Carbon Foam for Fuel Cell Humidification

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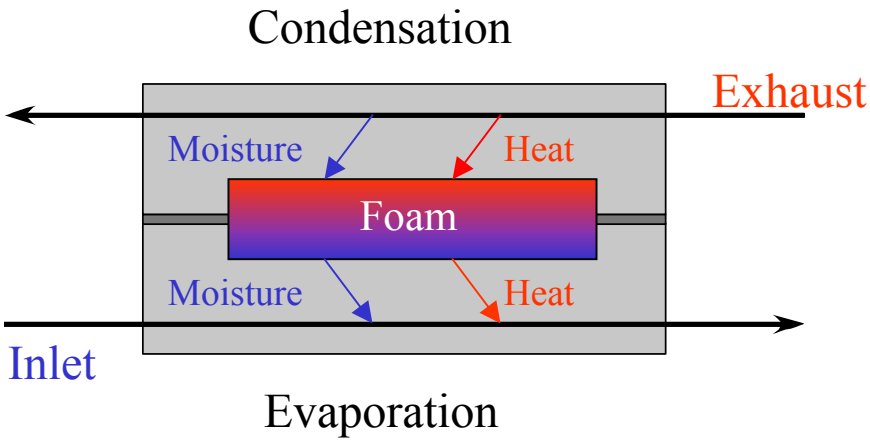
Graphite Foam for PEM Fuel Cell Humidification

➢ Research Objective

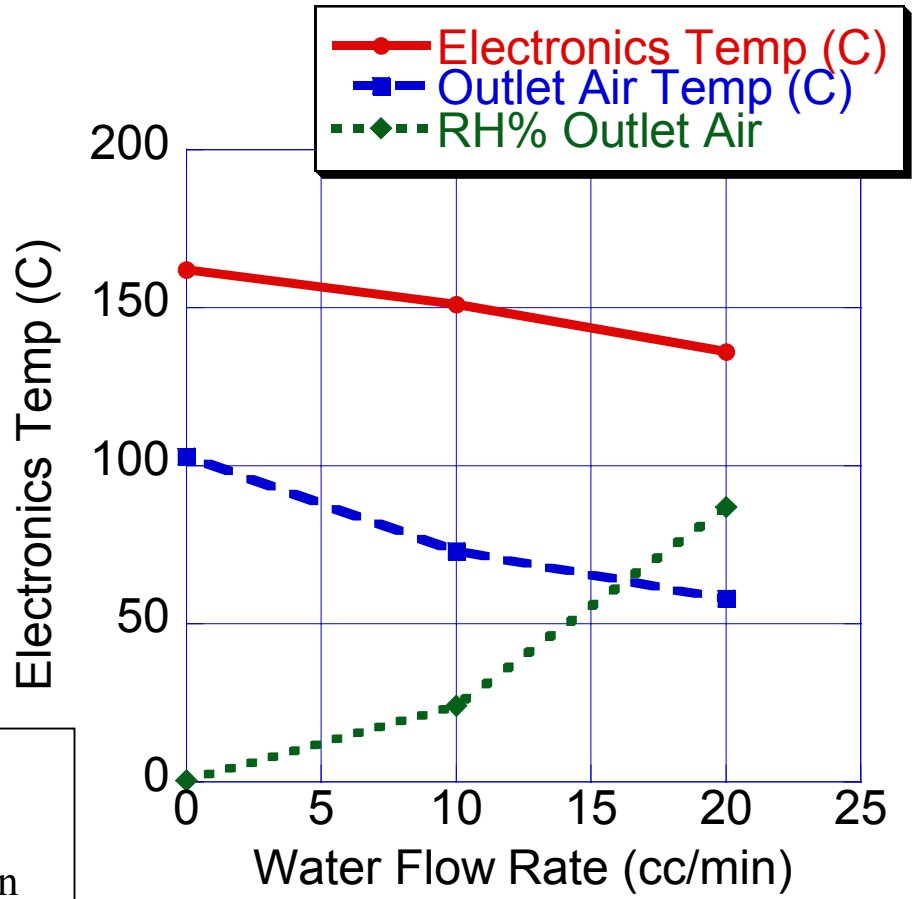
- Develop efficient designs for humidification systems for PEM fuel cells utilizing high thermal conductivity graphite foam
- Collaboration with Porvair Fuel Cell Technology
  - ➔ Expertise in heat exchange and recovery units
- Substitute graphite foam into a recovery unit illustrated below

