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MODIFICATION OF VOID FRACTION CORRELATION

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ABSTRACT

A void fraction correlation is useful in predicting the steam/water mixture level in the nuclear reactor during a loss of coolant accidnt. Many researchers compared their test data with the existing void fraction correlations and concluded that the correlation developed by the present author is in best agreement with the data. However, the correlation overpredicts the void fraction at the high void regime. In this paper, the correlation is modified for the high void regime.

INTRODUCTION

In a loss of coolant accident (LOCA), it is important to predict the steam/water mixture level in the nuclear reactor, since the uncovered core may result in an excessively high fuel temperature. The mixture level in the core depends on the core void fraction distribution, which can be calculated with a void fraction correlation.

There are two types of void fraction correlations: (a) drift flux correlations, and (b) dimensionless-group correlations. Anklam and Miller[1] compared the existing correlations with their test data and concluded that the dimensionless-group correlations agree better with their data, and among the dimensionless-group correlations, the correlation developed by the present author[2,3] gives the best void fraction prediction. Recently, Koizumi et al.[4] compared the collapsed liquid level data of their small break LOCA test with the liquid level predicted by RELAP-5 code using various void fraction correlations. They also concluded that the best prediction was obtained by using the void fraction correlation developed by the present author. However, the correlation was found to over-predict some test data at high void regime. Therefore, it is the purpose of this paper to modify the correlation for the high void regime, so that the mixture level in the nuclear reactor can be predicted more precisely.

OVER-PREDICTION OF THE CORRELATION

The derivation of the void fraction correlation by the author is presented in Appendix B of reference 2, and the summary of the correlation is in the earlier paper[3]. The correlation of the void fraction, α, is given by

$$\alpha=0.925\left(\frac{\rho_g}{\rho_f}\right)^{0.239}\left(\frac{V_g}{V_{bcr}}\right)^{b}\left[\frac{V_g}{(V_g+V_f)}\right]^{0.6} \quad (1)$$

= 1, *if the α computed from the above expression is greater than one,*

$$b=0.67,\quad if\ V_g/V_{bcr}\le 1,$$

$$=0.47,\quad if\ V_g/V_{bcr}>1,$$

$$R_{bcr}=\left(\frac{1.53}{2/3}\right)^{2}\left(\frac{\sigma}{g\rho_f}\right)^{1/2}$$

$$V_{bcr}=\frac{2}{3}(gR_{bcr})^{0.5}=1.53\left(\frac{g\sigma}{\rho_f}\right)^{0.25}$$

where V_g and V_f are the superficial velocities (volumetric flow rate divided by the flow area) of the vapor and the liquid, respectively, and g is the gravitational acceleration. Eq.(2) expresses the fact that there are two bubbly flow regimes: (a) small-bubble regime in which $V_g/V_{bcr} < 1$, and (b) large-bubble regime in which $V_g/V_{bcr} > 1$. The V_{bcr} and R_{bcr} in the above correlation are the critical velocity and the radius of bubbles, respectively, at the transition between the small-bubble regime and the large-bubble regime.

The comparisons with FLECHT reflood heat transfer test data (Fig. 10 of reference 2), however, show that the correlation over-predicts the data for high void regime. At the time when the reference 2 was written, the author thought that the reason for the over-prediction was because in those FLECHT tests, the rod bundle and the housing for the rod bundle are relatively small so that at the high void fraction, slug bubbles might have formed with the housing as the boundary of the slug bubbles. This can be seen from the reasonably good agreement in comparison between the FLECHT data and the Griffith's void fraction correlation for slug bubbles in a rod bundle as shown in Fig. 1. The Griffith's correlation[5] is given by

$$\alpha = \frac{Q_g}{Q_f + Q_g + V_b A},$$

$$V_b = K_1 K_3 \sqrt{g D_h} + K_2 \left(\frac{Q_f + Q_g}{A}\right),$$

where Q_f and Q_g are the liquid and vapor volumetric flow rats, respectively, V_b is the velocity of the slug bubble, A is the cross-section area of flow, D_h is the diameter of the bundle housing, and K's are the constants. Since the housings in the tests are non-typical to the nuclear reactor, the author thought that the void fraction correlation should not be modified for nuclear reactor applications.

