Evaluation of PCM Condenser for Containment Passive Cooling Using CAP

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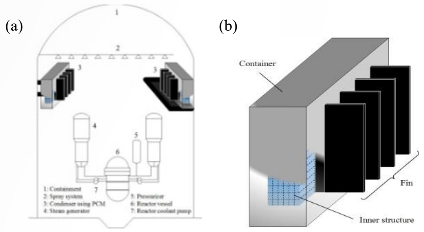
Motivation

KAIST research team proposed a new safety system concept that has the capability of passively cooling containment by using phase change material (PCM). This proposed PCM condenser has the advantage not limited to an application to existing power plants. In this study, a preliminary design is performed to evaluate whether the PCM condenser satisfies sufficient cooling performance in a hypothetical accident. Shin-Kori unit 3 is selected as a reference plant, which is one of the recently constructed and operating nuclear power plants. The performance of the PCM condenser compared to that of the existing spray system is evaluated. The accident analysis is performed with CAP (nuclear containment analysis package) code version 2.21. CAP is a lumped-parameter (LP) code developed by the Korean industrial consortium for the analysis of thermal-hydraulic behavior in the containment



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

Assumption for Accident Analysis

✓ Initial condition

Parameter		Initial value
Rx building	temperature	48.9°C
	pressure	0.1165 MPa
	relative humidity	5%
Spray system	temperature	10°C
	delay time	110sec

✓ The most severe accident is selected for the scenario, which is a double-ended discharge leg slot break (DEDLSB) with 0.9121 m² break size and maximum SIS capability
✓ Single failure of one of the two spray systems
✓ PCM-based PCCS is assumed as a solid but has a heat capacity profile with temperature simulating the latent heat

Established Design Criteria

In the previous work, the design criteria of the PCM condenser were determined as shown in Table by the case study with reactor building safety standards.

Design parameter	Design Criteria
Total volume of PCM Condenser	not exceeding 25% of free volume of containment building
Melting point of PCM	less than 78 ℃
Effective thermal conductivity	larger than 6.25 W/m-K
Heat transfer area	larger than 20,000 m²
Total amount of absorbed heat	larger than decay heat generated from 5min to 48hr (~5.2 TJ)

Design Requirements of other CCSs

Domestic and foreign design requirements related to the containment cooling system are reviewed and summarized. The performance of the PCM condenser is evaluated based on the design requirements of other containment cooling systems.

Design requirements of CCSs	APR1400	Containment Building Depressurization	reduce containment building pressure to less than 50% of the peak pressure within 24hours
	AP1000	Containment Building Depressurization	reach containment building pressure to about 40% of the design pressure within 5 hours
	AP1000	Heat Removal Capability	enough amount of energy to be able to remove decay heat generated from 5min to 72hr after shutdown.
	APR+	Heat Removal Capability	stably remove decay heat generated from 5min after shutdown.

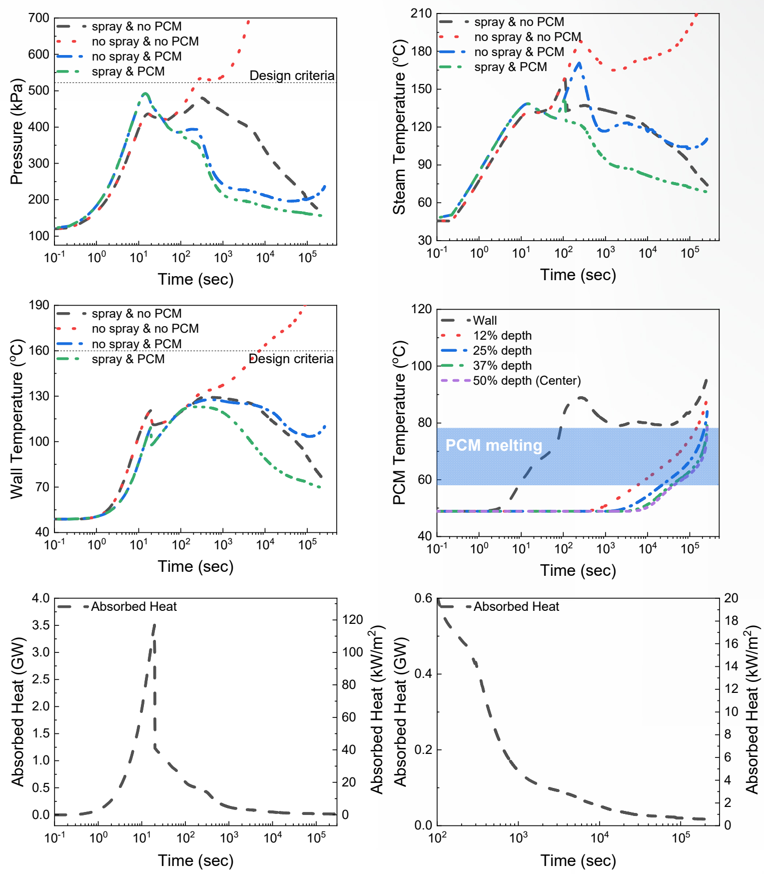
Preliminary Design and Evaluation

• **Design value of the PCM condenser**

Design parameter	Design Criteria
Total volume of PCM Condenser	25 %
Phase Change Material	PureTemp58
Effective thermal conductivity	12.5 W/m-K
Heat transfer area	20,000 m²
Total amount of absorbed heat	6.25 TJ

• **PCM condenser performance evaluation**

✓ For the DEDLSB accident scenario, safety analyses of containment building are performed for four cases, a combination of spray system single failure or total failure and with PCM condenser or without PCM condenser



• **Comparison with other CCSs**

✓ The first design requirement of the spray system in APR1400; the peak pressure is 492 kPa at 15 seconds and the pressure is 202 kPa at 24 hours after the accident when the PCM condenser is used, so the PCM condenser satisfies this requirement by reducing the pressure to 41.05% of the peak pressure within 24 hours.
✓ The second design requirement of the PCCS for AP1000; after 5 hours, the pressure of the containment building is reduced to 203 kPa, which is 39.04% of the design limit 520 kPa for APR1400, and this requirement is also satisfied.
✓ The third and fourth design requirements; PCCSs of AP1000 and APR+ include the amount of water that can absorb decay heat generated from 5 minutes to 72 hours by the water tank outside the containment building, which is the final heat sink. However, in this study, the final heat sink is the PCM condenser inside the containment building, so the total absorbed heat by the PCM condenser for 72 hours is compared with the decay heat. The decay heat released from 5 minutes to 72 hours after shutdown is 6.92 TJ, and the heat absorbed by the PCM condenser is 6.25 TJ, which removed about 90 % of the decay heat. It could not absorb a greater amount of heat than the generated decay heat. Still, considering that there is no external heat sink, it is considered to absorb a considerable amount of heat.

Conclusion

The performance of the PCM condenser, which is a new concept of containment passive safety system, was preliminarily designed and evaluated. The PCM condenser cools the containment building with a similar ability to the existing active single containment spray system, so the proposed PCM condenser can be sufficiently utilized for cooling containment passively for the operating nuclear reactor.