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Measurements of the Viscosity of Toluene + Mesitylene Mixtures at Pressures Up to 55 MPa

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New absolute measurements of the viscosity of mesitylene and binary mixtures of toluene + mesitylene are presented. The measurements were performed in a vibrating-wire instrument and cover a temperature range of 295–330 K and pressures up to 55 MPa. The concentrations studied were 40 and 70%, by weight, of toluene. The overall uncertainty in the reported data is estimated to be ±0.5%. A recently extended semiempirical scheme for the prediction of the viscosity of mixtures from the pure components is used to predict successfully the viscosity of these mixtures, as a function of composition, temperature, and pressure.

KEY WORDS: high pressure; mesitylene; mixtures; toluene; viscosity.

1. INTRODUCTION

In a series of recent papers, a semiempirical scheme based on considerations of the hard-sphere theory of transport properties has been applied for the correlation and prediction of the liquid-phase transport properties of simple molecular fluids [1], *n*-alkanes [2, 3], *n*-alkane mixtures [4], and aromatic hydrocarbons [5]. For the pure liquids it has been shown that the thermal conductivity, viscosity, and diffusion coefficients can, simultaneously, be successfully correlated over a temperature range of 100–400 K and pressures up to 600 MPa, with an uncertainty of ±6%. In the case of *n*-alkane mixtures it has further been demonstrated that, by adopting a simple mixing rule, the thermal conductivity and viscosity can

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successfully be predicted from the pure components, over the same temperature and pressure range, with an uncertainty of ±6%. The new measurements of the viscosity of toluene + mesitylene mixtures presented in this paper can be used as a test of the extension of the aforementioned scheme to aromatic hydrocarbon mixtures.

In this paper, new absolute measurements of the viscosity of pure mesitylene and toluene + mesitylene mixtures are presented. At atmospheric pressure, the measurements cover a temperature range of 295–330 K, while at 298.15 and 313.15 K the measurements extend up to 55 MPa. The choice of the two temperatures along which pressure measurements were per formed was dictated by the availability of density measurements. For the mixtures, two concentrations were studied, 40 and 70% by weight, of toluene.

2. EXPERIMENTAL

The viscosity measurements were performed with the high-pressure vibrating-wire instrument described in detail elsewhere [6–8]. The viscosity of toluene was measured before and after each liquid to assure the continuing good operation of the instrument. The overall uncertainty of the measurements is estimated to be ±0.5%, an estimate confirmed by the measurements of the viscosity of toluene [6]. The sample of toluene was supplied by Merck at 99.5% nominal purity, while the sample of mesitylene was supplied by BDH Chemicals Ltd. at 99.0% nominal purity.

The density data used for the measurements of toluene were obtained by Kashiwagi et al. [9]. In the case of the atmospheric-pressure measurements of mesitylene, the density values used were obtained from the measurements of Dymond and Robertson [10] and Easteal and Woolf

Table I. Viscosity of Mesitylene as a Function of Temperature at Atmospheric Pressure

Temperature T (K)	Viscosity μ (μPa·s)
295.010	686.1
298.376	659.5
302.822	622.7
307.784	587.9
312.695	556.1
317.529	526.9
322.262	501.7
327.227	476.6

Table II. Viscosity of Toluene + Mesitylene as a Function of Temperature at Atmospheric Pressure (Concentrations as Weight Percentage of Toluene)

40%			70%		
Temp. T (K)	Density ρ $(\mathrm{kg \cdot m^{-3}})$	Viscosity μ $(\mu\mathrm{Pa \cdot s})$	Temp. T (K)	Density ρ $(\mathrm{kg \cdot m^{-3}})$	Viscosity μ $(\mu\mathrm{Pa \cdot s})$
298.148	861.6	595.7	298.239	862.0	570.9
303.164	857.2	561.6	303.179	857.5	539.4
308.224	852.7	531.5	307.818	853.2	512.5
313.140	848.3	505.0	313.259	848.3	483.7
318.087	844.0	479.2	317.666	844.2	461.9
322.735	839.8	458.3	322.656	839.7	438.9

