TFAWS Interdisciplinary Paper Session

Proof of Concept Design and Analysis of Heat Reutilization of a Solid Oxide Electrolyzer Cell for Oxygen Supply

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Presented By
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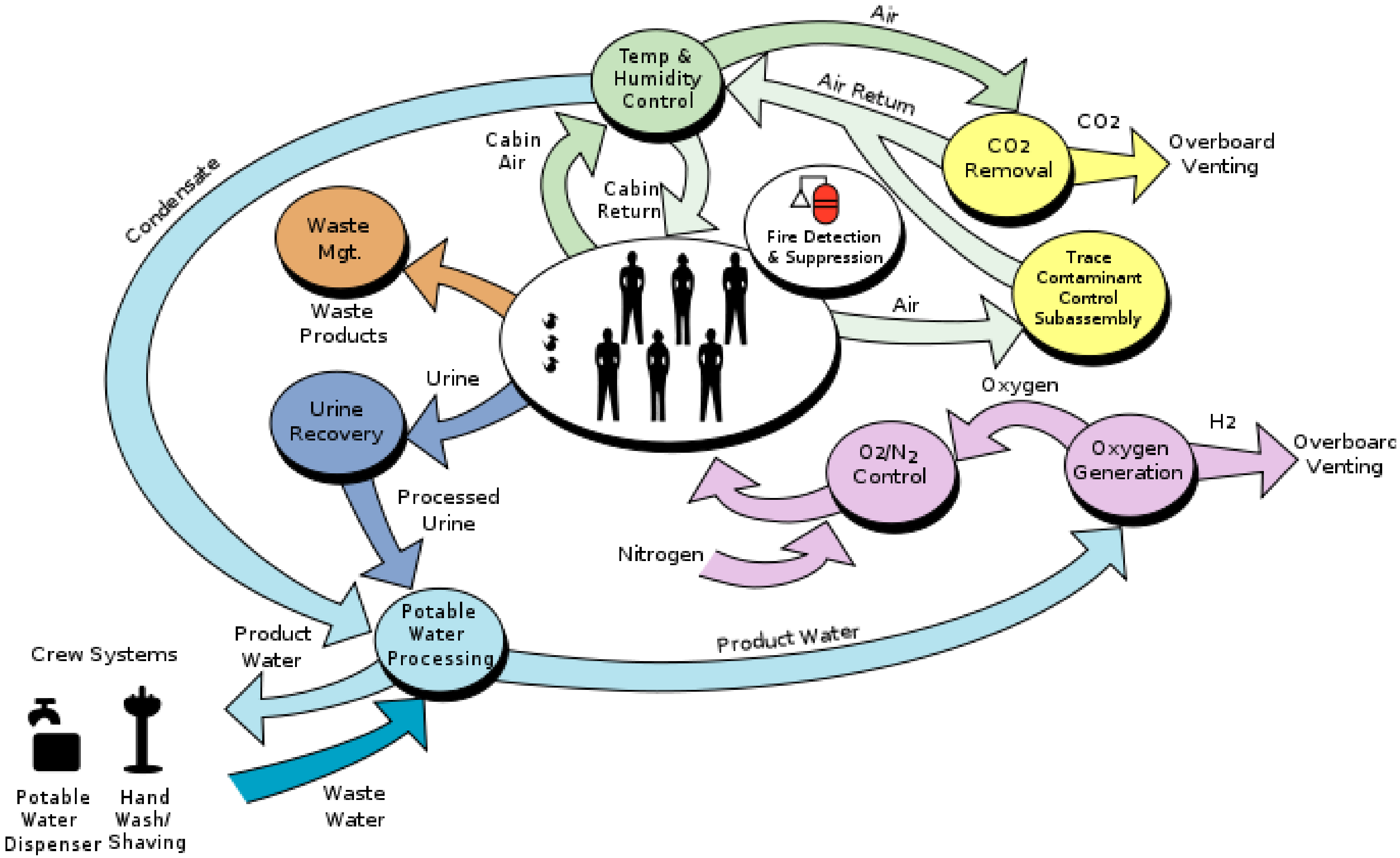
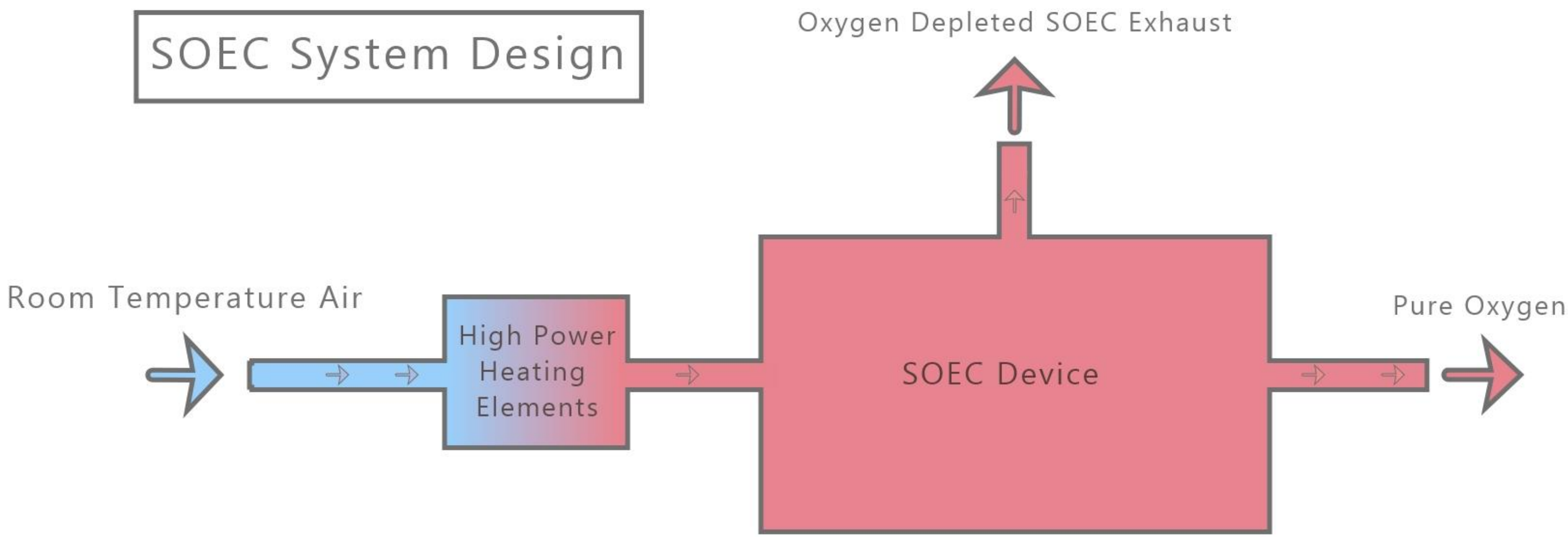
Innovation

