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Coiled Tube Gas Heaters for Nuclear Gas-Brayton Power Conversion

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ABSTRACT

This project will develop an alternative design for heat exchangers for use heating supercritical carbon dioxide (SCO_2) with sodium for SCO_2 power conversion. We have identified an annular coiled tube bundle configuration–where hot sodium enters tubes from multiple vertical inlet manifold pipes, flows in a spiral pattern radially inward and downward, and then exits into an equal number of vertical outlet manifold pipes–as a potentially attractive option. The SCO_2 gas flows radially outward through the tube bundle. Coiled tube gas heaters (CTGHs) are expected to have excellent thermal shock, long-term thermal creep, in-service inspection, and reparability characteristics, compared to alternative options.

CTGHs have significant commonality with modern nuclear steam generators. Extensive experience exists with the design, manufacture, operation, in-service inspection and maintenance of nuclear steam generators. The U.S. Nuclear Regulatory Commission also has extensive experience with regulatory guidance documented in NUREG 0800. CTGHs leverage this experience and manufacturing capability.

The most important difference between steam generators and gas-Brayton cycles such as the SCO_2 cycle is that the heat exchangers must operate with counter flow with high effectiveness to minimize the pinch-point temperature difference between the hot liquid coolant and the heated gas. SCO_2-cycle gas heaters also operate at sufficiently elevated temperatures that time dependent creep is important and allowable stresses are relatively low. Designing heat exchangers to operate in this regime requires configurations that minimize stresses and stress concentrations. The cylindrical tubes and cylindrical manifold pipes used in CTGHs are particularly effective geometries.

The first major goal of this research project is to develop and experimentally validate a detailed, 3-D multi-phase (gas-solid-liquid) heat transport model for CTGHs, using methods similar to earlier UCB multi-scale models for PCHEs, which will enable optimization of CTGH designs with respect to the number of manifold pipes, SCO_2 and sodium circulating power, and other design parameters.

CTGHs are relatively novel because the tubes loaded in compression as well as the manifold pipes which form the tube sheets. The second major goal of the experimental and modeling effort will be to optimize the assembly and heat treatment of the tube-to-tubesheet joints, using a novel tapered joint configuration, and to develop diffusion-bonded joints with high shear strength and creep resistance, as has been done in other applications for tapered plugs. The project will also conduct creep testing of these tubesheet joints in pressurized furnaces under prototypical conditions of stress and temperature.

Detailed microstructural investigations will be conducted on the diffusion bond interface, while the bond strength will be evaluated by tensile testing. The mechanical testing will quantify the overall strength of the bond and measure the pull out force as well as long term behavior, which will complement the microstructural analysis to give a complete understanding of the diffusion bond.