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# An External Condensation Heat Transfer Experiment for a Vertical Finned Tube

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## 1. Introduction

The Passive Containment Cooling System (PCCS) that will be introduced in the next generation Korean nuclear power plant guarantee the safety of the nuclear power to utilize the condensation heat transfer phenomenon. The condensation heat transfer phenomenon plays a key role in the event of the loss of coolant accident (LOCA) or main steam line break (MSLB) in suppressing the pressurization of the containment. Therefore, the heat capacity of the PCCS is an important factor.

This study focused to investigate the condensation heat transfer on a vertical finned tube for increase of the heat capacity by the fins under natural convection conditions. The fin's geometry is considered the PCCS's pitch to diameter and increment of the effective heat transfer area against the bare tube's area. A bare tube's heat transfer data are utilized as a reference. The finned tube experiments are conducted the same conditions as the bare tube experiments.

## 2. Experiment

### *2.1 Experiment Apparatus*

As described in Fig. 1, experimental loop consists of mainly two sections: condensation section and cooling section. The condensation section includes chamber which installed tube inside, steam generator, condensation water tank and recirculation pump. The cooling section has water storage tank and pump.

The diameter of chamber is 609 mm and the height is 1950 mm. A vertical tube with 40 mm in outer diameter, 3 mm in thickness and 1000 mm in length installed inside of the chamber. Both of them are made of SUS-304.

The steam is generated from submerging heaters (30 kW × 4) in the steam generator and it goes to chamber. The steam is mixed with air in the chamber and condensed on the tube. The condensate flows to the condensate tank and it is sent to steam generator using the recirculation pump to maintain the water inventory.

Fig. 2 describes the location of thermocouples (K-type) in the tube and the chamber. To find internal gas mixtures distribution, 14 thermocouples were installed inside of the chamber. For measurement of temperature on the tube, thermocouples (K-type) are installed along the axial direction. The motivation of the fin's geometry comes from the Liu's experiment [1]. The design of the fin is considered for the pitch to diameter of the PCCS and total effective heat transfer area. The total effective heat transfer area of the finned tube is designed almost 2 times against the effective heat transfer area of the bare tube. Finally, the finned tube has the 13 fins of the 80 mm in fin's outer diameter and 5 mm in fin's thickness.

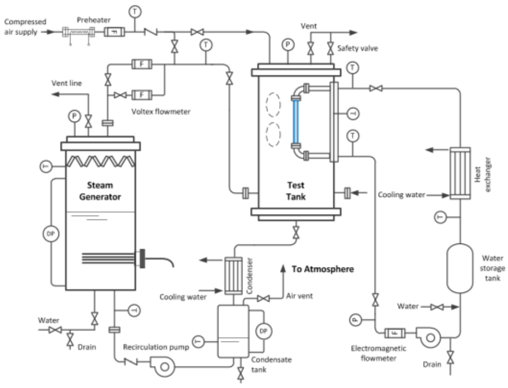


Fig. 1. Condensation experimental facility.

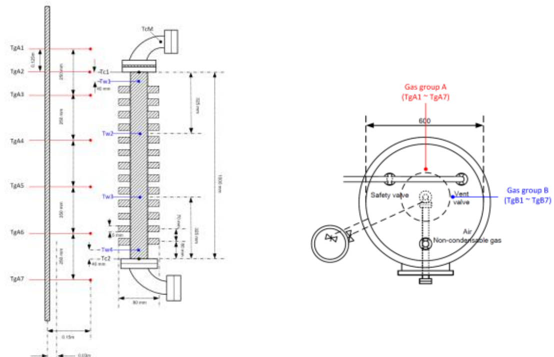


Fig. 2. Schematic diagram of temperature measurement in the chamber.

### 2.2 Data Reduction and Uncertainty

To find out the effect of the fins, the heat transfer rate is measured using the inlet and outlet temperature of the coolant in the tubes as:

$$Q = \dot{m} c_p \left( T_o - T_i \right) \tag{1}$$

where, $\dot{m}$, $c_p$, $T_o$ and $T_i$ represent mass flow rate of coolant, specific heat, outlet and inlet temperature of tube, respectively. Utilizing the Newton's cooling low, Eq. (1) can be used to express the average condensation heat transfer coefficient of the condensing surface as:

$$\bar{h} = \frac{\dot{m}c_p\left(T_o - T_i\right)}{A\left(T_b - T_w\right)} \tag{2}$$

where, $A$, $T_b$ and $T_w$ represent total heat transfer area, temperature of steam and noncondensable mixtures and temperature of outer surface of tube, respectively. The maximum uncertainty of the heat transfer rate is 16.3 % from analysis results.

### *2.3 Test Matrix*

Table II represents test matrix of this study. Generally, the design pressure of the containment is about 4 bar. In a view of conservatism, experimental range extended to 5 bar. Therefore, heat transfer rate is measured at 2, 3, 4 and 5 bar to reflect the various transient status of the containment in this experimental study. The air mass fraction is adjusted from 30 to 80 % to investigate the effect of noncondensable gas in the condensation.

