Experimental study of Condensation Heat Transfer Performance on an outer Super-hydrophobic tube with various materials

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1. Introduction

Energy efficiency has become one of the important issues in the today's world due to lack of energy problem. Thus, the condensation heat transfer which is a phenomenon related to the efficiency of nuclear power plant has also become important in its process of heat transfer. For such matter, this study proposes a new way of increasing its efficiency by applying S.A.M coating method.

This research conducted a dropwise condensation experiment with both the S.A.M coated tube and the bare tube of various materials (Cu, SUS, Al and Ti), and evaluates their heat transfer performance. All of the experiments were conducted in a way that could help to reduce the effect of NCG. The experimental data was obtained by DAS and analyzed with MATLAB.

2. Methods and Results

To focus on the dropwise condensation for the better heat transfer performance, we have applied a new coating method called, S.A.M (Self-Assembled Monolayer) coating [4] which is the key point of this research. With such coating method, the S.A.M coated surface will have super-hydrophobic surface property which induces the droplet condensation, making a large contact angle in its droplets. By making such surface of heat transfer tube, we could expect the increase in the heat transfer efficiency as well as the heat transfer performance in results.

2.1 Experimental Facility

The experiment was carried out using the experimental facility shown in the Fig. 1 and 2. The entire experiment had been conducted under limited conditions as it required to be insulated and closed completely while the S.A.M. coated tube and bare tube are placed inside the test chamber. To create an appropriate test conditions, a vacuum pump had been connected to the test chamber and had set the pressure inside the closed chamber as almost vacuum. The condensate gauge is also placed at the bottom of the test chamber to collect the condensate which is going to be used for deriving the overall heat transfer coefficient of the test tubes.

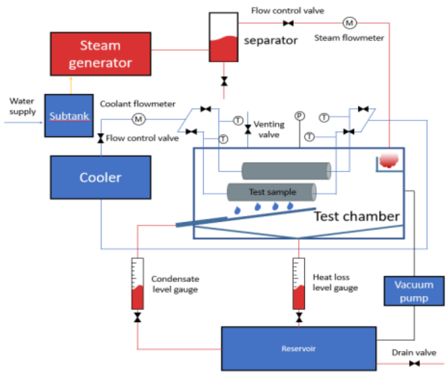

Fig. 1. Schematic diagram of experimental facility

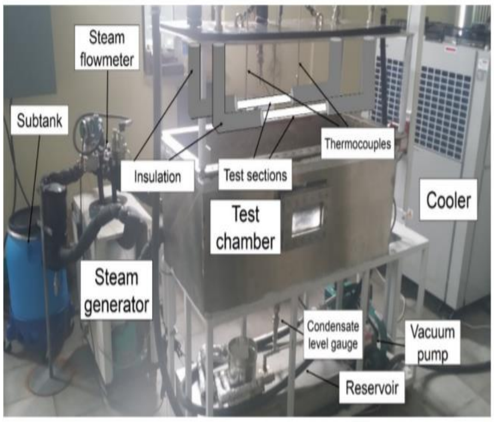

Fig. 2. Actual experimental facility

2.2 Calculation Process

To obtain the amount of heat transferred in usual way, the Energy Balance Equation is used which needs the value of difference in inlet and outlet temperature of the heat transfer tube. However, since the temperature difference measured is too small for this experiment, we have instead measured the volume of condensate falling from the heat transfer tube to calculate the overall heat transfer coefficient. The equation used for such calculation is shown in the equations below. For calculating the Equation 1, the modified latent heat equation is defined like shown in the Equation 2.

$$Q = \dot{m}_{cond} h_{fg}^{*} \tag{1}$$

$$h_{fg}^{*} = h_{fg} + C_{p,f}(T_{sat} - T_{surf}) \tag{2}$$

To calculate the Equation 2, surface temperature of the heat transfer tube has to be measured. However, since the experiment is conducted with super-hydrophobic tube surface, it is not possible to measure the surface temperature of the tube physically by using thermocouple. [4] Thus, to resolve such problem, LMTD method has been applied and an iterative calculation method has been used to predict the surface temperature.

$$U = \frac{Q}{A_{surf} T_{LMTD}} \quad (3)$$

$$\frac{1}{R_{cond}} = \frac{1}{\frac{1}{U} - \frac{1}{h_{conv}(D_o/D_i)} - \frac{\ln(D_o/D_i)}{2k_w/D_o}} = h_{cond} \quad (4)$$

$$\dot{Q} = \frac{1}{R_{cond}} A_{surf}(T_{sat} - T_{surf}) \quad (5)$$

With the assumption of the surface temperature, the Equation 2 can be calculated and the overall heat transfer coefficient is derived by the Equation 3. Following the iteration calculation flowchart shown in the Fig. 3, the condensation heat transfer coefficient is derived at the end. The values needed for iteration can be obtained with the Equation 4 and 5.

