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Thermal Characterization of Molten Salt Battery Materials

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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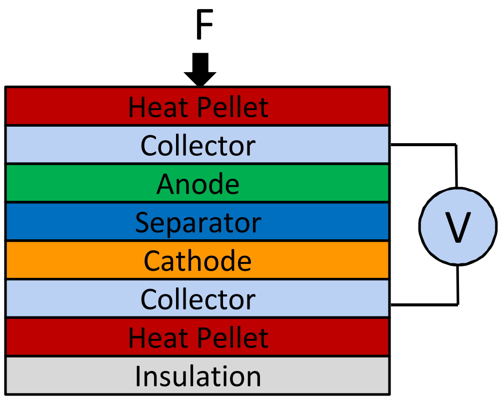
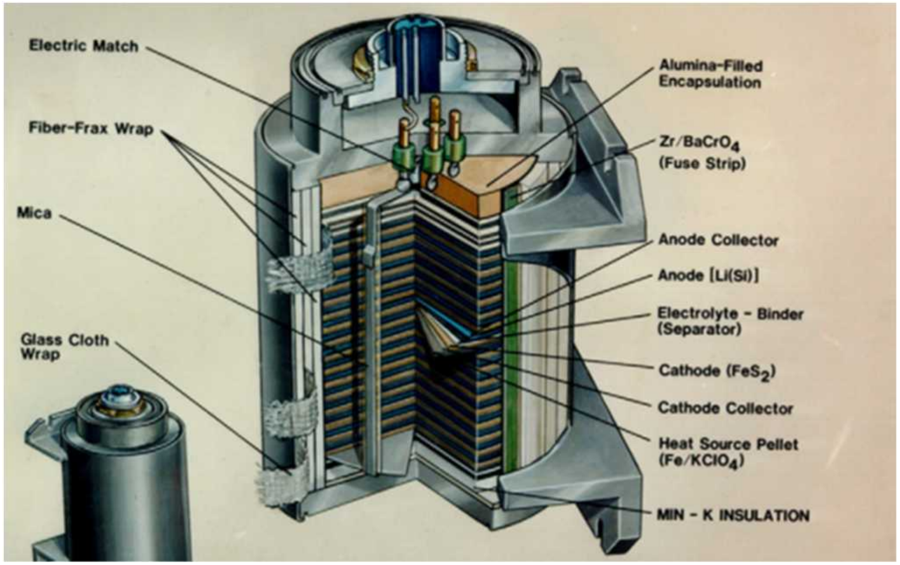
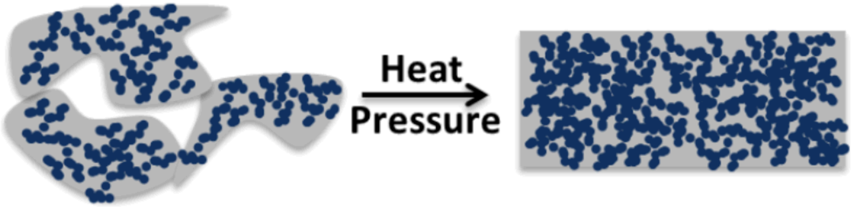
Introduction

- Initially developed to power V2 rockets in WWII
- Power sources for radar and guidance systems in military applications
- Activated by melting anode, electrolyte, and cathode above eutectic temperatures
- Molten separator creates electrically conductive pathway between anode and cathode
- Discharge rates dependent on cooling rate of separator
- Complex multi-physics problem (electrochemical, mechanical, thermal)
- Experimental values imperative to models for predicting battery and weapon lifetime





Reference 3



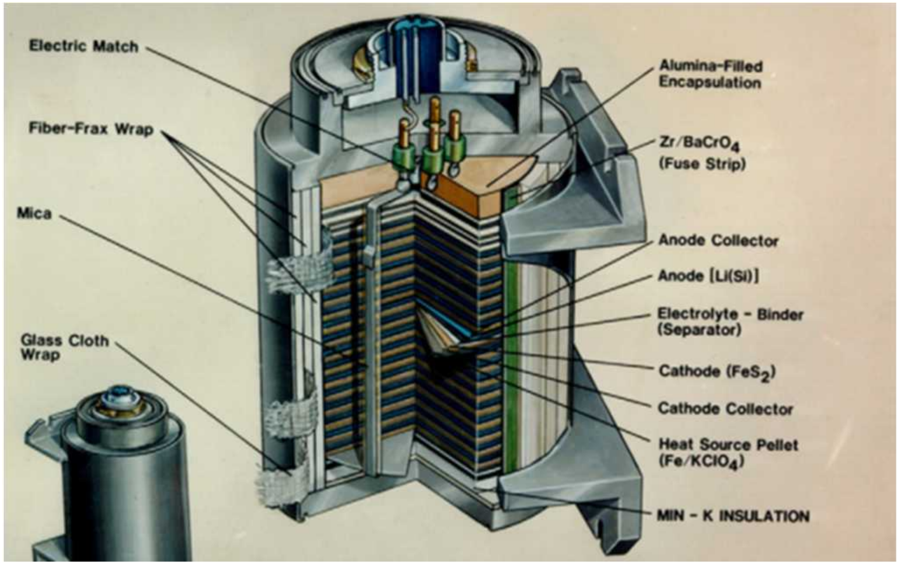
Reference 5

Agenda

- Measurement Apparatus
- Steady-State Thermal Transport
- Thermal Properties of Thermal Battery Materials
- Comparison to Other Sources

