An Experimental Study of the Dropwise Condensation on Physically Processed Surface

Jae Young Choi [a*], N. Watanabe [b], T. Sambuichi [b], D. Shiota [b], M. Aritomi [b], Soon Heung Chang [a]
[a]*Dept. of Nuclear and Quantum Engineering, KAIST*
335 Gwahak-ro Yuseong-gu, Daejeon, 305-701, Republic of Korea
[b]*Dept. Of Nuclear Engineering, Tokyo Institute of Technology*
[*]*Corresponding author: cjy89magic@kaist.ac.kr*

1. Introduction

The passive safety system against station blackout (SBO) condition becomes a main issue in the nuclear industries after Fukushima accident. Especially, passive containment cooling system (PCCS) is important candidate system for the advanced Gen III reactors to guarantee integrity of containment considered as a last barrier.

Few researches related to condensation heat transfer are conducted under LOCA conditions. Liu et al. [1] proposed simple exponential form of condensation heat transfer correlation valid for LOCA condition. Recent research by Kawakubo et al. [2] derived empirical condensation heat transfer correlation suitable for wider range of operating condition in presence of noncondensable gas. However, their proposals of PCCS are focused on plane tube surface.

To design better PCCS heat exchanger with high heat transfer coefficient new treatment on condensation surface can be considered in order to maintain dropwise condensation, the heat transfer coefficient of which has an order of magnitude larger than those of film condensation. Advanced research [3,4] measure dropwise condensation heat transfer coefficient of Au and Cr coated surface based on number of droplet and droplet growth rate. However, coated surface is not desirable in power plant due to its duration of few years.

On the other hand, physical processing (micro holes and patterns) on stainless steel and titanium surface is expected to perform better heat transfer, also is durable for the whole reactor lifetime. Since there is no published research about dropwise condensation for physically processed surface on SUS and Ti, the purposes of this research are to measure the condensation heat transfer coefficient and analyze its mechanism of enhanced heat transfer of treated SUS and Ti commonly used to nuclear plant.

2. Experiment Method and Result

2.1 Experimental Apparatus

As shown in Fig. 1, the experimental apparatus is mainly consisted of three parts: steam generating system, cooling system and test section. All systems are well insulated.

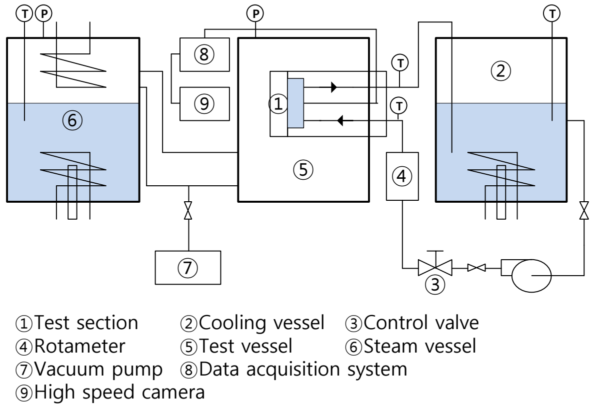

Fig. 1 Schematic of Experimental Apparatus

The steam generating system is consisted of electric heaters with a total capacity of 8kW and heat exchanger to control the amount of steam generation. They are in the 600mm height and 343mm diameter pressure vessel as the simulant of steam generation inside of the containment. The vessel is pressurized by steam up to 0.4MPa gauge pressure the design pressure of common concrete containment in the experiment.

The cooling system is consisted of cooling tank, heat exchanger, pump and control valve. It is connected to steam generating system and test section in order to control pressure and surface subcooled temperature, respectively. The cooling loop at test section is made of bakelite to minimize steam condensation outside of cooling surface and designed to replace the test section easily.

The material for test section is SUS or Ti and mainly two kind of geometry are used. The first test section is bare cylindrical shape with 13mm diameter and 6mm height. The second test section is cylindrical geometry with laser-processed surface. Various surface geometries are used for the result. Surface processed test section has 6mm diameter and 6mm height. Both of them have four 0.3mm holes for thermocouples installation in different depth of 2, 3, 4 and 5mm.

2.2 Comparison of the Experimental Result to Theoretical Equation

At first, the experimental result should be compared to well-known theoretical equation since there is no study that the reported theoretical analysis is also applicable to the physically processed surface on SUS and Ti.

Experimental condensation heat transfer coefficient is estimated from heat flux and surface subcooling. The heat flux can be estimated based on following Fourier conduction equation.

$$q'' = -k\frac{dT}{dx}. \qquad (1)$$

where, k is thermal conductivity of test section and dT/dx is a temperature distribution along the depth of test section, which is measured from the thermocouples. Then, the condensation heat transfer coefficient h_c from experiment is expressed as

$$h_{c,\exp} = \frac{q''}{\Delta T_{sub}} = -\frac{k}{\Delta T_{sub}}\frac{dT}{dx} \qquad (2)$$

where, ΔT_{sub} is subcooled temperature of test section, which can be predicted from the temperature distribution along the cooling depth by extrapolation.
According to the theoretical analysis suggested by Hatamiya at el. [3], dropwise condensation heat transfer is a function of droplet number density distribution function $N(r)$ and droplet growth rate $\dot{r}_e(r)$. The theoretical condensation heat transfer coefficient is expressed as

$$h_{c,th} = \int_{r_{cri}}^{R_{\max}} 2\pi r^2 \frac{h_{fg}}{\Delta T_{sub} v_l}\dot{r}_e(r)N(r)dr \quad (3)$$

where, $R_{\max}$ is maximum droplet radius without departure, r_{cri} is critical droplet radius and v_l is specific volume of water.

2.3 Comparison of Bare Surface to Various Geometries

The bare surface and different kinds of surface are compared in the view point of heat transfer coefficient under the same condition. Heat transfer performance under the accident condition of containment should be assessed that which one is better or not. Also the best condition of operation for each surface is confirmed.

The dropwise condensation characteristic should be assessed for different surfaces. Droplet number density, droplet growth rate and their relation to the measured characteristic of surfaces, droplet radius and experimental condition should be determined.

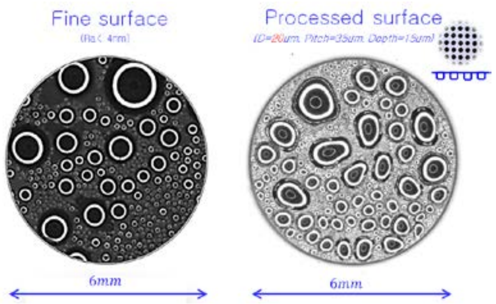

Fig. 2 Comparison of Processed Surface to Fine Surface (Visualization)

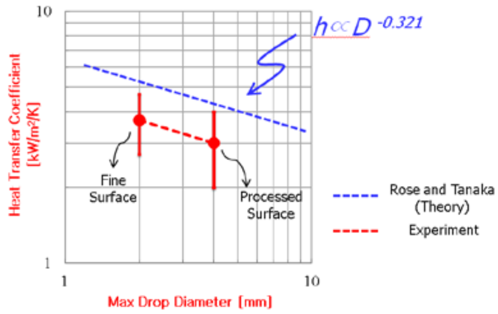

Fig. 3 Comparison of Processed Surface to Fine Surface (Heat Transfer Coefficient)

3. Conclusions

In the comparison of theoretical equation and experiment, it shows same result that heat transfer coefficient is proportional to maximum droplet diameter power to -0.321. Moreover, in the comparison of bare and processed surface, heat transfer coefficient decreases in processed surface.

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