperature, t, °C., A is the 0° C. thermal conductivity, and B is the temperature coefficient of thermal conductivity. B is usually negative for most liquids but may be positive as is the case for glycerol, ethylene glycol, kerosine, and a few other liquids.

The fact that this straight line relationship will not hold over large temperature ranges can be shown with reference to the benzene results. Careful scrutiny of the trends of the present benzene data reveal that there is a slight convex curvature of the results. Similar scrutiny of the results for benzene by Horrocks, McLaughlin, and Ubbelohde (*8*) confirm this convex curvature. However, over the temperature range from the freezing point to boiling point, this curvature will not affect estimates of the thermal conductivity made from the straight line analysis by more than 1%.

Table I presents the smoothed values of the coefficient of thermal conductivity for the liquids investigated. All of the experimental values were fitted by a least squares straight line analysis to obtain an equation of the form $\lambda = A + Bt$. Values of the constants A and B are included in Table I along with the standard and maximum deviations of the experimental values for the analysis.

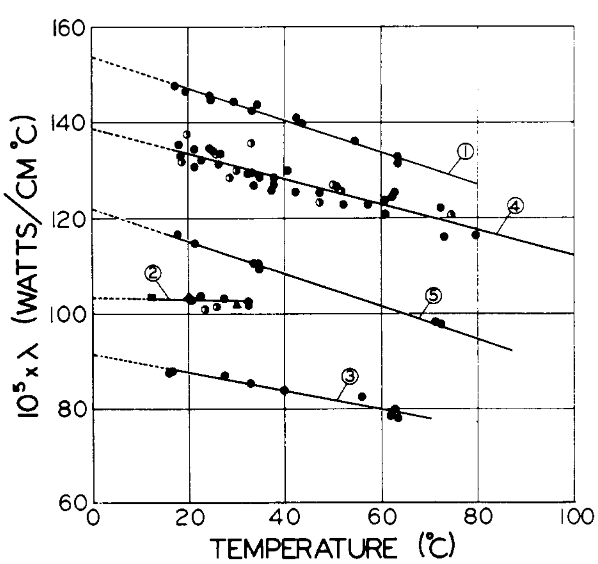

Figure 1. Liquid thermal conductivity data, λ vs. T
1, benzene; 2, ethyl bromide, ■ Weber (*21*), ◆ Reidel (*15*), ▲ Fillipov (*5*); 3, ethyl iodide; 4, toluene; 5, trichloroethylene
Series I measurements, ◑ ; series II, ●

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Table I. Thermal Conductivity of Liquids, $10^5 \times \lambda$ (Watt/Cm.° C.)

Liquid	Temperature, ° C. 0	10	20	30	40	50	60	70	80	A	B	S. D., (Maximum Deviation) From Proposed Equation, %
Benzene	154	150	147	144	140	137	134	131	127	153.6	−0.328	0.92 (1.2)
Ethyl bromide	104	103	102.7	102	...	...	...	...	...	104.1	−0.069	0.89 (1.6)
Ethyl iodide	92	90	88	86	84	82	80	78	...	91.7	−0.196	1.5 (2.0)
Toluene	139	136	133	131	128	125	123	120	117	138.8	−0.267	2.2 (4.0)
Trichloroethylene	122	119	115	112	108	105	102	98	95	121.9	−0.336	0.56 (0.91)

Table II. Thermal Conductivity of Toluene—A Comparison of Values

Author	Apparatus	A, 10^{-5} Watt/Cm. ° C.	B, 10^{-5} Watt/Cm. ° C.^{2}	Maximum Deviation From Proposed Equation, % A	B
Challoner and Powell (*4*)	Flat plate 0.2- and 0.3-cm. gap	144.0	−0.314	+3.7	+17.6
Riedel (*14*)	Coaxial cylinders; Flat plate; Concentric spheres	140.5	−0.272	+1.2	+1.1
Schmidt and Leidenfrost (*17*)	Coaxial cylinders 0.1 to 0.4-cm. gap	140.5	−0.259	+1.2	−3.0
Horrocks and McLaughlin (*6*)	Transient hot wire	140.3	−0.292	+1.2	+9.4
Ziebland (*23*)	Coaxial cylinders 0.026-and 0.076-cm. gap	140.2	−0.284	+1.1	+6.4
Vargaftik (*18*)	Steady state hot wire	141.3	−0.238	+1.8	−10.9
This work	Coaxial cylinders 0.05-cm. gap three cells	138.8	−0.267	...	...

In the case of ethyl bromide, the least squares analysis includes the experimental determinations of Weber (*21*), Riedel (*16*), and Filippov (*5*) since the temperature range covered by the present results is small.

DISCUSSION

In this section the results for each fluid have been considered in turn, and individual comparisons have been made to the most relevant data.

Benzene. The determinations shown in Figure 1 were obtained from a series of three tests employing two thermal conductivity cells and five separate fillings of A.R. quality benzene in the temperature range 17° to 63° C. The mean results of Riedel (*14, 15*) at 20° C. are 0.1% higher; Riedel's temperature coefficient, *B*, is 6.1% higher than in this work. Schmidt and Leidenfrost (*17*) obtained results in the temperature range 20° to 70° C. with 20° C. value which is 1.2% lower but with a 30% lower temperature dependence than is reported here. Although the present results are 2.3% higher over the common temperature range investigated, the temperature coefficients agree to within 2.1% with the work of Horrocks, McLaughlin, and Ubbelohde (*8*).

