Thermal Conductivity of Liquid Dimethyl Ether from (233 to 373) K at Pressures up to 30 MPa[†]

Jiangtao Wu,[*,‡] Xiaojing Li,[‡] Huifeng Zheng,[‡] and Marc J. Assael[§]

State Key Laboratory of Multiphase Flow in Power Engineering, Xi'an Jiaotong University, Xi'an Shaanxi 710049, People's Republic of China, and Thermophysical Properties Laboratory, Chemical Engineering Department, Aristotle University, 54124 Thessaloniki, Greece

The thermal conductivity of liquid dimethyl ether (DME) was measured from (233 to 373) K at pressures ranging from (0.6 to 30) MPa by the transient hot-wire technique with two anodized tantalum hot wires. The experimental data were correlated as a function of pressure and temperature. The average absolute deviation of experimental data from those calculated by the equation was 0.46 %, and the maximum absolute deviation was 1.6 %. The uncertainty of the thermal conductivity was ± 2.0 % with a coverage factor of $k = 2$.

Introduction

Dimethyl ether is an important chemical material and has many engineering applications such as fuel additive, assistant solvent, aerosol propellant, and so on. In particular, it is an ideal potential clean fuel and an alternative refrigerant because it is not harmful to the ozone layer and is easily degraded in the atmosphere.[1] At present, more and more researchers are carrying out research in this field. As a basis, the thermophysical properties of dimethyl ether (DME) are very important and indispensable in these applications. Recently, the measurement of thermophysical properties of DME has been carried out by our research group, which includes liquid viscosity, surface tension, saturated liquid density, gas-phase PVT properties, critical parameters, and the thermal conductivity of saturated liquid- and gaseous-phase vapor pressure.[2−9] To the best of our knowledge, there are no comprehensive experimental data of the liquid thermal conductivity of DME reported in the published literatures. In this work, the thermal conductivity of liquid DME was measured at temperatures from (233 to 373) K and pressures up to 30 MPa.

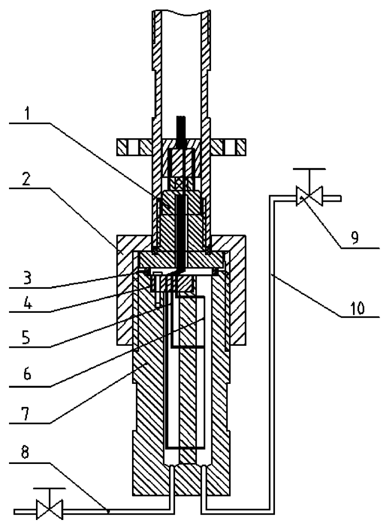

Figure 1. Hot-wire assembly: 1, seal connector; 2, nut; 3, Cu O-ring; 4, ceramic flake 5, Ta rod; 6, Ta wires; 7, pressure vessel; 8, inlet; 9, valve; 10, outlet.

Experimental Section

The description of the transient hot-wire technique, as employed for the measurement of the thermal conductivity of liquid 1,2-dimethoxyethane from (243 to 353) K at pressures from (0.1 to 30) MPa has been described elsewhere.[10] Only a brief introduction is presented here. The apparatus employs two anodized tantalum wires as hot wires, differing only in length, placed in a pressure vessel. A Wheatstone-type electronic bridge is used to measure the evolution of the resistance change of a finite segment of infinite wire and to ensure that a known constant heat flux is generated in the hot wires.

The apparatus is shown in Figure 1; the two identical wires are made out of 25 μm diameter tantalum and have lengths of

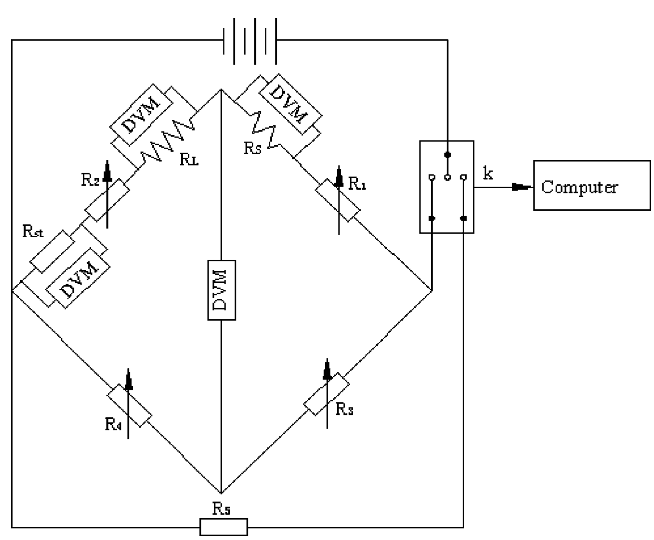

Figure 2. Block diagram of electrical system.

