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An Analysis of Heat Transfer and Subcooled Boiling in the Mixing Vane Grid

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1. Introduction

An analytic study of heat transfer behavior on the fuel rod surfaces has been performed to improve the design of the rod bundle spacer grid with the mixing vanes. The previous studies [1,2] are only focused on the single-phase heat transfer mechanism around the fuel rod surface induced by mixing vane grid. The objective of this study is to evaluate the heat transfer mechanism under the subcooled boiling condition in a 2x3 rod bundle spacer grid.

2. CFD Model Descriptions

2.1 Computational Domain and Meshes

FLUENT 6.2.16 is chosen to simulate the flow fields induced by the rod bundle spacer grid. The computational domain includes 2.25 inches height of a spacer grid with the mixing vanes. A diameter of the fuel rod is 0.360 inches. The lengths of inlet and outlet portion are chosen as –3.895 inches and +10.5 inches from a center of a height strap of spacer grid. As shown in Figure 1, the tetrahedral meshes were used in the mixing vane region due to the very complex geometry. Other regions such as the upstream and downstream regions were filled with the hexahedral meshes. Specially, the multiple thin layers were specified in the near rod wall regions to count for the near wall effect. From this treatment, the target y+ values could be kept between 50 and 150 in the near rod wall regions.

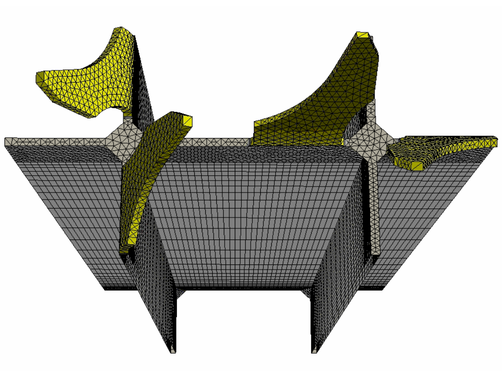

Figure 1. Mesh shapes on the grid and mixing vanes

2.2 Analytical Model

The convective subcooled boiling occurs when heated walls are superheated while bulk liquid is subcooled under given operating pressure. Such regime may happen in PWRs. Generally, subcooled boiling is also very effective heat transfer mechanism between wall and fluid. The mechanistic prediction of this phenomenon is possible by so called RPI model [3] developed at Rensselaer Polytechnic Institute.

The liquid and vapor properties are described in Table 1. The constant heat flux (946372.2 W/m^2) condition was set at the entire surface of all fuel rods. The uniform flow velocity at the inlet and the constant pressure at the outlet were set as boundary conditions.

Table 1. The liquid and vapor properties

Property	Liquid	Vapor
Density [kg/m³]	$-1631.823 + 11.0035T - 0.01183T^2$	$2591.012 - 8.16601T + 0.00657T^2$
Specific Heat [J/kg.K]	$87973.04 - 319.6048T + 0.30641T^2$	$31435.9 + 21.82975T - 0.11009T^2$
Thermal Conductivity [W/m.K]	$1.24591 - 0.00135T$	$5.08473 - 0.01634T + 1.33306\times10^{-5}T^2$
Viscosity [Pa.s]	$3.59648\times10^{-4} - 4.63292\times10^{-7}T$	$-2.77933\times10^{-5} + 8.6925\times10^{-8}T$

3. Simulation Results and Discussions

The above mentioned FLUENT code was used to solve the computational domain. About 40,000 iterations were performed to converge all residuals. As shown in Figure 2, the magnitudes of the lateral flow velocity on the several horizontal planes are continuously weakened due to decreasing lateral momentum induced by several mixing vanes.

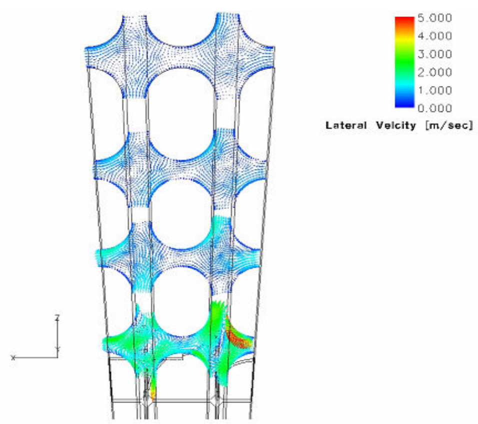

Figure 2. Lateral Flow Velocity Distribution

The volume fraction of vapor is given in Figure 3. It shows that vapor generated on the fuel rod surfaces is being gathered in the center region of subchannel by the swirl flow and the density difference between liquid and vapor.

