Preliminary Study on Passive Cooling of Instrumentation and Control Room Using PCMs

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1. Introduction

The role of the Passive Cooling Systems has become more significant since the Fukushima Daiichi nuclear power plant accident. Passive systems were adopted in reactor cooling, containment cooling and even Main Control Room (MCR) cooling. The Westinghouse Corporation was first in applying the MCR passive cooling. It uses the thermal mass of concrete walls to provide temperature control. Metal heat fins are installed on the concrete walls to increase the surface area. Passive cooling in near ambient temperature is possible because of the low operational power of the controls system of AP1000.

In Korea, several different passive cooling concepts have been developed. They range from heat exchanger modules to thermosyphon assemblies [1, 2, 3]. Theses PCCSs were designed to be installed inside the containment and transfer the released heat to the water pool outside the containment or to the PCM installed within the containment. However, passive cooling system for the MCR and Instrumentation & Controls (I&C) room has not been adapted in the APR1400. Direct adoption of passive cooling using concrete as heat sink is not applicable in case of APR1400 as current designs have not gone through power optimization.

In order to perform cooling in such disadvantageous conditions, Phase Change Materials (PCM) with low melting temperature must be used for heat sink instead of concrete. Operating temperature of processors is recommended to be between 18 and 27 degrees Celsius [4, 5]. Therefore, melting point of PCM must be in this range or lower.

Ice or materials with low melting temperature can also be used as a heat sink for more effective cooling. To use ice as a heat sink, the PCM cooler must be made mobile as shown in Fig. 1. The PCM cooler must be kept in a separate room below freezing point using active cooling during normal operation. If MCR and I&C room active cooling systems fail, the PCM coolers must be pushed into location by the personnel.

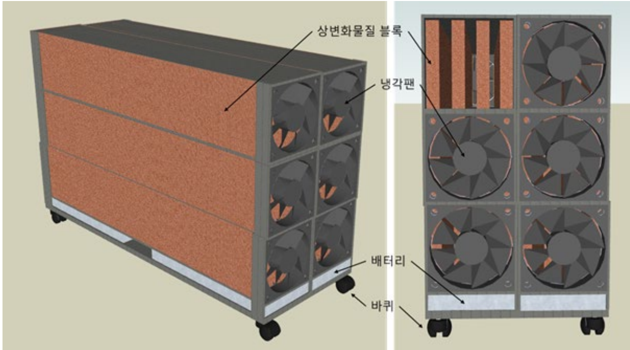

Fig. 1. Mobile PCM cooler

These systems must be operated passively or with a separate DC power supply installed on the mobile cooler. The DC power supply could power fans that could help the air circulation and cooling of the room.

This study aims to show the feasibility of PCM coolers for the I&C room cooling using CFD.

2. Methods

The reference plant of this calculation is the APR1400. In case of the AP1000, cooling capability of MCR and I&C room is provided in the Design Control Documents [6]. The MCR requires 3.928 – 12.823 Btu/sec of cooling and I&C room requires a maximum of 13.07 Btu/sec.

The Packaged Air Conditioning Unit (PACU) of APR1400 I&C room is 80 Btu/sec [5]. Therefore, our design objective is to replace the system in case of an active cooling system failure.

CFD calculation was performed using STAR CCM+ for a unit volume with the processors (heat source) on one side and PCM cooler (heat sink) on the other. Adiabatic floor and wall conditions were given as boundary. Environmental pressure boundary was given on the top. 50,000 polyhedral meshes were used to model a unit volume of 1m x 1m x 1m. K-epsilon turbulence model was used to capture the turbulent air circulation. Segregated Flow and segregated fluid temperature were used to model the flow and energy. Steady state solution was obtained

Constant volumetric heat source of 131.2kW/m^3 was given to the processors while the cooler was given -295.3kW/m^3. If we consider the volume of the heat source and sink, the net heat generated is zero, meaning all the heat generated is absorbed by the cooler. The cooler performance is one tenth of our target performance. Momentum of 100N/m^3 was given in the cooler to model the fan and help the flow.

