Design and Performance Analysis of the Vessel Air Cooling System of STELLA-2

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1. Introduction

Development of PGSFR (Prototype Generation-IV Sodium-cooled Fast Reactor) is underway as a long-term nuclear program of Korean government. STELLA-2(Sodium Test Loop for Safety Simulation and Assessment-2) program is a large-scale sodium thermal-hydraulic integral effect test program to support PGSFR [1]. STELLA-2 will evaluate the plant dynamic behavior of PGSFR transients and demonstrate decay heat removal performance [2].

A vessel air cooling system was introduced to facilitate cooling down of the reactor vessel of STELLA-2 at the major accident where the decay heat removal system (DHRS) has lost its function [2].

This study presents a design and performance evaluation of the vessel air cooling system of STELLA-2. Some requirements for the system design are first determined, and the performance of the designed system is evaluated by using a computational fluid dynamics (CFD) method.

2. Methods and Results

2.1 Design of Vessel Air Cooling System

Design requirements for the vessel air cooling system of STELLA-2 are as follows. The vessel should be directly cooled by using external air. And it should be able to cool down the outside of the vessel via the system in the event where the DHRS of STELLA-2 has lost its function.

To accomplish the design requirements, it is better for the incoming external air to be evenly contacted with the outer surface of the vessel to perform the cooling. The system is composed of air blower, air jacket, and air duct. The air blower capacity should be determined so that sufficient heat removal performance can be ensured. The air jacket should be designed to be detachable for easier installation and maintenance. A damper can be installed and closed to prevent heat loss during the test in normal condition. Appropriate protective structures can also be provided to prevent external objects or rainwater from entering the air outlet.

The design concept of the air jacket designed to reflect the above design requirements is shown in Fig. 1. In the air jacket where the air inlet and outlet are located, there is a separating plate which separates the inflowing air and the outflowing air so that the inflow air can be uniformly contacted to the outer surface of the vessel inside the jacket to the exit. The detailed shape of the separator is shown in Fig. 2.

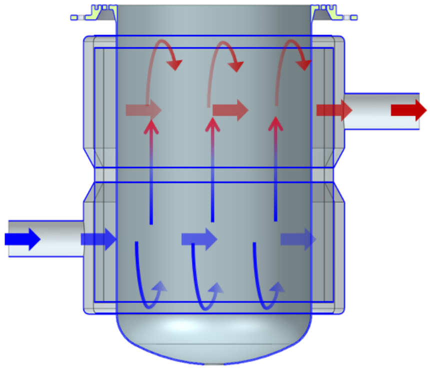

Fig. 1 Design concept of the vessel cooling system of STELLA-2

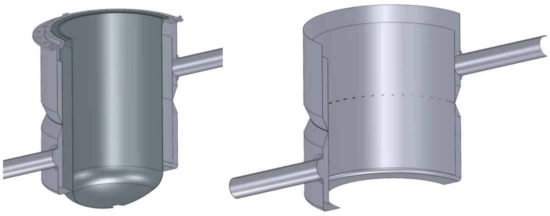

Fig. 2 Air jacket with separating plate

2.2 Performance analysis using a CFD Method

The domain for the performance analysis is shown in Fig. 3. Steady-state analysis was performed using STAR-CCM+, a commercial CFD program [3]. The k-epsilon turbulence model and the gravity condition were implemented. STAR-CCM+ polyhedral grid method was used and the total number of computational grids was about 630,000. It consists of 3 cm grid with three prism layers. Mesh model of the domain is shown in Fig. 4. The analysis was carried out with various conditions of the air inlet flow, which are 0.5, 1.0, and 2.0 kg/s.

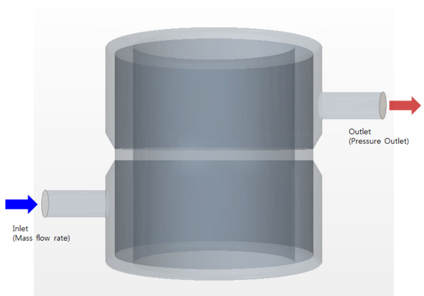

Fig. 3 Domain for performance analysis of the Vessel Air Cooling System

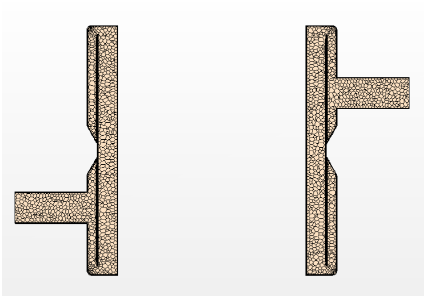

Fig. 4 Mesh model of the entire domain of Fig. 3

A virtual plane was created in the shape of a cylinder at 10 mm away from the outer surface of the vessel. The flow distribution at each flow rate on the surface is shown in Fig. 5. It can be seen that the flow at the shortest path from the inlet to the outlet is most developed in S-shape at all three cases of 0.5kg/s, 1.0kg/s, and 2.0kg/s. It has been confirmed that this design does not meet the design requirements owing to its uneven air flow distribution. Therefore, a complementary design was suggested and analyzed.

