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Pool Boiling Heat Transfer Enhancement by Varying Various Structures: A Review

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Abstract: *The rapid growth of modified different structured surfaces in recent years facilitated the enhancement of boiling heat transfer on these surfaces. In this paper, several researches on the different structured surfaces that have been reviewed to enhance boiling heat transfer like their design, modifications and different methods. The growth of bubbles and its dynamics depend on temperature excess, nature of the surface and thermo physical properties of test liquid, such as its surface tension, latent heat, etc. The major parameters affecting the heat transfer coefficient under nucleate pool-boiling conditions are heat flux, saturation pressure and thermo physical properties of a test liquid. Finally, the special features of different existing modified surfaces are summarized.*

Keywords: *Pool Boiling, Critical Heat Flux, Heat Transfer Enhancement Methods, Various Structures*

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I. Introduction

Boiling is a convective heat transfer process that involves phase change process at a constant temperature from liquid to vapor at liquid-vapor interface. The Pool Boiling Heat Transfer (PBHT) refers to the situation in which the heated surface is submerged below the free surface of stagnant liquid and its motion near the surface is due to free convection and the mixing is induced by bubble growth along with detachment. To achieve the better boiling heat transfer rate there are several different enhancement techniques are employed like micro or nano structured surfaces, use of treated surfaces, additives for working fluids, some mechanical aids, vibration of heating surface, vibration of working fluid, electrostatic field, compound techniques etc. In this paper, the theoretical and experimental researches on BHT and Critical Heat Flux (CHF) are introduced, based on which the outcome of PBHT enhancement using different structures is analyzed. Further, the researches on Nucleate BHT and CHF enhancement utilizing surface modification techniques are reviewed and analysis of research outcomes is presented. In conclusion, the boiling heat transfer characteristics of different structured surfaces are comprehensively described and the need for future is presented.

II. Literature Review

A.K. Das et al. [1] they have adopted the tunnel geometry as the basic structure for the investigation. Surfaces with parallel tunnels of constant width of 0.4 mm, constant pitch of 3 mm and constant depth of 2 mm from the top surface have been developed are schematically shown in Fig. 1.

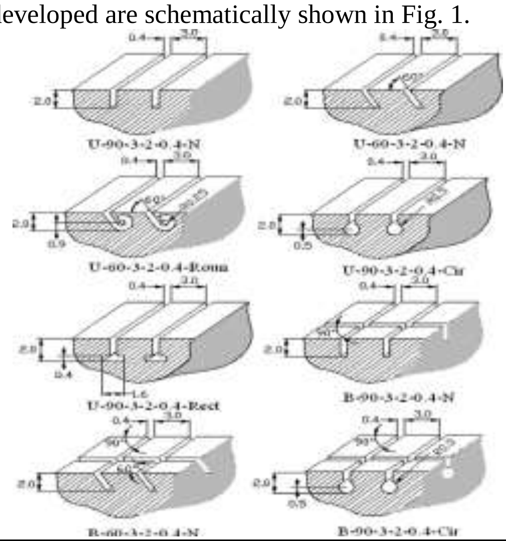

Fig. 1. Various Tunnel Geometries

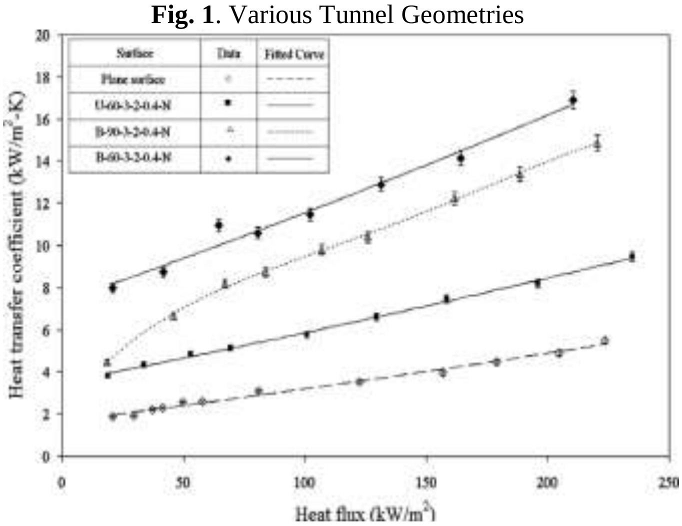

Fig.2: Boiling curve of B-60-3-2-0.4-N along with U-60-3-2-0.4-N, B-90-3-2-0.4-N and plane surface using water as test fluid

It was observed [12, 13] that the rate of heat transfer increases as the surface inclination increases from 0^o (upward facing, horizontal) to 175^o If the inclination is increased beyond 175^o at low heat flux. To make the comparison easier on the same figure, they presented the boiling curve obtained from the plane surface, surface with straight parallel tunnel (B-90-3-2-0.4-N) and surface with inclined parallel tunnel (U-60-3-2-0.4-N). The best performance has been exhibited by surfaces having vertical parallel tunnel with circular base. A further reduction in the enhancement is observed in case of tunnels with 60^o inclination and rounded base. It may also be concluded that out of the three modifications at the tunnel base the circular groove provides the best result.

