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Review of restraint frost method on cold surface

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A R T I C L E I N F O

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A B S T R A C T

Many researchers have focused on the investigation into frost formation mechanism and tried to find various effective defrosting methods in recent years. Study on frost is divided into three stages: the frost formation process and mechanism, defrosting methods, and restraint frost methods. The three stages are carried out sequentially or in parallel. Compared to defrost, restraint frost is becoming more welcomed by peoples because of no energy or smaller consume. The affecting factors on frosting directly induce frost formation on cold surface, which leads to blockage, performance decrease, and even malfunction of the low temperature heat exchanger. This paper divides the factors into three categories: the characteristics (temperature, humidity and velocity) of the moist air, the features (temperature, structure and position, treatment) of the cold surfaces, the interaction between the air or the formed frost and the cold surface (electric field, ultrasonic wave, magnetic field, oscillation effects). One or several of the factors must be changed in order to restrain frost formation. Relative humidity is considered as that it has a larger effect on the frost formation, compared to the air temperature and air velocity. However, only a few researches pay attention to the restraint frost by controlling the characteristics of moist air. The structural parameters such as the fin spaces have the most important effect on the heat transfer performance of a heat exchanger under frosting conditions. Therefore, an optimization of the heat exchanger design should be considered for restraint frost. Hydrophobic surface is recognized as an effective way to improve the energy efficiency of a refrigeration system under frosting conditions. However, the research results are not as satisfactory as expected because of the difficult fabrication of scalable hydrophobic properties.

1. Introduction

Frost formation is a very common phenomenon in cryogenic, refrigeration, and air conditioning engineering . Frost deposition on the cold surfaces produces a series of negative effects on heat transfer equipment, for example , increasing heat transfer resistance and resulting in poor heat transfer performance . In addition , frost layers may block flow passage and increase pressure loss . As an important energy saving equipment, heat pump is limited to the extensive application under frosting conditions. If the situation is out of control , malfunction or damage of the equipment may occur . Micro channel heat exchanger also faces the same problem although it has very high heat transfer efficiency under no frosting conditions. Many researchers have focused on the investigation into frost formation mechanism and tried to find various effective defrosting methods in recent years. Study on frost is generally divided into three stages: the frost formation process and mechanism studies, defrosting methods studies, and restraint frost methods studies. The three stages are carried out sequentially or in parallel. Some basic studies have been developed to research the frosting formation on the simple-shaped cold surfaces, in which the frosting growth process and mechanism [1,2] and the frost shape transformation [3–5] were investigated. A few methods and correlation equations were proposed in order to predict the frost property [6,7]. Defrosting methods had been investigated, including: (1) hot water spray [8], (2) electric heating [9,10], (3) compressor shut-down [11], (4) hot gas by-pass [12–14], (5) reverse cycle [15–17], and (6) using an air-particle jet [18].

However, defrosting process needs consume a lot of extra energy, which makes the total efficiency of the equipment decrease. Therefore, it's very necessary to carry out the research of restraint frost. The definition of the restraint frost is that the frost formation process is restrained by using a certain method, which induces that no frost is formed on the cold surface or the frost grows slowly. According to the former literatures, restraint frost can also be described as retardation frost, inhibiting frost, anti-frost, prevent frost, frost retention etc.

There are three following factors, which affect the frost formation :

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the characteristics (humidity, temperature, and velocity) of the moist air, the features (temperature, structure and position, treatment) of the cold surface , the interaction between the air or the formed frost and the cold surface (such as electric field, ultrasonic wave, magnetic field, oscillation effects etc.). According to the mechanism of frost formation, one or several of the above factors must be changed in order to restrain frost formation.

In this paper, research progress of restraint frost technology is summarized, and a variety of possible influencing factors are reviewed and summarized for each restraint frost method in recent years. In addition, the future research and potential application of restraint frost technologies are presented.

2. Restraint frost by changing the characteristics of the moist air

When the moist air passes the cold surface, vapor in the air may be possibly condensed, and be changed into frost. Vapor which exists in the moist air is the sources of the frost. However, in cases where the moist air temperature is cooled down to the dew-point, and the cold surface temperature is below 0 °C, the frost formation may occur. If both the surface temperature and the moist air dew-point are below 0 °C, de-sublimation phenomenon may occur, i.e., the vapor may change straightly into frost crystal [19]. Temperature difference between the cold surface and the air dew-point results humidity difference between the moist air and the cold surface, which is called super saturation degree. The frost formation process can be considered as a result of three continuous processes of humidity change as illustrated in Fig. 1. The moist air (A) is firstly cooled down to the dew-point (B), and then the temperature is cooled down to super cool temperature (C). Eventually, the phase change process takes place, the state of the moist air reaches to D point, and the frost formation occurs.