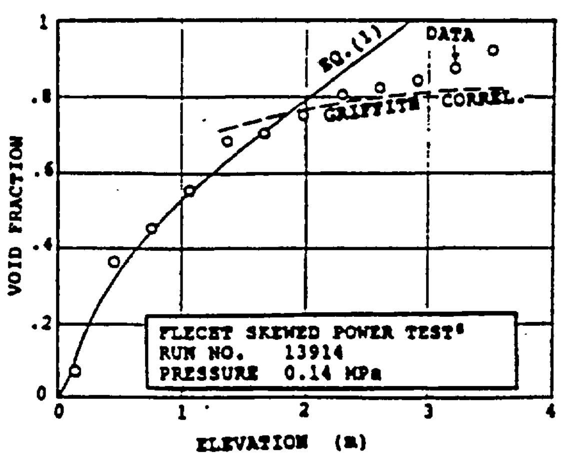

Figure 1. Comparison of the FLECHT Void Fraction Data, the Correlation of Eq.(1), and Griffith Correlation.

Recently, Anoda et al.[4] obtained void fraction data using the ROSA-IV large scale test facility. Among the correlations they compared, the correlation of Eq.(1) gives the best prediction for their data. However, it over-predicts the data in the high void fraction regime. On the other hand, Griffith's correlation significantly under-predicts the data (Fig.2). Although Griffith's correlation, which is derived from small tube bundle tests, may not be applicable to a large rod bundle such as ROSA-IV, it is questionable that large slug bubbles of 0.514 meter diameter (the diameter of ROSA-IV bundle) could exist. Therefore, the reason for the over-prediction by the correlation of Eq.(1) at high void fraction is not because of the housings in the tests, and it is necessary to modify the correlation.

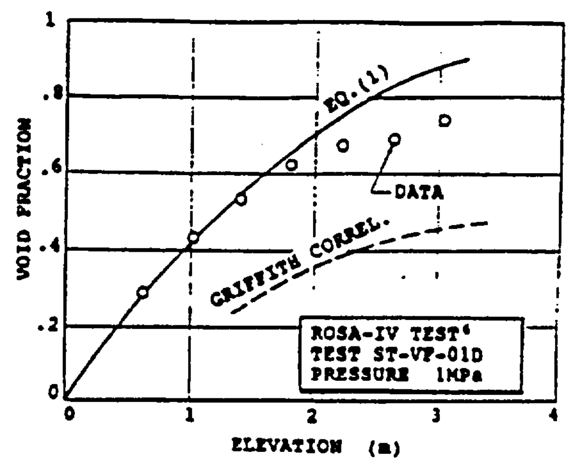

Figure 2. Comparison of the ROSA-IV Void Fraction Data, the Correlation of Eq.(1), and Griffith Correlation.

Realizing the over-prediction of the correlation of Eq.(1), Anoda et al.[4] have developed a correlation in the form similar th Eq.(1) except that the dimensionless group V_g/V_{bcr} is replaced by Kutateladze number Ku, which is defined as

$$Ku = \frac{V_g \rho_g^{0.5}}{[g\sigma(\rho_f - \rho_g)]^{0.25}}$$

The relation between Ku and V_g/V_{bcr} is $Ku = 1.53(V_g/V_{bcr})$. That is, Ku dffers from

V_g/V_{bcr} by only a constant factor of 1.53.

Although Anoda et al.[6] have developed a new correlation with the consideration of their high void fraction data, it is better to modify the correlation of Eq.(1) for the high void regime for the following reasons: (a) In developing their correlation, Anoda et al. considered only the data of one ROSA test [Test ST-VF-01D, i.e., LSTF(1MPa) in Fig.3] in the high void regime. In the present paper, more data will be considered. (b) In their correlation, there are two regimes: Ku < 3.3 and Ku > 3.3, which are equivalent to $V_g/V_{bcr} < 2.16$ and $V_g/V_{bcr} > 2.16$, respectively. The transition between the two regimes is Ku = 3.3 or $V_g/V_{bcr} = 2.16$. As stated above, in the correlation of Eq.(1) there are also two flow regimes: the small bubble regime and the large bubble regime. The transition between the two flow regimes is $V_g/V_{bcr} = 1$. As will be seen later, their data also appear to have the transition at $V_g/V_{bcr} = 1$ rather than at $V_g/V_{bcr} = 2.16$. (c) The use of the critical bubble velocity, V_{bcr}, between the small bubble and the large bubble in Eq.(1) is physically more meaningful for the transition between the small bubble regime and the large bubble regime.

