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Title: A TRAC MODEL OF THE LOS ALAMOS NATIONAL LABORATORY DELTA LOOP FACILITY

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Los Alamos NATIONAL LABORATORY

A TRAC Model of the Los Alamos National Laboratory DELTA Loop Facility

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Abstract–*Lead-bismuth eutectic (LBE) is being used as one of the prospective coolants in advanced reactors and accelerator-driven systems because of its attractive nuclear, thermal, physical, and chemical properties. However, LBE is very corrosive to many structure materials if they are exposed to LBE directly. Thus, one of the critical obstacles to the wide use of LBE as a nuclear coolant is corrosion. A materials test loop facility, the DELTA Loop, has been set up at Los Alamos National Laboratory (LANL) to study the long-term corrosion of various materials in flowing LBE and to study the thermal hydraulics of such systems.*

A TRAC model of the DELTA Loop has been developed. The modernized TRAC-M/F90 thermal-hydraulics code that is being developed by LANL for the United States Nuclear Regulatory Commission has been updated to include fluid properties used for advanced accelerator applications such as liquid sodium and LBE. The code also has the capability to track corrosion or oxidation products around the coolant loop. The TRAC DELTA Loop model has been benchmarked against a 48-h steady-state test run that was performed August 6-8, 2002. TRAC-calculated temperatures were within the experimental uncertainty of the measured temperatures at the selected loop locations when external heat losses were accounted for. The TRAC model will be used for the pre-test prediction of steady-state and transient test runs, natural convection flow, corrosion, and safety analysis studies.

I. FACILITY DESCRIPTION

The DELTA Loop is a test facility designed to help establish the material and thermal-hydraulic performance of lead-bismuth-eutectic (LBE) systems. The facility,[1] shown in Fig. 1, consists of a melt tank with heaters, an electrically driven mechanical pump submerged in a sump tank, an oxygen control system, an LBE-to-LBE recuperator, a horizontal 8.23-m (27 ft) electrically heated section, a 3.35-m (11 ft) vertical test section, and an LBE-to-LBE-to-water heat exchanger. All components are made of 316/316L stainless steel. The facility uses 0.05-m (2 in.) piping except in the test section where 0.025-m (1 in.) piping is used. The pump-rated flow capacity is 0.0043 m^3/s (68 gal./min). The heat exchanger is a vertical counter-current concentric tube design that uses an intermediate annular cavity of LBE to control the heat transfer between the LBE and water. The recuperator is a tube-and-shell counter-current flow design. Heat is transferred from the hot-side LBE, which reduces the heat removal load on the heat exchanger. The heat transferred to the cold-side LBE reduces the heat input load in the heater section. The heater section consists of nine independently heated zones, each having a capacity of 6.75 kW, for a total heat input of 60.75 kW. The total LBE fluid path length is ~33 m (110 ft). The change in elevation is ~3.8 m (12.5 ft). The initial flow tests were conducted in late 2001, and in August 2002, a 48-h steady-state test was performed.

II. TRAC CODE DESCRIPTION

The TRAC code[2] is an advanced multicomponent, multidimensional, and multifluid thermal-hydraulics code that has been under development at Los Alamos National Laboratory (LANL) since the mid-1970s. It is the thermal-hydraulics code selected by the United States (US) Nuclear Regulatory Commission (NRC) and by Knolls Atomic Power Laboratory. The code is highly modular and has been updated to the Fortran 95 coding standards. The capabilities of other thermal-hydraulic codes (TRAC-BWR and RELAP5) have been integrated into TRAC by the NRC. The code was updated by LANL to include modeling capabilities needed for advanced accelerator transmutation of waste applications.[3] Additional fluid properties were added for heavy water, helium, liquid sodium, LBE, and oil. Trace species tracking and solubility models also were added.[4]

III. TRAC MODEL DESCRIPTION

The TRAC model of the DELTA Loop is shown in Fig. 2. The thermal-hydraulic geometry data for this

