

Viscosity Measurements of Molten LiCl in the Temperature Range 886–1275 K

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The viscosity of molten lithium chloride has been measured with an oscillating-cup viscometer in the temperature range from 886 to 1275 K along the saturation line. Lithium chloride has been proposed as a heat-transfer fluid for high-temperature applications. Previously reported viscosity data for lithium chloride show sizable discrepancies. The accuracy of the present measurements is estimated as $\pm 2.0\%$.

KEY WORDS: lithium chloride; molten salt; oscillating-cup viscometer; viscosity.

1. INTRODUCTION

Among various high-temperature melts proposed for industrial applications, lithium chloride has potential for use as an electrolyte for high-temperature fuel cells and thermal energy storage material. The merits of using molten salts for these applications are several. The electrical conductivity of molten salts is about one order greater than that of aqueous solutions. Because of higher working temperatures, a molten-salt fuel cell can attain higher voltage and electric current. Lithium chloride is, moreover, proposed as a thermal-energy storage material because of its large heat capacity and heat of fusion. One drawback of lithium chloride is that its melting temperature (610°C) is relatively high. Especially for a heat-storage material or a heat-transfer medium, an accurate knowledge on the thermo-physical properties at high temperatures is essential. However, little reliable information on high-temperature melts is presently available. There

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are sizable discrepancies among the viscosity values of lithium chloride reported in the literature. In previous reports [1, 2], the present authors reported measurements of the viscosity of two alkali chlorides, namely, sodium chloride and potassium chloride. The present paper describes measurements of the viscosity of molten lithium chloride obtained with an oscillating-cup viscometer in the temperature range 886–1275 K along the saturation line.

2. EXPERIMENTAL

The principle, the working theory, and the experimental details of the oscillating-cup viscometer used in the present study have been described in previous publications [1–3]. As shown in Fig. 1, a hollow cylindrical cup

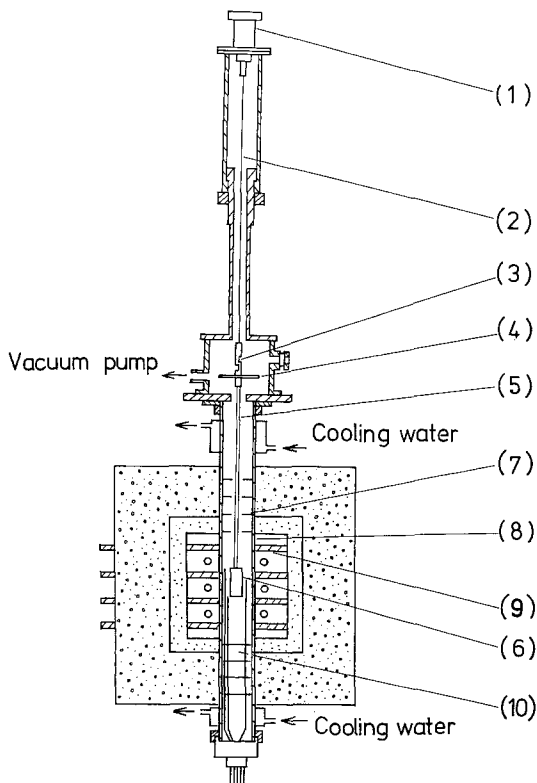


Fig. 1. High-temperature oscillating-cup viscometer. 1, Oscillation initiator; 2, Pt-W suspension wire; 3, mirror; 4, inertial disk; 5, connecting rod; 6, cylindrical cup; 7, molybdenum radiation shields; 8, SUS pipe; 9, SiC heating elements; 10, thermocouples.

containing the liquid specimen is suspended in vacuum by a thin wire. Once a torsional oscillation of the suspension system is started, this oscillation is gradually damped by the viscous resistance of the specimen exerted on the inner wall of the cylindrical cup. The viscosity of the liquid is then determined from the period and the logarithmic decrement of this damping oscillation. The experimental apparatus consists of four subsystems: a suspension system, an optical measurement system, a heating system, and a vacuum system. In the present study, the cylindrical cup is suspended by a thin wire (0.2 mm in diameter) made of Pt 92%–W 8% alloy. The fluid was tightly sealed in the cup by electron beam welding in a vacuum of 10^{-2} Pa. The viscometer vessel surrounding the oscillation system was evacuated to 10^{-2} Pa during operation so as to avoid the influence of drag from the remaining gas on the suspension system. The motion of the torsional oscillation was monitored with a reflection of the He–Ne laser beam from a mirror attached to the suspension system. The specimen is heated utilizing heating elements made of SiC and the temperature is measured with three chromel–alumel thermocouples positioned around the cylindrical cup. Figure 2 shows the cylindrical cup employed in the present

