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TRANSIENT SIMULATION OF A HELICAL-COIL SODIUM/WATER STEAM GENERATOR

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The MINET (Momentum Integral Network) code[1] heat exchanger model was used to analyze transient test data[2] provided by PNC of Japan. Testing of the MINET model is part of a larger effort to facilitate and validate the use of the SSC/MINET code[3] for MONJU plant transient analysis.

In MINET, a heat exchanger is modeled using one or more representative tubes, with each tube consisting of the fluid inside the tube, the tube wall, and the fluid outside that is associated with the tube. The heat exchanger tube is divided into one or more axial nodes of equal length. Five time dependent equations are utilized per node, including the wall heat conduction equation and donor-cell differenced conservation of mass and energy equations for the fluids on both sides of the tube. These nodal equations are used to constrain the tube wall temperature, fluid mass flow rates, and fluid enthalpies. Fluid pressures are imposed as boundary conditions from other parts of the system, and are not calculated locally in the heat exchangers. Heat transfer coefficients are evaluated using correlations, each of which is valid for a given heat transfer regime. Interfaces between regimes are calculated within the nodes so that the heat transfer can be piece-wise calculated and averaged.[3]

The MINET heat transfer correlation package includes Graber-Rieger for the sodium, Dittus-Boelter for subcooled forced convection, Chen for subcooled nucleate boiling and forced convection vaporization, Bishop for film boiling, and Heineman for superheated convection.[3] An alternate package of correlations, including Hoe for sodium, MORI-NAKAYAMA for subcooled and superheated convection, Shrock-Grossman for forced convection vaporization, interpolation in the film boiling regime, and suppression of any subcooled nucleate boiling, was also developed for MINET usage, as required by PNC.

The initial conditions for a 70% load test were analyzed using 19 axial nodes and both sets of correlations, with the results as shown in Figure 1. The temperature profile produced by the standard MINET correlations includes a 2% overall increase in heat transfer area, as was required to match inlet and outlet temperatures to the experiment values. The PNC correlations were factored individually to represent the experiment conditions even more accurately.

The transient simulated was a 20% step reduction in feedwater mass flow rate after 25 seconds of null transient. Steam outlet pressure, which decreases in response to the reduced feedwater flow was input as a transient boundary condition. Feedwater temperature, sodium inlet mass flow rate and temperature, and sodium outlet pressure were held constant. Temperatures at the heat exchanger inlets and outlets, as observed and calculated, are shown in Figure 2.

Transient behavior of the steam outlet temperature was simulated almost exactly by MINET, regardless of which package of heat transfer correlations was employed. Simulation of the sodium outlet temperature was relatively accurate, although the temperature increase develops more rapidly in the calculations than in the experiment. This error, believed to be attributable to imprecise representation of the boiling boundary, is relatively small and short-lived, and is considered acceptable for a systems code such as MINET. It is noted that trends in simulation of the inlet and outlet temperatures accurately reflect those in simulating the internal temperatures, i.e., errors in the superheated steam region temperatures were very small, and those in temperatures near the sodium outlet were somewhat larger.

In summary, the MINET heat exchanger model was used to simulate test transient performed at a PNC helical coil sodium-to-water heat exchanger test facility. Results obtained in simulating initial conditions and transient behavior were relatively good, regardless of whether the standard MINET heat transfer correlations, or the alternate set required by PNC, was utilized.