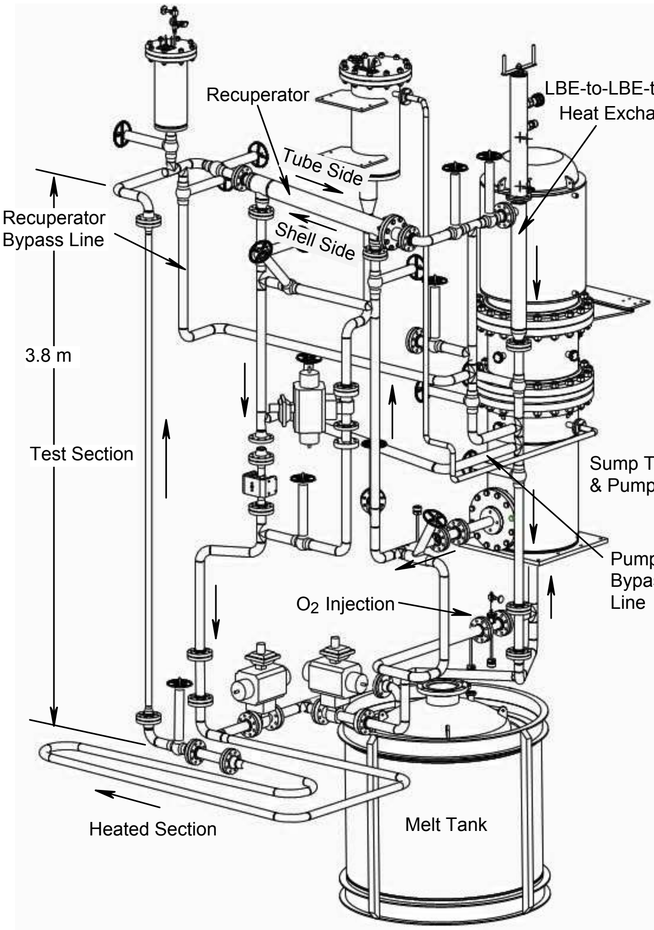

Fig. 1. An isometric view of the DELTA Loop.

model were obtained from facility drawings and design calculation notes. A total of 30 hydro components and 5 heat-structure components are used to model the facility. The average cell node length is 1 ft (0.3048 m), except in the recuperator and heat-exchanger components, where finer noding is used. There are a total of 191 computational fluid cells. Although they are not shown in the noding diagram, the walls of the piping also are modeled as part of the hydro components so that external heat losses can be accounted for. The recuperator and pump bypass lines are included in the TRAC model so that natural convection tests can be simulated.

The TRAC model was developed in stages. The initial model did not include the heat-exchanger secondary side. Instead, a simple heat-removal boundary was used to model the heat-exchanger secondary-side heat removal. The facility test runs performed in late 2001 were used to verify the correct pump flow and pressure losses in the model. External heat losses in the piping were later modeled when the 48-h test of August 6-8, 2002, showed that there were significant heat losses. The secondary side of the heat exchanger then was modeled. A simple control was added to vary the intermediate LBE channel to control the heat removed.

IV. TRAC MODEL BENCHMARK CALCULATION

The DELTA Loop TRAC model has been benchmarked to the 48-h test of August 6–8, 2002. The 48-h test data showed that there were significant external piping heat losses. The measured temperature increase across the heater section was ~23°C compared to the measured temperature drop across the heat exchanger of only ~15°C. The DELTA Loop model was updated to include external heat losses. The external heat losses were modeled using the pipe walls and assuming a constant heat transfer coefficient to standard room temperature. The wall external heat-transfer coefficient was adjusted until the calculated temperatures at selected points in the

