Off-take Model of the SPACE Code and Its Validation

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1. Introduction

Liquid entrainment and vapor pull-through models of horizontal pipe have been implemented in the SPACE code. The model of SPACE accounts for the phase separation phenomena and computes the flux of mass and energy through an off-take attached to a horizontal pipe when stratified conditions occur in the horizontal pipe. This model is referred to as the off-take model.

The importance of predicting the fluid conditions through an off-take in a small-break LOCA has been well known. In this case, the occurrence of the stratification can affect the break node void fraction and thus the break flow discharged from the primary system. In order to validate the off-take model newly developed for the SPACE code, a simulation of the HDU experiments [1] has been performed. The main feature of the off-take model and its application results will be presented in this paper.

2. Off-take Model

2.1 General Description

In small break scenarios the stratification can occur in the hot legs, cold legs and loop seals. In this situation the steam and water in the pipe may separate to form a liquid level. When the stratification occurs in the pipe containing the break, the quality of fluid discharged from the break greatly depends on whether the break is above or below the liquid level. This dependence is not simply dictated by the break elevation. In fact even if the level is higher than the upper side of the break, a quantity of vapor can be entrained in a vortex and reach the break (vapor pull through). Similarly, if the break is located above the horizontal interface, liquid from the interface can be entrained due to inter-phase shear stress produced by the vapor acceleration in the vicinity of break branch (liquid entrainment). In order to simulate these phenomena correctly, an off-take model has been contained in the code. Apart from small break LOCA, such a model is also needed for analyzing other abnormal conditions in PWRs.

2.2 Model Implementation

The off-take pipe is located at the top, bottom, or side of the large horizontal pipe. In order to determine the onset of liquid entrainment or gas pull-through at various oriented branches, the correlation suggested by Smoglie [2] is implemented in the SPACE code. The inception height, h_b, associated with the onset of liquid entrainment or gas pull-through is represented as follows:

$$h_b = \frac{C_1 W_k^{0.4}}{(g\rho_k \Delta\rho)^{0.2}}$$

Where, k refers to the continuous phase, which is the gas phase for upward oriented branch and liquid phase for downward oriented branch. For a side off-take, the gas phase is the continuous phase when the liquid level is below the off-take center and the liquid phase is the continuous phase when the liquid level is above the off-take center. Various values of C_1 are determined for the direction of branches by experiment. The variable W_k is the mass flow rate of the continuous phase in the off-take.

Once the inception criterion for the given geometry of off-take location has been satisfied, pull-through or entrainment will begin. Correlations used for calculation of flow quality, X, at the branch entrance with off-take are dependent on the connection angle between a large horizontal and branch pipes, and represented as follows:

<u>For a top off-take</u>

$$X = R^{3.25(1-R)^2}$$

Where, $R = h / h_b$ and h is distance from the stratified liquid level to junction.

<u>For a bottom off-take</u>

$$X = X_0^{2.5R}[1-0.5R(1+R)X_0^{(1-R)}]^{0.5}$$

Where, $X_o = 1.15/(1+\sqrt{\rho_f/\rho_g})$

<u>For a side off-take</u>

$$X = X_0^{(1+C_2R)}[1-0.5R(1+R)X_0^{(1-R)}]^{0.5}$$

Where, C_2 = 1.09 for a gas pull-through and C_2=1.0 for liquid entrainment.

3. Application Results

The off-take model implemented in the SPACE code is assessed to HDU experiments, which were conducted to investigate the off-take phenomena at the T-junction installed between the header and branch pipes. The test facility contains various branch pipes not only for three directions (top, side and bottom), but for arbitrary directions. The experiments about the onset of entrainment and branch quality only for three directions (top, side and bottom) were carried out by using air-water as working f1uids under the conditions of about 20 °C temperature and of pressures up to 0.95 MPa.

