International Journal of Thermophysics, Vol. 8, No. 6, 1987

Viscosity of Liquid Toluene in the Temperature Range 25–75°C

F. A. Gonçalves,[1,2] K. Hamano,[1,3] J. V. Sengers,[1] and J. Kestin[1,4]

Received April 8, 1987

New accurate experimental data are presented for the viscosity of liquid toluene. The viscosity was measured relative to the viscosity of liquid water with the aid of an Ubbelohde capillary viscometer. The data cover a temperature range from approximately 25 to 75°C and are represented with high precision by an Arrhenius equation.

KEY WORDS: Arrhenius equation; capillary-flow viscometry; toluene; Ubbelohde viscometer; viscosity.

1. INTRODUCTION

In this paper we present new accurate experimental data for the viscosity of liquid toluene. Our investigation of the viscosity of liquid toluene was motivated by the following two considerations. First, we are in the process of measuring in our laboratory the viscosity of several liquid compounds of relevance to synfuel research. Toluene is a coal-derived liquid which is frequently used as a solvent. Second, toluene is often used as a calibration fluid for the measurement of the thermal conductivity of liquids [1, 2]. Therefore, in the deliberations of the Subcommittee of IUPAC Commission I.2 on the Transport Properties of Fluids, the question has arisen whether toluence would also be a suitable reference liquid for viscosity

---

[1] Institute for Physical Science and Technology, University of Maryland, College Park, Maryland 20742, U.S.A.

[2] Permanent address: Laboratório de Química, Academia Militar, Paço da Rainha, 1100 Lisboa, Portugal.

[3] Permanent address: Department of Polymer Science, Faculty of Technology, Gunma University, Kiryu, Japan.

[4] Division of Engineering, Brown University, Providence, Rhode Island 02912, U.S.A.

measurements. Accordingly, an attempt is being made to measure the viscosity of liquid toluence accurately with a number of different techniques in various laboratories.

The present paper presents the results of our study of the viscosity of liquid toluene with a capillary-flow method. Measurement of the viscosity of a reference fluid with a capillary-flow method is important, since capillary viscometers are most frequently used for measuring the viscosity of nonvolatile liquids at atmospheric pressure. Measurements of the viscosity of liquid toluene with an oscillating-disk viscometer are currently in progress [3].

2. EXPERIMENTAL METHOD

The viscosities reported in this paper were measured with a suspended level capillary viscometer of the type originally introduced by Ubbelohde [4]. It is schematically shown in Fig. 1. We prefer Ubbelohde viscometers to capillary viscometers of the Ostwald type, since the former do not

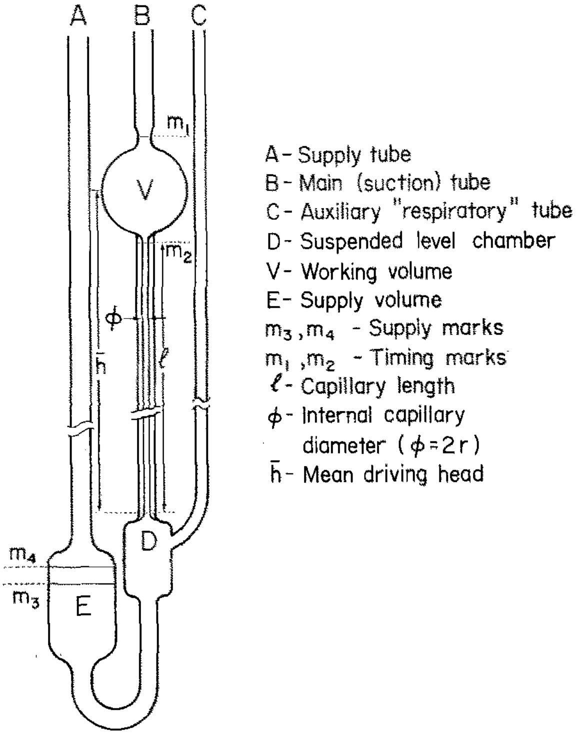

Fig. 1. Schematic representation of the Ubbelohde viscometer.

