Effectiveness of Blockage Index for the Detection of Blockage in an SFR Subassembly

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1. Introduction

Detection of flow blockage formation in a subassembly of Sodium-cooled Fast Reactor (SFR) has been an important safety issue from the early stage of the SFR development history. This is mainly due to the fuel rods in SFR subassemblies are tightly configured and the flow channel is very narrow to take advantage of the excellent heat transfer of coolant and also fast neutron characteristics. When an internal partial blockage occurs somewhere in the flow channel, a recirculation wake is formed after the blockage and an abrupt temperature increase is usually observed. Therefore, the occurrence of flow blockage may threat the heat removal from the surface of fuel rods and cause the failure of fuel rods.

In SFR designs, the detection of flow blockage is facilitated by use of thermocouples located at the core exit plenum for each subassembly. It is known that a temperature fluctuation gives very useful information on the blockage formation [1]. However, a more practical method is to measure the increase of exit temperature itself and generate a scram signal to protect the reactor in the case of flow channel blockages. In the present study, we introduce a concept of blockage index and investigate the possibility of a more effective detection of blockage by use of the blockage index.

2. Blockage Detection Logics

The existing direct temperature difference method and the proposed blockage index method are explained here. Usually, two or more core exit thermocouples per subassembly are installed for the detection of blockage as early as possible. However, it is assumed that only one representative temperature data per subassembly is given in the present study.

2.1 Temperature Difference Method

As a flow blockage is formed and grows in a subassembly of SFR, a remarkable temperature increase is obtained near the recirculation zone at inner location of subassembly. However, we cannot detect this temperature increase directly in real reactor operation condition because the insertion of thermocouples into the subassemblies would distort the core flow quite much. Instead, we install the thermocouples at the exit of each subassembly to detect the temperature increase at that location. It is known that the flow reduction caused by the blockage is not so large that the increase of core exit temperature is also small up to a certain size of blockage.

Even though the detection of increase of core exit temperature is not effective for a very small blockage, it is possible to detect a subsequent buildup of the blockage to a larger size. For example, in PFBR design [2] the temperature increase from the core inlet to the subassembly outlets, i.e., the temperature rise across each subassembly is monitored to catch the formation of a significant size of blockage. With the PFBR blockage detection logic, they generate an alarm signal when the assembly-wide temperature rise deviates 5 K from the pre-determined value and scram signal for the deviation greater than 10 K.

2.2 Proposed Blockage Index Method

One of the ultimate goals of core exit temperature monitoring in SFR designs is to provide a reliable detection of blockage as early as possible. It is evident that when the flow rate in a blocked subassembly is being reduced the flow rates and temperatures at neighboring subassemblies are also affected. If we are able to take into account these changes in the neighboring subassemblies and the temperature increase in the blocked subassembly altogether, it is expected to revise a more reliable blockage detection method.

For this we propose a concept of blockage index (BI) by adopting a kernel function of Gaussian type to take advantage of the thermal-hydraulic information in neighboring subassemblies. With the blockage index, described in Eq. (1), we obtain a distance-weighted temperature changes for each subassembly.

$$BI_i = \sum_{k=1} e^{-\frac{\sqrt{\Delta x_{ki}^2+\Delta y_{ki}^2}}{D_{ref}}} \frac{|\Delta T_{ki}|}{T_{ref}} . \qquad (1)$$

In Eq. (1), i is the subassembly number for which the blockage index is evaluated and k means other subassemblies including subassembly i itself. D_{ref} and T_{ref} are reference distance and reference temperature, respectively. By combining the blockage index for each subassembly into a core wide map of blockage indices, it is possible to have useful information to determine whether any blockage is introduced or not at some location of subassembly. It is also possible to adjust the range of influence by performing sensitivity studies on reference distance in advance to select a distance factor which describes the blockage phenomena most correctly for the given subassembly design.

3. Analysis and Results

The effectiveness of proposed blockage detection method by use of the blockage index is analyzed with the CFD results, which has been provided in the study by Seong *et al.* [3]. The same temperature distribution data is also evaluated with the existing temperature difference method which utilizes the temperature rise across the subassemblies.

3.1 Upper Plenum Temperature Distribution

As a first step to evaluate the effectiveness of blockage detection methods it is required to have a measured temperature data obtained at core exit plenum. However, this kind of data is not available to the authors. Therefore, we borrowed the temperature distribution from the CFX calculation which has been performed for the situation with a partially blocked subassembly in the core.

Fig. 1 is the upper plenum temperature distribution at 15 cm above the subassembly exits. In SFR designs, the exit thermocouples are usually located between 10 cm and 15 cm from the core exit. In Fig. 2, the same temperature data extracted for the 1/6 core is plotted 3-dimensionally. In the analysis, it is assumed that the blockage of 10% is introduced at the active core elevation. We can consider the extracted temperature data as a temperature data set measured by the exit thermocouples at a given time.