Materials of Interest

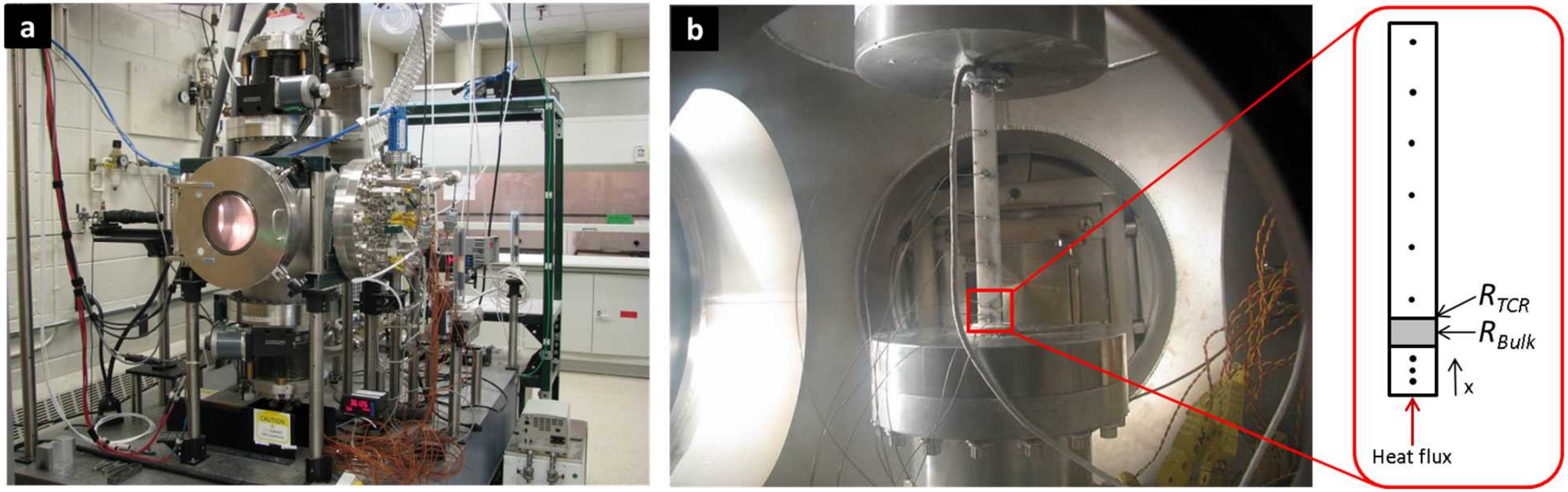
- Anode/Separator/Cathode: mixture of LiCl, MgO, and KCl
- Thermal Insulation
  1. Min-K
  2. Fiberfrax Board
  3. Fiberfrax Wrap
- Heat pellets



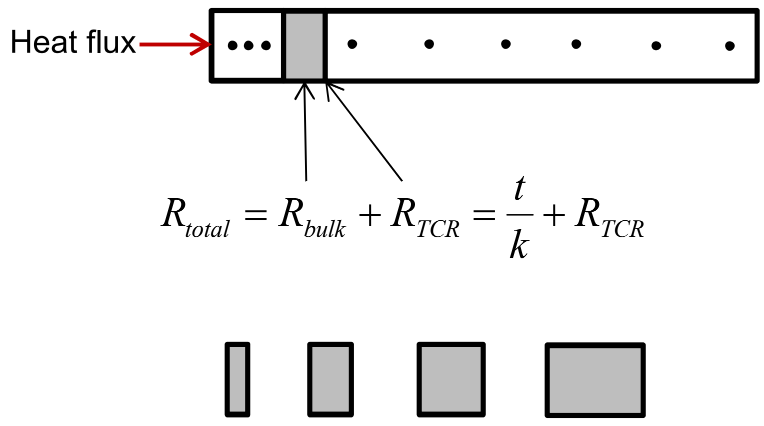
Reference 3

1-D Steady State Experimental System

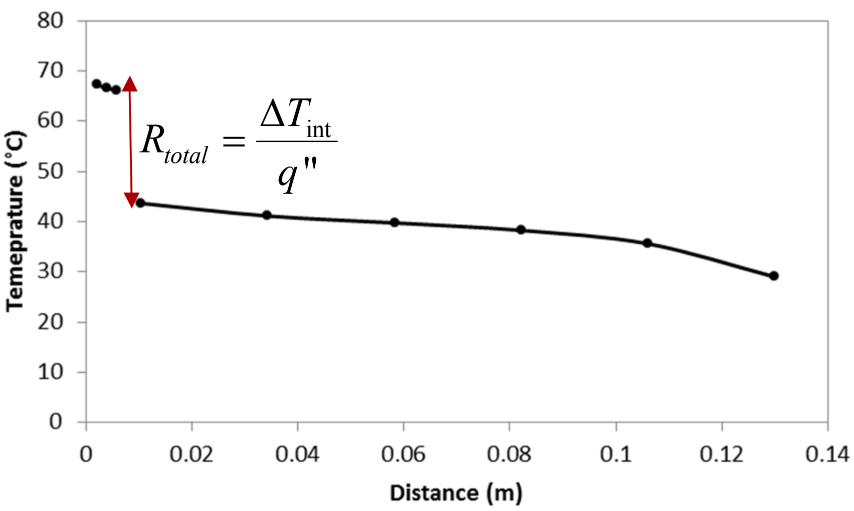
- Minimum chamber pressure: 2 x 10^{-6} torr
  - Capabilities in N_2, Ar, He, air and other gas environments up to 630 torr
- Maximum interface pressure: 10,000 psi
- Temperature range: 20 to 80℃
- Macor heat flux meters (HFMs)
- 10 thermocouples (9 for heat flux meters, 1 for ambient)

