The Modeling of a High Temperature Gas-Cooled Reactor for control analysis

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Key words : modeling, control analysis, HTGR

1 Introduction

In KAERI (Korea Atomic Energy Research Institute), the development of a pre-conceptual design for an HTGR is to be carried out. For the control characteristics and dependence of the control on the system design features, HTR-10 was used as the reference design for simulating the control. This paper describes the development of analysis program for reactor control.

2 Description of the system

The HTR-10 reactor which was used as the reference system design in this study is a high temperature gas-cooled research reactor of a pebble bed reactor type. It was designed and constructed by the Institute of Nuclear and New Energy Technology (INET) of Tsinghua University[1].

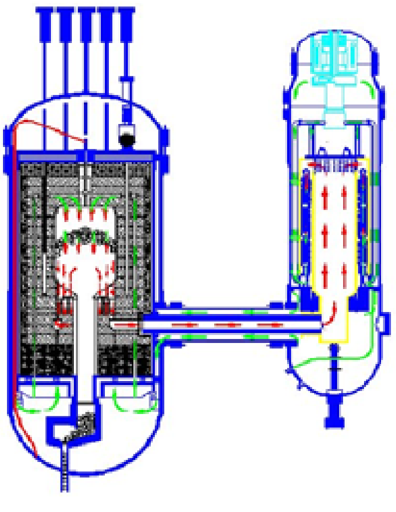

Fig. 1 the reference of high temperature gas-cooled reactor

In HTR-10, helium is used as the coolant and its nuclear core where heat is generated from the nuclear fuel is in a form of a pebble bed. HTR-10 consists of a reactor core, a steam generator, a hot gas duct, a helium blower, and the coolant flow is shown in Fig 1.

The helium gas heated at the core region exits the core region by the path located at the bottom of the core region and flows to the SG (Steam Generator) through the piping which connects the reactor block and the steam generator block[2].

The reactor block is surrounded by a building structure. The external surface of the reactor vessel is cooled by air convection[4].

3 Analysis Modeling

An analysis program for the reactor control was developed and it uses the following one-dimensional equations as its governing equations.

- Flow momentum equation

$$\left(\dot{m}^{j+1}-\dot{m}^{j}\right)\frac{1}{\Delta t}\sum\frac{\Delta S_i}{A_i}-\dot{m}^{j+1}\sum\frac{\Delta S_i}{A_i\rho_i}\frac{\Delta\rho_i}{\Delta t}=-Sign(\dot{m})\left(\dot{m}^{j+1}\right)^2\sum C_i+\Delta H_{pump} \quad (1)$$

$$C_i\equiv\frac{\Delta HeadLoss_i}{\left(\dot{m}_i\right)^2}$$

- Flow energy equation

$$(\Delta M_{st}C_{v.st}+\rho_{He}C_{v.He}\Delta V)\frac{dT_{He}}{dt}= \quad (2)$$

$$C_{p.He}\left(\dot{m}_{in}T_{in}-\dot{m}_{ex}T_{ex}\right)_{He}+\dot{Q}_s+\sum_k(UA)_k(T_{sur.k}-\bar{T}_{He})$$

where *UA* means the overall heat transfer coefficient of the heat transfer path *k*.

The left hand side term represents the transient effect and the expression is for the case where structure temperature is modeled as the same as the fluid temperature. A pre-evaluation of the density change effect on the mass flow rate showed that the magnitude of the flow rate caused by the density change in a calculation cell is about 0.01% of the rated system flow rate and its effect on the energy transfer rate was only

0.0001% of the core power. It means the equation can be simplified as Eqs. (3) and (4)

$$\dot{m}_{in} = \dot{m}_{ex} = \dot{m} = const \qquad (3)$$

$$(\Delta M_{st} C_{v.st} + \rho_{He} C_{v.He} \Delta V)\frac{dT_{He}}{dt} = C_{p.He}\,\dot{m}\,(T_{in} - T_{ex})_{He} + \dot{Q}_s + \sum_k (UA)_k (T_{sur.k} - \bar{T}_{He}) \qquad (4)$$

- Structure energy equation

$$(\Delta M_{st} C_{v.st})\frac{dT_{St}}{dt} = \sum_k (UA)_k (T_{sur.k} - \bar{T}_{St}) \qquad (5)$$

The governing equations (2), (4) and (5) were converted to a system of algebraic equations using the finite difference scheme. In the conversion, the boundary node scheme [3] which places a node at the calculation cell boundary and utilizes the transient property distribution information in taking the cell average to reduce the truncation error was used. For the reactor structure, Eq (5) was applied two-dimensionally in space.

The next figure shows the node configuration for the reactor block. In the steam generator, feedwater system was connected so that steam temperature control performance can be evaluated.

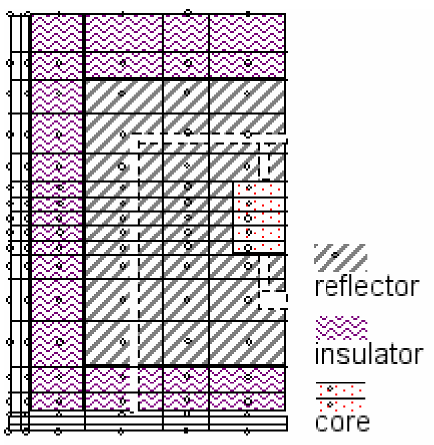

Fig. 2 The reactor block configuration

In writing the program, consideration was made for the program to be able to easily check the design change effects on control and some parameters written below were introduced to the program for this purpose.
- *CreflV* and *CinslV*: adjust the specific heat of the reflector and insulator material, respectively.
- *CuaCore* :adjusts the heat transfer coefficient between the helium and the structure surface in the core region.

The thermal capacity and coefficient comes to change proportionally to the value of the factors.

The developed program was tested for the reliability of its calculation
- Error in the energy balancing: In the tested conditions, the error was less than 0.06% for the whole calculation period.
- Convergence of the solution in the final iteration

As the solutions passed all the internal iteration criteria, the numbers of iterative calculations in the various iteration levels became 1.
- Smooth convergence and calculation trend

During the iteration, the change of the calculation results was smooth and the calculation converged to the level of typically 0.0002C and at maximum 0.0005C.

4 Conclusions

The test results show that developed analysis program can be used for the intended purpose of the investigation of the control characteristics and relation between the system design and control.

Acknowledgment

This work has been carried out under the national nuclear long-term R&D program which is supported by MOST (Ministry of Science and Technology).

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