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Numerical Study on the Effect of the Bottom Gap on the Wet Thermal Insulator Performance

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1. Introduction

In SMART, the wet thermal insulator (WTI) [1] is installed between the main flow path of the reactor coolant system and the pressurizer. It is constituted of stacked thin stainless steel plates. Water layers between the plates are maintained by dimples that were formed on the plates themselves. Water temperature of WTI is changed from the temperature of the pressurizer to that of the hot part of RCS.

The WTI's function is to reduce heat transfer through it, so the pressurizer heater requires less power to maintain the system pressure during normal operation. To achieve this, the layer between the plates is so narrow that the effect of convection on heat transfer is negligibly small when compares to that of conduction.

When installed horizontally, the wet thermal insulator has no problem because the temperature field formed inside is so stable that there is no convection at all. When it is installed vertically, there may be a problem at the top and bottom ends. This is because the plates are thin and the vertical length of the plates requires a margin for thermal expansion. It is difficult to make the wet thermal insulator without any gap at the top and bottom ends.

In this paper, the effect of gap on the performance of the wet thermal insulator is studied. This research was conducted by using CFD to analyze the flow field. The effect of gap will be shown as well as the allowable gap size to prevent deterioration of the wet thermal insulator performance.

2. Methods and Results

2.1 Computational Methods

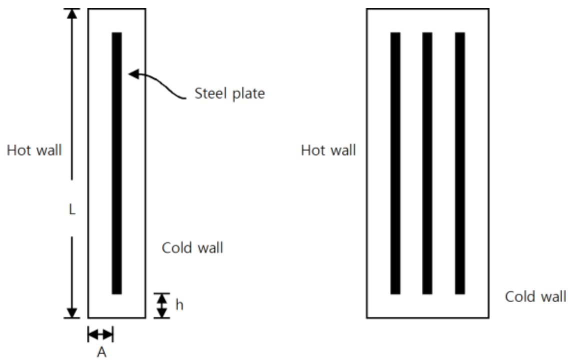
This study was conducted by using the commercial CFD program, FLUENT [2]. Solved equations were the mass, momentum, energy transport equation, and turbulence model. The SST k-ω model was chosen to account for the turbulence effect. The momentum transport equation was simplified by the Boussinesq approximation, in which the effect of density change due to temperature difference was considered only in the gravity acceleration term. Since the geometry was simple, the computation was performed using a two-dimensional approximation.

Computational domain and boundary conditions were chosen under consideration of the normal operating condition of SMART. In the SMART design, the number of WTI layers is 20 and the thickness of layer (A) is 3 times thicker than the plate. For the computation, the vertical length (L) was chosen to be 2000A. A measurement [3] showed that A has little effect on the Nusselt number for A>25. The hot wall temperature is the temperature of the pressurizer. The cold wall temperature was decided by considering the layer number in the simulation and in the SMART design. If the simulation was performed with 20 layers, the cold wall temperature will be the RCS hot part temperature. Properties of water and steel at the average temperature of both walls were used. The maximum number of grid was about 1.6 million.

2.2 Cases with gaps of the layer thickness (h=1A)

At first, the two-layer cases with and without gaps of 1A at bottom and top ends were simulated. Estimated heat transfer rate of the case with gaps was 5% higher than the other. This can be explained by the fact that flowfields of both cases are different from each other. When there was no gap, each layer works as a cavity and there was circulation in each layer. However, the flow circulated in such a way that the cold-side layer moved downward and the hot-side upward when there were gaps. Each layer worked as a single channel, so the velocity magnitude was higher and the heat transfer rate was also increased.

This phenomenon was also observed in the cases with 4 and 8 layers. As the number of layers increased, the velocity of the side layers was faster and the heat transfer was more active. The estimated heat transfer rate for 8 layers was 3.4 times higher than that of the no-



(a) Two-layer case (b) Four-layer case

Fig. 1. Computational domains.

