Transient Simulation for Flow Instability Propagation during a Flow Blockage Accident

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1. Introduction

A plate-type fuel is generally used to enhance heat transfer in the research reactors (RRs) with high power density. When a complete flow blockage abruptly occurs at the one of cooling channels in a plate type fuel assembly, the coolant flow through the blocked cooling channel will be stopped and the blocked cooling channel loses its cooling capability. This event may cause an initiation of two-phase flow instability (FI) in the first neighboring unblocked cooling channel and FI can propagate to other cooling channels in consecutive order. That can lead to damages of fuel plates during the accident, which should be evaluated for safety assessment. Therefore, the numerical study was performed to examine the condition where FI occurs in the first neighboring unblocked cooling channel [1]. In the present work, numerical simulations has been carried out for transient phenomena that FI propagate sequentially from the first unblocked cooling channel to other unblocked cooling channels during a flow blockage accident in a RR.

2. Numerical Method

2.1 Numerical model

The numerical model (computational domain, mesh, etc.) used in the present work is the same as the previous work [1]. The quarter model of the plate-type fuel assembly is used as shown in Fig. 1. 2 million computational meshes are generated in the fluid and solid domains for 3-dimensional conjugate heat transfer analysis.

2.2 Numerical method

The general numerical method (two-phase subcooled boiling model, turbulence model, etc.) used in the present work is the same as the previous work [1]. Two-fluid model is used with conventional wall boiling scheme. The local boiling models, such as bubble departure diameter and active nucleate site density, were implemented on the CFX code to calculate heat partitioning on the wall at low pressure condition using user defined function. The Hibiki's mean bubble diameter model [2] was also implemented on the CFX code to calculate bubble size in the liquid bulk under low pressure boiling flow.

It is impossible to simulate all transient behavior during the accident at once using the CFD code. In this study, therefore, transient simulation is performed step by step as a FI propagates sequentially to neighboring unblocked cooling channels as below.

1) Transient simulation with increasing number of blocked cooling channels is performed until a FI occurs in the first nearby unblocked cooling channel. Then the analysis result at the time of occurring FI is used as initial condition of the next step transient simulation.
2) Numerical model is modified. The unblocked cooling channel where a FI occurred in the previous step is treated as same as a blocked cooling channel. This is because that unblocked cooling channel loses practically its cooling capability due to the occurrence of a FI. The transient simulation is performed using the modified numerical model with the initial condition given in the previous step until FI occurs in the second unblocked cooling channel. Then the analysis result at this step is used as an initial condition of the next step transient simulation.
3) Repeat above process (step 2) for all unblocked cooling channels (3rd unblocked cooling channel, 4th unblocked cooling channel, etc.) of a plate-type fuel assembly.

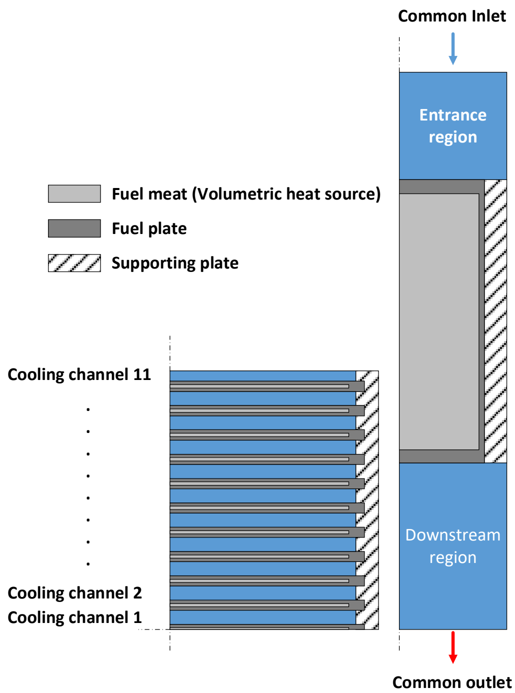

Fig. 1. Schematic for computational domain

3. Results

3.1 Initiation of OFI

The transient simulation was carried out with increasing the number of blocked cooling channels until a FI occurred in the nearby unblocked cooling channel as the first step transient simulation. As a results, it was founded that the coolant flow in the first unblocked cooling channel began to decrease at 3 seconds after the occurrence of a flow blockage as shown in Fig. 2. After then the flow rate in the first unblocked cooling channel was continuously decreased with an increasing of void fraction. Finally, FI occurred in the first unblocked cooling channel at about 6 second after a flow blockage as shown in Fig. 2 and Fig. 3.

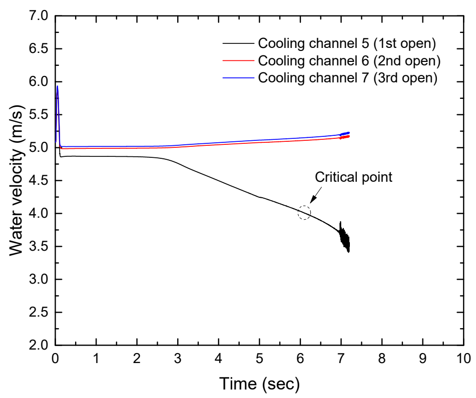

Fig. 2. Variation of water velocity in unblocked cooling channels for 8 cooling channels blockage

