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Experimental study on condensation heat transfer of steam on vertical titanium plates with different surface energies

Qi Baojin, Zhang Li *, Xu Hong, Sun Yan

State-Key Laboratory of Chemical Engineering, School of Mechanical and Power Engineering, East China University of Science and Technology, Shanghai 200237, China

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ABSTRACT

Visual experiments were employed to investigate heat transfer characteristics of steam on vertical titanium plates with/without surface modifications for different surface energies. Stable dropwise condensation and filmwise condensation were achieved on two surface modification titanium plates, respectively. Dropwise and rivulet filmwise co-existing condensation form of steam was observed on unmodified titanium surfaces. With increase in the surface subcooling, the ratio of area (η) covered by drops decreased and departure diameter of droplets increased, resulting in a decrease in condensation heat transfer coefficient. Condensation heat transfer coefficient decreased sharply with the values of η decreasing when the fraction of the surface area covered by drops was greater than that covered by rivulets. Otherwise, the value of η had little effect on the heat transfer performance. Based on the experimental phenomena observed, the heat flux through the surface was proposed to express as the sum of the heat flux through the dropwise region and rivulet filmwise region. The heat flux through the whole surface was the weighted mean value of the two regions mentioned above. The model presented explains the gradual change of heat transfer coefficient for transition condensation with the ratio of area covered by drops. The simulation results agreed well with the present experimental data when the subcooling temperature is lower than 10 °C.

1. Introduction

Titanium heat exchange components have been widely applied in various fields such as chemical engineering, power and seawater desalination for their advantages of high strength, low density, high corrosion resistance, and less fouling. However, heat transfer characteristics of titanium have not been adequately investigated compared with numerous researches on anti-corrosion properties.

Two different points of view about steam condensation on the titanium surface were held among researchers: One is that dropwise condensation is promoted on the titanium surface owing to its low surface energy; another view supports that filmwise condensation may occur, the same as steam condensation on carbon steel and copper surfaces [1,2]. O' Keefe [3] obtained filmwise condensation on a sodium hydroxide and ethanol preoxidation titanium tube wall at large mass flow of cooling water in tube. While at low mass flow, intermittent dropwise condensation occurred in some small scope. Yu and Huang [4,5] reached the same conclusions using similar preoxidation process, but failed to achieve stable filmwise condensation on unoxidation surface. Song et al. [6] plated a 1 μm thick titanium layer on the copper surface and injected oxygen into this layer by ion beam implantation. They obtained stable dropwise condensation on this surface. Moreover, stable dropwise condensation of steam was also achieved by ion beam implantation of N^+ on titanium surfaces by Rausch [7]. Besides, McNeil [8] and Wang [9] supported the viewpoint that dropwise condensation occurred on modified titanium surface, and untreated tubes condensed filmwise.

Previous experimental investigations by the authors indicated that the heat transfer coefficient in the condenser of the titanium/water two-phase closed thermosyphon was about 2–3 times higher than that of the copper/water two-phase closed thermosyphon, and is not consistent with the Nusselt's theoretical correlation based on laminar filmwise condensation. In view of this, a deduction of dropwise and film co-existing condensation based on surface energy difference was introduced to elucidate heat transfer characteristics in the condensing section of the titanium/water two-phase closed thermosyphon [10]. In this paper, condensation heat transfer characteristics of steam on vertical titanium plates were investigated experimentally. Furthermore, visual observation of condensate behavior and theoretical analysis were conducted.

* Corresponding author. Tel./fax: +86 21 64253810.
E-mail address: lzhang@ecust.edu.cn (Z. Li).

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