[†] Part of the special section "2008 European Conference on Thermophysical Properties".

* Corresponding author. E-mail: jtwu@mail.xjtu.edu.cn. Fax: +86-29-82668789. Tel: +86-29-82666875.
[‡] Xi'an Jiaotong University.
[§] Aristotle University.

10.1021/je800964k CCC: $40.75
Published on Web 05/01/2009

Table 1. Thermal Conductivity of Liquid Dimethyl Ether

T_r / K	P / MPa	Q / mW·m^{-1}	λ / W·m^{-1}·K	T_r / K	P / MPa	Q / mW·m^{-1}	λ / W·m^{-1}·K
234.20	0.6	0.4627	0.1534	314.66	1.0	0.5493	0.1137
234.29	0.6	0.5538	0.1530	314.01	5.1	0.3516	0.1191
234.58	0.6	0.6532	0.1538	314.11	5.2	0.4590	0.1189
234.04	5.1	0.4628	0.1561	314.39	5.1	0.5489	0.1195
234.66	5.3	0.7241	0.1568	314.43	10.2	0.3553	0.1242
234.72	5.3	0.7986	0.1562	314.81	10.2	0.4459	0.1241
234.33	10.0	0.6533	0.1600	315.06	10.1	0.5120	0.1242
234.71	10.4	0.7986	0.1605	315.07	20.1	0.5826	0.1318
235.32	10.7	1.0441	0.1598	315.01	20.4	0.5826	0.1313
234.70	20.2	0.7988	0.1655	315.55	20.0	0.6972	0.1318
235.00	20.1	0.9174	0.1654	314.60	30.1	0.5119	0.1385
235.27	20.2	1.0443	0.1655	314.88	30.0	0.5826	0.1382
234.43	29.8	0.6532	0.1704	315.37	30.4	0.6970	0.1384
234.44	30.0	0.7239	0.1709	334.03	1.5	0.1764	0.1075
234.79	30.1	0.9169	0.1703	333.73	1.5	0.0992	0.1079
254.02	0.6	0.4117	0.1422	334.47	1.5	0.2755	0.1078
254.16	0.6	0.4686	0.1427	333.92	5.2	0.1763	0.1113
254.42	0.6	0.5608	0.1427	334.55	5.1	0.3456	0.1108
254.42	5.1	0.5609	0.1467	334.85	5.2	0.4515	0.1116
255.08	5.0	0.8087	0.1471	334.70	10.2	0.4513	0.1156
254.88	5.1	0.7332	0.1466	334.91	10.2	0.5399	0.1154
253.99	10.2	0.4783	0.1528	335.37	10.1	0.6366	0.1151
254.22	10.4	0.6513	0.1529	335.76	10.3	0.6979	0.1146
254.81	10.1	0.8096	0.1522	334.31	20.2	0.3555	0.1229
254.11	20.4	0.4125	0.1582	334.79	20.2	0.4461	0.1224
254.20	20.1	0.4696	0.1579	335.29	20.1	0.5830	0.1228
254.37	20.1	0.5619	0.1583	335.72	20.0	0.6976	0.1223
254.34	30.3	0.5621	0.1643	334.09	30.0	0.3554	0.1283
254.12	30.2	0.4697	0.1633	334.38	30.1	0.4459	0.1287
257.35	29.9	1.2118	0.1640	334.90	30.2	0.5120	0.1288
275.31	0.7	0.9317	0.1342	335.09	30.4	0.5828	0.1294
275.74	0.7	1.0699	0.1343	354.21	2.3	0.2268	0.0973
276.44	0.7	1.3217	0.1347	354.45	2.3	0.2745	0.0970
273.93	5.0	0.4199	0.1396	354.86	2.3	0.3544	0.0971
274.08	5.1	0.5148	0.1396	355.18	2.3	0.4447	0.0971
274.48	5.0	0.7009	0.1404	354.15	5.8	0.1412	0.0998
274.90	10.5	0.7746	0.1456	354.29	5.3	0.2269	0.1005
275.22	10.2	0.8583	0.1452	354.97	5.2	0.2725	0.1000
276.02	10.5	1.0872	0.1459	355.46	5.2	0.5107	0.1012
274.60	20.0	0.6569	0.1523	353.73	10.3	0.0627	0.1059
274.90	20.3	0.7747	0.1522	354.06	10.2	0.1837	0.1053
275.12	20.3	0.8586	0.1523	354.10	20.4	0.1742	0.1145
274.57	30.4	0.6570	0.1579	355.08	20.0	0.4461	0.1141
274.56	29.8	0.8274	0.1585	355.36	20.1	0.5338	0.1142
275.30	30.6	0.8587	0.1582	353.93	30.5	0.1741	0.1206
293.80	0.8	0.2779	0.1249	353.97	30.1	0.2107	0.1208
294.15	0.8	0.4504	0.1252	354.59	30.1	0.3918	0.1208
294.45	0.8	0.5170	0.1248	374.85	3.3	0.1742	0.0871
293.79	5.1	0.3589	0.1305	375.13	3.3	0.2108	0.0869
294.45	4.9	0.5884	0.1305	375.38	3.3	0.2722	0.0867
294.84	5.2	0.7041	0.1307	374.85	5.1	0.1741	0.0908
294.16	10.0	0.4503	0.1362	374.91	5.0	0.2107	0.0908
294.22	10.2	0.5170	0.1364	375.27	5.0	0.2721	0.0911
295.22	10.0	0.8302	0.1356	374.25	10.7	0.0979	0.0988
294.68	20.6	0.7040	0.1417	376.38	10.6	0.5334	0.0976
295.13	20.3	0.8303	0.1417	374.25	20.5	0.1409	0.1071
296.32	20.2	1.0711	0.1415	375.68	20.2	0.4457	0.1065
294.30	29.8	0.5392	0.1495	376.02	20.0	0.5333	0.1065
294.59	29.9	0.6370	0.1486	374.30	30.4	0.2716	0.1129
314.06	1.0	0.3519	0.1143	374.62	30.3	0.3911	0.1133
314.39	1.0	0.4594	0.1145	374.81	29.9	0.4454	0.1135

