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Evaluation of Internal Structure Effects on Thermal-Hydraulic Behavior in a Sodium-cooled Pool Type Reactor

Ji-Woong Han, Tae-Ho Lee and Seong-O Kim
Korea Atomic Energy Research Institute, #150, DeokjinDong, YuseongGu, Daejeon, Republic of Korea, 305-353
jwhan@kaeri.re.kr

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 point in this concept is the flow-guide, which induce the stack effects. Stack effect is the phenomenon caused by pressure and temperature differentials which results in fluid being drawn through stack. In this geometry, the flow-guide is installed in the hot pool and partially divides the hot pool into two regions such as UIS region and annular region.

In this study the effects of the flow guide on thermal-hydraulic behaviors of 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, the imaginary reactor having the same geometry except flow-guide is modeled additionally. The overall thermal-hydraulic behaviors in the reactor pool have been evaluated at a steady state condition and the effects of flow-guide are discussed.

2. System Heat Balances

Fig. 1 shows the steady state heat balance of PHTS in demonstration reactor[2]. The power and mass flow rate of each internal structure was modeled based on this information.

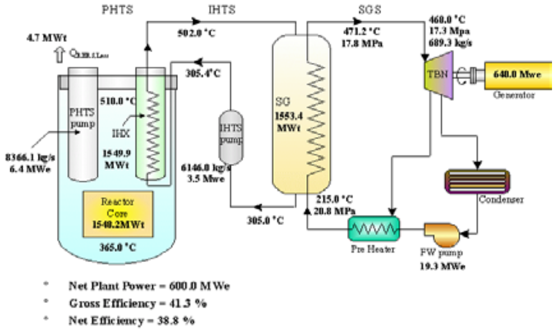
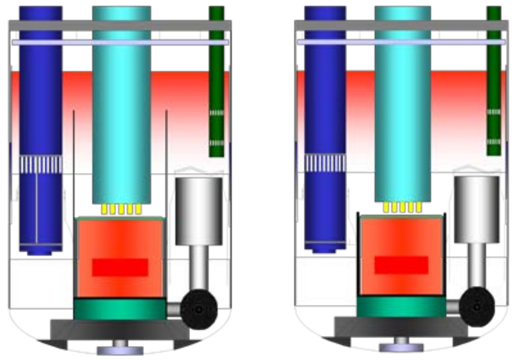


Fig. 1 System heat balance for 600MWe demonstration reactor[2]

3. Numerical Modeling

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. In order to analyze the thermal-hydraulic behavior correctly the related information for each component should be provided. In this modeling, a quarter of the reactor was considered in a cylindrical coordinate system, which includes a quarter of a reactor core and a UIS, half of a DHX and a pump and a full IHX.



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

Fig. 2 Schematics of Reference Reactor and Reactor without Flow-guide

3.1 Core

The active reactor core is 85.0cm in height and 219cm in equivalent radius with 1548.2MWt of thermal power. The core region can be classified into two fuel regions (inner and middle core regions), as well as other regions (reflector, B_4C shield, IVS (In Vessel Storage), etc.). In our calculation, a hexagonal core is modeled by an equivalent radius circular porous medium, and the regional power is allocated to each thermal structure as shown in Table.1 The inner core region and middle core region are divided into four and two grids respectively, in the radial direction. The other region is divided into two grids.

