High-Efficiency Insulation Materials for Fuel Cell Applications

Edward Dan

Solon High School

Mentor: Dr. Yanhai Du

KSU College of Aeronautics and Engineering

Acknowledgements

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Experimental Questions:

- What possible types of insulation can reduce the thickness of insulation around a Fuel Cell?
- How does the insulation thickness affect the effectiveness of the insulation?

Goals:

- Create/combine insulation materials to create a highly efficient and lightweight cover for high temperature fuel cells
- Effectively maintains 800℃ within the cell with no more than 80℃ outside
- Lightweight and requires thinner thickness than current insulation

Materials

- Fuel Cell, heater or furnace
- Thermocouple (measuring range at least from 70C to 810C)
- Computer (with Minitab software)
- Insulating materials to test
  - WDS LambdaFlex 5mm -Morgan Advanced Materials
  - MicroTherm-Promat (to be tested)
- Heat proof gloves
- Ring stand
- Clamps (attachable to Ring stand)
- Transistor (0-150 Volts)
- Inconel Wire
- Ceramic tape
- Aluminum foil

Plan:

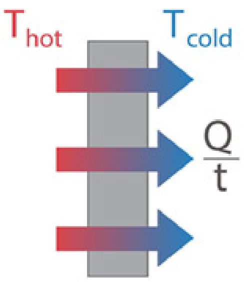
1. Research possible materials and commonly used high-efficiency insulation materials for high temperature usage
2. Purchase and obtain multiple insulation materials to test
3. Design (an) experiment(s) to test effectiveness of insulation materials
   a) find a heater to heat up one side of insulation to 800C
   b) find how to maintain 800C temperature using the heater (calibrate heater)
   c) calibrate/setup multiple thermocouples to test temperatures in different places along the insulation
4. Run experiment & collect data
5. Analyze collected data

Procedures

1. Find insulation material to test
2. Cut insulation material to panels to create a box
3. Cover insulation panels with aluminum foil
4. Bend Inconel wire into a support shape to hold the insulating materials in place
5. Put ceramic tape around insulation “box” to hold insulation in place
6. Setup ceramic heater and insulation materials for experimenting (held in place with ring stand and clamps)
7. Place one insulated thermocouple in the center gap of the ceramic heater
8. Place another insulated thermocouple between the insulation and the ceramic heater (make sure the tip of the thermocouple is not touching the Inconel wire)
9. Place the last thermocouple on the outside of the insulation (hold it in place using ceramic tape
10. Plug the thermocouples into the reader and hold all three together in a bundle using ceramic tape
11. Connect heater to the transistor and the transistor to the wall outlet (AFTER making sure the transistor is on OFF first)
12. Place a piece of ceramic wool lightly on top of the insulation box
13. Turn on auto record temperature on thermocouple reader to every 5 or 10 mins
14. Turn up transistor by 10V and record temperature
15. Repeat step 13 until max voltage of heater or 600 °C
16. Analyze recorded data

Research:

Formula used to calculate the amount of insulation needed to separate certain temperatures from each other:



$$Q = \frac{KA(T_{hot} - T_{cold})}{d}$$

Where:

*Q = Conduction heat transfer (**W**)*

*K = Materials thermal conductivity (**W/mK**)*

*A = Cross sectional area (**m²**)*

*T_{Hot} = Higher temperature (**°C**)*

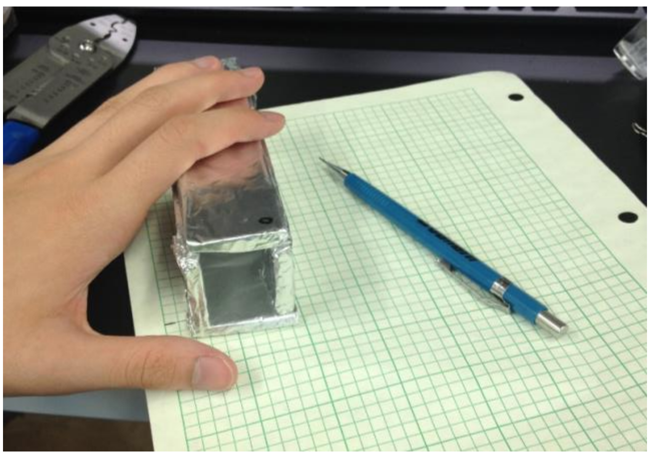
*T_{Cold} = Colder temperature (**°C**)*

