INL/CON-21-65124-Revision-0

Implementation of an Experimental Setup Based on the Three-Omega Method for Thermal Conductivity Measurements of Molten Salts

December 2021

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Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

Implementation of an Experimental Setup Based on the Three-Omega Method for Thermal Conductivity Measurements of Molten Salts

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GOALS

Main goal

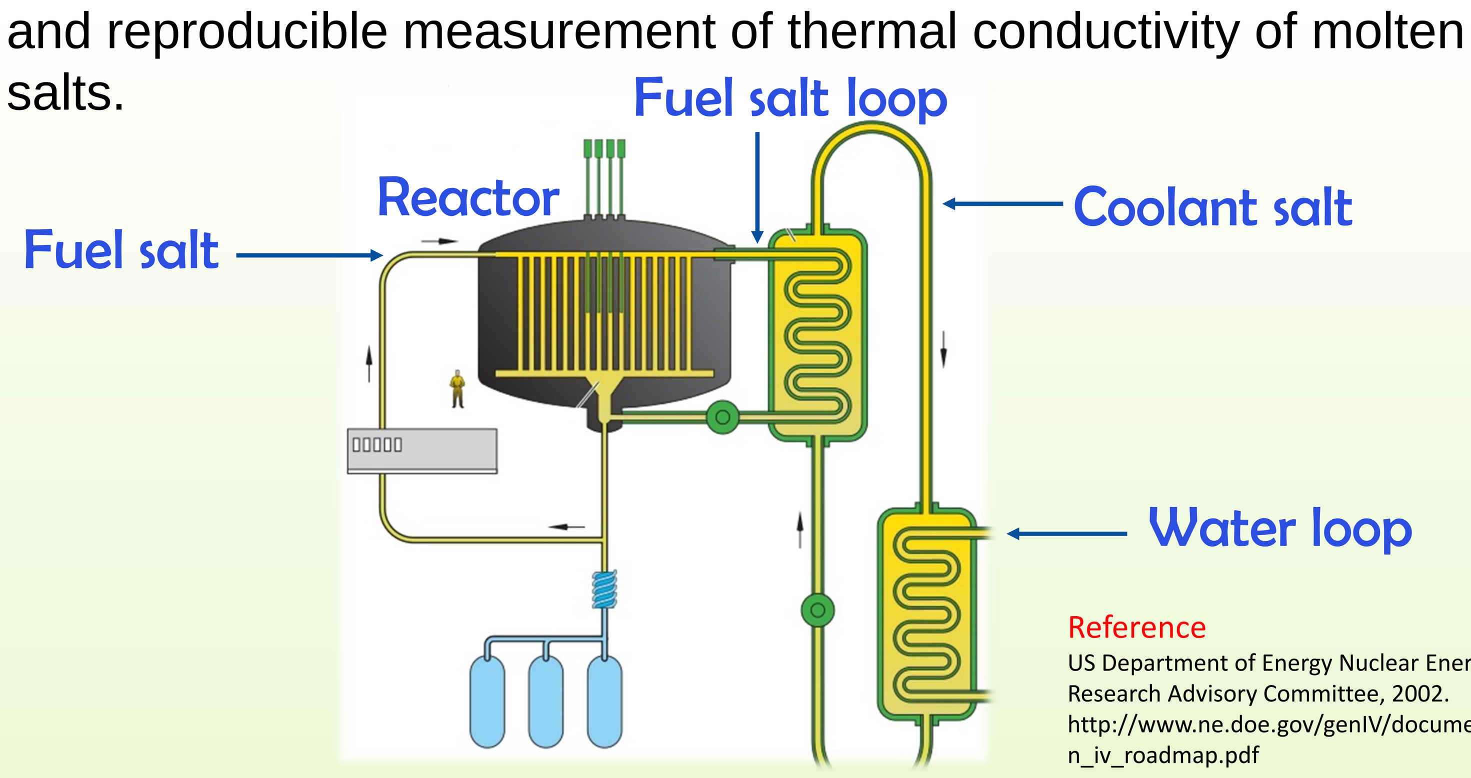
Produce high-fidelity thermal conductivity data on molten material/salts at high temperature

Sub-goals

- Design and fabricate a three-omega sensor
- Assemble an electric circuit capable of accurately measuring the three-omega (3-ω) voltage.
- Develop a reliable thermal model to link the experimental measurement to the thermal conductivity.

MOTIVATION

To design, model, predict, license, and operate molten salt reactors (MSRs), the behavior of the fuel and coolant must be understood as a function of temperature. Of particular importance is the reliable and reproducible measurement of thermal conductivity of molten salts.



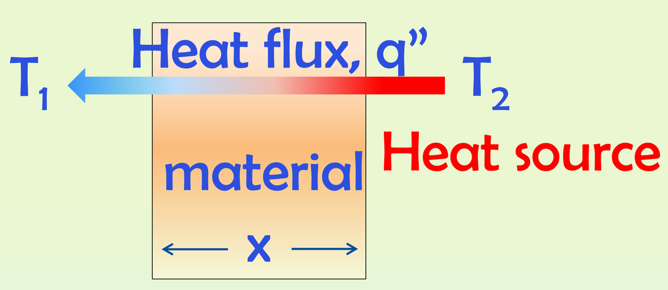
Reference
US Department of Energy Nuclear Energy Research Advisory Committee, 2002. http://www.ne.doe.gov/genIV/documents/gen_iv_roadmap.pdf

THERMAL CONDUCTIVITY – THE BASICS

The thermal conductivity, k, of a material provides information on its ability to conduct heat. A thermal conductivity of 1 W/m·K indicates that an amount of heat of 1 Joule propagates in 1 second through a thickness of 1 m, when the temperature between the two faces is 1 K.

