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A COMPUTATIONAL STUDY ON THERMAL CONDUCTIVITY MEASUREMENTS OF HIGH TEMPERATURE LIQUID MATERIALS

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- Research objective
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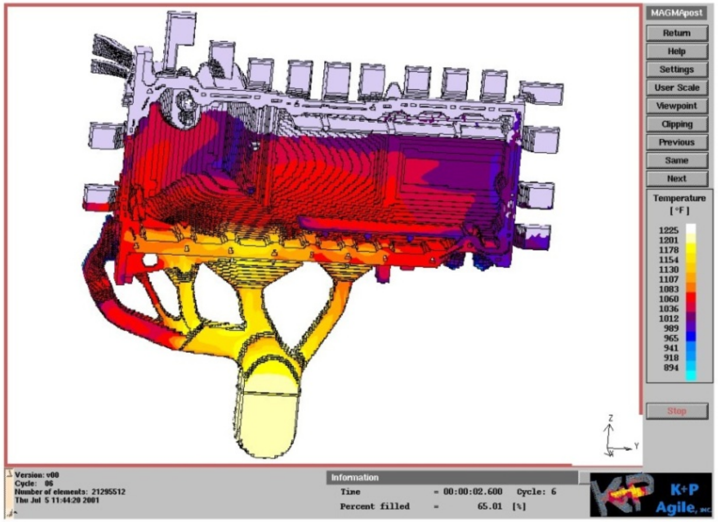
Motivation

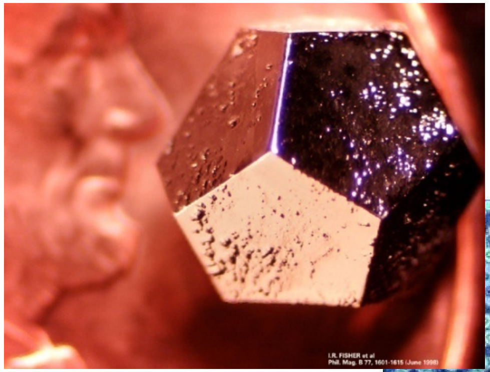
- Industry application:

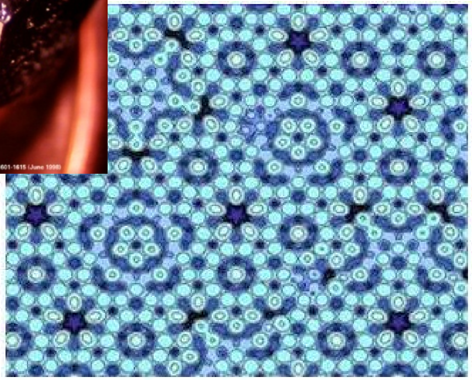
  Modeling the casting process of car engine



- Scientific research

  Study solidification kinetics of quasicrystals

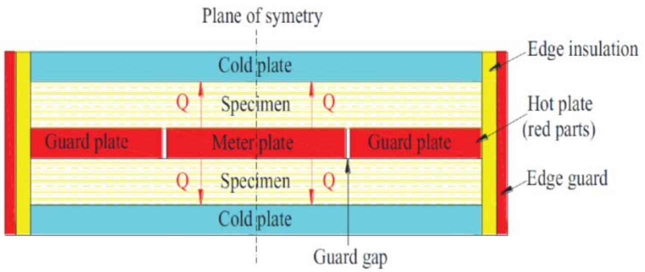




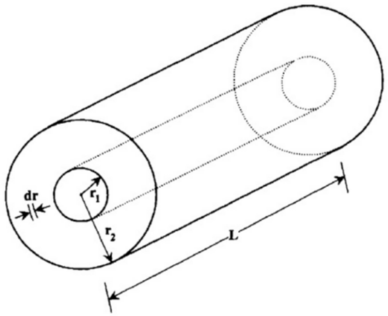
[1] Fecht, H.-J. and Wunderlich, R.K., The thermolab project: thermophysical properties of industrially relevant liquid metal alloys. In *Microgravity Research and Aplications in Physical Sciences and Biotechnology, Proceedings of the First International Symposium* (2001), European Space Agency, p. 545. ESA SP-454.