*d = Material thickness (**m**)*

[1]

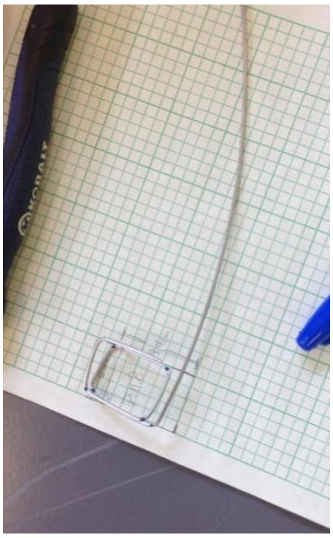
Building

After receiving the LamdaFlex material, it was observed that the material was far from what was expected. Both the 5mm and 10mm sheets seemed to be only slightly flexible. After consulting the salesman for being safe to cut open the outer plastic wrapping, I decided to see if the material is more flexible outside of the wrap. The material is highly fragile. With just a slightly angular bend, the material cracks into smaller pieces and powder spills out. The original design plan was to wrap the material around the ceramic heater to test. However, now seeing that the material is not flexible enough to wrap around the small circumference of the heater, a new plan was devised. Cutting the insulation into rectangles, a box can be made to fit around the heater. The material easily breaks into powder, so the process of cutting and building the box will be difficult.

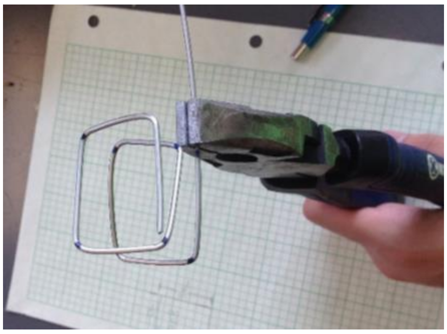


After measuring out the box size dimensions, marks were made on the wrapping to show where to cut. The cutting was done using a ruler and a box cutter/utility knife. For temporary storage before the cutting is finished and the box can be wrapped using ceramic tape (that withstands high temperatures), the cut pieces were wrapped in aluminum foil. The cutting produced large amounts of powder, so a portable vacuum was used to clean up the mess. It was decided to use only the 5mm sheet of insulation due to it being easier to cut and build a box with than the 10mm thick panel. The material is hard to cut due to how fragile and how easily it breaks into smaller pieces and powder.

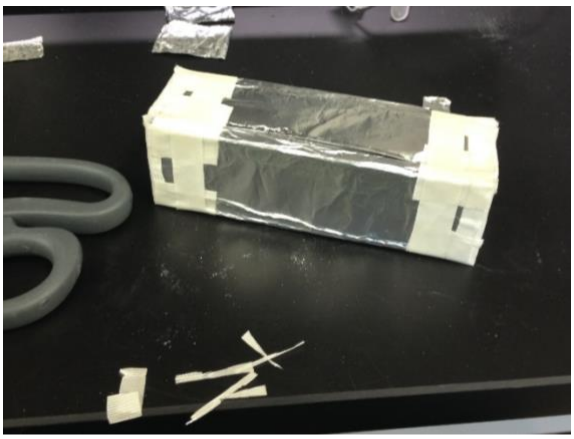
Creating the Inconel wire structure

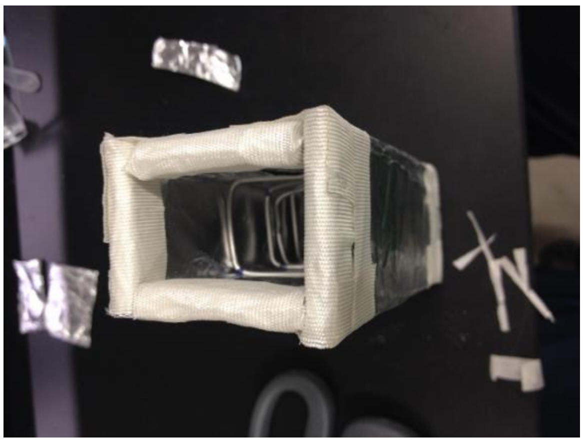


It was decided to use a spiral shape for the Inconel wire support for the insulation to provide it maximum support at high temperatures. The Inconel material is a special material that can withstand high temperatures. It is also a very hard and tough material and was very difficult to bend to the proper shape.

