Prediction on Mixed Convection Sodium Flow using MULTID Component Model of the MARS-LMR Code

Jae-Ho Bae [a*], Hae-Yong Jeong [b]
[a]*Korea Atomic Energy Research Institute, 111, Daedeok-daero 989ben-gil, Yuseong-gu, Daejeon, Korea*
[b]*Sejong University, 209, Neungdong-ro, Gwanjin-gu, Seoul, Korea*
[*]*Corresponding author: jhbae822@kaeri.re.kr*

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1. Introduction

In the development of next generation nuclear power plants, Sodium-cooled Fast Reactor (SFR) has been under development since earlier times. The SFR prototype developed in Korea adopts pool-type reactor. In the design of pool-type SFR, all components, e.g., reactor core, pumps, heat exchangers, etc., are located in large pool together. Following this design characteristic, various flow patterns show in the pool, and it has very complex. Therefore, multi-dimensional model is required to predict specific flow patterns and thermal-hydraulics behavior.

Among possible phenomena in the pool-type SFR, this study deals with mixed sodium convection sodium flow in the hot pool. After the reactor shutdown, relatively cold sodium jets leave the reactor core. It causes density difference and affects to flow conditions and temperature distribution. Therefore, mixed convection zones are formed, of which the thermal stratification phenomenon is representative. These phenomena were investigated in SUPERCAVNA facility at CEA in the years 1980-1990 [1]. The purpose of this experiment was the characterization of the mixed convection zones and the quantification of the thermal stratification effects in sodium flow condition.

In this study, one of the experimental cases (steady-state) in SUPERCAVNA was analyzed using MARS-LMR (Liquid Metal Reactor) code. This study was carried out to see whether MULTID (Multi-Dimensional) component could better predict flow in large pool compared to one-dimensional component.

2. Experiment Description and MARS-LMR Modeling

2.1 SUPERCAVNA Experiment

The SUPERCAVNA facility geometry is shown in Fig. 1. The detailed information is presented in Table I. This facility has rectangular cavity, which simulates hot pool, connected to inlet and outlet channels at the bottom. And there is heating channel on the wall of the outlet channel.

The steady-state and transient experiments conducted to confirm the thermal stratification formation and the buoyancy effect by density difference. In this study, only the steady-state experiment was analyzed. The steady-state experiment is that one of the cavity walls is heated by heating channel, while the other walls is adiabatic condition. The flow velocity and temperature at the inlet is constant with the time.

The steady-state experiment consists of four results according to non-dimensional number (Peclet number (*Pe*), Richardson number (*Ri*)) as shown in Table II. Among them, the P3 case is selected for this analysis, because it shows the best mixed convection characteristics such as thermal stratification phenomena. The initial condition of P3 case is shown in Table III.

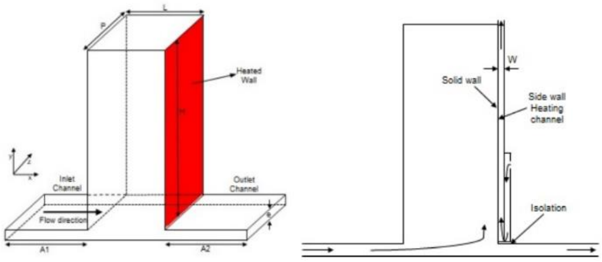


Fig. 1. Geometry and flow direction of SUPERCAVNA facility.

Table I: Dimension of SUPERCAVNA facility [1]

Dimension (m)	
Cavity height (H)	3.2
Cavity length (L)	1.6
Cavity depth (P)	0.8
Inlet/Outlet channel thickness (e)	0.03
Inlet channel length (A1)	1.52
Outlet channel length (A2)	1.52
Heating channel width	0.035
Solid wall thickness	0.006

Table II: Non-dimensional number of steady-state experiment [1]

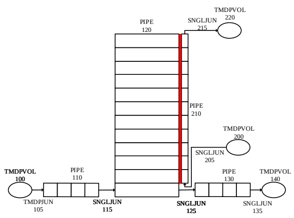
Cases	*Pe*	*Ri*
P1	41,000	0.03
P2	22,000	0.19
P3	16,900	0.36
P4	6,900	2.20

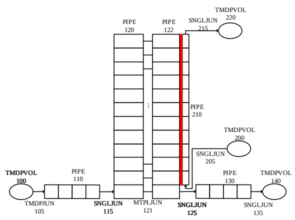
Table III: Initial condition of P3 case [1]

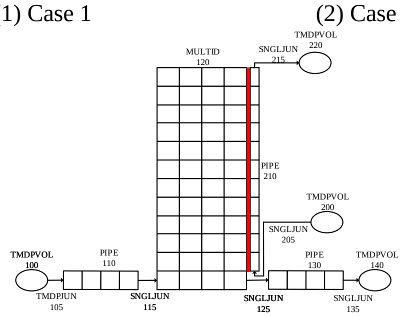
Parameter	Value
Inlet channel velocity (m/s)	0.69
Heating channel velocity (m/s)	0.69
Mean temperature of cavity (K)	523.15
Mean temperature of inlet channel (K)	523.15
Mean temperature of heating channel (K)	576.15

