A Preliminary Analysis of PHTS Preheat Using High-Temperature Gas

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1. Introduction

Prior to introducing the molten sodium in the reactor vessel, the Primary Heat Transport System(PHTS) should be heated up to the refueling temperature 200℃ to prevent the sodium solidification and thermal shock. The PHTS is planned to be preheated with the high-temperature inert gas, which circulates inside and outside reactor vessel. The heat from the high-temperature inert gas will be transferred to the low-temperature components by conjugate heat transfer. During preheating, the temperature can be unevenly distributed in the PHTS since the inert gas cannot uniformly reach to the whole surface of pool shaped reactor. Therefore, the temperature distribution of the PHTS during preheating process should be evaluated. The heat rate of PHTS with operating conditions should be also evaluated to set up the overall preheating plan. This research contains the numerical analysis procedures and results for evaluating the preheating process of the PHTS.

2. Methods and Results

The PHTS will be heated by hot inert gas which is injected through four temporarily installed pipes. Two pipes are routed to the bottom region of the reactor vessel and other two pipes are installed between the reactor vessel and containment vessel. The position of the inlet and outlet for the preliminary analysis is shown in Fig. 1.

Followings have been done in the preliminary analysis of preheating the PHTS.

- Determining the operating condition using an adequate lumped model for predicting preheat rate.
- Constructing the efficient CFD model by mesh resolution test and turbulence model selection.
- Validating the operating condition by comparing the heating rate between the lumped model and CFD model.

2.1 Operating Condition

The operating condition should be determined before the CFD analysis. Since the transient analysis by CFD takes very long time, the operating condition is determined by lumped model. The physical time for preheating the PHTS is assumed as seven days.

In the lumped model, the components of PHTS are assumed as a simple block with same temperature. The energy equation for the solid region is as follows.

$$(\mathrm{CM})_{PHTS}\left(\frac{dT_{PHTS}}{dt}\right) = h_g A_s \Delta T_{lm} \quad (1)$$

Here, $(\mathrm{CM})_{PHTS}$, h_g , A_s , T_{PHTS} and T_{lm} are respectively the heat capacity of PHTS, heat transfer coefficient of the gas, the total heat transfer area, the temperature of PHTS and log mean temperature difference between the gas and PHTS. The log mean temperature can be defined as follows.

$$\Delta T_{lm} = \frac{T_{g,in} - T_{g,out}}{\ln \dfrac{T_{g,in} - T_{PHTS}}{T_{g,out} - T_{PHTS}}} \quad (2)$$

The energy equation for the gas region is as follows.

$$c_{p,g}\dot{m}_g\left(T_{g,in} - T_{g,out}\right) = h_g A_s \Delta T_{lm} \quad (3)$$

Here, $c_{p,g}$, $\dot{m}_g$, $T_{g,in}$ and $T_{g,out}$ are the specific heat, mass flow rate, gas inlet temperature and gas outlet temperature respectively. By substituting Eq. (1) into Eq. (3), the temperature change of PHTS can be defined as follows.

$$\frac{dT_{PHTS}}{dt} = \frac{h_g A_s}{(\mathrm{CM})_{PHTS}} \times \frac{T_{g,in} - T_{g,out}}{\ln \dfrac{T_{g,in} - T_{PHTS}}{T_{g,out} - T_{PHTS}}} \quad (4)$$

The temperature of PHTS is derived from Eq. (4) using modified Euler's method.

Fig. 2 shows the temperature change with time. The operating conditions for the temperature and mass flow rate of gas are derived as 600℃ and 0.7 kg/s to preheat the PHTS from 25℃ to 200℃ for seven days.

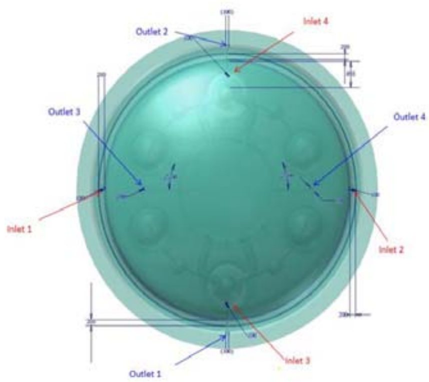

Fig. 1. The inlet and outlet position of the PHTS.

