Experimental Test of the Concept of Long-term Passive Cooling System of Emergency Cooling Tank

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1. Introduction

Recently emergency cooling tank is a great concern of passive cooling system for the safety of nuclear reactor. When an accident occurs in nuclear reactor, passive cooling system is operated to cool down a huge amount of steam by naturally circulating water in condensation heat exchanger which is immersed into emergency cooling tank as shown in Fig. 1 [1]. For the long-term operation of secondary passive cooling system, however, water level goes down by evaporation in succession at emergency cooling tank. At the end there would be no place to dissipate heat from condensation heat exchanger due to exhausted water supply. Therefore, steam cooling heat exchanger is put on the top of emergency cooling tank to maintain appropriate water level by collecting evaporating steam. Steam cooling heat exchanger is installed inside an air chimney and evaporated steam is cooled down by air natural convection at tubes of the steam cooling heat exchanger.

In this study, an experimental setup was figure out by measuring water level inside emergency cooling tank for the validation of the concept of long-term passive cooling system of emergency cooling tank.

2. Methods and Experiments

2.1 Experimental setup

Figure 2 shows an experimental setup for air natural convective passive cooling system of emergency cooling tank. A volumetric capacity of water tank, which is an emergency cooling tank, is 200 liter. The emergency cooling tank was manufactured by using SUS 304L plate to 4 mm thick. 2″ inner diameter pipe was adopted for the evaporating steam path on the top of the emergency cooling tank. A level transmitter and gauge pressure transducer (OMEGA PX01C1-015GV) were mounted on the top lid of the tank. A safety valve, which maintains pressure by the maximum of 1.5 atm, was located at the side of the very top of emergency cooling tank. An immersion heater (~ 5 kW, OMEGA VTS-3200/240) was mounted at the tank to supply heat into water to simulate condensation heat exchanger of passive cooling system. A programmable AC power supply was connected to the heater. Four of type T sheathed thermocouples were placed at the side of the

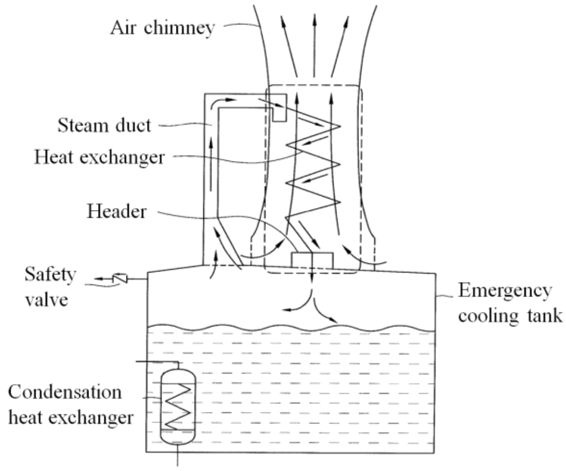


Fig. 1. Schematic of air natural convective cooling system of emergency cooling tank.

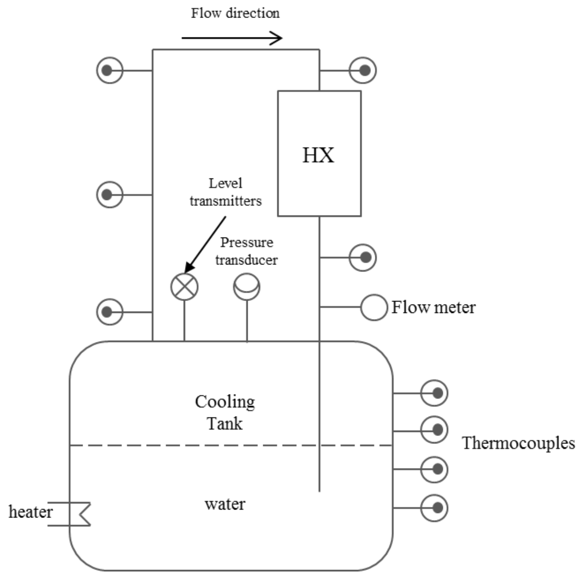


Fig. 2. Schematic diagram of the experimental setup.

tank. Five more of type T sheathed thermocouples were places at the side of the 2″ I.D. pipe to measure the steam temperature and enthalpy of both inlet and outlet of the steam cooling heat exchanger.

