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Development of a Preliminary Model for Analyzing Performance of PHTS and IHTS loop in a SFR

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1. Introduction

We developed a simple model for the performance analysis code of a SFR. To develop the performance analysis, we adopted a commercial modular modeling system (MMS) code as a base solver for the code, which was developed by nHance Technology in USA. [1] It has lots of basic component modules as well as an intrinsic solver for the thermodynamic equations with a pressure/flow solver and an enthalpy equation.

However, the MMS modules have been developed for a water or gas plant. Thus, it does not have the properties of sodium. We attached the sodium properties to the MMS code. [2] Also, we modified some modules to be adequate for a SFR. After modifying the MMS, we developed a preliminary model for analyzing performance of PHTS and IHTS loop in a SFR. Then, we analyzed a steady state and a simple power reduction event. We concluded the model had a good capability to analyze a steady state and a transient event like a power reduction event.

2. MMS Features

The MMS has a graphical user interface as well as a mass and an energy solver for analyzing the transient behaviors. Thus, it can enable a modular approach in developing a new analysis code and can analyze a plant in a real time by using the simplified modules. Since it doesn¡t have a sodium property in MMS, we developed the sodium property routines in MMS for developing a sodium loop of a SFR. In addition, fuel and pipehx modules provided by MMS were modified in order to be adequate to the SFR components. The fuel module and pipehx module were significantly modified and we called then MMS-LMR (liquid metal reactor) modules.

2.1 Fuel Module

A fuel module can calculate the reactor thermal power using a point kinetic model. It has a 6 delayed neutron group model, a 3 decay heat group model, an Iodine-Xenon chain model, a temperature dependent Moderator Temperature Model (MTC) and a Doppler Coefficient model. The reactivity models of the Doppler and MTC for a SFR are different with those of a conventional PWR and we changed the reactivity models to be suitable to the SFR. The coefficient and the reactivity table were given through the safety analysis of KALIMER-600. [3][4]

$$d\rho_{density} = a\frac{\rho_{Na}(T_i)-\rho_{Na}(T_{ref})}{\rho_{Na}(T_{ref})}$$

$$d\rho_{density} = reactivity\ due\ to\ density\ chnage$$
$$a = 2.5818\times10^{-4}\ for\ KALIMER-600$$
$$\rho_{Na}(T_i) = reactivity\ at\ T_i$$
$$\rho_{Na}(T_{ref}) = reactivity\ at\ T_{ref}\ (= 467.5\ ^{\circ}C)$$

$$d\rho_{Doppler} = \rho_i - \rho_0$$
$$\rho_i = bT_i^{-0.12}$$
$$b = \frac{0.0122517}{0.12}\ for\ KALIMER-600$$
$$T_{ref} = 370.9\ ^{\circ}C$$

Additionally, we eliminated the effect of the reactivity change from the density change of the poisoning materials like Xenon because the absorption cross section could be negligible in a fast reactor due to the fast neutron spectrum in the SFR.

2.2 Pipehx Module

It is used to simulate the heat transfer with an appropriate heat transfer correlation between a heat structure and a fluid. So, it is used to model various heat exchangers like the intermediate heat exchanger (IHX) of the SFR.

For the simulation of a heat transfer between a heat structure and a liquid metal, several heat transfer correlations for the sodium flow were implemented in the MMS-LMR code. Modified Schad correlation was applied in the rod bundle region in the core and the Graber-Rieger correlation was implemented for the sodium of heat exchanger shell side. For the inside of a pipe or tube the Aoki model was applied. [4]

- *Modified Schad correlation*

$$Nu = \left[-16.15 + 24.96\left(\frac{P}{D}\right) - 8.55\left(\frac{P}{D}\right)^2\right]Pe^{0.3}$$

- *Graber-Rieger*

$$Nu = 0.25 + 6.2\left(\frac{P}{D}\right) + \left[0.032\left(\frac{P}{D}\right) - 0.007\right]Pe^{0.8-0.024\frac{P}{D}}$$

- *Aoki correlation*

$$Nu = 6.0 + 0.025\left[0.014\,\mathrm{Re}^{1.45}\,\mathrm{Pr}^{1.2}\left(1-\frac{e^{-71.8}}{\mathrm{Re}^{0.45}\,\mathrm{Pr}^{0.2}}\right)\right]^{0.8}$$

