Wettability Effect on CHF in Subcooled Boiling Region using Cu-coated Surfaces under Flow and Atmospheric Pressure Conditions

Dong Hoon Kam [a], Young Jae Choi [a], Yong Hoon Jeong [a*]
[a]*Department of Nuclear and Quantum Engineering , Korea Advanced Institute of Science and Technology, 291, Daehak-ro, Yuseong-gu, Daejeon, 305-701, Republic of Korea*
[*]*Corresponding author: jeongyh@kaist.ac.kr*

1. Introduction

In heat transfer systems, where coolants are utilized, boiling occurs on the surface with increasing wall superheat. In normal cases, beyond certain wall temperature, there is a point beyond which irreversible dry patches are formed. The point is called Critical Heat Flux(CHF), and under heat flux control condition, wall temperature increases abruptly to reach the same heat flux level in film boiling region. During the process, because of the radical increment rate and too high surface temperature, material integrity can be threatened. Therefore, CHF is one of important parameters that directly affect material integrity especially during accidental conditions, and it is widely known to be affected by environments such as coolant properties, heating material, surface conditions, etc. To figure out the important parameters on CHF occurrence, many researchers carried out related studies so far. In this study, among them, wettability effect has been considered under flow boiling condition. Hydrophilic state of the surface is known to increase CHF results, and further academic approaches seem needed to be covered considering local conditions. On this basis, enhancement especially in subcooled region will be dealt with in this study since wettability effect has been addressed by Ahn et al. [1] and Lee et al. [2] in saturated flow conditions.

2. Methods and Results

In this section experimental apparatus will be introduced with certain treatment, and CHF results will be addressed.

2.1 Test Facility

Figure 1 shows overall schematic of flow boiling test facility used in this study. Pump and needle valve before the inlet make the hydraulic flow conditions, and pre-heaters adjust the inlet temperature conditions. Condenser is located after the exit, and a surge tank is situated after the condenser part where atmospheric pressure condition is made.

For the test tube, stainless steel 316 has been used with 12.7 mm OD and 1.24 mm thickness. To achieve different wettability conditions on the surface, copper coating was made by electroplating method. The thickness was around 1 micro meter to minimize copper material effect. To assure tight and firm adhesion on the surface, inner surface of the base material(SS316L) has been polished with electrolytic polishing method.

Firstly, non-oxidized Cu surfaces were used and compared with the bare cases. After then, oxidized Cu surfaces were used. For the oxidation process, dry oxidation method was adopted, and the surface temperature & time conditions were based on Wang and Dhir's study [3] where surface wettability with oxidation time was represented (same condition that matched to about 20^{o} of contact angle). Upper copper electrode was located to make the most upstream place during boiling experiments situated in the middle(figure 2). After the oxidation, several colors were formed on the surface which all were in the form of copper oxides.

Atomic percent of oxide before the experiments has increased about double that of non-oxidized Cu surfaces as seen in figure 3.

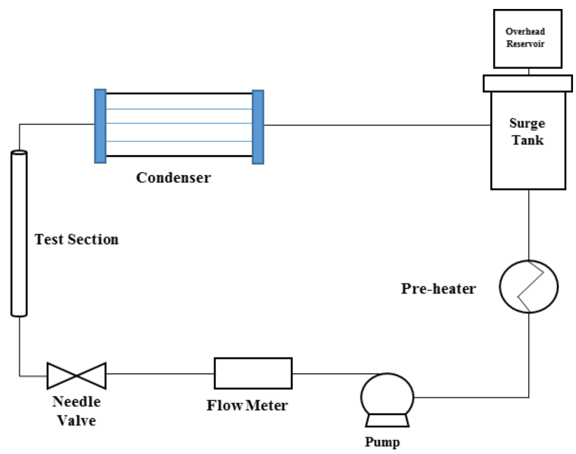

Fig. 1. Test loop used in the study.

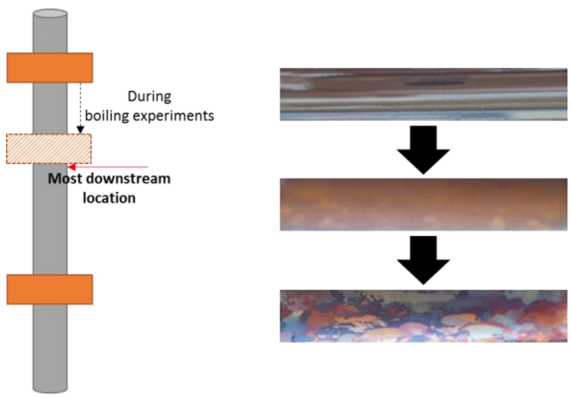

Fig. 2. Dry oxidation method, Cu-coated and oxidized Cu

surfaces.

Element	Wt%	At%
C	7.9	27.8
O	5.5	14.6
Cu	86.6	57.6

Element	Wt%	At%
C	3.8	12.9
O	14.0	35.2
Cu	82.1	51.9

Fig. 3. Element analysis on non-oxidized Cu(Up) and oxidized Cu(Down) surfaces.

Two kinds of mass flux conditions(7000 kg/m^2-s, 200 kg/m^2-s) were considered to assess the overall trends. Also, for each mass fluxes, inlet subcoolings were considered as follow: 60, 40, 3 K for the first and 65, 15 K for the latter..

2.2 CHF Results

When non-oxidized Cu surfaces were used, their CHF results were almost the same with the bare cases regardless of the flow conditions. The enhancement ratio were within the deviation range of experimental results. It also guarantees the elimination of Cu material effect in the results. In figure 4, condition numbers 1-3 were performed with mass flux condition 7000 kg/m^2-s, and the others with 200 kg/m^2-s.

