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Measurement Method of Interfacial Area Concentration for Highly Fluctuating Bubbly Flow

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1. Introduction

Thermal hydraulic behavior in the downcomer during the LBLOCA reflood period is important in safety analysis of nuclear power plant. KAERI performed the separate effect test to simulate the phenomena in the reactor downcomer during the LBLOCA reflood period. The downcomer boiling tests showed strong multi-dimensional phenomena including a definite bubbly boundary layer near the wall. Therefore, the predictability of the safety analysis code for the multi-dimensional flow is important and it is needed to generate experimental data for local two-phase parameters.[1]

The interfacial area concentration (IAC) is one of the important parameters in analyzing two phase flow. Currently, three types of probe methods have been used, which are the double-, four-, and five-sensor methods. The five-sensor probe method proposed in their study is essentially based on the four-sensor probe method and has an advantage that a more systematic approach for the missing bubbles can be made than four-sensor probe method. To verify the applicability of the five-sensor probe method, numerical tests were performed with the consideration of the bubble lateral movement.[2] The recent five-sensor method is optimized to a given configuration of the sensor tips consisting the probe by correction factors which should be changed for the configuration of the probe that is used for the downcomer boiling test.

2. Methods and Results

Figure 1 shows the configuration and dimensions of the five sensor tips of probe that is used in the downcomer boiling test. The sensors 0 and 1 are aligned parallel to the heated wall and sensors 0, 1, 3, and 4 are on a plane. As shown in the figure 1, sensors 2, 3, and 4 also form a plane perpendicular to the sensors 0 and 1 line. The interfacial area concentration is obtained by five-sensor method that classifies the types of the interfaces passing through the sensors into four categories.

2.1 Measuring Method for Category I interfaces

Category I interfaces pass all of the sensors. For the bubbles, four-point method of four-sensor method is applied by using sensors 0, 2, 3 and 4 of figure 1.[2]

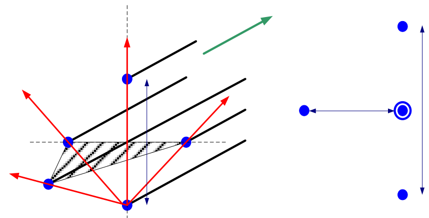
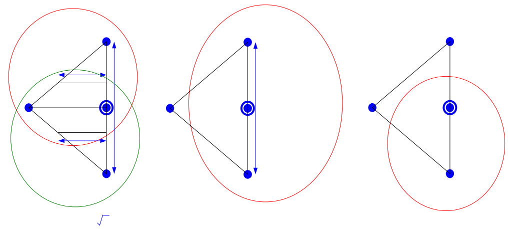


Figure 1. Configuration of five-sensor tips

2.2 Measuring Method for Category II interfaces

Category II interfaces bypass one of sensors 2, 3 and 4. For figure 2(a) cases, two sub-cells are considered and the IAC is obtained as follows:

$$a_{ij} = \frac{(a_{ij})_{Cell\ 1} + (a_{ij})_{Cell\ 2}}{2} \qquad (1)$$



(a) (b) (c)

Figure 2. Model for the Category II and III Interfaces

For red colored interface of figure 2(a), the IAC of sub-cell 1 can be obtained from the four-point method, but in the other sub-cell, following formula is applied.

$$\text{for } \left|(a_{ij})_{Cell1,bottom} - \frac{1}{\Omega}\frac{1}{v_{iz}}\right| < \varepsilon, \quad (a_{ij})_{bottom} = (a_{ij})_{Cell1,bottom} \qquad (2a)$$

$$\text{for } \left|(a_{ij})_{Cell1,bottom} - \frac{1}{\Omega}\frac{1}{v_{iz}}\right| > \varepsilon, \quad (a_{ib})_{Cell2} = \frac{\tau_b}{\Omega}\frac{l_{d2}}{s_{p2}} \qquad (2b)$$

The above relation can be simplified as follows:
For steep upper + steep bottom interface:

$$(a_{ib})_{II,0} = \frac{(a_{ij})_{Cell\ 1,upper} + (a_{ij})_{Cell\ 1,bottom} + (a_{ib})_{Cell\ 2}}{2} \qquad (3a)$$