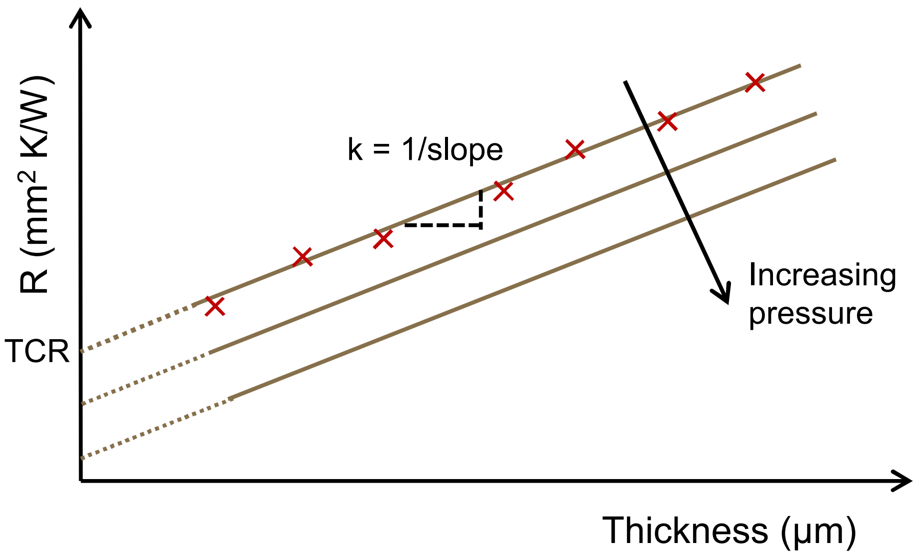


Measuring Thermal Conductivity and Thermal Contact Resistance

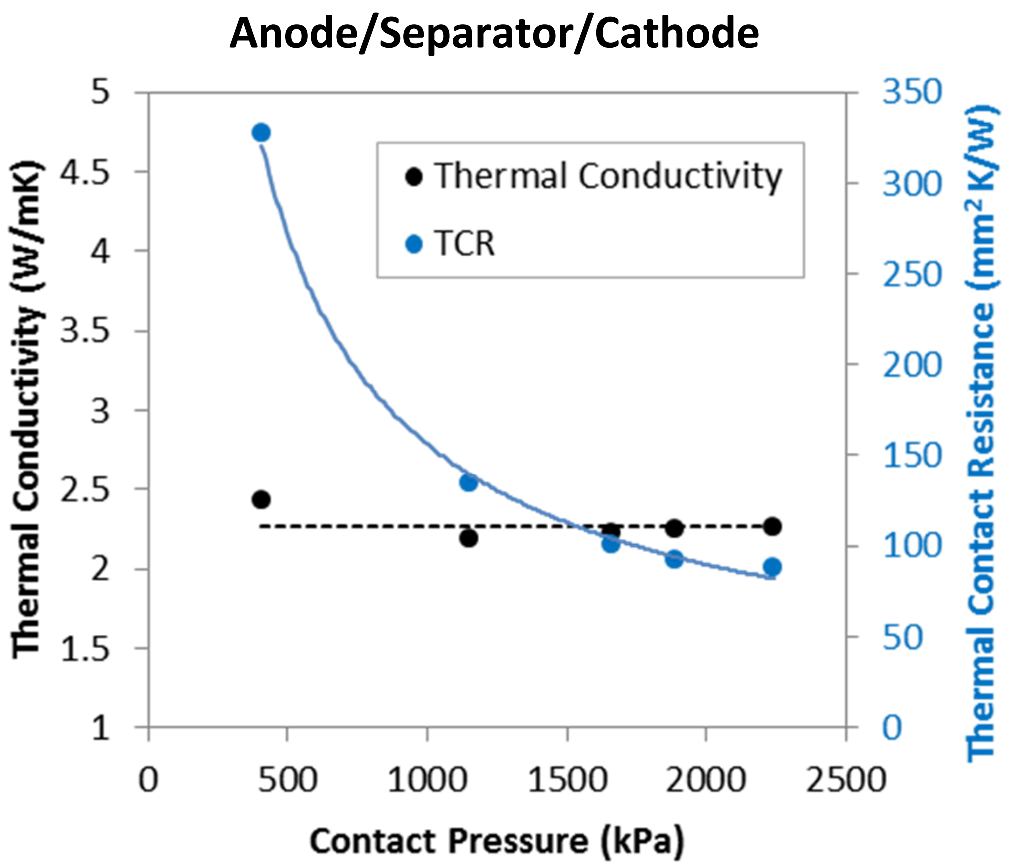


$$R_{total} = R_{bulk} + R_{TCR} = \frac{t}{k} + R_{TCR}$$

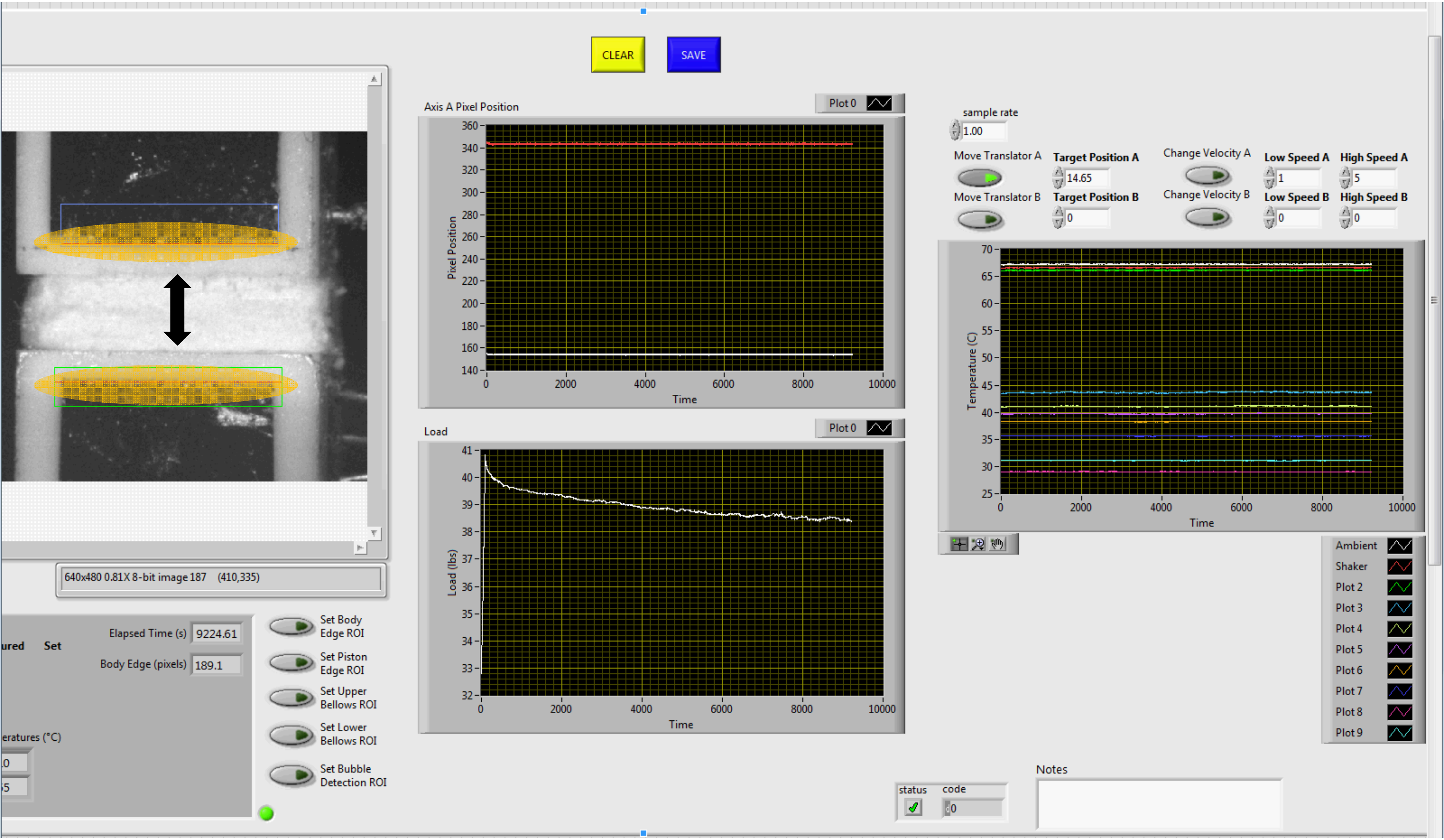




Example

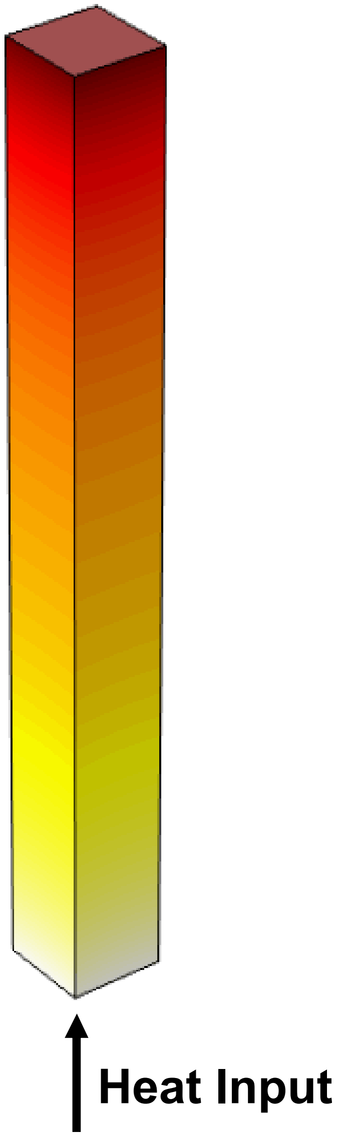

Anode/Separator/Cathode
Thermal Conductivity
TCR
Thermal Conductivity (W/mK)
Thermal Contact Resistance (mm² K/W)
Contact Pressure (kPa)
5
4.5
4
3.5
3
2.5
2
1.5
1
350
300
250
200
150
100
50
0
0
500
1000
1500
2000
2500

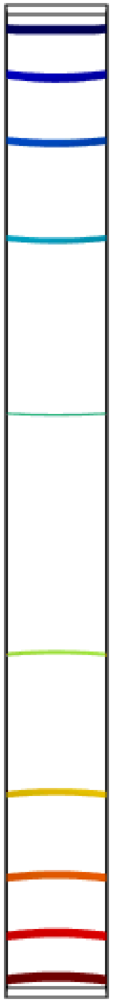
LabVIEW GUI



CLEAR
SAVE
Axis A Pixel Position
Plot 0
Pixel Position
Time
Load
Plot 0
Load (lbs)
Time
sample rate
1.00
Move Translator A
Target Position A
14.65
Change Velocity A
Low Speed A
1
High Speed A
5
Move Translator B
Target Position B
0
Change Velocity B
Low Speed B
0
High Speed B
0
Temperature (C)
Time
Ambient
Shaker
Plot 2
Plot 3
Plot 4
Plot 5
Plot 6
Plot 7
Plot 8
Plot 9
640x480 0.81X 8-bit image 187 (410,335)
Elapsed Time (s) 9224.61
Body Edge (pixels) 189.1
Set
Set Body Edge ROI
Set Piston Edge ROI
Set Upper Bellows ROI
Set Lower Bellows ROI
Set Bubble Detection ROI
status
code
0
Notes