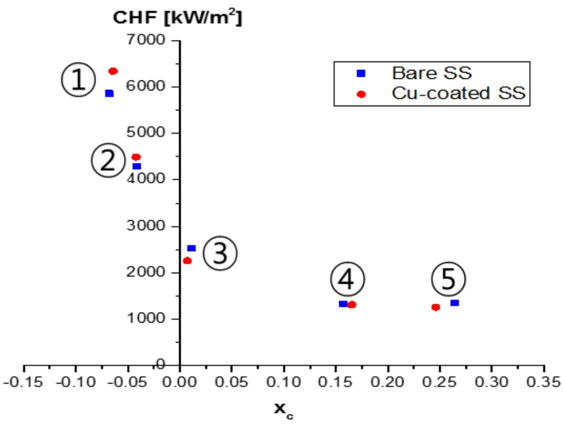

Fig. 4. CHF results from Cu-coated and bare surfaces.

In comparison, when oxidized Cu surfaces were utilized, there were both enhanced and non-enhanced results depending on local conditions. The results can be divided into two perspectives: Inlet perspective and local perspectives. When inlet conditions were same, the enhancement was almost zero at subcooled region, but steadily increased in saturated boiling regions. When the same local conditions were selected, it still showed the same trend. For the same local conditions, mass flux and local quality conditions were considered.

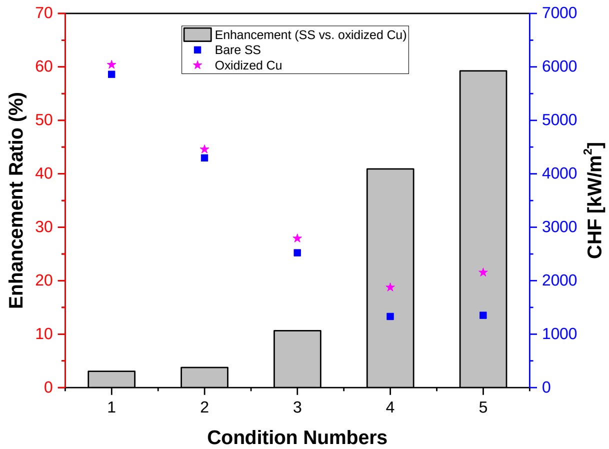

Fig. 5. CHF results from the inlet perspective.

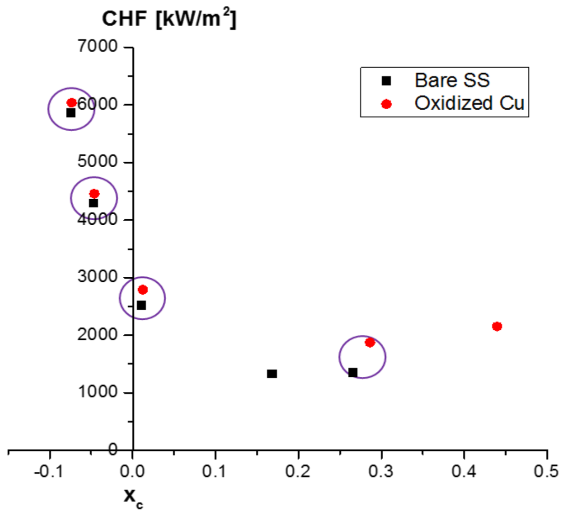

Fig. 6. Selection of the data within same local conditions.

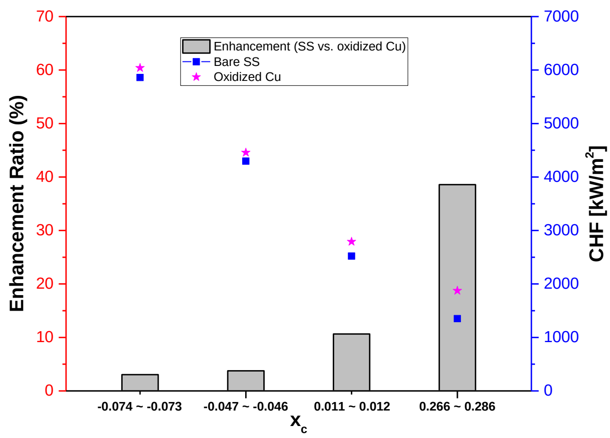

Fig. 7. CHF results from the local perspective.

3. Conclusions

Wettability effect on CHF results were addressed in subcooled boiling region. Different from previous conclusions(which were normally based on saturated boiling region), in subcooled region, wettability effect was suppressed. Since nucleate boiling term is suppressed as subcooling increases and highly wetted conditions are already formed by subcooling effect, wettability effect will become less effective than saturated boiling region.

REFERENCES

[1] H. S. Ahn, C. Lee, M. H. Kim, The effect of liquid spreading due to micro-structures of flow boiling critical heat flux, International Journal of Multiphase Flow, Vol.43, p. 1, 2012.

[2] T. Lee, D. H. Kam, J. H. Lee, Y. H. Jeong, Effects of two-phase flow conditions on flow boiling CHF enhancement of magnetite-water nanofluids, International Journal of Heat and Mass Transfer, Vol.74, p. 278, 2014.

[3] C. H. Wang, V. K. Dhir, Effect of Surface Wettability on Active Nucleation Site Density During Pool Boiling of Water on a Vertical Surface, Journal of Heat Transfer, Vol.115, p. 659, 1993.