An Improvement of MATRA-LMR/FB for the Blockage Depth Analysis

Won-Pyo Chang, Young-Min Kwon, Ki-Suk Ha, Hae-Yong Jeong
Korea Atomic Energy Research Institute
P.O.Box 105, Yuseong, Daejeon, 305-600, Korea
*Corresponding author: wpchang@kaeri.re.kr

1. Introduction

The present manuscript demonstrates a capability of the MATRA-LMR/FB [1] which featured a blockage heat removal model newly, so as to analyze the effect of the blockage depth as well as the blockage heat generation. Under a certain limiting circumstance in the flow blockage for the SFR (**S**odium cooled **F**ast **R**eactor), the blockage material could comprise the fragments from the molten fuel which leaked from the cladding in consequence of the fuel rod damage. The blockage in this event would generate the fission power. Although no problem might be encountered in the previous studies [1], an energy unbalance became deteriorated as the size of the blockage depth went more than one node in the case. Since the problem was found to be caused by no available energy release path, this study addressed the removal of the total power generated in the blockage.

2. Analysis

2.1 Blockage heat removal model

The subroutine 'HEAT' allocates the fractional power input (*PHI(N,L),* $0 \le PHI(N,L) \le 1.0$) of the total power generation by a fuel rod into the 6 adjacent sub-channels surrounding it as delineated in Fig. 1. Here, *N* denotes the rod number and *L* does the properly ordered number between 1 and 6, representing adjacent 6 sub-channels. The fraction is usually provided with an equal share of 1/6 unless there is a particular reason. So this fractional power input was adjusted to open a path for the removal of the total blockage power generation in the present model.

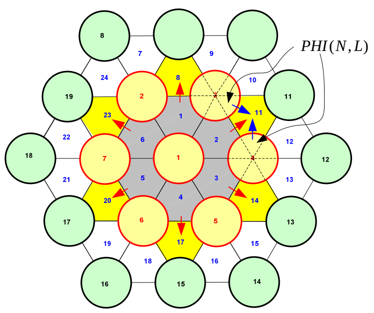

Fig. 1 Fractional power input into surrounding sub-channels

Three rods, i.e. a central rod (#1 rod in Fig. 1) and 1/3 of each of the 6 rods located at the edges in the blockage (#2,3,4,5,6,7 rods), effectively contributes to the blockage power generation for the 6 sub-channels blockage, for instance. Therefore, the model assumed that all the power inside the blockage would be removed through those edge rods into the adjacent sub-channels (#8,11,14, 17,20,23 in Fig. 1). The model also assumed that the blockage except the rods had the same volumetric heat generation as that of the fuel for conservatism. Therefore, total heat generation in the blockage could be written as:

$$Q = NN8 \times q''' \times \left(\frac{\pi d^2}{4} \right) + q''' \times A_b \qquad (1)$$

Where, Q , $NN8$, q''', d, and A_b were the total power, numbers of the effective fuel rods for the blockage power generation, volumetric heat generation, rod diameter, and blockage surface area contacting the surrounding sub-channels, respectively. Hence, the heat removal per the surrounding rod was *Q/NN7*, where *NN7* was number of the edge rods. The volumetric heat generation was related with the rod surface heat flux (q'') as:

$$q''' = 4q''/d \qquad (2)$$

As demonstrated in Fig. 1, *Q/NN7* was removed through two sectors of a rod. Thus, the fractional power input to one adjacent sub-channel should be divided into 2. Therefore, the power removed by one of 6 rod sectors now could be written as:

$$Q_L = \left\{ \left(NN8 + \frac{A_b}{A_f} \right) / NN7 \right\} \bullet (1 - RRA) \bullet \frac{1}{2} \bullet q''(\pi d) \qquad (3)$$

Where, *RRA* was the ratio of the top and bottom area to the total blockage heat transfer area. For example, *PHI(3,3)* or *PHI(3,5)* in Fig. 1 was given as:

$$PHI(3,3) = 1/6 + \left\{ \left(NN8 + \frac{A_b}{A_f} \right) / NN7 \right\} \times (1 - RRA) \times (1/2) \qquad (4)$$

Here, 1/6 was the fractional power input without the blockage power, and the rest term was an additional power faction that should be removed by one edge rod sector due to the blockage power. A similar method was applied to the heat removal through the top and bottom of the blockage.

2.2 Blockage temperature calculation

A formal conduction model could not be applied to estimate the maximum blockage temperature because of the geometrical complexity of the blockage. To avoid the difficulty, an equivalent disk which preserved the blockage area and power generation was devised as shown in Fig. 2. A one dimensional, steady state heat conduction equation for a cylinder was applied using a few conservative assumptions for such parameters as volumetric power, heat transfer coefficient, et al.

