Evaluation of Sensitivity Study on the Reactor Power Effect for Complete Flow Blockages of Plate-type Fuel Assembly

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1. Introduction

A plate-type fuel assembly is widely used in the research reactors in order to enhance power density. When complete blockage at the inlet of the cooling channel of this type fuel assembly occurs, the coolant flow through the blocked cooling channel will be completely interrupted. Accordingly, the blocked cooling channel loses its own cooling capability. This event may cause initiation of two-phase flow instability in the first unblocked cooling channel. If two-phase flow instability occurs in the first unblocked cooling channel, the instability can propagate to other cooling channels and lead to that a number of fuel plates damaged during the accident. This safety issue is one of the great concerns in safety analysis of research reactors.

The preliminary study has been performed to assure possibility of a CFD application for this safety issue [1] and to look for a certain condition that onset of flow instability (OFI) occurs in the first unblocked cooling channel due to the flow blockage under a given power condition [2]. Based on the this study, in the present work, numerical simulation for complete flow blockage of a plate-type fuel assembly under various power conditions (with or without hot channel factor) was performed to evaluate threshold that generate an OFI causing damaged propagation in flow channels.

2. Methods and Results

Two types of simulation were performed using the commercial CFD code, CFX 16.1. The steady state simulation without flow blockage was carried out to provide the initial condition for the transient simulation. The transient simulations under various power conditions were performed to evaluate thermal-hydraulic phenomena and threshold that generate an OFI causing damaged propagation in flow channels.

2.1 Numerical model

The numerical model (computational domain, mesh, etc.) used in the present work was maintained the same as the previous works [2]. The quarter model of the plate-type fuel assembly was used. The 2 million computational meshes are generated in the fluid and solid domains for 3-dimensional conjugate heat transfer analysis.

2.2 Numerical Method

The numerical method (two-phase subcooled boiling model, turbulence model, boundary condition, etc.) used in the present work was also maintained the same as the previous works [2]. Two-fluid model based on Eulerian multiphase flow was used with conventional wall boiling scheme [3], because the boiling in unblocked channels is expected due to the enhanced heat by the fuel plate of blocked channels. In addition to this, Kocamustafaogullari's bubble departure diameter model [4], Hibiki and Ishii's active nucleate site density model [5], and Kocamustafaogullari and Ishii's bubble departure frequency model [6] were implemented in the CFX code to calculate heat partitioning on the wall at low pressure condition using user defined function (CEL function). The mean bubble diameter model suggested by Hibiki et al. [7], which was develop to predict bubble size under low pressure boiling flow, was also implemented in the code.

2.3 Initial and boundary conditions

The initial and boundary conditions for the present simulation are summarized in Table 1. In case of the steady state simulation, the inlet boundary condition is set constant mass flow rate at the entrance of fuel assembly and the outlet boundary condition is modeled as a relative pressure of 0 Pa at the end of downstream region. In case of transient simulations, while, the inlet boundary condition with time dependent mass flow rate is specified at the entrance of fuel assembly to simulate inlet flow reduction of computational domain due to the flow blockages. The entrance region and downstream region are sufficiently long to provide a fully developed flow at the inlet and outlet in order to obtain an appropriate converged solution. The volumetric uniform heat source of the fuel meat is taken into consideration as shown in Table 1.

Table 1: Initial conditions

Initial temperature [°C]	36
Initial pressure [kPa]	202.63
Inlet mass flow rate [kg/s] : Steady state	4.09
Volumetric heat source [W/m^3]	
High power condition	6.415e9
Medium power condition	5.903e9
Low power condition	5.391e9

3. Results

3.1 Steady State Simulation

The results for steady state show that the nucleate boiling does not take place for all power conditions though wall boiling model is applied on steady state simulation. It is because the water temperature of the computational meshes near the wall does not exceed boiling activated temperature

