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RELAP5 Analysis of a Condensation Experiment in an Inverted U-tube

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Abstract

Two-phase transient phenomena in the noncondensable gas-filled colsed loop was investigated numerically using the RELAP5/MOD3 version 3.1 computer code. The condensation heat transfer correlation for noncondensable gases was studied in detail. Two modes of the reflux condensation which can be characterized by countercurrent flow of steam and its condensed water and the oscillatory between reflux condensation and natural circulation were predicted well. However, the natural circulation mode which the condensed water carried over the U-bend cocurrently with steam was failed to predict.

I. Introduction

A number of experiments have been conducted to study the effects of noncondensable gases on the condensation heat transfer. A U-tube condensation experiment was performed by Hein *et. al.* [1] to study the steady phenomenon of steam condensation in the presence of nitrogen in a single inverted U-tube that was the primary side and a tank containing water for the secondary side. In their experiment, several steady states were obtained for a range of nitrogen injections by changing the secondary temperature at a constant primary pressure and a constant steam flow rate. To determine the effects of pressure, wall temperature subcooling, length, and air content of the mixture on the condensation heat transfer, the condensation experiment was performed in a containment-type setup by Dehbi *et. al.* [2]. Recently, Hassan and Raja [3] assessed the steam condensation model of RELAP5/MOD3 by performing assessmental calculations of the above two experiments. These studies were focused on the steady state condensation heat transfer, however, the transient thermal hydraulic phenomena are usually occurred in the real situation. A transient condensation experiment in an inverted U-tube was performed by Nguyen and Banerjee

[4]. They reported that three different modes in the inverted U-tube, *i.e.*, reflux condensation, natural circulation and oscillatory mode, were observed. These flow modes could be encountered during the mid-loop operation or a loss of coolant accident of light water nuclear reactors.

II. RELAP5 Model Description

A transient steam condensation experiment in an air-filled single inverted U-tube which was conducted by Nguyen and Banerjee [4] at University of California was chosen for analysis in the paper. The test apparatus, as shown in Fig.1 schematically, consisted of a single inverted U-tube that was the primary side and a cooling water jacket for the secondary side. Heat in the primary was transferred into the subcooled water in the secondary. The riser, identical to the downside, was an assembly of two concentric Pyrex tubes consisted of the inner tube with 2.165 m long, 16 mm inner diameter, 1.5 mm thick and the cooling jacket with 2 m long, 40 mm inner diameter, 2.5 mm thick. Subcooled cooling water of constant conditions entered continuously at the bottom of the assembly, flowed upward in the annular space, and left the cooling jacket at the top. The boiler of 36 liters, which was made of aluminum, supplied steam to the riser. To generate steam, power was delivered to electric heaters which were submerged in 30 to 31 liters of deionized, deaerated water.

The RELAP5 nodalization of the experiment was plotted in Fig.2. The U-tube and the cooling jackets were modeled as a pipe component . The boiler was modeled by two branch components and two pipe components for the fallback flow path of condensed water in the U-tube. Two heat structures were added to model the heater and the boiler wall. The cooling water supply was modeled by the time dependent volumes and time dependent junctions. The pipe walls in the riser and the downside were modeled by heat structures. Properties of the Pyrex glass and the aluminum were used for the heat structure material property data. The vertical stratification model was turned off because the noncondensable gas in hydrodynamic volumes may cause heat transfer coefficients that are too low for stable calculations for low heat transfer regimes such as the vertical stratification flow regime.

III. Results and Discussions

One of important phenomena observed from the transient U-tube condensation experiments was that three flow modes, *i.e.*, reflux condensation, natural circulation, and oscillatory mode were found. Reflux condensation was characterized by a stable liquid column in the riser. Natural circulation characterized by the cocurrent flow of steam and water over the U bend. The oscillatory mode was constituted by accumulation of water in the riser and periodic dumping of the liquid column over the U-bend.

Three tests representing these flow modes, as summarized in Table 1, were chosen in the present study. Air level and water flow rate in the cooling jackets of the chosen tests were constant values of 0.03 mole and 25 ml/s, in respectively. The flow mode depended on the level of input power. At low level, all steam generated in the boiler were condensed in the riser and the condensed liquid flow back to the boiler. When the input power was increased to such a level that inlet steam velocity exceeds the flooding value, the oscillatory mode prevailed the system. At sufficiently high level, the cocurrent flow of steam and water became stable. Therefore, three different power levels of 1.93 kW, 2.51 kW and 4.86 kW were chosen.

