Preliminary analysis of a flashing experiment using the CUPID code

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1. Introduction

The component-scale thermal-hydraulic code, CUPID has a model for flashing phenomenon. Currently, in the CUPID code, the model uses constant value for an interfacial heat transfer coefficient when a flashing occurs. The flashing model in the CUPID code doesn't consider variables which could affect a flashing. However, the flashing is a significant phenomenon in transient analyses of a nuclear power plant. For this reason, analyzing the flashing accurately becomes more important. So, we intend to improve the flashing model in the CUPID code. By analyzing a flashing experiment, the variables which have significant effects on the flashing will be investigated and, later, incorporated into the flashing model in the CUPID code.

In this paper, a preliminary analysis is carried out to prepare a flashing experiment which will be performed at KAERI. With various combinations of inlet water temperature and velocity, the CUPID code calculates conceptual flashing experiments and, then, the initial conditions for the flashing experiment will be decided based on the calculation results. This paper presents the results of the preliminary analysis.

2. Mathematical Model

2.1 Governing Equation

A two-fluid, three-field model for a two-phase flow is adopted in the CUPID code. The three fields represent a continuous liquid, an entrained liquid, and a vapor field. The mass, energy, and momentum equations for each field are established separately and, then, they are linked by the interfacial mass, energy, and momentum transfer models [1]. The continuity, momentum, and energy equations for the k-phase are given by

$$\frac{\partial}{\partial t}(\alpha_k\rho_k) + \nabla\cdot(\alpha_k\rho_k\underline{u}_k) = \Gamma_k \quad (1)$$

$$\frac{\partial}{\partial t}(\alpha_k\rho_k\underline{u}_k) + \nabla\cdot(\alpha_k\rho_k\underline{u}_k\underline{u}_k) = -\alpha_k\nabla P + \nabla\cdot[\alpha_k\tau_k] + \alpha_k\rho_k\underline{g} + P\nabla\alpha_k + M_k^{mass} + M_k^{drag} + M_k^{VM} + M_k^{non-drag}, \quad (2)$$

$$\frac{\partial}{\partial t}[\alpha_k\rho_k e_k] + \nabla\cdot(\alpha_k\rho_k e_k\underline{u}_k) = -\nabla\cdot(\alpha_k q_k) + \nabla\alpha_k\tau_k:\nabla\underline{u}_k - P\frac{\partial}{\partial t}\alpha_k - P\nabla\cdot(\alpha_k\underline{u}_k) + I_k + Q'''_k \quad (3)$$

where, $\alpha_k, \rho_k, u_k, P_k, \Gamma_k, I_k$ are the k-phase volume fraction, density, velocity, pressure, an interface mass transfer rate, and energy transfer rate, respectively. M_k represents the interfacial momentum transfer due to a mass exchange, a drag force, a virtual mass, and non-drag forces. And k=l, v, or d (liquid, vapor, or droplets)

2.2 Flashing Model in the CUPID Code

In the continuity equation for vapor-phase, the interface mass transfer rate, Γ_v is given by

$$\Gamma_v = \frac{\frac{P_s}{P}H_{ig}[T^s(P_s)-T_g] + H_{if}[T^s(P_s)-T_l]}{h_g^*-h_f^*} \quad (4)$$

where, P_s, T^s, H_{if}, H_{ig} are the partial pressure of steam, the saturation temperature, the interfacial heat transfer coefficient for liquid phase, and the interfacial heat transfer coefficient for vapor phase, respectively.

When the liquid temperature is greater than the saturation temperature, a flashing will occur. In this case, the interfacial heat transfer coefficient for liquid phase (H_{if}) determines the rate of a flashing in the CUPID code, where H_{if} is modeled as a constant, 1.0×10^6.

3. Analysis Result

In this chapter, the flashing simulation is performed in a test section which is full of water and its geometry is 10m×0.08m vertical square tube. We performed the analysis to validate the flashing model in current version of the CUPID code (ver.1.6) and obtain initial conditions for flashing experiment.

Water at a constant temperature is injected through the test section from bottom to top. In this simulation, we changed the water temperature and the inlet velocity to analyze their effects on flashing. The inlet water temperature varies from 373.15 to 393.15K and the inlet water velocity varies from 0.05 to 0.20m/s, for each case.

3.1 Initial Conditions

For a preliminary simulation, it is assumed that the flow in the test section is two-dimensional. Water is injected from inlet boundary and flows through test section with constant temperature and velocity. The initial water temperature in the test section is 370.15K. The pressure of outlet is set to 0.1MPa. Computational mesh and boundary conditions are depicted in Fig. 1.

