Thermo-Fluid Verification of Fuel Column with Crossflow Gap

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1. Introduction

After Fukushima, passive safety is getting great interest in the field of nuclear power plants and Gen-4 reactors with inherent safety are considered to enter the global market sooner than expected. Very High Temperature Reactor (VHTR), one of Gen-4 reactors, has ability to cool down reactor core by natural convection and radiation without electric supply. VHTR is designed to operate at high pressure and temperature to produce process heat.

Korea Atomic Energy Research Institute (KAERI) has been developing thermal-hydraulic code to design a safe and effective VHTR. Core reliable Optimization & Network thermo-fluid Analysis (CORONA)[1][2] is a code that solves the fluid region as 1-D and the solid domain as 3-D. The postulated event is modeled to secure safety during design process. The reactor core of VHTR is piled with multi-fuel block layers. The helium gas goes through coolant channel holes after distributed from upper plenum. The fuel blocks are irradiated during operation and there might be cross gaps between blocks. These cross gaps change the passage of coolant channels and could affect the temperature of fuel compact. Therefore, two types of single fuel assembly (i.e., standard and Reserved Shutdown Control (RSC) hole fuel assemblies) were investigated in this study.

2. Methods and Results

Fluid region is solved by below one-dimensional governing equations.[3][4]

$$\frac{\partial \rho_f}{\partial t} + \frac{\partial(\rho_f w A)}{A\partial z} = 0 \qquad (1)$$

$$\frac{\partial(\rho_f w)}{\partial t} + \frac{\partial(\rho_f w^2 A)}{A\partial z} + \frac{\partial p}{\partial z} + \rho_f g \cos\theta + f\,\frac{\rho_f w|w|}{2D_h} = 0 \qquad (2)$$

$$\frac{\partial(\rho_f C_f T_f - P)}{\partial t} + \frac{\partial(\rho_f w A C_f T_f)}{A\partial z} - q'''_{conv} = 0 \qquad (3)$$

Each coolant holes and solid domain are connected by network model to transfer heat and flow.

The fuel compact has power of 28.4MWt/m^3. The inlet temperature and pressure are specified as 490^{0}C and 7MPa. 1.268kg/s of helium coolant passes the coolant channels. Commercial computational fluid dynamics (CFD) software, CFX, was used to compare with the result of CORONA.

Fig. 1 shows the meshes of RSC fuel assembly of CFX.

Fig. 1. CFD mesh for RSC fuel assembly

2.1 Standard Fuel Assembly

The standard fuel assembly was analyzed first to verify CORONA calculation.

The coolant / fuel compact hole are 0.635cm and 0.79375cm in radius. The height of one fuel block is 79.3cm and 6 fuel block layers are considered in this study. Fig. 2 and 3 represent the axial temperature variation at the point where hot spot in fuel blocks exist. Non-continue regions between fuel blocks are generated due to graphite plug and seat. The calculated data are well agreement with CFX.

