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Experimental Setup of Steam to PCM Heat Transfer Experiment

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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.

Each concept was designed to be applicable to a specific type of nuclear reactor. The nuclear power plant structure of AP1000 (i.e. steel containment) is different from the Korean nuclear power plants (i.e. pre-stressed concrete with inner steel liner). Thus, 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 release of the radioactive material, 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.

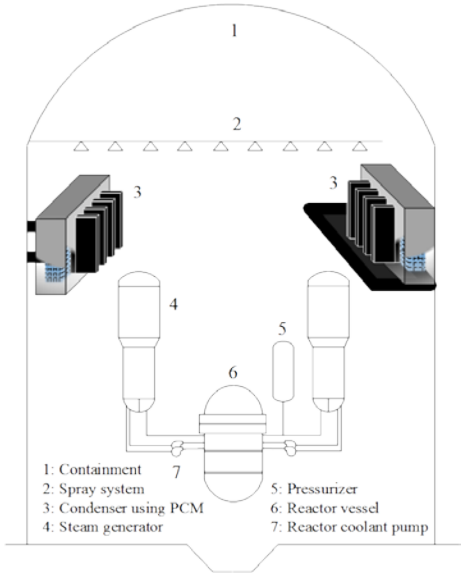

Fig. 1. Schematic diagram of the PCCS and Primary cooling system within the containment

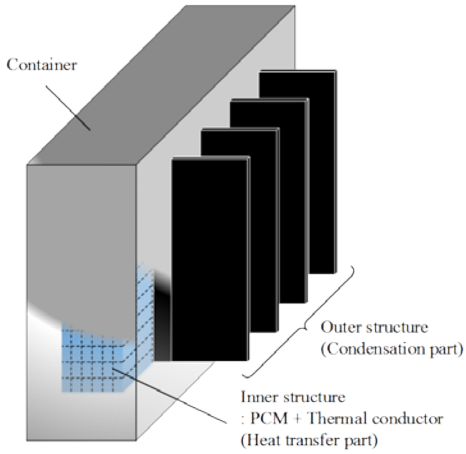

Fig. 2. Conceptual Design of PCM steam condenser module

2. Experiment Setup

Several candidate PCMs were selected for PCCS in previous works. [4] Although vendors provide thermal properties of these materials, the heat transfer phenomenon cannot be predicted exactly without experimental validation. The heat transfer effectiveness depends not only on the themodynamic condition within the containment but also on the configuration of the heat transfer module, the number of heat transfer fins, the length and thickness of fins, the composition of PCMs, etc. In addition, the PCM is not exposed to constant temperature in an accident situation. Therefore, the heat transfer from steam to PCM must be tested in various conditions.

As shown in Fig.3, the facility mainly consists of a steam supplier, steam chamber, copper heat fins, and a PCM chamber. Steam is supplied from the steam generator into the steam chamber. The steam then condenses on the copper fins as heat is transferred from the steam to the PCM through the fins. The condensed water accumulates on the bottom of the steam chamber, while the PCM melts. The experiment ends when all the PCM has successfully melted.

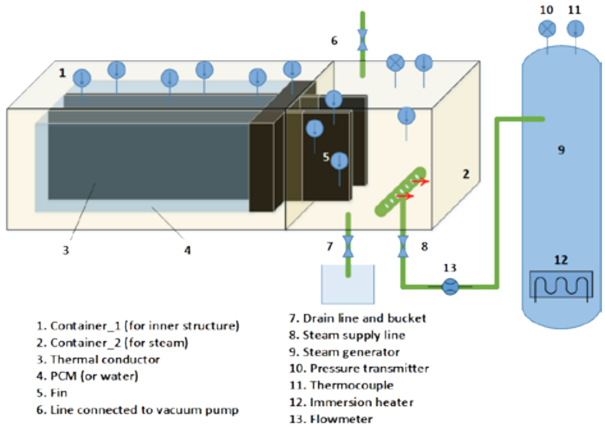

Fig. 3. Layout of facility with the heat transfer module(left) & steam supplier(right)

Fig. 4. Photo of facility setup

Temperature measured from 22 different points will help us understand the distribution of heat and can be used for the V&V process of numerical calculation in the future. The positions of thermocouples are shown as dots in Fig. 5.

The copper walls of steam chamber and PCM chamber only touch each other on one face. Notice there is a slight gap between the two walls on the edges to prevent heat transfer through the sidewalls.

The PCM chamber can be removed from the system so that many different PCMs can be tested. During an experiment, the PCM chamber is pushed towards the steam chamber using compressed air to fix it in position and maximize then heat transfer area between the two chambers. Thermal grease is applied on the copper walls to remove any gaps between the two chambers.

The whole heat transfer module is covered in insulating material to minimize heat loss to the environment.

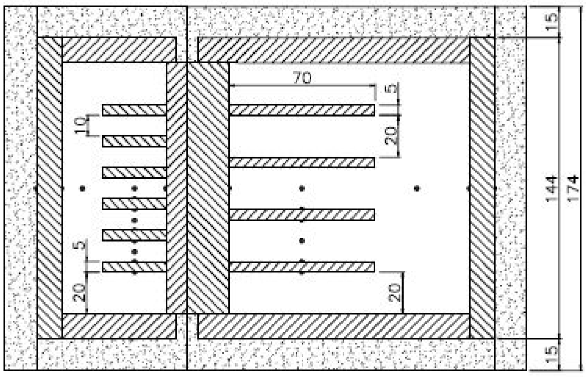

Fig. 5. Cross-sectional view of heat transfer module with the PCM chamber (left) & steam chamber (right)

Fig. 6. Close-up photo of heat transfer module with the PCM chamber (left) & steam chamber (right)

4 different types of PCM will be tested. Two organic material from PureTemp Corporation and two inorganic material from Climsel Corporation will be tested. Many more materials may be tested in the future including a combination of different materials. The code for organic materials from PureTemp are PureTemp58X and PureTemp53X, showing that their melting points are 58 and 53 degrees Celsius. The code name of inorganic materials from Climsel are C70 and C58, also meaning that their melting points are 70 degrees and 58 degrees Celsius.

The steam temperature will be 100 to 150 degrees Celsius with a 10 degrees increment. The PCM may disintegrate at high temperatures so only one test will be performed at 200 degrees Celsius. The pressure of the steam chamber will be maintained between 1 bar and 5 bar with a 1 bar increment. Although the pressure difference may not have a big effect on the test, it may affect the condensation process so it must also be checked.

The experiment will start with the PCM chamber separated from the steam chamber. Once boiling starts, the steam generator will supply steam to the steam chamber. Steam will be vented from the steam chamber until all air is removed from the chamber. Also, 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 may be pushed in position with the thermal grease applied and the experiment starts. The experiment will last around 2 hours with the given volume of PCM.

3. 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

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