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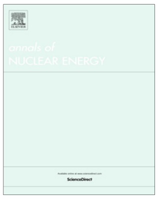

Feasibility test of the concept of long-term passive cooling system of emergency cooldown tank

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ABSTRACT

When a passive cooling system is activated in the accident of a nuclear reactor, the water in the emergency cooldown tank of that system will eventually be fully depleted by evaporation. If, however, the evaporating water could be returned to the tank through an air-cooled condensing heat exchanger mounted on top of the tank, the passive cooling system could provide cooling for an extended period. This feasibility of new concept of long-term passive cooling with an emergency cooldown tank was tested by performing an energy balance test with a scaled-down experimental setup. As a result, it was determined that a naturally circulating steam flow can be used to refill the tank. For an air-cooled heat exchanger, the cooling capacity and air-side natural convective heat transfer coefficient were obtained to be 37% of the heat load and between 9 and 10.2 $W/m^2/K$ depending on the heat load, respectively. Moreover, it was clearly verified that the water level in the emergency cooldown tank could be maintained over the long-term operation of the passive cooling system.

1. Introduction

Recently, passive cooling systems have been assigned great importance given their contribution to the safety of nuclear power plants. In the event of a “loss of coolant accident” (LOCA) and a non-LOCA in the primary system of a nuclear reactor, the secondary passive cooling system would be activated to cool the steam in a condensing heat exchanger that is immersed in an emergency cooldown tank. Currently, the capacities of these emergency cooldown tanks are designed to be sufficient to remove the sensible and residual heat from the reactor coolant system for 72 h after the occurrence of an accident. After the operation of a conventional passive cooling system for an extended period, however, the water level falls as a result of the evaporation from the emergency cooldown tank, as steam is emitted from the open top of the tank. Therefore, the tank should be refilled regularly from an auxiliary water supply system when the system is used for more than 72 h. Otherwise, the system would fail to dissipate heat from the condensing heat exchanger due to the loss of the cooling water. Ultimately, the functionality of the passive cooling system would be seriously compromised. As a passive means of overcoming the water depletion in the tank, Kim et al. (2013) applied for a Korean patent covering the concept of a long-term passive cooling system for an emergency cooldown tank. The basic idea behind this concept involves the installation of an air-cooled condensing heat exchanger on the top of the emergency cooldown tank so that the water level can be maintained by collecting the steam from the tank, as shown in Fig. 1. Although Fig. 1 shows the helical coil tubes within an air chimney, the authors suggested that the tube may have at least a part formed in a combined shape of a curved tube and a straight tube or in a helical shape so as to ensure a sufficient heat-exchange area with the air. As compared with the cooling efficiency of the heat exchanger formed in the straight tube, forming a complicated flow line may allow more chances for heat exchange with the air. However, the helical pipe is difficult to be manufactured, so the shape of the heat exchanger may be selectively chosen for convenience. An optimization process including array and configuration of heat exchanger remains for the future work. On the other hand, the authors calculated the actual sizing of an air-cooled condensing heat exchanger of passive residual heat removal system (PRHRS) in the system-integrated modular advanced reactor (SMART). For reference, the maximum height of four heat exchangers is 7.3 m and 3600 tubes with a diameter of 10 mm would be sufficient to cool a 1.8 MW heat load (0.45 MW per each heat exchanger).

Recently, there have been a number of research efforts that have studied a condensation heat exchanger, accident analyses,

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Nomenclature

A	area [m^2]
D	tube diameter [m]
Gr	Grashof number
h	heat transfer coefficient [W/m^2/K]
i	enthalpy [J/kg]
L	tube length [m]
$\dot{m}$	mass flow rate [kg/s]
N	number of tubes
$\dot{Q}$	heat load [W]
Pr	Prandtl number
Ra	Rayleigh number
T	temperature [°C]

Subscripts

∞	ambient
cond	condensation
cal	calculation
exp	experiment
in	inlet header
nc	natural convection
out	outlet header
s	tube surface

performance tests, etc. for a passive cooling system. Park et al. (2008) investigated the natural circulation characteristics of the PRHRS following a safety-related event in SMART of the Korea Atomic Energy Research Institute (KAERI). Wang et al. (2014) investigated the core residual heat removal capability of the PRHRS by using Relap5/MOD3.4. Min et al. (2014) verified the integrity and performance of the PRHRS design in the steady-state condition by investigating the characteristics of the natural circulation and heat transfer characteristics of the PRHRS heat exchanger and emergency cooldown tank (ECT). In addition to those mentioned above, there have been a number of articles that have emphasized the importance of the secondary passive cooling system to the safety of a nuclear plant. However, none of these previously published papers have been dedicated to the long-term operation of a passive cooling system for an emergency cooldown tank, which would enable the ongoing operation of the system, without having to replenish the water in the tank.