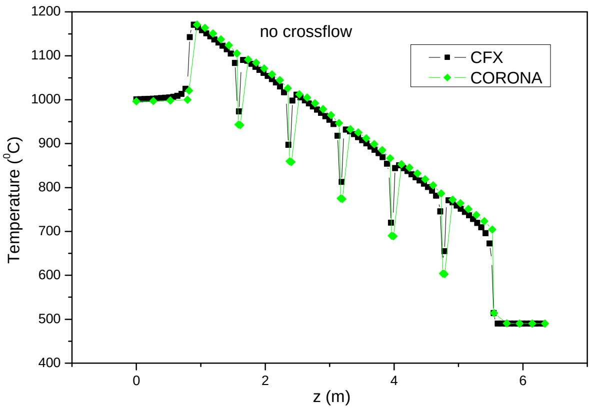

Fig. 2. Axial temperature variation for standard fuel assembly without crossflow

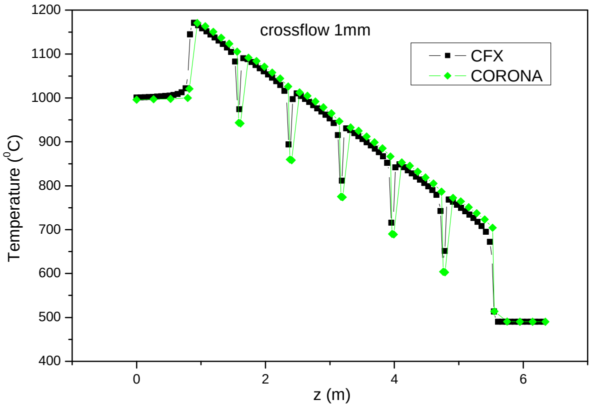

Fig. 3. Axial temperature variation for standard fuel assembly with crossflow

2.2 RSC Fuel Assembly

The RSC hole is 9.625cm in diameter. In the RSC fuel assembly, coolant passes coolant channel and bypass gap. Top and bottom of RSC hole are blocked. As a result, without crossflow gap, there would be no mass flow within the RSC hole. However, due to crossflow gap, RSC hole absorbs some of coolant and releases it again at the bottom of assembly. Fig. 4 and 5 represent the axial temperature variation for the RSC fuel assembly. The results of CORONA also match well with CFX in the RSC fuel assembly.

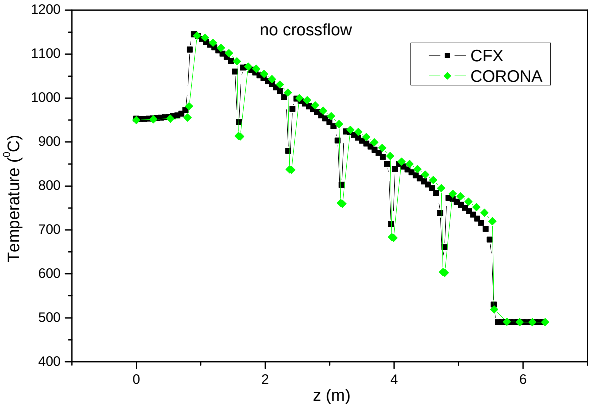

Fig. 4. Axial temperature variation for RSC fuel assembly without crossflow

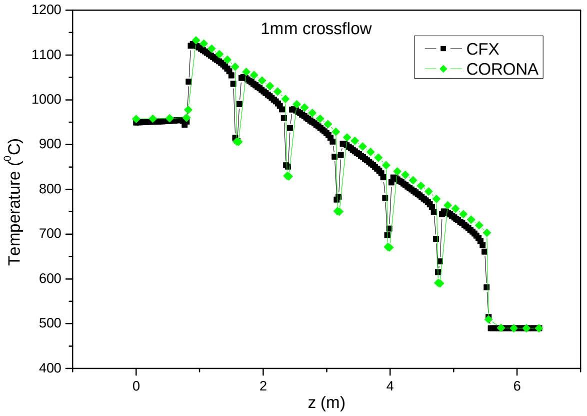

Fig. 5. Axial temperature variation for RSC fuel assembly with crossflow

The data of CFX and CORONA in RSC fuel assembly are compared in Table I. Hot spot temperature was similar and flow distribution due to crossflow was also almost same.

Table I: Crossflow with 1mm gap

	CFX	**CORONA**
Max Fuel T	**1126.43**	**1129.9**
Coolant flow	**1.234782kg/s**	**1.23056 kg/s**
Bypass flow	**0.033111 kg/s**	**0.03744 kg/s**

3. Conclusions

The CORONA, thermo-fluid analysis code, has been developing to compute the reactor core of VHTR. Crossflow model was applied to predict temperature and flow distribution between fuel blocks in this study. The calculated results are compared with the data of commercial software, CFX. The temperature variations along the axial direction well agree for both standard / RSC fuel assemblies. The flow redistribution due to crossflow matches well. The hot spot temperature and locations might differ depending on the cross gap size. This research will be done in detail for further study.

Acknowledgements

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