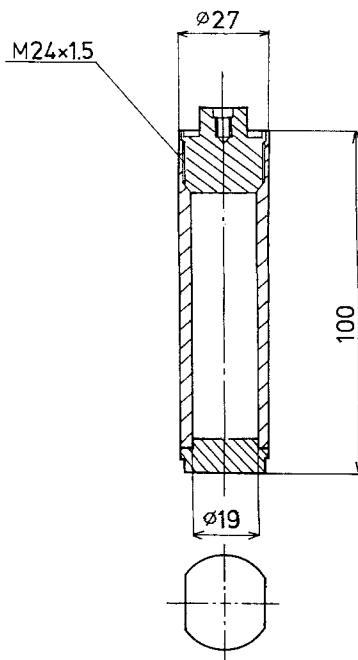


Fig. 2. Cylindrical cup.

measurements. As illustrated, the height of the cylindrical cup is 100 mm and the inner diameter is 19 mm. To ensure stability against corrosion by lithium chloride, good heat resistance, and machinability, the cup was made of an alloy of titanium, zirconium, and molybdenum, so-called TZM alloy. Before the cup was sealed by electron beam welding, it was filled with the specimen in its solid state in an argon dry box and it was temporarily sealed with a tapered lid after evacuation. Then the top of the cup was tightly sealed by welding. The purity of the lithium chloride was better than 99.9% and the density ρ was calculated using the equation recommended by the Molten Salts Data Center (MSDC):

$$\rho = 1.8842 - 4.328 \times 10^{-4} T \quad (1)$$

The viscosity of the fluid determined from the imaginary part of a rigorous solution of the Kestin–Newell equations [4]:

$$(S + \Delta_0)^2 + 1 + D(S) = 0 \quad (2)$$

where $D(S)$ is the characteristic function

$$D(S) = \frac{I'}{I} S^2 \sum_{n=1}^{\infty} \frac{8}{\mu_n^2} \left\{ 1 - \frac{S}{S_n^2} \left[1 - \frac{\tanh(S_n \zeta_0)}{S_n \zeta_0} \right] \right\} \quad (3)$$

and S is the complex frequency

$$S = \frac{T_0}{T} (-\Delta \pm i) \quad (4)$$

and Δ , Δ_0 , S_n , ζ_0 , and ξ_0 are defined as follows:

$$\Delta = \frac{\delta}{2\pi}, \quad \Delta_0 = \frac{\delta_0}{2\pi}, \quad S_n^2 = \frac{\mu_n^2}{\xi_0^2} + S \quad (5)$$

$$\zeta_0 = h \sqrt{2\pi\rho/\eta T_0} \quad \text{and} \quad \xi_0 = r \sqrt{2\pi\rho/\eta T_0} \quad (6)$$

In these equations, Δ and Δ_0 denote the logarithmic decrements of the suspension system with and without the fluid, respectively, I' the moment of inertia of fluid, I the moment of the suspension system alone, r the inner radius of the cup, h the height of the fluid column, η the viscosity, ρ the density, and μ_0 the root of the first-order Bessel function $J(\mu_0) = 0$, while T and T_0 are periods of oscillation with and without the fluid, respectively.

