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A new insight of temperature distribution on superhydrophilic surface horizontal tubes falling film at low spray density

Yi Zheng, Zhong Lan, Kejian Cao, Rui Jiang, Xuehu Ma*

Liaoning Key Laboratory of Clean Utilization of Chemical Resources, Institute of Chemical Engineering, Dalian University of Technology, Dalian 116024, China

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ABSTRACT

Falling film on horizontal tube banks is widely used in heat and mass transfer processes, because it leads to a higher heat and mass transfer performance. In this paper, a series of experiments were conducted to investigate the temperature distribution and local temperature evolution feature of liquid film at low spray density on superhydrophilic surfaces by thermal tracing method. The experimental results revealed that the temperature distribution of liquid film on the superhydrophilic surfaces presented a sub-region effect for different flow mode, a uniform and repeated distribution for jet mode and two totally different zones for droplet mode. Besides, for there existed a new high temperature band, which was first observed in the center of saddle-shaped lamella for droplet mode and a lower temperature region coinciding with the interaction ring between each pair of jets for local temperature feature due to the effect of the collision and overlap of spread film on superhydrophilic surfaces.

1. Introduction

Falling film process has been widely used in the petrochemical industry, desalination processes, ocean thermal energy conversion system, refrigerator and air conditioning system. In the past several decades, lot of experiments and theoretical analysis were carried out in terms of the falling film flow pattern and the heat and mass transfer performance [1–4]. Hu et al. [5] classified the inter-tube flow into five modes: droplet mode, droplet-jet mode, jet mode, jet-sheet mode and sheet mode. Xu et al. [6] analyzed the effects of liquid load, evaporation temperature and tube diameter on the falling film evaporation. In addition, according to the different heat transfer performance, three regions [7], impingement zone, which had a higher HTCs, thermal developing zone, where the fluid was superheated and no evaporation occurs, and fully developed region, where evaporation at the interface existed, were distinguished for falling film evaporation process around tubes.

With the developing of enhanced heat and mass transfer technology, many researches had focused on the enhanced tubes [8–10]. Zhao et al. [8] studied the heat transfer performance of R134a and R123 for four enhanced tubes and a smooth rube. Li et al. [9] investigated four types of tubes and found that the surface structures of tube had great influence on heat transfer performance. Thome et al. [10] investigated enhanced tubes falling-film evaporation and boiling characteristics using refrigerant and proposed an empirical approach to predict falling film heat transfer coefficients. It should be pointed out that the above mentioned efficient methods mostly were used at the high spray density due to the surface wettability.

As for low spray density, both the flow mode and the dry spots play a key role for the heat and mass transfer performance. At low spray density, the inter-tube flow mode maintained the droplet mode which provided a higher heat and mass transfer performance compared with the other flow modes due to the refreshment of liquid-vapor interface and low film thickness [11–12]. However, for the higher spray density, wavy film and turbulent film resulted by droplet impact had been considered for the improvement of heat and mass transfer [13]. Few works considered the temperature evolution especially for horizontal falling film at low spray density, which is crucial to the heat and mass transfer microcosmic mechanism of falling liquid film [14–16]. Kabov et al. [14] experimentally and theoretically studied the film temperature distribution and the effect of the Marangoni effect in the heated falling liquid films. Zhang et al. [15] revealed that the temperature distribution of heated water films were evidently contracted in the lateral direction by the transverse surface tension gradient using infrared camera on a vertical heated/cooled plate. Wang et al. [16] used the coated division tubes to investigate the effect of the surface configurations on temperature evolution for vertical tube falling film at a relatively lower liquid spray density.

Most previous researches had focused on the falling liquid film heat and mass performances at high spray density due to the surface

* Corresponding author.
E-mail address: xuehuma@dlut.edu.cn (X. Ma).

