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Study on restraining frost growth at initial stage by hydrophobic coating and hygroscopic coating

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ABSTRACT

For finding an effective method of restraining frost growth, the growing processes of frost on the surfaces of normal copper, hydrophobic coating (car wax coating) and hygroscopic coating (glycerol coating) were studied experimentally. The processes were recorded by photography. The quantitative analysis to the experimental images by digital image processing method was conducted. The results indicate that there is evident effect of hydrophobic coating and hygroscopic coating on frost growth at initial stage. Compared to normal copper surface, frost on the hydrophobic coating surface and on the hygroscopic coating surface appears later with lower frost height, sparse distribution and less aggradations of ice crystals. There is no evident effect of hygroscopic coating thickness on frost height. However, there is evident effect of hygroscopic coating thickness on frost height. The thicker the coating is, the effect on frost growth is bigger. Therefore, frost growth can be restrained by both hydrophobic coating and hygroscopic coating at the initial stage of its formation, and application of hydrophobic coating and hygroscopic coating to heat exchanger in refrigeration and air conditioning equipments would be promising.

1. Introduction

Energy consumption of heating, ventilation and air conditioning in housing occupies about 55% proportion in China and 65% in North America and Europe. In southern part of Yangtze River in China and Europe, air-cooled heat pump has high prevalence because of its outstanding energy saving effect. Southeast University [1–4] has been in-depth studying on the air-cooled heat pump, and not only proposed the efficient energy saving programs, but also investigated stable operation of this system. Frost occurs during the operation of air-cooled heat pump, directly affect not only the system's energy consumption, but also its stable performance [5–7]. This paper investigates frost effect on different surfaces, and explores frost mechanism, which is a good foundation for both fundamentally solving frost problems of air-cooled heat pump and providing protection of stable and energy-saving operation of air-cooled heat pump, so as to achieve housing energy-saving effects.

More and more attention has be given to frost growth since 60s of 20th century. Hayashi et al. [8] studied experimentally about frost growing processes, and indicated that frost formation might consist of three stages: crystal growth, frost growth and full growth of frost layers. Sami and Duong [9] concluded that the water vapor diffusing into frost layers could be divided into two parts: one part was to increase the density of frost layers, and the other was to increase the height. As a result, the height and the density of frost layers would increase with time. Tao et al. [10] studied the initial stage of frost growth on a plane plate, and they thought that frost formation consisted of two stages: in the first stage, the water vapor coagulated into water drops, and then became ice balls; in the second stage, ice balls began to grow.

In order to decrease the influence of frost layer on the performance of heat exchanger, some methods should be taken to remove the frost layers when they come to a certain height. However, it would absorb heat from the heat exchanger and indoor environment while removing frost. In addition, it would take a long time to remove the frost, which might influence the indoor comfort [11]. Besides, if the water drops after frost thaw were not removed thoroughly from the outdoor heat exchanger, the following refrigeration would make ice layers appear on the surface of the heat exchanger. In order to avoid the negative effect above, some measures can be taken to postpone the frost growth and to remove the water left on the surface after thaw as soon as possible. At this rate, the time interval of removing frost would be extended, and also the time of removing frost would be shortened.

At present, it was reported that different contact angles had important influences on the configuration and the distribution of frost. Seki et al. [12] and Hoke et al. [13] had studied frost structure on the hydrophobic coat surface. They thought that the density of frost layer on hydrophobic coating surface was relatively big; however, Ryu et al. [14] had the opposite results. So it is necessary to

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study and contrast frost growth on different surfaces and to find an efficient method of restraining frost formation.

2. Methodologies

The whole experiment setup consisted of four parts: (1) refrigerating unit; (2) temperature measurement setup; (3) image collecting system and (4) environment controlling system. Fig. 1 shows the experiment setup.

The experiment adopted semiconductor as refrigerating unit. With voltage on two poles of the semiconductor, there would be fixed temperature difference between the two poles. The circulating water was used to cool the hot pole of the semiconductor refrigerating slice (TEC1-12708T125).

In order to study the influence of different surface contact angles on frost growth, such materials as follows were used to create different frosting surfaces:

(1) Slick normal copper surface. First purple copper was processed by a milling machine, and then was polished with sand papers.
(2) Copper surface with car wax coating. After processed by milling machine and polished by sand papers, the copper surface was smeared with car wax. The main components of wax are silicon–ketone compound and lipid. The contact angle was 108°, which was a hydrophobic surface.
(3) Copper surface with glycerol coating. After processed by milling machine and polished by sand papers, the copper surface was smeared with glycerol, which was a hygroscopic surface.

Several groups of copper plates were prepared in the experiment, and each group had three copper plates with different coatings.

