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Thermal Conductivity of Liquid 1, 2-Dimethoxyethane from 243 K to 353 K at Pressures up to 30 MPa

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Abstract The thermal conductivity of liquid 1, 2-dimethoxyethane was measured from 243 K to 353 K at pressures from 0 to 30 MPa by the transient hot-wire technique employing 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 0.24 %, and the maximum absolute deviation was 0.80 %. The uncertainty of the thermal conductivity was 2.0 % with a coverage factor of $k = 2$.

Keywords 1, 2-Dimethoxyethane · Thermal conductivity · Transient hotwire

1 Introduction

Alkyl ethers, such as 1, 2-dimethoxyethane and dimethoxymethane, are regarded as good fuel additives and potential alternative fuels in the future as a result of their high oxygen content, suitable boiling points, and good solubility in diesel fuel. Experimental results have shown that particulate matter emissions can be reduced using a dimethoxyethane oxygenated compound, while diesel engines fuelled with dimethoxyethane additive have improved combustion and emission performance [1,2]. However, although more and more researchers are investigating these compounds at present, the thermophysical properties of alkyl ethers are still scarce. Thus, there is an

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urgent need for thermophysical property experimental data, and especially at high pressures. The thermal conductivity and vapor pressure of liquid 1, 2-dimethoxymethane [3,4], and the density and viscosity of dimethoxymethane and 1, 2-dimethoxyethane [5] have been previously reported by our group. To the best of our knowledge, thermal conductivity data of 1, 2-dimethoxyethane are scarce. Only two points at 298.15 K and 323.15 K were reported by Burgdorf et al. [6]. In this work, the thermal conductivity of liquid 1, 2-dimethoxyethane was measured at temperatures from 243 K to 353 K and pressures from atmospheric pressure up to 30 MPa.

2 Principle of Technique

The transient hot-wire technique is widely recognized as the most accurate method to measure the thermal conductivity of fluids. In this work, an improved transient hot-wire apparatus was used with two anodized tantalum wires, differing only in length. The fundamental working equation takes the form,

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

where q is the power input per unit length of wire, $\lambda(T_{\mathrm{r}}, P)$ represents the thermal conductivity of the fluid at a reference temperature T_{r} and the working pressure P, $\mathrm{d}\Delta T/\mathrm{dln}t$ is the slope of a linear fit to the ideal temperature rise versus the natural logarithm of elapsed time.

3 Experimental

3.1 Hot-Wire Sensor

The two wires in Fig. 1 are made out of 25 μm diameter tantalum and have lengths of 29 mm and 58 mm, respectively. They are placed one after the other, and spot-welded to three 1.0 mm diameter tantalum rods which are attached to a ceramic flake. The tantalum rods act both as electrical contacts and supports. This arrangement ensures that as the temperature changes, the wires always remain under the same tension because it has the same linear expansion coefficient as its support. The whole structure was anodized in situ to form a layer of insulating tantalum pentoxide on their surface [7]. This design is also simpler and more robust compared to our previous one [8].

3.2 Hot-Wire Cell

A schematic diagram showing the transient hot-wire assembly is shown in Fig. 1. Two 10-mm diameter cavities have lengths of 107 mm and 117 mm in the pressure vessel. The ceramic flake is fixed by three screws on the top of the short cavity. Support tantalum rods and hot wires are within the short and long cavities, respectively. Then the two wires are placed in the pressure vessel to perform measurements after screwing

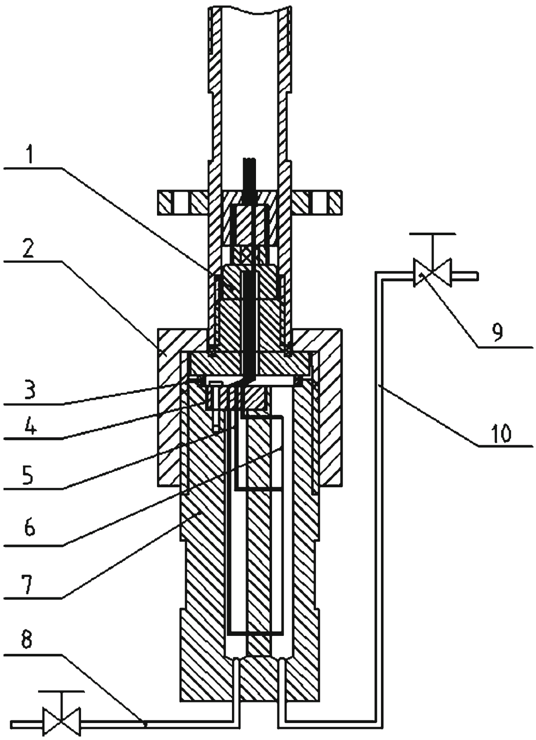

Fig. 1 Hot-wire assembly: 1, seal connector; 2, nut; 3, Cu O-ring; 4, ceramic flake 5, Ta rod; 6, Ta wires; 7, pressure vessel; 8, inlet; 9, valve; 10, outlet