Initial conditions for transient calculations were obtained by reading the initial pressures from experimental data and by assuming a constant liquid temperature of 20 ^{o}C. The constant water flow rate of 25 ml/s at the cooling jacket inlets was set up by time dependent junctions. It was also assumed that the noncondensable gas was distributed uniformly in the vapor region. The transient calculations were started by turning on the power of the heaters. The calculations were performed to 5000 s using a HP-735 workstation.

In Fig. 3, the predicted absolute pressure at the boiler, temperature at cooling jacket exits, and differential pressure between the boiler and the horizontal top tube for test no. 305 are compared with experimental data. The predicted results are plotted by solid lines. The oscillatory flow behavior with a high frequency between the natural circulation and the reflux mode is predicted, while the natural circulation mode was observed in the experiment. The predicted boiler pressure is stabilized at higher pressure of about 0.42 MPa than experimental value of 0.07 MPa. Temperature at the riser side outlet is also overpredicted, but temperature at the downside outlet shows good agreement except the oscillation of small amplitude. The predicted pressure drop along the riser shows larger value of about 20 kPa which means a single phase liquid column was formed along the almost entire riser side tube of 2 m height, while initially formed liquid column of about 1.2 m length was cleared and maintained at low level in the experiment.

The predicted results for test no. 308 of the oscillatory mode are plotted in Fig. 4. The oscillatory flow behavior is predicted well. However, the boiler pressure and the pressure drop along the riser are also overpredicted. Higher frequent oscillation than the experiment is predicted. The formed liquid column is carried over partially the U-bend while the condensed water in the riser is carried over completely in the experiment. Much water is still remained in the riser after occurring the natural circulation mode. Therefore, the reformation of the single phase liquid column takes shorter time than the experiment. Higher amplitude of the temperature oscillation at the riser side cooling jacket outlet is caused from the heat transfer overprediction due to the overpredicted two phase region.

The predicted results for the reflux condensation mode are shown in Fig.5. The reflux condensation mode which can be occurred during the mid-loop operation is predicted well except the overprediction of the boiler pressure and the pressure drop along the riser. It is noted that the pressure overprediction is conservative in evaluating the integrity of the temporary boundaries installed during the mid-loop operation.

IV. Conclusions

The transient thermal-hydraulic phenomena in the closed loop with a noncondensable gas were investigated numerically by using RELAP5/MOD3. All major thermal-hydraulic phenomena observed in the experiment were predicted well. Two modes of the reflux condensation and oscillatory flow were predicted well. However, the boiler pressure and the length of a liquid column formed along the riser side tube were overpredicted.

References

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Table 1. Summary of simulated tests.

Test No.	Air Level (mole)	Coolant Flow Rate (ml/s)	Power (kw)	Flow Regime
305	0.03	25	4.86	Natural Circulation
308	0.03	25	2.51	Oscillatory Mode
310	0.03	25	1.93	Reflux Mode

