PCM-based Passive containment cooling system modeling using CAP and MARS-KS

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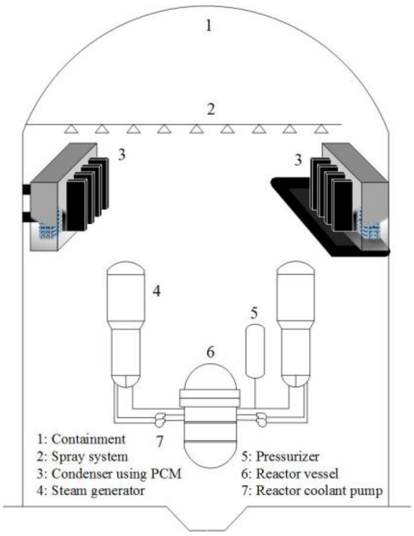
1. Introduction

The role of the Passive Containment Cooling Systems (PCCSs) has been emphasized since the Fukushima Daiichi nuclear power plant accident. In response, the KAIST research team proposed a new PCCS concept using phase change material (PCM) as shown in Fig 1 [1]. Heat transfer performance experiment was conducted by Cho [2] to apply PCM to PCCS effectively, but the performance of the PCM-based PCCS was not confirmed during DBA. In this study, PCM-based PCCS is modeled in system analysis code and confirms the modeled PCCS has a similar heat transfer pattern as in the experiment. The utilized system analysis code is CAP (nuclear containment analysis pack) version 2.21 and MARS-KS version 1.5. CAP is a transient analysis code for the analysis of thermal hydraulic behavior in the containment. PureTemp 58 was used for heat sink, as in the experiment.

(a)



(b)

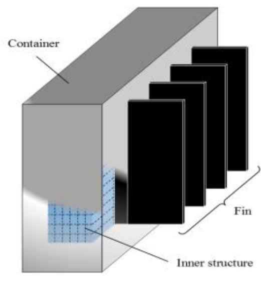


Fig. 1. Configuration of PCM-based PCCS (a) within the containment, and (b) PCM steam condenser module.

2. Methodology

Since the system analysis code is not optimized to simulate the phase change from solid to liquid, PCM-based PCCS is modeled as a heat conductor or heat structure component with heat capacity of PCM. Plate shape heat conductor is utilized, and the effect of fins installed to increase the heat transfer amount is considered by modifying heat transfer area and material properties. In order to verify that the modeled PCM-based condenser simulates the actual phenomena well, the safety analysis code simulation is performed with nodalization as shown in Fig 2.

(a)

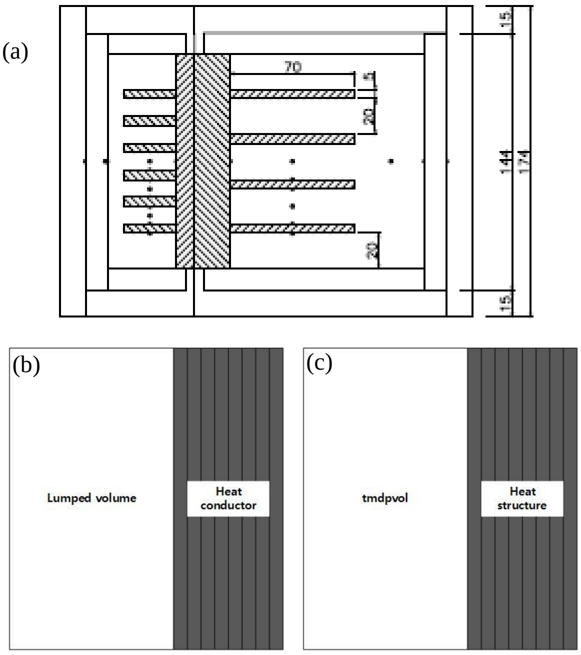


Fig. 2. Schematic of (a) experimental equipment modelled (b) in CAP, and (c) in MARS-KS.

To apply PCM-based PCCS to reactor containment building system, the results from the experiment should be scaled up and design criteria are needed. Domestic and foreign regulatory requirements and design requirements related to passive containment cooling system were first reviewed. Common regulatory requirements include keeping containment building pressure and temperature below the design criteria. In case of containment spray system of APR1400, the regulatory requirement is to reduce the pressure of reactor building to less than 50% of the peak pressure within 24 hours. The design criteria of PCS in AP1000 are that reactor building pressure reaches about 40% of the design pressure within 5 hours of the accident, and PCS water storage tank stores enough coolant to remove heat for 72 hours or more [3]. PCCS of APR+ is designed to stably remove decay heat generated after 5 minutes of reactor shutdown [4]. Based on the design or regulatory requirements described above, the design criteria of PCM-based PCCS are set as shown in Table I.

