A Comparative Study of MATRA-LMR/FB for Local Flow Blockages with SABRE4

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1. Introduction

A sub-channel blockage may be caused by ingression of damaged fuel debris or foreign obstacles into a core fuel subassembly for a liquid metal reactor (LMR) due to its geometrical compactness of the core design. Local coolant temperature could rise during the incident and it might eventually lead to the degradation of the fuel rods. An analysis computer code is obviously needed not only to assure the safe design of the core, but also to design an effective monitoring system to prevent it from propagating to a serious consequence. The code, therefore, must be capable of predicting the thermal-hydraulic phenomena anticipated during the incident reasonably enough to be used to evaluate fuel rod intactness. The MATRA-LMR/FB code has been developed for this purpose. It is a revised version of the existing MATRA-LMR code which was aimed for the sub-channel analysis of LMR. Some of its models have been improved so appropriately to be able to analyze the sub-channel blockages. Nevertheless, very few experimental data are available on published papers or reports world wide. As an effort to evaluate the prediction capability of the MATRA-LMR/FB code, the present comparative study has been made to compare its prediction with the results with the SABRE code, which had already been applied to EFR design.

2. Development of the MATRA-LMR/FB code

The MATRA-LMR code [1] was developed for application to LMR(Liquid Metal Reactor), based on the frame of the COBRA-IV-i code, which is a sub-channel analysis code for LWR. MATRA-LMR/FB is a revised version of MATRA-LMR. Some of its models have been improved so appropriately to be able to analyze a blockage in the sub-channels with wire-wrapped rods.

The existing Wire-forcing-function, which allocates the forced swirling flow with a given correlation, has been replaced with the Distributed Resistance Model [2]. It can represent the effects of the cross- and swirling flows more realistically than the Wire-forcing-function. The semi-implicit numerical method is adopted to resolve the flow reversal problem, which could not be handled by the fully implicit method. Differencing scheme is improved to get a stable solution with reduced numerical diffusion. An improvements are also made in the turbulent mixing model as well as in the transient time-step control. Since the practical blockage usually makes a permeable medium rather than impermeable one, a porous blockage model has been developed by adapting the correlation suggested by Ergun.

3. Results of comparison analyses for KALIMER

3.1 KALIMER-150 Input Modeling

The sub-channel blockage for the breakeven core design of KALIMER-150 [3] has been analyzed to compare the predictions by MATRA-LMR/FB with SABRE4 calculations already made. [4] It is assumed that the blockages occur near the highest heat flux region in the channel. Three blockage areas for 6-, 24-, and 54 sub-channels are simulated in the analyses. The permeability of the blockage is set to zero('0') for a conservative assumption. The hot assembly which represents the highest average coolant temperature is chosen for the analysis. It generates a total heat of 6.11 MW and the assembly flow rate is 27.2 kg/s. The subassembly consists of 271 rods and the sub-channel is divided axially into 117 nodes (3.02 cm/node) for the MATRA input, while 103 nodes (3.44 cm/node) were used for the SABRE4 calculation. The inlet coolant temperature is 386.2 ^{o}C. Figure 1 demonstrates both a 271 rod core sub-assembly and the three blockage positions, namely, center, middle between the core center and wall, and the edge of the assembly for the analyses. Radial direction for the calculated temperature demonstration is indicated with the A-'A' cross-section.

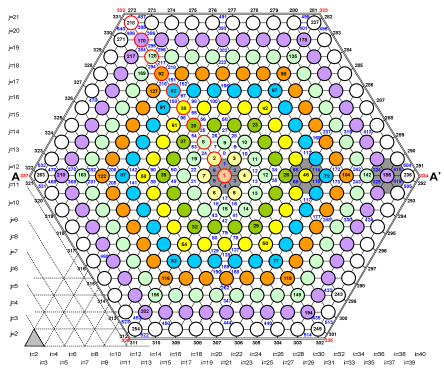

Fig. 1 Display of the core assembly for MATRA inputs

3.2 6 sub-channel blockage analysis

The highest temperature occurs at the top with no blockage, while it appears near the fuel slug end position with the blockage. Coolant re-circulates right above the blockage and it is stagnant for a time and heats up. Figure 2 represents the temperature contour at the outlet, and Fig. 3 shows the radial positions of the highest temperature occurrences depending on the blockage positions. The results show the flow blockage is a local phenomenon. The highest temperature is found axially above the blockage, and coolant mixes as it flows upward.

