A Low-Cost Method for Determining Molten Salt Density

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As we transition to a decarbonised world, different forms of renewable and reliable energy supply are crucial. One method of energy generation which can achieve this, if costs can be reduced, is concentrating solar power (CSP). One way to decrease CSP cost is to operate at higher temperatures (> 700°C). However, to take advantage of higher temperatures, new storage materials are required. To assess whether newly developed storage materials are capable of lowering the cost of CSP, their properties must be determined. While effective methods of latent heat, melting point, and specific heat determination are available, other properties such as liquid density (required to determine the storage system volume) are not as easily found.

Of particular interest for high temperature thermal energy storage (TES) are multi-component salt phase change materials (PCMs). While multi-component molten salt density is commonly evaluated theoretically (Janz 1988), doubt remains around its accuracy. Typically, experimentally measuring molten salt density is performed using either the Archimedean (An et al. 2019; Xiong et al. 2016) or pycnometric (Wang 2014) methods. Current methods are capable of producing uncertainties in the order of 0.1% of standard melts of sodium chloride. Achieving this level of accuracy requires complexity in the setup and analysis which utilises expensive equipment and materials.

Multi-component molten salts have shown variations of up to 10% between published experimental and predicted values (Raud et al, 2017). This type of inaccuracy can lead to significant over- or under-sizing, significantly increasing capital costs or inefficient operational costs, respectively. Furthermore, in the course of developing and investigating large numbers of potential storage materials, it is prudent to have a robust method of density determination that is inexpensive and quick to analyse, so that the selection of promising materials can be made.

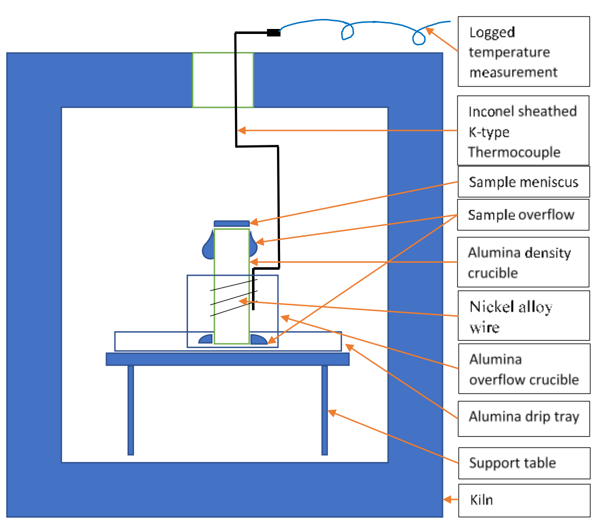

Figure 1. Experimental setup

The experimental method described herein is pycnometric and utilises readily available high temperature laboratory equipment (*Figure 1*). Unlike the phase change of ice to water, the phase change of solid salt to liquid is that of a continuously decreasing density. This implies that for a given mass of solid or liquid salt, its volume will continue to increase with increasing temperature. In an unconstrained container, such as an open crucible (of known volume), the liquid salt will continue to overflow up until its maximum uniform temperature is reached. Cooling down from this point will preserve the mass of salt that was liquid at this maximum temperature, which can then be weighed. After weighing the cooled crucible, the next higher temperature/density point can be determined by reinserting that very sample back into the kiln and repeating the process.

The accuracy of this experimental method as depicted in *Figure 1* is in the order of 1% for liquid sodium chloride when compared with published measured and theoretical density values (*Figure 2*).

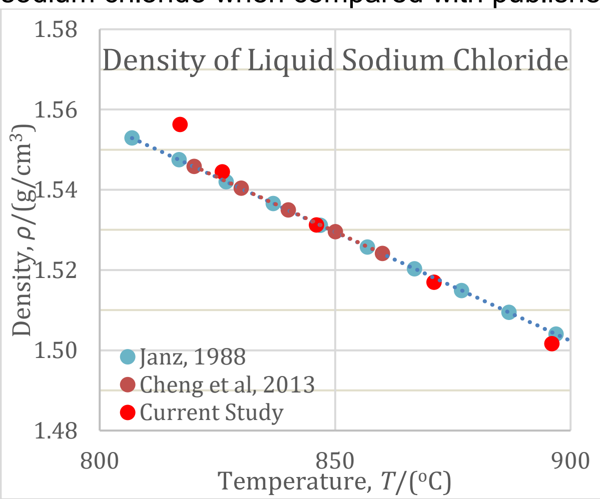

Figure 2. Theoretical (Janz, 1988) and experimental (Cheng et al, 2013 and current study) comparisons of liquid density for the single component salt, sodium chloride.

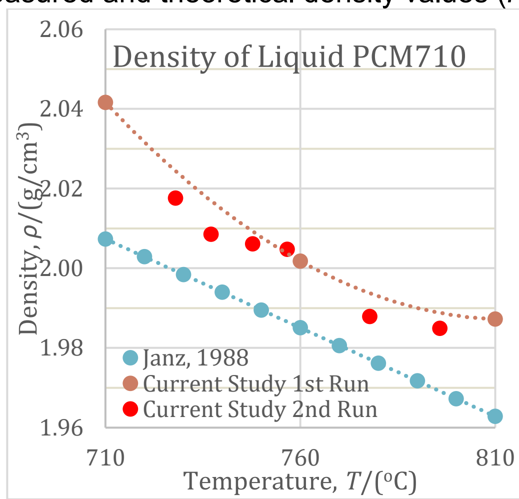

Figure 3. Comparison between theoretical (Janz, 1988) and experimental (current study) liquid density of the multi-component salt, PCM710.

When this method is extended to multi-component salts, a 2% variation of the theoretical to experimental determination of density exists (*Figure 3*). While this work is only preliminary, the results to date using this method have proved promising.

References

Janz, G. J., 1988, 'Thermodynamic and Transport Properties of Molten Salts: Correlation Equations for Critically Evaluated Density, Surface Tension, Electrical Conductance, and Viscosity Data' Journal of Physical and Chemical Reference Data, 17, Supplement No. 2.

An, X. H., Cheng, J. H., Su, T. and Zhang, P, 2017, 'Determination of thermal physical properties of alkali fluoride/carbonate eutectic molten salt', AIP Conference Proceedings 1850, 070001

Xiong, Y., Shi, J., Wu, Y., Ma, C. and Chen, H, 2016, 'Preparation and investigation on density and surface tension of quaternary bromides for concentrating solar power', Solar Energy Materials & Solar Cells, 157, p709-715

Cheng, J. H., Zhang, P., An, X. H., Wang, K., Zuo, Y., Yan, H. W. and Li, Z, 2013, 'A Device for Measuring the Density and Liquidus Temperature of Molten Fluorides for Heat Transfer and Storage', Chin. Phys. Lett., Vol. 30 No. 12, p126501-1 126501-4.

Raud R, Jacob R, Bruno F, Will G, Steinberg T. *A critical review of eutectic salt property prediction for latent heat energy storage systems*. Renewable and Sustainable Reviews (2017), **70**: 936-944.