Conjugated Heat Transfer Phenomena in a Obstacle Annulus of VHTR

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1. Introduction

A very high temperature reactor (VHTR) is a graphite-moderated and helium-cooled reactor and selected as a next-generation nuclear reactor [1] for its ultimate safety among various advantages. This type of reactor has become of great interest in terms of using a process heat. To utilize VHTR safely and practically, an in-depth study on a passive heat removal system is needed.

Reactor cavity cooling systems (RCCS) have been considered until now as equipment that guarantees the passive safety in a VHTR under any accident. To remove decay heat effectively, various studies have been conducted. The obstacle annulus may be an option by activating natural convection. Before the test, numerical simulation is in demand to predict the heat transfer by obstacle annulus. However, a thermal analysis of a passive heat removal system has faced severe problems like mesh generation for a full reactor building including the reactor core, RPV and containment, and time costs conjugated with radiative heat transfer. Therefore, simplified approaches have been applied to predict the total heat flux in passive cooling. Hans D. Gougar et al.[2] analyzed the reactor pressure vessel temperature of a VHTR under a depressurized conduction cooldown accident by assuming an one-dimensional analysis. Kim et al.[3] studied heat removal by a passive cooling system with GAMMA+ for a transient 1D analysis and CFX codes for predicting a steady pressure vessel temperature. The full modeling with each fuel block consisting of the fuel compacts and coolant channels would be the most accurate solution. However, still, the mesh generation problem for full reactor core remains. In this report, CFX code is applied to predict passive heat removal depending on obstacle annulus while assuming the reactor core as a porous medium.

2. Modeling and Schematic of Reactor

A schematic of the reactor vessel in the containment is shown in Fig 1 and 2. To investigate the heat transfer, a 1/12 model was chosen for simple calculations with reliable accuracy. The domain include a reactor core, permanent side reflector, core barrel, RPV gap, RPV, reactor cavity, and RCCS. Figure 2 shows the obstacle annulus with 3cm in height and 8cm in length on the core barrel to enhance the heat transfer during the shutdown condition. The obstacle annulus in Fig. 2 is considered to lower the fuel temperature in the case of a loss of coolant accident, but it is necessary to study the priority of the effect under the normal operating condition. The inlet and outlet structure of the RCCS on the ground was omitted to simplify the computational domain. The reactor core of the fuel block is 2.87m in diameter and 5m in height. The height of the computational domain is 7.1m with top/bottom reflector and outlet plenum. The side reflector and core barrel is 0.715m and 0.05m in each web thickness. The porosity of coolant channel is set to 0.078382. The reactor power is thermally 100MW.

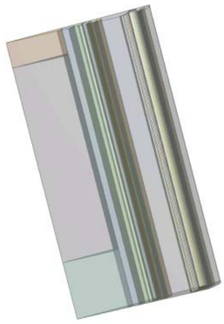

Fig. 1 Computational domain for CFX

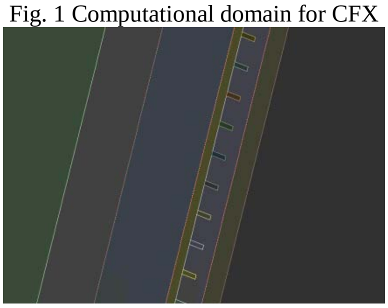

Fig. 2 Obstacle annulus on the core barrel

The commercial CFD code, ANSYS CFX, is applied here. The shear stress transport model with an automatic wall treatment was applied. The discrete transfer model is selected to predict a radiative heat flux for the RPV gap and RCCS duct. The helium coolant flows at a fixed mass flow rate of 40kg/s. Inlet temperature and pressure at the riser inlet are 370^0C and 70 atm. The adiabatic condition between the reactor cavity and downcomer walls is selected to prevent heat transfer from RPV to the containment of the concrete wall. The inlet temperature and mass flow rate are 40^0C and 2.13kg/s at the RCCS inlet by the GAMMA+ result. The thermal conductivity and viscosity of helium are calculated as a polynomial equation below.

$$\kappa[W/mK] = 0.05027 + 3.5151e-4\times T - 3.0099e-8\times T^2 \quad (1)$$

$$\mu[Pa\cdot s] = 5.42994e-6 + 5.44595e-8\times T - 1.63587e-11\times T^2 + 2.894521e-15\times T^3$$
(2)

The core barrel is Alloy 800H and the permanent side reflector is made from H451 graphite. RPV uses SA-508.