3. RESULTS AND DISCUSSIONS

The viscosity measurements were performed in the temperature range 886–1275 K at temperature intervals varying from 10 to 50 K. At each

Table I. Experimental Viscosities for LiCl

T (K)	η (mPa·s)
886	1.508
895	1.469
900	1.456
920	1.372
934	1.261
949	1.226
997	1.074
1048	0.963
1097	0.843
1150	0.765
1199	0.688
1248	0.622
1275	0.588

temperature, the measurements were repeated several times and a reproducibility of $\pm 0.8\%$ was obtained. In view of the various errors in measuring the logarithmic decrement, period, temperature, etc., the final accuracy of the present measurements was estimated as $\pm 2.0\%$. The experimental results for the viscosity of lithium chloride are listed in Table I. Figure 3 shows a plot of the viscosity vs the temperature in

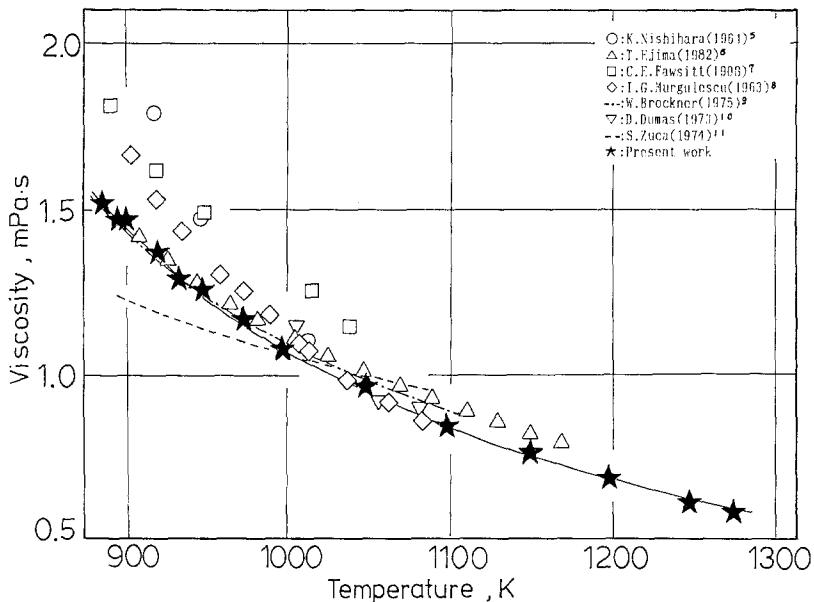


Fig. 3. Viscosity of LiCl as a function of temperature.

which available literature data are given together with the present results. Figure 4 shows the Arrhenius plot of the measured viscosities, i.e., the natural logarithm of the viscosity plotted as a function of the inverse temperature. In the temperature considered, it shows good linearity and agrees with the tendency exhibited by ordinary liquids. A least-squares yielded, for the Arrhenius equation,

$$\eta = 7.056 \times 10^{-2} \exp(2720/T) \quad (7)$$

where η is the viscosity in $10^{-3} \text{ Pa} \cdot \text{s}$ and T the absolute temperature in K. This equation reproduces the experimental results with a standard deviation of $\pm 1.4\%$ and a maximum deviation of $+2.7\%$. In Fig. 5, deviations of data reported by other authors from Eq. (7) are plotted as a function of temperature. Our data for lithium chloride are in agreement with the values reported by Brockner et al. [9] and Ejima et al. [6] at lower temperatures. However, the discrepancies are larger at higher temperatures and the maximum deviations reach $+7.4\%$ for the data of Brockner et al. [9] at 1118 K and $+9.7\%$ for Ejima et al. [6] at 1169 K. Brockner and co-workers used an oscillating-sphere method and Ejima and co-workers used a capillary method. The origin of these discrepancies is not presently clear. The data of Nishihara et al. [5] and Fawsitt [7] exceed our data by 15–30%. In these two studies [5, 7], an oscillating-disk viscometer was used. However, since the specimens were exposed to the atmosphere, there

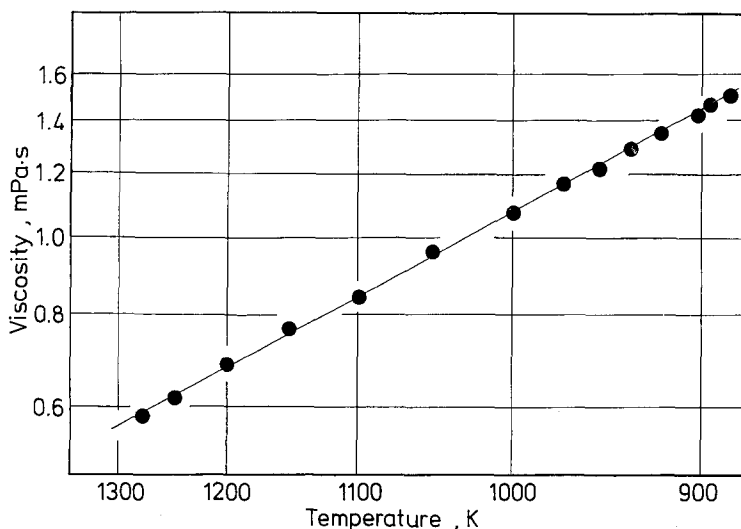


Fig. 4. Arrhenius plot of the measured viscosities.