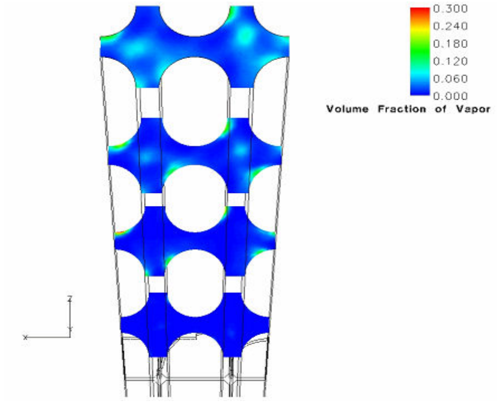

Figure 3. Volume Fraction of Vapor

Figure 4 shows the vapor diameter distribution on the fuel rod surfaces. The scale change of vapor diameter occurs around the mixing vane region. However, the vapor diameter in other regions sustains constantly because the surface temperature is enough higher than that for vapor size determination.

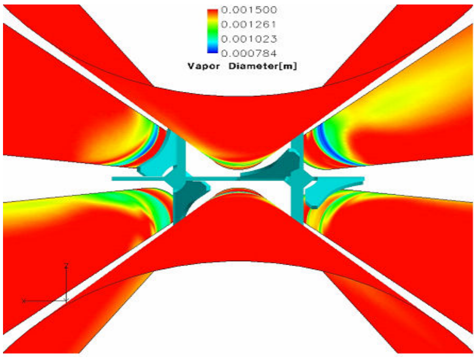

Figure 4. Vapor Diameter Distribution

Figure 5 shows that the average fluid temperature including the subcooled boiling model is lower than that excluding the subcooled boiling model in the 2x3 rod bundle spacer grid.

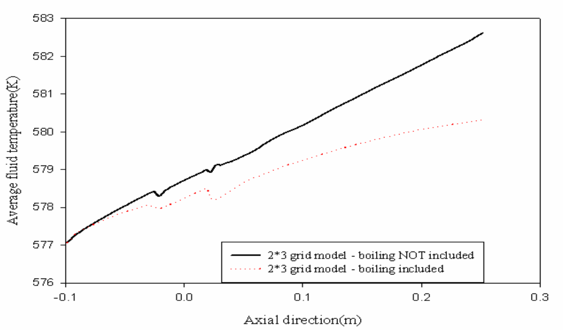

Figure 5. Average Fluid Temperature Comparison

The average wall temperature on the fuel rods is given in Figure 6. It also shows that the trend of the average wall temperature is similar to that of the average fluid temperature. From these comparison results, the subcooled boiling is very effective to the heat transfer mechanism between fuel rod wall and fluid in the subchannels. And, these analytic results are consistently matched to the well-known empirical results.

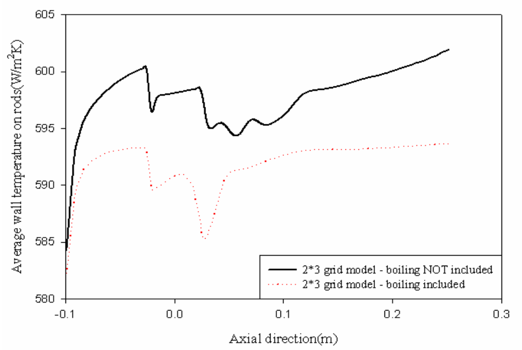

Figure 6. Average Wall Temperature Comparison

4. Conclusions

Based on the results of this study, it is concluded that the characteristics of the lateral flow velocity and the surface heat transfer mechanism show more realistic results through using the subcooled boiling model. And, the subcooled boiling is very effective to the heat transfer mechanism between fuel rod wall and fluid in the subchannels. This study can be properly applied to the development of the mixing vane design and Critical Heat Flux (CHF) correlation.

RFERENCES

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[3] Podowski, M.Z., "Toward Next Generation Multiphase Models of Nuclear Thermal Hydraulics," Proceeding of Eighth International Topical Meeting on Nuclear Reactor Thermal-Hydraulics, Kyoto, Japan, 1997.

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