High Thermal Conductivity Polymer Composites for Low-Cost Heat Exchangers

DE-EE0005775

United Technologies Research Center/ University of Massachusetts (Lowell)/ University of Akron

12/15/2014-09/30/2016

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Project Objective

- Deliverable: Database of relevant material properties and characteristics to provide guidance for future heat exchanger development. (1 year project – started 12/15/2014)
- Identify and evaluate polymer-based material options for industrial and commercial heat exchangers (commercially available / state of the art)
- Enable replacement of metals by polymer-based materials to:
  - Reduce cost by 50%
  - Reduce manufacturing cost
  - Reduce component weights
  - Enable additional design degrees of freedom
  - Mitigate corrosion risks

Technical Approach

- Most heat exchangers are constructed from heavy and costly metals that are subject to corrosion and pose manufacturing constraints
- Identify and evaluate optimal filler material, shapes, and orientation to enhance polymer thermal conductivity
- Evaluate other relevant properties such as strength, fluid compatibility, permeability, flammability
- What is innovative about your project and approach?
  - Couple unique materials and heat transfer expertise
  - Work with experts in the field:
    - University of Massachusetts, Lowell
    - University of Akron
  - Leverage UTC's market leadership in HVAC&R and Aerospace segments

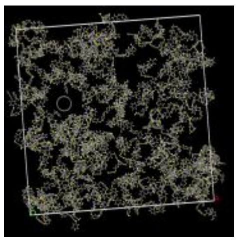
United Technologies
Building & Industrial Systems

UTC Aerospace Systems
Where ingenuity takes off

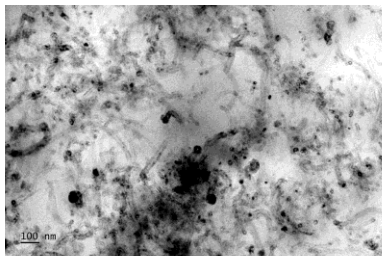
Technical Approach

Material Composition

- Minimize interfacial resistance
- Filler type/ shape/aspect ratio/ functionalization
- Filler dispersion/Homogeneity

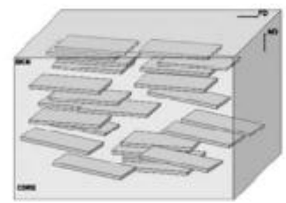


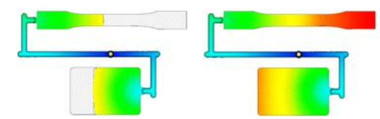
Molecular Dynamics Modeling



Manufacturing Process

- Preferred filler orientation
- Extrusion, injection molding
- Joining, bonding





Mold Flow

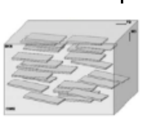
Modeling and validation

- Molecular dynamics modeling
- Finite Element thermal modeling
- Thermal conductivity, mechanical validation

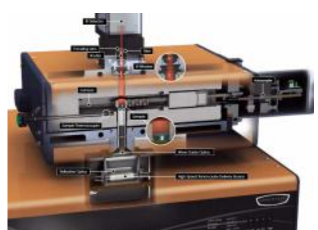
Apply effective medium theory

$$K_c = K_m \frac{3 + f(\beta_x + \beta_z)}{3 - f\beta_x}$$

Finite Elements Model of Composite

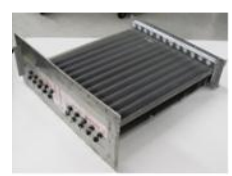


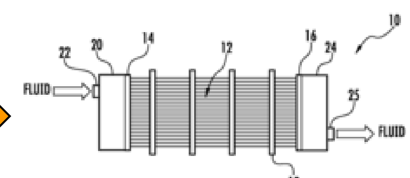
Composite Thermal Conductivity



Heat exchanger design

- Leverage flexibility afforded by composites
- Optimize surface topology
- Leverage multi functionality





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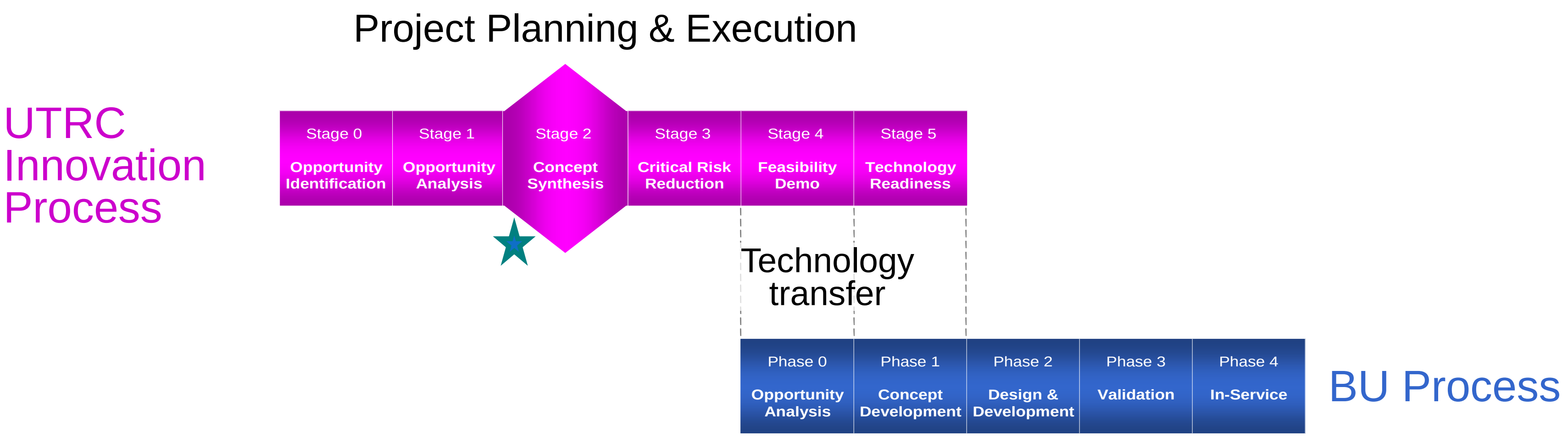
Transition and Deployment