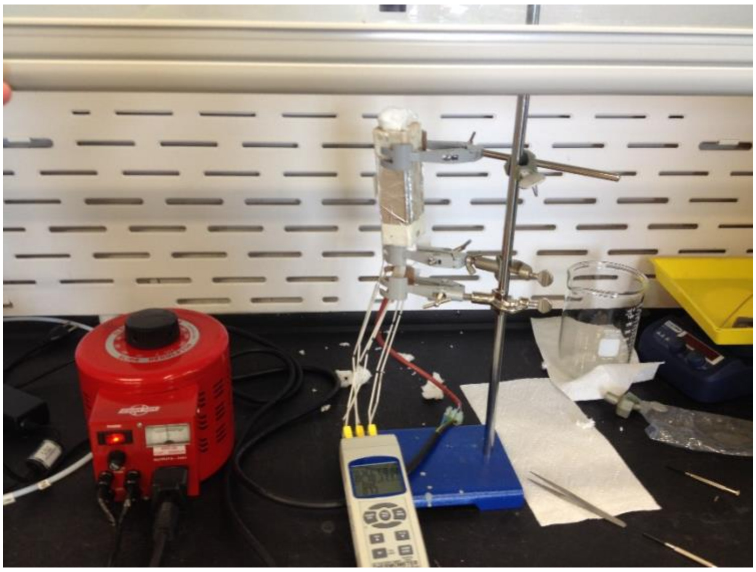


The setup of the insulation material in the ring stand covering the ceramic heater. The Inconel wire was made sure not to touch the ceramic heater to prevent temperature differences between the heater and the surrounding to prevent breakage of the heater.





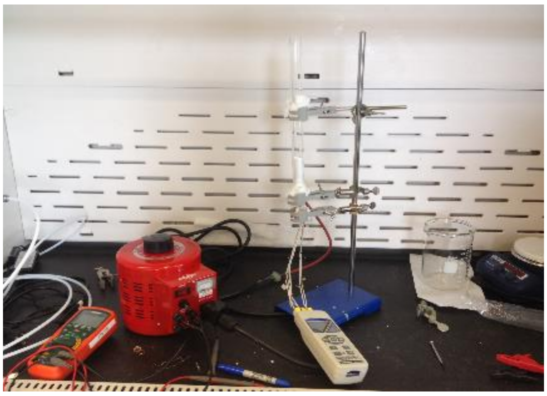
The thermocouples setup with the heater and insulation

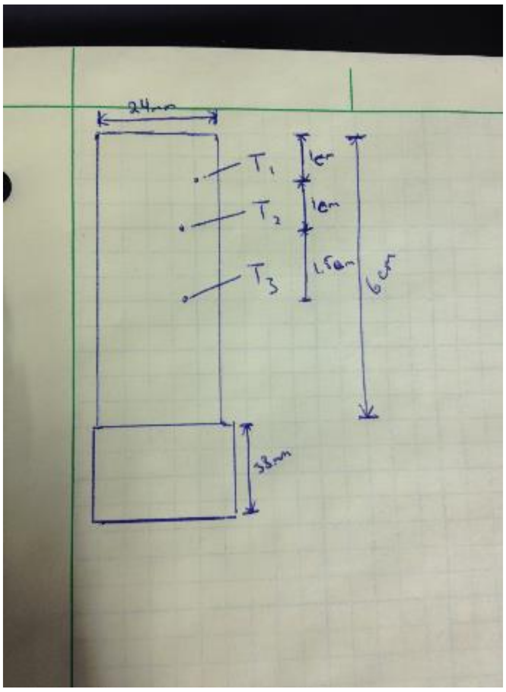


(Ceramic wool was placed on top of insulation to bring up temperature inside of insulation.)

