Development of Interfacial Drag Model for Bubbly Flow in Downcomer Annulus during Late-reflood phase of DVI Plant, APR1400

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1. Introduction

APR1400 LBLOCA safety issues have been raised during the design evaluation process. The downcomer boiling is one of these LBLOCA safety issues. The possibility of boiling during LBLOCA reflood phase had been stimulated from the best estimate (BE) calculation using RELAP5/MOD3[1] code. Many controversial arguments in BE calculation have been followed, since there is no reflood boiling model in licensing calculation and no direct evidence of boiling. The possibility of downcomer boiling during late and/or post reflood phase has been also indicated by the independent PIRT expert group[2] The prediction of void fraction of downcomer during post-reflood phase has a significant importance to evaluate the reheating of core. The void fraction of vertical geometry is highly dependent with interfacial drag of two fluid model. However the interfacial drag model of RELAP5 is mainly based on the circular pipe data, the model should be examined for annulus downcomer geometry and improved to get more reliable calculation.

2. Results

2.1. Full Scale Experiment for Downcomer Annulus Geometry

The slab test section has been designed to simulate a full scale sector of downcomer annulus. The section has a dimension of 250x250 mm in cross section, and 4.3 m in length. The sketch of test facility and measurement location are shown in Fig.1.

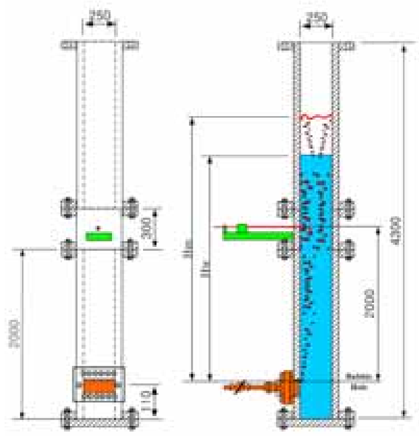

Fig. 1 Slab test facility

The air bubble generator is installed at the bottom level of side wall. The air is injected into the stagnant water at horizontal direction. The air injection rates in the test section were varied from 0 to 11.3 g/sec.

The bubble velocity was measured by two-sensor probe. Since highly churn turbulent and oscillatory flows were observed in this air-water experiment, sufficient sampling time as long as 5 minute is needed to get averaged bubble velocity. Obtained experimental bubble rise velocities in the annulus gap are presented in Fig 2. In order to determine the drift velocity, one dimensional bubble rise velocity has been calculated from data by volume averaging of local bubble velocities. The observed bubble rise velocity is enhanced due to recirculating internal flow. The enhancing factor with respect to RELAP5 original drift velocity has been plotted in Fig. 3.

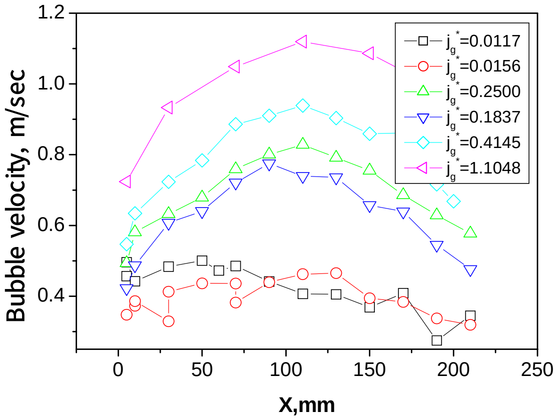

Figure.2 Measured local bubble rise velocities in the gap according to the different air injection rate

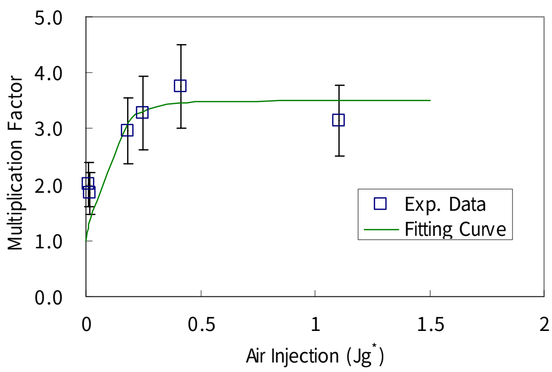

Figure.3 Enhancing factor of drift velocity

The following correlation of enhancing factor is suggested as a best fitting curve of the data.

$$F_v = 1.0 + 2.5\,(1 - e^{-10 \cdot j_g^*}) \qquad (1)$$

2.2. Implementation of Experimental Correlation

For vertical bubbly flow, the interfacial drag terms of RELAP5/MOD3 are calculated using drift flux correlations from the literature based on Putney's work[3]. Table 1 indicates which correlations are used for different geometry and flow condition. The correlation labeled "churn turbulent bubbly/kataoka-ishii" is by Zuber-Findlay and Kataoka-Ishii[4]. The correlation labeled "Churn-turbulent bubbly (annulus)" is by this works. The correlation has been developed only for the DVI plant geometry during LBLOCA reflood condition and based on the experimental data of 25 cm annulus gap size under low pressure and low flow condition. However the annulus multiplier of Eq. (6) has been implemented to the whole range of large annulus gap (> 8 cm) to be consistent to vertical pipe.

Table 1 Drift Velocity Models for Vertical Geometry

Flow Condition	Bundle	Small Pipes D_H< 0.018 m	Intermediate Pipes 0.018 m < D_H < 0.08 m	Large Pipes D_H > 0.08 m	Downcomer Annulus D_H > 0.08 m
High UP		EPRI	EPRI	Churn-Turbulent bubbly / Kataoka-Ishii :	Churn-Turbulent bubbly (annulus)
Medium		Transition			
Low	EPRI	Zuber-Findly Slug	Churn-Turbulent bubbly/Kataoka-Ishii		
Med. Down		Transition			Correlation (1)
High Down		EPRI	EPRI		

High flow : |G|>100 kg/m^{2}s ,
Low flow : -50 kg/m^{2}s < G < 50 kg/m^{2}s
Medium flow : 50 kg/m^{2}s < |G| < 100 kg/m^{2}s

3. Conculsion

The experiment has been done using full scale slab test section, which represents a sector of annulus downcomer. The measured data reveals that vapor drift velocities are much higher than velocity in pipe. The coefficients of annulus multiplication factor have been determined by the experimental data, and the correlation is successfully implemented to system analysis code, RELAP5/MOD3. The APR1400 LBLOCA calculation using the new version code shows that the vapor slip velocity has increased significantly compared to the original version, and vapor can be released effectively when the boil occurs in downcomer annulus during post-reflood phase.

It was concluded that the correlation suggested in this paper can be used for more reliable interfacial friction model of downcomer annulus during reflood phase of LBLOCA..

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