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Flow Analysis in the Helical Wire Inserted Tube using CFD code

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1. Introduction

Bubble departure from the surface is an important physical phenomenon in flow boiling CHF especially in subcooled and low quality region. It is necessary to remove the bubbles near the wall surface because relevant escape of bubble from the heated wall makes the CHF increase. It is possible to remove bubbles on tube wall by the centrifugal force due to the swirl flow using swirl flow generators. However, at the same time, an increase of the energy consumption in the entire system is generated because the flow resistance also increases. In this context, only when the increased CHF is profitable compared to the increased pressure drop, the use of swirl generator is justifiable.

The purpose of this study is to clarify the effect of an inserted helical wire on the pressure drop in the tube balancing swirl generation. Using commercial CFD code, CFX 11.0, two-phase flow (air-water) in the helical wire inserted tube was analyzed over the bubbly and annular flow regime. Helical wire inserted tube with 10 mm inner diameter was simulated in the bubbly and annular flow region to see the wire effect on the pressure drop, swirl flow, and the liquid film thickness. From these analyses, the important design point to be considered of inserted helical wire was derived.

2. Validation of the Analysis Method

2.1 Set the reference experiment

The up-ward air-water flow in the helical wire inserted tube experiment which was performed by Keishi Dakeshima(2002) was used as the reference experimental data.[1] The wire with 3mm diameter with 50mm pitch length was selected as the reference case and smooth tube case was tested also. The superficial velocities of each phases and the void fraction of bubbly and annular flow regime were selected from this reference experimental condition. [2]

2.2 CFD Modeling

The commercial CFD code, CFX 11.0, was used to model this experiment. For the smooth tube modeling, Shear Stress Transport (SST) model was selected for the turbulence modeling. Drag force with Grace Model, wall lubrication force with Antal model and turbulence dispersion force with Lopez de Bertodano model are also considered for the inter-phase momentum transfer. Because the lift force is different with bubble size, the lift force coefficient was calculated by Tomiyama model[3] for the different bubble size. As shown in the Fig. 1, 2.685 mm bubble size with lift coefficient of 0.2873 shows the best agreement with the experimental result.

Based on those modeling method, bubbly flow with 3mm wire diameter and 50mm pitch length was also modeled. Other conditions are the same with the case of smooth tube except the turbulence model. The k-ε turbulence model was used and the average void fraction was 0.13 from the experimental data. For the annular flow modeling, mixture model was used for the inter-phase transfer with the void fraction of 0.8281. According to the simulation result as shown in the Figure 2, the average liquid film thickness was 3.145 mm that is similar with the experimental result, 3mm.

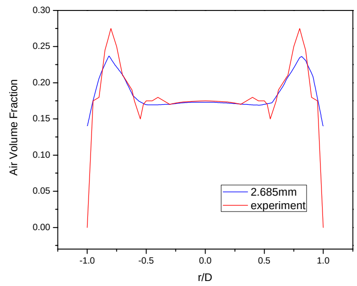

Fig. 1. Air volume fraction distribution (Bubble size is 2.685 mm).

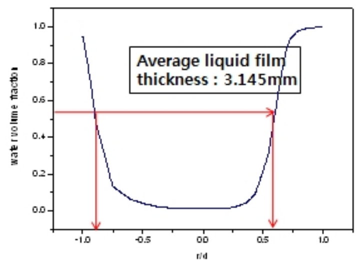

Fig. 2. Water volume fraction distribution of the annular flow case

3. Application

3.1 Geometry selection and modeling

Those CFD analysis methods were applied to the other helical wire inserted tube case with 10mm tube inner diameter. 12 geometries that has the similar e/D and p/D ratio with experimental case were selected and those are 0.8, 1, 1.2 mm wire diameters and 10, 20, 30 and 40 mm pitch lengths.

In CFD modeling for the bubbly flow, mean bubble diameter was 1.075 mm with the lift force coefficient 0.2460. The superficial velocities of air and water were

2.905 m/s and 4.4789 m/s respectively. For the annular flow modeling, superficial air velocity was set to 10.2 m/s and superficial water velocity was 0.098 m/s. Other conditions are the same with the previous modeling of the experimental cases.

3.2 Results

The simulation result of the axial air distribution in the bubbly flow region with 1mm inserted wire diameter was shown in the Figure 3. As pitch length was increased, the flow shows more stable pattern. The frictional pressure drop and the swirl number for each geometry were calculated and shown in the Figure 4 and 5. As one can expect, frictional pressure drop and the swirl number was decreased as the inserted wire diameter was decreased and the pitch length was increased.

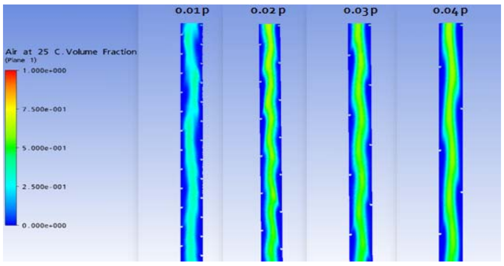

Fig. 3. Axial air distribution in the bubbly flow region with 1mm inserted wire diameter.

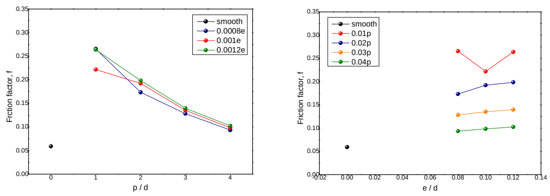

Fig. 4. Effects of the pitch length and the inserted wire diameter on the friction factor.

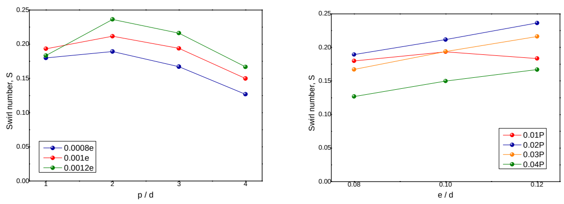

Fig. 5. Effects of pitch length and inserted wire diameter on the swirl number.

The effects of the pitch length and the inserted wire diameter on the liquid film thickness were shown in the Fig. 6. The average liquid film thickness was increased as pitch length and inserted wire diameter were increased. Especially, inserted wire with 1.2 mm diameter case showed significant increase.

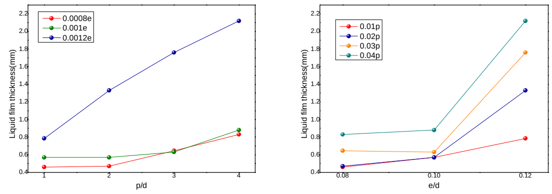

Fig. 6. Effects of the pitch length and the inserted wire diameter on the liquid film thickness

4. Discussion

According to the simulation results, general trends were confirmed as one can expect. In the bubbly flow region, the friction factor was decreased as the inserted wire diameter was decreased and the pitch length was increased. And the swirl number was decreased as the inserted wire diameter was decreased and the pitch length was increased. However, in the view point of the frictional pressure loss, pitch length has dominant effect than the inserted wire diameter. On the other hand, pitch length has dominant effect than the wire diameter on the swirl number.

In the annular flow region, the average liquid film thickness was increased as pitch length and the inserted wire diameter were increased. In this flow regime, wire diameter has dominant effect than the pitch length, especially 1.2 mm case.

From those result, we should choose the important design factor carefully between the inserted wire diameter and the pitch length. If a system is working in the bubbly flow region mainly, more important should be attached to the pitch length than the wire diameter and vice versa in the case of the annular flow regime.

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