Tests/Experiments/Results

Tubular shaped ceramic heater calibration conducted using 3 thermocouples placed inside different areas within the heater connected to the transistor with everything held in place with a ring stand. A quartz tube (decent insulator) was placed around the ceramic heater to prevent air flow around the heater from disrupting the data. The tube was held in place using a ring stand clamp with some fiberglass cloth. The ceramic heater was held in place in the same way, however, the base of the ceramic heater needed to be fully covered and insulated with the fiberglass cloth to prevent the high temperature of the heater from damaging the base where the electrical wires are. The thermocouple wires going into the ceramic heater is semi-insulated using ceramic tubes cut into sections. It is difficult to find insulated, high-temperature thermocouples that are thin enough in diameter to fit multiple into the ceramic heater for testing. Below (left) is a drawn diagram of the thermocouple placements in the ceramic heater.

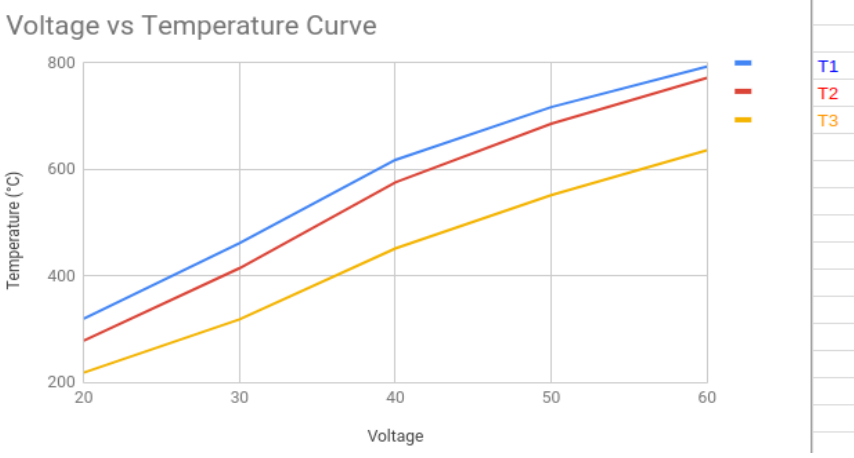




Data was collected by moving the voltage input up by 10 Volts every 10 minutes. Data was collected every 10 minutes. Data was collected while the input ranged from 20 Volts to 70 Volts. Below (right) is the table of data collected.

	Voltage	T1 max	T2 max	T3 max
1	20	320	279	219
2	30	462	415	319
3	40	618	576	452
4	50	717	686	552
5	60	793	772	636
6	70	800+		

The data is drawn in a line graph below.



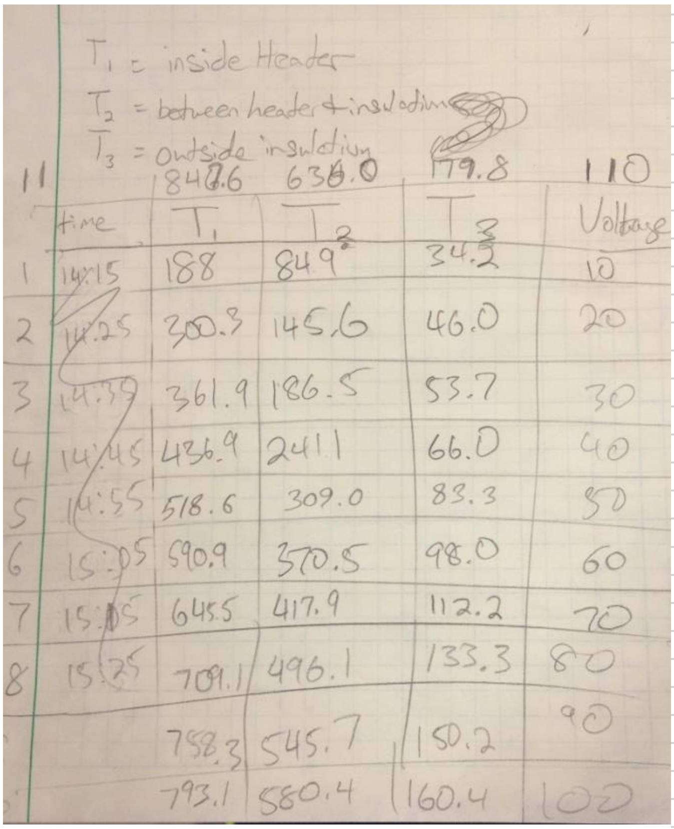
Since the T1 temperature probe was placed slightly above the middle the heater, it resulted in measuring the highest temperature every time. As the temperature and voltage of the ceramic heater increases, the difference between T1 and T2 decreases. Near 800C the T1 and T2 temperature differences are around only 20C. Considering the error from measuring in different locations within the heater, when testing the insulation efficiency, locations near T1 and T2 will be used. Locations in the bottom half of the ceramic heater will not be used because the difference between T1 and T3 seems to increase as the temperature & voltage increases. Using T3 would result in data being measured at a completely different temperature. When T1 was at 793C, T3 was at 636C—a 153C difference.