3.2 Transient Simulation under High Power

Fig 1 shows the mass flow rate of coolant at the outlet of each cooling channel for the complete blockage of eight cooling channels under high power condition. The coolant flow begins to be redistributed in unblocked cooling channels three seconds after blockage occurs. After then the flow rate in the first unblocked cooling channel is continuously decreased with an increase in pressure drop due to increased bubble generation. Finally, mass flow through the first unblocked cooling channel oscillates violently seven seconds after blockage occurs. As a result of transient CFD analysis under high power condition, an OFI occurs in the first unblocked cooling channel if the eight cooling channels are completely blocked as shown in Fig. 2

3.3 Transient Simulation under Medium Power

Fig 3 shows the mass flow rate of coolant at the outlet of the first unblocked cooling channel under medium power condition. After blockage occurs, the coolant flow begins to be decreased in the first unblocked cooling channels due to the flow redistribution. These thermal-hydraulic phenomena are the same as previous CFD results under high power condition. For medium power condition, however, the same flow rate as steady state flow rate is maintained after maldistribution takes place. For medium power condition, OFI does not take place in the first unblocked cooling channel, even though the number of blocked cooling channel is higher than high power condition as shown in Fig. 4.

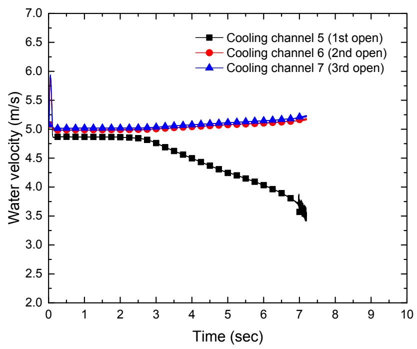

Fig. 1. Variation of coolant mass flow rate for blockage of eight cooling channels under high power condition.

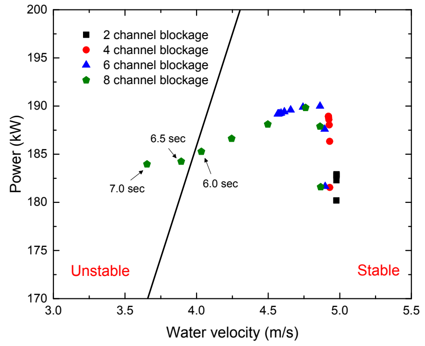

Fig. 2. Comparison of the CFD results with proposed threshold map under high power condition.

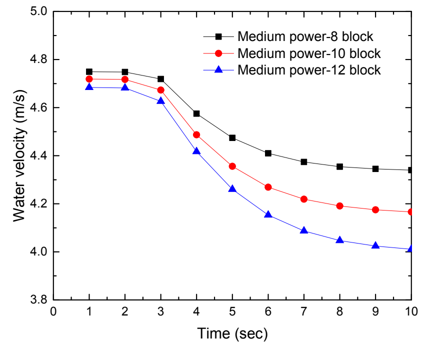

Fig. 3. Variation of coolant mass flow rate in unblocked cooling channel for medium power conditions.

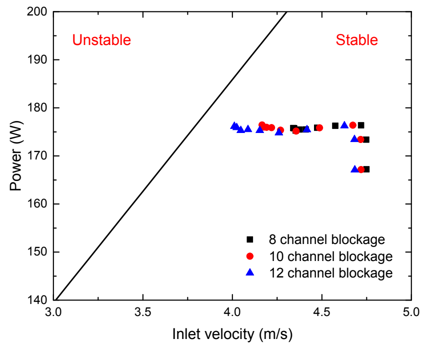

Fig. 4. Comparison of the CFD results with proposed threshold map under medium power condition.

3. Conclusions

Even if a number of cooling channels are blocked, the damage propagation does not occur under the conditions assumed in this sensitivity study on power expect for a highly conservative condition (high power condition). However, it is necessary to assess the proposed threshold map (stability boundary).

The threshold map in the present work was proposed based on Whittle and Forgan's OFI correlation [8]. This correlation has been developed based on experiment results for narrow rectangular channels with the same heat flux on both sides. However, the heat generation of fuel plates adjacent to the first unblocked channel is not the same.

Acknowledgement

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