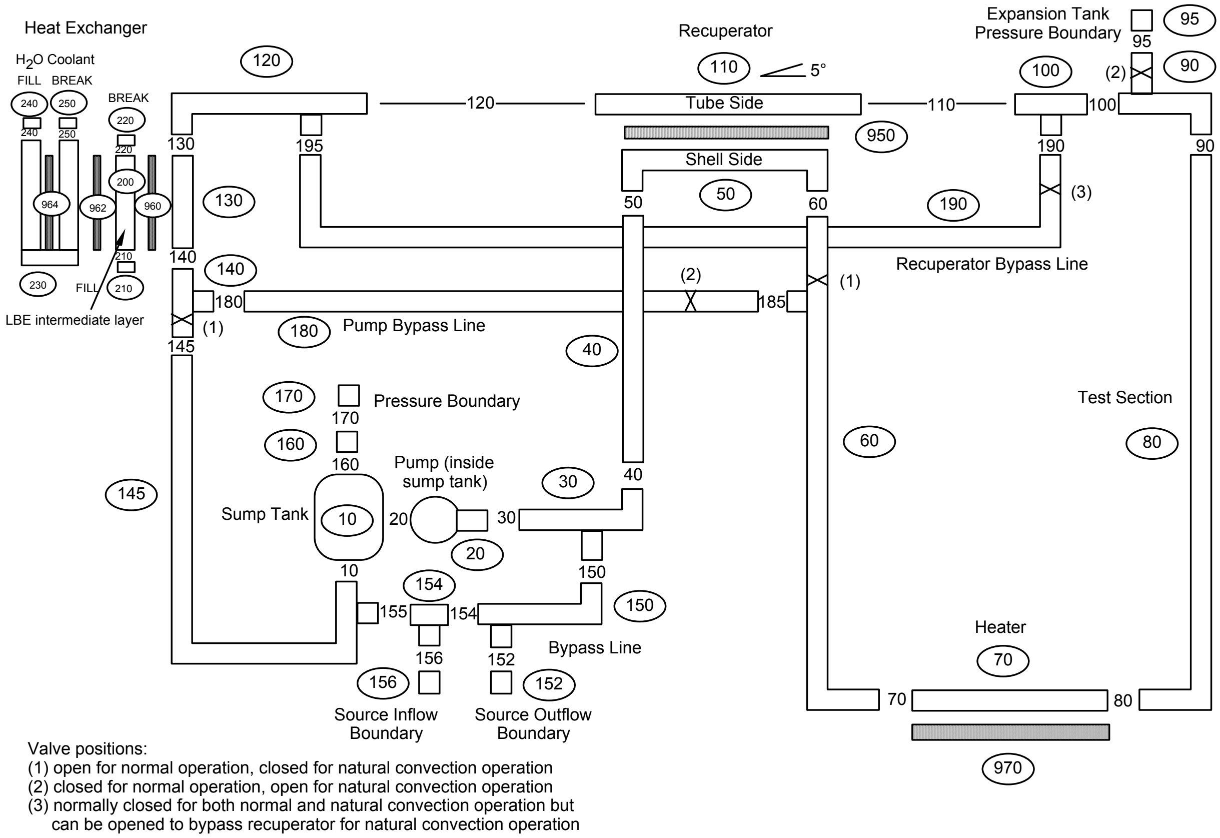

Fig. 2. TRAC noding diagram of the DELTA Loop.

loop matched the measured temperatures. We did not compare the heat-transfer coefficient used to standard heat-transfer correlations. Time and programmatic constraints did not permit us to go into a detailed investigation of the facility heat losses. The DELTA Loop model was updated to include the water-to-lead-bismuth heat exchanger. The stand-alone model was benchmarked against the 48-h test. This was done by first developing a standalone heat-exchanger model and benchmarking the model to the 48-h-test water-flow rate and to the measured lead-bismuth temperature decrease and water temperature increase. Control modeling was added to vary the height of the lead-bismuth intermediate channel. This modeling controlled the heat transfer to the water side so that the lead-bismuth-coolant outlet temperature could be controlled to a specified value. The DELTA Loop model was updated to include the heat-exchanger secondary-side control modeling.

The heat-exchanger model then was integrated into the DELTA Loop model, and the full DELTA Loop model then was benchmarked against the 48-h test. Figure 3 shows a comparison of the measured temperatures to the TRAC-calculated temperatures. Figure 4 shows a comparison of the measured temperature differences across the recuperator, heater section, and heat exchanger to the TRAC-calculated results.

V. PRETEST PREDICTION CALCULATIONS

Two pretest prediction calculations were performed with the DELTA Loop model. The first pretest prediction calculation was to determine the power and flow conditions needed to obtain a heater outlet temperature of 500°C (773 K) and a heat-exchanger outlet temperature of 400°C (673 K), with a flow velocity of 2 m/s through the test section. The second pretest prediction was to determine the natural convection flow conditions for the case where the pump is bypassed, the heater section power is maintained at the power from the previous pretest calculation, and the heat-exchanger heat-removal rate is controlled to maintain the heat-exchanger outlet temperature at 400°C (673 K). The flow still is assumed to pass through the recuperator tube side. The calculation results for these pretest predictions are shown in Table I.

