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Evaluation on Cooling Performance of Vessel Air Cooling System with Flow Guide for STELLA-2

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1. Introduction

Development of PGSFR (Prototype Generation-IV Sodium-cooled Fast Reactor) is a long term nuclear program of Korea Government. To support this program, KAERI(Korea Atomic Energy Research Institute) is carrying out STELLA-2(Sodium integral effect test loop for safety simulation and assessment) program, which aims to evaluate the plant dynamic behavior of PGSFR transients by demonstrating the decay heat removal performance and by performing verification and validation of the developing computational code [1].

An air cooling system for the reactor vessel of STELLA-2 is required to demonstrate the heat release from the reactor vessel in case even the decay heat removal system (DHRS) has lost its function [1]. The vessel air cooling system, therefore, has been designed so that the cooling air can effectively remove the heat from the reactor vessel. The vessel is to be directly cooled by using external air and the air blower capacity should be also considered. The incoming air should be evenly contacted with outer surface of the vessel so that the air cooling can be performed as efficiently as possible. A type of air jacket has been adopted because it is easy for installation and maintenance and has been considered to be effective for external air cooling.

The designed air jacket is as shown in Fig. 1 of which performance on air flow distribution was evaluated in our previous study [2]. It was found that the designed air jacket shows uneven air flow distribution because the air flow path mostly takes the shortest path from the air inlet to air outlet. The air jacket was modified so that position of the air outlet was changed and a flow guide with spiral-shaped vane was attached on to the inner surface of the air jacket. The air flow showed improved distributions by attaching the flow guide. This study reports a performance evaluation of the vessel air cooling system with flow guide by using a computational fluid dynamics (CFD) method, where thermal effects such as heat transports, temperature of the reactor vessel, and thermal properties of the material and air are considered.

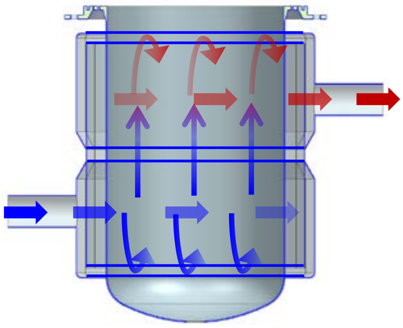

Fig. 1. Design concept of air jacket for vessel air cooling system of STELLA-2

2. Methods and Results

The domain for the performance analysis is shown in Fig. 2. The domain is composed of three solid regions, which are reactor vessel, flow guide, and air jacket, and an air region. A commercial CFD program, STAR-CCM+, was used to perform a steady-state analysis [3]. The k-epsilon turbulence model and the gravity condition were applied. For solid region domain, STAR-CCM+ polyhedral mesh method was used, whereas for the air region domain, thin layer mesh was used.

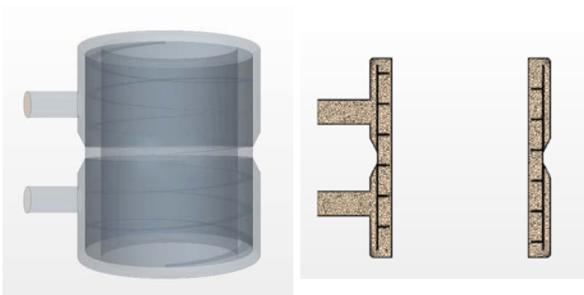

Fig. 2. Domain for the performance analysis of the vessel air cooling system (left), and mesh model of the domain (right)

Boundary conditions for the analysis are summarized in Table 1. The heat transports take place from the outer surface of the reactor vessel and air jacket, to the air inlet and outlet, which are conjugated heat transports of conduction, convection, and radiation [4]. In this evaluation, however, heat transport by radiation was not taken into account.

Table 1. Boundary conditions for the evaluation

region		boundary conditions
solid	reactor vessel	wall, adiabatic, inner surface of vessel : 550 °C (static)
	air jacket	wall, adiabatic
	flow guide	wall, adiabatic
air (fluid)	air inlet	mass flow inlet, 300 K, at 0.1 ~1.0 kg/s
	air outlet	pressure outlet
	inside air jacket	wall

Fig. 3 shows the comparison of the air flow distribution with the flow guide with that without the guide. It is apparent that the flow distribution was improved by attaching the flow guide. Fig. 4 indicates that the air temperature distribution around the outer surface of the reactor vessel shows even distribution with the flow guide.

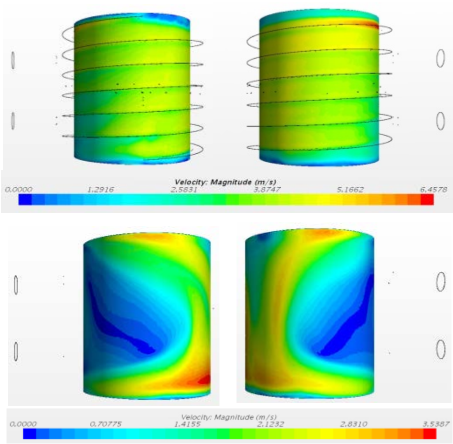

Fig. 3. Air flow distribution at 10 mm from the outer surface of the vessel (top: with flow guide, bottom:without flow guide)

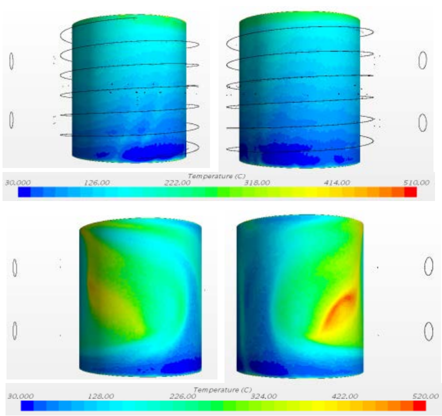

Fig. 4. Temperature distribution at 10 mm from the outer surface of the vessel (top: with flow guide, bottom: without flow guide)

Table 2 summarizes the effect of attaching the flow guide by comparisons of the velocity magnitude and distribution as well as of the heat removal. It is apparent that applying the flow guide improved the air flow distribution, therefore, heat removal performance was enhanced.

Table 2. Comparisons of flow distribution and heat removal

		Air jacket without flow guide	Air jacket with flow guide
values on 10 mm from reactor vessel surface	avg. velocity [m/s]	1.359	3.554
	standard deviation [m/s]	0.966	1.005
	uniformity	0.685	0.893
heat removal performance	Heat removal [kW]	57.02	117.89
	Air outlet temp.[K] (at 300 K of air inlet temp.)	356.57	416.72

$$standard\ deviation\ of\ \emptyset = \sqrt{\frac{\sum_f (\emptyset_f - \bar{\emptyset})^2 A_f}{\sum A_f}}$$

$$uniformity\ of\ \emptyset = 1 - \frac{\sum_f |\emptyset_f - \bar{\emptyset}| A_f}{2|\bar{\emptyset}| \sum_f A_f}$$

$\bar{\emptyset}$: surface average of $\emptyset$
$\emptyset_f$: face value of the selected scalar
A_f: $face\ area$

3. Conclusions

A vessel air cooling system of an air jacket type with flow guide was designed for STELLA-2 and its cooling performance was evaluated by using a CFD method. When thermal effects are taking into account, the air flow distribution inside the air jacket was improved by installation of the flow guide. The heat removal performance was also enhanced by the installation.

Acknowledgment

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