Table III. Viscosity of Mesitylene as a Function of Pressure

Pressure P (MPa)	Temp. T (K)	Density $\rho(T, P)$ $(\mathrm{kg \cdot m^{-3}})$	Viscosity $\mu(T, P)$ $(\mu\mathrm{Pa \cdot s})$	Density $\rho(T_{\mathrm{nom}}, P)$ $(\mathrm{kg \cdot m^{-3}})$	Viscosity $\mu(T_{\mathrm{nom}}, P)$ $(\mu\mathrm{Pa \cdot s})$
		$T_{\mathrm{nom}} = 298.15$ K			
0.10	298.376	860.7	659.5	860.9	661.1
5.37	298.370	864.7	688.1	864.8	689.7
10.54	298.370	867.9	718.9	868.1	720.6
15.60	298.327	871.1	747.3	871.2	748.8
20.67	298.364	874.1	779.3	874.3	781.1
31.01	298.315	880.2	845.4	880.3	847.0
36.58	298.298	883.4	880.3	883.5	881.7
42.66	298.263	886.8	918.9	886.8	920.1
46.51	298.254	888.8	945.5	888.9	946.6
51.57	298.333	891.5	980.4	891.6	982.4
		$T_{\mathrm{nom}} = 313.15$ K			
0.10	312.695	848.7	556.1	848.3	553.0
6.38	312.562	853.9	585.2	853.4	580.8
11.45	312.573	857.3	609.5	856.9	605.0
16.52	312.969	860.4	630.2	860.3	628.8
21.68	312.975	863.7	656.7	863.6	655.2
26.95	312.960	867.1	682.2	867.0	680.5
36.78	312.942	873.1	732.8	873.0	730.8
41.75	312.963	876.0	759.9	875.9	758.0
46.71	312.997	878.8	786.6	878.7	785.0

[11]. Both sets of measurements, performed with a quoted accuracy of better than ±0.1%, were in full agreement with each other. At high pressures the only available density measurements were those performed by Easteal and Woolf [11] at 298.15 and 313.15 K, with a quoted accuracy of better than ±0.1%. Thus, the present high-pressure viscosity measurements were restricted to these two temperatures. The density of the mixtures was calculated from the density of the pure components assuming no change of volume during mixing. The two mixtures studied, 40 and 70%, by weight, of toluene, were prepared gravimetrically and the uncertainty in their composition was less than 0.005%.

3. RESULTS

Tables I and II present the atmospheric-pressure viscosity measurements of mesitylene and the two binary mixtures of toluene + mesitylene as

Table IV. Viscosity of Toluene + Mesitylene as a Function of Pressure (40%, by Weight, of Toluene)

Pressure P (MPa)	Temp. T (K)	Density $\rho(T, P)$ $(\mathrm{kg \cdot m^{-3}})$	Viscosity $\mu(T, P)$ $(\mu\mathrm{Pa \cdot s})$	Density $\rho(T_{\mathrm{nom}}, P)$ $(\mathrm{kg \cdot m^{-3}})$	Viscosity $\mu(T_{\mathrm{nom}}, P)$ $(\mu\mathrm{Pa \cdot s})$
		$T_{\mathrm{nom}} = 298.15$ K			
0.10	298.148	861.6	595.7	861.6	595.7
5.37	298.177	865.5	621.5	865.5	621.7
10.54	298.184	869.0	646.1	869.0	646.3
15.81	298.190	872.5	671.7	872.5	672.0
20.67	298.184	875.6	697.5	875.6	697.7
25.74	298.177	878.8	723.0	878.8	723.2
30.70	298.168	881.8	748.7	881.8	748.9
36.17	298.168	885.0	779.0	885.0	779.2
41.14	298.165	887.9	806.5	887.9	806.6
45.70	298.214	890.4	832.0	890.4	832.6
50.87	298.037	893.4	860.2	893.3	859.2
		$T_{\mathrm{nom}} = 313.15$ K			
0.10	313.140	848.3	505.0	848.3	504.9
5.78	313.241	853.0	528.5	853.1	529.1
11.04	313.232	856.9	548.8	857.0	549.3
15.81	313.226	860.3	569.5	860.3	570.0
21.08	313.247	863.9	592.4	864.0	593.1
26.14	313.232	867.3	614.4	867.4	615.0
31.01	313.238	870.5	636.8	870.5	637.5
36.07	313.226	873.7	659.2	873.7	659.8
41.44	313.204	877.0	683.0	877.0	683.5
44.89	313.146	879.2	698.1	879.2	698.0