Table 1 Volumetric heat generation rate

IC(Inner Core)	983.17E+6 [W/m3]
OC(Outer Core)	814.33E+6 [W/m3]
Reflector, IVS, etc.	0.0

3.2 IHX

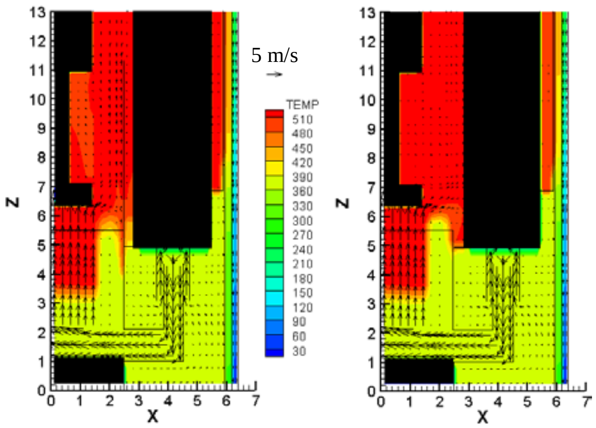
The IHX is 4.25m in tube length and 2.3m in diameter with 1549.9 MWt. The heat loss via the IHX tube bundle is modeled by adopting a constant heat sink at the tube side porous medium region. A downcomer, which is positioned at the center of the IHX, and tube bundles are modeled using porous medium approaches.

3.3 DHX

The DHX is 1.73m in tube length and 0.71m in diameter, with 1.2 MWt under normal power operation mode. The heat loss and the pressure drop at the inlet and outlet of DHX is the same as that of the IHX and that of the IHX inlet respectively.

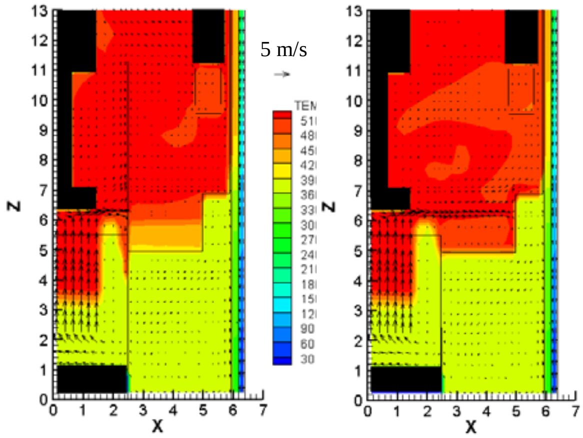
4. Thermal-Hydraulic Distribution

Based on the described thermal hydraulic parameters, the numerical analysis for two reactors has been performed. Fig. 3 shows axial temperature and velocity distribution at J=1. The thermal-hydraulic distribution in reference reactor is shown in Fig.3(a) and compared to that of reactor without flow-guide(Fig.3(b)).



(a) with Flow-guide (b) without Flow-guide
Fig. 3 Axial distribution of temperature and velocity (J=1)

For temperature distribution there's little differences between two reactors. For velocity distribution of reference reactor, however, shows some differences from that of reactor without flow-guide. For reference reactor the flow of UIS region in radial direction is separated from that of annular region, so that mixing in radial direction is confined at UIS region until hot sodium passing through core approaches the top of flow-guide. The axial velocity of 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 represents that the axial momentum increases by confining the radial movement with the flow-guide installation. It also confines the convective heat transfer in radial direction.



(a) with Flow-guide (b) without Flow-guide
Fig. 4 Axial distribution of temperature and velocity (J=6)

Fig. 4 shows the thermal-hydraulic distribution at J=6, where DHX is located. For reference reactor in Fig. 4(a) temperature of hot pool sodium becomes relatively low by passing through DHX. The thermally-stabilized region is also found near bottom of annular region. However, for the reactor without flow-guide sodium passing through DHX diffuses more actively and stagnant region near lower hot pool region also disappears.

From Fig. 3 and Fig. 4 it could be concluded that the flow-guide could 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.

5. Conclusion

In order to evaluate the effects of internal structure, the numerical model based on COMMIX-1AR/P was settled down, and the thermal-hydraulic behaviors of reference reactor were compared to those of reactor without flow-guide under a steady state condition. It was found that flow-guide could 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.

REFERENCES

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[2] Han, J. W., Decision of Preliminary Design Requirement for PHTS of 600 MWe SFR, Transactions of the Korean Nuclear Society Spring Meeting, 2010

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