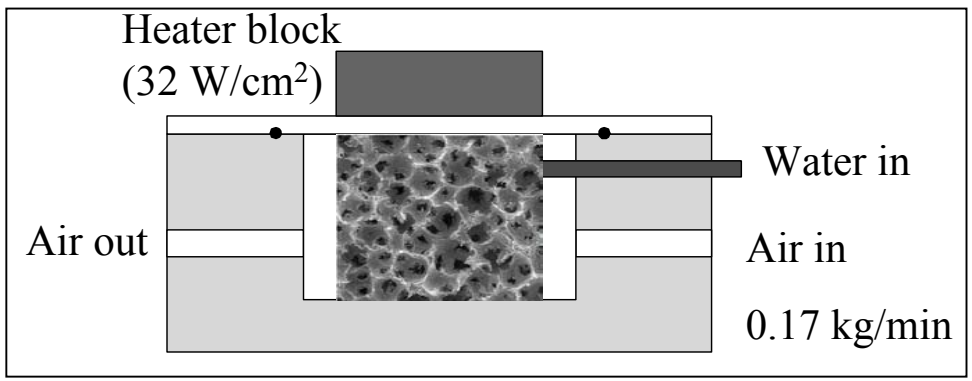


Schematic of heat/moisture recovery unit

Graphite Foam as a Humidifier

- Tests conducted to quantify the foam's ability to saturate air with water
  - With increased water flow rate into the foam
    - ➔ Decreased simulated electronics temperature (heater block)
    - ➔ Decreased outlet temperature
    - ➔ Increased RH of outlet air



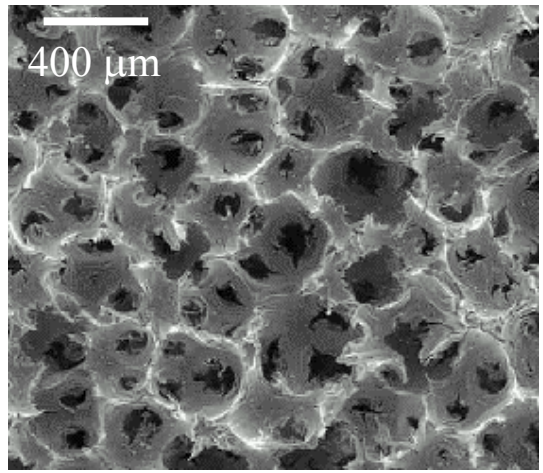


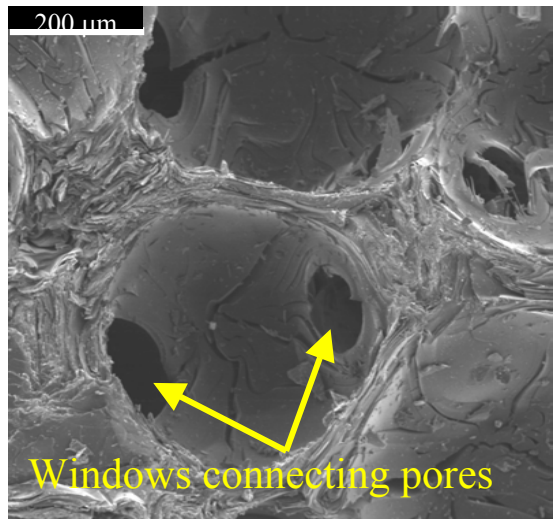
Current Status of Research

- Previous results show that the graphite foam has the ability to wick water by capillary action
- Goals for the graphite foam recovery unit
  - Maximize the recovery of the water from the outlet side of a fuel cell by condensation
  - Wick the water in order to evaporate it on the inlet side
  - Transfer adequate heat from exhaust side to inlet side
    - ➔ Ideal inlet conditions – saturated air at 80°C
- Current recovery units utilizing metal and ceramic foams
  - Not able to remove adequate heat from exhaust side to increase the temperature of inlet side – not able to deliver saturated air at 80°C
- Apply existing mathematical model to optimize humidification system with the graphite foam to obtain conditions that give:
  - Lowest pressure drop in system
  - Highest humidification of inlet air
  - Adequate heat flow to inlet air from exhaust

Near Term Research Tasks

- Evaluate the pore structure of the graphite foam
  - Optimize the pore structure to allow adequate capillary action to occur by condensation of water from the exhaust side in order to humidify the inlet air by evaporation
  - Determine what processing parameters control the size of the windows that connect the pores
    - ➔ The size of the windows will have a significant role in the capillary action of the graphite foam