Table V. Viscosity of Toluene + Mesitylene as a Function of Pressure (70%, by Weight, of Toluene)

Pressure P (MPa)	Temp. T (K)	Density $\rho(T, P)$ $(\text{kg}\cdot\text{m}^{-3})$	Viscosity $\mu(T, P)$ $(\mu\text{Pa}\cdot\text{s})$	Density $\rho(T_{\text{nom}}, P)$ $(\text{kg}\cdot\text{m}^{-3})$	Viscosity $\mu(T_{\text{nom}}, P)$ $(\mu\text{Pa}\cdot\text{s})$
		$T_{\text{nom}} = 298.15$ K			
0.10	298.239	862.0	570.9	862.0	571.4
5.57	298.260	866.1	595.4	866.2	596.0
10.54	298.248	869.8	619.3	869.8	619.9
15.81	298.248	873.3	643.8	873.4	644.4
20.87	298.260	876.7	668.4	876.8	669.1
25.94	298.272	879.9	692.4	880.0	693.2
31.01	298.257	883.1	716.8	883.2	717.6
36.38	298.257	886.4	744.2	886.5	745.0
41.14	298.278	889.2	769.1	889.3	770.1
45.50	298.303	891.7	791.2	891.8	792.4
		$T_{\text{nom}} = 313.15$ K			
0.10	313.259	848.3	483.7	848.4	484.4
5.88	313.250	853.2	505.9	853.2	506.5
10.84	313.256	857.0	525.7	857.1	526.3
15.81	313.229	860.7	545.5	860.8	546.0
20.97	313.244	864.4	566.9	864.5	567.6
26.04	313.244	867.9	588.1	868.0	588.7
31.01	313.241	871.3	607.5	871.3	608.2
36.17	313.238	874.6	629.6	874.7	630.3
41.54	313.238	878.0	652.4	878.1	653.1
46.20	313.262	880.9	672.7	881.0	673.6
51.47	313.308	884.0	694.0	884.1	695.4

a function of temperature. The high-pressure measurements of mesitylene and the two binary mixtures are presented in Tables III, IV, and V. In these tables, the viscosity adjusted to the nominal temperatures of 298.15 and 313.15 K, respectively, by means of a linear correction, is also provided. Since this correction is very small, however, less than 0.3%, the uncertainty introduced with this assumption is negligible.

Table VI. Coefficients in Eq. (1) (Concentrations as Weight Percentage of Toluene)

Conc. (%)	A $(\mu\text{Pa}\cdot\text{s})$	B (K)	σ (%)
0	16.78 ± 0.20	1094.7 ± 3.7	± 0.12
40	19.05 ± 0.28	1026.1 ± 4.5	± 0.09
70	17.83 ± 0.11	1033.9 ± 1.9	± 0.03
100	16.09 ± 0.04	1055.4 ± 0.7	± 0.08

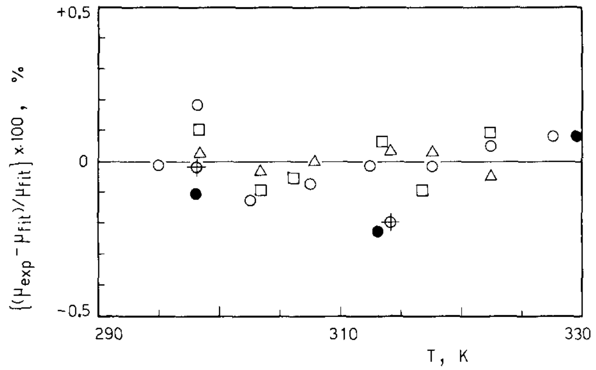

Fig. 1. Percentage deviations of the atmospheric-pressure viscosity measurements, from Eq. (1). Present measurements: (○) mesitylene; (□) 40%, by weight, toluene; (△) 70%, by weight, toluene. Other mesitylene measurements: (●) Ref. 10; (⊕) Ref. 13.