require filling with a definite volume of the liquid, which is particularly advantageous when the viscosity is measured as a function of temperature. The viscometer used for this project was taken from a set of Ubbelohde viscometers constructed and tested by one of the authors some time ago [5]. Specifically, we selected the viscometer designated Ub 1 in the previous work, because it was shown to exhibit reasonably small surface-tension and edge effects [5, 6]. The characteristic dimensions of this instrument are presented in Table I. The viscometer was located in a water bath whose temperature was controlled to within 0.01°C.

The principles and operation of Ubbelohde viscometers have been described by various authors [7–9]. Initially, the viscometer is filled so that the meniscus is located between the supply marks m_3 and m_4 in the supply bulb E. The auxiliary tube C is closed and suction is applied till the liquid meniscus is well above the mark m_1. The auxiliary tube is then opened again, the liquid falls into the chamber D, and the time t is measured for the meniscus to pass from mark m_1 to mark m_2. This flow time was measured with an electronic stopwatch; at each temperature the time could be measured with a reproducibility of about 0.05%.

To determine the viscosity we adopted the usual working equation [7–9]

$$\nu = \eta/\rho = Ct - B/t \tag{1}$$

where ν is the kinematic viscosity, η the dynamic viscosity, and ρ the density. The instrument constants C and B were determined by calibrating the viscometer with doubly distilled water at temperatures between 24 and 60°C which correspond to flow times between 800 and 1520 s. For this purpose we represented the viscosity of η of water by the IAPS Formulation 1985 for the Viscosity of Ordinary Water Substance [10] with the densities ρ calculated from the IAPS Formulation 1984 for the Thermodynamic Properties of Ordinary Water Substance for Scientific and General Use [11]. These equations are the same as those earlier recommended by Kestin et al. for fluid H_2O [12]. A least-squares analysis of the calibration data yielded

$$C = (5.9506 \pm 0.0010) \times 10^{-4}\ \mathrm{mm}^2 \cdot \mathrm{s}^{-2}, \qquad B = (0.11 \pm 0.10)\ \mathrm{mm}^2 \tag{2}$$

Table I. Characteristic Dimensions of the Capillary Viscometer

Capillary radius	$r = 0.020$ cm
Capillary length	$l = 44.2$ cm
Mean driving head	$\bar{h} = 47.0$ cm
Upper bulb volume	$V = 11.3$ cm^3

The working Eq. (1) with the coefficients given above reproduces the calibration data with a standard deviation of 0.025%. The correction term B/t in the working equation turns out to be hardly significant; it contributes less than 0.04% in the entire range of flow times encountered in the experiments.

3. EXPERIMENTAL RESULTS

The measurements were performed with high-performance liquid chromatographic (HPLC)-grade toluene supplied by Aldrich Chemical and having a stated purity of 99.9+%. The viscosity was measured at temperatures from 24.5 to 76.6°C. The measurements at 76.6°C, involving a flow time of about 680 s, required a slight extrapolation of the working Eq. (1) to flow times less then 800 s.

The measurements yield the kinematic viscosity ν. To convert the experimental results into values for the dynamic viscosity η we used an equation for the density of liquid toluene proposed by Kashiwagi et al. [13]:

$$\rho = 1103.06 - 0.68074\,T - 0.4229 \times 10^{-3}\,T^{-2} \qquad (3)$$

with ρ in $\text{kg} \cdot \text{m}^{-3}$ and T in K. The experimental results are presented in Table II. The values quoted for the kinematic viscosity ν at each temperature are averages obtained from three independent determinations.

The values obtained for the viscosity of toluene relative to that of water have an estimated accuracy of 0.1%. The representative equation employed for the calibration reproduces the experimental viscosity data of water to well within 0.2% [14]. We expect, therefore, that our viscosity data for toluene have an absolute accuracy ob about 0.3%.