the seal connector and nut. The apparatus and connections were all made of stainless steel (1Cr18Ni9Ti), and the volume of the sample employed in the measurements does not exceed 30 cm^3 including that in the pipelines, to facilitate measurements on scarce or hazardous materials.

3.3 Measurement Bridge Circuit

The block diagram in Fig. 2 shows the data acquisition system used in this work. 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. The Wheatstone bridge included four high-accuracy dc decade resistance boxes (minimum step of 0.001 Ω), a 10 Ω standard resistance (uncertainty of 0.002 %), and two wires in opposing legs of the bridge. The Keithley 2400 source meter was used as a constant voltage source with low noise and high precision. The voltages of the bridge imbalance and standard resistance from which the difference of two wires can be obtained were recorded by the Keithley 2010 digital multimeters, while voltages of two wires were measured by the Agilent 34410A digital multimeters. All the data acquisition and instrument control were performed by a computer via IEEE-488 interfaces.

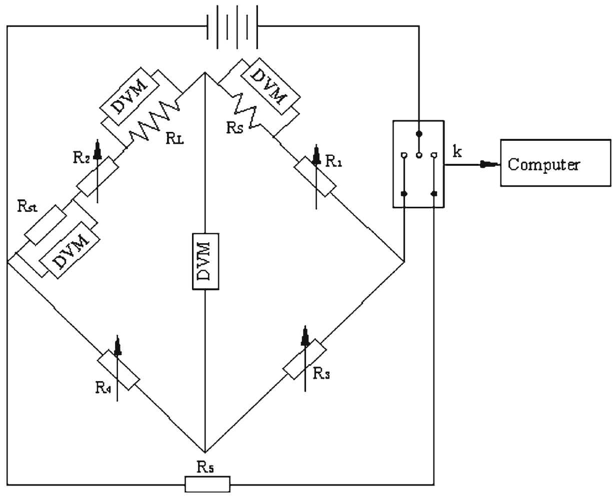

Fig. 2 Block diagram of electrical system

3.4 Temperature and Pressure Control

The transient hot-wire apparatus was immersed completely in a thermostatic bath (Fluke, Model 7037). Methyl silicone oil was selected as the bath fluid for the temperature range from 243 K to 353 K. The temperature was measured with a platinum resistance thermometer. The total uncertainty of temperature for the thermal conductivity measurements was less than 10 mK.

The pressure of liquids in the cell was achieved with an HPLC pump (Beijing Satellite Manufactory, Model 2PB00C). The pressure was measured with a resistance pressure transducer (Micro Sensor Co., Ltd., Model MPM480) from 0 to 40 MPa with an uncertainty of 0.1 MPa.

3.5 Test

The performance of the apparatus was tested by measuring the thermal conductivity of saturated liquid toluene (mass fraction purity better than 99.5 %) from 273 K to 373 K. The measurements are shown in Table 1, it can be seen that agreement with recommended values [9] is within a maximum deviation of 0.51 % and an average absolute deviation of 0.23 %. This comparison indicates that the uncertainty in the measurement of the thermal conductivity should be better than ±1.0 %.

4 Results and Discussion

The sample of 1, 2-dimethoxyethane was provided by Jixi Sanming Industry of Fine Chemicals Co., Ltd. The mass fraction purity of 1, 2-dimethoxyethane was 99.9 %. No further purification was performed.

