Low Cost Glass-Ceramic Matrix Composite Heat Exchanger
Daniel Mosher, Raytheon Technologies Research Center

Project Vision
Develop ceramic class heat exchangers by advancing the application of long fiber Glass-Ceramic Matrix Composite (GCMC) material to complex geometries.
Brief Project Overview

Context/history of the project

- RTRC resurrecting prior experience in GCMC materials (fibers, glass types, molding methods).
- DOE AMO project (DE-EE0008318) concluding exploration of simpler geometry HX development.
- HITEMMP program takes to the next level with higher temperature (glass type) and greater geometric complexity (design and molding type).

<table>
<thead>
<tr>
<th>Team member</th>
<th>Location</th>
<th>Key Personnel</th>
<th>Role in project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raytheon Technologies Research Center</td>
<td>East Hartford, CT</td>
<td>Daniel Mosher, Justin Alms, Katie Kirsch, John Holowczak, Mark Hermann, John Gangloff, Paul Sheedy</td>
<td>Project lead, HX design, material development and characterization, glass transfer molding, coupon level HX testing</td>
</tr>
<tr>
<td>TEAM, Inc.</td>
<td>Woonsocket, RI</td>
<td>Steve Clarke, Aaron Tomich</td>
<td>Fiber preform design and fabrication</td>
</tr>
<tr>
<td>Materials Research &amp; Design, Inc.</td>
<td>Wayne, PA</td>
<td>John Podhiny, William Higginson</td>
<td>Fiber architecture and structural analysis/design</td>
</tr>
<tr>
<td>University of Michigan</td>
<td>Ann Arbor, MI</td>
<td>Prof. Xiaodong Sun</td>
<td>CFD HT modeling</td>
</tr>
</tbody>
</table>

This document has been publicly released and is not subject to export controls.
Heat Exchanger Design Details

Novel aspects of GCMC HX

- High temperature capability of ceramics
- Flaw tolerance of long fiber composites
- Faster, lower cost matrix formation than conventional CMCs
- Significantly lower porosity (<1%) than conventional CMCs

- For this approach, the design is particularly influenced by the manufacturing processes.

- Primary steps in the manufacturing:
  - Development of fiber preform
  - Insertion of high temperature tooling
  - Glass transfer molding, crystallization
  - Removal of tooling

This document has been publicly released and is not subject to export controls.
Heat Exchanger Design Details

- Preliminary design undergoing continuing refinement.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Estimated performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperatures (hot; cold)</td>
<td>1,100 °C; 300 °C</td>
</tr>
<tr>
<td>Inlet pressures (cold; hot)</td>
<td>250 bar; 80 bar</td>
</tr>
<tr>
<td>HX effectiveness</td>
<td>≥ 0.5</td>
</tr>
<tr>
<td>Mass-based power density – core</td>
<td>45 kW/kg</td>
</tr>
<tr>
<td>Mass-based power density – full HX</td>
<td>14.1 kW/kg</td>
</tr>
<tr>
<td>Volume-based power density – core</td>
<td>27,000 kW/m^3</td>
</tr>
<tr>
<td>Volume-based power density – full HX</td>
<td>19,000 kW/m^3</td>
</tr>
<tr>
<td>Cold side pressure drop</td>
<td>0.015% - core only</td>
</tr>
<tr>
<td>Hot side pressure drop</td>
<td>0.005% - core only</td>
</tr>
</tbody>
</table>

- Cost: pathways for enabling technologies have been defined to reduce cost to ~ $7,000 / (kW/C).

For power densities dashed: core solid: full HX

This document has been publicly released and is not subject to export controls.
Heat Exchanger Design Details

- Analyses of composite architectures and structures being applied to evaluate design concepts and risks.
- Tubes and interface header section have been primary focus. Other headering in progress.

Design tuning resulted in significant reduction of axial loads.
Manufacturing Process Development Updates

- Overall design and manufacturing strategy was developed considering the geometry requirements and primary fabrication steps of:
  - Fiber preform
  - Tooling insertion
  - Glass transfer molding

- Combined design/manufacturing elements led to revisions in the tubing fiber architecture and fabrication method to achieve improved strength and high power densities.

- Tube fiber preform trials have been successful in producing tubes with the desired inner diameter.

- Integrated tube/header fiber preform fabrication trials have produced closer tube spacing than originally anticipated and addressed challenges with tow fraying.

- No evolution in the material section.
Manufacturing Process Development Updates

Glass Transfer Molding

- Modeling of GTM: Evaluate temperature profiles, permeabilities, flow front progression.

- Tooling has been designed. COVID-19 facility closure / partial reopening combined with vacuum press recommissioning issues have delayed trials which will be conducted in the near term.

Graphite tooling for material test specimens and coupon level HX

150 ton vacuum press

This document has been publicly released and is not subject to export controls.
Technology-to-Market Updates

The team is working internally within Raytheon Technologies to keep potential stakeholders informed of progress

- Presentations to Collins Air Management Systems, Materials and Process Engineering
- Quarterly review content with Collins senior engineering leadership
- Raytheon Technologies – biennial symposium on Mechanical, Materials and Structures
- Pathway to reduced cost includes 1) use of low cost Advanced Ceramic Fiber, 2) interfacial fiber coating formed via in situ reaction as with other GCMC system and 3) continuous glass transfer molding operation. Result is a learned-down cost projection of ~ $7,000 / (kW/C).

This document has been publicly released and is not subject to export controls.
Risk Update

<table>
<thead>
<tr>
<th>Risk</th>
<th>#</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power densities</td>
<td>1</td>
</tr>
<tr>
<td>Tube strength</td>
<td>2</td>
</tr>
<tr>
<td>Assembly strategy</td>
<td>3</td>
</tr>
<tr>
<td>Header design</td>
<td>4</td>
</tr>
<tr>
<td>Fiber preform manufacturing</td>
<td>5</td>
</tr>
<tr>
<td>Glass transfer molding</td>
<td>6</td>
</tr>
<tr>
<td>Cost (near term &amp; future pathway)</td>
<td>7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Almost Certain</th>
<th>Likely</th>
<th>Moderate</th>
<th>Unlikely</th>
<th>Rare</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consequences</td>
<td>Insignificant</td>
<td>Minor</td>
<td>Moderate</td>
<td>Major</td>
<td>Catastrophic</td>
</tr>
</tbody>
</table>

a: Tube-to-header leak rate: 4, 5  
b: Single piece woven core (N/A): 3  
c: Manufacturability: 3, 5, 6  
d: Cost: 7

This document has been publicly released and is not subject to export controls.
Phase 1

- **Task 1: HX Design & Requirements**
  - Revised fiber architecture approach developed: improved strength & increased power densities. Updated header design in progress.

- **Task 2: Fiber Preform Development**
  - Tube fiber preforms at desired diameter demonstrated; headered tube spacing density higher than anticipated.

- **Task 3: CMC Manufacturing Studies**
  - Glass transfer molding tooling and modeling developed; panels with IFC obtained; trials to begin in near term once vacuum furnace is recommissioned.

- **Task 4: Coupon-Level HX Demonstration**
  - Housing has been developed and will be used for single layer tube sheet testing.
Acknowledgment: “The information, data, or work presented herein was funded in part by the Advanced Research Projects Agency-Energy (ARPA-E), U.S. Department of Energy, under Award Number DE-AR0001122. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.”

Q & A

https://arpa-e.energy.gov