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Measurement of the Thermal Conductivity of Liquid Dimethoxymethane from 240 to 362 K

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The thermal conductivity of liquid dimethoxymethane was measured by the transient hot-wire method using a bare platinum wire in a temperature range from 240 to 360 K. The experimental data were fitted by a function of temperature. The average absolute deviation of experimental data from those calculated by the equation was 0.18%, and the maximum deviation was 0.41%. The uncertainty of the thermal conductivity was less than ± 2% with a coverage factor of $k = 2$. The uncertainty of the temperature was within ± 10 mK ($k = 2$).

KEY WORDS: dimethoxymethane; liquid phase; methylal; thermal conductivity; transient hot-wire method.

1. INTRODUCTION

Methylal (CH3–O–CH2–O–CH3), known as dimethoxymethane or DMM, is extensively used as a solvent in household and industrial spray, as a blowing agent for polyurethane foam and in the production of ion exchange resins. High-purity methylal is also used in cosmetics and pharmaceuticals [1]. DMM is increasingly used as a diesel fuel additive since it has a large content of oxygen (42% by mass) and is miscible in diesel fuel. The investigations have indicated that methylal fuel additive can effectively reduce particle emissions [2, 3]. There are no experimental data for the thermal conductivity of methylal reported until this study. These data are thus important for thermal design in those applications mentioned above. In this paper, measurements of the liquid thermal conductivity of

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methylal in the temperature range from 240 to 360 K are presented with an estimated uncertainty of ±2.0% with a coverage factor of $k=2$.

2. MEASUREMENTS

2.1. Experimental Principle

The measurements of the liquid thermal conductivity for methylal were performed with an uncertainty of less than ±2.0% in a transient hot-wire instrument with a single bare platinum wire. The fundamental working equation of the transient hot-wire technique takes the form,

$$\lambda(T_{\mathrm{r}}, P) = \frac{q}{4\pi} \Big/ \frac{d\Delta T}{d\ln t} \tag{1}$$

where q is the power input per unit length of wire, $\lambda(T_r, P)$ is the thermal conductivity of the fluid at a reference temperature T_r and at a working pressure P, $\frac{d\Delta T}{d\ln t}$ is the slope of a line fit to the ideal temperature rise ΔT vs. $\ln t$ data, and t represents the time. Details of the transient hot-wire method have been described in many other papers [4–7].

2.2. Experimental Apparatus

A schematic diagram of the hot-wire cell and the pressure vessel is shown in Fig. 1. The diameter of the bare platinum wire is 30 μm in this instrument. The wire is welded to the upper and lower platinum hooks with an axial stress of predetermined magnitude by hanging a copper weight at the bottom of the platinum wire. In order to compensate for the end effect of the hot wire, two voltage potential leads of the same platinum wire are spot-welded at positions nearly 12 mm from each end of the wire [8]. An aluminum cylindrical cap was inserted into the stainless steel pressure vessel in order to reduce both the temperature gradients in the cell and the internal volume of the instrument. The pressure vessel is sealed with a Teflon o-ring. Between the two potential leads, with a constant current through the platinum wire, the transient voltage rises, which is proportional to the temperature rise in the wire, is measured directly by a high-resolution, 7.5-digit, digital voltmeter (Keithley DVM 2010). The calibration of the resistance-temperature relation of the platinum wire was carried out in the temperature range from 235 to 373 K in the temperature-controlled bath.

The transient hot-wire apparatus was immersed completely in a thermostatic bath for all the experiments. The working medium of the thermostatic bath was alcohol for the temperature range from 193 to