Ethyl Bromide. Three test series were made on commercial purity (no analysis available) and B.P. quality ethyl bromide over the temperature range 20° to 36° C. For the least squares analysis, the single determinations of Weber (*21*), Riedel (*16*), and Filippov (*5*) were used since these results lay very close to the mean straight line and extended the data range to 12° C. The agreement with the above works is less than 0.4% (Weber, −0.1%; Riedel, −0.2%; Filippov, +0.4%). Unfortunately, the agreement with Cecil and Munch (*3*), Vargaftik (*18*), Powell and Tye (*12*), and Bridgman (*2*) is poor. In all cases, these workers were higher by 17%; also, the only previous determination of the temperature coefficient by Bridgman is 75% greater than in the present measurements.

Ethyl Iodide. Measurements for two test series on B.P. and commercial (no analysis available) quality ethyl iodide have been presented in Figure 1. The data (*2, 5, 7, 9, 13, 16, 21*) reported previously range from 2.5 below to 35% above the present measurements. The only previous determination of the temperature coefficient, by Bridgman (*2*), is lower by 81% than the value reported here. Confirmation of the present value of temperature coefficient is shown by the agreement to the computed line of the individual determinations of Weber (*21*) 4.0% higher, Riedel (*16*) 1.7% higher, Filippov (*5*) 4.9% higher, and Horrocks and McLaughlin (*7*) 2.5% lower.

Toluene. As earlier workers (*6, 14, 23*) have commented on the use of toluene as a thermal conductivity standard, the author's previous measurements (*19*) were supplemented by two further experimental studies utilizing two different cells to extend the temperature range to 80° C. These results as well as the previous ones for A.R. toluene are shown in Figure 1. A least squares analysis of the 39 data points yielded the equation and smoothed values of Table I. A comparison of this work with earlier research was limited to six papers published since 1951 (*4, 6, 14, 17, 18, 23*) and was thought to represent the considered best data for this liquid. Table II represents the detailed comparisons of the above works with the present research.

In addition to the above, Poltz (*11*) who has investigated the influence of radiation on the thermal conductivity of liquids, determined a true thermal conductivity of toluene at 25° C. of $10^5\lambda_{25}$ = 129.1 watt/cm.° C., a value which is 2.2% lower than this work and between 3 to 5% lower than all the other workers considered.

The available evidence indicates that for values of the thermal conductivity of toluene to within ±1% over the temperature range 0° to 80° C., either the proposed equation of Ziebland (*23*) or the equation presented here may be used.

Trichloroethylene. Trichloroethylene. B.P. quality, was tested in the temperature interval 18° to 72° C. The agreement with previous workers (*1, 10, 14, 15, 22*) is between +11.2 to −1.13%. Riedel's (*14, 15*) measurements are +1.04 and −1.13% at 20° C. from the measurements presented here with a 26.5% lower temperature coefficient. This lower temperature coefficient may be partially explained by the fact that Riedel's measurements were in the −60° to +20° C. temperature range, and it would thus be expected that over the −60 to +80° C. range the coefficients would be incompatible.

CONCLUSIONS

New absolute thermal conductivity measurements for A.R. and B.P. quality benzene, ethyl bromide, ethyl iodide, toluene, and trichloroethylene have been presented. The body of data for each fluid has been analyzed by the method of least squares to yield a linear equation of the form $\lambda = A + Bt$ for the thermal conductivity over the temperature range 15° to 80° C. The data presented provide a useful addition to the available data adding confirmation and extending the data of Riedel, Schmidt and Liedenfrost, Horrocks and McLaughlin, and Ziebland.

The temperature coefficients of thermal conductivity for ethyl bromide and ethyl iodide have been measured over the range of 15° C. to their normal boiling points. Serious discrepancies arise in the comparison of this work to that of Powell and Tye, and it is thought that the comparator method used by them is possibly in error owing to the reaction and subsequent softening of the plastic membrane used with these fluids.

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Coefficients of Thermal Expansions of Alloys at Low Temperatures

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The interferometric method was used to determine linear thermal expansion coefficients of Monel, 1020 low carbon steel, 410 stainless steel, and yellow brass from 18° to 300° K.

LINEAR thermal expansion coefficients have been determined in the temperature interval from approximately 18° to 300° K. for the four alloys, cold rolled free cutting "R" Monel, 1020 low carbon steel, 410 stainless steel, and yellow brass ASTM B 16. The apparatus and experimental technique are the same as described for the thermal expansion of copper (*10*).

The alloys were obtained from commercially available bar stock. The Monel and yellow brass were obtained from the Columbus Ohio supplier, Williams and Co. The other alloys were supplied by the Carnegie-Illinois Steel Co. The samples were used without further heat treatment. Each sample consisted of three sectors cut from the bar, filed to the same length (within ⅕ of the wave length of sodium D