Table II. Kinematic Viscosity ν and Dynamic Viscosity η of Liquid Toluene

Temperature (°C)	ν ($\text{mm}^2 \cdot \text{s}^{-1}$)	η ($\mu\text{Pa} \cdot \text{s}$)
24.523	0.6466	558.0
29.097	0.6155	528.5
41.162	0.5454	462.1
48.684	0.5087	427.4
59.336	0.4636	384.8
76.638	0.4045	328.9

In the limited temperature range of our experiments the viscosity of toluene can be represented by an Arrhenius equation

$$\eta = A\exp(E/T) \tag{4a}$$

with

$$A = (16.09 \pm 0.04)\ \mu\mathrm{Pa\cdot s}, \qquad E = (1055.4 \pm 0.7)\ \mathrm{K} \tag{4b}$$

This equation reproduces the data with a standard deviation of 0.045%.

4. COMPARISON WITH LITERATURE DATA

Values for the viscosity of toluene have been reported by a number of authors [15–25]. A comparison between the values found in the literature and our experimental results as represented by Eq. (4) is shown in Fig. 2. The values most recently reported by Dymond and Robertson in this journal [25] agree with our results within the stated accuracy of 0.5%. The values reported by Teja and Rice [20] and by Kashiwagi and Makita [22]

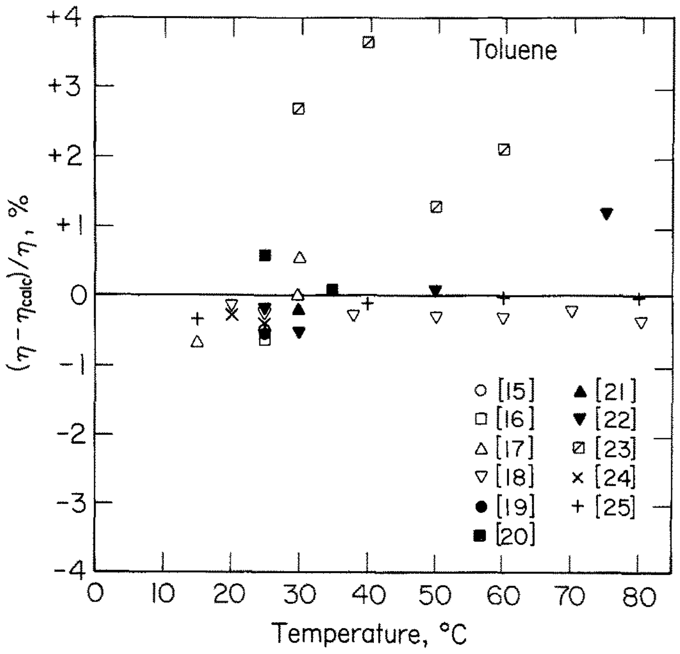

Fig. 2. Comparison between experimental viscosity data from the literature and our experimental results as represented by Eq. (4).

also agree with our results within the state accuracy of 1 and 2%, respectively; the accuracy of these data, however, is insufficient to determined the temperature dependence of the viscosity accurately. The data of Singh and Sinka [23] appear to have errors substantially larger than 1%. Most other data agree with our results to within about 0.5%.

Of particular interest is the value of the viscosity of toluene at 25°C. A careful measurement of the kinematic viscosity relative to that of water was recently reported by Bauer and Meerlender [24] with a stated accuracy of 0.3 to 0.4%. They used Ubbelohde viscometers with trumpet-shaped capillary exits, and consequently, their measurements had to be corrected for estimated surface-tension effects. Bauer and Meerlender [24] found a value $\nu = 0.6404\ \mathrm{mm^2 \cdot s^{-1}}$ for toluence at 25°C, which differs from our value $\nu = 0.6432\ \mathrm{mm^2 \cdot s^{-1}}$ by 0.45%. This difference is within the combined accuracy of the two experiments but slightly larger than the estimated accuracy of the separate experiments.