29 mm and 58 mm, respectively. They are placed one after the other and are spot-welded to three 1.0 mm diameter tantalum rods, which are attached to a ceramic flake. The tantalum rods act as both electrical contacts and supports. The whole structure was anodized in situ to form a layer of insulating tantalum pentoxide on their surface.

The two wires and supports were placed in the pressure vessel (Figure 1) and sealed with the connector and nut. The apparatus and connections were all made of stainless steel (SSL 316), and the volume of the sample needed in the measurements did not exceed 30 cm^3 including that in the pipelines. This small volume facilitates measurements on scarce or hazardous materials.

The block diagram in Figure 2 shows the data acquisition system used. It consists of several components: a Wheatstone bridge, Keithley 2400 Source Meter, two Keithley 2010 digital multimeters, two Agilent 34410A digital multimeters, Keithley 7001 switch systems, and an industrial computer. All of the data acquisition and instrument control were performed by a computer via the IEEE-488 interfaces.

The transient hot-wire apparatus was completely immersed in a thermostatic bath (Fluke, model 7037). The temperature was measured with a platinum resistance thermometer. The total uncertainty of the temperature for the thermal conductivity measurements was less than ± 10 mK.

The pressure of liquids in the cell was achieved by an HPLC pump (Beijing Satellite manufactory, model 2PB00C) with the pressure readings acquired. The pressure was measured with a resistance pressure transducer (Micro Sensor

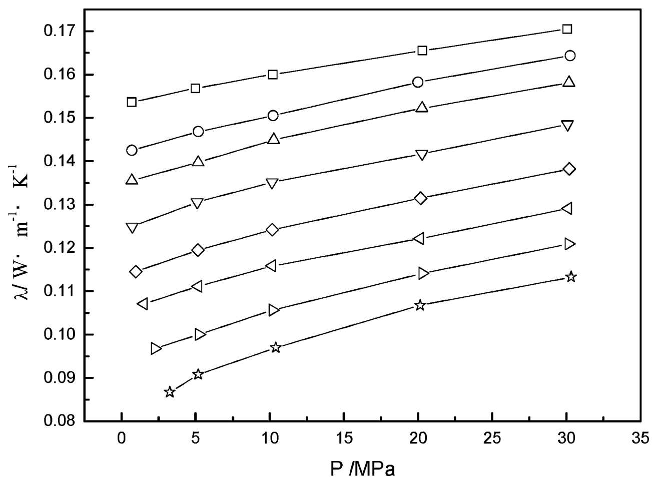

Figure 3. Pressure dependence of the thermal conductivity of dimethyl ether at different temperature: ☆, 373 K; right tilted triangle, 353 K; left tilted triangle, 333 K; ◇, 313 K; ▽, 293 K; △, 273 K; ○, 253 K; □, 233 K.

