Nuclear Energy University Programs
U.S. Department of Energy

Compact Heat Exchanger Design and Testing for Advanced Reactors and Advanced Power Cycles

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Program: RD&D: Component and Technology Development

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ABSTRACT

The supercritical carbon dioxide (s-CO_2) Brayton cycle shows promise as a power conversion system for advanced nuclear reactors, including the High-Temperature Gas-cooled Reactor (HTGR), the Sodium Fast Reactor (SFR), and the Fluoride salt High-temperature Reactor (FHR). Coupling the s-CO_2 Brayton cycle to Small Modular Reactors (SMRs) results in significant benefits (i.e., large cost reduction) due to the relatively small size of the turbo-machinery required for the cycle. However, in order to achieve high thermal efficiencies, the cycle must recuperate the heat it receives several times thus requiring a large number of heat exchangers. Reducing the size and cost of the IHX/recuperators of the s-CO_2 Brayton cycle is critical in demonstrating its usefulness for SMRs and can also further increase the benefits for large scale (>500 MWe) and higher temperature reactors (450-700ºC).

This proposal will focus on demonstrating the thermal hydraulic performance of innovative channel geometries usable in compact and low-cost IHXs/recuperators for the s-CO_2 Brayton cycle. The major effort will focus on advanced printed-circuit heat exchanger (PCHE) flow channel geometries. These advanced chemically etched passages on substrate plates can be diffusion bonded to form a high strength large surface area per unit volume heat exchanger. Also of interest are formed plate type heat exchangers that can be manufactured with larger flow passages, which allow coupling to sodium, liquid salt, or gas to reduce pressure drop and minimize plugging issues. While these types of heat exchangers have been extensively used in the oil industry, there are some questions with regard to severe transient thermal stresses that could occur if one of the flow paths is interrupted. Furthermore, numerical simulations near pseudo-critical point in s-CO_2 are still questionable due to significant property change. In addition, experience has shown that diffusion bonding technology for high-temperature alloys in PCHE configurations is not yet a reliable, commercially available process. Therefore, we will also examine the diffusion bonding parameters and potential bond degradation issues.

The goal of the proposed research is to investigate optimal heat exchanger designs as IHXs/recuperators for SMRs and other advanced reactors that use the s-CO_2 Brayton power cycle. The specific objectives are: 1. To propose optimized PCHE designs for liquid salt to s-CO_2, helium to s-CO_2, sodium to s-CO_2, and liquid salt to helium working fluids under various IHX/recuperator conditions; 2. To perform computational fluid dynamics (CFD) modeling and calculations for the PCHEs, considering the highly variable properties of s-CO_2 near the pseudo-critical point; 3. To experimentally investigate thermal performance, thermal stress, deflection, and breach of the PCHEs during various transients; 4. To study optimal diffusion bonding parameters for several high-temperature alloys and examine post-test material integrity of the PCHEs, including the bond-line corrosion effect.