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Reactor Simulator Testing

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Abstract. As part of the Nuclear Systems Office Fission Surface Power Technology Demonstration Unit (TDU) project, a reactor simulator test loop (RxSim) was design & built to perform integrated testing of the TDU components. In particular, the objectives of RxSim testing was to verify the operation of the core simulator, the instrumentation and control system, and the ground support gas and vacuum test equipment. In addition, it was decided to include a thermal test of a cold trap purification design and a pump performance test at pump voltages up to 150 V since the targeted mass flow rate of 1.75 kg/s was not obtained in the RxSim at the originally constrained voltage of 120 V. This paper summarizes RxSim testing. The gas and vacuum ground support test equipment performed effectively in NaK fill, loop pressurization, and NaK drain operations. The instrumentation and control system effectively controlled loop temperature and flow rates or pump voltage to targeted settings. The cold trap design was able to obtain the targeted cold temperature of 480 K. An outlet temperature of 636 K was obtained which was lower than the predicted 750 K but 156 K higher than the cold temperature indicating the design provided some heat regeneration. The annular linear induction pump (ALIP) tested was able to produce a maximum flow rate of 1.53 kg/s at 800 K when operated at 150 V and 53 Hz.

Keywords: fission, space power, nuclear, liquid metal, NaK.

BACKGROUND

A 40 kWe fission power system Technology Demonstration Unit (TDU) is being developed under the Fission Power Systems project. The TDU is comprised of a non-nuclear core simulator, sterling engine power conversion system, Annular Linear Induction Pump (ALIP), liquid sodium/potassium (NaK) coolant, and radiator heat rejection. In support of TDU development, the RxSim test loop was developed to perform integrated component testing to verify operability prior to the TDU development. The RxSim was a NaK filled test loop comprising of a 37 pin reactor core simulator, NaK-GN_2 HX (for simulating the thermal load of the sterling power conversion system), an electromagnetic flow meter, and the TDU ALIP. In addition, although not part of the TDU, the RxSim had a secondary bypass loop across the ALIP to test a cold trap purification design. Figure 1 shows the RxSim layout. This report covers testing in the RxSim loop while details of the design and development are in a separate report.

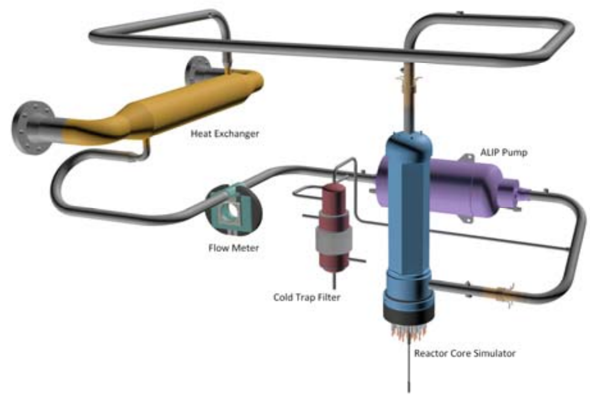

FIGURE 1. RxSim Test Loop Layout.

TESTING

RxSim testing involved operational checkouts of the loop control and instrumentation system and the gas and vacuum test support equipment. To accomplish this, the RxSim was to be operated at TDU representative temperatures and flow rates (800 K and 1.75 kg/s). Vacuum and gas support equipment were used for NaK transfer operations (evacuating the RxSim loop, lower reservoir or accumulator, applying Ar pressure head, and actuating a remote operating valve). The gas system also supported the TDU ALIP by supplying and regulating (relief valve and regulator in conjunction) He pressure in the electrical areas of the ALIP. In the past, this support equipment was provided by the test facility. These gas and vacuum racks were built to provide dedicated support equipment for the TDU. The vacuum and gas support equipment proved to be sufficient. The system's control and instrumentation program provided control algorithms to operate the loop at targeted core outlet temperatures and either mass flow rates or pump voltage. The control algorithms also controlled the slew rate within constraints. These algorithms proved to be sufficient and effective.