Table 2. Coefficients a_{ij}/W·m^{-1}·K$^{-(i+1)}$·MPa^{-j} Employed in Equation *1*

	$j = 0$	$j = 1$	$j = 2$	$j = 3$
$i = 0$	$4.7499 \cdot 10^{-1}$	$-9.0167 \cdot 10^{-9}$	$4.4622 \cdot 10^{-3}$	$-7.1135 \cdot 10^{-5}$
$i = 1$	$-2.7107 \cdot 10^{-3}$	$9.4554 \cdot 10^{-4}$	$-4.4996 \cdot 10^{-5}$	$7.1232 \cdot 10^{-7}$
$i = 2$	$7.8106 \cdot 10^{-6}$	$-3.1369 \cdot 10^{-6}$	$1.4854 \cdot 10^{-7}$	$-2.3339 \cdot 10^{-9}$
$i = 3$	$-9.0167 \cdot 10^{-9}$	$3.4419 \cdot 10^{-9}$	$-1.6178 \cdot 10^{-10}$	$2.5196 \cdot 10^{-12}$

Co. Ltd., model MPM480) from (0 to 40) MPa with an uncertainty of 0.1 MPa.

Measurements

Test. We tested the performance of the apparatus by measuring the thermal conductivity of saturated liquid toluene (mass fraction purity better than 99.5 %) from (273 to 373) K. The maximum deviation and average absolute deviation from the recommended values[11] are 0.51 % and 0.23 %, respectively.

Dimethyl Ether. The sample of DME was provided by Shangdong Jiutai Chemical (the largest DME supplier in China). The mass fraction purity of DME was 99.9 %. No further purification was performed.

Table 1 presents the experimental data for the thermal conductivity of DME as a function of temperature and pressure. Accounting for all of the random errors of measurement and following our previous discussion, it is estimated that the tabulated thermal conductivity data have an uncertainty of better than ± 2.0 %. The temperature dependence of the thermal conductivity of DME at different pressures is shown in Figure 3.

The experimental results of liquid DME were correlated by a polynomial of temperature and pressure

$$\lambda/\mathrm{W{\cdot}m^{-1}{\cdot}K^{-1}} = \sum_{i=0}^{3}\sum_{j=0}^{3} a_{ij}(T/\mathrm{K})^{i}(P/\mathrm{MPa})^{j} \qquad (1)$$

The coefficients in eq 1 for DME are listed in Table 2. The correlation of eq 1 is suitable only for interpolation and cannot be used for extrapolation or prediction. The correlation represented the experimental data for liquid DME with the average absolute deviation of 0.46 % and an absolute maximum deviation of 1.6 %, as shown in Figure 4.

The data points reported by Wang et al.,[6] Wu et al.,[7] and Burgorf et al.[12] were also compared and shown in Figure 4. It can be seen that the agreement with Wang[6] is within a maximum deviation of 3.5 % and an average absolute deviation of 1.2 %.

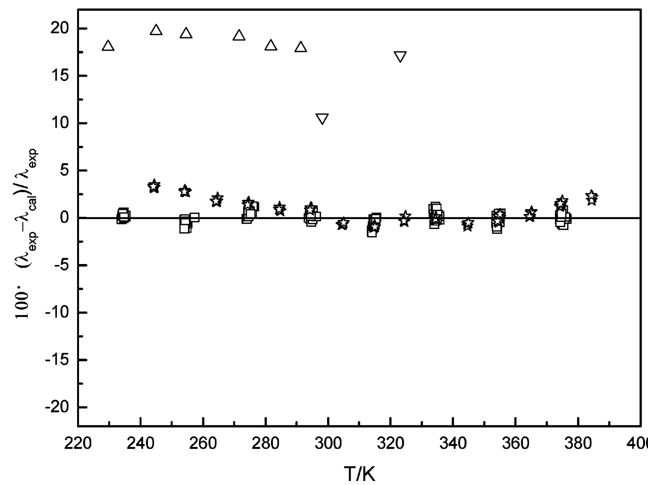

Figure 4. Relative deviations of calculated values by eq 1 from experimental data for pure dimethyl ether: □, this work; ☆, ref 6, △, ref 7; ▽, ref 12.

