U.S. DEPARTMENT OF
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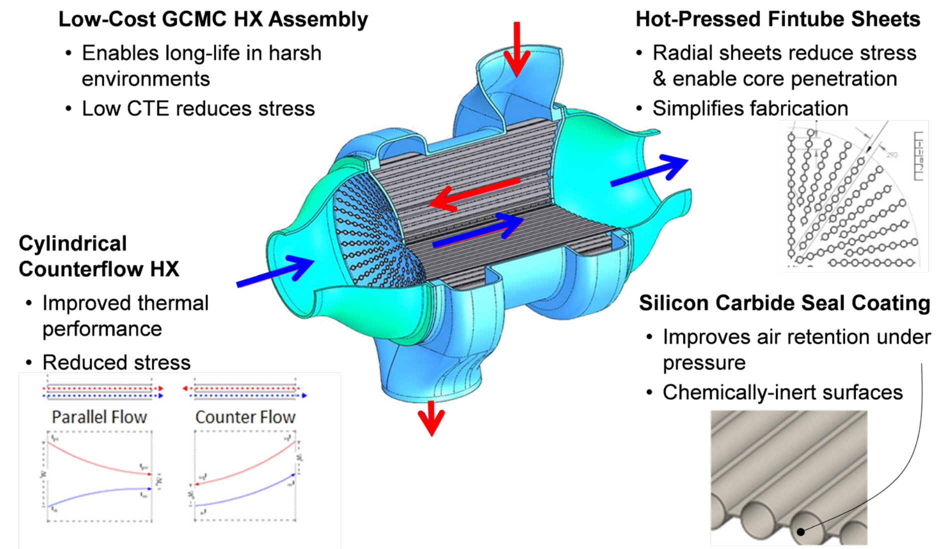
RENEWABLE ENERGY

Low Cost Glass Ceramic-Matrix Composites for Harsh Environment Heat Exchangers



Overview of the key components and their potential benefits for the glass ceramic-matrix composite (GCMC) heat exchanger (HX) concept. *Graphic image courtesy of United Technologies Research Center (UTRC)*

Heat exchangers (HXs) are used extensively in many industrial and power generation applications. Thermal efficiencies and fuel consumption depends heavily on HX performance. As system temperatures and pressures increase, HXs need to be able to withstand harsher environmental conditions. Despite extensive HX device technology advances in harsher environments, materials that are capable of withstanding wide ranges of harsh environments over long operational life currently are expensive, and therefore less economically attractive. Improving HX designs with more advanced, low-cost materials will help increase thermal efficiencies, and HX product lifetimes, while reducing component manufacturing costs and HX volumes.

This project intends to develop heat exchanger technology capable of long operational life in harsh environments with low cost and high reliability. The Counterflow Tube Heat Exchanger (CTHX) under development consists of a novel glass-ceramic matrix composite (GCMC) material, which is developed from a boron-doped lithium aluminosilicate matrix consolidated with a long-fiber reinforced architecture. The CTHX geometry will be tailored specifically for GCMC material manufacturing and part fabrication. The project will begin by developing the GCMC material performance limits with respect to the HX's operating conditions. The proposed GCMC HX will then be designed and tested at the laboratory scale with respect to performance criteria. The HX will then be modeled at full-scale to predict the final prototype performance and refine component designs prior to fabrication. The final HX prototype will be fabricated, assembled, and tested with respect to key critical performance metrics.

Benefits for Our Industry and Our Nation

The proposed GCMC material can improve mechanical, and thermal-fluid properties of HXs in harsh environments, while reducing costs and fuel consumption. Current materials that can withstand these conditions include monolithic ceramics and metallic superalloys, which have individual issues in properties and fabrication costs. Using state-of-the-art GCMC materials are expected to have extensive benefits for HXs in harsh environments, including:

- Reduced U.S. energy consumption in power generation and industrial applications such as supercritical carbon dioxide (SCO2) plants
- Decreased fuel costs for fossil-based power plants, such as an estimated 5-9% reduction in a coal plant, from which savings could be passed on to customers

Applications in Our Nation's Industry

This low-cost, high-reliability GCMC HX technology will have a variety of benefits to power generators and manufacturing industries. Potential applications include HXs used for steam cycles, SCO2 cycles, industrial gas turbines, and thermal rectifiers. GCMC materials have previously been demonstrated to perform well in applications with harsh environments such as engine turbine vanes, combustion liners, and hot structure control surfaces in hypersonic vehicles. When used in HXs, the materials will be capable of higher durability in harsher environments with lower manufacturing costs.

Project Description

The project objective is to develop, design, and validate a GCMC HX for operation in harsh environments. The GCMC material is expected to have favorable properties, and reduced fabrication cost over conventional materials for HXs in harsh environments. The project outcomes include the following HX developments: (a) verification of material limits with respect to design specifications and requirements; and (b) prototype demonstration of both lab-scale and full-scale GCMC HX performance and leakage characterization. The prototype should validate increased cycle thermal efficiency and reduced HX volume.

Barriers

- Ability to achieve 100% leak-free operation in harsh conditions with no fluid loss to the ambient environment, and internal cold-to-hot side leakage <0.1% to ensure negligible impact on recuperator effectiveness and cycle efficiency
- Ability to retain HX durability over 20 cycles with no loss in performance

Pathways

The project is structured to address the key barriers and minimize risk. The ultimate goal is to develop and validate heat exchanger technology capable of long operational life in a 1600°F and 1000 psi differential pressure (between hot and cold HX sides) operating environment at a cost and reliability consistent with commercialization requirements.

The first project pathway will determine and establish design requirements for the high pressure, high temperature GCMC HX prototype. These design criteria will use SCO2 power plants for application-specific requirements, which will then guide the inlet temperatures, inlet pressures, flow rates, pressure drops, and heat transfer rates for the HX's hot side and cold side. A preliminary HX design will be determined to guide prototype manufacturing, which will reference thermal, fluidic, and structural performance analysis results under given boundary conditions.

The second pathway will fabricate and refine the HX prototype. The lab-scale HX prototype will be tested for sufficient mechanical and thermal-fluid performance, as well as pressure/burst testing, and leakage characterization. The HX performance will be compared to critical success factors such as maximum temperature and pressure (1600°F, 1000 psi).

The third pathway will scale-up the HX prototype for final design validation and refinement. This will first be modeled using previous test data, processing specifications, and design constraints to predict HX performance and reliability targets. The final design from this model will then be fabricated, assembled, and tested.

Milestones

This three year project began in July 2018.

- Establish whether sufficient mechanical performance exists within the CMC system and joining technique to proceed to a sub-scale HX demonstrator design (2019)
- Verify whether sufficient mechanical and thermal-fluid performance exists within the CMC sub-scale HX system including tube-to-header joining technique to proceed to a full-scale HX demonstrator design (2020)
- Complete test of thermal-fluid performance, as well as the leakage rate of coated and non-coated full-scale HX prototypes at design conditions (2021)

Technology Transition

United Technologies Research Center (UTRC) is partnering with Materials Research & Design, Inc. and Oak Ridge National Laboratory for the design, fabrication and testing of the GCMC HXs. Following successful development, this HX could be broadly utilized in many power applications that require less harsh conditions than those imposed during this project. The project team plans to advance this technology using UTRC's Innovation Business Development (IBD) team for intellectual property and licensing purposes. The project team plans to leverage this experience to pursue commercialization of this technology in both core and adjacent markets, such as ceramics manufacturing, power generation, and heat recovery.

Project Partners

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