Condensation heat transfer enhancement by copper based superhydrophobic surface modification

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Introduction

Dropwise condensation is difficult to produce and maintain for a long time on conventional metals. The hydrophobic coating was prepared by electrostatic spraying on the copper-based heat exchanger surface to realize the transformation from filmwise condensation to dropwise condensation during the condensation process. The prepared hydrophobic material and thermosetting powder with a ratio of 5:1 showed the best stability performance with a contact angle of 154.3° and the best coating performance. The gas condensation experiments on the heat exchanger surface showed that the superhydrophobic filmwise could effectively achieve droplet jumping and self-removal, and the high temperature airflow did not cause the superhydrophobic filmwise to peel off or lose its superhydrophobic performance, and the heat transfer coefficient was 38% higher than that of conventional coils. [1,2].

Experimental setup

System setup

The system consists of temperature sensor (MIK-WZPK, Hangzhou meacon Automation Technology Co., Ltd.), micro electromagnetic pump (KP1, Dongguan Caurent Electronics Co., Ltd.), paperless recorder (MIK-R6000C, Hangzhou Mike Sensing Technology Co., Ltd.), steam generation system, water pump, pressure gauge, valve, water tank and some connecting pipes. Firstly, a micro electromagnetic pump and a pressure gauge are connected at both ends of the steam generation system. The copper-based heat sink is placed above the steam outlet of the steam generation system, and a acrylic plate is placed around it. The inlet and outlet ends of the copper-based heat sink are connected with a temperature sensor respectively, and a pump is installed on the inlet and outlet path to realize the circulation of cooling water. The system schematic diagram and the physical diagram are shown in Fig.1(a) and (b), respectively.

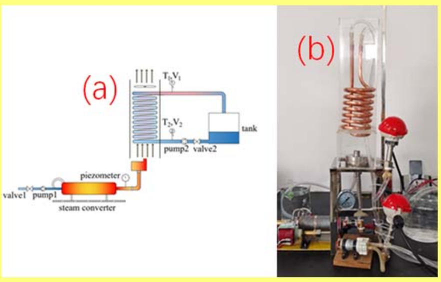

Fig.1. System schematic diagram, physical diagram

Experiment

1.Preparation and characterization of hydrophobic film

Hydrophobic copper stearate powder was prepared by the reaction of anhydrous copper sulfate with sodium stearate. It was mixed with epoxy resin in the ratio of 5:1 by mass and coated on the copper sheet uniformly by electrostatic spraying method. The powder was cured in an oven at a temperature of 80 °C for 12 h and then removed. As shown in Figure 2a,b, the light blue copper stearate powder evenly covers the copper base surface, and the film is stable and not easy to peel off. The surface water droplets appear as full spheres and do not appear to be spreading. SEM images are shown in Fig. 2c, and the microscopic morphology shows scale-shaped and staggered stacking arrangement, forming a micro- and nano-graded structure. Its static contact angle was tested to reach 154.3°, and the superhydrophobic film layer was successfully constructed on the copper surface.

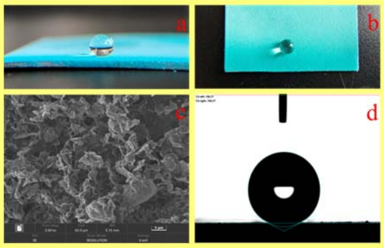

Fig.2. Superhydrophobic film on copper surface (a,b), microstructure of superhydrophobic film (c), static contact angle test diagram (d)

2.Heat transfer enhancement study of heat exchanger

The same process conditions were used to construct a superhydrophobic film on the coil heat exchanger surface to realize the transformation of its surface filmwise condensation to dropwise condensation and to strengthen the heat and moisture transfer during water vapor condensation. The steam generation system is used to provide constant steam to the coil heat exchanger without interruption, as well as to enable high-precision temperature and flow measurement. The unit design diagram is shown in Fig. 3.

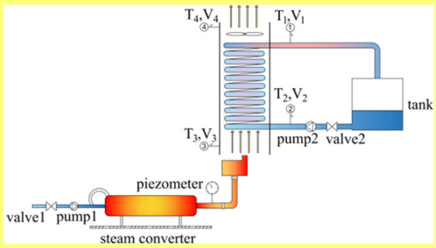

Fig.3. System structure diagram

In the condensation process, the total heat transfer coefficient can be calculated by the following equation

$$k = \frac{1}{\left(\frac{1}{h_0} + r_0\right) + r_w + r_i\left(\frac{A_0}{A_i}\right) + \frac{1}{h_i}\left(\frac{A_0}{A_i}\right)}$$

where:

h_i、h_o - heat transfer coefficient of the inner and outer side of the tube, W/(m2·K)

r_i、r_o - thermal resistance of the inner and outer coating of the tube;

r_w - thermal resistance of the tube wall thermal conductivity;

Results

As shown in Fig. 4c, when water vapor comes in contact with the wall of the copper tube below its saturation temperature, the condensate quickly spreads into a liquid film and adheres to the wall. It continuously accumulates until gravity is greater than the viscous force and slowly slides off from the wall. As shown in Fig. 4b, when the surface of the heat exchanger coil is transformed into a superhydrophobic state, the condensate cannot wet the wall surface well and forms multiple small droplets and then drips down rapidly, which can effectively achieve droplet jumping and self-removal. The heat transfer performance of the tube was studied in convective heat transfer experiments. Due to the good balance between droplet nucleation and separation, the heat transfer coefficient of the superhydrophobic tube was increased by 38 % compared with that of the copper tube. The superhydrophobic film did not peel off or lose the superhydrophobic performance when the high temperature air flowed through.

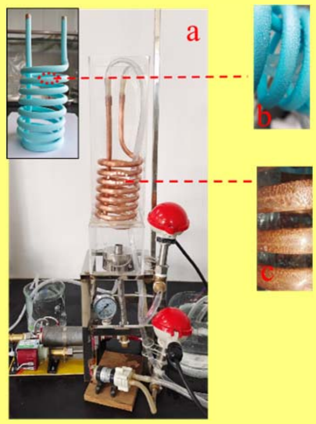

Fig. 4. System picture

Conclusions

The superhydrophobic film was prepared on the surface of copper-based heat sink by electrostatic spraying technology. The effects of different mixing ratios of hydrophobic materials and thermosetting powders on the properties of hydrophobic films were studied. When the ratio increases from 1:3 to 1:5, the static contact angle of the superhydrophobic surface decreases first and then increases. When the mixing ratio was 1:5, a superhydrophobic structure was formed on the copper substrate surface, and the static contact angle was 153.4°, which could still maintain superhydrophobicity in high temperature airflow. The heat transfer coefficient of the superhydrophobic heat exchanger was 38% higher than that of the conventional heat exchanger under a steaady steam flow.

References

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