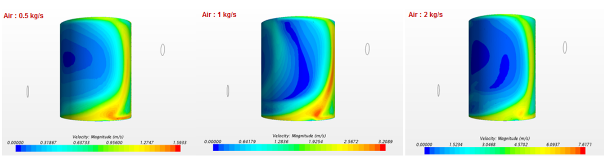

Fig. 5 Air flow distribution at 10mm from the outer surface of the vessel

2.3 Improvement on Design for Air Flow Distribution

First, considering that the flow path is most developed at the shortest path from the inlet to the outlet, direction of the air outlet was changed to the opposite direction. The flow distributions with this change are shown in Fig. 6. The air flow direction is changed and the flow distribution is slightly improved but it still shows uneven air flow distribution.

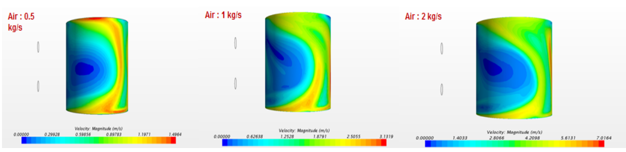

Fig. 6 Air flow distribution at 10mm from the outer surface of the vessel with the changed direction of air outlet

Additionally, flow guides of spiral-shaped vane type were installed in the air jacket for uniform flow distribution. Two types of guide were designed to cover 1/3 and full height of the surface respectively, and to be directly attached to the inner surface of the jacket as show in Fig. 7. The total numbers of computational grids for the shape were about 670,000 for to 1/3, and about 760,000 for the full height, respectively. The mesh models are shown in Fig. 8.

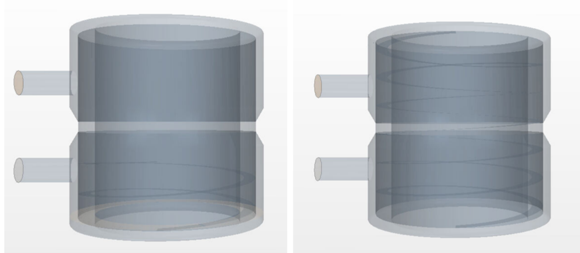

Fig. 7 Air jackets with two types of flow guide

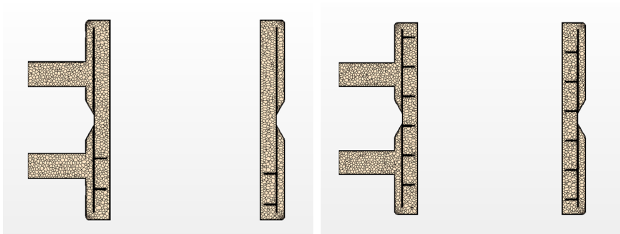

Fig. 8 Mesh models of the entire domain of Fig. 7

Air flow distributions in the air jackets in Fig. 7 were analyzed. It was found that when the vane was installed up to 1/3 of the height, the air flows along the vane, and then directly moves to the air outlet at the end of the vane. The results are shown in Fig. 9. When the vane was installed up to the full height, however, the air flows along the vane and is uniformly distributed in the entire region. The results are shown in Fig. 10.

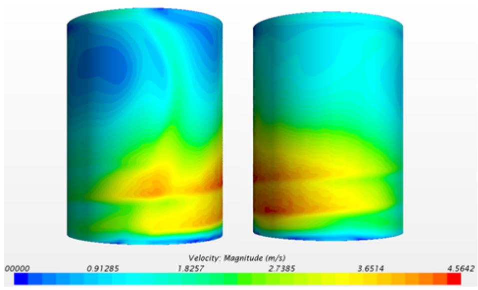

Fig. 9 Flow distribution at 10mm from the outer surface of the vessel of Fig.7 left (left: front view, right: back view)

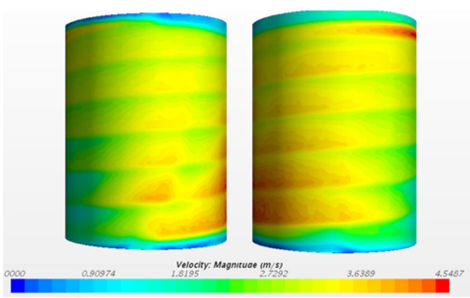

Fig. 10 Flow distribution at 10mm from the outer surface of the vessel of Fig.7 right (left: front view, right: back view)

Installing the flow guide inside the air jacket can affect the pressure drop which the air blower should overcome. The pressure is therefore analyzed and shown in Table 1. It is found that the pressure drop with the guides is not much different from that with the original design. Therefore, we confirmed that the installation of the vane does not affect the blower capacity.

Table I: Pressure drop in different shapes of air jacket

	Pressure drop (Pa)
No Vane (Original)	194
No Vane (air outlet changed)	186
Vane with 1/3 height	194
Vane with full height	205

3. Conclusions

A vessel air cooling system of STELLA-2 was designed and performance was analyzed using CFD method. Improvement on design was carried out with reference to the analysis results. The direction of the air outlet was changed and inner vane was installed. As a result, it was confirmed that the flow distribution was improved uniformly and that installation of the vane did not affect the blower capacity.

AKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP). (No. 2012M2A8A2025635)

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