

Characterization of Electrical Conductivity, Density, and Viscosity of Molten Salts for Molten Salt Reactor Applications

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1. Introduction

For the efficient and safe operation of molten salt reactors (MSRs), the thermophysical properties of candidate fuel salts (such as NaCl–KCl–UCl₃) must be clearly characterized [1]. However, despite nearly six decades of discussion regarding the applicability of chloride-based molten salts as nuclear fuel, fundamental data on the electrical conductivity, density, and viscosity of the NaCl–KCl–UCl₃ system remain insufficient.

In this study, we present the development of techniques for evaluating the electrical conductivity, density, and viscosity of NaCl–KCl–UCl₃ molten salt, along with preliminary measurement results, as part of establishing essential baseline property data for the advancement of MSR applications.

2. Methods and Results

2.1 Electrical Conductivity

For the measurement of molten-salt electrical conductivity, a microsecond staircase voltammetry system developed by our research group was employed [2]. Using this system, the electrical conductivity of the LiCl–KCl eutectic salt was successfully measured with a relative error of less than 2%.

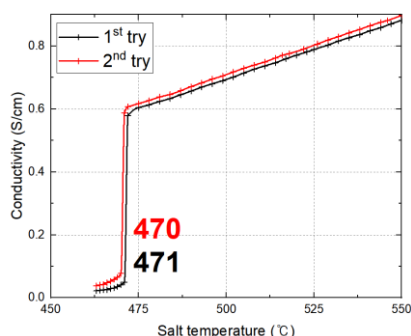


Fig. 1. Measured electrical conductivity and phase transition temperature of 0.433NaCl–0.217KCl–0.350UCl₃ (molar fraction basis) of quasi-ternary salt.

Fig. 1 presents the in situ electrical conductivity of the quasi-ternary salt 0.433NaCl–0.217KCl–0.350UCl₃ (molar fraction basis) as a function of temperature. An abrupt decrease in conductivity was observed at around

470 °C. This sharp drop serves as evidence of complete solidification of the liquid phase, thereby confirming that the system represents a eutectic composition with a eutectic temperature of approximately 470 °C. To the best of our knowledge, this constitutes the first experimental validation of the eutectic composition and eutectic temperature for the NaCl–KCl–UCl₃ quasi-ternary system.

The strategy of detecting phase transitions and eutectic behavior from changes in conductivity profiles has previously been demonstrated successfully in the LiCl–KCl quasi-binary system [2]. Nevertheless, further validation is currently pursued by comparison with thermally based methods such as differential scanning calorimetry, with the goal of enhancing measurement reliability.

2.2 Density

The density of molten salts was measured using a specially designed motor-driven dynamic bubbler system. A schematic representation of the dynamic bubbler system is provided in Fig. 2. Using molten KNO₃ as a reference medium, the system was demonstrated to be capable of measuring molten salt densities with a relative error of approximately 7% [3]. For application to chloride-based molten salt systems, the device was installed inside a glovebox, which required additional miniaturization of the apparatus.



Fig. 2. Dynamic bubbler system for density measurement.

For the quasi-ternary salt 0.433NaCl–0.217KCl–0.350UCl₃, the density measured at 580 °C was 3.32 ± 0.20 g/cm³. This value is in close agreement with

the density of an ideal solution (3.29 g/cm^3), calculated under the assumption of ideal mixing of NaCl, KCl, and UCl_3 .

Although no published results are available for exactly the same composition, Parker's neutron-radiography study [4] reported a markedly (16%) lower density than the ideal-solution prediction for $0.505\text{NaCl}-0.130\text{KCl}-0.365\text{UCl}_3$, which contrasts with the present finding. It should be noted, however, that in Parker's work [4] the measured densities of the quasi-binary systems ($\text{NaCl}-\text{UCl}_3$ and $\text{KCl}-\text{UCl}_3$) were consistent with those calculated assuming ideal mixing. Consequently, further literature investigation and cross-validation experiments are necessary to reconcile these discrepancies.

Accurate determination of molten salt density is considerably more challenging than density measurements under ambient conditions, and even when relatively simple techniques such as the Archimedes' method are applied, relative measurement errors on the order of 5–10% are commonly observed. To improve the reliability of the measurement results, the present study is also conducting validation efforts using auxiliary approaches, including an indirect estimation method based on the level-detection functionality of our bubbler system [3].

2.3 Viscosity

Viscosity measurements were performed using the rotational method. A Brookfield rotational viscometer, commonly employed for multidisciplinary applications, was extensively modified to allow operation under molten salt conditions. Since molten salts often exhibit very low viscosities similar to those of water, a specialized ceramic spindle for low-viscosity fluids was developed to suppress vortex formation while maintaining minimal measurement error. In addition, an automated program was implemented for remote calibration and measurement control. A schematic diagram of the molten salt viscosity measurement system used in this study is shown in Fig. 3.

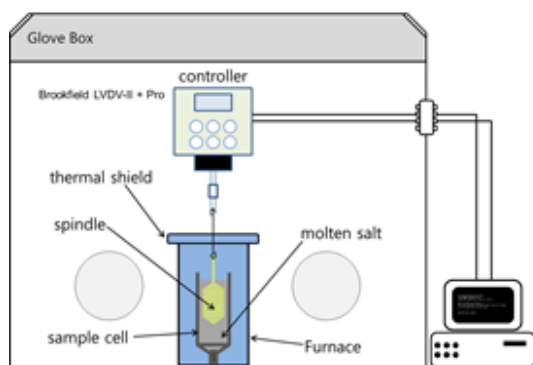


Fig. 3. Schematic diagram of modified Brookfield rotational viscometer system.

For the quasi-ternary salt $0.433\text{NaCl}-0.217\text{KCl}-0.350\text{UCl}_3$, the viscosity measured at 580°C was

determined to be $5.87 \pm 0.03 \text{ cP}$. To the best of our knowledge, this represents the first viscosity measurement ever reported for the $\text{NaCl}-\text{KCl}-\text{UCl}_3$ quasi-ternary system. In order to reinforce the reliability of the measurement, additional studies are being conducted, including round-robin testing on identical salt samples and comparative validation against molecular dynamics simulation results.

3. Conclusions

We present the development of measurement systems for determining the electrical conductivity, density, and viscosity of molten salts, along with preliminary experimental results for the quasi-ternary $\text{NaCl}-\text{KCl}-\text{UCl}_3$ system, considered a prospective fuel salt for molten salt reactors. Notably, by employing electrical conductivity as a probe, we were able to precisely track phase transition temperatures and, for the first time, experimentally confirm the eutectic behavior of the $\text{NaCl}-\text{KCl}-\text{UCl}_3$ system. Furthermore, the viscosity data reported herein represent the first experimental results ever published for this salt system. Ongoing work is being carried out to refine the measurement techniques through multiple methodological approaches.

4. Acknowledgement

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