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Evaluation of Conceptual Heat Exchanger Design for passive containment cooling system of SMART

Min-Ki Kim *, Soon Joon Hong [a], Young In Kim [b], Seok Kim [b]
[a]*FNC Technology Co., Ltd.,32 Fl., 13 Heungdeok 1-ro, Giheung-gu, Yongin-si, Gyeonggi-do, Korea*
[b]*Korea Atomic Energy Research Institute, Daedeok-daero, Yuseong, Daejeon 305-353, S. Koreah*
**Corresponding author: manggi@fnctech.com*

1. Introduction

After Fukushima Daiichi nuclear disaster, the need for completely passive systems that can be driven to a safe state without an external power supply and operator actions has increased. Particularly, PCCS (passive containment cooling system) is the passive safety system which ultimately removes the reactor decay heat.

PCCS was initially developed to cool down the in-containment temperature by cooling water flowing through the tubes of the heat exchanger located inside of the containment. However, the current development of PCCS is divided into air-cooled PCCS and water-circulation cooling PCCS, having a heat exchanger is located out of the containment in both types.

The purpose of this study is to analyze the performance of PCCS as the ultimate heat sink based on the conceptual design. Thus, the cooling performance of both types of PCCS is evaluated using CAP.

2. CAP

The CAP (Containment Analysis Package) is a computer program used in conjunction with SPACE for the assessment of containment specific phenomena. CAP is composed of interfacial heat/mass and momentum transport models, and wall heat/mass, and momentum transport models. SPACE (Safety and Performance Analysis CodE) is used for the design of the reactor coolant system (RCS).

3. Concept of PCCS

3.1 Air-cooled PCCS

The heat exchanger of air-cooled PCCS is installed outside the containment building. Therefore, the steam inside the containment building is cooled by the external air out of the containment building. There are four redundant systems to organize the air-cooled type of PCCS, and each system consists of one heat exchanger, inlet and outlet ducts, and pipes penetrating the containment wall and connecting between the inside of the containment building and the heat exchanger on the outside. Fig.1 shows a system schematic of the air-cooled PCCS. It briefly describes the system that air from the outside flows into the heat exchanger through the inlet duct, removes heat, and flows out of the system through the outlet duct. During the heat exchanging process, the steam with hot air from the inside of the containment building is condensed in heat exchanger and formed the condensate. Then, the condensate along with cooled air is discharged into the containment building.

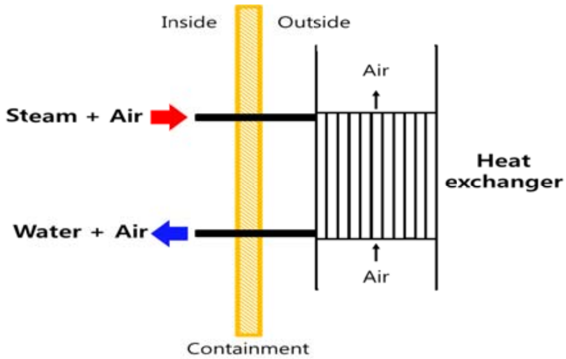

Fig.1. A schematic of air-cooled PCCS

3.2 Water-circulation cooling PCCS

Water-circulation cooling PCCS removes the heat of the in-containment building by transferring the heat to the outside through natural circulation of water in the circulating path. This type of PCCS also has four redundant systems and each system consists of a heat exchanger box inside and outside of the containment building, circulating water storage tank, chimney, and pipes penetrating the containment wall and connecting between the heat exchanger shells inside and outside of the containment building. Fig. 2 shows a system schematic of water-circulation cooling PCCS. For the heat exchanger box inside the containment building, steam with hot air flows into the tubes in the heat exchanger box. This steam is condensed by circulating water while it is passing through the tube. For the heat exchanger box outside the containment building, the external air flows into the tubes in the heat exchanger box and removes the heat from the circulating water. Then, the heated air is emitted to the outer environment through the chimney. Between the heat exchangers inside and outside the containment building, water is circulated through the pipes and transfers the heat from inside to outside of the containment building.

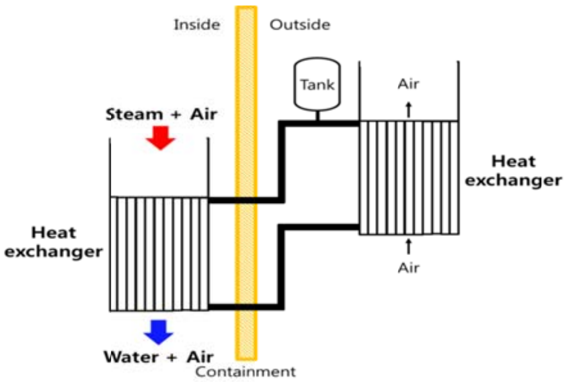

Fig.2. A schematic of water-circulation cooling PCCS

4. Setup for PCCS Performance Analysis

For the performance analysis of PCCS, the containment building was modeled to the multi-control volumes with eight-nodes and simulated. To simulate the accident situation, the mass and energy data were taken from the double-ended-guillotine-break of safety injection line with maximum safety. The external air out of the containment building was simulated by using the flow and pressure boundary models. For the air-cooled PCCS, it was installed at the dome of the containment building as shown in Fig. 3. Also, for the water-circulation cooling PCCS, it was installed in the middle of the containment building as shown in Fig.4.