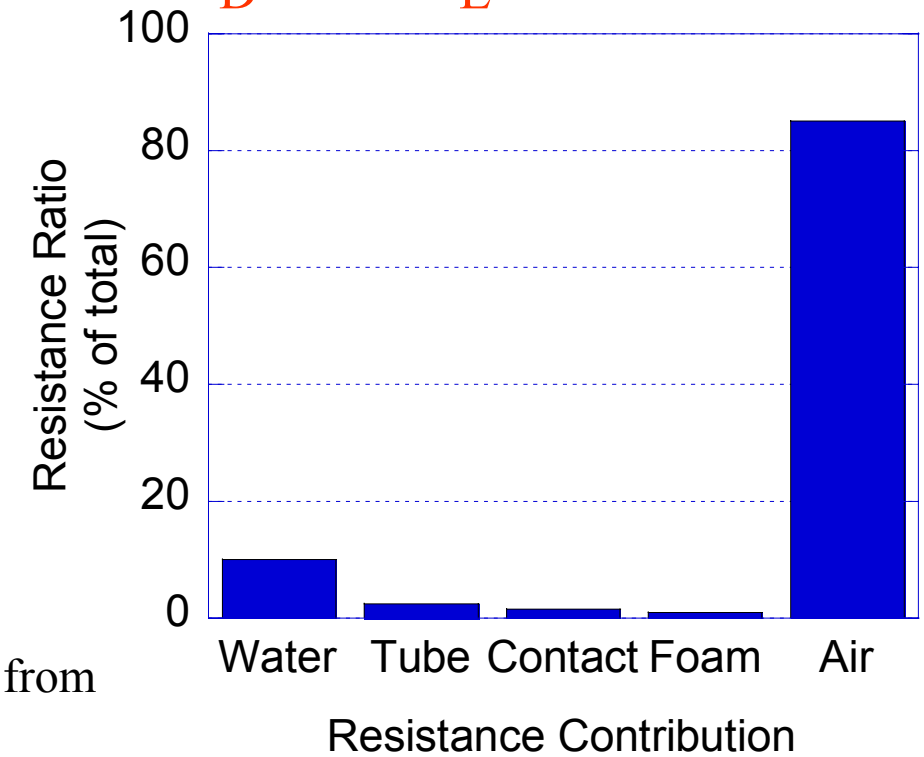




Resistance Model for Graphite Foam Radiator

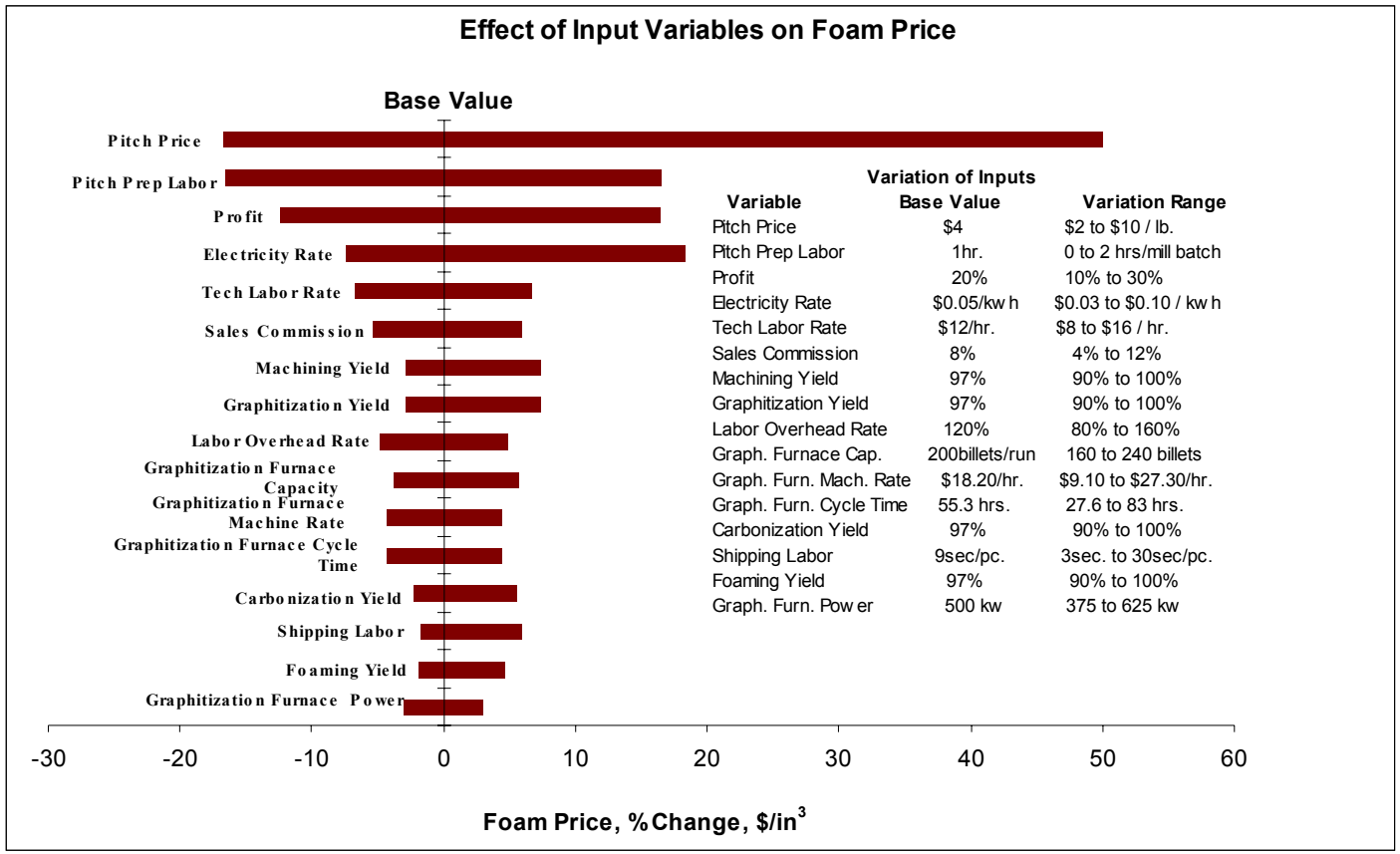
A B C D E

A	Convective resistance of water
B	Conductive resistance due to tube
C	Conductive resistance due to tube/foam contact
D	Conductive resistance due to foam
E	Convective resistance of air



- Highest resistance is on the air side
  - Function of how the heat is removed from the surface of the foam by air
- Shows that high thermal conductivity is not as crucial for radiator applications, possibly able to reduce cost by reducing furnace time, or a different type of pitch
- The foam's pores structure plays a significant role on being able to reduce the convective resistance of the air

Cost Model for Graphite Foam Production



Variation of Inputs

Variable	Base Value	Variation Range
Pitch Price	$4	$2 to $10 / lb.
Pitch Prep Labor	1hr.	0 to 2 hrs/mill batch
Profit	20%	10% to 30%
Electricity Rate	$0.05/kwh	$0.03 to $0.10 / kwh
Tech Labor Rate	$12/hr.	$8 to $16 / hr.
Sales Commission	8%	4% to 12%
Machining Yield	97%	90% to 100%
Graphitization Yield	97%	90% to 100%
Labor Overhead Rate	120%	80% to 160%
Graph. Furnace Cap.	200billets/run	160 to 240 billets
Graph. Furn. Mach. Rate	$18.20/hr.	$9.10 to $27.30/hr.
Graph. Furn. Cycle Time	55.3 hrs.	27.6 to 83 hrs.
Carbonization Yield	97%	90% to 100%
Shipping Labor	9sec/pc.	3sec. to 30sec/pc.
Foaming Yield	97%	90% to 100%
Graph. Furn. Power	500 kw	375 to 625 kw

- Cost model shows the ability to significantly reduce the manufacturing cost of the graphite foam by taking advantage of several factors such as:
  - Low cost pitch if appropriate for the given graphite foam application
  - Less furnace time if full graphitization is not needed for given application
- This shows that for a given application it may be possible to tailor the cost such that graphite foam has a similar cost as currently employed materials for that application

Research Tasks/Future Work

- Collaborate with Porvair Fuel Cell Technology in the following areas:
  - Modify current bench top test rig in order to correlate the pore/window size with the graphite foams ability to wick water by capillary action
  - Evaluate what effect altering the pore/window size has on the thermal properties of the graphite foam
  - Build a full scale recovery unit utilizing the graphite foam
- Need to recover as much water from the exhaust in order to minimize carrying water onboard vehicle
- Need to capture as much heat as possible from exhaust to adequately heat the inlet air to 80°C

Millstones

- 2003
  - Identify a pore size of graphite foam that will effectively wick water (by capillary action) and transfer heat through the foam for use in a humidification system that will deliver saturated air at 80°C
    - ➔ Currently on track
- 2004
  - Collaborate with a component manufacturer to build and test a full scale humidification system that utilizes graphite foam to condense moisture from the exhaust and reduce or minimize water additions.
    - ➔ Contacts have been made and discussions have been started on how best to attack this issue
- 2005
  - Work alongside a fuel cell manufacturer to field test a graphite foam recovery unit on a PEM fuel cell