



## A STUDY ON THE BEHAVIOR OF STEAM CONDENSATION IN U-SHAPED HEAT TUBE

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### ABSTRACT

Isolation condenser (IC) is considered as an important equipment for especially severe accident management because IC has the ability to cool reactor core without power source. In order to evaluate heat transfer performance of IC accurately, experiments for the detailed performance evaluation in two-phase flow in a condenser are required. Thus, completion position of condensation in heat tube of a condenser is important to calculate heat transfer area of steam portion in heat tube. Experimental apparatus was fabricated for evaluation of heat transfer performance inside heat tube which simulated IC. Heat tube of test section was U-shaped horizontal tube and is installed in condensation tank with coolant water. In this study, temperature distribution in the heat tube was measured to estimate completion position of condensation. The experiment was carried out with changing steam flow rate and steam pressure. As a result, movement of completion position of condensation was suggested with increasing steam flow rate and maintaining temperature distribution of the coolant water. Therefore, availability of this method is validated.

**Keywords:** isolation condenser, u-shaped heat tube, heat transfer, cooling capacity, steam, condensation.

### INTRODUCTION

Isolation Condenser, IC, is a kind of core cooling system equipped mainly in BWR-3 type nuclear power reactor [1]. IC doesn't require any electric power except relating valve opening, thus, IC can be very useful to cool down the core during a severe accident like a station black out (SBO) accident. IC is filled of large amount of coolant water, and the coolant water can receive condensation heat from steam which is generated by residual heat of the reactor core after SCRAM. The residual heat conveyed by the steam is transferred in IC to the coolant water in outside water tank without direct contact, and the coolant water is evaporated to steam. The outside, not contaminated steam is released to atmosphere, and IC can condense the steam from the core during the designed time. Moreover, IC has an injection of the coolant water, which can extend the working time of the IC. As a result, IC is adopted in SBWR in which the basic concept is passive safety, thus, IC is focused again as a powerful tool of the Core Cooling System.

The purpose of this work is to apply for new core cooling system which has ability of steam condensation. In this study, condensation behavior in heat tube is studied to reveal the basic character of the cooling equipment like IC. Condensation heat transfer is very fast, however, heat transfer between different temperature water is relatively slow when compared with condensation heat transfer, thus, obtaining the behavior of water level in the condenser is very important to reveal detailed heat transfer behavior [2]. The method to estimate the condensed water level in an experimental apparatus like IC is reported.

### METHODOLOGY

Isolation condenser (IC) of BWR nuclear reactor has large amount of water and IC condenses steam from a

reactor core generated due to residual heat. However, heat transfer rate with steam condensation and that between different temperature water is quite different, thus, obtaining the behavior of water level in condenser is important when detailed condensation behavior is necessary. Consequently, an experimental apparatus which simulates IC was constructed and detailed condensation behavior in it was estimated from temperature distribution along the heat tube. The temperature distribution suggested the completion position of condensation, and finally the behavior of position movement will reveal the detailed heat transfer performance of condensation in the heat tube.

### Experimental setup

The experimental setup was composed of test section and its supporting piping system (Figure-1). Table -1 shows symbols of Figure-1. The test section was a heat exchanger with a horizontally placed cylindrical water tank and an inner U-shaped heat tube, both of them were made of stainless steel. The outside cylindrical tank had diameter of 345 mm and length of 1200 mm, the inner U-shaped heat tube has 12.7 mm O.D. and 10.6 mm I.D., U-shaped curve has 38 mm radius and whole length of U-shaped tube was almost 950 mm. Steam was injected into the heat tube from upper side and remained steam and/or condensed water exited from lower side. 13 thermocouples were installed into the heat tube as shown in Figure-2. Cylindrical water tank was filled of coolant water, surrounding the heat tube. 4 thermocouples were installed around the center point of tank (Figure-3), to obtain the vertical temperature distribution in the tank. Coolant water could be changed through water supply and exit to adjust water temperature.



Diagram of piping system of the apparatus was also depicted in Figure-1. Steam was generated in an electrical boiler of 50 kW (ME-50, Miura co ltd). Through a steam header, steam with stable pressure was supplied the piping system. Unnecessary condensed water before the test section was separated by a steam separator (DC3S-10, TLV co ltd), and pressure was adjusted with pressure regulator (DR20-6/B, TLV co ltd, V4 in Figure-1). Flow rate of steam measured by vortex flow meter (EF73, TLV co ltd, F1) with sufficient entrance length. Flow rate of the steam was controlled by pressure regulator V4 and bypass valve V7, finally adjusted by a needle valve, V6, installed after the test section. Steam trap (SS1NL, TLV co ltd) was also installed just before of the test section to remove condensed water, and temperature and pressure was

measured by thermocouple (Type-T, T6) and pressure meter (MBS33M, TLV co ltd, P2), respectively.