Traditional Methods

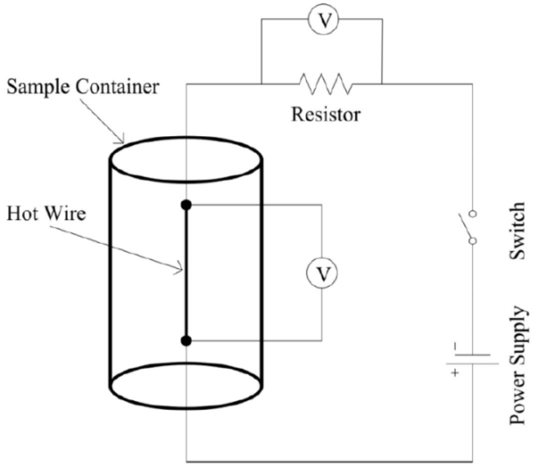
- Guraded hot plate method



- Radial heat flow Method

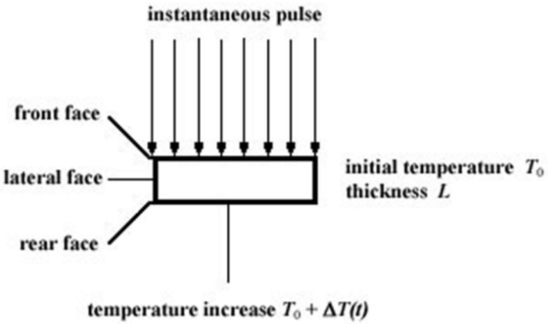


- Hot Wire Method



Measure T on the surface of the hot wire:

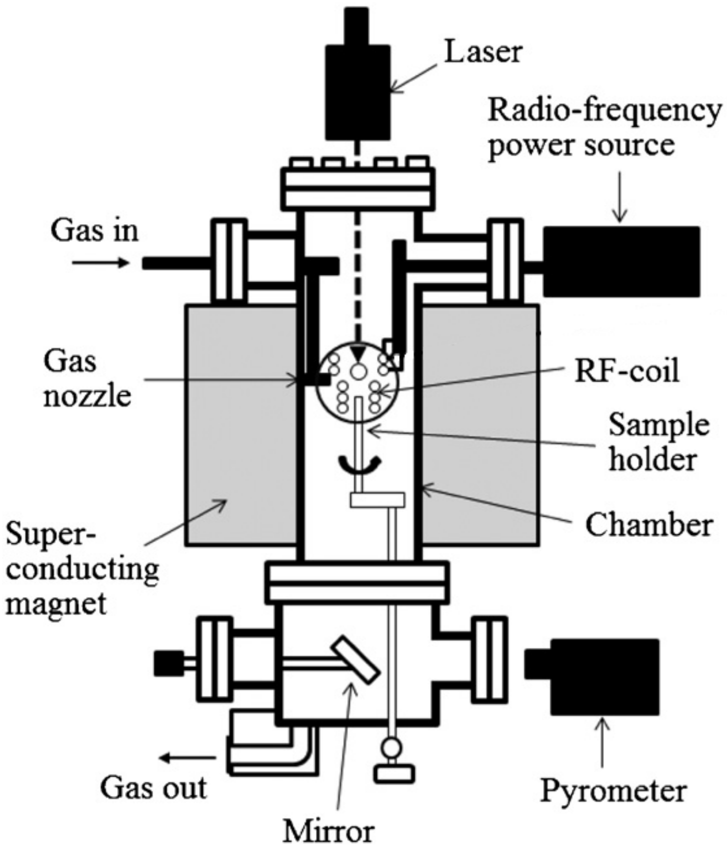
- Flash Method

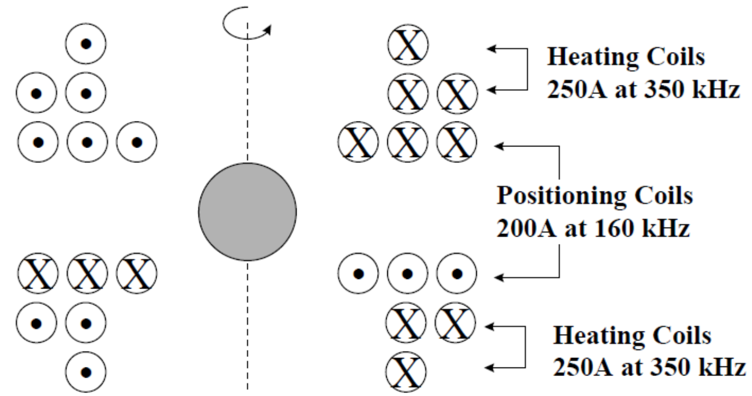


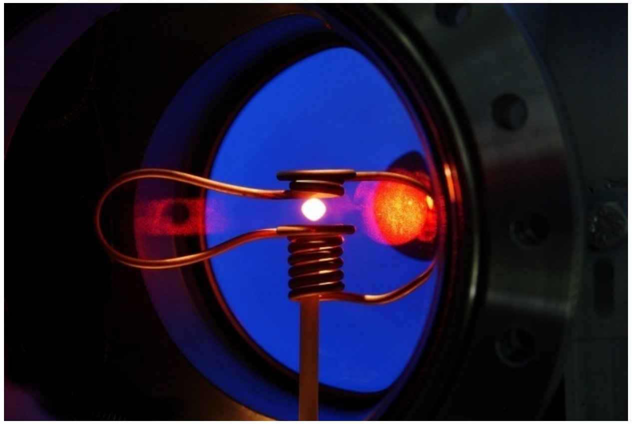
Measure T of the back side of the sample

Electromagnetic Levitation based Modulation Calorimetry (EML-MC)

- Initially proposed by Fecht & Johnson[3] in 1991.