A ONCE IN A LIFETIME GETAWAY
THE GRAND TOUR
JUPITER / SATURN / URANUS / NEPTUNE
EXPERIENCE THE CHARM OF GRAVITY ASSISTS
EVERY 175 YEARS
NOW BOARDING
VISIT THE
HISTORIC SITES
MARS
MULTIPLE TOURS AVAILABLE

Current Oxygen Production Systems



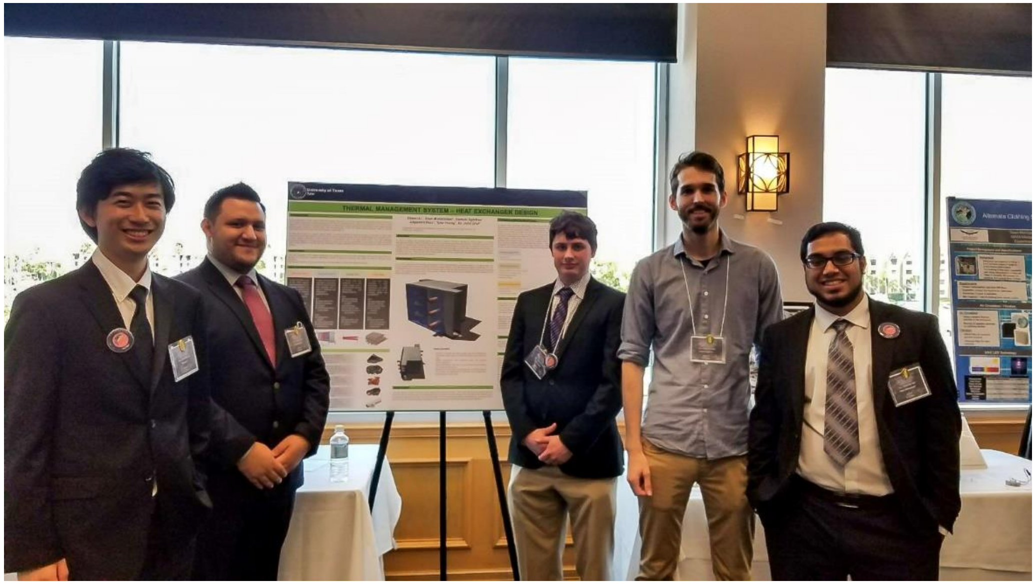
Solid Oxide Electrolyzer Cell



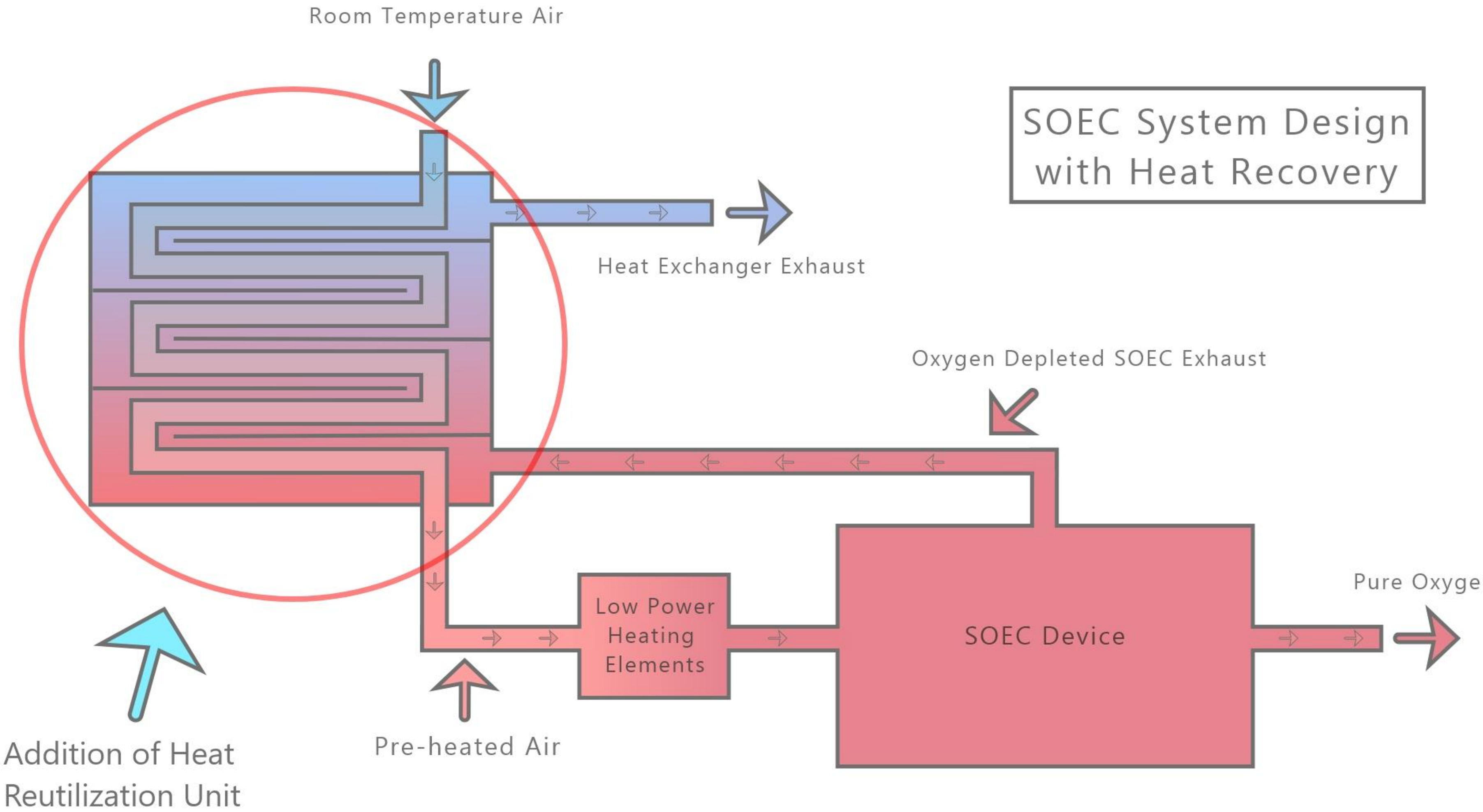
Road to Implementation

- Reliable large scale thermal management capabilities
  - High Temperature Operation
  - Minimize Power Consumption
- Scale in-situ oxygen production to more than 10 kg/day