Heat Transfer Mechanisms

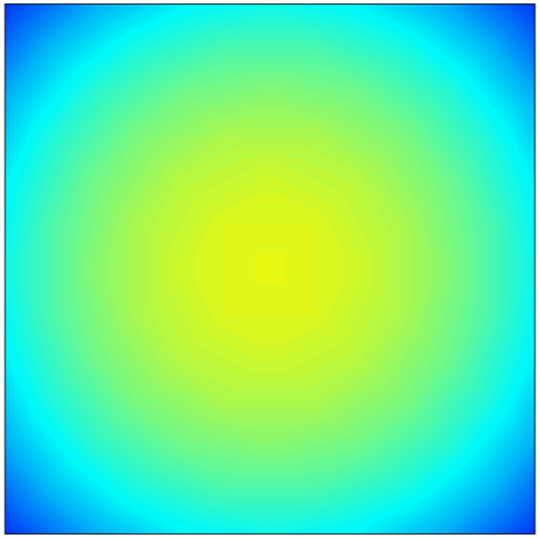


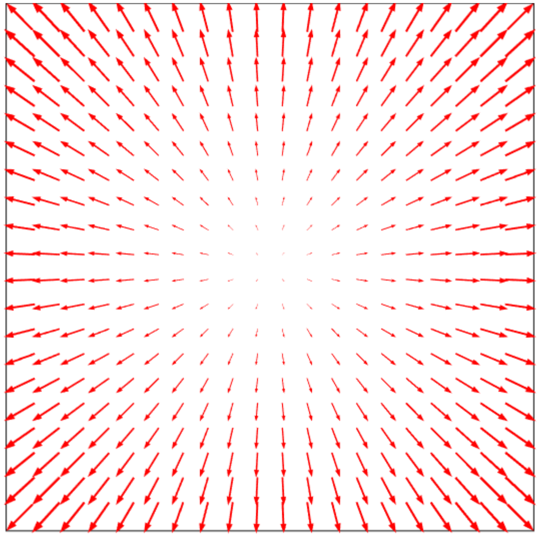


Conduction

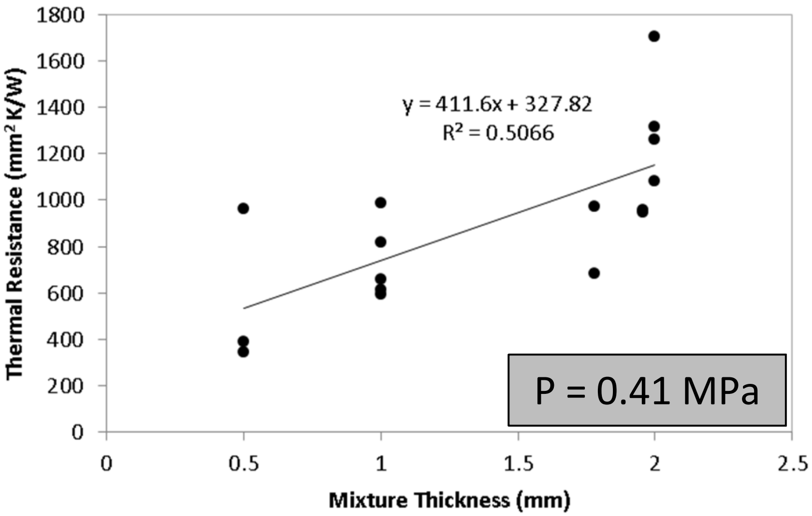
Convection

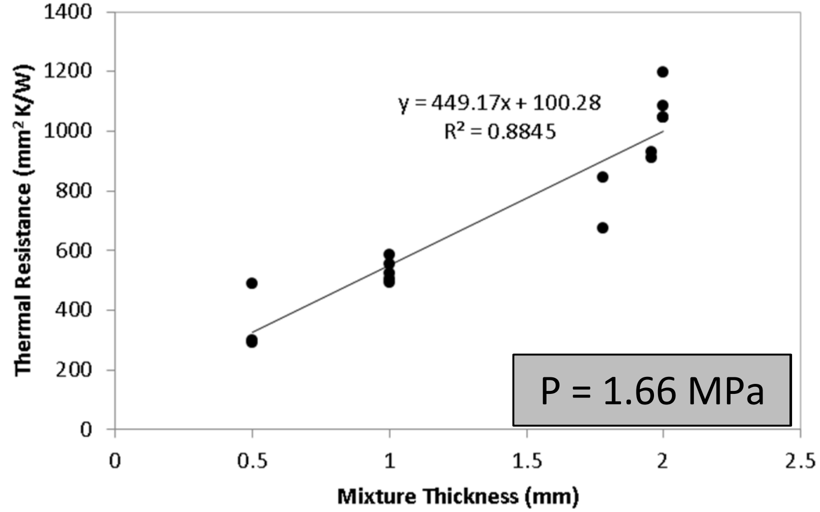
Radiation

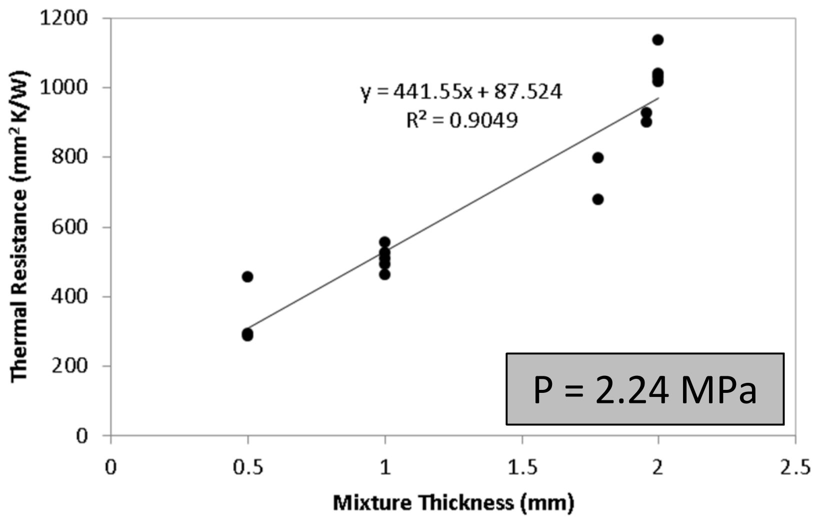




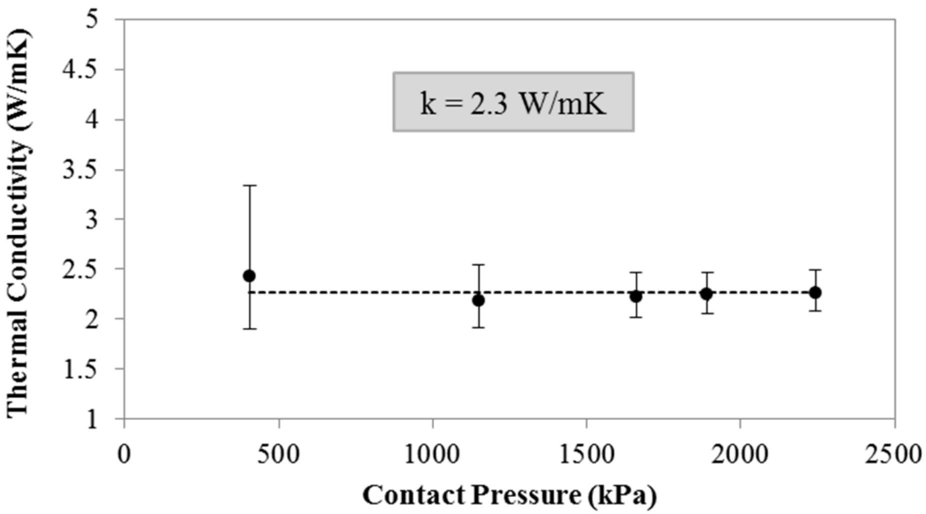
Dependence of Thermal Resistance on Thickness: Separator