In this study, the feasibility of the concept of the long-term passive cooling system for an emergency cooldown tank as patented by Kim et al. (2013) was tested by experiment. Energy balance experiments were conducted to measure the condensing flow rate of the naturally circulating steam and monitor the water level in an emergency cooldown tank in a scaled-down experimental setup. In addition, the cooling capacity and natural convective heat transfer around a vertical-type air-cooled condensing heat exchanger were evaluated.

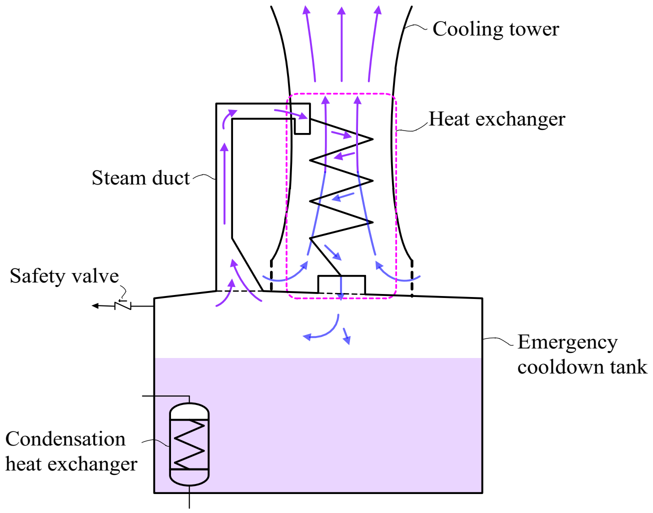

Fig. 1. Schematic of long-term passive cooling system for emergency cooldown tank (Kim et al., 2013).

2. Experiments

2.1. Experimental setup

Experiments were conducted to examine the passive cooling system of an emergency cooldown tank to test the feasibility of the concept of long-term passive cooling, that is, naturally circulating steam and the maintenance of the water level in the emergency cooldown tank. Min et al. (2014) reported a 1/1310-volume scaled PRHRS test facility based on the design features of SMART. Since they reported the scaled volume of the emergency cooldown tank is 0.43 m^3, we assumed that the actual design volume of the

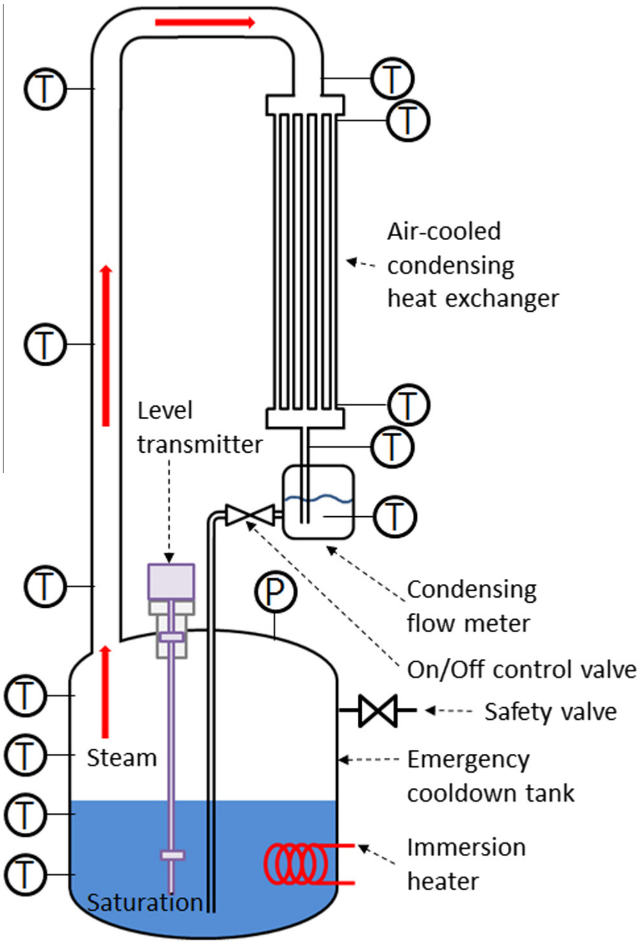

Fig. 2. System diagram of experimental setup.