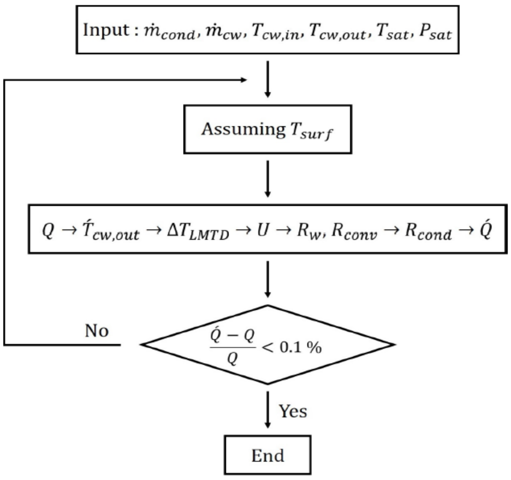

Fig. 3. Iteration calculation flowchart.

2.3 Test Matrix

Experiment was conducted according to the test matrix shown in Table I. In order to prevent the effects of NCG during the experimental process, the saturation pressure was controlled by adjusting the amount of steam injected into the vacuumed chamber. The temperature of coolant and the Reynolds number were adjusted according to the test matrix in Table I.

Table I: Test matrix for condensation heat transfer experiments

Coolant flow rate / Saturation pressure	*Reynolds* number 10,000	*Reynolds* number 20,000
0.2 bar	Condition #1	-
0.4 bar	Condition #2	Condition #5
0.6 bar	Condition #3	Condition #4

2.4 Results

According to the Fig. 4 and Fig. 5, the calculated value of overall heat transfer coefficient is mostly higher than that of bare tube in all materials for S.A.M coated tube. Specifically, there is a large increase in its value in condition #1 and #2. However, at the moment where the condition number increases from condition #4 to #5, there is a huge decrease in the value of overall heat transfer coefficient which means the heat transfer performance decreases immensely. The reason for such decrease is due to the effect of attached condensation which is the condensation phenomenon where the droplets are already finned into the surface structure deeply, creating a large sized droplet under the heat transfer tube. Such droplets greatly increase the heat resistance which reduces the heat transfer performance.

At the condition #1, all of the S.A.M coated tubes have shown similar values of overall heat transfer coefficient. The heat transfer performance has improved for all the materials compared to that of bare tube. At the condition #2, even though the other S.A.M coated tubes still show the phenomenon of dropwise condensation at the surface, the S.A.M coated titanium(Ti) tube had shown the flooded condensation. Such results can be explained that the flooded condensation had started sooner for titanium compared to the other materials in which the detachment frequency decreased. As the condition proceeds from condition #3 to condition #4, the Reynolds number increases. Thus, the overall heat transfer coefficient increases for all the materials in general. At the condition #5, the attached condensation has occurred where the finning effect has already affected the heat transfer performance significantly.

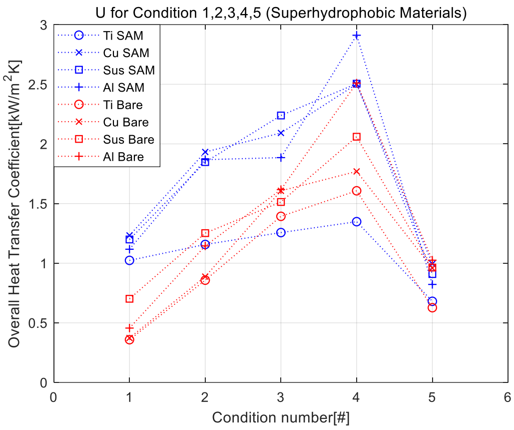

Fig. 4. Overall heat transfer coefficient of S.A.M coated tube and Bare tube of various materials (Cu, SUS, Al and Ti)

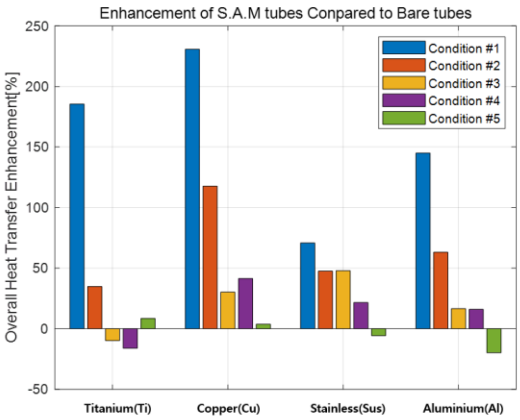

Fig. 5. Enhancement of heat transfer performance in S.A.M coated tube with various materials (Cu, SUS, Al and Ti)

3. Conclusions

In this research, the condensation heat transfer performance of the S.A.M coated tube and that of the bare tube have been compared. As the result, the values of overall heat transfer coefficient of S.A.M tubes for all materials (Cu, SUS, Al and Ti) are higher than that of bare tubes in condition #1 and #2. Only titanium(Ti) S.A.M tube showed worse heat transfer performance in condition #3. The reason for such result can be explained that the flooded condensation had started sooner for titanium S.A.M tube than that of the other materials in which the finning effect has been induced early. The results showing a large enhancement in the heat transfer performance in condition #1 and #2 can possibly lead us for the future study. It can be done by segmenting the current test matrix with the gap of only 0.1 bar of saturation pressure to focus more on the dropwise condensation.

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