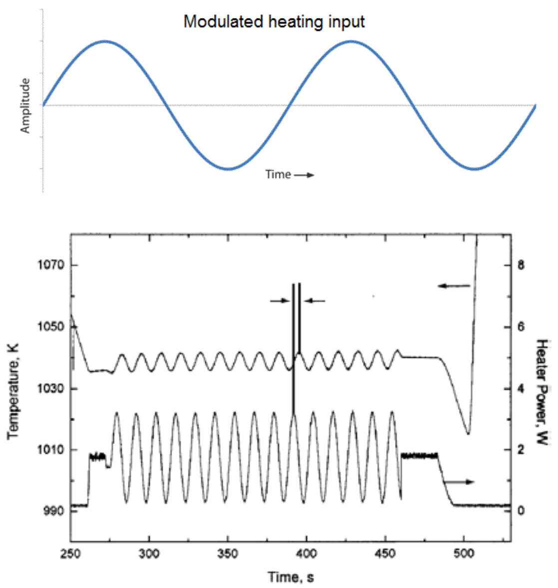


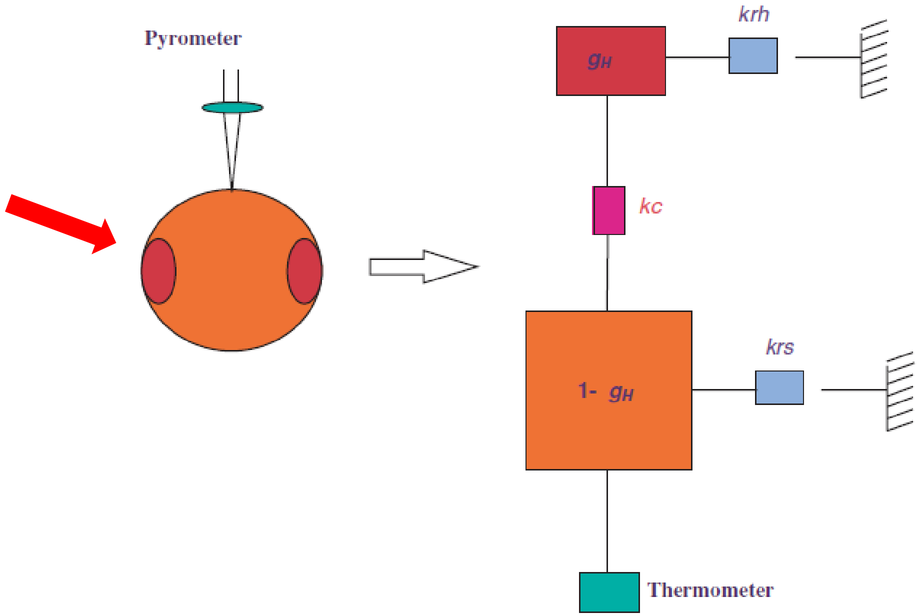




[3] Fecht, H.-J. and Johnson, L., A conceptual approach for noncontact calorimetry in space. *Review of scientific instruments 62*, 5 (1991), 1299–1303.

Principles of EML-MC





Heat transfer model for solids

1. Measure phase lag φ_S
2. Solve for internal relaxation rate of coupled heat transfer system $\lambda_2 = \dfrac{k_c}{c_p \cdot m}$
3. Solve for k with conductive heat transfer coefficient $k_c = \dfrac{4}{3}\pi^3 Rk$

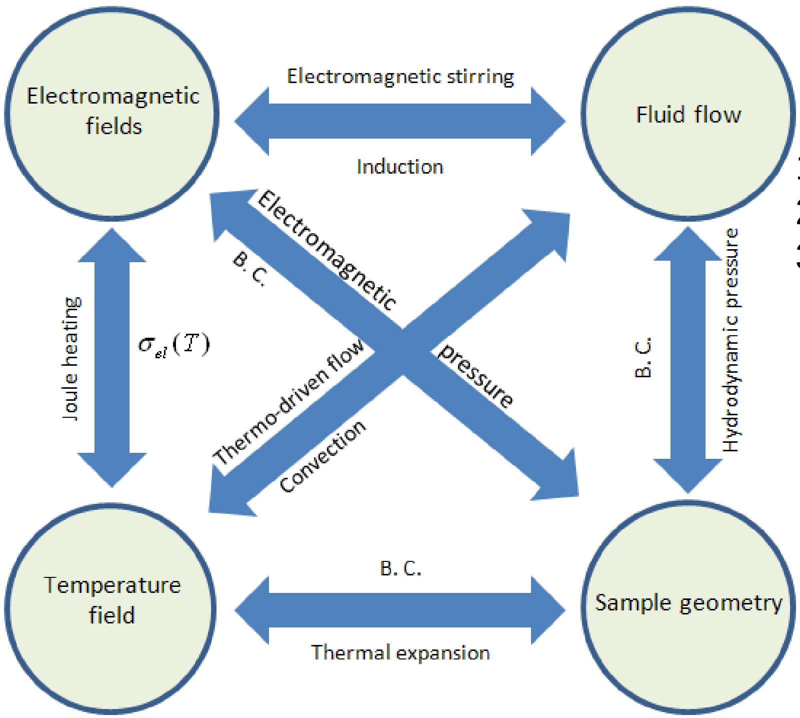
Research Objective

1. Determine true k of liquid materials using numerical simulation;
2. Understand the dependence of convective error on experimental parameters;
3. Provide guidance to future k measurements.

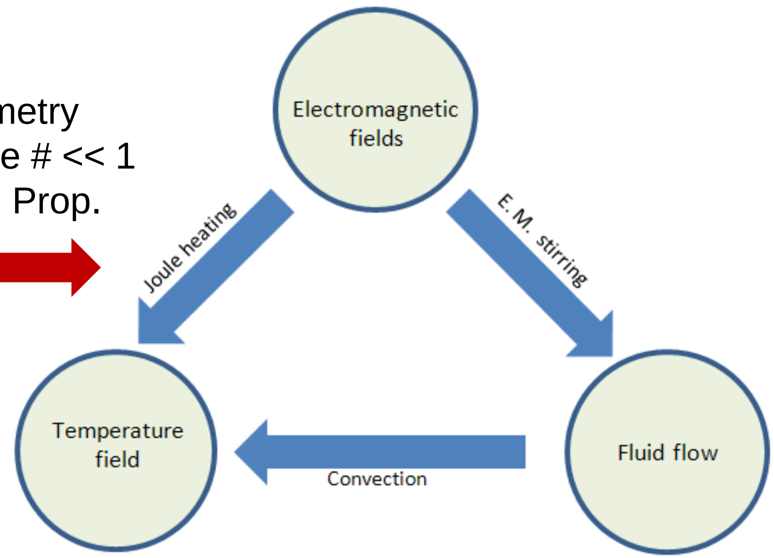
Numerical Modeling

- COMSOL Multiphysics:

  Laminar flow + heat transfer
- Physics coupling scheme



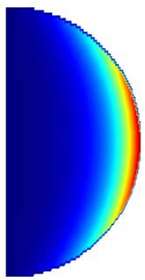
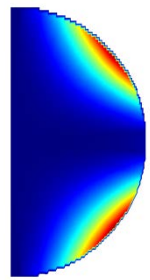
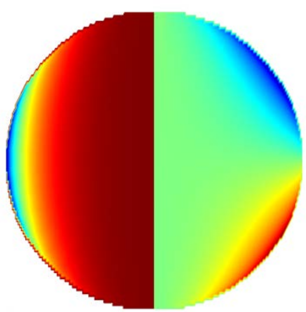
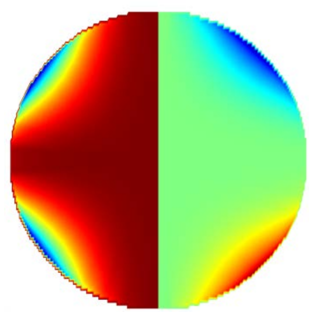
1). Fixed geometry
2) Magnetic Re # << 1
3) Const. Mat. Prop.



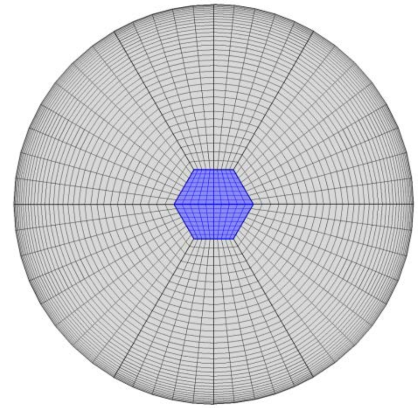
[4] Etay, J., Schetelat, P., Bardet, B., Priede, J., Bojarevics, V., and Pericleous, K.. Modelling of electromagnetic levitation – consequences on non-contact physical properties measurements. *High temperature materials and processes 27*, 6 (2008), 439–447.

Meshing

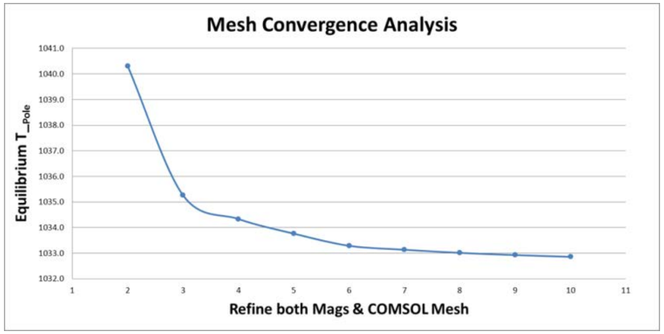
- ❖Electromagnetism (calculated with Mags)

	Heater	Positioner
Heating (W/m³)		
Forces (N/m³)		

- ❖ Meshing:



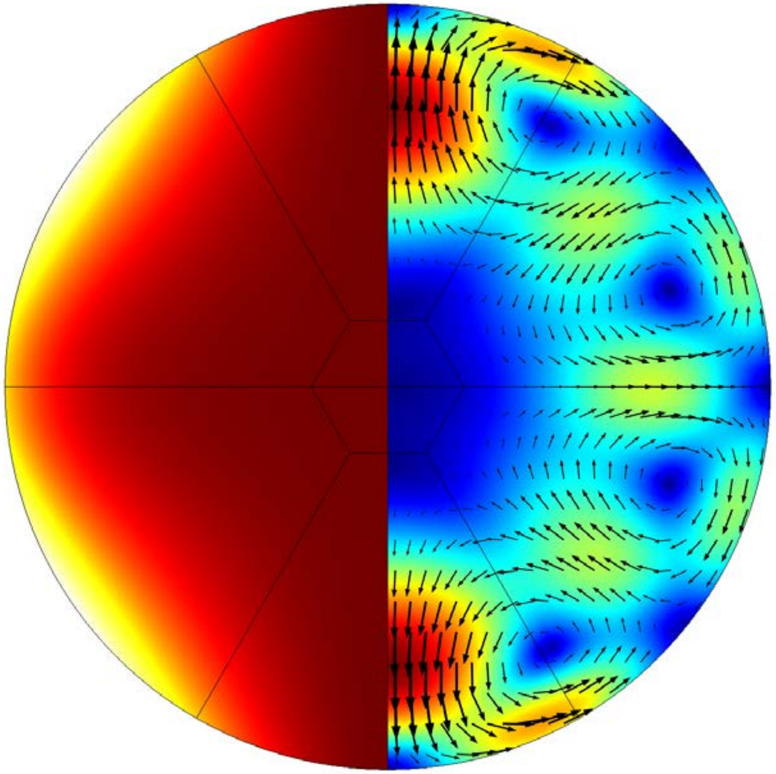
- ❖Convergence Analysis (Based on 1033K liquid Zr-Alloy)



Model Validation

- Isothermal holding of liquid FeCrNi alloy with I_H = 135A and I_P = 150A.

	Current Simulation	Reported Value
Max. T (K)	1543.7	1480.5
Min. T (K)	1539.9	1477.9
Max. Surface T difference (K)	1.38	1.1



Error source:

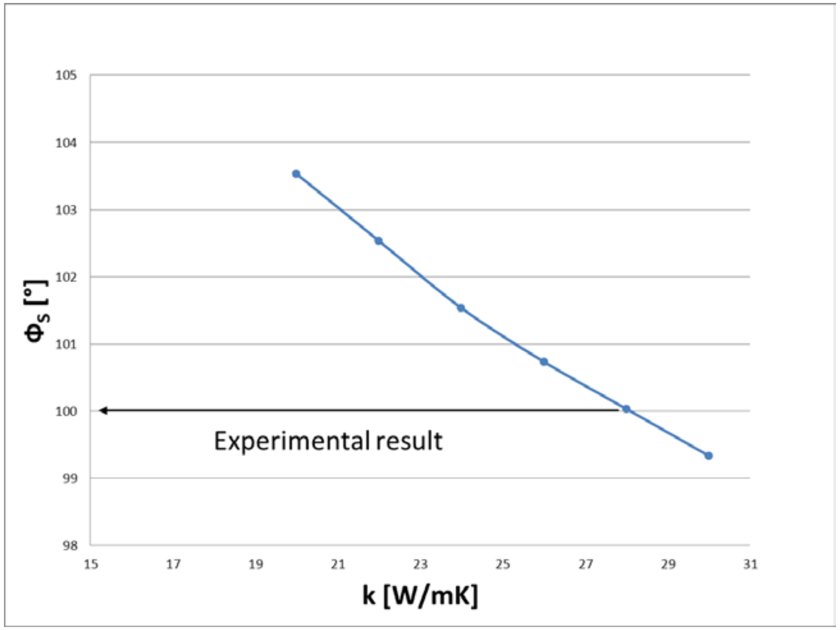
Simple surface to ambient radiation

vs. Gas atmosphere

Results

- Determination of K of liquid ZrAlCuNi alloy at 1024K

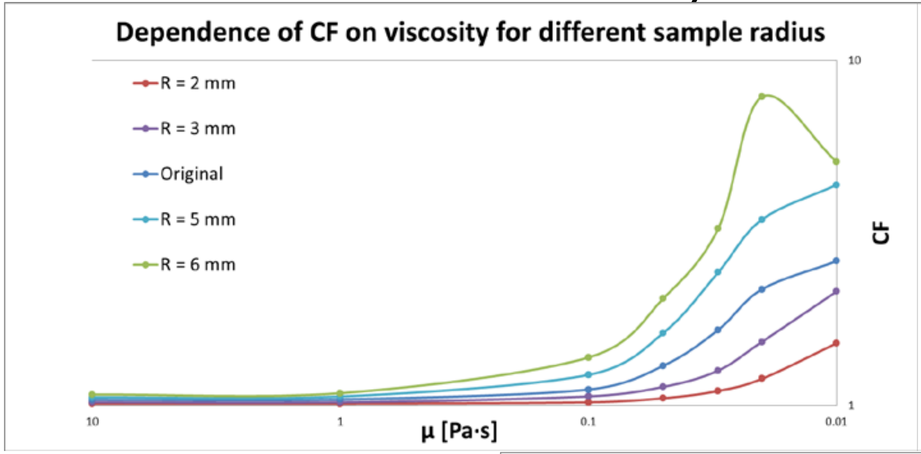
- Reported experimental condition:
  Coil: TEMPUS
  Modulation mode: power
  I_H =106 A
  I_P = 24 A
  w_H = 351kHz
  w_P = 160kHz
  $\mu = 0.27 Pa \cdot s$

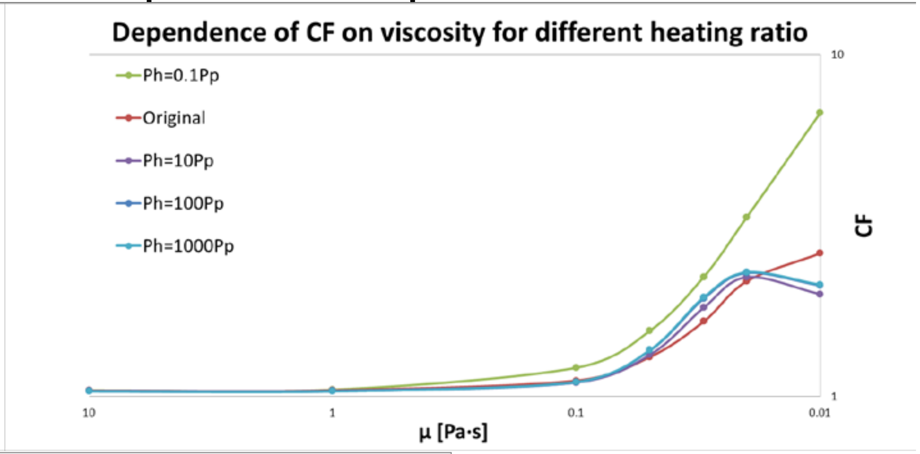


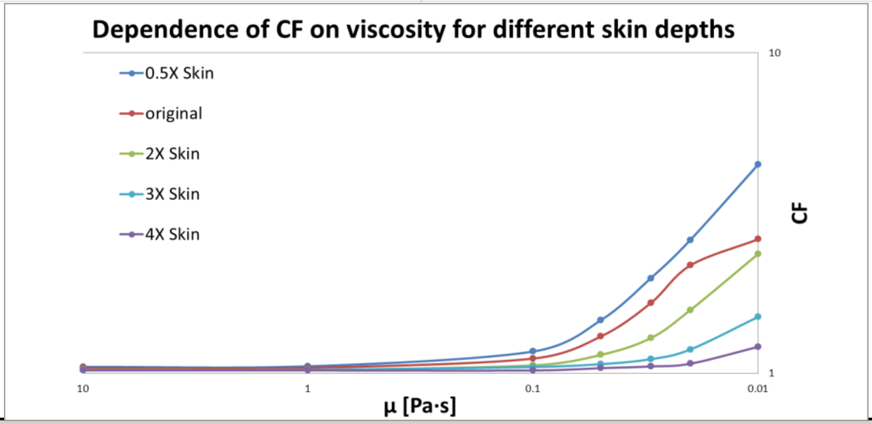
- True k = 28W/mK ~ Measured k = 31.2W/mK.
  Indicating small convective interference at this viscosity.

Results

- Dependence of convective error (correction factor, CF = measured k/true k) on different experimental parameters.







Conclusion

- CFD + EML-MC is a viable method for k measurement of high temperature liquid metallic materials.
- CFD simulation could be used to guide future experimental designs.

Acknowledgement

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