Experimental Study on Secondary Passive Residual Heat Removal System

Haiyan Xu, Xiaohang Wu, Qinglong Wen, Donghua Lu and Liangguo Li

Abstract The secondary passive residual heat removal system, which is one of several passive safety systems, is designed to enhance the safety of the reactor core. Experiments on transient and steady state natural circulation performance of the secondary passive residual heat removal system had been performed by using the high temperature, high pressure, and thermal–hydraulic test facility (natural circulation test loop of FITY, CGN). The experiment results showed that the residual heat can be removed successfully from the steam generator to atmosphere by steady state and transient natural circulation in test facility, and the heat transfer capability gets stronger with the increase of loop pressure. The result also shows natural circulation can be set up with good stability.

Keywords Passive · Residual heat removal · Experimental study

1 Introduction

As we know, nuclear safety is the most important issue in the nuclear industries, especially after the Fukushima nuclear accident. In most of the existing second-generation and second-generation plus nuclear power plants, residual heat is usually removed by active system to ensure the safety of the reactor core. However, in case of a station blackout accident, active system based on electrical supply is off, the core will be melt down. The advanced secondary passive residual heat removal system (ASP) is designed to solve this problem and then improve the integrated safety. ASP system, which has a simple structure, can set up natural circulation in the loop and remove the residual heat to the atmosphere in 72 h without human operation and power supply.

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To ensure the reactor core safety, the ASP system needs to remove the residual heat from the system in a stable and continuous way. Xiong [1] and Zhou [2] studied the start-up characteristic and influence factor of secondary passive residual heat removal system with RELAP5/MOD3.3. Yan [3] calculated the transient characteristics of the secondary passive residual heat removal system under station blackout accident condition with RELAP5/MOD3.2 and investigated the factor influence the capability of natural circulation. Zhang [4] and Chen [5] studied the characteristic of flow in the secondary passive residual heat removal system of CPR1000. Chen [6] conducted experimental study on secondary passive residual heat removal system of AC600, Hyun-sik Park [7] investigated influence of open time and water capability on SMART test facility, Xi [8] designed test facility based on secondary passive residual heat removal system of HPR1000 and conducted experimental study on 72 h natural circulation test.

An experimental facility was built to study the advanced secondary passive residual heat removal system and characteristics of start-up and heat transfer were obtained.

2 Test Facility

The tests were carried out in the high-pressure and high-temperature steam water two-phase flow test loop, named Secondary Passive Residual Heat Removal system Test facility, SPRHRTY). The SPRHRTY was designed according to H2TS scaling method. Scaling ratio of the test facility is shown in Table 1.

The schematic diagram of the test facility is shown in Fig. 1.

The test facility represents the primary and secondary side of reactor. The major components of the test facility are as follows: the steam generator, C-type condenser, core simulator, high-pressure canned motor pump, pressurizer, water storage tank, valve, and associated piping. Test part includes the following: the C-type condenser, steam generator, riser, and down-comer of the secondary passive residual heat removal system. Deionized water was used as the flowing media.

Primary side of test facility was designed with a maximum pressure of 17.2 MPa and a maximum temperature of 360 °C, while secondary side was designed with a maximum pressure of 9.0 MPa and a maximum temperature of 310 °C.

The 1.0 MW capability heater was mounted in the core simulator to simulate the variation of decay heat. High-precision N-type and T-type thermocouples were used

Table 1 Simulation scaling of test facility

Parameter	Scaling ratio
Height	1:4
Pressure, temperature	1:1
Time	1:2
Volume	1:207
Power	1:104