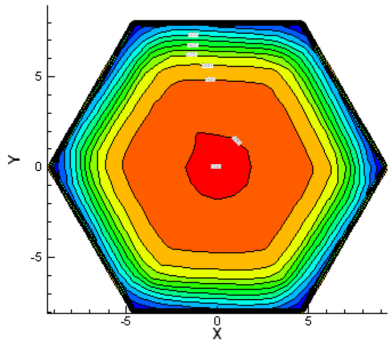

Fig. 2 Temperature contour at the core outlet for the 6 central sub-channels blockage

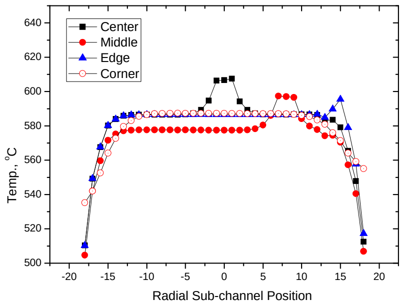

Fig. 3 Radial positions of the highest temperature occurrences with the blockage positions

3.3 24 and 54 sub-channel blockages analyses

The temperature contours for 24 and 54 channel blockages are quite the same as those of the 6 channel blockage cases in the behavior.

3.4 Comprisons

Figure 4 represents a summary of the two calculations.

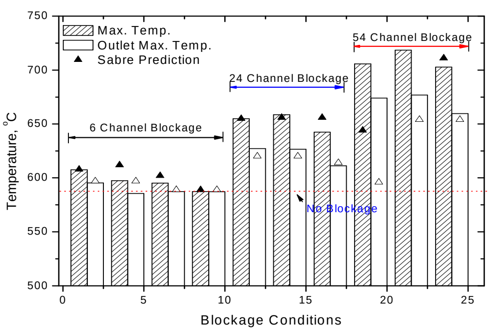

Fig. 4 Summary of the two code predictions

The highest temperatures as well as the occurrence positions are generally agreed. Even though the positions are not exactly the same, but they are close each other in the open channels so that it may not be said they show discrepancy. The temperatures for 6 and 24 channel blockages show an agreement, while a discrepancy is found for the 54 channel blockages. Especially, the result of the middle blockage case by SABRE4 is quite questionable because they are consistent with neither the results of other 54 blockage cases nor the MATRA results.

4. Conclusions

A comparison analysis for the sub-channel flow blockages with the KALIMER-150 core design has been conducted to assess the prediction capability of the MATRA-LMR/FB code by comparing the results calculated with SABRE4. Figure 5 illustrates a comparison of the two predictions. Almost all results are agreed within 78 °C when one case for the 54 channel middle blockage is not included. SABRE4 calculated that case about 830 °C, which is abnormally higher than other cases by over than 100 °C. The SABRE4 calculations for the case do not appear to be consistent with other cases. Since recalculation with SABRE4 is not possible at this time, a clear conclusion can not be drawn immediately. The discrepancy between two codes lies below 15 °C if those for the 54 channel blockage cases are excluded.

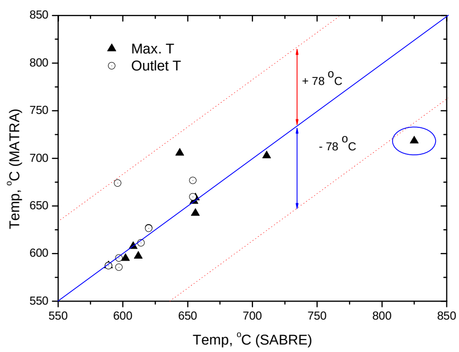

Fig. 5 Comparison of the two code predictions

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