The atmospheric-pressure measurements of pure mesitylene and both mixtures have been correlated, for the purpose of interpolation only, by an equation of the form

$$\mu = Ae^{B/T} \tag{1}$$

The values of the constants are shown in Table VI. In the same table, the standard deviation of each fit is shown. It can be seen that the maximum standard deviation is ±0.12%. Also shown for comparison purposes are the constants for our previous measurements of the viscosity of toluene [12]. In Fig. 1, the deviations of the present atmospheric-pressure

Table VII. Coefficients in Eq. (2) (Concentrations as Weight Percentage of Toluene)

Temp. (K)	Conc. (%)	μ_0 (μPa·s)	E (–)	D (MPa)	σ (%)
298.15	0	661.10	2.281	271.7	±0.11
	40	595.72	1.929	241.8	±0.09
	70	571.38	1.769	223.6	±0.06
313.15	0	553.00	2.522	312.8	±0.07
	40	504.94	1.490	183.6	±0.11
	70	484.37	1.474	184.3	±0.07

measurements from those correlated by Eq. (1) are shown. It can be seen that the maximum deviation is less than ±0.2%. In the same figure measurements of two other investigative groups are also shown. The mesitylene measurements of Dymond and Robertson [10], performed in a calibrated suspended-level viscometer with a quoted accuracy of ±0.5%, and those of Nissema and Kokkonen [13] both show a maximum deviation of ±0.25% from Eq. (1), which is well within the mutual uncertainty of the instruments.

The high-pressure viscosity measurements of pure mesitylene and both mixtures have been correlated with pressure along each isotherm, for the purpose of interpolation only, by a Tait-like equation as

$$\ln\left[\frac{\mu}{\mu_0}\right] = E \ln\left[\frac{D+P}{D+0.1}\right] \tag{2}$$

where μ_0 represents the experimental viscosity at atmospheric pressure. The values of the constants for each isotherm for all systems are shown in Table VII. In the same table, the standard deviation of each fit is shown. It can be seen that the maximum standard deviation is ±0.11%. In Fig. 2 the deviations of the present high-pressure measurements of the viscosity from those correlated by Eq. (2) are presented. It can be seen that the maximum deviation is less than ±0.2%. To our knowledge, no other high-pressure viscosity measurements of mesitylene or of toluene + mesitylene mixtures exist.

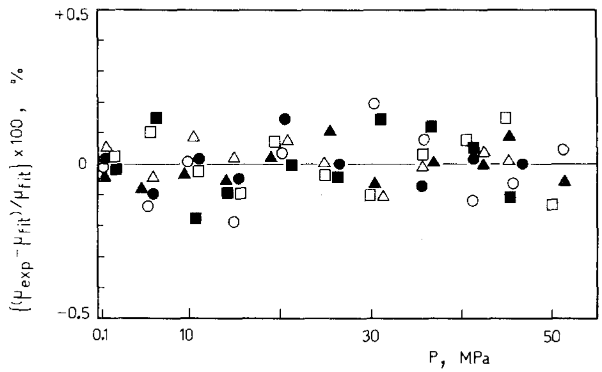

Fig. 2. Percentage deviations of the present high-pressure viscosity measurements, from Eq. (2). Mesitylene: (○) 298.15 K; (●) 313.15 K. 40%, by weight, toluene: (□) 298.15 K; (■) 313.15 K. 70%, by weight, toluene: (△) 298.15 K; (▲) 313.15 K.

4. DISCUSSION

4.1. The Pure Liquids

Whereas the correlations of Eqs. (1) and (2) are suitable for interpolation, they have little or no value for extrapolation and prediction. For such purposes it has been shown [1–5] that a correlation in terms of the molar volume, V, is much more suitable. In the specific case of the viscosity, this scheme, described in detail elsewhere [1], suggests that the dimensionless viscosity, μ^*, defined by the equation

$$\mu^* = 6.035 \times 10^8 \left[\frac{1}{MRT}\right]^{1/2} \mu V^{2/3} \tag{3}$$

is a function of the reduced molar volume $V_r = (V/V_0)$ and the factor R_μ only, where V_0 is a characteristic molar volume of the fluid which is but weakly temperature dependent, while R_μ accounts for deviations from the behavior of smooth hard spheres. In the above equations M represents the molar mass, R the universal gas constant, and T the absolute temperature. According to this scheme, the function obtained was [1]

$$\begin{aligned}\log \frac{\mu^*}{R_\mu} = {} & 1.0945 - 9.2632 V_r^{-1} + 71.0385 V_r^{-2} - 301.9012 V_r^{-3} + 797.6900 V_r^{-4} \\ & - 1221.9770 V_r^{-5} + 987.5574 V_r^{-6} - 319.4636 V_r^{-7}\end{aligned} \tag{4}$$

