Experimental Validation of a Compact Double-walled Twisted-Tube Heat Exchanger Concept

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ABSTRACT:

Double-walled heat exchangers have been used in a variety of applications in the nuclear industry where there are concerns about the interaction of the primary fluid with the secondary fluid. Classic examples include sodium fast reactor (SFR) steam generators where the concern is sodium reacting violently with water and lithium blankets for fusion applications where tritium migration to the outside environment is of principal concern. In this proposal, we will investigate a new compact double-walled heat exchanger concept for Fluoride salt-cooled High-temperature Reactors (FHRs) that utilizes an outer twisted tube configuration in order to enhance shell-side heat transfer and make the overall bundle more compact while utilizing a traditional circular inner tube to withstand high pressure differentials across the tube wall. Traditional double-walled heat exchangers utilize concentric circular tube configurations that require support plates and baffles typical of conventional shell and tube heat exchanger designs. Utilizing an outer twisted tube geometry allows for a tube bundle that does not require support plates, anti-vibration bars (for U-tube designs), and complex baffling. One challenge with twisted-tube heat exchangers is their pressure containment capability at elevated temperatures between primary and secondary sides due to manufacturing limitations on wall thickness when forming the non-circular cross section of the tube. By utilizing an inner circular tube, this proposed design can be utilized in conditions that traditional twisted-tube heat exchanger designs cannot, such as the liquid-to-gas and liquid-to-supercritical fluid heat exchangers needed to couple FHRs to helium and supercritical CO2 Brayton power cycles.

The supercritical CO2 (S-CO2) cycle is currently being investigated for SFR applications both for small and medium-sized plants, however, the cycle may be suitable for coupling to FHRs. The main advantages of S-CO2 cycles are their high efficiencies over a range of source temperatures and the high density of the working fluid, which translates to very small power conversion systems with low pumping power requirements. One of the challenges associated with coupling a low-pressure heat source to a high-pressure power conversion cycle is that the pressure boundary (tube wall) is at elevated temperatures, which can lead to thick tube walls. Additionally, there is the danger that, should a tube rupture occur, the primary coolant could become pressurized leading to failure of another pressure boundary elsewhere in the primary system. Using a double-wall design allows this pressure differential to be contained by two tube walls. Another challenge to the design of this heat exchanger is that FHRs produce large quantities of tritium in the reactor coolant due primarily to the parasitic neutron capture of Li-7, Li-6, and Be-9. This aspect of FHRs incentivizes the use of double-wall heat exchangers where a purge gas can be used in the annulus to reduce or eliminate tritium diffusing through the heat exchanger walls. This project will demonstrate the thermal performance of this technology using scaled experiments with high levels of physical similitude.