Thermal Conductivity Measurements of Molten Salts Using a Modified Transient Hot-wire Needle Probe

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Some advanced nuclear reactor designs feature high-temperature molten salts as the working heat transfer fluid in fuel-coolant systems. Thermophysical property measurements of these salts have proven exceptionally challenging due to their electrical conductance and corrosive nature. Additional measurement challenges have arisen due to the difficulty in accounting for convective and radiative heat transfer. In general, experimental measurements of thermophysical properties on these salts are few, and those that have been done are often in significant disagreement with one another. In particular, the majority of the primary reference data for thermal conductivity for high-temperature fluoride salts demonstrates an upward trend with increasing temperature. Theory of material kinetics and simulated molecular dynamics studies, however, suggest a negative temperature dependence. Before molten salts can be employed in commercial applications, it is requisite that the experimental work on property measurements be improved such that their thermophysical behavior is adeptly and safely understood.

This work presents a new method for measuring the thermal conductivity of several fluoride and chloride-based molten salts. The transient hot-wire technique is modified to take the form of a needle probe and is then combined with principles from the concentric-cylinders approach to create a robust instrumental system capable of surmounting the challenges faced with experimental testing of these materials. An analytical heat transfer model is developed to account for thermal radiation in a semi-transparent, non-scattering medium. This model is validated with finite-element methods. Sensitivity analyses are performed to quantify the influence of parametric model inputs on the measured thermal conductivity. An experimental apparatus is designed in accordance with these results to measure thermal conductivity with greatest accuracy. Total measurement uncertainty is quantified using the Monte Carlo approach, which ranges between 14.2-17.8%.

Measurement values are presented for molten LiF-NaF-KF, NaF-KF-MgF_2, and LiCl-KCl in the range of 500-750 °C. Among the three salts, thermal conductivity is measured between 0.490-0.849 W/mK. In all cases, there is a clear downward trend when linearly fitting the data points across the range of measurement temperatures. These results are impactful to the nuclear industry in that the safety and efficiency of molten salt coolants may be optimized in terms of their ability to conduct heat. Future work using this modified transient hot-wire needle probe will entail testing for thermal conductivity in molten salts bearing actinide impurities, which will provide an even better representation of real-world nuclear applications.