The dimensions of the materials were 40 mm × 40 mm × 1.5 mm. Four pinholes, whose diameters were 2 mm, were drilled in each cold surface for installing thermocouples, as shown in Fig. 2.

After electrifying the refrigerating unit, the temperature began to decrease. The temperature varied similarly on three different surfaces when the wax coating was thin, as described in Fig. 3.

Fig. 4 shows the microscopically photograph system which was used in the experiment. The system consisted of the microcomputer, the system display, the image collecting card, the microscope, the CCD video, the system software, and so on. Optics microscope system was comprised of the ocular, the objective, and the lighting system. Objective was more important in contrast with the ocular, because the reflex light from the cold surface collected by the objective determined image information. In the experiment, three-ocular body style microscope made by the HengYe Apparatus Factory was used to magnify observation (the maximal blowup rate up to 320; therein the optics blowup may be 2, 4, 8). In order to achieve a better observation effect, critical lighting that had enough brightness and produced little heat was adopted in the experiment, which could ensure the quality of the image and make little influence on ambient environment at the same time.

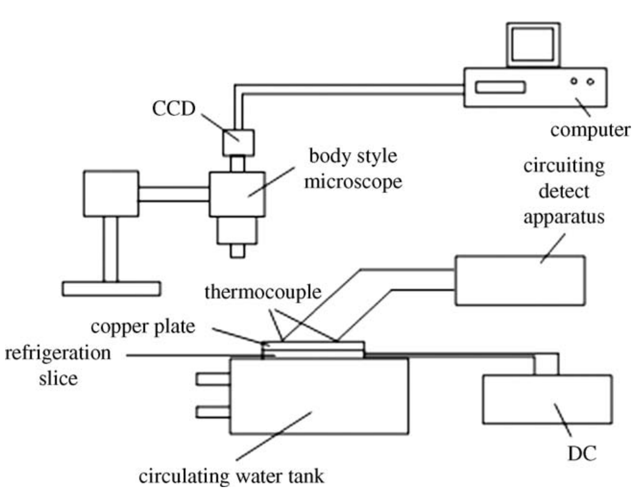

Fig. 1. Experiment setup.

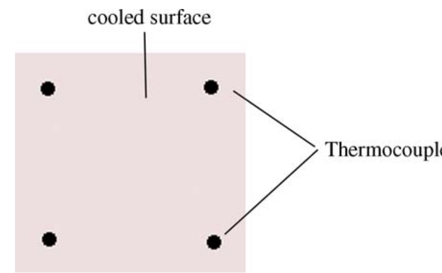

Fig. 2. Schematic diagram for burying thermocouples.

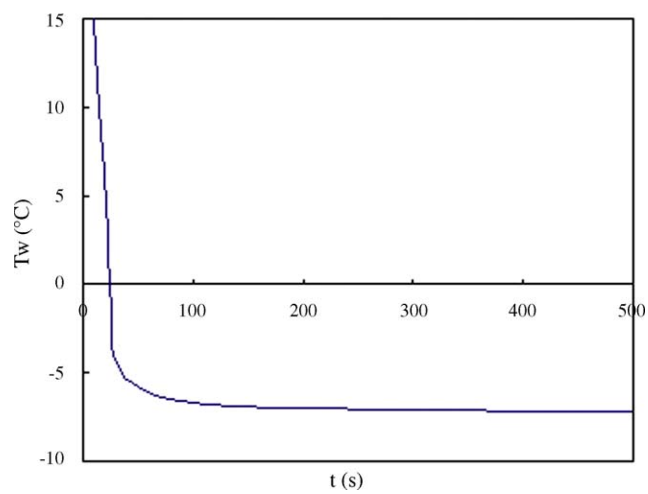

Fig. 3. Temperature curve of cold surface with time.

The experiment was done in the constant-temperature and constant-humidity room. The air velocity in the room was almost constant value about 0.25 m/s, and temperature fluctuation was less than 0.5 °C as well as relative humidity fluctuation less than 3%.

The repeatability of experiment is well. The main factors, affecting frost growth, are environment temperature, humidity, coating thickness, contact angle and the surface temperature of copper. All of these parameters were controlled precisely. From the microscopical point of view, the growth of frost is stochastic. But from the macroscopical point of view, the frost layer height, density and other parameters are statistically stable.

3. Results and discussion

Many experiments were made on each group, and one of the experimental results of each group is shown in this paper.

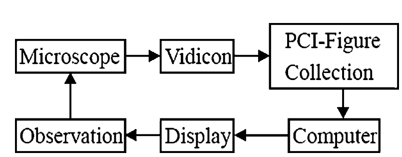

Fig. 4. Schematic diagram for image collecting system.