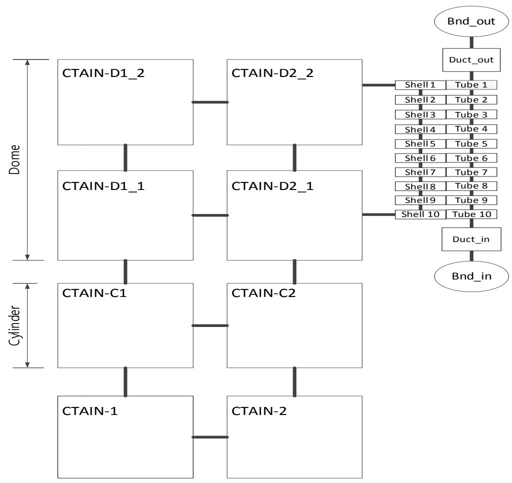

Fig.3. Nodalization of SMART with Air-cooled PCCS

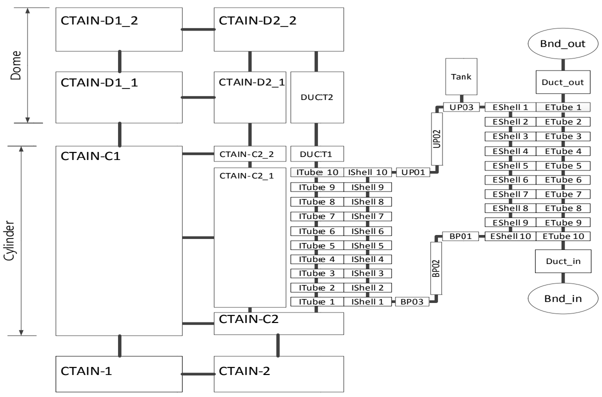

Fig.4. Nodalization of SMART with water-circulation cooling PCCS

5. Analysis for PCCS Performance

The in-containment pressure and temperature results from CAP are shown in Fig. 5 and 6. In the case of water-circulation cooling PCCS, the peak pressure and temperature in the containment were lower than the air-cooled PCCS case. It is because the heat transfer of water-circulation cooling PCCS is better than that of air-cooled PCCS. Therefore, the water-circulation cooling PCCS is applicable to lower the peak pressure and temperature in the containment building. However, the air-cooled PCCS was effective to the long-term cooling because the tube-outside condition is kept as constant.

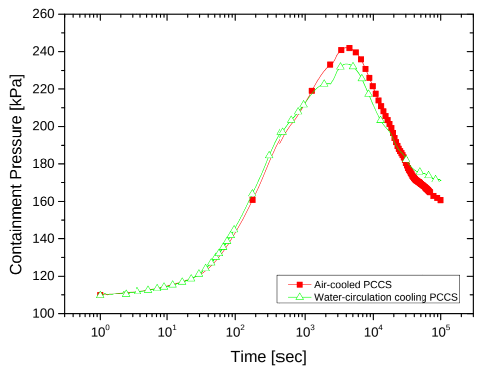

Fig.5. Analysis result for PCCS performance (Containment Pressure)

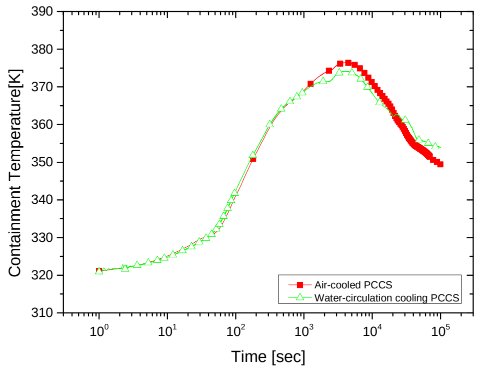

Fig.6. Analysis result for PCCS performance (Containment Temperature)

6. Conclusions

Cooling performance of the air-cooled type and water-circulation cooling type of PCCS were analyzed using CAP version 2.21. The analysis results show the water-circulation cooling PCCS is more effective in lowering the peak pressure and temperature in the containment building. However, the air-cooled PCCS is more effective to the long-term cooling.

From this study, the efficiency evaluation results for the two PCCS designs are obtained. These results may be applied in the PCCS design improvement. Moreover, these results will be used as a reference for the later PCCS design and analysis.

Acknowledgement

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