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Transient Performance Analysis of the Passive DHR System in KALIMER-600

Jae-Hyuk Eoh, Seyun Kim and Seong-O Kim

Division of Fluid System Engineering, Korea Atomic Energy Research Institute
150 Dukjin-dong, Yuseong-Gu, Daejon, Korea, 305-353
jheoh@kaeri.re.kr ; seyunkim@kaeri.re.kr ; sokim@kaeri.re.kr

1. Introduction

The conceptual design of the sodium cooled fast reactor, KALIMER-600 (Korea Advanced LIquid MEtal Reactor) of which electric output is 600MWe, is currently being developed. The main design features of the reactor are the pool type primary heat transport system (PHTS), the two-loop intermediate heat transport system (IHTS), the steam generator system (SGS) and the passive decay heat removal (DHR) system. In particular, a completely independent safety-grade passive decay heat removal circuit (PDRC) system is provided to cope with a total loss of normal heat sink accident[1]. The PDRC system has an innovative superiority from the aspect that an operational reliance of the DHR can be remarkably enhanced by excluding either any operator's action or any moving parts operated by an external power supply. This feature makes the PDRC system very reliable during a harsh condition. The work described in this paper is a continuation of Eoh (2004) [2], and it includes the overall design characteristics and transient performance analysis of the PDRC system.

2. Methods and Results

Post shutdown DHR performance should be assured with a very high reliability in the nuclear reactor system. Therefore a transient simulation method for the PDRC system was developed and quantitative transient analysis results were provided by using the developed computer code POSPA. The guidelines for the PDRC design procedure are also proposed in this study.

2.1 Overall descriptions of the PDRC system

The PDRC system is comprised of two independent loops, and each loop is equipped with a single sodium-sodium decay heat exchanger (DHX), a single sodium-air heat exchanger (AHX), an intermediate sodium loop connecting the DHX with the AHX, and a DHX support barrel situated in the hot sodium pool region. A typical configuration of the system is shown in Figure 1, and the schematics of the major components with the flow streams are shown in Figure 2.

The main function of the PDRC system in KALIMER-600 is to remove the core decay heat generated just after a reactor trip such that the system shall be safely cooled down under abnormal conditions without damaging the mechanical integrity of the structures and components in the sodium coolant boundary. Since the PDRC system employs a completely passive concept without the provision of dampers located in an air inlet or outlet path of the sodium-air heat exchanger and the isolation valves mounted on the hot and cold legs of the PDRC sodium loops, it has great advantages in the point that an operational reliance of the DHR system can be considerably enhanced. This total passive feature also makes the heat loss through the system during a normal plant operation pretty small.

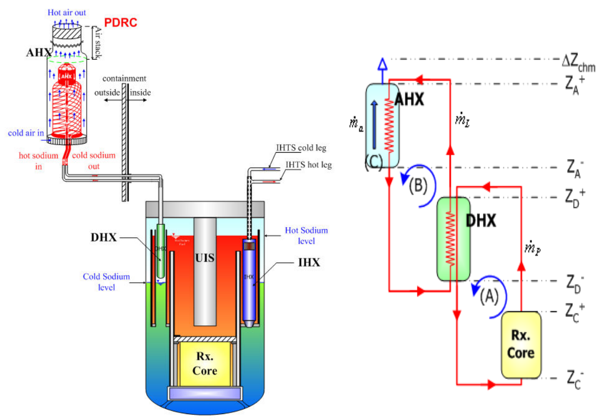
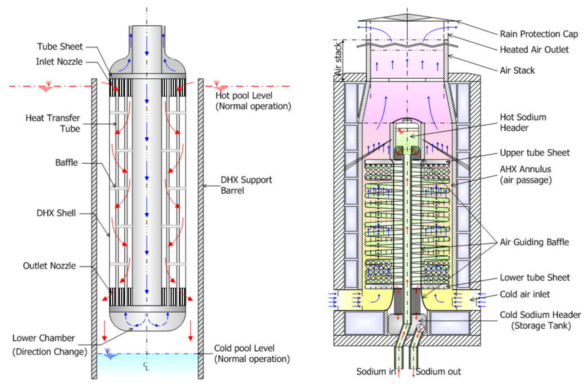


Fig. 1 Configuration of the PDRC system



(a) DHX (b) AHX

Fig. 2 Schematics of DHX and AHX with flow streams

2.2 Transient performance analysis

2.2.1 POSPA code

POSPA is one-dimensional lumped parameter system analysis code for modeling all the naturally circulated thermal portions of **i)** the PHTS sodium paths composed of the core - hot pool - DHX shell side - cold pool, **ii)** the PDRC loop sodium path including the DHX tube side - hot leg - the AHX tube side - cold leg, and **iii)** the AHX shell-side air path including the high air chimney. The following governing equations for the thermal-hydraulic system models to simulate these complexly coupled heat transfer paths are obtained for each set of the discrete control volumes described in Figure 3, where the subscript i means the i_{th} segment along the stream line (or direction) of each natural circulation path and the subscript k implies the PHTS sodium circuit, loop sodium, and air, respectively.