Student Partnership



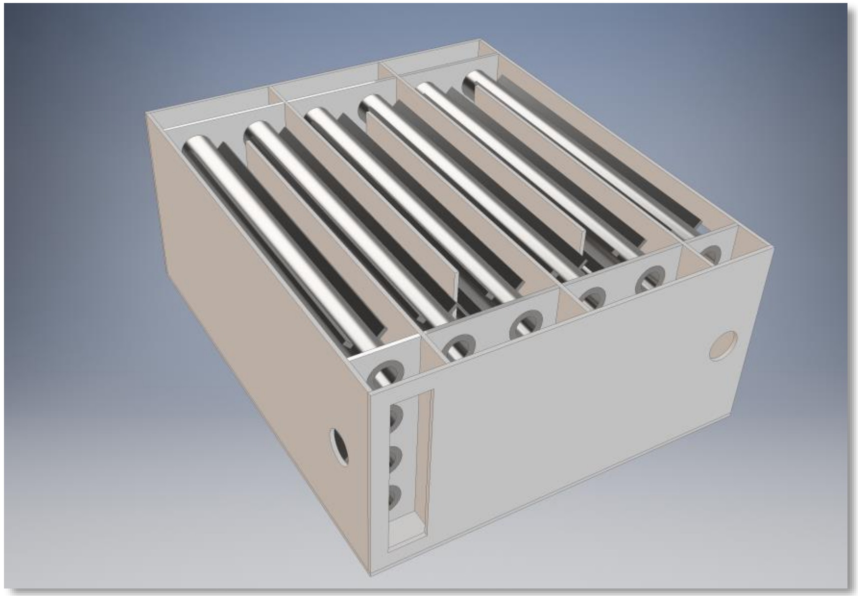
Project Design Goal

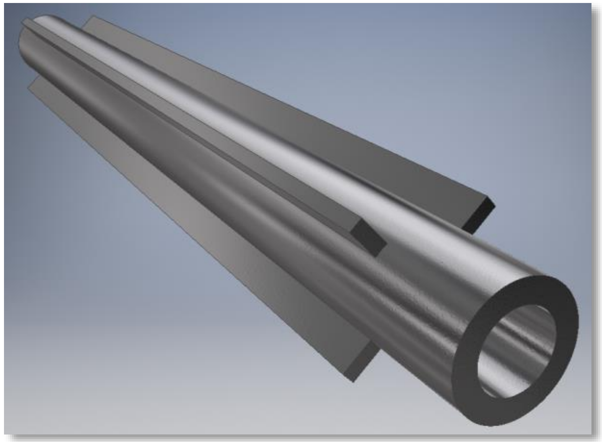


Design Phase

Heat Exchanger Design Pugh Chart				
Desired Properties	Double-Pipe	Plate	Cross-Flow	Shell and Tube
Pressure Drop	0	-	0	0
HX size	-	+	+	0
HT surface Area	0	+	+	+
Cost	+	-	-	0
Simplicity of Design	+	0	0	0
Ease of Manufacturing	+	-	-	0
Durability	0	+	0	0
Maintenance	+	0	0	0
Availability of Parts	+	-	-	+
Effectiveness	-	+	-	+
Design Flexibility	-	+	+	+
Total	**2**	**1**	**-1**	**4**
Rank	**2**	**3**	**4**	**1**