During the first series of test, pump voltages and frequencies were ramped up and varied to achieve the maximum flow rate. It was found that the maximum flow rate obtainable in the RxSim loop with the TDU ALIP pump was about 1.33 kg/s (when the ALIP was provided 120 V at 55 Hz and a NaK temperature of 800 K). Thus it was decided to extend the pump to a maximum of 150 V in which a maximum flow rate of 1.53 kg/s was obtained (Figure 2).

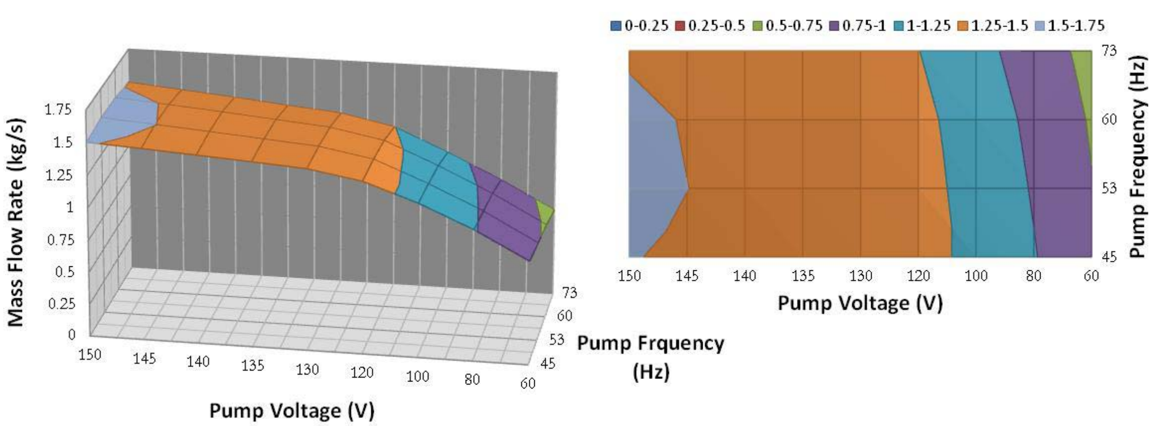

FIGURE 2. Expanded Pump Testing up to 150 V at T_{core}^{out} = 800 K. Maximum Mass Flow Rate Observed for the TDU ALIP in the RxSim Test Loop was 1.5 kg/s at 150 V and 73 Hz.

Thermal performance of a cold trap design with heat regeneration was tested. The design consisted of a bellows jacketed GN_2-NaK HX for cooling and accommodating thermal expansion. The NaK flow path consisted of a downcomer flow through alternating disk and donut baffles to create cross flow and increase NaK residing time within the cold trap. The volume between the baffles was packed with stainless steel wool to provide a reaction surface for oxide precipitation. The return flow path was through a tube running up the centerline of the cold trap and then terminating in a coil that was bathed in hot NaK from the inlet at the top of the cold trap. A cold temperature of 480 K was the targeted goal of the cold trap design as analysis had indicated that purification of the NaK could be obtained within a reasonable period of time with this cold temperature. The analysis also indicated that a return flow through a coil would provide sufficient heat regeneration so cold NaK would not be put back into the system acting a thermal load. However, for this performance, the analysis indicated that a very slow NaK flow rate was required. The design proved to provide a good cooling capacity to reach a sufficiently low cold temperature with slow NaK flow rates as predicted. Heat regeneration was observed to occur more effectively within the cold trap return line than predicted but not as effectively within the coil regenerator than predicted. An outlet temperature of about 750 K was predicted but 636 K was observed (Figure 3).