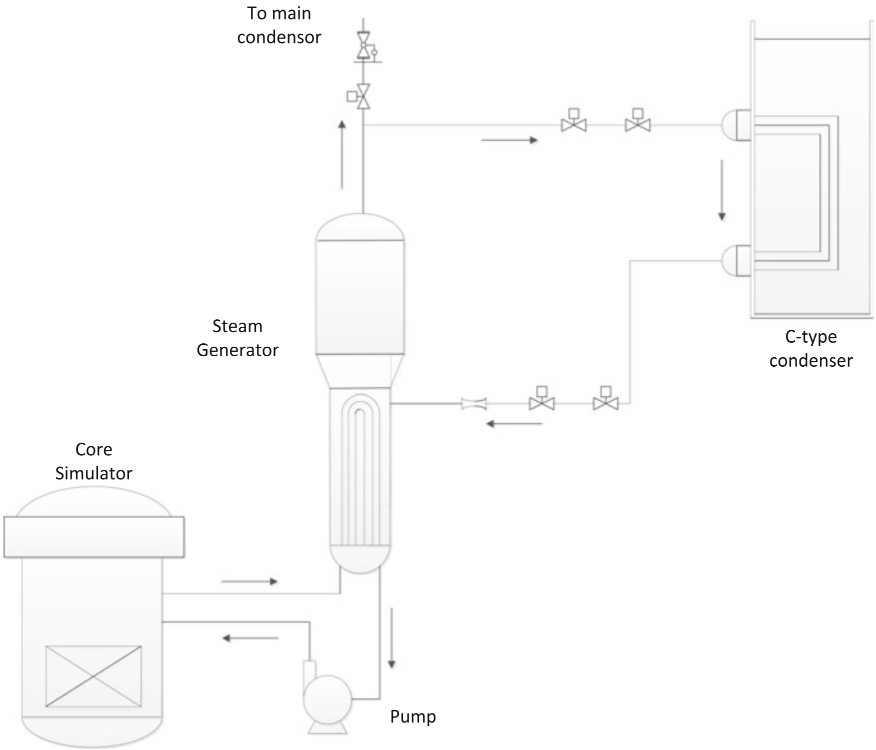

Fig. 1 Schematic of test facility

to measure the temperature of flow and tank, and the measurement accuracy was ±0.25 °C. Differential pressure sensors and pressure sensors with an accuracy of 0.065% at full scale were used to measure the pressure. The flow rate was measured using a venture flowmeter with an accuracy of 0.5% at full scale. A comprehensive measurement and control system was built to record all the measurement data and control instrument using an industrial computer.

The instruments and pipeline were wrapped by the polythene insulating material to reduce the heat loss of the experiment system.

3 Test Matrix and Test Procedure

3.1 Test Matrix

In this paper, steady state heat transfer test and transient natural circulation test were conducted. The test matrix is shown in Tables 2 and 3.

Table 2 Transient natural circulation test conditions

Pressure of SG (MPa)	8.6
Temperature of C-type cooling water pool (°C)	Room temperature
Water level of SG (%)	20%
Open time of inlet valve(s)	10
Interval (s)	5
Open time of outlet valve(s)	10

Table 3 Steady heat transfer test matrix

Case	Pressure of SG (MPa)	Temperature of C-type cooling water pool (°C)
C1-1	1.5	Room temperature
C1-2	1.5	60
C1-3	1.5	100
C1-4	3	Room temperature
C1-5	3	60
C1-6	3	100
C1-7	6	Room temperature
C1-8	6	60
C1-9	6	100
C1-10	8	Room temperature
C1-11	8	60
C1-12	8	100

3.2 *Test Procedure*

The non-condensable gases were excluded from the whole loop and instruments before the start-up. Then the power of electrical heater was increased and the pump keeps on working to transfer the heat from primary side to secondary side. Then the test loop was adjusted to the test temperature and pressure.

During the transient test process, the valves open following the order reset by measurement data and control system, the ASP start operation. The steam was discharged into the C-type condenser, which was flooded in the pool, and then the condensed water flowed back to the steam generator. Natural circulation was built automatically, and the data was collected and saved.

During the steady test process, the heater in primary loop was maintained at steady state. The test section kept the same water capability and the same valve position. The water level in the C-type heater cooling water pool kept higher than tubes, while water temperature kept steady. The power of electrical heater was changed until the pressure and temperature met requirement, and data was collected and saved.

4 Results and Discussion

4.1 Transient Natural Circulation

Figures 2 and 3 show that mass flow rate of natural circulation and pressure varies with time. It is obviously that as the riser valve is open, pressure of C-type heat exchanger region increases rapidly and keep the same as that in steam generator. After 5 s, the down-comer valve opens, mass flow increase rapidly and became reduce shortly, while pressure started reduces. At the initial state, the down-comer pipe was full of water, when valve is open, water flows into the steam generator, so water level of down-comer drops while water level in steam generator rises (Fig. 4), respectively, the force that drives water flow became smaller and smaller. Meanwhile, steam in the steam generator was injected into heat transfer pipes, intensive condensation happens. Large quality of condensed water fall into the down-comer, and then wave crest happened, making continuous natural circulation. The flow rate and pressure of steady state natural circulation depends on electrical power, so finally flow became stable.

