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Evaluation of Flow-Guide Effects in a Sodium-cooled Pool Type Reactor

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1. Introduction

Under a mid- and long-term nuclear R&D program, various conceptual design options for a sodium-cooled fast reactor have been proposed to fulfill the safety criteria and secure a reliable decay heat removal performance. Every design option has its own features to enhance and secure a decay heat removal performance. In the recently proposed reactor pool design for a 600MWe demonstration reactor, DHX was positioned in the hot pool, and the baffle plate was removed.

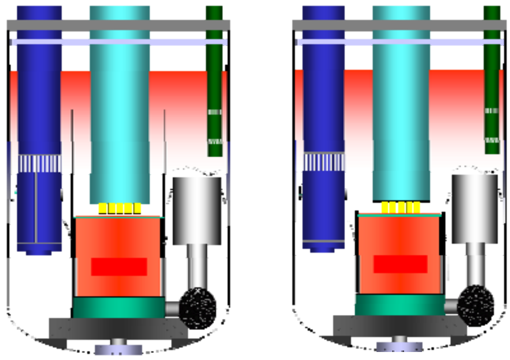
The one of the important design points in this concept is the flow-guide, which induces stack effects. A stack effect is the phenomenon caused by pressure and temperature differentials, which results in fluid being drawn through the stack. In this geometry, the flow-guide is installed in the hot pool and partially divides the hot pool into two regions, a UIS region and annular region.

In this study, the effects of the flow-guide on cooling performance of the reactor pool are investigated numerically. A complex geometrical arrangement in the reactor pool was modeled in COMMIX-1AR/P[1] using a porous-medium approach. In order to estimate the effects of flow-guide in the reactor pool, an imaginary reactor having the same geometry except the flow-guide is modeled additionally. The overall thermal-hydraulic behaviors in the reactor pool have been evaluated at a transient state condition as well as a steady state condition and the effects of flow-guide are analyzed.

2. Numerical Modeling

In order to investigate the effect of flow-guide, imaginary reactor pool geometry without flow-guide is modeled as well as reference reactor and temperature and velocity distributions are compared as shown in Fig. 1.

The PHTS and surroundings have been modeled using the cylindrical geometry option in the COMMIX-1AR/P. The COMMIX-1AR/P code is a multi-dimensional numerical code designed for analyzing steady and transient states of a fluid flow and heat transfer. The UIS (Upper Internal Structure) is modeled as a solid internal structure without any holes. A quarter of the containment vessel is considered in a cylindrical coordinate system, which includes a quarter of a reactor core and a UIS, half of a pump, and a full DHX and IHX. The radial extent of the model is bounded by the centerline of the reactor vessel (RV). Axially, the model begins at the bottom of the RV and extends to the top of the hot pool. The hemispherical shape of the bottom of the RV is ignored. The cell sizes are normally chosen so that the face locations correspond to the significant features within the system. There are 32 nodes in the radial direction: nodes 1 through 28 contain the sodium within the RV, nodes 29 and 30 contain the argon between the RV and the CV, node 31 and 32 contain the air between the CV and air separator. There are 14 nodes in the azimuthal direction: nodes 1, 2 contain half of each pump, node 5 through 7 contains DHX, IHX is located from node 10 to 12. There are 39 nodes in the axial direction: nodes 1 through 38 are used for the sodium region, node 39 is used for the expansion cells of sodium and argon gas. The more detailed modeling descriptions are written in the references[2, 3].



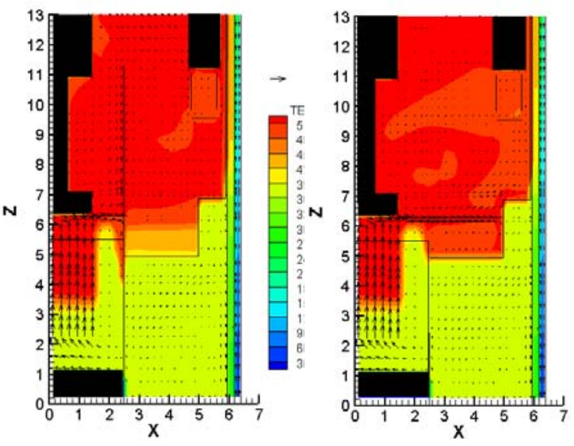
(a) with Flow-guide(Reference) (b) without Flow-guide