For steep upper + flat bottom interface:

$$(a_{ib})_{II,0} = \frac{(a_{ij})_{Cell\ 1,upper} + (a_{ib})_{Cell\ 2}}{2} + (a_{ij})_{Cell\ 1,bottom} \qquad (3b)$$

For figure 2(b) case, the following formula for missing bubble is applied since the three velocity vectors are not independent.

$$\left(a_{ib}\right)_{II,0} = \frac{\tau_b}{\Omega}\frac{l_d}{s_p} \quad (4)$$

The above model assumes that the interface is a steep shape and parallel to the probe. However, for the high lateral bubble motion case, the assumption can be invalid. Therefore, the above model is corrected as follows:

$$\left(\bar{a}_i^t\right)_{II} = \left(\bar{a}_i^t\right)_{II,0} I_{II} \quad (5)$$

2.3 Measuring Method for Category III interfaces

Category III interfaces bypass two of sensors 2, 3 and 4. Figure 2(c) shows one of the three cases that belong to this category. The measuring method is referred to Euh et al.(2004) in which the correction factor for the turbuent ratio is changed as follows:

$$\left(\bar{a}_i^t\right)_{III} = \left(\bar{a}_i^t\right)_{III,0} I_{III} \quad (6)$$

2.4 Measuring Method for Category IV interfaces

The bubbles that pass only sensors 0 and 1 or have very small size are measured by double-sensor method with correction factor.

2.5 Numerical Simulation

The numerical method to simulate the interfacial area concentration measurement is referred to Euh et al. (2004). The problem assumes main flow direction as upward or downward with fluctuate motion. The correction factors were developed based on the numerical simulation as follows:

$$I_{II} = 0.81 + 0.33H_m - 0.38H_m^2 \quad (7a)$$
$$I_{III} = 1.84 + 1.44H_m - 2.2H_m^2 \quad (7b)$$
$$I_{IV} = \left(1.38 - 0.39H_m + 1.28H_m^2\right)\left(0.6 + 0.4*(D_{av}/D_{av0})\right) \quad (7c)$$

where

H_m: measured bubble turbulent intensity ratio

D_{av0}=3.0mm

Figure 3 and 4 show the performance of the five-sensor probe method for 3.0mm and 7.0mm of average bubble size, respectively. The categorical results as well as the total IAC agree well with the exact values.

3. Conclusions

A five-sensor probe method considering the bubble fluctuation effect is proposed in this study for the given configuration of the sensor tips. As a result, the five-sensor method shows better features than the previous IAC measuring method. However, this study assumes the major flow direction as upward or downward. More study should be performed for the mixed condition that the main flow direction is changed very frequently. The proposed method will be applied to the downcomer boiling test.

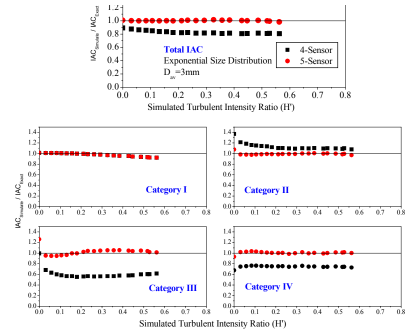


Figure 3. IAC Simulation Results for D_{av}=3.0mm

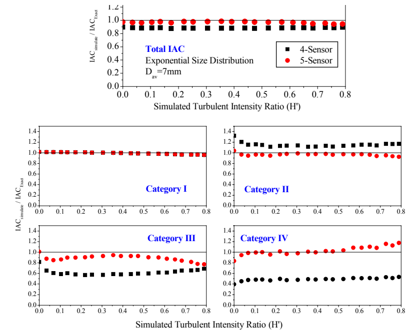


Figure 4. IAC Simulation Results for D_{av}=7.0mm

Acknowledgement

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[1] B.J.Yun et al. "Downcomer Boiling Phenomena During Reflood Phase in the Postulated LBLOCA of the APR1400 ", NTHAS4, Japan, 2004

[2] D.J. Euh et al., "Numerical Simulation of an Improved Five-Sensor Probe Method for local Interfacial Area Concentration measurement", *Nucl. Eng. Des., 234, pp. 99-116,* 2004