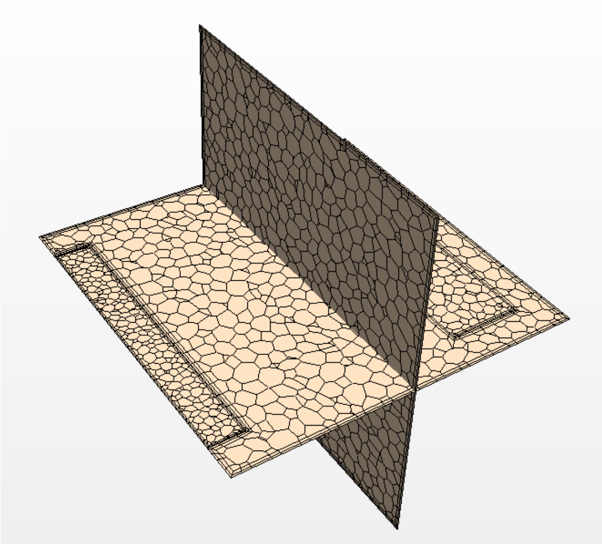

Fig. 2. Cross sectional view of mesh system

3. Results

The results show a stable flow of air circulating between the processors and PCM cooler. The temperature range and velocity range are maintained over iteration. The calculation ended when continuity, momentum, and energy residual reached 10^{-6}.

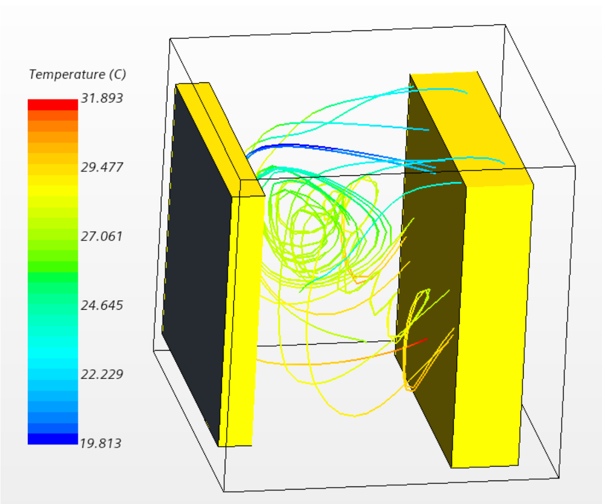

Fig. 3. Streamline of airflow from cooler(left) to server rack (right)

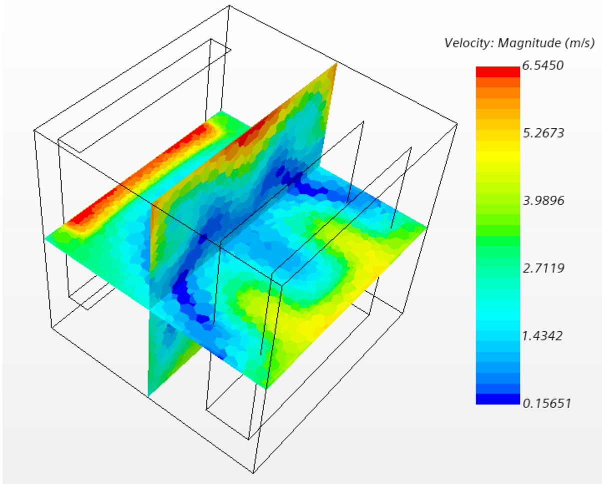

Fig. 4. Cross sectional view of velocity

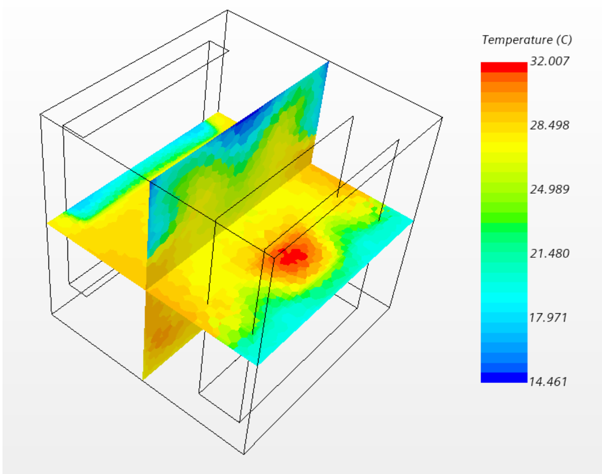

Fig. 5. Cross sectional view of temperature

4. Conclusion and Future Works

The feasibility of PCM coolers for MCR and I&C room was tested on CFD. By obtaining a stable steady state solution, we have obtained a basis for optimization in the future. Complicated heat structures must be modeled to test the feasibility of the coolers with actual geometry and heat properties.

ACKNOWLEDGEMENTS

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