The TRAC calculations for the first pretest prediction show that the desired temperature and flow conditions can be met with a power input of 54.76 kW and with a pump

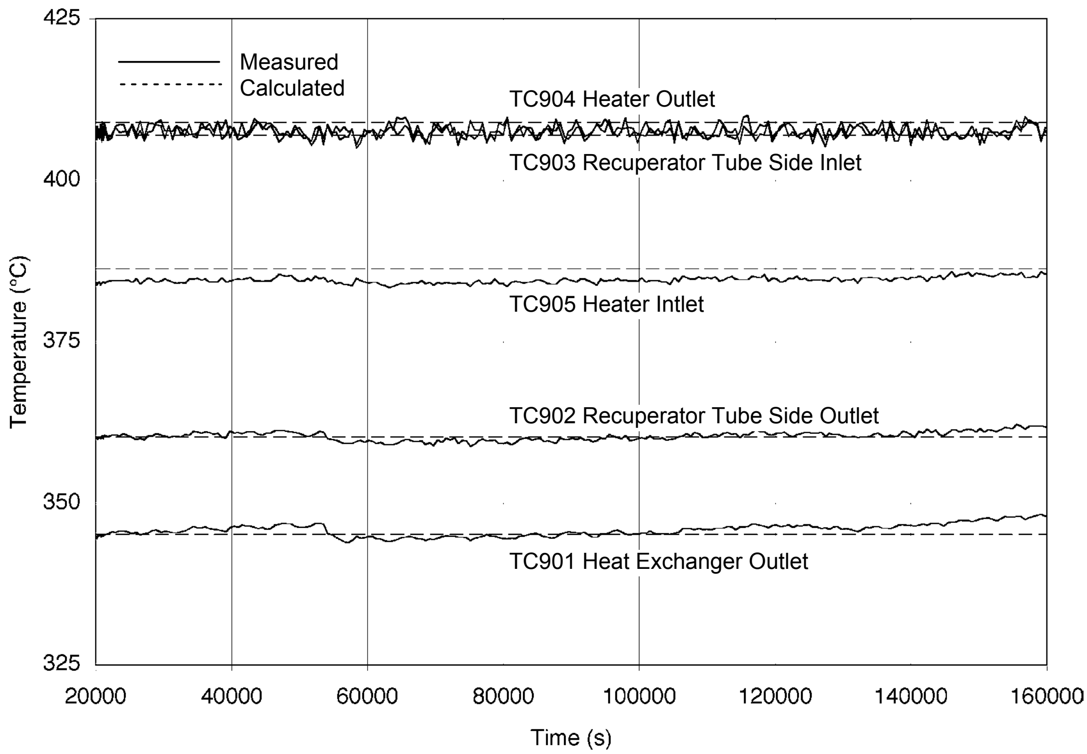

Fig. 3. Comparison of measured temperatures to TRAC calculated temperatures.