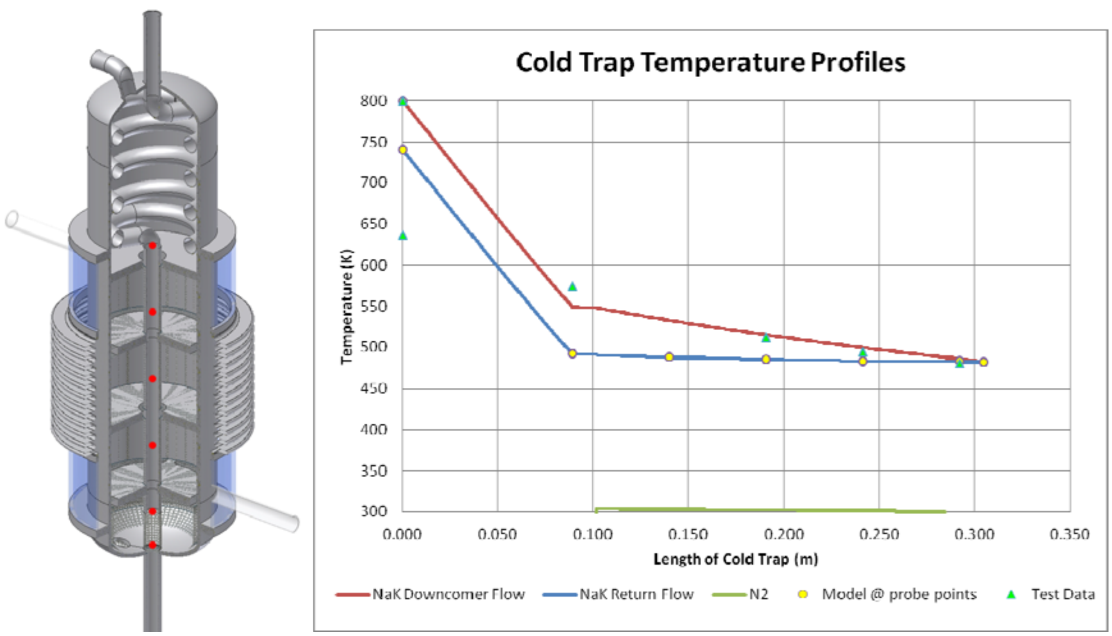

FIGURE 3. Cold Trap Design and Performance. Left: Cold Trap Design. Dots Correspond to the Locations of the Thermocouple Probe Locations. Right: Comparison of Cold Trap Thermal Model and Measured Temperatures. The Modeled Flow Rates were 0.00635 kg/s (NaK) and 0.078 kg/s (N_2). The Actual NaK Flow Rate Through the Cold Trap was not Measured but in the Primary Loop it was 0.068 kg/s with the Cold Trap Loop Bypass Valve Open ¼ turn. The Actual N_2 Flow Rates Were Not Measured but the Supply Pressure was 6 psi Above Ambient. Modeled Inlet Temperature was Set to Actual Cold Trap Inlet Temperature of 800 K. NaK & GN_2 Mass Flow Rates were Then Tweaked to Get Modeled T_{cold} Approximately Equal to Measured T_{cold}. Yellow Dots are Model Temperature Predictions at Locations Expected to Correspond with Thermocouple Probe Locations Which are the Green Triangles.

CONCLUSION

Integrated testing of the TDU control and instrumentation, vacuum and gas ground test support equipment, and reactor core simulator components in the RxSim test loop demonstrated them to be operationally ready for TDU integration. The ALIP pump was found to not produce the desired flow rate for the RxSim test loop and thus is being considered as a backup pump for TDU testing. In addition, heat regeneration design feature for cold trap purification was demonstrated with thermal testing of a cold trap integrated into the RxSim test loop.

NOMENCLATURE

ALIP	=	annular linear induction pump
GN_2	=	gaseous nitrogen
He	=	helium
HX	=	heat exchanger
K	=	Kelvin
NaK	=	eutectic alloy of sodium (Na) and potassium (K) liquid metals
RxSim	=	Reactor Simulator Test Loop
TDU	=	Technology Demonstration Unit

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