Final Design





Experimental Results

Shell		Tube	
Temperatures [$°C$]		Temperatures [$°C$]	
Inlet (t_1):	23.7	Inlet (T_1):	559.1
Outlet (t_2):	206.8	Outlet (T_2):	88.7
Differential (ΔT_s):	183.1	Differential (ΔT_t):	470.4
Mass Flow Rate [$^{kg}/_{s}$]		Mass Flow Rate [$^{kg}/_{s}$]	
2.99×10^{-4}		1.95×10^{-4}	

Analysis Approach

Analysis of Heat Exchanger:

- Reynolds Number
- Convective and Conductive Coefficients
- Overall Heat Transfer Coefficient
- Heat Duty
- Effectiveness
- Required Heater Power

Assumptions and Properties

- Steady-State Mass Flows
- Fully Developed Flows
- Constant Fluid Properties on shell and tube sides
- Flows Along respective Streamlines
- Well-insulated heat exchanger mass flows
- Constant heat flux along heat exchanger
- No external work
- Hot fluid in the tubes
- Counter current flow configuration

Fluid Properties			
Symbol	Property	Shell Fluid @ 115 $°C$	Tube Fluid @ 324 $°C$
ρ	Density	$0.899\ ^{kg}/_{m^3}$	$0.586\ ^{kg}/_{m^3}$
c_p	Specific Heat	$1.01\ ^{kJ}/_{kg \cdot K}$	$1.05\ ^{kJ}/_{kg \cdot K}$
ν	Kinematic Viscosity	$25.1 \times 10^{-6}\ ^{m^2}/_{s}$	$52.4 \times 10^{-6}\ ^{m^2}/_{s}$
k	Thermal Conductivity	$0.0324\ ^{W}/_{m \cdot K}$	$0.0455\ ^{W}/_{m \cdot K}$

Calculations

Reynolds Number:

$$Re = \frac{VD}{\nu}$$

Where:

- *Re* is the Reynolds Number
- *V* is the average fluid velocity
- *D* is the flow section effective diameter
- ν is the kinematic viscosity

Result:

Shell Flow:	198.0	[laminar flow]
Tube Flow:	127.6	[laminar flow]

Calculations

Convective Coefficient:

$$h = \frac{N_u k_f}{D}$$

Where:

- h is the convective coefficient
- N_u is the Nusselt Number
- k_f is the fluid thermal conductivity
- D is the flow section diameter

Result:

Shell Convective Coefficient (h_o): 1.82 $W/_{m^2 \cdot K}$

Tube Convective Coefficient (h_i): 12.5 $W/_{m^2 \cdot K}$

Calculations

Conductive Coefficient:

$$h_t = \frac{k_t}{L \cdot \ln\left({}^{r_2}/_{r_1}\right)}$$

Where:

- h_t is the conductive coefficient
- r_1 is the tube's inner diameter
- r_2 is the tube's outer diameter
- k_t is the tube thermal conductivity
- L is the tube length

Result:

$$h_t = 63.9\ {}^{W}/_{m^2 \cdot K}$$

Calculations

Overall Heat Exchanger Coefficient:

$$\frac{1}{UA_o} = \frac{1}{h_i A_i} + \frac{1}{h_t A_o} + \frac{1}{h_o A_o}$$

Where:

- U is the overall heat transfer coefficient
- A_i is the tubes inner surface area
- A_o is the tubes outer surface area

Result:

Overall Heat Transfer Coefficient: 1.48 $^{W}/_{m^2 \cdot K}$

Calculations

Overall Heat Duty:

$$Q = UAT_{LMTD}$$

Where:

- Q is the heat duty
- A is the heat transfer surface area
- T_{LMTD} is the log mean temperature difference

Result:

Heat Duty: $70.7W$

Calculations

HX Effectiveness:

$$\varepsilon = \frac{t_2 - t_1}{T_1 - t_1}$$

Where:

- ε is effectiveness
- t_1 is shell inlet temperature
- t_2 is shell outlet temperature
- T_1 is tube inlet temperature

Result:

Effectiveness: 0.342

Calculations

Heater Power Consumption:

$$E = \dot{m} c_p \Delta T$$

Where:

- E is the required power
- $\dot{m}$ is the mass flow rate
- c_p is initial temperature heat capacity
- ΔT is the needed change in temperature

Result:

Power Required	
Without Heat Reutilization	With Heat Reutilization
$303.8\ W$	$232.1\ W$

