Assessment of TRACE CCFL Model with Air-Water Countercurrent Flow Test

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1. Introduction

The TRAC/RELAP Advanced Computational Engine (TRACE) is the latest in a series of advanced, best-estimated reactor systems codes developed by U.S. Nuclear Regulatory Commission for analyzing transient and steady-state neutronic-thermal-hydraulic behavior in light water reactors [1].

In this study, we assess the ability of TRACE code (version 5.0 patch 4) to predict the countercurrent flow limitation (CCFL) at the perforated plate. The tests conducted by NO et al. [2] are used in this assessment. The results of TRACE calculation are compared with the CCFL curve derived from the experimental data.

2. Test Facility Description

Figure 1 shows the schematic diagram of the experimental apparatus. The main components are the test vessel, the water supply and the air supply systems. The upper and lower plenums are 1 m high with an inner diameter of 0.48m. The perforated plate with four holes (0.05 m in diameter and 0.096 m in pitch) was installed at the middle height of the test vessel. The water is supplied from the water storage tank and injected into the upper plenum. The air is supplied from an air blower into the lower plenum. The water drained from the lower plenum is collected in a drain storage tank. Two water pumps pump the water back to the water storage tank.

The tests were conducted under atmospheric pressure. The range of the water injection superficial velocity ($j^*_{f,in}$) at plate holes was from 0.021 to 0.076 m/s. The test procedure consisted of establishing the water flow into the upper plenum at a given flow rate and then supplying the air into the lower plenum. After allowing sufficient time for a quasi-steady state to be attained, the air flow rate is increased in a stepwise manner until the onset of CCFL is observed. This procedure was repeated for different water flow rates.

On the basis of the onset of CCFL data, NO et al. developed the following Wallis-type correlation:

$$j_g^{*1/2} + 1.22\, j_f^{*1/2} = 0.88 \qquad (1)$$

where j^* is defined as the dimensionless superficial velocity, subscripts g and f refer to gas and liquid respectively.

3. TRACE Model Description

The experiment is modeled using the nodalization shown in Figure 2. The noding diagram was built using the SNAP version 2.2.7. The upper and lower plenums are modeled using PIPE components (130 and 100) with ten and five axial cells, respectively. As the air flow rate required for the onset of CCFL was independent of the plate thickness, the perforated plate is modeled as a restriction in the flow area at the cell face (edge) between components 100 and 130. Two FILL components (210 and 220) are used to model the air and water injections. The BREAK component (230)

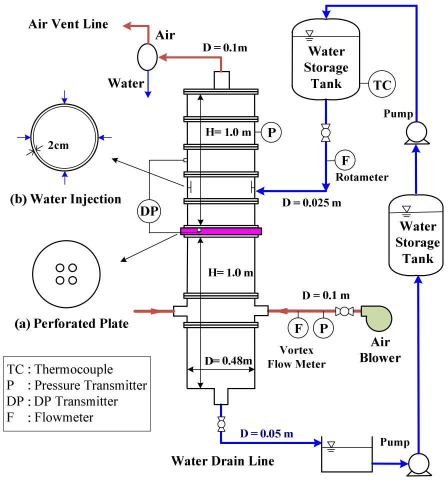

Fig. 1. Schematic Diagram of Experimental Apparatus.

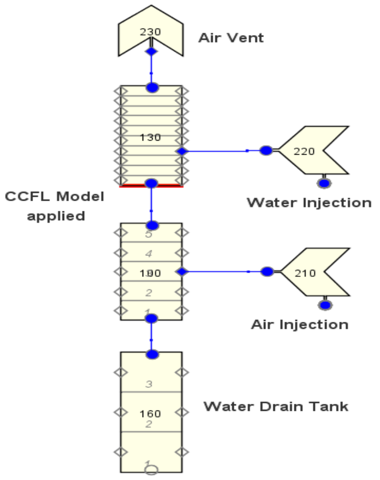

Fig. 2. TRACE Nodalization.