2.2 Modeling for MARS-LMR Code

The MARS-LMR code was developed and has been used for the system safety analysis of liquid metal reactor. The modeling methods using the MARS-LMR code are shown in Fig. 2. The inlet/outlet channel was simulated as PIPE component. And the side wall heating channel also used PIPE component. In the case of cavity that simulates hot pool, it was modeled as three cases; single PIPE component (Case 1), two PIPE components with cross-junction (Case 2), and MULTID component (Case 3). The cavity and the heating channel were connected by heat structure. Previous studies [1][2] suggest that two-dimensional analysis is sufficient for the analysis of steady-state experiment. Therefore, the depth direction was not divided in the MULTID modeling. The calculation was performed for 6,000 seconds for all analysis cases.


(1) Case 1


(2) Case 2



(3) Case 3

Fig. 2. MARS-LMR nodalization of SUPERCAVNA experiment.

3. Results and Discussion

The results of the analysis are shown in Fig. 3. The temperature in cavity is higher towards the top by heat transfer by heating channel. The bottom part is calculated to have lower temperature due to the cold sodium injected from the inlet channel. However, in Case 1 and 2, it shows that it does not match that temperature profile of the experiment. Also, it can be seen that there is no thermal stratification layer. On the other side, the MULTID analysis (Case 3) shows relatively similar temperature profiles. The thermal stratification layer is predicted be lower than the experiment, but it shows better prediction results compared to the one-dimensional analysis. It means that multi-dimensional modeling is necessary for thermal hydraulics analysis in such large pool instead of one-dimensional modeling.

In this study, the more mesh in MULTID is divided, the lower thermal stratification layer is predicted. It is judged that heat transfer increases on the wall or the velocity within the cavity is calculated differently as the mesh is further divided. This will be analyzed in detail in the future.

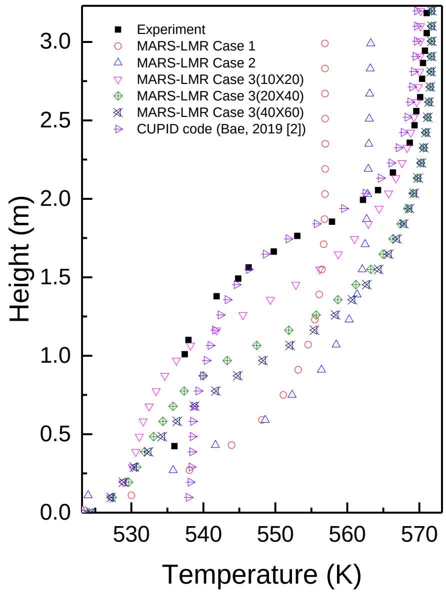
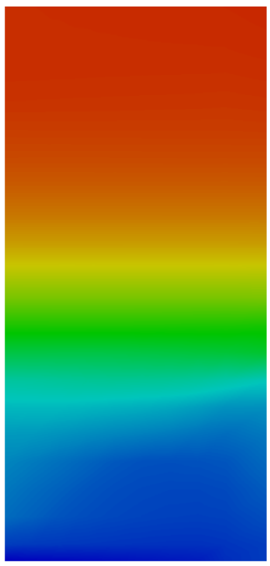


Fig. 3. Comparison of temperature profiles.


(a) MARS-LMR MUTLID

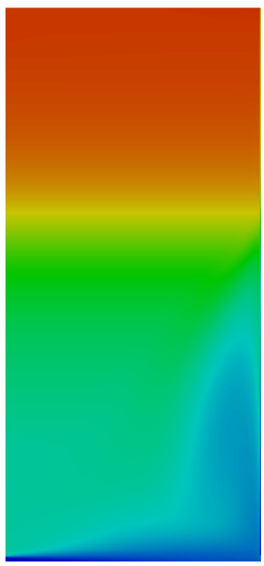

(b) CUPID

Fig. 4. Temperature distribution in cavity.

Additionally, the results of MULTID model are compared with the analysis results of the CUPID code.

Figure 4 compares temperature distribution between the MULTID component of MARS-LMR and the CUPID code. It shows that the CUPID code predicts the thermal stratification layer very close to the experiment (see Fig. 3.), because it calculates for relatively more detailed flow patterns such as recirculation flow, thermal boundary layer, etc. [2]. Nevertheless, it shows that the MARS-LMR is also predictable for thermal stratification, which is the most important phenomenon of the SUPERCAVNA experiment.

4. Conclusion

This study analyzed the SUPERCAVNA experiment (steady-state P3 case) using the MARS-LMR code. The results of one-dimensional PIPE component modeling (Case 1 and 2) and the MULTID component modeling (Case 3) are compared. It is found that the MULTID modeling calculates the thermal stratification layer of the experiment that are not predicted by one-dimensional modeling. Therefore, the MULTID modeling should be performed for large pool of SFR modeled with MARS-LMR code when detailed temperature distribution is important. However, future work will analyze the predicted low thermal stratification layer on more meshes.

REFERENCES

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