PCM Heat Transfer Experiment with PureTemp58X

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1. Introduction

The role of the Passive Containment Cooling Systems (PCCSs) has become more significant since the Fukushima Daiichi nuclear power plant accident. The Westinghouse Corporation was first in applying the PCCS to a commercial nuclear power plant, AP1000 [1]. In Korea, several different PCCS concepts have been developed. They are heat exchanger modules and thermosyphon assembly [2, 3]. Theses PCCSs were designed to be installed inside the containment and transfer the released heat to the water pool outside the containment. However, the PCCS of AP1000 cannot be applied to the Korean PWRs directly. On the other hand, several limitations exist for the heat exchanger modules and thermosyphon assembly. Since they can only be installed in newly constructed nuclear power plants, it is not suitable for application in operating nuclear power plants. Also, both PCCS concepts were designed to penetrate the containment wall to connect the heat exchangers to the outside water pool. The penetration adds the risk of radioactive material release by introducing another potential pass way.

In order to simplify the PCCS design and eliminate the risk of radioactive material release, the KAIST research team proposed a new PCCS concept, a condenser using a phase change material (PCM) as shown in Fig. 1. The PCM acts as the final heat sink and absorbs the heat. The heat is transferred through the copper thermal conductor. As a simple system, this condenser does not need to penetrate the containment wall for installation. Thus, it has the potential applicability for operating PWRs and can work with other PCCSs to improve the cooling efficiency. The main target nuclear reactor is the APR1400 but it also can be applicable to many other designs.

To apply the PCM heat sink to a commercial reactor, it is crucial to understand how much and how fast heat can be removed from the system. However, most of the PCM candidates have very low thermal conductivity. To efficiently remove heat, heat fin structure is essential. This study aims to see the heat transfer performance of a certain PCM with a given heat transfer structure.

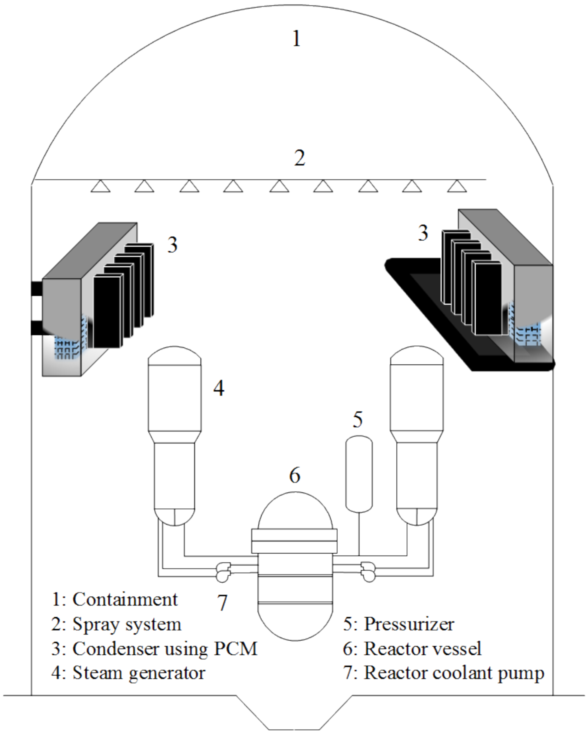

Fig. 1. Schematic diagram of the PCCS and Primary cooling system within the containment