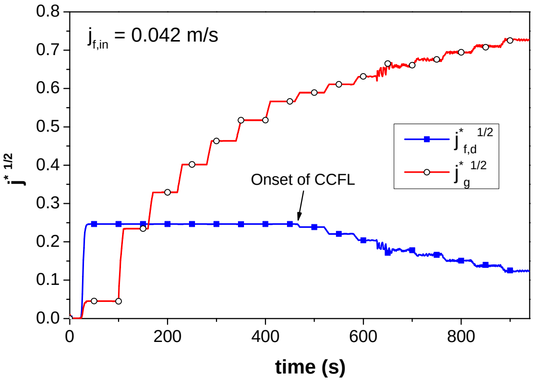

Fig. 3. Calculated Dimensionless Water and Air Superficial Velocities at Plate.

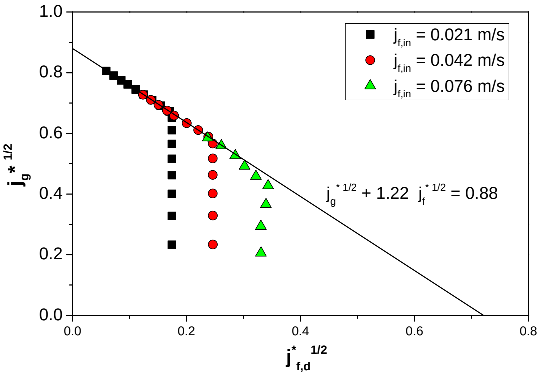

Fig. 4. Comparison of Calculated Velocities with CCFL Curve.

is used for the upper air vent line. The water drain line is modeled using the 6 m long PIPE component (160) to prevent the air from flowing down.

The TRACE code adopts a general CCFL model proposed by Bankoff et al. [3]. This model allows the user to select the Wallis form (diameter dependence), the Kutateladze form (surface-tension dependence), or a combination of the two. From the definition of onset of CCFL, we assume the CCFL curve follows the onset of CCFL correlation. The CCFL model is applied at the edge between components 100 and 130. The CCFL input data for this edge used the following values: edge hydraulic diameter = 0.05 m, Bankoff interpolation β = 0 (Wallis scaling), slope m = 1.22, and correlation constant (gas intercept) C = 0.88.

The semi-implicit numerical scheme is chosen as the time integration method. The initial pressures of FILL (water injection), BREAK, and PIPE components are set to 1.0E+5 Pa. The pressure of FILL (air injection) is set to 1.016E+5 Pa. The initial temperatures of water and air are set to 293K.

4. Results and Discussion

Figure 3 shows the relation between the water down flow rates and the air flow rates at the water injection superficial velocity of 0.042 m/s. The air flow is increased over a 10 second period and then maintained for 50 seconds before increasing the air flow rate. The dimensionless superficial water and gas velocities are calculated from the mass flow rates through the plate. The calculated results are plotted using the square root of dimensionless superficial velocities.

As the air injection rate is increased, the water down flow rate remains equal to the injection rate until the onset of CCFL occurs. Further increases in the air flow rates beyond the onset of CCFL results in the decrease in the water down flow rate ($j^{*}_{f,d}$). The decrease in water down flow rate means that the two-phase mixture level on the plate increases continuously even at a constant air flow rate.

Figure 4 compares the calculated dimensionless superficial velocities at various water injection flows with the CCFL curve. The range of the water injection superficial velocities at plate holes is from 0.021 to 0.076 m/s consistent with the experiment. The points in Fig. 4 are the mean values at each air injection flow rate.

As shown in Fig. 4, the points of onset of CCFL lie on the CCFL curve. As the air flow rate is further increased beyond the onset of CCFL, the water down flow rates into the lower plenum follow with considerable accuracy the CCFL curve. The slight deviations between the calculated values and CCFL curve at $j^{*}_{f,in}$ = 0.076 m/s are probably caused by the oscillation in the calculated values. The maximum error between the calculated $j^{*}_{f,d}{}^{1/2}$ and the value predicted by CCFL curve is 7.4%.

5. Conclusions

We assessed the ability of TRACE code (version 5.0 patch 4) to predict the CCFL at the perforated plate. The results show that the calculated results are in excellent agreement with the Wallis-type CCFL curve. This study provides the code users with the insight that TRACE code predicts fairly well the CCFL behavior of air-water countercurrent flow.

Acknowledgments

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