4.2 Steady State Natural Circulation

The variations at the heat transfer capability of C-type heat exchanger vs the pressure under four different C-type water pool temperatures are shown in Fig. 5. Similarly mass flowrate vs the pressure under four different C-type water pool

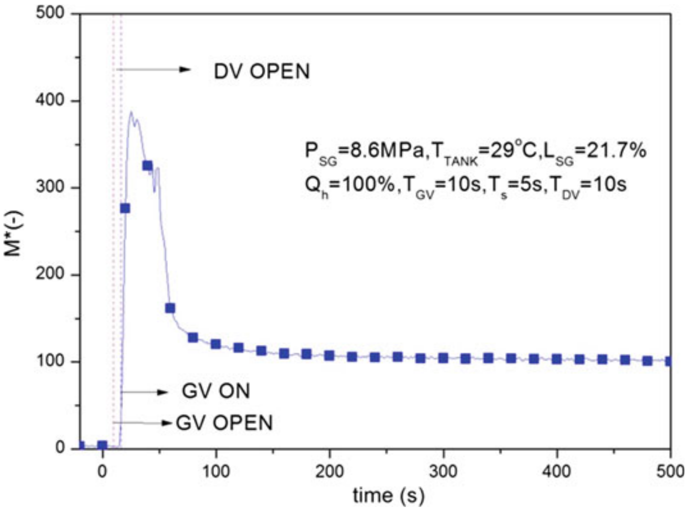

Fig. 2 Mass flow of natural circulation in system start-up experiment

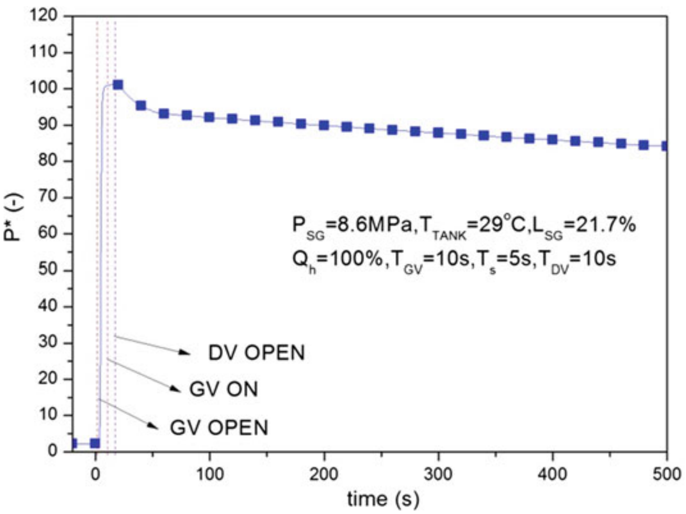

Fig. 3 Variation of pressure in start-up experiment

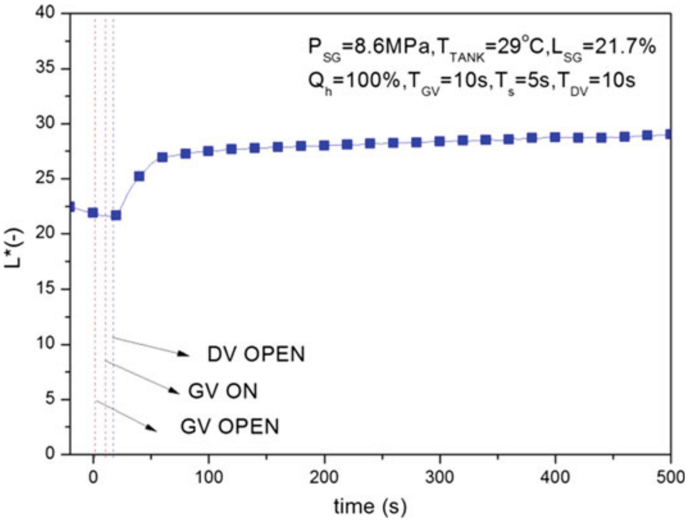

Fig. 4 Variation of SG water level in start-up experiment

temperatures are shown in Fig. 6. Under the same water pool temperature, the heat transfer capability and mass flow rate increased as the pressure increased, indicating that the pressure affects the heat transfer capability and mass flow rate significantly. In addition, at the same pressure, the heat transfer capability increased as the water pool temperature increased, while the mass flow rate increased as the temperature increased to 1.5 MPa, but similar with that at higher temperature. Compare to