After the test section, temperature and pressure was measured again with Type-T thermocouple (T7) and pressure meter (Nagano Keiki co ltd, P3), respectively, and steam and condensed water was gathered into a heat exchanger to condense all of steam. The condition of the steam was obtained and adjusted using the values of flow rate measured by F1 and pressure at P2. Bypass valve V7 was also utilized to stabilize the pressure of steam generated by the electrical boiler. Insulator surrounded around the tube, and the effect of radiation was confirmed enough small for this experiment.

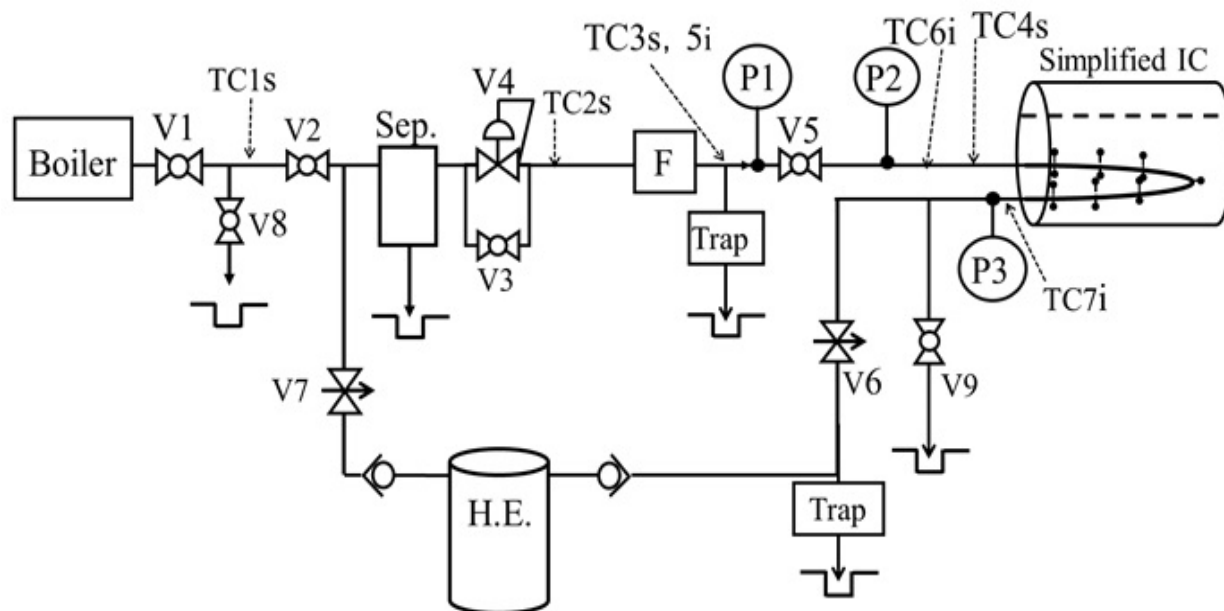


Figure-1. Test section and steam lines.

Table-1. Symbol and experimental device.

Valve		Equipment		Thermocouples	
Symbol	Type	Symbol	Name	Symbol	Location
V1	Master valve	F	Flow meter	TC1s	Pipe surface at steam header
V2	Gate valve	Trap	Steam trap	TC2s	Pipe surface near the V4
V3	Gate valve	F1	Pressure gauge	TC3s	Pipe surface near the V2
V4	Pressure reducing valve	P2	Pressure gauge	TC4s	Pipe surface at inlet test section
V5	Gate valve	P3	Pressure gauge	TC6i	Pipe inside near the V5
V6	Needle valve	H.E.	Heat exchanger	TC7i	Inlet test section
V7	Needle valve	Sep.	Mist separator		Outlet test section
V8	Gate valve				
V9	Gate valve				

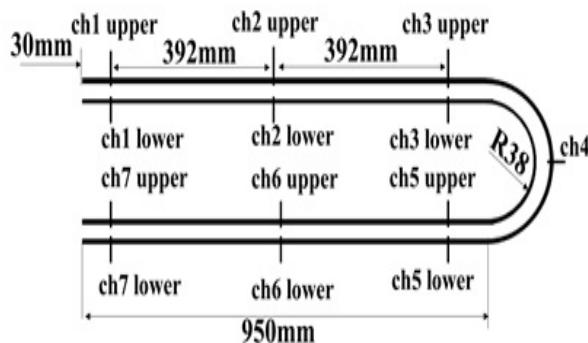


Figure-2. U-shaped heat tube and position of thermocouples.