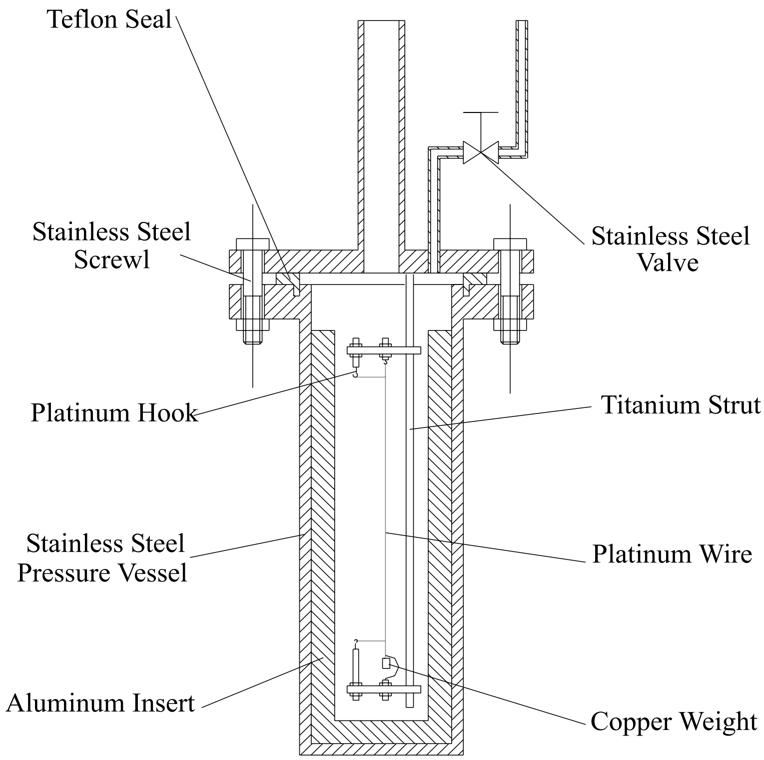

Fig. 1. Schematic of the hot-wire cell and pressure vessel.

303 K and silicon oil for the temperature range from 303 to 403 K. The temperature stability of the thermostatic bath was better than ±4 mK once a 30 min period. The total uncertainty of temperature for thermal conductivity was less than ±10 mK (ITS-90) with a coverage factor of $k = 2$. More details about the thermostatic bath and temperature measurement system have been described in previous work [9, 10].

Figure 2 shows the measurement system used in the present study. The measurement system consisted of several components as follows: a PC, a constant current power supply, two DVMs (HP34401A for measuring the current, Keithley 2010 for measuring the voltage applied to the wire), three electronic switches, two ballast resistances, a standard resistor, and the hot-wire cell. The thermostatic bath was controlled by another PC and is not shown in Fig. 2. All data acquisition and instruments were controlled and monitored by a PC via an IEEE-488 interface.

The uncertainty of the temperature coefficient of the platinum wire was ± 0.1%, the uncertainty of the temperature rise slope of the hot wire

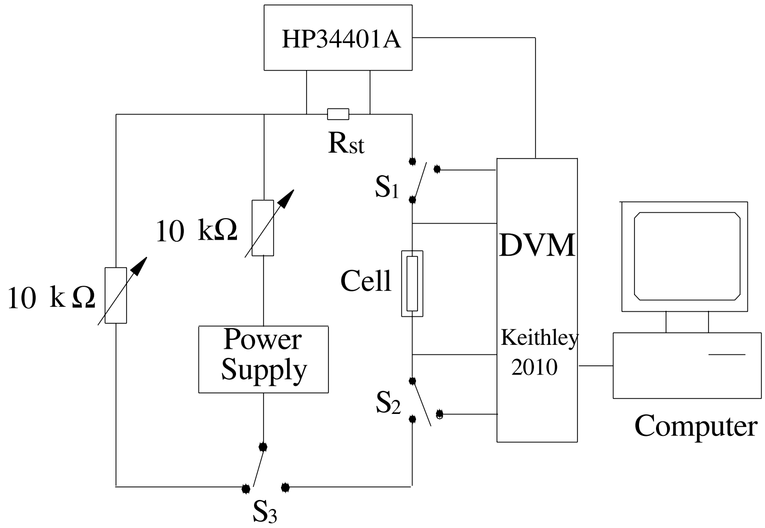

Fig. 2. Measurement system diagram.

was less than ±0.5%, and the uncertainty of the heat generation of the hot wire was less than ±0.2%. Accounting for other small factors, such as the end effect of the hot wire, the radiation, the overall uncertainty of the present thermal conductivity measurements was estimated to be better than ±2.0%.