MODIFICATION OF THE CORRELATION

The high pressure void fraction data of Anoda et al.[6] and the low pressure data of FLECHT tests[7,8] are plotted in Fig. 3 in terms of α^* versus V_g/V_{bcr}, where

$$\alpha^* = \alpha/[(\rho_g/\rho_f)^{0.239}\{V_g/(V_g+V_f)\}^{0.6}].$$

Also plotted in Fig. 3 is the correlation of Eq.(1). Since the data of references 1 and 3 are in good agreement with the correlation of Eq.(1), they are not plotted in Fig.3. The low α^* data ($\alpha^* < 2$ or $V_g/V_{bcr} < 5$) in Fig.3 are from reference 6. Note that there is only one test with high α^* [LSTF(1MPa)] in reference 6, which is also plotted in Fig. 3.

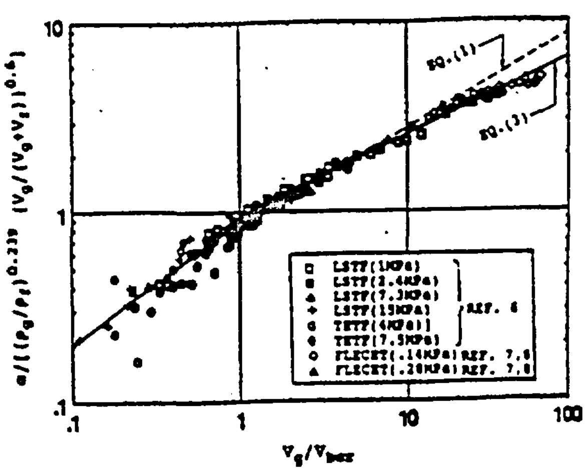

Figure 3. Comparison of the Predicted and the Measured Void Fraction.

Fig. 3 shows that the correlation of Eq.(1) is in good agreement with the low α^* ($V_g/V_{bcr} < 5$) data. The data trend in Fig. 3 also shows that the transition (change of slope) between the small bubble regime and the large bubble regime occurs at $V_g/V_{bcr} = 1$ rather than at 2.16, which can be clearly seen by viewing the figure at a glazing angle (i.e., holding the paper in such a way that the paper and the sight line forms a small angle).

It is, therefore, only necessary to modify the high void regime for the correlation of Eq.(1). The correlation of Eq.(1) is modified for $V_g/V_{bcr} > 4.31$ as follows:

$$\alpha = C\left(\frac{\rho_g}{\rho_f}\right)^{0.239}\left(\frac{V_g}{V_{bcr}}\right)^{b}\left[\frac{V_g}{(V_g+V_f)}\right]^{0.6} \qquad (3)$$

=1, *if the α computed from the above expression is greater than one,*

where

C=0.925 and b=0.67, if $V_g/V_{bcr} \leq 1$,

C=0.925 and b=0.47, if $1 < V_g/V_{bcr} < 4.31$,

C=1.035 and b=0.393, if $V_g/V_{bcr} \geq 4.31$.

The modified correlation is plotted in Fig.3. The modified correlation allows the steam/water mixture level in the core to be predicted more precisely during a LOCA, which is important for core covering.

CONCLUDING REMARK

In this paper the void fraction correlation has been modified for the high void regime. The high void regime is not the slug flow regime, because of the large disagreement between the void fraction predicted with Griffith correlation for the slug flow and data of Anoda et al. Therefore, it is the large bubble regime.

The present modified correlation is divided into three segments. The fist segment, $V_g/V_{bcr} \le 1$, represents the small bubble regime, and the other two segments, $1 < V_g/V_{bcr} < 4.31$ and $V_g/V_{bcr} \ge 4.31$, represent the large bubble regime. The data trend in the large bubble regime as plotted in Figure 3 is a curve rather than a straight line. In the present modified correlation, the large bubble regime is represented by two linear segments instead of a curve.

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