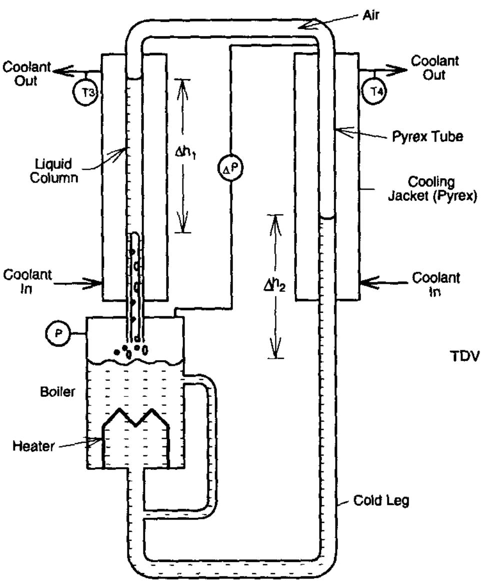

Fig.1 Schematic of the inverted U-tube condensation experiment

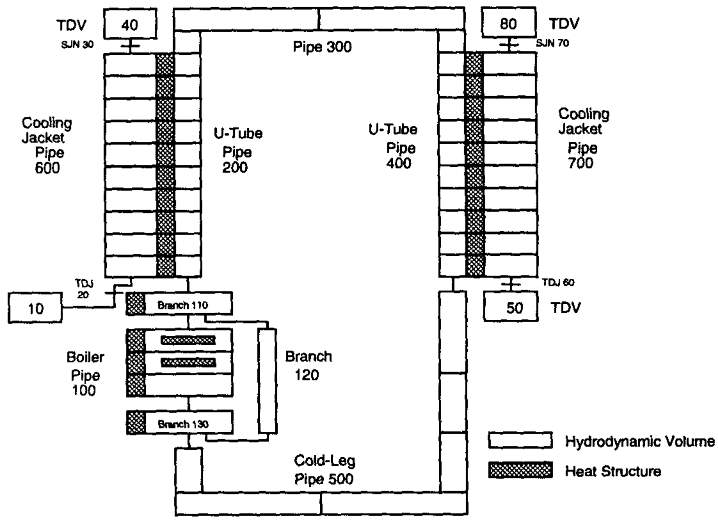

Fig.2 REALP5 nodalization of the inverted U-tube experiment.

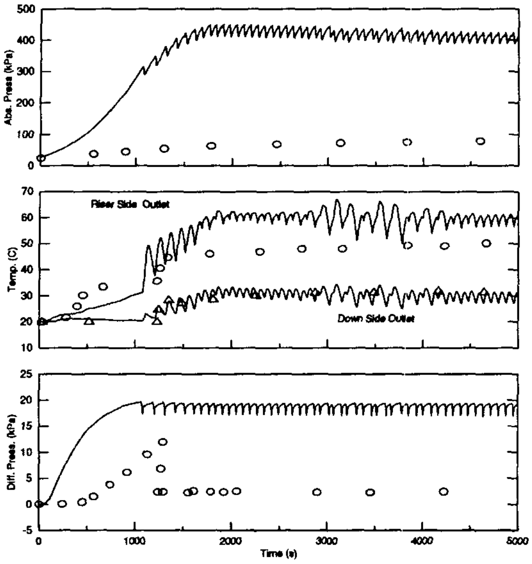

Fig. 3 Pressure at the boiler, water temperature at the cooling jacket outlets, and pressure drop along the riser for test no. 305.

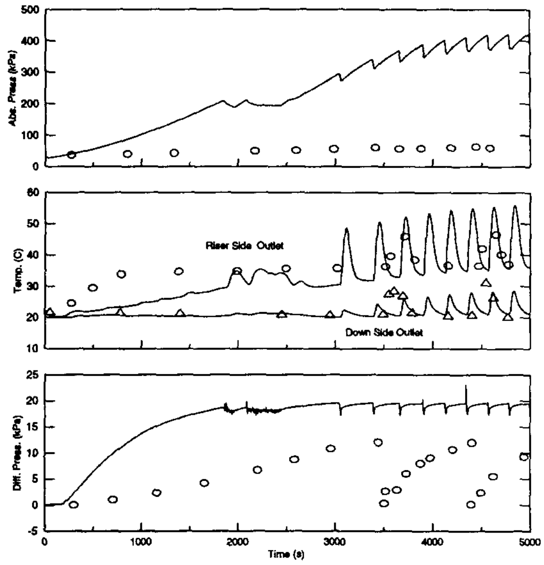

Fig. 4 Pressure at the boiler, water temperature at the cooling jacket outlets, and pressure drop along the riser for test no. 308 (solid line: prediction, symbols: data).

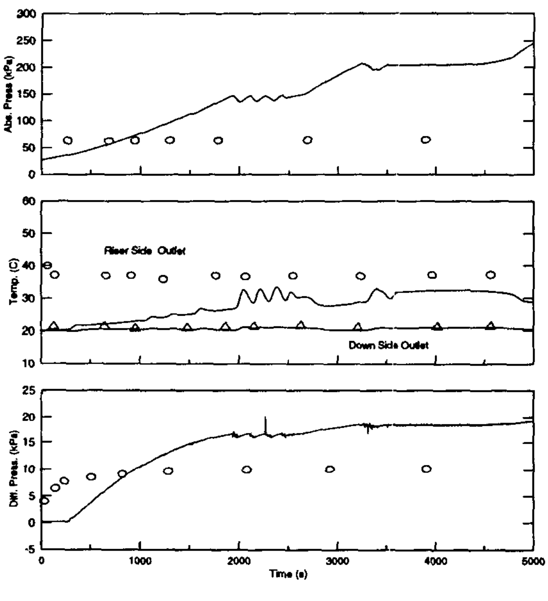

Fig. 5 Pressure at the boiler, water temperature at the cooling jacket outlets, and pressure drop along the riser for test no. 310 (solid line: prediction, symbols: data).