In the case of the pure aromatic hydrocarbons, the characteristic molar volume, V_0 (in $m^3 \cdot mol^{-1}$), was calculated [5] as a function of the carbon atoms, C, and the absolute temperature, T, as

$$\begin{aligned}10^6 V_0 = {} & -3324.7 C^{-2} + 529.47 C^{-1} + 12.163 C \\ & + T[9.48786 C^{-2} - 8.55176 \times 10^{-2} C + 6.03463 \times 10^{-3} C^2] \\ & + T^2[-1.5797 \times 10^{-3} + 3.9901 \times 10^{-4} C - 2.2309 \times 10^{-5} C^2]\end{aligned} \tag{5}$$

while R_μ was calculated to be 1.0 and 0.9 for toluene and mesitylene, respectively. This scheme, Eqs. (3)–(5), was found to correlate the viscosity of the pure aromatic hydrocarbons in the temperature range 280–400 K and pressures up to 600 MPa, with an uncertainty of ±6% [5].

4.2. The Mixtures

In a recent paper [4] the following procedure was successfully adopted to correlate the viscosity and the thermal conductivity of *n*-alkane

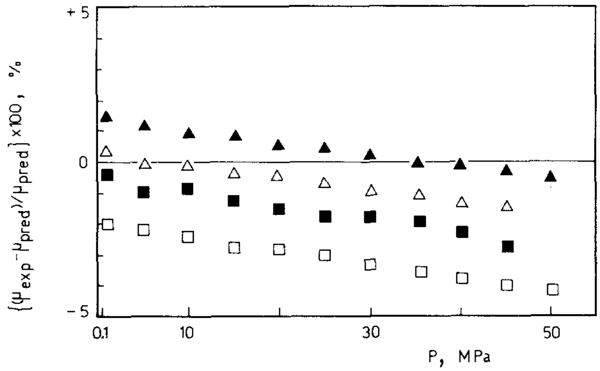

Fig. 3. Percentage deviations of the present mixture viscosity measurements, from the values predicted by the scheme of Eqs. (3)–(6). 40%, by weight, toluene: (□) 298.15 K; (■) 313.15 K. 70%, by weight, toluene: (△) 298.15 K; (▲) 313.15 K.

mixtures from the pure components. It was postulated that the mixture behaves as a single-component liquid with molecular parameters given by the mole fraction average of the values for the individual components. Thus

$$V_{0,\mathrm{mix}} = \sum x_i V_{0,i} \qquad \text{and} \qquad R_{\mu,\mathrm{mix}} = \sum x_i R_{\mu,i} \tag{6}$$

This simple mixing rule was found [4] to predict successfully the viscosity (and the thermal conductivity) of binary, ternary, and quaternary *n*-alkane mixtures in the temperature range 280–400 K and up to 600-MPa pressure, with an uncertainty of ±6%.

The present viscosity measurements can be used to test the applicability of this scheme to aromatic hydrocarbon mixtures. In Fig. 3, the deviations of the present measurements from those predicted by the scheme of Eqs. (3)–(6) are presented. It can be seen that, for the pressure range examined, the maximum deviation is less than ±5%. Thus, the predictive power of this scheme is demonstrated.

5. CONCLUSION

New measurements of the viscosity of mesitylene and of two binary mixtures of toluene + mesitylene have been presented. The measurements were performed in a vibrating-wire instrument; at atmospheric pressure they cover a temperature range of 295–330 K, while at 298.15 and 313.15 K they extend up to 55-MPa pressure. The overall uncertainty in the reported data is estimated to be ±0.5%.

A recently extended semiempirical scheme for the prediction of the viscosity of mixtures from the pure components is used to predict successfully the viscosity of these mixtures, as a function of composition, temperature, and pressure, with an uncertainty of better than ±5%.

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