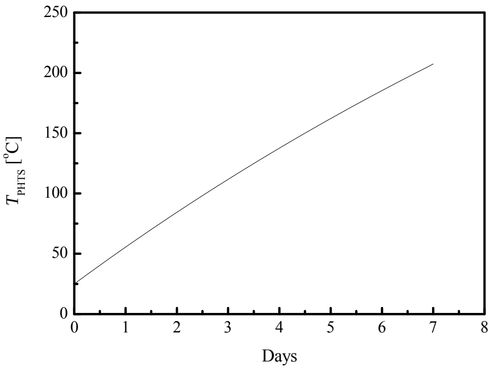

Fig. 2. The temperature change of the PHTS from the lumped model.

2.2 CFD Analysis

Since the transient analysis takes very long time, the number of mesh should be minimized. The mesh resolution test for three cases of 3, 5 and 12 million has been implemented. The convergence and flow stabilization was improved for higher mesh resolution, however, the difference was not significant. Therefore, the mesh resolution of 3 million is used in this analysis. The assumptions and analysis method used for analysis are as follows.

- 3-D transient: 1/2 circumferential symmetric
- Consideration of Conjugate Heat Transfer
- Turbulent model: Standard k-ϵ Two-Layer Model
- Two-Layer All y+ Wall Treatment
- Solver: Segregated Flow & Segregated Fluid Temperature

The temperature distribution of the solid region at 12.4 hour is shown at Fig. 3. The figure shows that the PHTS is heated up with any hot spot.

Fig. 4. shows the temperature change at the reactor core and radial core shielding structure which forms the maximum and minimum temperature within the PHTS.

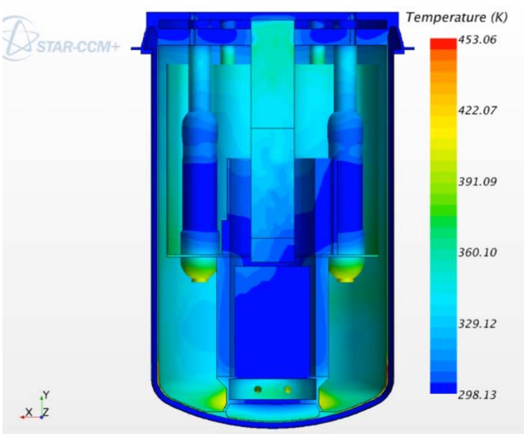

Fig. 3. Temperature distribution of solid region at 12.4 hours.

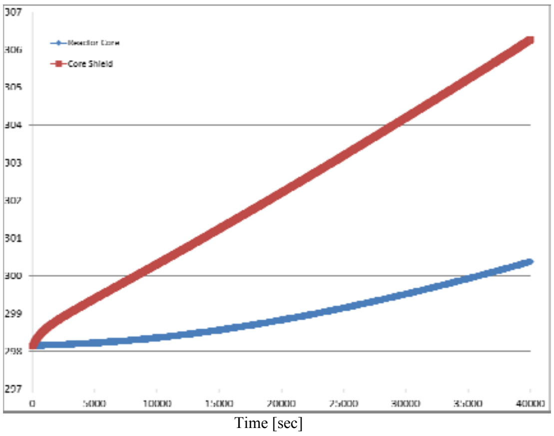

Fig. 4. The temperature change at the reactor core and radial core shielding structure from the CFD model.

The physical time to preheat the PHTS from 25℃ to 200℃ is expected for 5 days at the radial core shielding structure and 9.5 days at the reactor core according to the trend line. The preheating time from lumped model exists almost middle of the maximum and minimum time. Therefore, the operating condition from the lumped model can be concluded to be valid.

3. Conclusions

This research contains the numerical analysis procedures and results of the preheating process of the Sodium-cooled Fast Reactor. From this preliminary analysis, the procedure to set the operating condition and the suitable CFD model is developed. Especially, the development of CFD methodology to calculate and predict the thermal characteristics of the PHTS in accurate and efficient manner. From the lumped model and CFD model, the detailed analysis of preheating, which contains specific inlet and outlet configuration and operating condition, will be performed in the near future.

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