Table 1 Thermal conductivity of saturated liquid toluene

T_r (K)	q ($mW \cdot m^{-1}$)	λ ($W \cdot m^{-1} \cdot K^{-1}$)	λ_{ref} ($W \cdot m^{-1} \cdot K^{-1}$)	$(\lambda_{exp} - \lambda_{ref})/\lambda_{ref}$ (%)
274.65	0.5075	0.1387	0.1381	0.43
275.40	0.6914	0.1382	0.1379	0.22
275.95	0.8155	0.1384	0.1377	0.51
276.31	0.9038	0.1380	0.1376	0.18
287.33	1.0787	0.1345	0.1343	0.11
288.72	1.3334	0.1336	0.1339	−0.22
289.65	1.6152	0.1335	0.1336	−0.07
297.45	1.0975	0.1318	0.1313	0.38
298.60	1.3562	0.1313	0.1309	0.31
300.43	1.6435	0.1303	0.1304	−0.07
294.45	0.5088	0.1318	0.1322	−0.28
294.69	0.5792	0.1318	0.1321	−0.21
295.08	0.6931	0.1321	0.1320	0.08
295.47	0.8175	0.1314	0.1319	−0.38
295.79	0.9060	0.1320	0.1318	0.15
307.66	1.0993	0.1287	0.1282	0.39
308.62	1.3583	0.1283	0.1279	0.33
310.22	1.6457	0.1274	0.1274	0.00
317.94	1.1172	0.1251	0.1251	0.00
319.32	1.3805	0.1245	0.1247	−0.17
319.96	1.6719	0.1245	0.1245	0.00
314.69	0.5089	0.1261	0.1261	0.00
314.74	0.5793	0.1264	0.1261	0.26
315.55	0.8175	0.1253	0.1258	−0.37
315.85	0.9059	0.1254	0.1257	−0.24
316.70	1.1472	0.1251	0.1255	−0.29
327.65	1.1170	0.1225	0.1222	0.24
329.50	1.3803	0.1214	0.1217	−0.19
330.77	1.6719	0.1209	0.1213	−0.35
338.39	1.1169	0.1188	0.1190	−0.25
339.77	1.3800	0.1181	0.1187	−0.48
340.62	1.6713	0.1181	0.1184	−0.26
355.63	0.7716	0.1140	0.1142	−0.18
355.95	0.8551	0.1140	0.1141	−0.09
357.02	1.0829	0.1137	0.1138	−0.09
375.26	0.6533	0.1086	0.1090	−0.37
375.71	0.7705	0.1087	0.1089	−0.18
375.26	0.6533	0.1086	0.1090	−0.37

Table 2 presents the experimental data for the thermal conductivity of 1, 2-dimethoxyethane 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 ±1.0 %. The temperature dependence of the thermal conductivity of 1, 2-dimethoxyethane at different pressures and the pressure dependence of the experimental results of 1, 2-dimethoxyethane at different temperatures are shown in Figs. 3 and 4, respectively.

Table 2 Thermal conductivity of liquid 1, 2-dimethoxyethane

T_r (K)	P (MPa)	q (mW · m^{-1})	λ (W · m^{-1} · K^{-1})
245.46	0.1	1.0999	0.1648
246.49	0.1	1.3594	0.1650
247.52	0.1	1.6473	0.1647
246.06	5.0	1.1000	0.1665
246.52	5.0	1.3593	0.1666
246.79	5.0	1.6468	0.1662
245.95	9.8	1.0999	0.1669
246.69	10.0	1.3591	0.1683
246.75	10.0	1.6466	0.1682
246.06	20.1	1.1000	0.1711
246.24	20.0	1.3590	0.1706
245.69	30.0	1.0997	0.1742
245.96	30.1	1.3587	0.1746
256.02	0.1	1.1048	0.1606
256.95	0.1	1.3654	0.1610
257.58	0.1	1.6539	0.1607
256.21	5.1	1.1049	0.1623
256.90	5.1	1.3652	0.1625
257.48	5.1	1.6536	0.1625
256.10	10.0	1.1047	0.1643
256.83	10.0	1.3651	0.1642
257.62	10.0	1.6538	0.1643
255.91	20.0	1.1045	0.1675
256.81	20.0	1.3649	0.1679
257.56	20.0	1.6535	0.1674
256.02	30.0	1.1045	0.1706
256.75	30.0	1.3647	0.1707
257.66	30.0	1.6536	0.1708
266.41	0.1	1.1089	0.1580
266.26	0.1	1.3698	0.1580
267.50	0.1	1.6598	0.1578
266.18	5.0	1.1088	0.1601