Dwight Cooke et al. [2] fabricated copper chips of dimensions 20 mm by 20 mm square with 3 mm thick as shown in fig. 3 (3D representation of test chips, with channels shown on top surface (a), thermocouple hole to centre of chip and bottom side of chip facing heater (b)) An inherent parameter of the chips is the surface area augmentation factor, which is the ratio of the surface area to the projected area of the chip. This wetted area is due to the fin width and channel depth. The boiling curves for the tested chips are shown in Fig. 4.

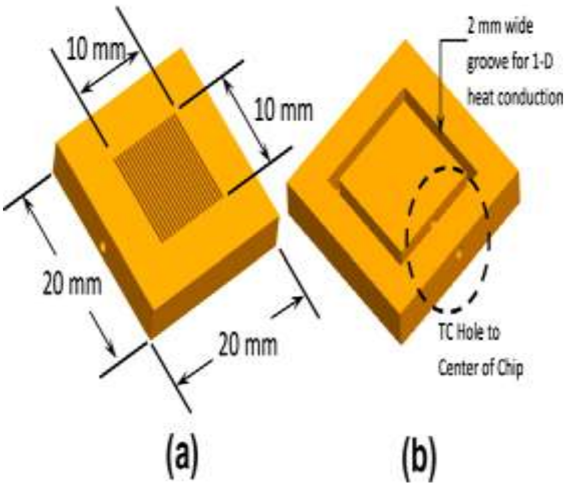

Fig. 3. 3D representation of test chips

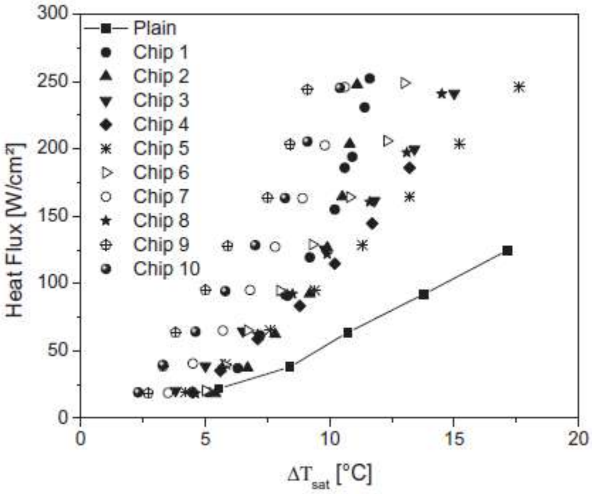

Fig. 4. Boiling curves for the tested chips, using projected heater area.

It is well known fact that cavities acts as nucleation sites. They not only provide continuous formation of bubble but also initiate the bubbling process at a low degree of superheat. Almost 100% enhancement has been noticed using the surface. The heat flux in these plots is based on the projected area of the micro channel surface. In this study the chips are ranked according to the maximum heat transfer coefficient measured during testing. By plotting the heat transfer coefficient against the wall superheat in Fig. 5, the trend shows that as the surface temperature increases, the heat transfer coefficient increases as well for all surfaces. This is expected because the boiling process enhances heat transfer through the micro convection, micro layer evaporation, and transient conduction mechanism.

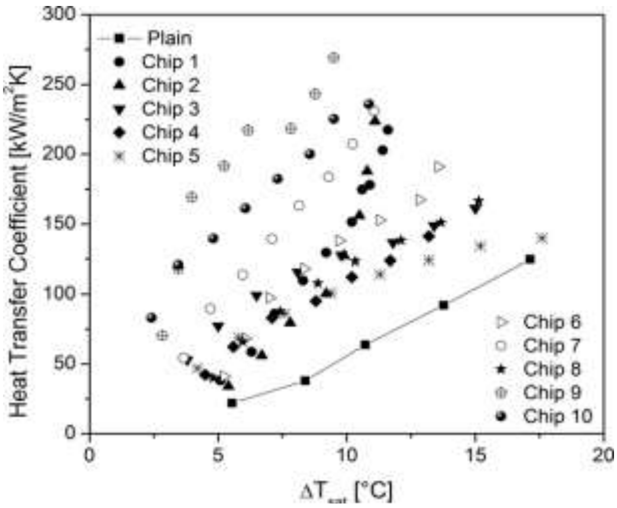

Fig. 5. Heat transfer coefficients for the tested chips using projected heater area.