The test geometry is modeled using the pipe and branch components. The off-take model is used at the junction of branch pipe connected to a horizontal pipe. On the whole, the off-take model in the SPACE predicts well the present experimental results such as the onset of off-take and the branch quality. A comparison of the Froude number versus the non-dimensional level in term of the ratio of inception height to branch diameter (h_b/d) at the onset of gas pull-through is shown in Figure 1. At the side branch, the calculated quality data are compared with the measured data in terms of the ratio of distance from the stratified liquid level to junction to inception height (h/h_b) as depicted in Figure 2. As shown, a good agreement with the data is observed.

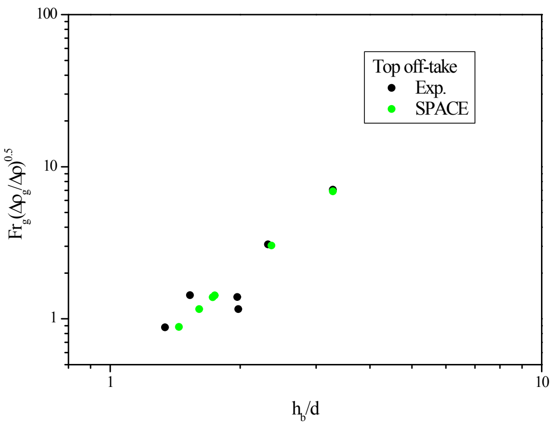

Figure 1. Onset of entrainment at the top branch

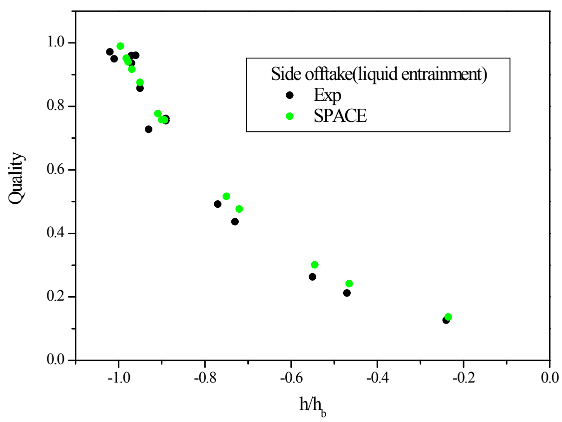

Figure 2. Discharge flow quality vs. liquid depth for the side branch

Especially, for the branch quality with the top branch, the results are shown in Figure 3. The calculated results are compared with the existing experimental data set such as UCB [3] and with the present experimental data. It is found that the simulated results don't show good agreements with the data obtained from the top branch because of the unstable state in the horizontal pipe and the different branch diameters. It seems to be difficult for the correlations in the code to capture this unstable flow regime. However, it can be seen that the correlations give a reasonable overall representation of the test data.

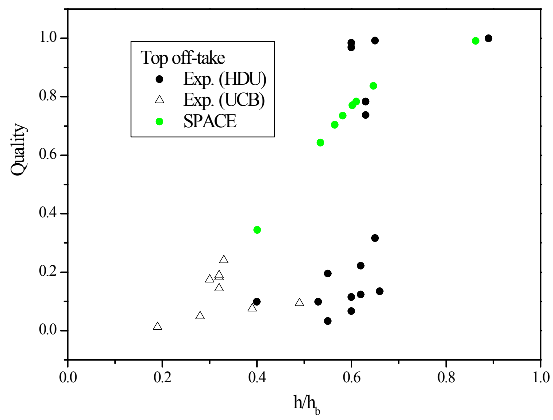

Figure 3. Discharge flow quality vs. liquid depth for the top branch

4. Conclusions

The off-take calculation module was incorporated into the SPACE code. As an effort for validation, the off-take model was assessed for the HDU experiments. Overall, the calculated results agreed well with the measured data. It is concluded that the SPACE code with the off-take model predicts the complex phenomena of liquid entrainment and vapor pull-through properly.

Acknowledgment

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