The solved outlet temperature was 850^0C which is same as GAMMA+. The maximum RPV wall temperature was 345/355℃ with/without obstacle annulus by CFX in Fig. 3.

Figures 4 and 5 represent the stream line in the gap between the core barrel and RPV. The enhanced natural convection by the obstacle annuls makes the temperature of RPV wall higher than the normal core barrel shape. A vessel cooling system would be desired to maintain the limited temperature of the RPV material under normal operating conditions in Fig. 3.

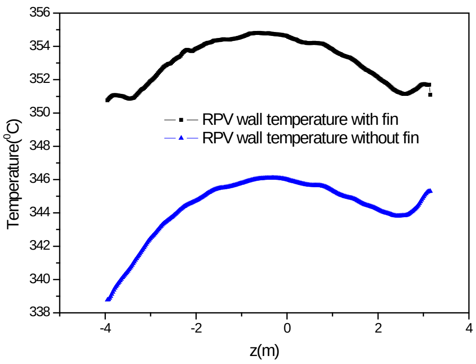

Fig. 3 RPV wall temperature with/without obstacle annulus

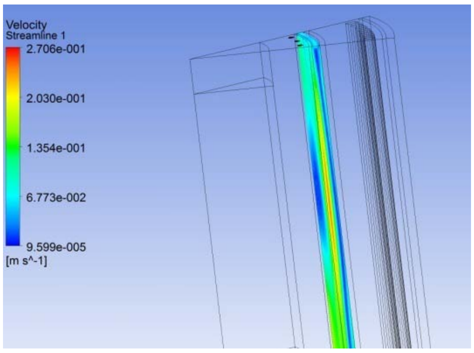

Fig. 4 Stream line in RPV gap without obstacle annulus

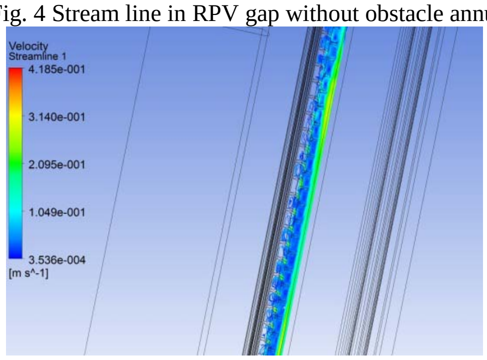

Fig. 5 Stream line in RPV gap with obstacle annulus

Figure 6 plots the temperature variation along the axial line for the reactor. The temperatures of the RPV and reactor cavity are higher than those without an obstacle annulus.

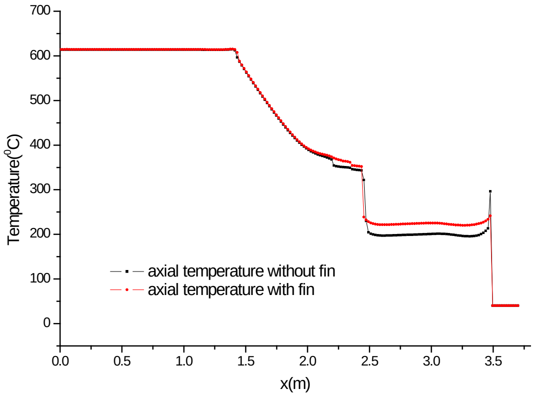

Fig. 6 axial wall temperature variation

3. Conclusions

In this report, the thermally steady state of the VHTR was studied to predict heat transfer by RCCS with an obstacle annulus on the core barrel. To solve the conjugate heat transfer from fuel to the reactor pressure vessel, the porous medium approach in CFX was applied and compared with the GAMMA+ results. The CFD code also made it able to predict 3-dimensional flow analyses. There was an increase in RPV wall temperature with obstacle annulus. The fin may have an advantage in heat removal in the case of a reactor shutdown by lowering the fuel temperature under a no-coolant accident. However, an additional vessel cooling system is needed to decrease the RPV wall temperature during normal operation condition. A detailed study for the effect of the obstacle annulus will be conducted both under normal operating and shutdown conditions.

Acknowledgements

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