The equation that describes and defines thermal conductivity is known as Fourier's law for heat conduction, for a one-dimensional-case (equation below), where *q"* is the heat flux (W/m^2), *k* is the thermal conductivity (W/m·K), $(T_2 - T_1)$ is the thermal gradient (K), and *x* is the thickness of the material (m):

$$q" = -k\frac{(T_2 - T_1)}{x}$$



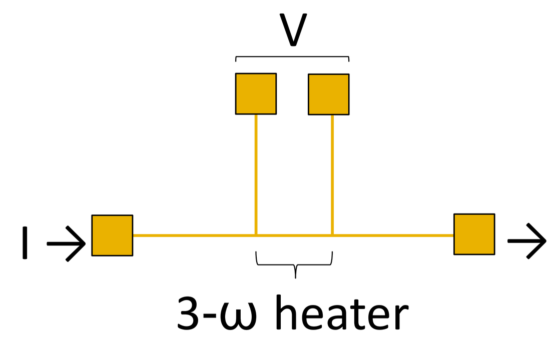
To determine the thermal conductivity, it is necessary to:

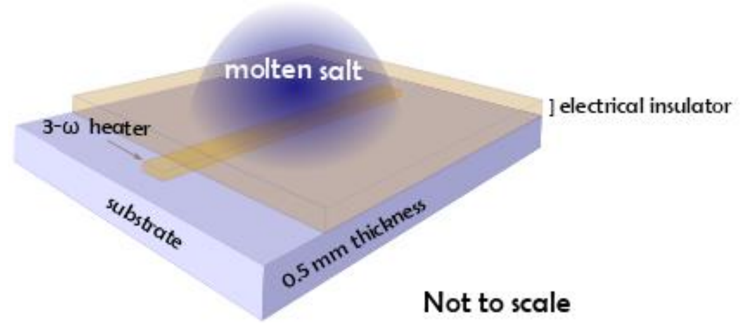
- Create a heat flux through the material by using a heat source (e.g., resistor).
- Determine the resulting temperature gradient.
- Solve the heat equation for the specific system/geometry to obtain an expression that links the resulting temperature gradient to the thermal conductivity.

THREE-OMEGA TECHNIQUE

3-ω technique: thermal conductivity determination

The 3-omega technique is based on electrically heating a thin planar resistor using an AC harmonic current at a frequency ω.





The magnitude of the temperature rise of the resistor, ΔT, will depend on the thermal conductivity of the surrounding material. The temperature change results in a resistance, *R*, and voltage fluctuation across the resistor. Subsequently, by measuring the resultant voltage drop, *V*, at the first (ω) and third (3ω) harmonics, the temperature oscillation can be determined. The 3-omega voltage, $V_{3\omega}$, is proportional to the temperature oscillation.

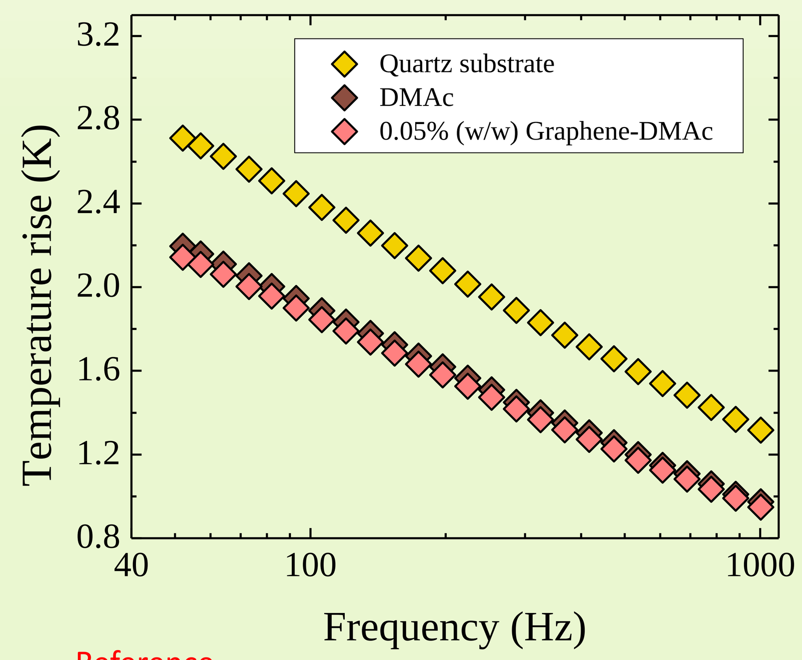
To determine the temperature rise:

$$\Delta T_{AC} = \frac{2R_0|V_{3\omega}|}{(\partial R/\partial T)|V_\omega|}$$

To determine the thermal conductivity:

$$\Delta T_{AC} = -\frac{P_{rms}}{2\pi l k}\ln(2\omega)$$

where:
P_{rms} is the power that drives ΔT_{AC}
l is the length of the heater
k is the thermal conductivity
ω is the frequency



Reference
Rodríguez-Laguna, M. R. et al. Nanoscale 10, 15402–15409 (2018).

Advantages of the technique

Characteristics	Advantages
Small sample volume	Perfect for radioactive material
Fast measurement	Suppress interference from convection
Direct measurement	Smaller uncertainty than other techniques (e.g., laser flash)

ACKNOWLEDGEMENTS

Thanks to the Pyrochemistry & Molten Salt Systems department and the Glenn T. Seaborg Institute at Idaho National Laboratory. The work is supported through the INL Laboratory Directed Research & Development (LDRD) Program under DOE Idaho Operations Office Contract 21P1056-013FP.