Insulation Test

T1 = inside hole of ceramic heater
T2 = between heater and insulation
T3 = outside of insulation, taped to surface of insulation

Max temperatures recorded during every voltage increase of 10 (left hand-drawn table).

All data recorded with auto-recording every 5 minutes.



T1 = inside Heater
T2 = between heater + insulation
T3 = outside insulation

	time	T1	T2	T3	Voltage
11		846.6	636.0	179.8	110
1	14:15	188	84.9	34.2	10
2	14:25	300.3	145.6	46.0	20
3	14:35	361.9	186.5	53.7	30
4	14:45	436.9	241.1	66.0	40
5	14:55	518.6	309.0	83.3	50
6	15:05	590.9	370.5	98.0	60
7	15:15	645.5	417.9	112.2	70
8	15:25	709.1	496.1	133.3	80
		758.3	545.7	150.2	90
		793.1	580.4	160.4	100

Max temperature reached by the heater inside the insulation (T2) is 635.4°C. Max temperature reached on the outside is 180.5°C (T3). The insulation used for this test was 5mm thick WDS LambdaFlex. The high temperature reached outside was higher than the goal of reaching only 80°C outside.

The sample that was used for testing was too thin to be enough insulation (calculations require at least 6.5mm). Also there is additional heat loss due to the panels being wrapped with aluminum foil to prevent crumbling. The aluminum foil must have transferred some heat from the inside of the box to the outside through conduction.

T1	T2	T3
22.3	22.4	22.1
129.4	50.8	25.9
169.3	71.7	31.1
183.3	81.2	33.4
191.4	85.6	33.9
275.8	123.8	40.4
295	140.2	44.3
310.2	149.1	46.5
350.2	174.1	49.6
358	182.9	53.5
361.2	185.8	54.7
416.9	217.6	58.7
433.2	235.2	63.7
437.1	240.7	66
502.1	284.5	72.1
515.1	301.6	78.8
517.3	306.6	81
518.3	308.4	82.8
522.6	310.5	83.1
582.6	358.7	92
589.5	368.7	97
615.3	384.7	99.5
641.4	411.8	108.8
644.7	416.6	112.9
687.6	465.4	118
706.4	490.9	131.2
709.1	495.9	133.5
754.8	536.8	143.5
757.9	544	149.3
756.9	544.2	150.7
758.3	545.6	150.5
757.7	545.4	149.9
787.7	569.8	153.4
794.2	580.3	159.9
835.4	615.4	165.3
845.2	631.2	177.1
846.7	633.9	172.7
846.9	634.6	180.5
845.6	634.3	179
847.2	635.3	176.6
847.2	635.4	175.7
846.6	634.8	176.6
846.7	635	177.9
845.8	634.4	180.2
847.1	635.4	179

Next Step

Due to a purchasing order processing mistake, the second material, MicroTherm, was not received by the committed date of July 20. The PO was placed again at Aug 2 and processed successfully. The material will be tested in the fall after material arrives.

Conclusion

From the results collected with the 5mm WDS LambdaFlex material, it proves the calculations of requiring at least 6.5 mm of insulation. But because the material is not flexible enough to wrap around the heater without breaking, the material had to be cut into a box shape to fit around the heater. This broke the structure of the insulating material and left gaps in the corners of the boxes leaving spaces for heat loss. This means that with this experimental setup, thicker than 6.5 mm of insulation would be needed to maintain temperatures to be less than 80°C outside the insulation.

References

1. https://thermtest.com/thermal-resources/conduction-calculator