In order to check the performance of the present instrument, the thermal conductivity of liquid toluene was measured in the temperature range from 230 to 373 K at the saturated vapor pressure. Toluene is recommended as a reference standard for liquid thermal conductivity by the International Union of Pure and Applied Chemistry (IUPAC) [11]. The sample of toluene was provided by TEDIA in the USA with a stated purity of better than 99.9%. The experimental results were compared with the values of Ramires et al. [12]. Table I lists the experimental data and comparisons of the thermal conductivity of liquid toluene. The results showed that the experimental data agreed with the recommended data very well. The maximum deviation was 1.03%.

3. RESULTS AND DISCUSSION

The sample of methylal was provided by ShangHai Yongfu Aerosol Manufacturing Co. Ltd., and its mass purity was claimed to be better than 99.5%. No further purification was processed.

Table I. Thermal Conductivity of Liquid Toluene at the Saturated Vapor Pressure

T (K)	λ_{exp} $(W \cdot m^{-1} \cdot K^{-1})$	λ_{ref} $(W \cdot m^{-1} \cdot K^{-1})$	$100(\lambda_{exp} - \lambda_{ref})/\lambda_{ref}$
234.60	0.1477	0.1491	−0.94
254.58	0.1434	0.1439	−0.35
273.17	0.1374	0.1385	−0.83
293.23	0.1334	0.1325	0.64
314.68	0.1264	0.1260	0.25
334.99	0.1211	0.1200	0.83
354.89	0.1136	0.1144	−0.76
373.92	0.1105	0.1094	1.03

Table II lists the experimental data of the thermal conductivity of methylal in the temperature range from 241 to 364 K at the saturated vapor pressure and the uncertainty [13] with a coverage factor of $k = 2$. These values provided here were the averages of four to six runs, whose reproducibility was better than $\pm 0.5\%$ at the same temperature and the same pressure. Figure 3 shows a plot of the liquid thermal conductivity

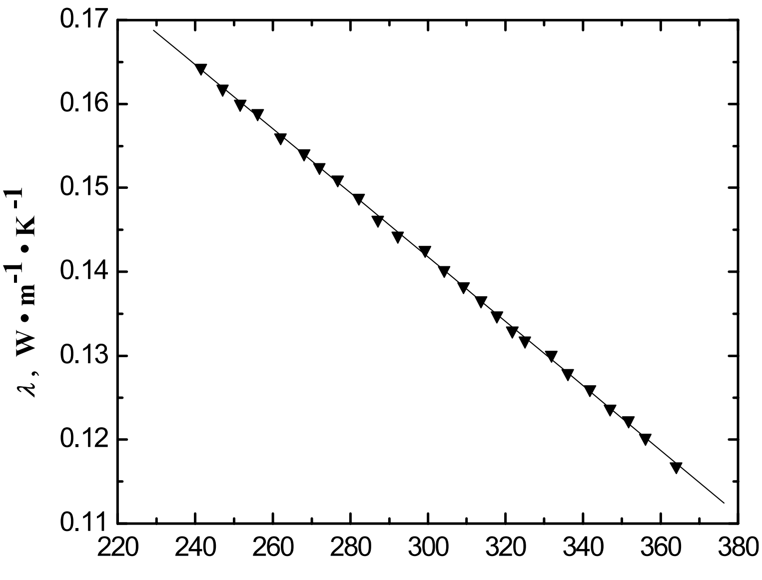

Fig. 3. Dependence of the thermal conductivity of liquid dimethoxymethane on temperature at the saturated vapor pressure.