Table 2 continued

T_r (K)	P (MPa)	q (mW · m^{-1})	λ (W · m^{-1} · K^{-1})
266.58	5.0	1.3699	0.1598
267.84	5.0	1.6597	0.1598
266.32	10.0	1.1089	0.1618
266.15	10.0	1.3699	0.1617
267.37	10.0	1.6597	0.1617
266.26	20.0	1.1089	0.1654
266.87	20.0	1.3701	0.1650
267.35	20.0	1.6596	0.1653
266.19	30.0	1.1088	0.1688
266.95	30.0	1.3702	0.1684
267.11	30.0	1.6595	0.1683
276.34	0.1	1.1353	0.1547
276.49	0.1	1.4026	0.1543
278.62	0.1	1.6996	0.1539
275.72	5.0	1.1350	0.1567
276.94	5.0	1.4024	0.1567
277.55	5.0	1.6988	0.1565
275.68	10.0	1.1349	0.1585
277.29	10.0	1.4024	0.1584
277.95	10.0	1.6987	0.1585
276.21	20.0	1.1348	0.1624
276.52	20.0	1.4019	0.1623
277.53	20.0	1.6983	0.1623
276.45	30.0	1.1346	0.1657
277.11	30.0	1.4018	0.1654
277.31	30.0	1.6976	0.1653
286.23	0.1	1.1436	0.1512
287.06	0.1	1.4130	0.1509
288.62	0.1	1.7117	0.1504
286.18	5.0	1.1435	0.1531
287.46	5.0	1.413	0.1530
288.65	5.0	1.7118	0.1525
285.80	10.0	1.1434	0.1551
287.28	10.0	1.4129	0.1549
288.14	10.0	1.7114	0.1545
286.51	20.0	1.1435	0.1590
286.80	20.0	1.4127	0.1590
287.68	20.0	1.7110	0.1586
286.40	30.0	1.1433	0.1626
286.67	30.0	1.4123	0.1625
287.07	30.0	1.7105	0.1621
294.68	0.1	0.5783	0.1466

Table 2 continued

T_r (K)	P (MPa)	q (mW · m^{-1})	λ (W · m^{-1} · K^{-1})
294.75	0.1	0.6918	0.1463
295.38	0.1	0.8162	0.1474
295.36	0.1	0.9042	0.1467
294.83	5.0	0.5781	0.1500
294.98	5.0	0.6918	0.1495
295.07	5.0	0.8158	0.1490
296.00	5.0	0.9048	0.1498
294.64	10.0	0.5082	0.1527
294.52	10.0	0.5784	0.1516
294.85	10.0	0.6921	0.1514
295.37	10.0	0.8162	0.1515
295.83	10.0	0.9046	0.1522
294.53	20.0	0.5081	0.1566
294.68	20.0	0.5783	0.1566
295.24	20.0	0.6921	0.1569
295.11	20.0	0.8161	0.1557
295.36	20.0	0.9045	0.1558
294.55	30.0	0.5079	0.1589
294.89	30.0	0.5783	0.1609
295.00	30.0	0.6920	0.1595
295.32	30.0	0.8161	0.1600
295.28	30.0	0.9045	0.1598
314.60	0.1	0.5084	0.1394
314.65	0.1	0.5787	0.1386
314.90	0.1	0.6924	0.1402
315.27	0.1	0.8167	0.1395
315.51	0.1	0.9050	0.1391
314.84	5.0	0.6923	0.1415
315.23	5.0	0.8165	0.1424
315.46	5.0	0.9049	0.1419
314.87	10.0	0.5786	0.1443
315.06	10.0	0.6923	0.1440
315.17	10.0	0.8165	0.1447
315.42	10.0	0.9049	0.1445
314.83	20.0	0.5786	0.1491
314.95	20.0	0.6923	0.1476
315.30	20.0	0.8164	0.1484
315.31	20.0	0.9049	0.1483
314.79	30.0	0.5787	0.1522
315.14	30.0	0.6925	0.1529
315.26	30.0	0.8167	0.1519
334.58	0.1	0.5081	0.1320