Table I. PCM-based PCCS design criteria

Criteria	Development target
Rx building overpressure protection	less than 0.52 MPa
Rx building overheating protection	less than 140 °C
amount of PCM	Enough PCM to remove decay heat generated from 5min to 24hr after shutdown.
Rx building free volume reduction rate	less than 25 %

The size of PCCS compared to the experimental equipment for the removal of decay heat from 5 minutes to 24 hours after shutdown was calculated. To evaluate the decay heat, Patterson-Schlitz''s empirical decay heat curve of ANS-5 is utilized with assumption of 3 years operation time and 4000 MWth. As a result, PCCS should be designed to contain a total of 7,580 tons or 8517 m^3 of PCM, which is approximately 3.58 million times larger than that of the experiment.

3. Results & Discussion

Fig 3 shows the wall and PCM temperature changing simulated in CAP and MARS-KS and in experimental equipment during 1000 seconds of test. It can be seen that the tendency of temperature change in both codes and experiment is similar, but the saturated temperature of heat fin is quite different. This is because the amount of condensation heat transfer predicted by the code is different. The heat transfer coefficient of MARS-KS has a value of about 3,800 W / m^2-K, while the cap code has a heat transfer coefficient of about 11 W / m^2-K. This is because MARS-KS uses Nusselt (laminar) and Shah correlations for condensation model, but CAP adopts Uchida model as the default condensation model. In this study, Tagami model is selected. In the experimental data and the results from MARS-KS, it is seen that the phase change occurs suddenly in the PCM, while the results from CAP does not reach melting point of 58 °C, so the change cannot be confirmed.

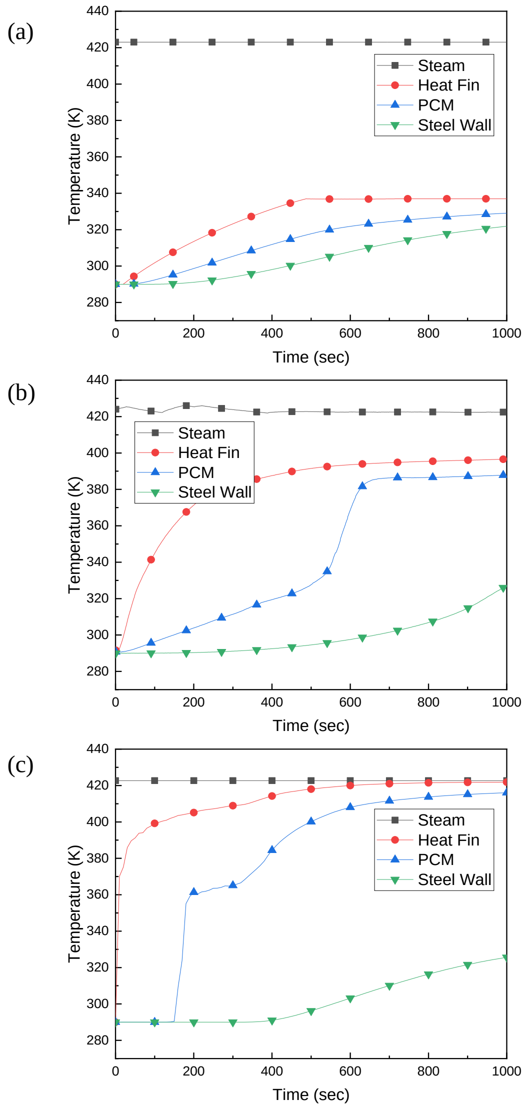


Fig. 3. Temperature from (a) CAP, (b) Experiment, and (c) MARS-KS.

4. Conclusions & Further works

KAIST research team proposed a new PCCS concept using PCM and heat transfer performance experiment was conducted but the performance of the PCM-based PCCS was not confirmed for DBA previously. In this study, PCM-based PCCS experiment is modeled in CAP and MARS-KS codes respectively. The tendency of temperature change in both codes are similar to the experiment, but they have different saturated temperature and phase change behavior. The saturated temperature is important for determining total heat removed. Therefore, factors that affect final temperature should be investigated in the future.

After PCCS is modeled in CAP with performance similar to results from MARS-KS and experimental results, the accident analysis will be performed by scaling up the PCCS to confirm how much PCCS affects accident mitigation.

ACKNOWLEDGEMENT

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