3. SFR Analysis Model

Based on the MMS-LMR modules, we have developed the KALIMER-600 loop model. Figure 1 shows the developed model using the heat balance and each component data. [Hahn 2007][Cha, 2007] We modeled each loop (PHTS, IHTS) as a single loop, respectively, and the model was composed of a fuel module, a loop module with various pipe modules including a pump module, some heat exchanger models composed of a pipehx module and Qmetal modules in the MMS-LMR. The model for the BOP cycle including a turbine was not modeled, because we have not finished the detailed design for the cycle. So, we considered the steam generator as a heat sink and analyzed the thermodynamic behaviors including the reactor in the PHTS and the ITHS of KALIMER-600.

3.1 Steady State Analysis

For verifying the developed model, we analyzed the steady-state of KALIMER-600. The reference values were obtained from the data of a heat balance and the results of a steady state by MARS-LMR code which was developed for a safety analysis for the SFR in KAERI.

Table 1 Steady State Analysis

parameters	reference	result
Reactor Power (%)	100%	100.08
Temperature at core (C) inlet/outlet	390/545	390.2/545.3
PHTS flow rate (Kg/sec)	7731.3	7732.3
Temperature at IHX inlet/outlet in IHTS	320.7/526.0	319.9/525.7
IHTS flow rate	5800.7	5802.1

3.1 Power Reduction Analysis

We have studied a simple power reduction event. When the turbine load was decreased, we examined the system performance. Since we didn¡t have the control program of temperature and flow, we only examined the turbine leading mode for a load following operation by reducing the heat removal rate through the turbine. Figure 2 shows the analysis results. The reactor power appropriately followed the turbine power through the developed reactivity feedback model in the core. As for the load reduction in the SG, the temperature of the PHTS cold leg temperature was increased. So, the negative reactivity was injected into the core due to the change of the sodium density in the PHTS and the fuel temperature originated from the change of the temperature in the PHTS loop. Finally, the reactor power followed the turbine power (heat removal rate). The amount of power reduction in the core was the same as the load rejection (heat removal rate) of the turbine.

4. Conclusions

Although the analysis results were a little limited due to a lack of BOP cycle data and some components data, we concluded that the developed code revealed a good performance for analyzing the PHTS and the IHTS loop of KALIMER-600 in thermodynamic and reactivity models from a steady state and a transient analysis. After an appropriate turbine model with a control algorithm and detailed components are designed, we can finalize and verify the performance code of KALIMER-600 plant.

REFERENCES

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[3] Hahn D.H. et al., KALIMER-600 Conceptual Design Report, KAERI/TR-3381/2007.
[4] Ha, K.S. et al, Development of MARS-LMR and Steady-state Calculation for KALIMER-600, KAERI/TR-3418/2007.

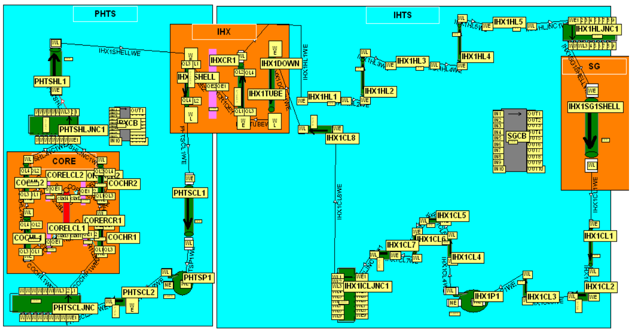
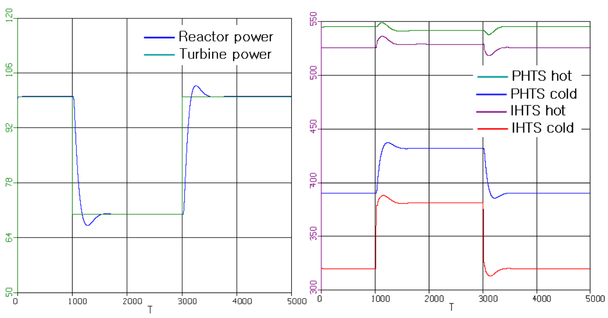


Figure 1 MMS-LMR model for KALIMER-600



(a) power (b) temperature
Figure 2 Analysis results for power reduction event