Conclusion

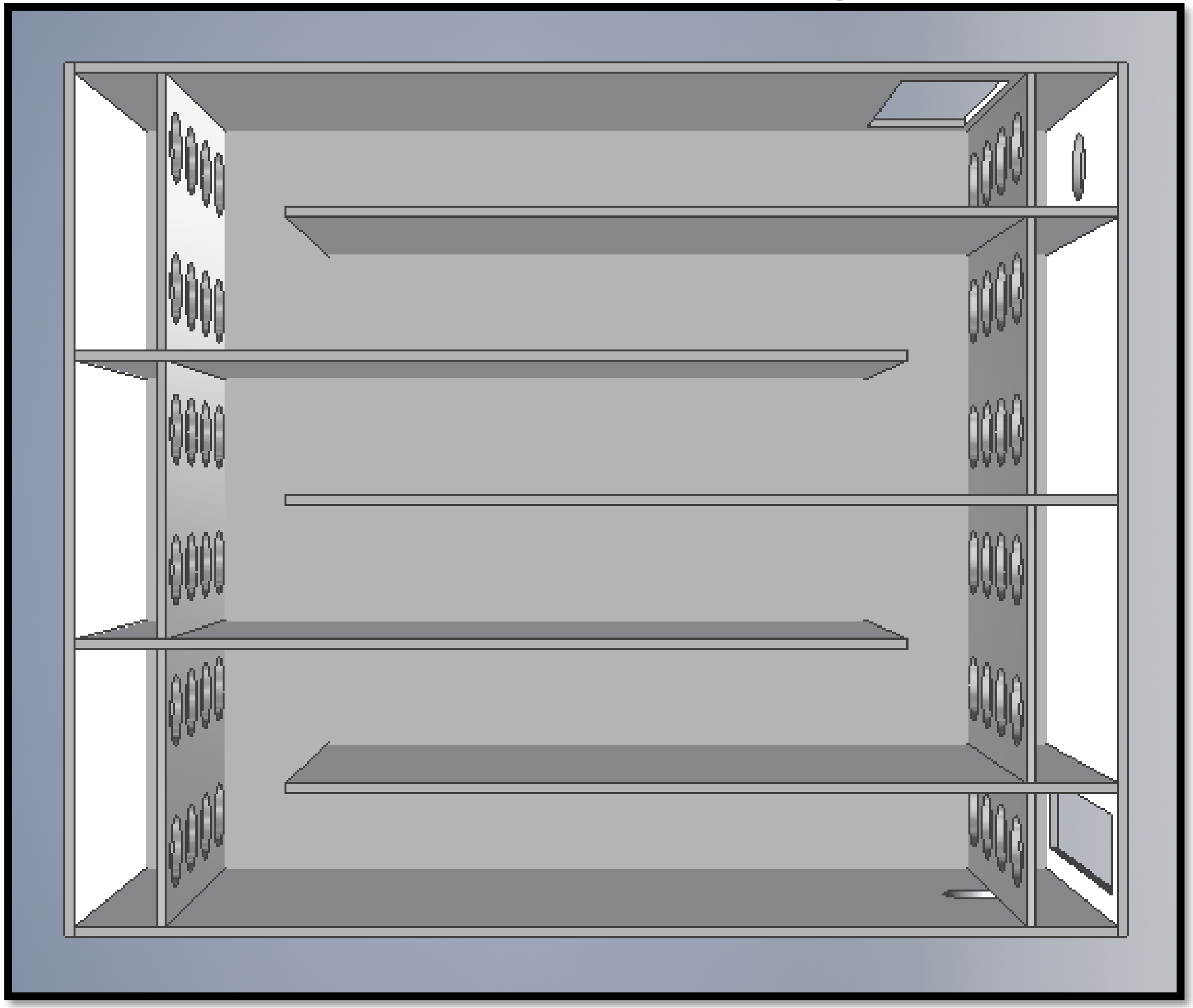
- The biggest resistances to heat transfer are shell and tube fluid convection coefficients
  - Low flow velocity in both channels
- Tube structure had minimal affect on overall heat transfer resistance
- 25% reduction in heater power is a great start, but further modifications can be made to increase power reduction.

Future Considerations

Modified Tubing Design

Future Considerations

Modified Flow Design



Acknowledgements

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- KBRWiley

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Thank you!