S. Mori et al. [3] prepared the porous layer on the test surface by spraying or sintering metal particles of the order of several dozen to hundreds of microns. They investigated experimentally that the CHF increases approximately 2.5 times by the attachment of a honeycomb porous plate, compared to that of a plain surface with 30 mm diameter of heated surface, which is relatively large. The saturated boiling curves of the honeycomb porous plates at different heights and that of a plain surface are compared in Fig. 6.

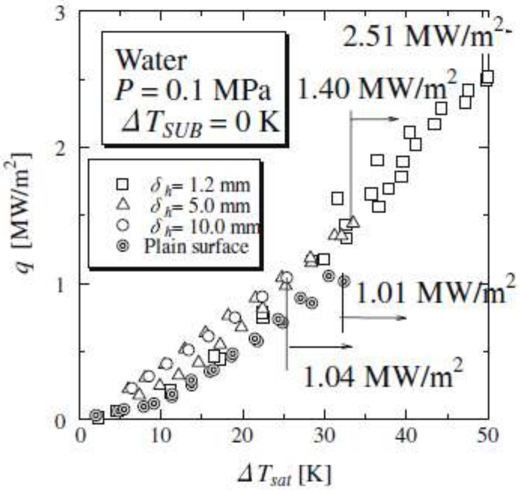

Fig. 6: Boiling curves for honeycomb porous plates of different heights

As mentioned above, the three possible CHF enhancement mechanisms for the use of porous media. The first is the capillary suction effect, second is an extended surface area effect, and the third is the effect of a decrease in the flow-critical length scale, or the distance between vapor columns, which is regulated by the modulation in a porous layer, corresponding to Rayleigh-Tayer wavelength in Zuber's hydrodynamic model, as suggested by Liter and Kaviany (2001). The CHF increases significantly as the height of the honeycomb porous plate decreases; this indicates the decrease in the extended surface area.

Seol Ha Kim et al. [4] designed twelve samples with a micro structured surface and one sample with a bare surface was fabricated by Micro Electro-Mechanical Systems (MEMS) techniques. They evaluated the BHT and CHF of pool boiling on well-organized micro scale structured surfaces. As a result, the BHT change on micro structured surfaces was shown to be strongly dependent on pin–fin effects. This study provides fundamental insight into BHT and CHF enhancement of structured surfaces, and an optimal design guide for the required CHF and BHT performance.

H. S. Ahn [5] used an anodic oxidation process (HF 0.5%, 20 V) to prepare the test surfaces, which consisted of thermally heated zinc-conium alloy plates of 25 mm in width, 15 mm in height and 0.7 mm in thickness. In the liquid spreading region below a contact angle of 10^o the predictions of Kandlikar [12], which include a wettability effect, could not explain the dramatic CHF enhancement. It is well known that micro, nano, and micro/nano structures influence the spreading ability of a surface, effectively supplying liquid to the heating surface, thereby delaying the formation of hot spots and increasing the CHF. The micro/nano surfaces had the most capillary wicking action and gave the greatest CHF increase.

III. Conclusion

In this paper, different structure surfaces which have designed to enhance the boiling heat transfer are introduced. The boiling heat transfer rate can be increased by following ways,

- Combination of inclined tunnel up to 60^o with the circular groove at the tunnel base.
- Microstructure with wider channels, thinner fins and deep channels facilitates the early bubble nucleation, large bubble departure diameters and low wall superheats for enhancement in heat transfer.
- Micro drilled holes surface shows distinct increase in the rate of heat transfer (increase in nucleation sites).

From the above outcomes and the existing experimental results, we can suggest that the types of surface morphology in order to enhance heat transfer. The micro porous and small size roughness structures on a surface can play the important role to increase the active nucleation cavities and promote bubble initiation and growth.

Though, the different boiling enhancement surfaces with innovative performance have been developed, a few critical engineering problems still exist. The micro/nano structured surfaces are made with electricity due to that it fail to maintain original size and shape in harsh environment, thermal stresses, impact stresses, etc. In conclusion, this review article gives the several different researches on boiling enhancement surfaces. From this review it is clear that, the thorough knowledge of boiling heat transfer model and different boiling regimes which are necessary for designing and fabricating modified surfaces for enhancement in boiling heat transfer.

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