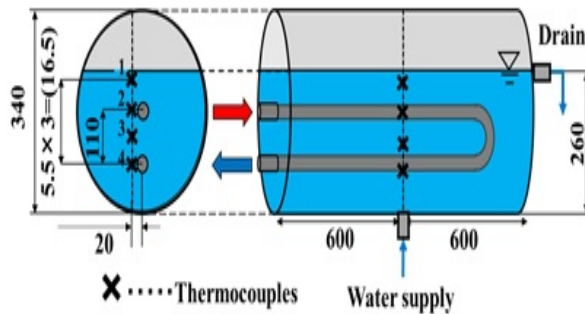


Figure-3. Condensation tank and position of heat tube.

## RESULTS AND DISCUSSION

Position of the condensation completion can be estimated by measured temperature along the heat tube. Judgement whether the position was filled with gas phase or liquid phase was examined by the temperature of the point. Temperature of the liquid phase could be measured as subcooled temperature, thus, the temperature was lower than the saturation temperature. Therefore, completion position of condensation can be estimated when temperature of the point is obviously lower than the saturation temperature. However, the judgement will be difficult when the temperature difference between temperature of the point and the saturation temperature was small. In the case, completion position of condensation was estimated considering another temperature of the neighboring upstream point.

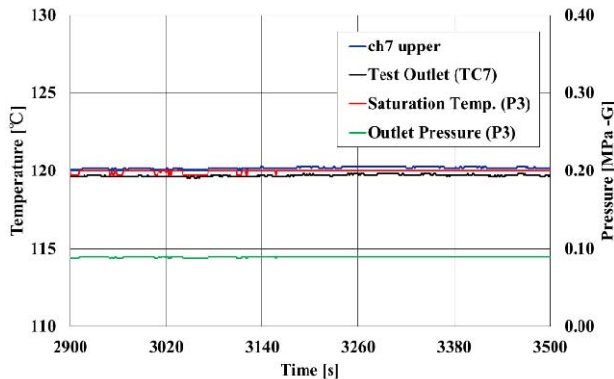


Figure-4. Temperature of test outlet.

To calibrate the temperature measurement, an experiment without coolant water in outside tank, only filled of the air, was examined. The temperature profiles obtained in the experiment were shown in Figure-4. Steam flow rate in this condition was 3.5 kg/hr. From the result, temperature of the most downstream point, TC7, and other temperatures was almost coincident with the saturation temperature of outlet pressure, P3, thus, the accuracy of temperature measurement was enough good, however, quality of two-phase flow at the most downstream point, ch7, was not clear since the temperature was the saturation

temperature, it means the flow was two-phase flow with both gas and liquid.

Experiment was carried out for observation of condensation completion before the outlet of the test section. Condensation tank was filled of coolant water. Coolant water was injected to condensation tank constantly and was overflowed to maintain the temperature distribution of water in the tank.

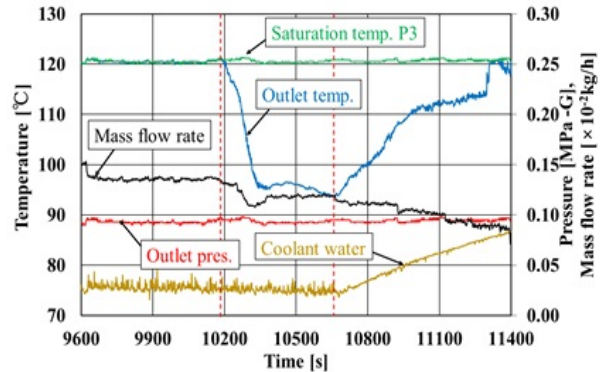


Figure- 5. Temperature of test outlet.

Experiment was carried out with condition of steam flow rate 14 kg/hr, outlet steam pressure P3 0.1 MPa-G. Two-phase or saturated water was flowed out at the position of outlet of test section at 9600 sec to 10200 sec because the temperature of outlet of test section agreed with saturation temperature. Heat supply to test section was decreased due to decrease of opening of outlet valve (V6). Movement of complete position of condensation to upstream was observed by comparison between saturation temperature of P3 and outlet temperature. Temperature of coolant water in the condensation tank increased by stopped injection of coolant water to observe the movement of complete position of condensation. Outlet temperature increased with increasing temperature of coolant water and also agree with saturation temperature. Movement of complete position of condensation to lower stream was observed.