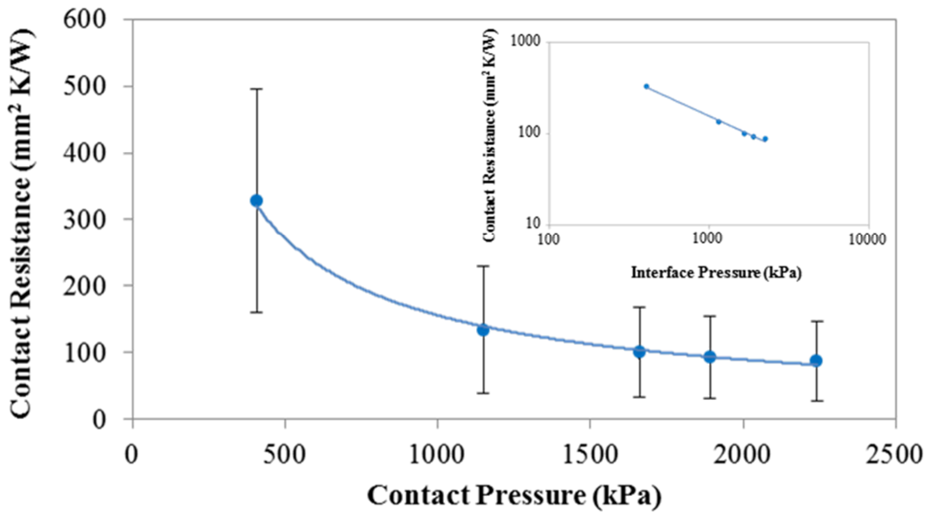






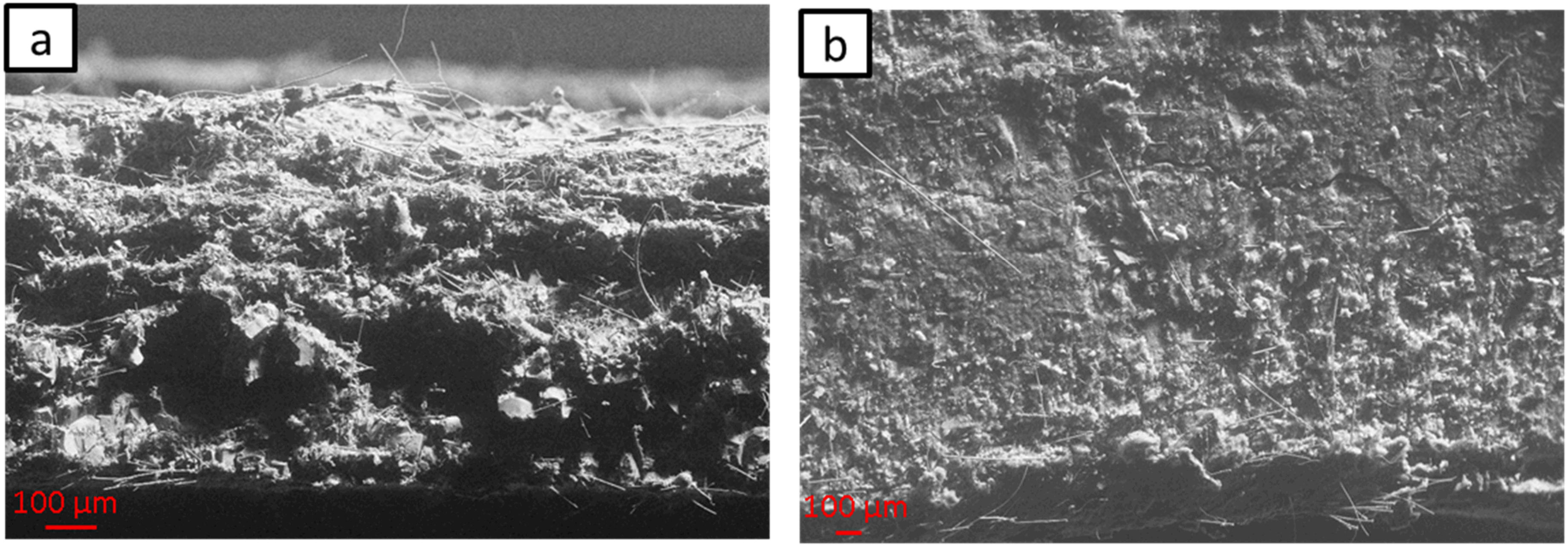
Thermal Conductivity and TCR of Separator





Test Sequence: 350 psi in Air ➔ 350 psi in Vacuum ➔ 500 psi in Vacuum ➔ 500 psi in Air ➔ Unload in Air

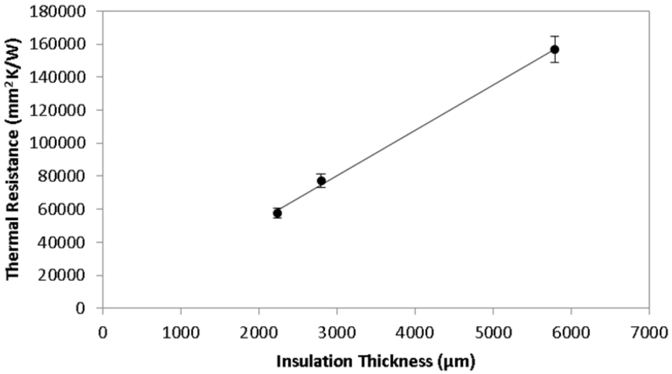
Fiberfax Board and Min-K

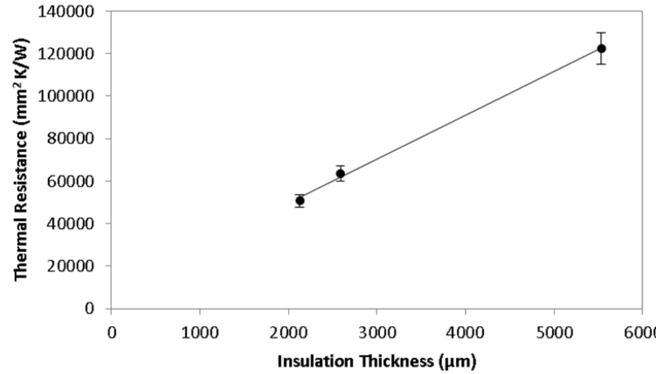


Test Sequence: 350 psi in Air → 350 psi in Vacuum → 500 psi in Vacuum → 500 psi in Air → Unload in Air