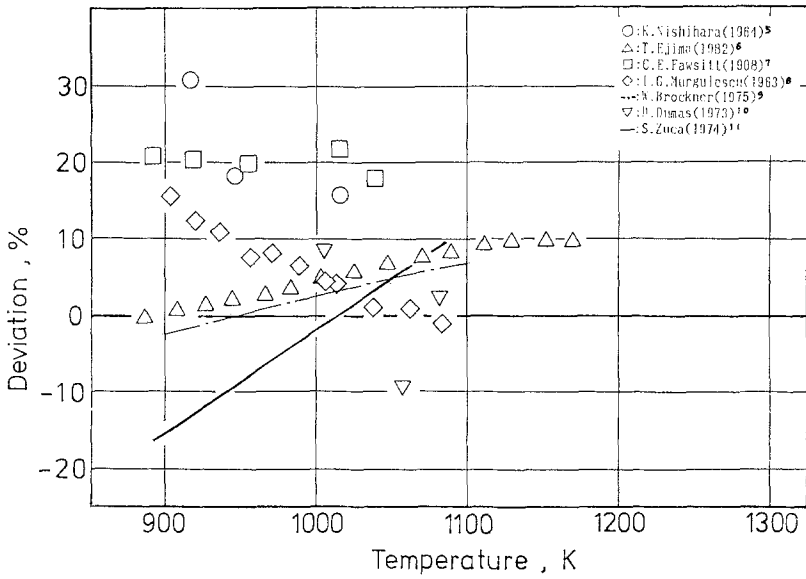


Fig. 5. Comparison with viscosity data obtained by other investigators.

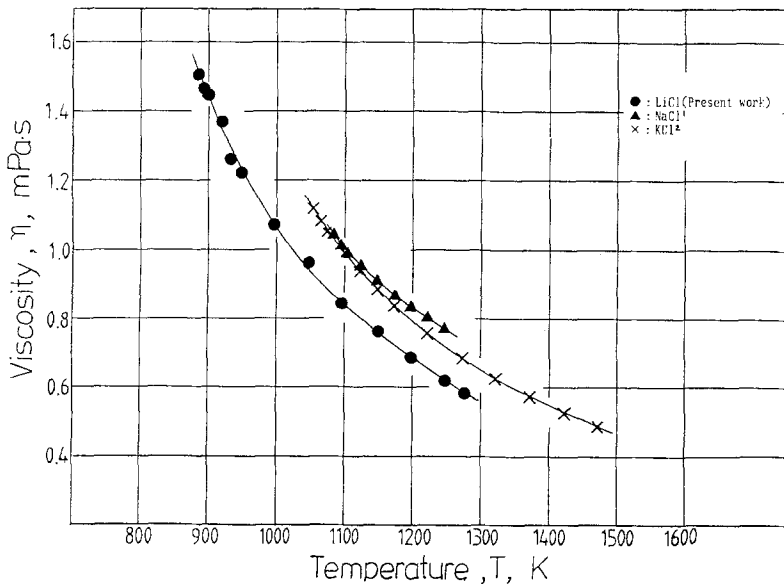


Fig. 6. Viscosity of LiCl, NaCl, and KCl as a function of temperature.

is a strong possibility of chemical degradation. Figure 6 shows the viscosity of lithium chloride together with our earlier measurements of the viscosity of sodium chloride [1] and potassium chloride [2] as a function of temperature. As shown in the figure, viscosity curves of these three materials do not cross each other. Sodium chloride has the highest viscosity, and lithium chloride the lowest. It is interesting that the order of viscosity for these substances does not correlate with the order of cation radius.

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