Table 2 continued

T_r (K)	P (MPa)	q (mW · m^{-1})	λ (W · m^{-1} · K^{-1})
334.69	0.1	0.5782	0.1320
335.06	0.1	0.6918	0.1322
335.53	0.1	0.8157	0.1314
336.14	0.1	0.9040	0.1319
334.58	5.0	0.5078	0.1342
334.65	5.0	0.5780	0.1347
334.98	5.0	0.6916	0.1344
335.39	5.0	0.8157	0.1347
335.96	5.0	0.9038	0.1343
334.53	10.0	0.5078	0.1361
334.76	10.0	0.5779	0.1366
334.94	10.0	0.6915	0.1373
335.31	10.0	0.8154	0.1374
335.59	10.0	0.9037	0.1366
334.62	20.0	0.5076	0.1418
334.78	20.0	0.5778	0.1413
334.86	20.0	0.6913	0.1421
335.21	20.1	0.8153	0.1415
335.45	20.0	0.9035	0.1411
334.73	30.0	0.5076	0.1453
335.60	30.0	0.8153	0.1461
335.36	30.0	0.9035	0.1456
354.58	0.1	0.5068	0.1237
354.83	0.1	0.5768	0.1241
355.35	0.1	0.6902	0.1246
355.83	0.1	0.8138	0.1241
356.15	0.1	0.9019	0.1241
354.55	5.0	0.5068	0.1277
354.75	5.0	0.5768	0.1264
355.13	5.0	0.6902	0.1273
355.52	5.0	0.8139	0.1268
355.98	5.0	0.9020	0.1267
354.50	10.0	0.5068	0.1296
354.72	10.0	0.5768	0.1300
355.08	10.0	0.6901	0.1300
355.46	10.0	0.8138	0.1295
355.74	10.0	0.9019	0.1298
354.76	20.0	0.5067	0.1354
354.82	20.0	0.5768	0.1357
354.97	20.0	0.6901	0.1348
355.36	20.0	0.8138	0.1347

Table 2 continued

T_r (K)	P (MPa)	q (mW · m^{-1})	λ (W · m^{-1} · K^{-1})
355.62	20.0	0.9018	0.1349
354.87	30.0	0.6901	0.1385
355.28	30.0	0.8138	0.1399
355.53	30.0	0.9018	0.1394

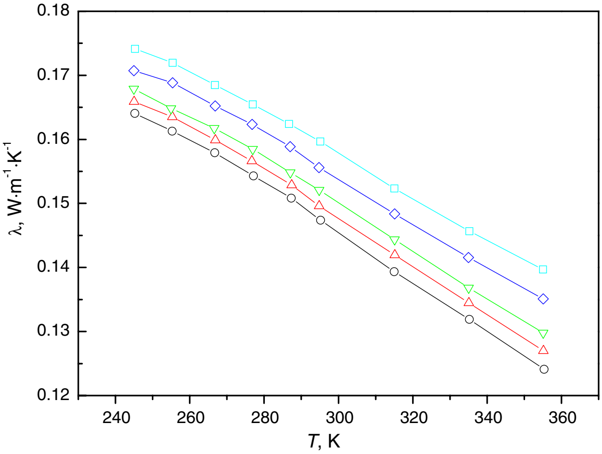

Fig. 3 Temperature dependence of the thermal conductivity of 1, 2-dimethoxyethane at different pressures: ○ 0.1 MPa, △ 5 MPa, ▽ 10 MPa, ◇ 20 MPa, □ 30 MPa

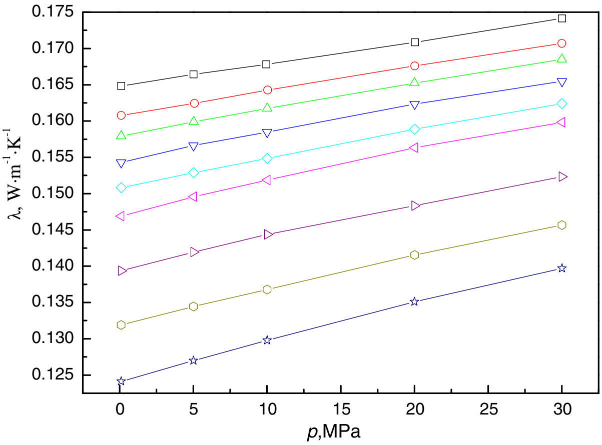

Fig. 4 Pressure dependence of the thermal conductivity of 1, 2-dimethoxyethane at different temperatures: □ 243 K, ○ 253 K, △ 263 K, ▽ 273 K, ◇ 283 K, ◁ 293 K, ▷ 313 K, ○ 333 K ☆ 353 K

Table 3 Coefficients $a_{ij}/\text{W} \cdot \text{m}^{-1} \cdot \text{K}^{-(i+1)} \cdot \text{MPa}^{-j}$ employed in Eq. 2