## Temperature profile with varying water level in coolant tank

Another series of experiments were executed varying heat transfer area continuously by changing water level in the coolant tank. At first the coolant tank was vacant, filled of the air, and water was injected into the tank with constant flow rate through water supply of the tank. The water level inside of the tank was observed and change of condensation behavior was observed. Since the coolant tank was horizontally placed cylinder, the water level in the tank was changed as black line and point in Figure-6 though the flow rate was constant. Coolant water exit was placed around the height 26 cm, thus, water level couldn't arise higher than 26 cm. Coolant water supply was continued after the water level reached to the exit. Vertical temperature distribution inside the coolant tank



was also depicted in Figure-6. Temperature of upper part was suddenly increased when the water level reached to the heat tube, however, temperature of lower part was not so changed.

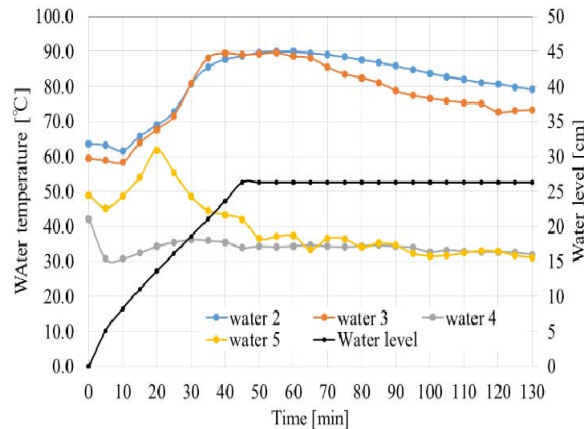


Figure-6. Water temperature in the tank.

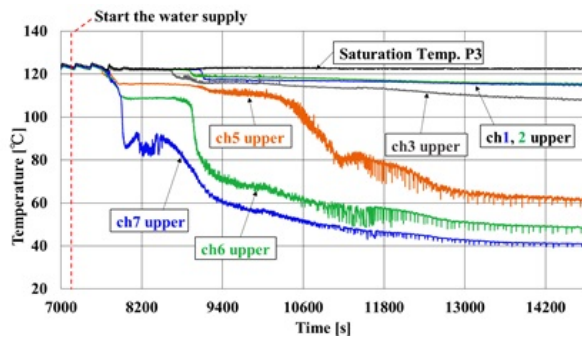


Figure-7. Temperature in the heat tube (changing water level)

Temperature inside of the heat tube was depicted in Figure-7. Temperature of lower part of the heat tube, ch5, ch6 and ch7 began to decrease at the time around 7600 second, when the water level of outside coolant water reached to the bottom part of the heat tube. Temperature of the ch5 also became obviously lower than the saturation temperature, thus, the completion point of condensation might be at upstream of ch5 at the time. Around 9000 sec, the upper part of U-shaped heat tube was also covered with the coolant water. However, temperature of ch1 and ch2 almost coincide. The result suggests that steam flow or two-phase flow existed around ch1 and ch2. Consequently, the status of flow could be estimated from the temperature distribution inside the heat tube, and the validity of this method was confirmed.

#### Temperature profile inside of heat tube varying flow rate and pressure of steam

Experiment with varying steam pressure and flow rate with constant coolant water temperature was also examined. The result was shown in Figure-8.

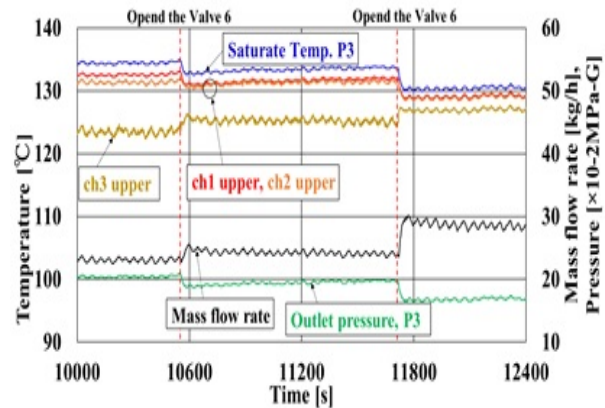


Figure-8. Temperature in the heat tube (varying flow rate and pressure)

The coolant temperature was maintained as 40 °C by changing water through water supply and exit, and steam pressure and flow rate was changed by the opening of needle valve at outlet, V6. The profiles of steam flow rate and pressure were also depicted in Figure-8, as well as temperature profiles of inside the heat tube, ch1 to ch7.