- End users
  - HVAC industry
  - Aerospace
  - Heat recovery at moderate temperatures

- Benefits
  - Lower cost
  - Lightweight
  - Corrosion resistance
  - Multifunctionality

Transition and Deployment

- The team is working closely with UTC business units, in particular Carrier Corporation (the world's largest manufacturer and distributor of HVAC&R equipment) to ensure specific requirements are integrated in material selection.
- The team is also following UTRC's project planning and execution process (PPE) to ensure continuity from research and development to commercialization.



- Leveraging synergy with thermal management for electronics, LEDs

Measure of Success

CURRENT PROJECT IMPACT

Thorough material database to enable selection of optimal material for industrial HX applications

FUTURE IMPACTS

- Projected 50% cost savings (Materials and Manufacturing)
- Increased energy productivity
- Reduction in GHG emission
- Fuel savings due to lightweighting (shipping / transport application)

Project Management & Budget

1 Year project – 12/15/2014 to 12/31/2015

	Task Name
1	**Project Management**
M1.1	Program management plan
	Monthly meetings with EERE
M1.2	Final report
2	**Materials Requirements definition**
M2.1	List of potential applications
M2.2	Material properties requirements for 3 selected applications
3	**Review of COTS and SOTA Composite Materials**
3.1	Compilation of COTS and SOTA relevant properties
3.2	Updated compilation of COTS and SOTA relevant properties
4	**Model based evaluation and optimization**
4.1	Modeling tools development
4.2	Validation of modeling tools
4.3	Virtual space Material Design
4.4	Manufacturability Study
M4.1	Predicted thermal conductivity and mechanical properties
5	**Material Characterization and Model Verification**
5.1	Material characterization protocols
5.2	Material characterization of downselected composites
M5.1	Identification and verification of most suitable candidates
6	**HX concept development**
6.1	Brainstorming of HX system concepts including manufacturing options
6.2	Modeling of downselected HX system concept
6.3	Manufacturing risk assessment
M6.1	HX concept, projected cost, performance and energy reduction impact

2015												2016		
J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
X	X	X	X	X	X	X	X	X	X	X	X			

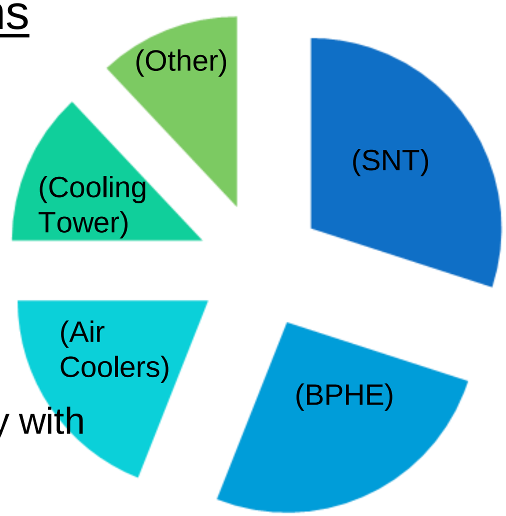
Total Project Budget

DOE Investment	$ 744,154
Cost Share	$ 186,039
Project Total	$ 930,194

Results and Accomplishments

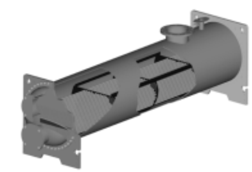
Task #	Task Title or Brief Description	Task Completion Date			Task Progress Notes
		Original Planned	Actual Complete	% Complete	
1	Project Management	3/31/2016		10	PMP submitted
2	Material Requirements Definition	3/31/2015	3/31/2015	100	Milestones completed
3	Review of COTS and SOTA Composite Materials	5/31/2015		90	
4	Model-based evaluation and optimization	10/31/2015		20	
5	Material Characterization and Model Verification	12/31/2015		20	
6	Heat Exchanger Concept Development	11/30/2015		0	

- <u>Downselected applications</u>



Enabling application:
Air/2-phase condensers
Impact: increased cycle efficiency with evaporative cooling
Applications: HVAC, refrigeration

Shell and Tube
Liquid/Liquid or Liquid/2-phase
Impact: reduced weight and cost, reduced fouling and erosion
Applications: chiller, industrial, food and beverage, marine



Brazed plate heat exchanger (BPHE)
Liquid/Liquid or Liquid/2-phase
Impact: Reduced weight and cost
Applications: commercial HVAC chillers, aerospace, process industry

- <u>Commercially Available Materials</u>
  - Suppliers: Celanese CoolPolymer, PolyOne, RTP
  - Thermal conductivity range: up to 35 W/mK (In-plane) –10 W/mK (Through-Plane)

Acknowledgement

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