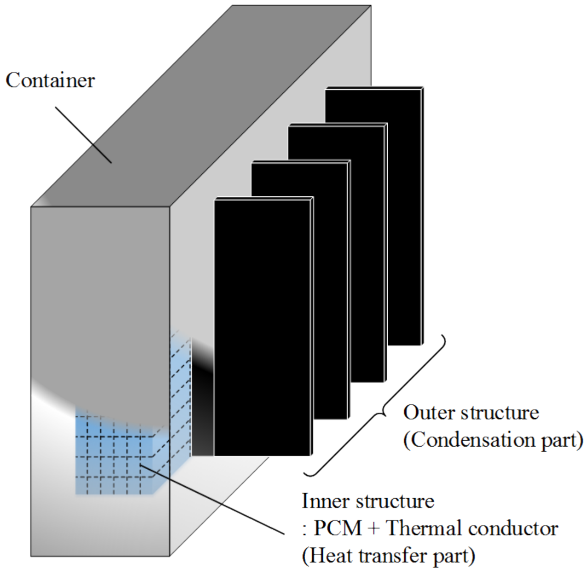

Fig. 2. Conceptual Design of PCM steam condenser module

2. Experiment Setup

Several candidate PCMs were selected for PCCS in previous works. [4] PCM product named PureTemp58X was selected for this case. As can be inferred from the name, the material melts at 58 degrees Celsius. Thus, it will stay solid in normal operation of NPP and only go through phase change in accident situations.

Steam Temperature was set to 150 degrees Celsius and pressure was maintained at saturation pressure, which is around 4.7MPa.

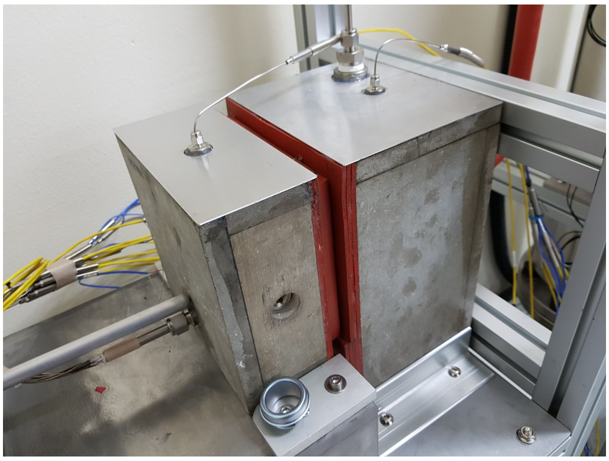

Fig. 3. Heat Exchanger with PCM chamber on the left and steam chamber on the right

The experiment starts with the PCM chamber separated from the steam chamber. Once boiling starts, the steam generator supplies steam to the steam chamber. In addition, the copper walls of the steam chamber need to be preheated to minimize heat loss to copper. Once air is removed and copper is heated, the PCM chamber is pushed in position with the thermal grease applied and the experiment starts.

3. Results

It took nearly 1000 seconds for the whole PCM volume to change from solid to liquid phase. The heat energy is supplied by the steam and it is important to maintain a steady heat input in order to see the effects on the PCM module. The steam pressure and temperature are shown in the figure below. Initially, the pressure and temperature drops because of the big temperature difference between the steam temperature and the PCM module structure. Once the copper structure absorbs the heat and reaches a certain temperature, the temperature and pressure recovers their original conditions. However, the temperature difference is only around 1 degrees Celsius and this is negligible compared to the temperature difference between the steam and PCM structure. Therefore, we may say that heat supply was stable.

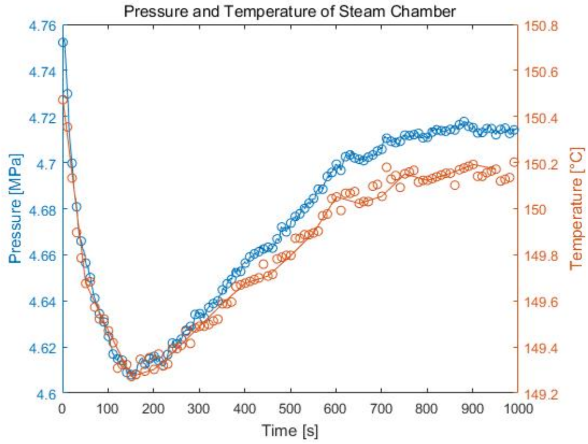

Fig. 4 Pressure and Temperature of steam

Temperautre profiles at different measure points are shown in Fig. 4. The blue dotted line shows the melting point of the PCM used. Temperature of copper heat fins increased steeply while the temperature of PCM increased slowly. Temperature of PCM near the copper fins reached melting point in around 150s while the temperature in the middle of the PCM bulk took around 400s to reach melting point. It shows that the performance of the PCM system deeply relies on the configuration of the heat fins as temperature rise is highly dependent on the distance to the copper fins.