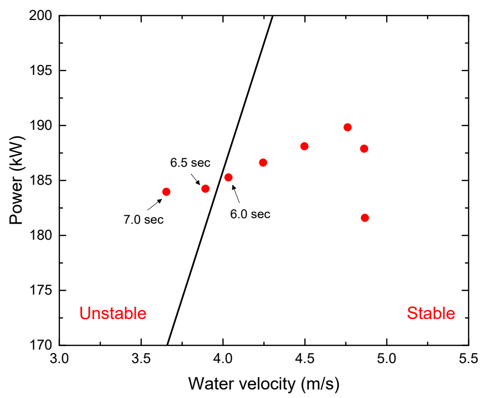

Fig. 3. Comparison of the CFD results with proposed FI threshold map

3.2 OFI propagation

Transient simulations were performed step by step to assess thermal-hydraulic phenomena during the flow blockage accident. If FI occurred in the first unblocked cooling channel, the second unblocked cooling channel has to additionally remove the heat that is not cooled in blocked cooling channels as well as the first unblocked cooling channel. In this way, the heat which has to be cooled down through the unblocked cooling channel increases as FI propagates to neighboring channels. Therefore, FI propagation can proceed faster.

Fig. 4 shows the variation of water velocity at inlet of the unblocked cooling channels as FI propagates. It can be seen that flow rate in unblocked cooling channel decreases faster as the FI propagates. As a result, an initiation of FI also is accelerated as shown Fig. 5.

Fig. 6 shows temperature variations of the fuel plates during the accident. The temperature of fuel plates between blocked cooling channels (fuel 1~4) increases sharply and reaches melting temperature (570 °C) early in the accident as shown in Fig. 6. The temperature of the intact fuel plates at the beginning the accident (5~9) also increase sharply and reach melting temperature as FI propagates along unblocked cooling channels. Hence, most fuel plates of a plate-type fuel assembly could be damaged at about 16 seconds after 8 cooling channels are completely blocked under given condition.

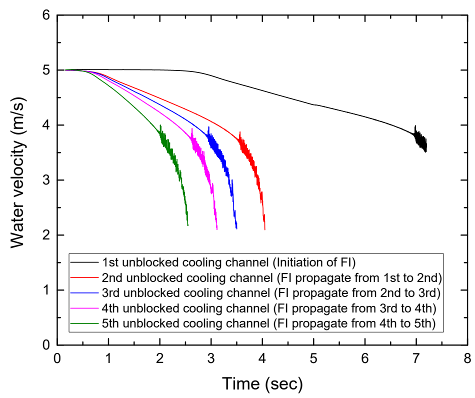

Fig. 4. Variation of water velocity in unblocked cooling channels as FI propagation

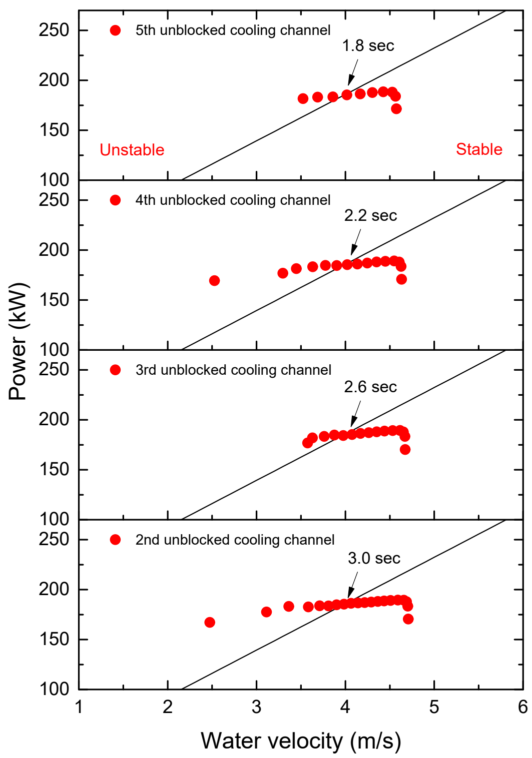

Fig. 5. Comparison of the CFD results as FI propagation with proposed FI threshold map

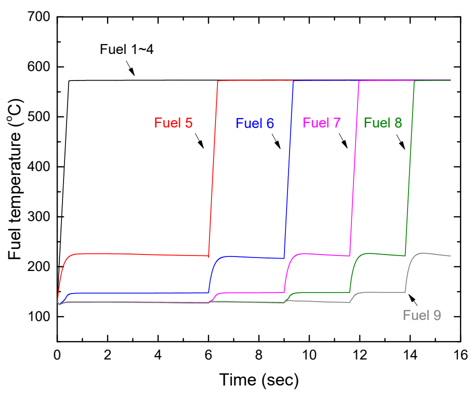

Fig. 6. Temperature variation of the fuel plates during the accident

4. Conclusions

The transient simulations have been performed for FI propagation in a plate-type fuel assembly during a flow blockage accident. The results show that FI can occur in the first nearby unblocked channel if 8 cooling channels are completely blocked. It is also founded that FI in the first unblocked channel can lead to FI propagation to other unblocked cooling channels. Accordingly, most of fuel plates in a plate-type fuel assembly can be damaged for a short time. The results of this work is expected to be used for the analytical evaluation on the amount of damaged fuel during the flow blockage accident in RRs with plate type fuels.

ACKNOWELGEMENTS

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