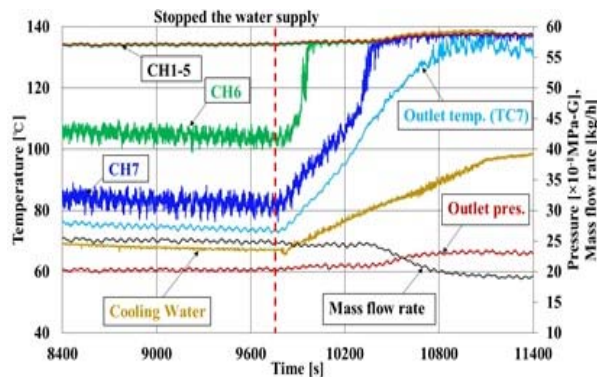
From 10800 sec to 11710 sec, before changing the opening of V6, temperature of ch1 and ch2 were almost coincide with their saturation temperature. It means that condensation was not completed before ch2. However, temperature at ch3 was lower than the saturation temperature, the result shows that condensation was completed between ch2 and ch3.

V6 was slightly opened at 11710 sec to increase the steam flow rate. Temperatures of ch1 and ch2 were still close to their saturation temperature, however, temperature of ch3 was still lower than the saturation temperature. It is assumed that condensation was completed before ch3. Reason of temperature increase of ch3 may be increase of heat input due to steam flow rate increase. Another steam flow rate increase was executed at 13015 sec. Pressure of the steam was decreased because the valve after outlet of the test section was opened. The saturation temperature in the heat tube was also decreased, and the temperature difference between the saturation temperature and temperature of ch3 became smaller. It suggests that completion position of condensation became closer to ch3, as a result, it also suggests the completion position of condensation moved to the downstream. The movement of completion position of condensation was also estimated in this experimental condition.

#### Temperature profile inside of heat tube with steady state

Experiment was carried out for approximating the overall heat transfer coefficient between steam condensation and coolant water. The result was shown in Figure-9.





**Figure-9.** Temperature in the heat tube with steady state.

In order to estimate heat transfer area accurately, completion position of condensation was controlled to the point which was close to outlet of test section. Heat transfer conditions were maintained at steady state with condition of steam flow rate 25 kg/hr and outlet steam pressure P3 0.2 MPa-G. Condensation tank was filled of coolant water whose near center line of condensation tank temperature was maintained as 70 °C. Coolant water was injected to condensation tank constantly and was overflowed to maintain the temperature distribution of water in the tank. The temperature from ch1 to ch5 showed good agreement with saturation temperature. However, temperature at ch6 was lower than the saturation temperature, thus, the result shows that condensation was completed between ch5 and ch6. In this case, heat input was calculated as approximately 15 kW with mass flow rate 25 kg/hr, and 2163 kJ/kg specific enthalpy when steam pressure was 0.2 MPa-G.

Temperature of coolant water in the condensation tank was increased by stopped injection of coolant water at 9720 sec. With increasing temperature of coolant water in the tank, condensation rate was decreased, thus, temperature of ch6 and ch7 showed saturation temperature at 10380 sec. Completion position of condensation was moved to outlet of test section at 10800 sec.

## CONCLUSIONS

Experimental apparatus, which simulated Isolation Condenser (IC) usually equipped in BWR-3 type nuclear reactor, was manufactured and experiments were carried out for evaluation of steam condensation performance. 90 degree rotated U-shaped heat tube of 10.6 mm I.D. was installed in a horizontally placed cylindrical tank, and the outside cylindrical tank was filled of coolant water. Completion points of condensation were estimated from temperature distribution inside the heat tube to evaluate characteristics of the steam condensation. Movement of the completion position of condensation was observed when steam flow rate in the heat tube was increased and temperature distribution of the outer coolant water was maintained by exchanging the coolant water. Besides, temperature in the heat tube was decreased and condensation in the tube was enhanced when coolant water was injected into the outer water tank from almost vacant state and water level in the tank arisen to the heat tube. Further study about condensation characteristics will be widely studied changing the steam flow rate, steam pressure in the heat tube or temperature distribution in the outer water tank.

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