$$\oint \frac{1}{A}\cdot\frac{\partial \dot{m}}{\partial t}ds - \oint \frac{1}{v}\frac{\partial \rho}{\partial t}ds + \oint \frac{\dot{m}}{A}dv = \oint \rho\vec{g}\cdot d\vec{s} - \sum_i k_i \frac{\rho_i v_i^2}{2}\cdot\frac{v_i}{|v_i|} + \sum_i \Delta H_{P/P}\cdot\left(\frac{\vec{P}\cdot d\vec{s}}{|\vec{P}\cdot d\vec{s}|}\right) \quad (1)$$

$$\frac{\partial}{\partial t}\{A_c\cdot\Delta x\cdot\rho_k\cdot c_{p,k}\cdot T_k\} = \dot{m}\cdot c_{p,k}\cdot(T_{k,i-1}-T_{k,i}) + \Delta Q_{i/o} + Q_{gen} + Q_{cond} \quad (2)$$

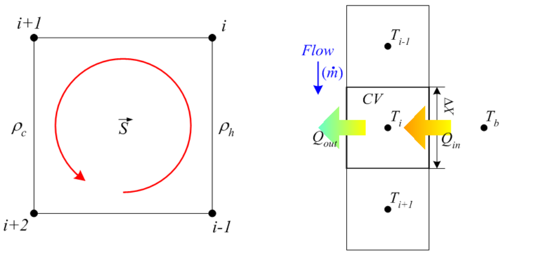


Fig. 3 Node arrangement for $\dot{m}$ and T calculation

Since the heat transport paths in the PDRC system are strongly coupled with each other, a system modeling is very complicated and an iterative numerical scheme to simulate the system behavior is required by considering a successive time marching. The conversion of the governing equations into finite difference equations was properly made by using the upwind-difference scheme with a node system located at the center of the control volume. The fine mesh approach with a larger number of nodes is also made to obtain reasonable calculation results for the given condition.

The fully implicit scheme was also employed for a transient term. In the long-term system dynamic responses, since the system transient behavior such as a sodium pool temperature variation is very slow and it becomes almost steady at the later stage of an event, in the POSPA code, the calculation time step is internally adjusted and thus the time step becomes larger and larger as time goes by. To this end, the fully implicit numerical scheme rather than the explicit one is appropriate to treat a transient term with a large time step. This is because the fully implicit scheme has a great advantage in that there is no restriction for the numerical stability criterion even with a relatively large time step, and an effective time marching is possible during a long-term transient calculation as a result.

2.2.2 Results of transient analysis

By using the developed POSPA code, the transient analysis was performed. Figure 4 shows the transient behavior of the system temperature variations. At the initial stage, since the core decay heat generation rate is much larger than the PDRC heat removal rate, the system temperature gradually increases. As time goes by, the increased sodium temperature enhances the PDRC heat removal capability but the core decay heat decreases. Therefore, the pool temperature reaches its peak (T_{peak}) at the peak time (t_{peak}) when the PDRC heat removal rate matches the core decay heat generation rate.

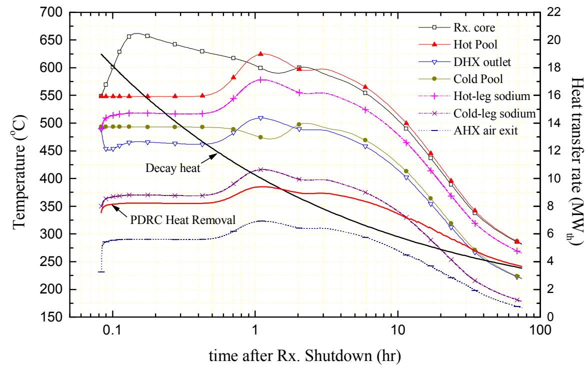


Fig. 4 Transient behavior of the PDRC system

Based on the investigation results of the effects of the reactor pool volume change on T_{peak} and t_{peak}, it was found that, as the pool volume increases, the sodium peak temperature decreases and it is reached at a later time. This means a lager pool sodium volume has an advantage for a system design from the aspect that there is enough margin to the design temperature limit and it can make flexible system operation due to a larger thermal inertia of the sodium pool. However, since a larger sodium pool volume also has economic disadvantages, an optimal design should be made through a quantitative analysis.

3. Conclusions

The transient performance analysis code POSPA was developed and applied to a transient simulation. The transient analysis results were obtained through a comprehensive thermal-hydraulic analysis model, and it was found that a larger sodium pool volume becomes beneficial to a system design.

ACKNOWLEDGEMENT

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