References

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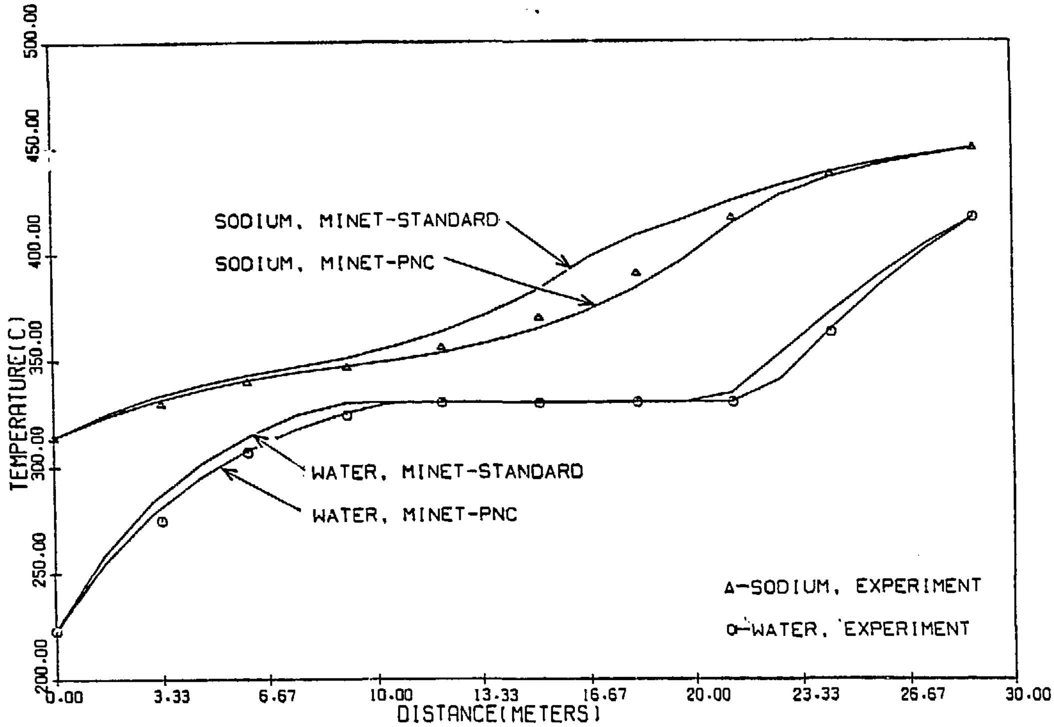

Figure 1. Water and Sodium Temperatures vs. Distance Along Helical Coil

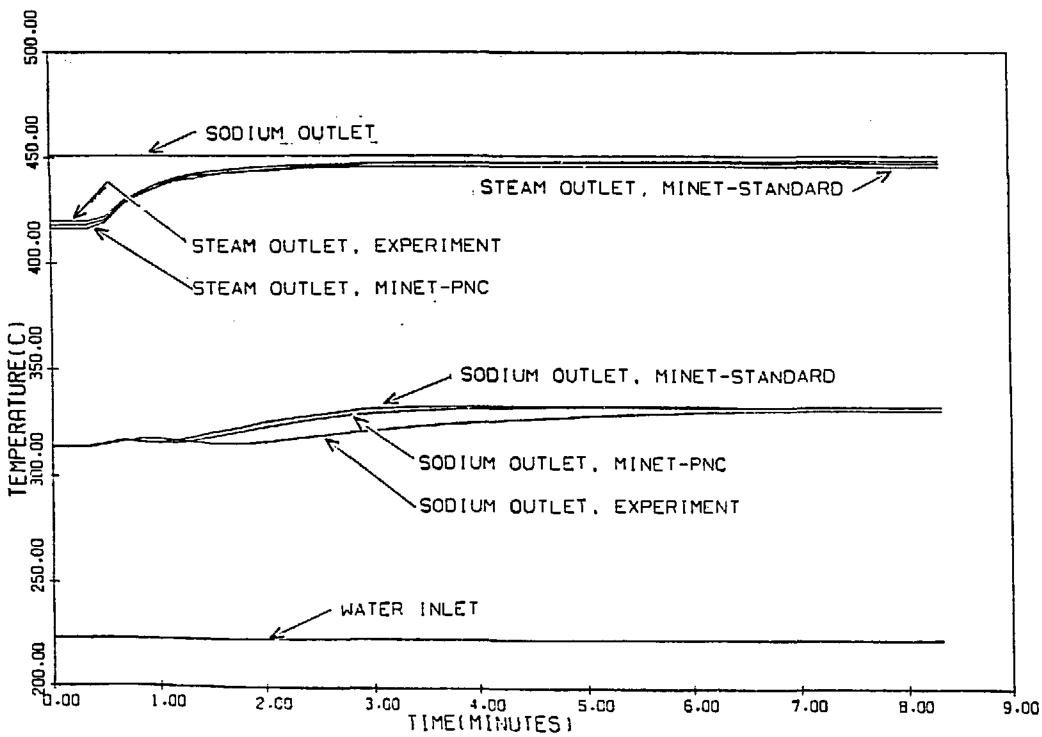

Figure 2. Inlet and Outlet Temperatures vs. Time