Thermal Conductivity of Fiberfrax Board and Min-K

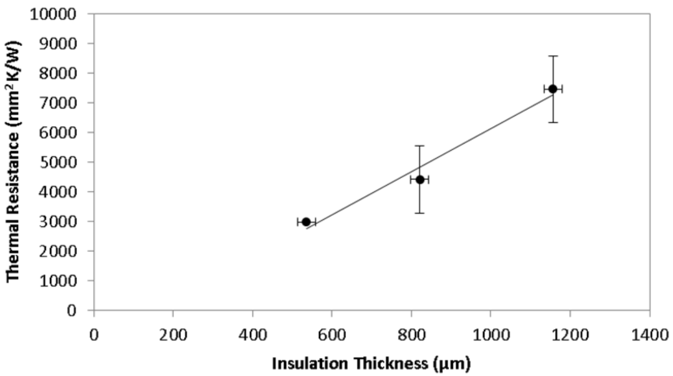
Min-K
350 psi
Air

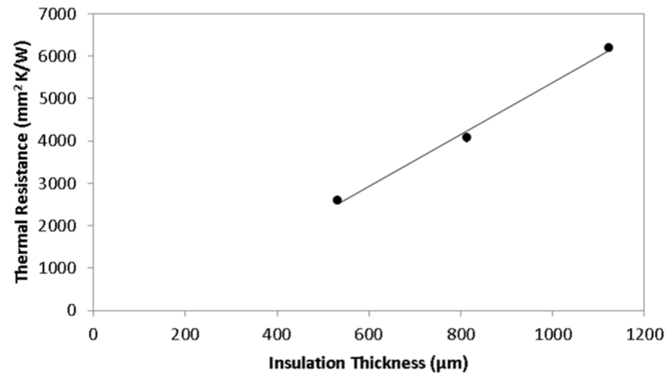




Min-K
500 psi
Air

Fiberfrax
Board
350 psi
Air

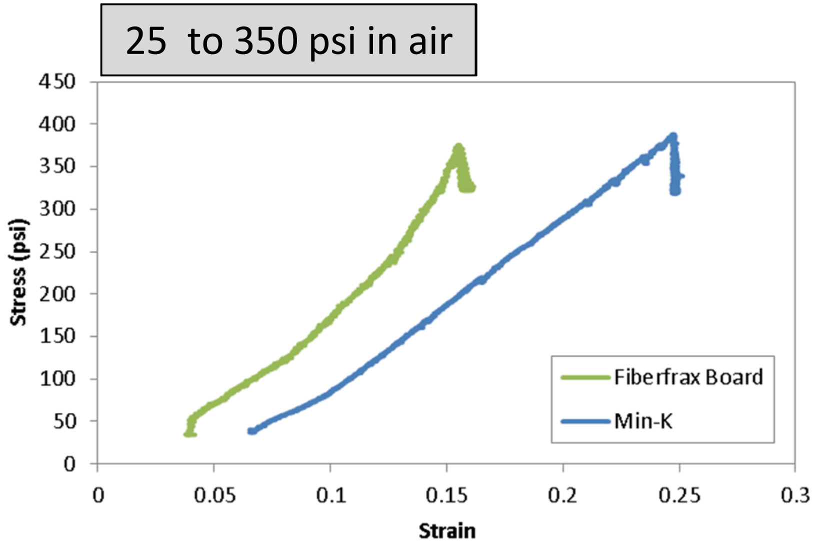


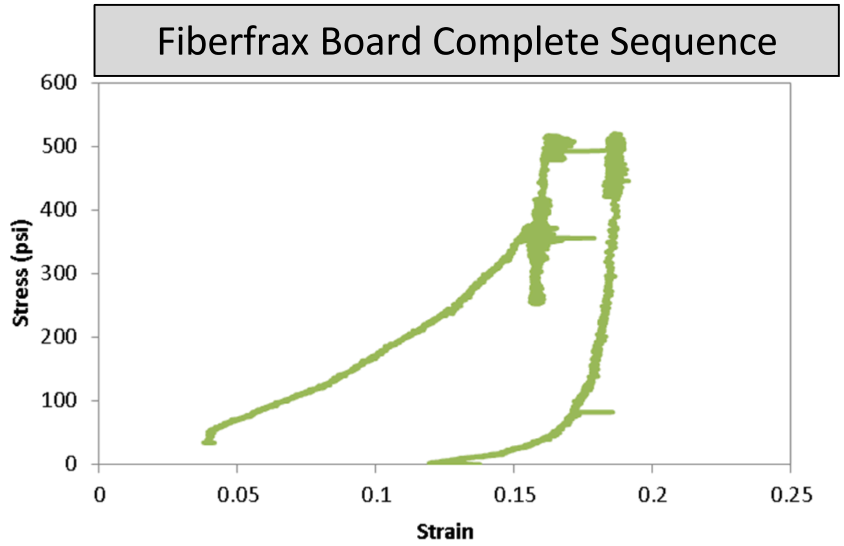


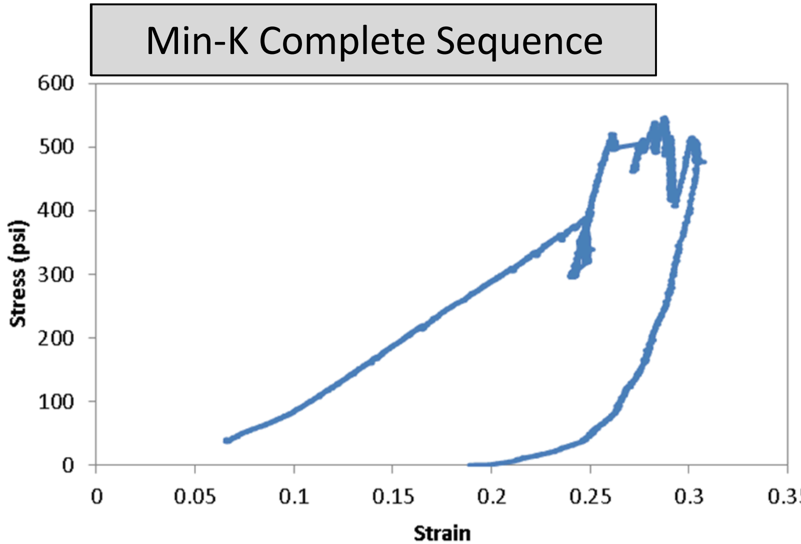
Fiberfrax
Board
500 psi
Air

k (W/mK)	Min-K		Fiberfrax	
Compressive stress (psi)	Air	Vacuum	Air	Vacuum
350	0.036	0.027	0.138	0.079
500	0.048	0.032	0.164	0.092