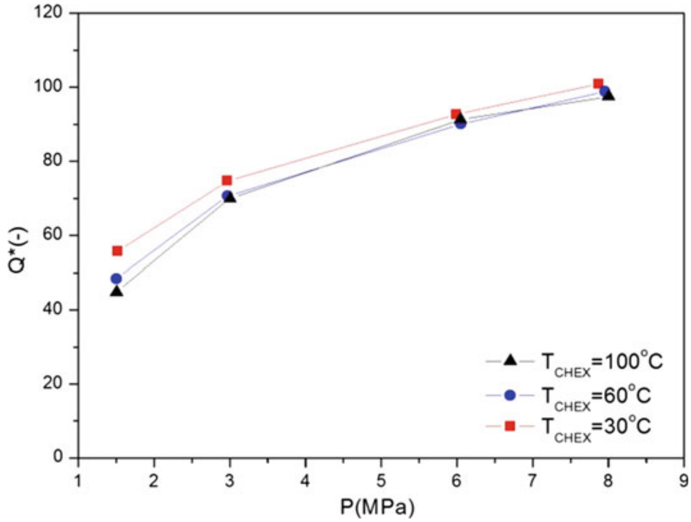

Fig. 5 Heat transfer capability in steady state experiment

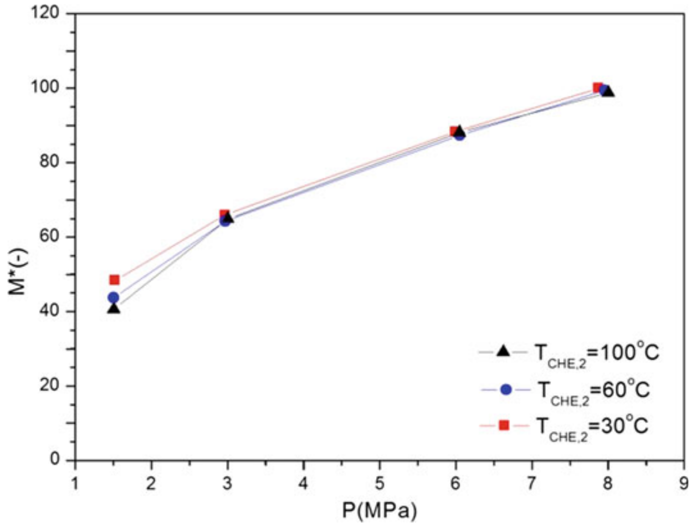

Fig. 6 Mass flow rate of natural circulation in steady state experiment

temperature of water pool, pressure has large impact on the natural circulation more significantly.

Figure 7 shows that the variation at the heat transfer coefficient vs the increasing pressure under four different C-type water pool temperatures. The heat transfer coefficient increased with pressure, when pressure is higher than 3 MPa, the heat

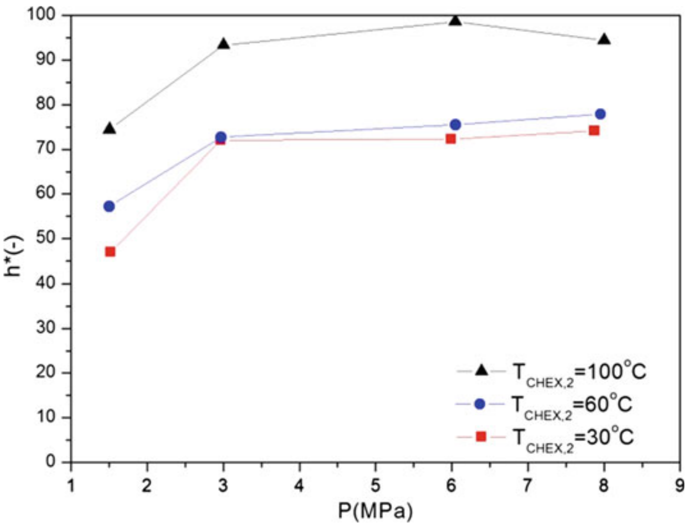

Fig. 7 Heat transfer efficiency in steady state experiment

transfer increased much slower. This is because when the pressure was low, heat transfer capability was low, and water around the C-type heat exchanger was heated but far from boiling. While the higher pressure means higher heat transfer capability, the water around the heat exchanger tubes start boiling and create more and more bubble. As a result, heat transfer coefficient keeps low increase rate in this stage.

5 Conclusions

A set of tests were performed to investigate the steady state and transient of ASP test facility according to the scaling laws. The experiments lead to the following conclusions:

(1) The residual heat is successfully removed from the steam generator to atmosphere by natural circulation in the test facility.
(2) The system shows good stability in the start-up process of transient natural circulation.
(3) The characteristics of steady state natural circulation and heat removal capability at varying pressure and C-type cooling water pool were obtained. Heat transfer capability keeps positive increases with pressure, while decreases with temperature of cooling water.

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