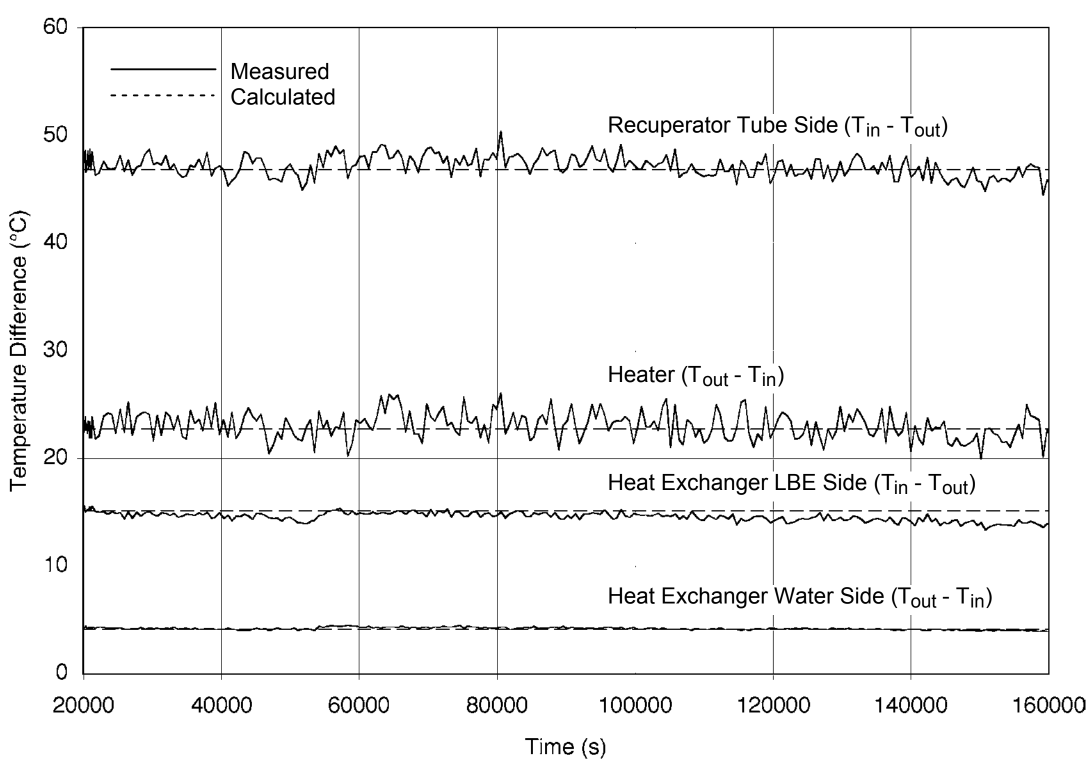

Fig. 4. Comparison of measured temperature differences across the recuperator, heater section, and heat exchanger to TRAC-calculated results.

flow of 16.2 kg/s. The second TRAC pretest calculation shows that with a heater power of 54.76 kW and controlling the heat exchanger to maintain a heat-exchanger outlet temperature of 400°C, a natural convection mass flow of 2.63 kg/s can be maintained. This flow corresponds to a flow velocity of 0.468 m/s through the test section.

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TABLE I. Pretest Prediction Calculation Results

Calculated Parameter	**500°C/400°C Test Case**	**Natural Convection Flow Test Case**
Heater section power	54.76 kW	54.76 kW
Pump total mass flow	16.2 kg/s (25.1 gal./min)	N/A
Test section mass flow	11.26 kg/s (17.65 gal./min)	2.63 kg/s (4.13 gal./min)
Test section flow velocity	2 m/s	0.468 m/s
Sump tank temperature	670.4 K (397.2°C)	N/A
Recuperator shell-side inlet temperature	668.4 K (395.2°C)	N/A
Recuperator shell-side outlet temperature	741.7 K (468.5°C)	N/A
Recuperator shell-side ΔT (T_{out} - T_{in})	73.3°C	N/A
Heater section inlet temperature	740.1 K (467.0°C)	664.9 K (391.8°C)
Heater section outlet temperature	773.5 K (500.4°C)	808.1 K (535.0°C)
Heater section ΔT (T_{out} - T_{in})	33.4°C	143.2°C
Recuperator tube-side inlet temperature	771.1 K (498.0°C)	797.4 K (524.3°C)
Recuperator tube-side outlet temperature	697.0 K (423.8°C)	793.2 K (520.0°C)
Recuperator tube-side ΔT (T_{out} - T_{in})	-74.1°C	-4.3°C
Heat-exchanger inlet temperature	696.6 K (423.4°C)	791.1 K (518.0°C)
Heat-exchanger outlet temperature	673.0 K (399.9°C)	672.0 K (498.8°C)
Heat-exchanger ΔT (T_{out} - T_{in})	-23.6°C	-119.1°C
Heat-exchanger heat removal rate	37.48 kW	44.23 kW
Piping external heat losses	17.28 kW	10.53 kW
Secondary-side water mass flow	1.42 kg/s (22.5 gal./min)	1.42 kg/s (22.5 gal./min)
Secondary-side water inlet temperature	295 K (21.8°C)	295 K (21.8°C)
Secondary-side water outlet temperature	301.3 K (28.1°C)	302.4 K (29.3°C)
Secondary-side water ΔT (T_{out} - T_{in})	6.3°C	7.4°C