The deviation of two data points at (298.15 and 313.15) K reported by Burgorf[12] were 10.6 % and 17.2 %. The thermal conductivity of DME in saturated liquid phase from (229 to 375) K were reported by Wu et al.[7] The average absolute deviation and maximum absolute deviation of experimental data from those calculated by the equation were 19.7 % and 18.7 %, as shown in Figure 4. Since our previous work[6,7] was done, the experimental system has been concededly improved. The purpose of Burgorf et al.[12] was to measure a multitude of reliable data with high efficiency but not high accuracy. Hence, the thermal conductivity data of this work should be more reliable.

Conclusions

New values for the thermal conductivity of DME were measured by a transient hot-wire instrument with an estimated uncertainty of ± 2.0 % at a confidence level of 95 %, over the temperature range (233 to 373) K at pressures up to 30 MPa. The experimental data were correlated as a function of pressure and temperature. The average absolute deviation and maximum absolute deviation of experimental data from those calculated by the equation were 0.46 % and 1.6 %, respectively.

Literature Cited

(1) Zhou, L. B.; Wang, H. W.; Wang, Y. Experimental Study on Performance and Combustion Characteristics of DME Powered Vehicle. In *Proceedings of the International Symposium on "Clean and High-Efficiency Combustion in Engines"*; Association of Engine Combustion, Emission, and Fuel Conversation of China: Tianjian, China, 2002; Vol. A.

(2) Wu, J. T.; Liu, Z. G.; Bi, S. S.; Meng, X. Y. Viscosity of Saturated Liquid Dimethyl Ether from (227 to 343) K. *J. Chem. Eng. Data* **2003**, *48*, 426–429.

(3) Wu, J. T.; Liu, Z. G.; Pan, J.; Wang, F. K.; Ren, C. Surface Tension of Dimethyl Ether from (213 to 368) K. *J. Chem. Eng. Data* **2003**, *48*, 1571–1573.

(4) Wu, J. T. Development of the New Thermophysical Properties Measurement System and Research of Thermophysical Properties of Dimethyl Ether. Ph.D. Thesis, Xi'an Jiaotong University, 2003.

(5) Wu, J. T.; Liu, Z. G.; Wang, B.; Pan, J. Measurement of the Critical Parameters and the Saturation Densities of Dimethyl Ether. *J. Chem. Eng. Data* **2004**, *49*, 704–708.

(6) Wang, Y. G.; Wu, J. T.; Liu, Z. G. Thermal Conductivity of Dimethyl Ether in Saturated Liquid Phase. *J. Xi'an Jiantong Univ.* **2005**, *39*, 1026–1034.

(7) Wu, J. T.; Liu, Z. G.; Jin, X. G.; Pan, J. Thermal Conductivity of Some Oxygenated Fuels and Additives in the Saturated Liquid Phase. *J. Chem. Eng. Data* **2005**, *50*, 102–104.

(8) Wang, Y. G.; Wu, J. T.; Liu, Z. G. Thermal Conductivity of Gaseous Dimethyl Ether from (263 to 383) K. *J. Chem. Eng. Data* **2006**, *51*, 164–168.

(9) Wu, J. T.; Yin, J. G. Vapor Pressure Measurements of Dimethyl Ether from (213 to 393) K. *J. Chem. Eng. Data* **2008**, *53*, 2247–2249.

(10) Wu, J. T.; Zheng, H. F.; Qian, X. H.; Li, X. J.; Assael, M. J. Thermal Conductivity of Liquid 1,2-Dimethoxyethane from 243 to 353 K at Pressures up to 30 MPa. *Int. J. Thermophys.* **2009**, *30*, 385–396.

(11) Ramires, M. L. V.; Nieto de Casto, C. A.; Perkins, R. A.; Nagasaka, Y.; Assael, M. J.; Wakeham, W. A. Reference Data for the Thermal Conductivity of Saturated Liquid Toluene over a Wide Range of Temperatures. *J. Phys. Chem. Ref. Data* **2000**, *29*, 133–139.

(12) Burgdorf, R.; Zocholl, A.; Arlt, W.; Knapp, H. Thermophysical Properties of Binary Liquid Mixtures of Polyether and *n*-alkane at 298.15 and 323.15: Heat of Mixing, Heat Capacity, Viscosity, Density and Thermal Conductivity. *Fluid Phase Equilib.* **1999**, *164*, 225–255.

Received for review December 15, 2008. Accepted April 9, 2009. This research was supported by the Foundation for the Author of National Excellent Doctoral Dissertation (grant 200540) and Program for New Century Excellent Talents in University (NCET-05−0836).

JE800964K