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Application of S_γ Model for the Mechanistic Bubble Size Prediction in the Subcooled Boiling Flow with CFD Code

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1. Introduction

Accurate simulation of subcooled boiling flow is essential for the operation and safety of nuclear power plants (NPP). In recent years, the use of computational fluid dynamics (CFD) codes has been extended to the analysis of multi-dimensional two-phase flow for the NPP. Among the applications of CFD code for the NPP analysis, the first target was selected as a mechanistic prediction of DNB (Departure from Nucleate Boiling) in PWR [1]. In DNB-type CHF (Critical Heat Flux), the expected flow regime is bubbly or churn turbulent flow in the high mass flux and high heat flux condition and thus subcooled boiling is also one of the key phenomena for the precise prediction of DNB.

In this paper, S_γ,which is a mechanistic transport equation for the bubble parameters, was examined in a CFD code with the objective of enhancing the prediction capability of subcooled boiling flows. The models were applied in the STAR-CD 4.12 software.

2. S_γ for the Bubble Size Prediction

To predict accurately the bubble size distribution, mechanistic modelling approach such as interfacial area concentration or bubble number density transport equation is needed. Recently, Lo [2] applied generalized S_γ equations for the prediction of droplet size in the oil/water flow. Later, it was extended to the air/water flows [3] even though source and sink terms for the S_γ have the same functional forms as those for droplet flows by applying similarity between two phases. In the present work, S_γ model was applied for the prediction of bubble size in the subcooled boiling flows. S_γ is defined as a generalized parameter for the size distribution of bubble/droplet as follows,

$$S_\gamma = nM_r = n\int_0^\infty d^\gamma P(d)d(d) \tag{1}$$

where, n is number density, M_r is the moment of the size distribution, d for the bubble/droplet size. *P(d)* is the bubble/droplet size distribution and assumed to be a log-normal distribution in the present work.

Here, the zeroth-moment of the distribution is the number density of the bubble/droplet, $n = S_0$. The second-moment, S_2, is related to the interfacial area density a_i (=πS_2) and the third-moment, S_3, is related to the void fraction (=$\pi S_3/6$). From these relations, the Sauter mean diameter can be calculated as follows,

$$d_{sm} = d_{32} = \frac{S_3}{S_2} = \frac{6\alpha}{\pi}\frac{1}{S_2} \tag{2}$$

The transport equation for the generalized S_γ is expressed as follows,

$$\frac{\partial S_\gamma}{\partial t} + \nabla \cdot (S_\gamma u_d) = s_{br} + s_{cl} + s_{mass} + s_{boil} \tag{3}$$

where, u_d is bubble/droplet velocity, s_{br}, s_{cl}, s_{mass}, s_{boil} are sources terms for breakup, coalescence, mass transfer and boiling, respectively. Detailed modeling for each term is found from Yun et al [4].

3. Calculation and Results

Benchmark calculations were carried out against 13 DEBORA experimental data set [5] by using STAR-CD 4.12. The test section is a vertical heated pipe of which the inner diameter is 19.2 mm. The total pipe length is 5m and it consists of three parts axially. The first part is an unheated section with a 1m length for the flow regulation at the inlet. The second part is a heated section with a 3.5m length for the simulation of wall boiling, and the third part located at the top region is an unheated section with a 0.5m length. The working fluid is R-12 and pressure of the experiment was in a range of 14.6~30 bars. Phasic density ratio of the test is equivalent to that of steam/water around 90~170 bars and thus it is expected to represent the qualitative bubble behaviors in the high pressure steam/water condition.

Fig.1 shows that the bubble size and its profile predicted by the S_γ model follows well the experimental data. Similar results are also found in the other eleven cases.

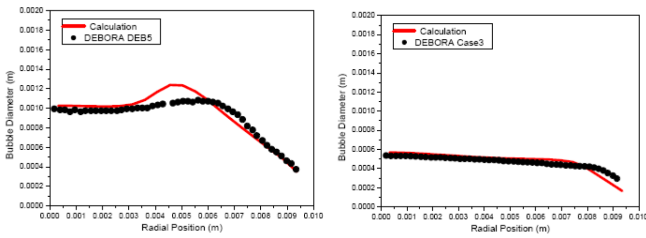

Fig. 1. Predicted bubble size distribution for DEBORA

4. Summary

In the present work, S_γ model was applied to predict the two-phase flow phenomena in DEBORA experiment. As S_γ model calculated a mechanistic transport equation for bubble parameters in STAR-CD 4.12 code, the analysis result follows well the experimental data of the bubble diameter distribution.

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