Fig. 1 Schematics of Reference Reactor and Reactor without Flow-guide

3. Thermal-Hydraulic Distribution at Steady State

Based on the described thermal hydraulic parameters, a numerical analysis for two reactors has been performed. Fig. 2 shows the axial temperature and velocity distribution at J=6, where the DHX is located. The thermal-hydraulic distribution in the reference reactor is shown in Fig. 2(a) and compared to that of a reactor without a flow-guide (Fig. 2(b)).

For the temperature distribution of the reference reactor in Fig. 2(a), the temperature of the hot pool sodium becomes relatively low by passing through the DHX. The thermally-stabilized region is also found near bottom of the annular region. However, the reactor without flow-guide sodium passing through the DHX diffuses more actively, and the stagnant region near the lower hot pool region also disappears.



(a) with Flow-guide (b) without Flow-guide
Fig. 2 Axial distribution of temperature and velocity (J=6)

For the velocity distribution of reference reactor, the flow of UIS region in radial direction is separated from that of annular region, so that mixing in the radial direction is confined at UIS region until hot sodium passing through the core approaches the top of the flow-guide. The axial velocity of the reference reactor near the lower UIS region is enhanced by a factor of 9, however, the radial velocity is reduced by a factor of 0.2. This shows that the axial momentum increases by confining the radial movement with the flow-guide installation. It also confines the convective heat transfer in the radial direction.

From Fig. 2 it can be concluded that the flow-guide can contribute to overall thermal-hydraulic behaviors in the pool, not only in a positive way but also in a negative way, in a steady state.

4. Thermal-Hydraulic Behavior at Transient State

In Fig. 3, the flow rate and the temperature variation for the pump trip condition during decay heat removal operation in reference reactor is compared to those in reactor without flow-guide. The solid line with symbol represents the calculation results in the reactor pool

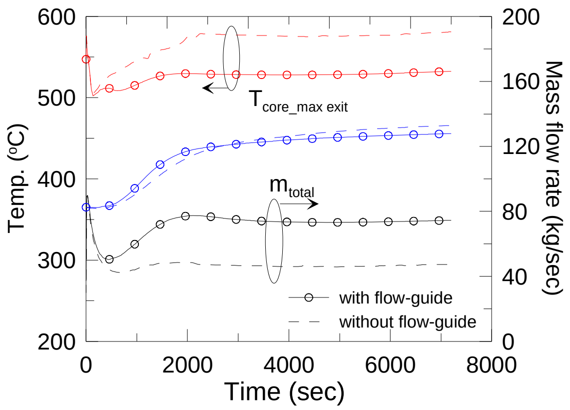


Fig. 3 Temperature and flowrate variation

with flow-guide, and the other represents the results without flow-guide.

In the reactor with flow-guide the flow rate passing through the core amounts to 77 kg/sec at t=2000 seconds after PHTS pump trip. The flow rate in the reactor without flow-guide, however, is 48 kg/sec in 2000 seconds. The flow rate increase amounts to 38% by installation of flow-guide. The increased flow rate contributes to decrease the core peak temperature in the reactor with flow-guide as shown in Fig. 3. For the core inlet temperature there's little differences between two reactors.

Based on the steady state and transient state analysis it was found that the flow-guide is effective to decrease the core peak temperature for the pump trip condition during decay heat removal operation, however, it could contribute to confine the active mixing in radial direction in hot pool. This would cause the thermal stress on the internal structure and should be considered in the structural design

5. Conclusion

In order to evaluate the effects of internal structure, a numerical model based on COMMIX-1AR/P was settled down, and the thermal-hydraulic behavior of a reference reactor was compared to those of a reactor without a flow-guide. It was found that flow-guide can contribute to decrease the core peak temperature effectively, however, the thermal stress on the internal structure should be taken into accounted at design process.

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