Conventional flow meter (orifice, vortex, rotameter, etc.) is not appropriate to measure very small flow rate of the condensing flow in the steam cooling heat exchanger due to its large loss coefficient. Moreover, its large coefficient may prevent the naturally circulating steam flow in the 2″ I.D. pipe. Therefore, a new conceptual device of a flow meter without loss coefficient was designed in this experiment. A chamber, which is a volumetric capacity of 525 mL, was manufactured with mounting a water level transmitter and an on-off valve. When the collected condensing water level reaches to the top of the chamber, the on-off valve is open and then the collected water drains into the emergency cooling tank. After finishing draining water, the on-off valve is closed and the valve opening time is recorded. To prevent pressurizing inside chamber, a tube was installed on the top of the chamber due to bypassing the evaporating steam which was not totally cooled down in the steam cooling heat exchanger.

The data acquisition system is a National Instrument cDAQ-9178 eight slot chassis with NI9203 analog current input module that acquires 200 kS/s for both the water level transmitter and condensing water flow rate, NI9205 analog voltage input module for the pressure transducer and NI9219 12 channels isolated universal AI module for temperature measurement. The measurement frequency was set to 1 Hz for this experiment.

2.2 Experimental procedure

100 liter of water was put into the emergency cooling tank. The safety valve was set to the maximum of 1.1 atm system pressure. Two heating conditions, 1.3 and 1.5 kW, were examined in this experiment. Once the water starts to boil and then generate the water steam after turning on the AC power supply, we let the water steam and air which coexists inside the tank initially get out the tank by opening a valve for the purpose of degassing to avoid noncondensable gas effect. After enough time goes on, the passive cooling system is closed. Finally, the water level was monitored at the steady state.

Heat loss was 64 ~ 70% in this experiment although multilayer insulation materials wrapped around the system shown in Table 1 by energy balance experiment.

Table I: Energy balance test at both 1.3 and 1.5 kW heat load

Heater Power (kW)	1.3	1.5
Pressure (kPa)	101.43	101.43
Water level (mA)	7.65	7.57
Temperature of HX inlet (°C)	99.0	99.0
Temperature of HX outlet (°C)	46.4	65.2
HX cooling heat (W)	0.457	0.452
Heat loss (%)	64.8	69.8

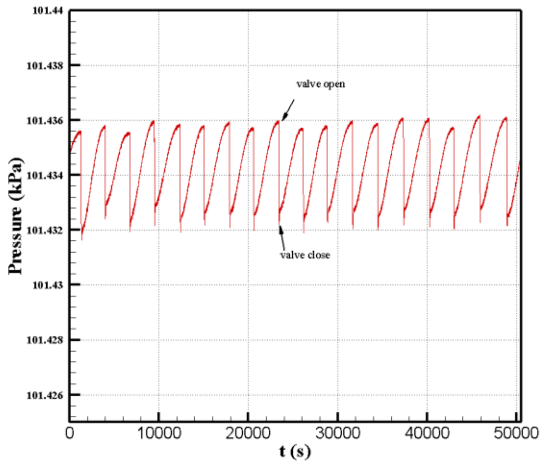
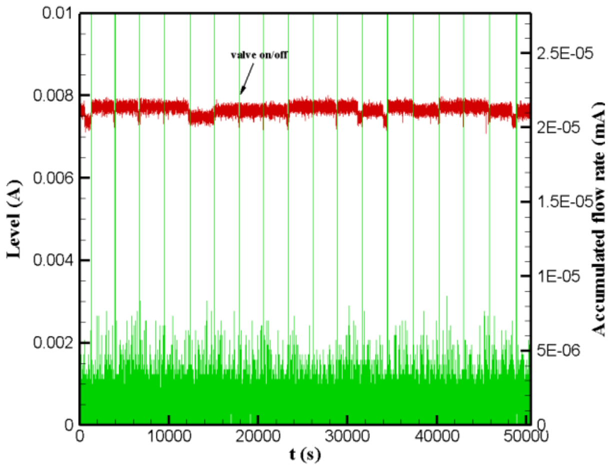
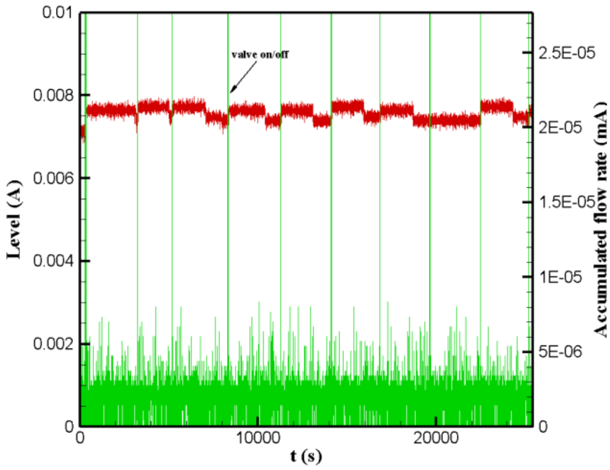