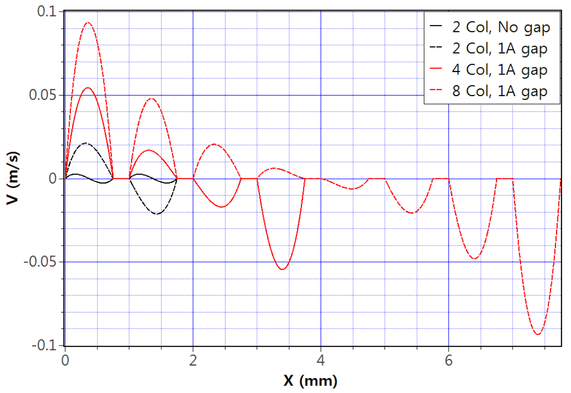


Fig. 2. Vertical velocity profile at the middle predicted with selected bottom gap sizes.

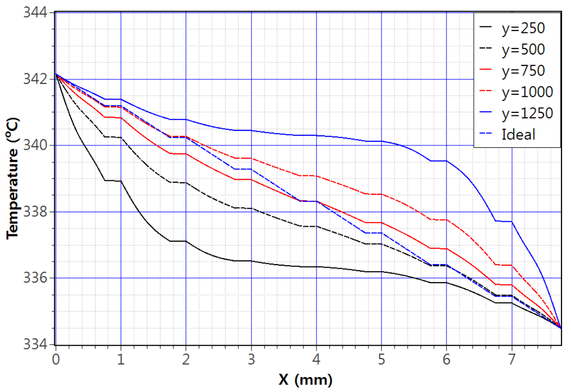


Fig. 3. Temperature profile at several heights (8 layers with top and bottom gaps of 1L).

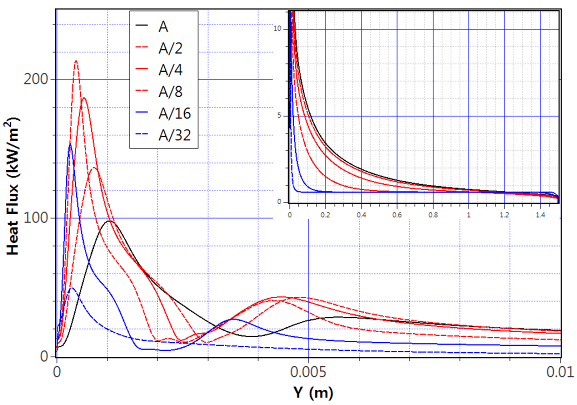


Fig. 4. Heat flux at the hot wall predicted with selected bottom gap sizes.

gap-case.

To examine the temperature variation in more detail, the temperature at several heights of the case with 8 layers was plotted in Fig. 3. The ideal temperature line indicates the expected temperature profile when there was no gap. At the lower part of the WTI, the temperature of water layers near the hot wall was increased but the temperature of other layers still remained near the cold wall temperature. As the height was increased, the flow got hotter in a wider range from the hot wall. The temperature in the layers at both sides was rapidly increased from the cold wall temperature to the hot wall temperature. This means that there was circulation through the layers at both sides and also the gaps in the WTI, and that heat transfer happens by this circulation.

2.3 How narrow should the gap be to reduce heat transfer?

After examining the previous results, a question arose; how small should the gap be to prevent this phenomenon? To get an answer, a series of simulations was conducted in a way that the gap was reduced by half. The gap at the top end, which was a thickness of 1A, remained the same throughout the simulations. Even when the gap size was reduced to A/16, the heat transfer rate was 40% higher than that of the no gap case. The case of A/32 gap, which was hardly achievable during the fabrication and installation of the WTI, the results still showed an 11% higher heat transfer rate. Most of heat transfer on the hot wall occurred at the bottom side by a flow that came from the cold wall through the gap (Fig. 4). As the gap was reduced, the heat transfer rate was reduced to what was expected in a single water layer.

3. Conclusions

The effect of end gaps on the performance of the wet thermal insulator was investigated by CFD. It was shown that even though the gap was small, it could deteriorate the performance of the wet thermal insulator. The main reason for increased heat transfer was circulation formed in water layers on the hot and cold walls and the top and bottom gaps. The flow rates in the other water layers were smaller than this.

To determine the optimal gap size to get a similar heat transfer rate to the design, which has no end gap, several gap sizes were selected and simulations were performed. The results show that it is not possible to get an intended heat transfer rate whenever a gap exists. To achieve the designed performance of the wet thermal insulator, its design at the ends should be changed to prevent global circulation through the gaps.

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