ACKNOWLEDGMENTS

The authors are indebted to A. H. Krall, D. Stewart, and J. W. Trembly for valuable technical assistance. The authors also acknowledge several discussions with E. A. Kearsley and L. J. Zapas of the National Bureau of Standards concerning capillary-flow viscometry. The research was supported by the Pittsburgh Energy Technology Center of the U.S. Department of Energy under Grant DE-FG22-85PC80505 and was pursued in consultation with the Subcommittee of IUPAC Commission I.2 on the Transport Properties of Fluids. Travel support for this project was provided by NATO Research Grant 259/81.

REFERENCES

1. C. A. Nieto de Castro, S. F. Y. Li, A. Nagashima, R. D. Trengrove, and W. A. Wakeham, *J. Phys. Chem. Ref. Data.* **15**:1073 (1986).
2. V. M. Shulga, F. G. Eldarov, Yu. A. Atanov, and A. A. Kuyumchev, *Int. J. Thermophys.* **7**:1147 (1986).
3. A. H.. Krall, J. V. Sengers, and J. Kestin, to be published.
4. L. Ubbelohde, *Ind. Eng. Chem. Anal. Ed.* **9**:85 (1937).
5. F. A. Gonçalves, *Problems in the Viscometry of Liquids*, Ph.D. thesis (Classical University of Lisbon, Lisbon, 1977).
6. F. A. Gonçalves, J. Kestin and J. V. Sengers, to be published.
7. J. F. Swindells, R. Ullman, and H. Mark, in *Techniques of Organic Chemistry, Vol. I, part 1*, A. Weissberger, ed. (Interscience, New York, 1949), p. 609.
8. R. C. Hardy, *NBS Viscometer Calibrating Liquids and Capillary Tube Viscometers*, NBS Monograph 55 (U.S. Government Printing Office, Washington, D.C., 1962).

9. J. R. Van Wazer, J. W. Lyong, K. Y. Kim, and R. E. Colwell, *Viscosity and Flow Measurement* (Wiley, New York, 1963).
10. J. V. Sengers and J. T. R. Watson, *J. Phys. Chem. Ref. Data* **15**:1291 (1986).
11. J. Kestin and J. V. Sengers, *J. Phys. Chem. Ref. Data* **15**:305 (1986).
12. J. Kestin, J. V. Sengers, B. Kamgar-Parsi, and J. M. H. Levelt Sengers, *J. Phys. Chem. Ref. Data* **13**:175 (1984).
13. H. Kashiwagi, T. Hashimoto, Y. Tanaka, H. Kubota, and T. Makita, *Int. J. Thermophys.* **3**:201 (1982).
14. J. T. R. Watson, R. S. Basu, and J. V. Sengers, *J. Phys. Chem. Ref. Data* **9**:1255 (1980).
15. J. Kendall and K. P. Monroe, *J. Am. Chem. Soc.* **39**:1787 (1917).
16. J. R. Lewis, *J. Am. Chem. Soc.* **47**:626 (1925).
17. J. Timmermans, *Physico-Chemical Constants of Pure Organic Compounds* (Elsevier, Amsterdam, 1950), Vol. I, p. 152.
18. L. W. Hammond, K. S. Howard, and R. A. McAllister, *J. Phys. Chem.* **62**:637 (1958).
19. A. Riddick and W. B. Bunger, *Organic Solvents* (Wiley, New York, 1970), Vol. 2.
20. A. S. Teja and P. Rice, *Chem. Eng. Sci.* **36**:7 (1981).
21. J. Nath and B. Narain, *J. Chem. Eng. Data* **27**:283 (1982).
22. H. Kashiwagi and T. Makita, *Int. J. Thermophys.* **3**:289 (1982).
23. R. Singh and C. P. Sinka, *J. Chem. Eng. Data* **29**:132 (1984).
24. H. Bauer and G. Meerlender, *Rheol. Acta* **23**:514 (1984).
25. J. H. Dymond and J. Robertson, *Int. J. Thermophys.* **6**:21 (1985).