Fig. 3. Pressure variation at 1.3 kW heat load.



(a) 1.3 kW

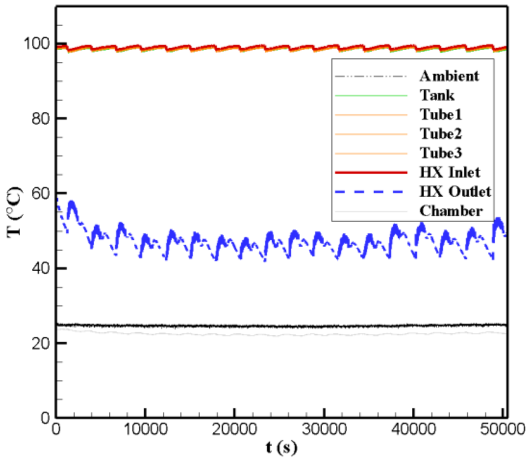


(b) 1.5 kW

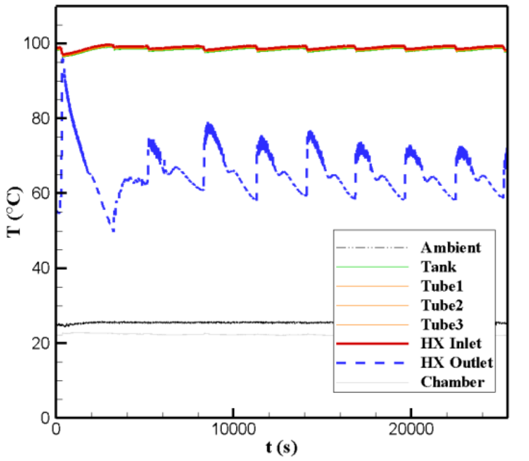
Fig. 4. Water level in the emergency cooling tank and accumulated flow rate at two different heat loads.

3. Results

Figure 3 shows system pressure measurement at 1.3 kW heat load. The pressure is fluctuated due to water drain from the flow meter chamber. The system pressure



(a) 1.3 kW



(b) 1.5 kW

Fig. 5. Temperature measurement at two different heat loads.

was averaged for one cycle of the collected condensing steam water in the chamber. Figure 4 shows water level measurement (red color line) in the emergency cooling tank corresponding to left y-axis and on-off valve signal (green color line) for the flow meter device corresponding to right y-axis at both 1.3 and 1.5 kW heat load. The on-off valve is designed to open at the current signal over 0.02 mA in this experiment. The volumetric capacity of 525 mL chamber is divided by the time between two peaks over 0.02 mA to measure condensing flow rate. At the steady state, the condensing flow rate is 0.181 g/s and 0.194 g/s for 1.3 and 1.5 kW heat load, respectively. After monitoring water level in the emergency cooling tank for 12 hours, the water level is not severely reduced by refilling the collected condensing water in Fig. 4.

Figure 5 shows temperature measurement inside the tank and pipe at both 1.3 and 1.5 kW heat load. It is identified that the passive cooling system is a steady state. The amount of cool-down heat was obtained by condensing flow rate and enthalpy difference at both inlet and outlet temperature of the steam cooling heat exchanger.

4. Conclusions

An experimental setup was figure out by measuring water level inside emergency cooling tank for the validation of the concept of long-term passive cooling system of emergency cooling tank. Natural circulation of condensing flow was identified by passive cooling system of emergency cooling tank experimentally. Moreover, the water level is not changed a lot by refilling the collected condensing water into the emergency cooling tank although the passive cooling system operates for long-term duration in this experiment.

ACKNOWLEDGEMENT

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