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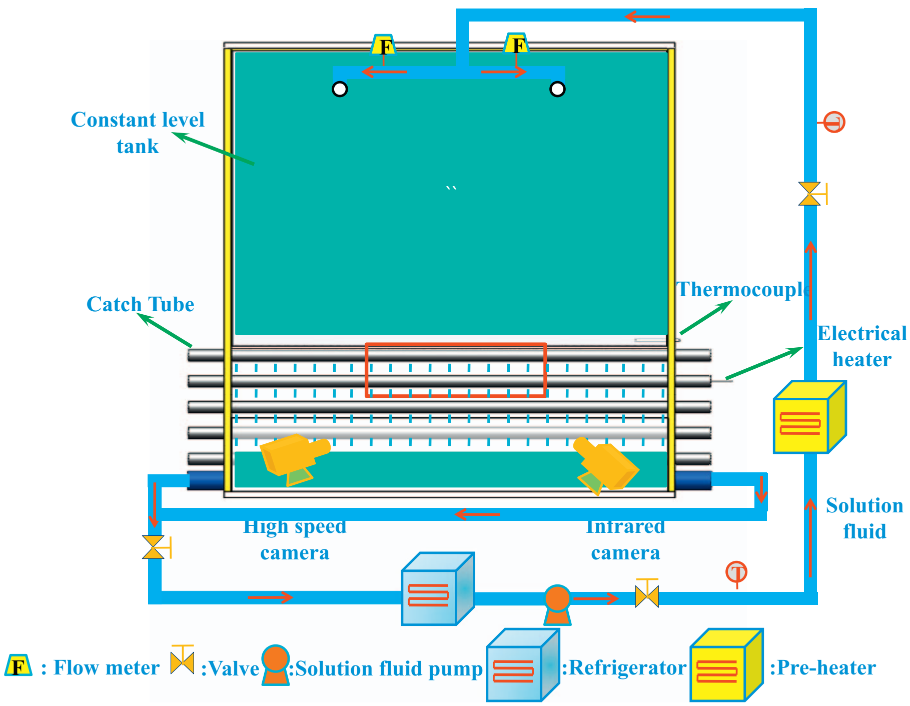


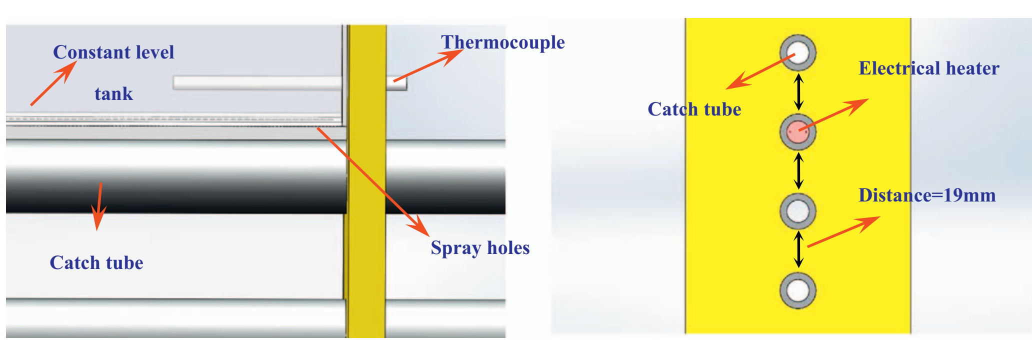
Fig. 1. Schematic of experimental setup for falling film heat exchanger.

wettability. Our recent experiments found that the superhydrophilic surface could intensify the heat transfer performance, especially at very low spray rate [12]. Furthermore, the temperature distribution of falling liquid film around a horizontal superhydrophlilic tube at low spray density are absolutely beneficial to explore the comprehensive understanding of heat and mass transfer process and the enhancement mechanism. Hence, in the present paper, the temperature distribution and local temperature evolution at low spray density were further experimentally investigated by thermal tracing method with a highly sensitive infrared camera and a high speed camera.

2. Experimental setup and procedure

Fig. 1 showed the schematic diagram of experimental setup, including falling film system, high speed video/infrared camera system, and electrical heater. The falling film systems were consisted of refrigerator, pre-heater and spray system. During the experiments, water was pumped into pre-heater where the liquid was heated to specified temperature by an electrical heater. Then, the water passed through a rotameter to a liquid distributor. The local magnification of the liquid distributor was indicated in Fig. 2. It had two sections, as shown in Fig. 2(a), including the constant level tank and catch tube to promote uniform liquid film along the tube length. And 334 spray holes of 1.2 mm diameter were drilled in a row with spacing of 1.5 mm on the bottom of the constant level tank. The distance between the constant level tank and catch tube was 1.5 mm. The water exuded from the spray holes and impinged on the catch tube. Then, liquid flowed through and formed uniform liquid film by gravity on the superhydrophilic surface. The electrical heater had two sections: electrical heating rob and variable transformer. During the experiment, the liquid film was heated by an electrical heater in tube side and constant heat flux was controlled by a variable transformer. The distance between the distributor and upper test tube and between the test tubes was equal, 19 mm, as shown in Fig. 2(b). It should be pointed that the middle part of the test tube was selected as the test area, as shown in Fig. 1 by a red box.

The temperature field on the test tube surface could be measured and analyzed by a highly sensitive infrared camera, THERMOVISION A40 (FLIR SYSTEM AB, Sweden), with the accuracy of ± 0.1 K and the spatial resolution of 0.08 K at 30 °C. The initial temperature of water was recorded online by two T-type thermocouples with uncertainty of ± 0.05 K, which all T-type thermocouples applied in the experiments were calibrated in high-precision constant-temperature bath (FLUKE9171, America) and a standard platinum resistance thermometer calibrated by the National Metrical Laboratory of China. The



(a) Local magnification of distributor (b) The image of inter-tube distance

Fig. 2. Image of spray distributor and inter tube distribution.