Compression of Fiberfrax Board and Min-K Materials

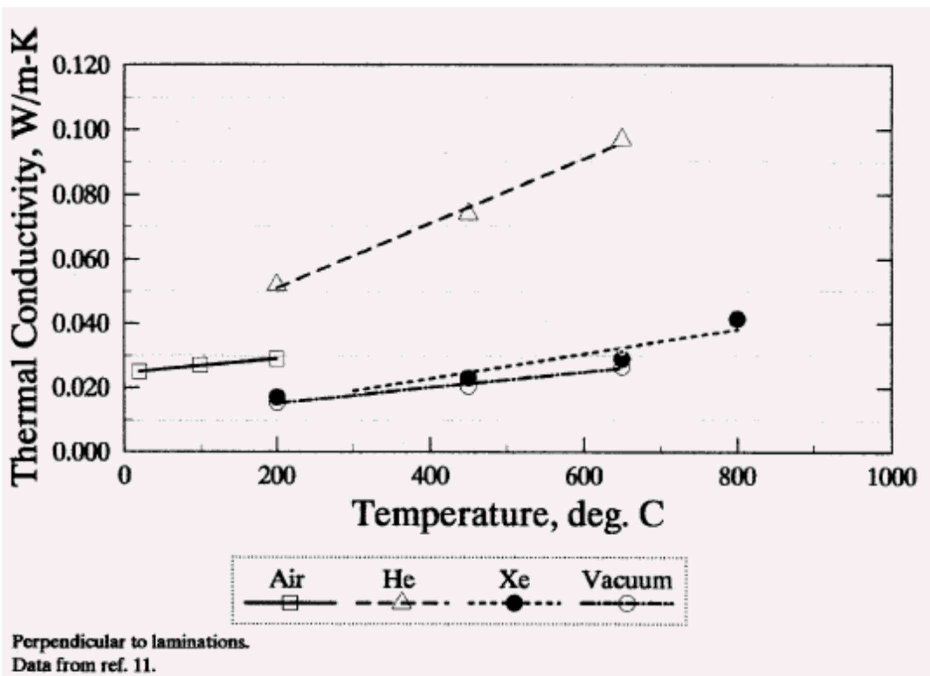


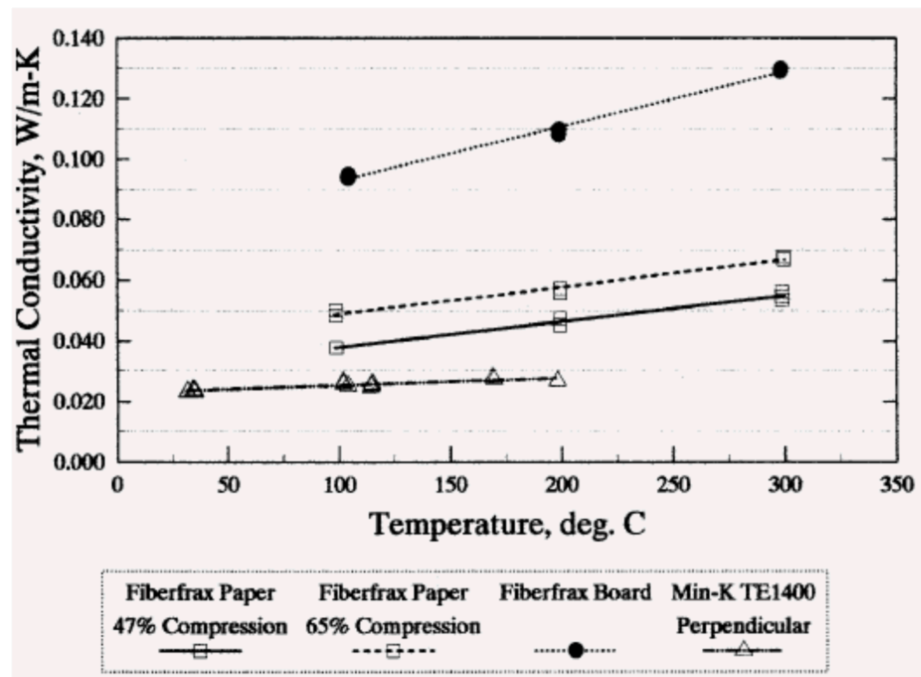




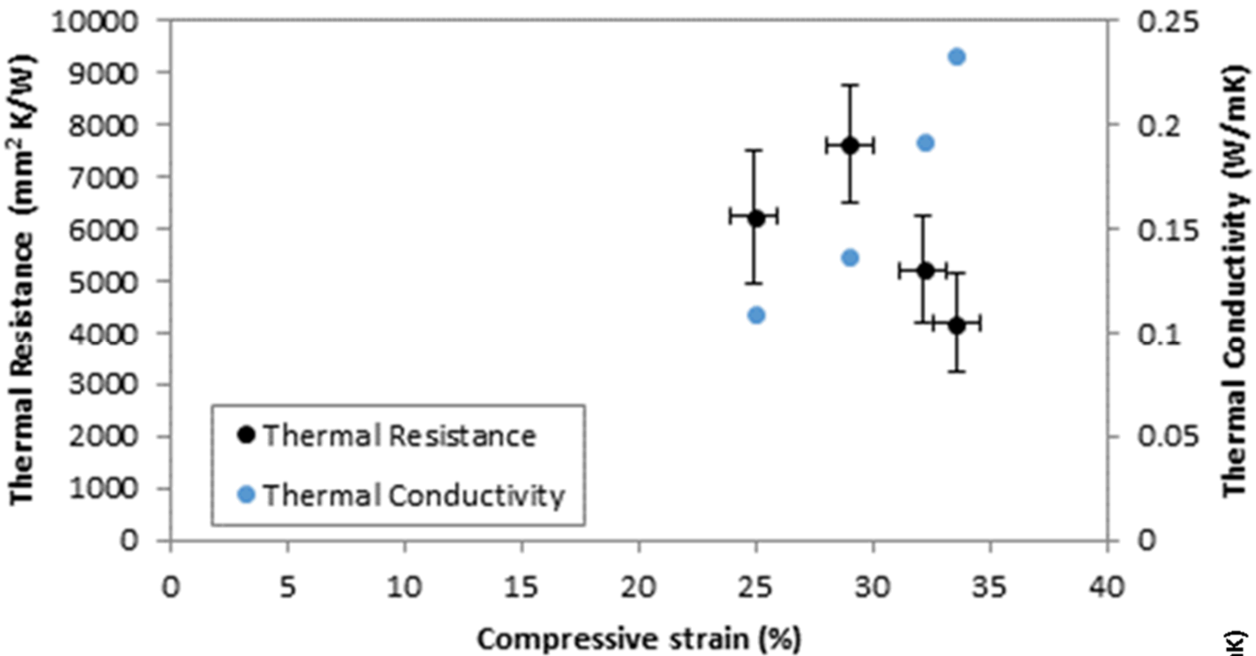
Comparison to Auxiliary Measurements and Citations

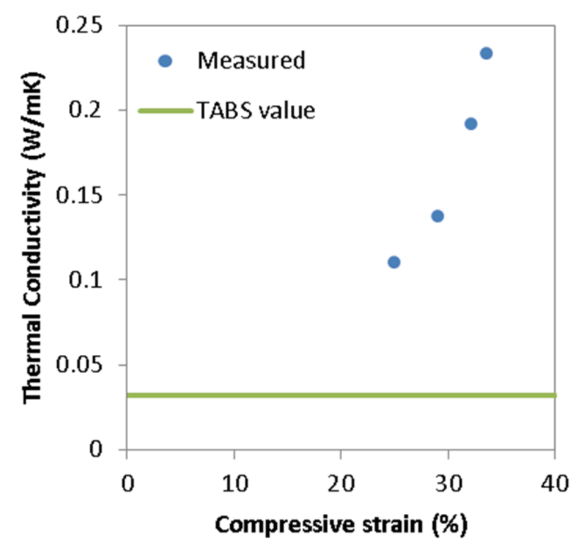
- Commercially available system:
  - Fiberfrax Board: 0.053 W/mK
  - Min-K: 0.037 W/mK
- Reference 3





Fiberfrax Wrap – In Progress





Review

- Introduced versatile measurement apparatus to measure thermal conductivity and TCR
- Materials of Interest
  - Anode/Separator/Cathode
  - Thermal insulation (Fiberfrax Board & Min-K)
- Key Findings
  - Thermal conductivity is dependent on ambient environment and density
- Next Steps
  - Quantify uncertainty in reported values
  - Characterize Fiberfrax Wrap and heat pellet material

References

1. R. A. Guidotti, F. W. Reinhardt, and T. Kaun. "Characterization of Small Vac. Multifoil Containers for a One-Hour Thermal Batt.," *Proceedings of the 40th Power Sources Conference*, pp. 299, 2002.
2. B. L. Trembacki *et al*. "Uncertainty Quantification, Verification, and Validation of a Thermal Simulation Tool for Molten Salt Batteries", *Proceedings of the 47th Power Sources Conference*, 2016.
3. R. A. Guidotti and M. Moss. "Thermal Conductivity of Thermal-Batt. Insulations," Technical Report SAND 95-1649, Sandia National Laboratories, August 1995.
4. "Standard Test Meth. for Thermal Trans. Prop. of Thermally Conductive Elect. Insulation Mat.," Annu. B. ASTM Stand., pp. D5470–06, 2011.
5. C. C. Roberts, M. E. Stavig, S. J. Bauer, P. S. Sawyer, L. A. Moody, and A. M. Grillet, "Characterization of Thermal Battery Separator Mechanical Properties at High Temperatures," *Proceedings of the 45th Power Sources Conference*, 2012.