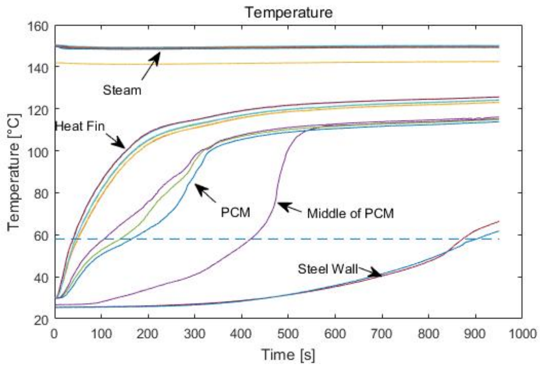

Fig. 5 Temperature Profile at different measure points

The melting point provided by the vendor is 58 degrees Celsius. However, it is difficult to see a temperature plateau near the melting point. This is probably because the product is a mixture of different compounds. However, the vendor does not disclose the chemical composition of its products. Therefore, tests must be performed in the future to confirm if this product is a mixture or not to explain the absence of temperature plateau. Additionally, the thermodynamic properties of the product must be measured over a wide temperature range.

The amount of heat absorbed by different parts of the heat transfer module is shown in Fig. 5. The average temperature of PCM bulk and PCM between the fins was used for the calculation. There is a steep increase of heat absorbed in the PCM at around 250s because this is when the temperature reaches the melting point. The latent heat is added at the given time to describe the heat absorbed during phase change. However, this sudden jump may have some distance from the reality. We will be able to calculate the amount of heat absorbed more accurately once we acquire the thermodynamic property database near the melting point.

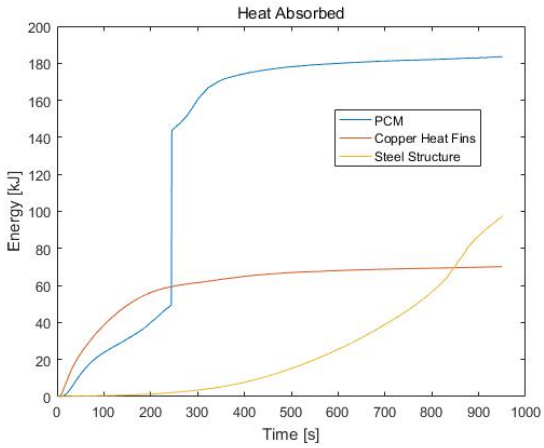

Fig. 6 Heat Absorbed by different parts of the module

By the end of the experiment, 357kJ of heat was absorbed in the PCM, copper fins, and steel walls. Half of the heat absorbed was absorbed in the copper heat fins and steel walls. The condensate was extracted after the experiment finished. The volume was measured to be around 300mL, showing around 554kJ of energy was released as steam condensed into liquid water. The difference between the energy released from steam and energy absorbed by the PCM module is due to the heat loss into the environment. Heat loss was higher than expected. Additional insulation will be installed before following experiments on this facility.

4. Conclusions

PCCS using PCM can be applied to existing nuclear power plants without containment penetration. The Steam to PCM Heat Transfer Experiment setup is planned to test the performance of the PCM in accident conditions. Various PCMs will be tested in different pressure and temperature conditions to secure database and find the optimum material or combination for future application. The facility is still under construction but we may be able to have some preliminary results to share by the conference date.

ACKNOWLEDGEMENTS

This research was supported by the KUSTAR-KAIST Institute, KAIST, Korea.

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