3.2 Simulation Result

We simulated two cases. The first case is performed with changing the inlet temperature and the other case with changing the inlet velocity. It leads significantly different result, which is described as follows.

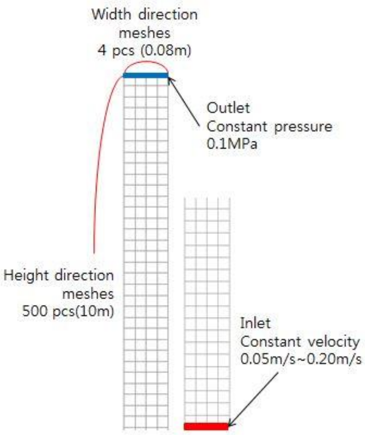

Fig. 1. Computational mesh and boundary conditions

As the water moves upwards, the local saturation pressure decreases because of gravity and, at some location, the liquid temperature exceeds the saturation pressure, resulting in a flashing. Thus, it is natural that the higher velocity leads to the earlier flashing. The results of calculations are shown in table 1.

Table 1. Flashing time versus inlet velocity

Inlet velocity [m/s]	Time that flashing occurs [sec]
0.05	219
0.10	110
0.15	74
0.20	52

Figure 2 shows the void fraction distribution soon after the flashing occurs. In this case, the inlet water velocity is 0.2m/s. Water comes up the 10m-long test section. The water velocity is the fastest at the center of the tube. Temperature of the center of the test section reaches saturation temperature first, and then the flashing occurs at the center as shown in figure 2. The inlet water temperature is 373.15K and the pressure of the top section is 0.1 MPa, which its corresponding saturation temperature is 372.78 K. For this reason, the CUPID code predicts that the flashing occurs at little lower height than the top.

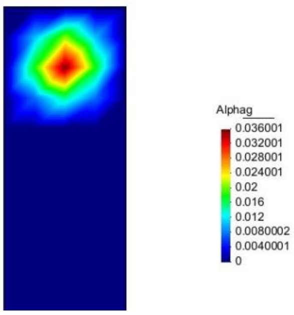

Fig. 2. The void fraction distribution at t=52sec (V_{in}=0.2m/s)

As the inlet water temperature increases, a height at which the flashing occurs is decreased. As shown in table 2, the height of the flashing is related to the inlet water temperature. The saturation temperature is determined by the local pressure. So, the flashing will occur at lower height as the inlet water temperature increasing. Figure 3 shows the void fraction distribution at 8m and the subcooling temperature distribution. As shown in figure 3, void fraction is concentrated at the center. Because the water velocity is the fastest at the center and its pressure is lower than the wall side, vapor bubbles caused by the flashing are entrained to the center. The flashing occurrence area spread out since the flashing occurs first. The inlet water temperature is 378.15K and the saturation temperature at h=8m is 377.95K.

Table 2: The height where a flashing occurs

Inlet Temperature [K]	Height [m]	Pressure at the Height [bar]	Saturation Temperature [K]	Error [%]
378	8	1.2	377.95	0.01
383	5.58	1.442	383.19	0.05
388	2.78	1.722	388.5	0.13
393	0.04	1.963	392.64	0.09

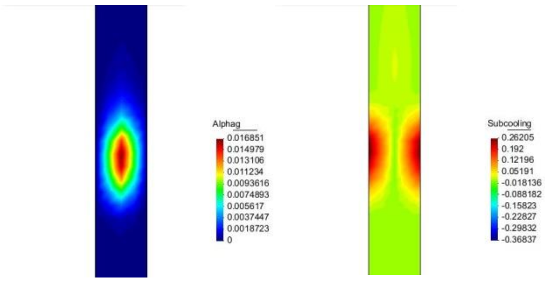

Fig. 3. The void fraction distribution and subcooling temperature distribution at h=8m. (T_{in}=378.15K)

3. Conclusions

In this paper, a preliminary analysis of the flashing experiment has been performed using the CUPID code. As we expected, the flashing occurs depending on inlet water temperature and inlet water velocity. In the test section, the flashing occurs differently depending on inlet condition, and we can obtain initial conditions for the flashing experiment.

Using the results of the experiments, the interfacial heat transfer model for a flashing in the CUPID code is to be developed.

REFERENCES

[1] Han Young Yoon, Hyoung Kyu Cho, Jae Ryong Lee, Ik Kyu Park, Jae Jun Jeong, Multi-Scale Thermal-Hydraulic Analysis of PWRs using the CUPID Code, Nuclear Engineering and Technology, Vol.44, No.8, pp. 831-846 (2012).