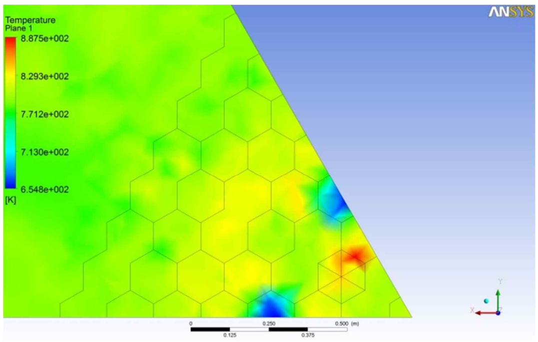

Fig. 1. Temperature profile at 15 cm above the exit of blocked subassembly calculated by CFX.

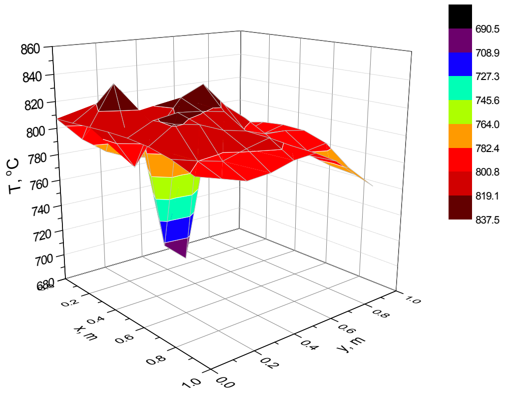

Fig. 2. Three-dimensional temperature plot for the extracted data at 15 cm above the exit of blocked subassembly.

3.2 Effectiveness of Blockage Detection

Using the temperature data in Fig. 2, it is evaluated whether the occurrence of blockage can be detected with the thermocouples located at 15 cm above the core exit. First, the data is analyzed with the existing temperature difference method, in which the blockage is identified by the temperature rise greater than 10 K. As shown in Fig. 3, the temperature at one point exceeds the blockage criteria, thus, the occurrence of blockage can be detected with this method.

With the same temperature data the blockage index for each subassembly is calculated and the BI map is constructed for the measurement elevation. Fig. 4 shows the map of blockage index evaluated at the elevation of 15cm above core exit. The blockage index corresponding to the temperature rise of 10 K is 0.012. Therefore, if we identify the flow blockage with the BI of 0.015, which includes the margin of 0.003, the blockage indices at 8 locations notify the occurrence of blockage in the core channel.

When BI method is compared to the existing temperature difference method, we can say the occurrence of flow blockage is confirmed with the indices at several subassemblies. This suggests the possibility of blockage detection with increased reliability if we adopt the blockage index.

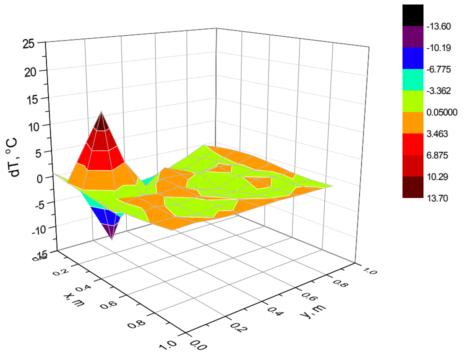

Fig. 3. Temperature change from the unblocked temperature at 15 cm above the core exit.

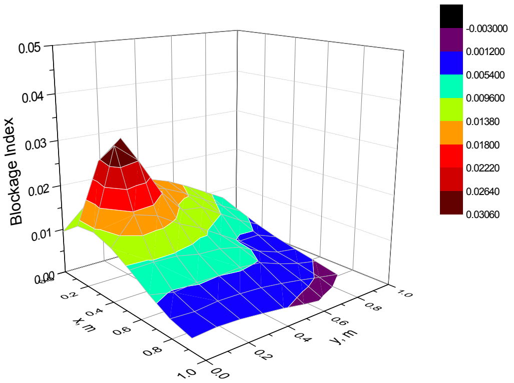

Fig. 4. Map of blockage index evaluated at the elevation of 15cm above core exit.

4. Conclusions

The concept of blockage index is proposed for the detection of flow blockage in a subassembly of an SFR. With blockage index, it is expected to take into account the core-wide changes in temperature and flow. The effectiveness of the blockage index method is evaluated with the data from CFX simulation results and compared with those obtained with the existing temperature difference method. The results suggest that the proposed method is applicable to the detection of flow blockage with higher reliability. It is still needed to evaluate the new blockage detection method with more realistic experimental or numerical data.

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