Table II. Thermal Conductivity of Liquid Dimethoxymethane at the Saturated Vapor Pressure

T(K)	$\lambda_{exp}(W \cdot m^{-1} \cdot K^{-1})$	$\Delta\lambda_{exp}(k=2)(W \cdot m^{-1} \cdot K^{-1})$
241.48	0.1643	0.0017
247.08	0.1618	0.0017
251.59	0.1600	0.0017
256.13	0.1589	0.0016
262.02	0.1560	0.0016
268.08	0.1541	0.0016
272.05	0.1525	0.0016
276.73	0.1510	0.0015
282.16	0.1488	0.0015
287.10	0.1462	0.0015
292.25	0.1443	0.0015
299.30	0.1426	0.0014
304.22	0.1402	0.0014
309.18	0.1383	0.0014
313.73	0.1366	0.0014
317.83	0.1348	0.0014
321.80	0.1330	0.0014
325.05	0.1318	0.0014
331.84	0.1301	0.0014
336.12	0.1279	0.0013
341.82	0.1260	0.0013
347.03	0.1237	0.0013
351.76	0.1223	0.0012
356.10	0.1202	0.0012
364.05	0.1168	0.0012

data for methylal as a function of temperature. In all measurements, the temperature rise of the platinum wire was about 2–5 K and the measurement time was 0.3–6 s after the initiation of heating by adjusting the current through the wire. A period of about 15 min was necessary between two sequential runs in order to ensure the temperature uniformity of the sample in the cell. Temperature fluctuations of the thermostatic bath were controlled to within ± 4 mK during all measurements at the same temperature.

The thermal conductivity data for methylal were correlated as a function of temperature using least squares:

$$\lambda = A + B(T - 273.15) + C(T - 273.15)^2 \tag{2}$$

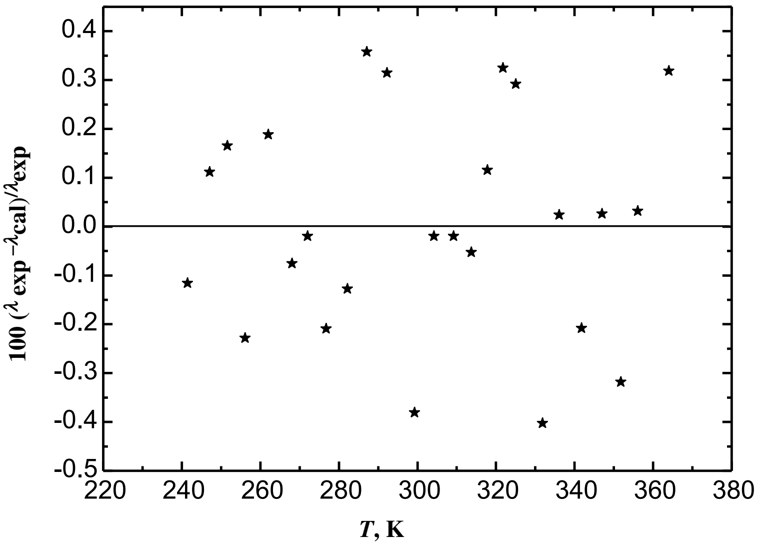

Fig. 4. Deviations of experimental results from Eq. (2).

where λ is the thermal conductivity, in $W \cdot m^{-1} \cdot K^{-1}$, T is the temperature, in K, and the fitted values of A, B, C are 0.15205, -3.81535×10^{-4}, and -2.37638×10^{-8}, respectively.

The deviations of the experimental data from Eq. (2) are shown in Fig. 4. The average absolute deviation was 0.18%, and the maximum deviation was 0.41%. Both were consistent with the estimated uncertainty. Because there have been no previous measurements of the liquid thermal conductivity for methylal, no comparisons can be made. A second series of measurements was carried out several days later so as to confirm the accuracy of the results after the first series of measurements was finished. The two series of measurements agreed well, within the claimed uncertainty.

4. CONCLUSION

The thermal conductivity of liquid methylal was measured in the temperature range from 240 to 362 K at the saturated vapor pressure by the transient hot-wire method with a bare platinum wire. The uncertainty of the results was less than $\pm 2.0\%$, and the repeatability was better than $\pm 0.5\%$. The experimental data were correlated as a function of temperature with an average absolute deviation of 0.18% and a maximum deviation of 0.41%.

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