The conduction equation was given as:

$$\frac{d^2T}{dr^2} + \frac{1}{r}\frac{dT}{dr} + \frac{q'''}{k} = 0 \qquad (5)$$

with boundary conditions of:

(1) $r \to 0, \; T = finite$

(2) $@\, r = R_1 \;\; T = T_1$

The final solutions were:

$$T_1 = T_f + \frac{k\,Nu}{D_H\, q''} \qquad (6)$$

$$T_c = T_1 + \frac{q'''\, R_1^2}{4k} \qquad (7)$$

Where, T_f, k, D_H, Nu were the coolant temperature, blockage thermal conductivity, hydraulic diameter of the sub-channel, and Nusselt Number, respectively.

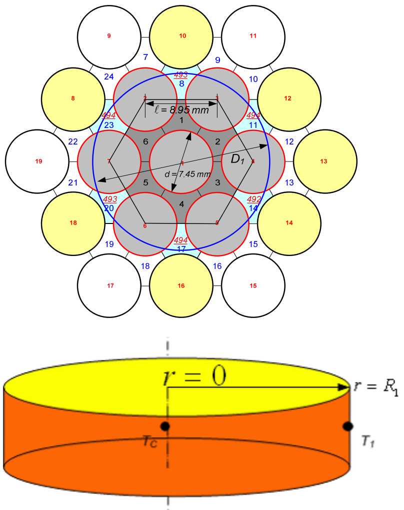

Fig. 2 Heat conduction model equivalent to the blockage

2.3 Analysis with the new model

The new model was applied to the analysis of the breakeven core assembly of the KALIMER-150 [1]. The axial blockage size ranged from one to six nodes for the 6 sub-channels blockage. Fig. 3 shows a result of the temperature and flow profiles for the 6 axial nodes blockage. No recirculation was predicted above the blockage. The maximum coolant temperature occurred near the end of the fuel slug (the node number 73) within the blockage channels, and its axial and radial positions were consistent with the previous prediction [1].

Fig. 4 compares the maximum coolant temperatures for the cases with/without blockage heat generation, with several axial blockage sizes. The difference between two cases was predominant, and the temperature got higher as the axial blockage node increased. The blockage size was deemed to limit the mixing region above the blockage.

2.4 Blockage temperature estimation

The maximum blockage temperature was calculated at 1229 °C using Eq. (7). Both the coolant temperature and velocity adjacent to the rod were obtained from the MATRA-LMR/FB calculation result. They were 493.4 °C and 3.94 m/s, respectively. The thermal conductivity was evaluated at the inlet temperature of 386.2 °C. The *Nu* of 4.36 was used borrowing the Aoki's model, because it gave the most conservative value among the applicable correlations.

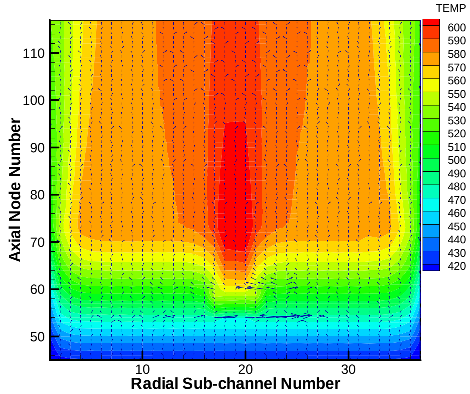

Fig. 3 Temperature and flow profiles for 6 axial nodes blockage

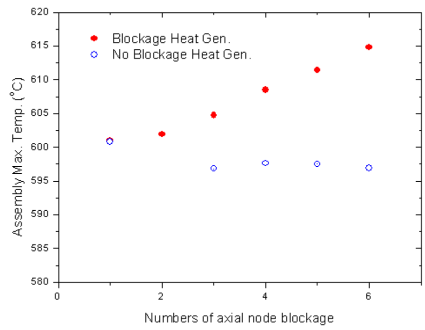

Fig. 4 Maximum coolant temperature with the axial blockage size

3. Conclusions

The capability for the multiple axial blockage analysis was featured for the MATRA-LMR/FB, and the axial blockages up to 6 nodes were analyzed when the 6 central sub-channels were blocked. As a result, the maximum coolant temperature went up with the axial blockage size. This result was consistent with another analysis with a different code [2]. The present demonstration elucidates that the new model may work reasonably. A detailed analysis, however, should be followed to draw a more meaningful conclusion for the estimation of the blockage maximum temperature.

REFERENCES

[1] W.P. Chang et al., "A Comparative Study of the Code Calculations for Local Flow Blockages in the KALIMER-150 Core," KAERI/TR-3860/2009 (2009).

[2] Y.M. Kwon et al., "Safety Analysis of Local Flow Blockage within KALIMER Fuel Driver Subassembly," KAERI/TR-2562/2003 (2003).