Table II: Test matrix

| Pressure (bar) | $W_a$ (%) | ΔT (K) | $\dot{m}$ (kg/s) |
|---|---|---|---|
| 2 | 30 ~ 80 | 34.2 ~ 38.7 | 0.12 ~ 0.25 |
| 3 | | 32.7 ~ 40.8 | 0.13 ~ 0.38 |
| 4 | | 38.2 ~ 40.8 | 0.12 ~ 0.35 |
| 5 | | 33.4 ~ 41.1 | 0.11 ~ 0.36 |

($W_a$: air mass fraction, ΔT : wall subcooling)

## 3. Result and Discussion

### *3.1 Condensation Heat Transfer Phenomenon*

Fig. 3 shows the installed vertical finned tube during the condensation heat transfer experiment. The condensate is produced on the surface of the tube and fin due to condensation phenomena. The condensate flows along the tube surface and it united condensate from the fin surface on the fin's upper surface.

### *3.2 Condensation in The Presence of Noncondensable Gas*

Fig. 4 describes the condensation heat transfer rate (HTR) of the finned tube in the presence of the noncondensable gas at each pressure. The heat transfer rates increase with increasing pressure. If the gas pressure is increase then the gas density also increase, generally. When gas density increases, the heat transfer coefficient increases due to an increase of contact efficiency between gas particles and condensing tube.

Fig. 5 shows the comparison between the condensation HTR of the finned tube and bare tube at 2 and 4 bar. The condensation HTR of the finned tube is higher than the condensation HTR of the bare tube. These trends were shown by the Liu and Tong [2], [3]. It is explained by the fins. Since the fins were installed on the tube surface, it induces the increment of the effective heat transfer area. At last, it makes increasing the condensation HTR. Thus, condensation HTR of the finned tube is higher than the condensation HTR of the bare tube. The finned tube's and bare tube's effective heat transfer area is 0.23 $m^2$ and 0.13 $m^2$, respectively. Therefore, the effective heat transfer area ratio (finned tube/ bare tube) is 1.8. The averaged condensation HTR ratio (finned tube/ bare tube) is 1.44. The condensation HTR is smaller than the effective heat transfer area ratio because of the condensate. The condensate remains the upper surface of the fin. It plays a role as an obstacle during the condensation phenomenon. It could find the fig. 3. The increment ratio of the effective heat transfer area without the fin's upper surface area is calculated for the comparison with averaged condensation HTR ratio. From the result of the calculation, the area ratio (1.46) is almost same with the averaged condensation HTR ratio (1.44). The condensation HTR of the disc type finned tube is affected by the increment area ratio and retention area of the condensate.

Fig. 3. The vertical finned tube during the experiment.

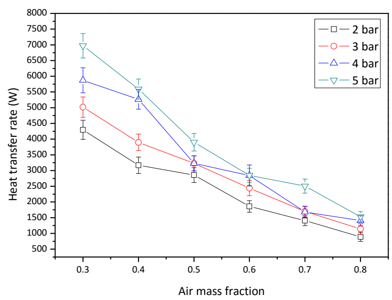


Fig. 4. The finned tube's HTR along the air mass fraction.

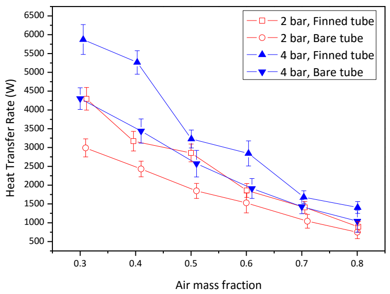


Fig. 5. Comparison between the HTR of the finned tube and bare tube.

## 4. Conclusions

The condensation heat transfer experiments were conducted utilizing the finned tube with disc type fin of 40 mm in tube's outer diameter, 80 mm in fin's outer diameter and 1000 mm in length under natural convection condition. The 13 fins are installed along the tube height, uniformly. Experimental results show that the condensation HTR reduces with an increase of the noncondensable gas mass fraction because the noncondensable gas acts as a resistance during the condensation phenomena. The fin for the increment of the effective heat transfer area affects the condensation HTR. The fin plays a positive role due to the increment of the effective heat transfer area. However, the condensate decreases the condensation HTR. Especially, a retention area of the condensate is the one of the main parameter for the HTR of the disc type finned tube.

In a view of the applicability to PCCS, for the single finned tube, HTR is higher than the bare tube, though the ratio of the HTR is the smaller than the ratio of the area. However, the realistic PCCS consists of the tube bundle. Generally, single tube's heat transfer is higher than tube bundle's heat transfer because of the shroud effect like Liu's experimental result. The finned tube also may affect the shroud effect, strongly. The condensate also may affect the condensation HTR. Thus, to apply the finned tube to PCCS has to need more studies to increase the heat transfer.

As a further work, optimization of the fin geometry utilizing the CFD code will be a next study.

## REFERENCES

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