	$j = 0$		$j = 1$		$j = 2$		$j = 3$	
	Value	Uncertainty	Value	Uncertainty	Value	Uncertainty	Value	Uncertainty
$i = 0$	8.40692×10^{-2}	4.1×10^{-6}	2.22542×10^{-3}	4.8×10^{-5}	-1.65916×10^{-3}	4.9×10^{-4}	4.93168×10^{-5}	1.7×10^{-5}
$i = 1$	1.32607×10^{-3}	2.3×10^{-5}	-3.18760×10^{-5}	8.0×10^{-6}	1.72313×10^{-5}	5.0×10^{-6}	-5.04521×10^{-7}	1.8×10^{-7}
$i = 2$	-5.50348×10^{-6}	1.5×10^{-7}	1.47050×10^{-7}	5.3×10^{-8}	-5.92828×10^{-8}	1.7×10^{-8}	1.71014×10^{-9}	5.9×10^{-10}
$i = 3$	5.87920×10^{-9}	2.5×10^{-10}	-1.99076×10^{-10}	8.6×10^{-11}	6.74214×10^{-11}	1.9×10^{-11}	-1.91951×10^{-12}	6.6×10^{-13}

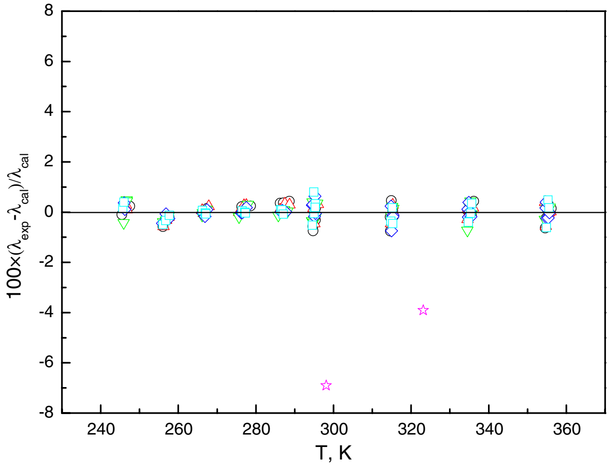

Fig. 5 Relative deviations of calculated values by Eq. 2 from experimental data for pure 1, 2-dimethoxy-ethane: ◯ 0.1 MPa, △ 5 MPa, ▽ 10 MPa, ◇ 20 MPa, □ 30 MPa, ☆ Burgdorf et al. [6]

The experimental results of liquid 1, 2-dimethoxyethane were correlated by a polynomial as a function of temperature and pressure:

$$\lambda/\mathrm{W}\cdot\mathrm{m}^{-1}\cdot\mathrm{K}^{-1}=\sum_{i=0}^{3}\sum_{j=0}^{3}a_{ij}(T/\mathrm{K})^{i}(P/\mathrm{MPa})^{j} \quad (2)$$

The coefficients in Eq. 2 for 1, 2-dimethoxyethane are listed in Table 3. The correlation of Eq. 2 is suitable only for interpolation and cannot be used for extrapolation or prediction. The correlation can represent the experimental data for liquid 1, 2-dimethoxyethane with an average absolute deviation of 0.24 % and an absolute maximum deviation of 0.80 % as shown in Fig. 5. Two data points reported by Burgdorf et al. [6] were also compared and shown in Fig. 5. The deviations were 6.91 % and 3.91 %.

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References

1. C. Bertoli, N.D. Giacomo, C. Beatrice, SAE Trans. **106**, 1557 (1997)
2. X.L. Cao, J.P. Zhu, Chemosphere **45**, 911 (2001)
3. K. Zhang, J.T. Wu, Z.G. Liu, J. Chem. Eng. Data **51**, 1743 (2006)
4. J. Pan, J.T. Wu, Z.G. Liu, J. Chem. Eng. Data **51**, 186 (2006)
5. P.J. Zheng, X.Y. Meng, J.T. Wu, Z.G. Liu, Int. J. Thermophys. **29**, 1244 (2008)
6. R. Burgdorf, A. Zocholl, W. Arlt, H. Knapp, Fluid Phase Equilib. **164**, 225 (1999)
7. M.J. Assael, E. Charitidou, G.P. Georgiadis, W.A. Wakeham, Ber. Bunsenges. Phys. Chem. **9**, 813 (1988)
8. Y.G Wang, J.T. Wu, Z.G. Liu, J. Chem. Eng. Data **51**, 164 (2006)
9. M.L.V. Ramires, C.A. Nieto de Casto, R.A. Perkins, Y. Nagasaka, M.J. Assael, W.A. Wakeham, J. Phys. Chem. Ref. Data **29**, 133 (2000)