The above process indicates that the temperature, humidity of the moist air and the cold surface temperature are the most important factors affecting on the frost formation, other factors such as the velocity of the air stream may change the development process of the frost formation, so it possibly produces effects on the frost formation [20].

2.1. Humidity

By theoretical and experimental investigation in laminar flow over the cold flat surfaces under conditions of variable and constant humidity, Max Kandula [21,22] revealed that relative humidity has considerably larger effect on frost thickness compared with the air temperature and air velocity. Xu et al. [23,24] investigated the performance of micro channel heat exchangers under moisture and frosting conditions. They found that the air humidity had a significant effect on the rate of frost formation, whereas the air velocity had a small effect on the process of the frost formation. Matsumoto [25,26] investigated that the characteristics of frost crystals (dimensions, distribution and scraping force) under constant cold surface temperature and the air humidity by using a scanning probe microscope (SPM), which resulted that the frost crystals formation, was influenced by the cold surface temperature rather than by the air humidity in the range of higher air humidity levels, while in the range of lower air humidity levels, it was clarified that frost crystals formation was influenced by the air humidity rather than by the cold surface temperature.

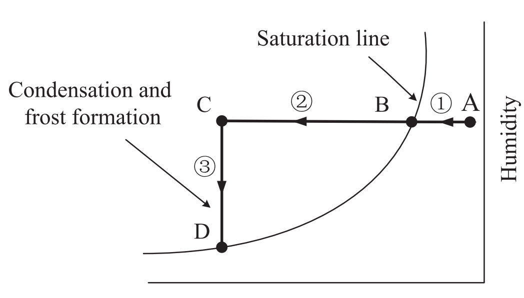

Fig. 1. Condensation and frost formation process.

All above references considered the air humidity as the most important factors affecting the frost formation process, but the specific methods by controlling the air humidity to restrain the frost formation were not presented. Generally, following several methods can be used for controlling humidity.

2.1.1. Pre-condensing

When the moist air is cooled down to the dew-point, a part of the vapor in the air can be pre-condensed and then drained out, therefore, the partial pressure of the vapor in the moist air declines, which leads to a smaller phase transition driving force and hence results in a longer time for the process of droplet growth and frost formation [27–29].

2.1.2. Absorption/adsorption of moisture

Air dehumidification technology can be realized by absorption/ adsorption of moisture by a solid or liquid desiccant [30–32], which has the special advantages that the sensible, the latent heat and vapor in the air can be processed separately. According to the references, the desiccant air dehumidification systems are quite efficient in dealing with removal of the partial vapor in the moist air.

2.1.3. Other methods such as membrane-based dehumidification, vapor-air separation, and electrochemical dehumidification etc

Refrigeration dehumidification system with membrane-based total heat recovery is reported in the Refs. [33–35]. The research results show that the performance coefficient of air dehumidification is approximately 2.3 times than a traditional refrigeration dehumidification system, as (1) and (2) mentioned.

Vapor-air separator is generally combined with other technology to realize dehumidification, such as pre-condensing, which is seldom used for dehumidification individually. Refs. [36,37] reported steam-water separators technology which was used in nuclear power plant.

A special dehumidification method was presented by Iwahara [38]. He studied electrochemical dehumidification method by using a proton conducting ceramic as a solid electrolyte. This dehumidification method may be suitable for some special apparatus such as scientific instruments. The working principle of electrochemical dehumidification is described in Fig. 2.

The dehumidification objectives of above researches are mainly for air conditioning process, frosting phenomenon is not considered during the dehumidification process. However, the dehumidification methods can also be used for restraint frost. Wang et al. [39] adopted solid adsorbent for preventing heat pump from frosting. Fig. 3 shows the principle of the adsorbent bed, which is made up of zeolite plates, active carbon coat and an electrical heater. When the moist air passes through the zeolite plates and active carbon coat, the water molecules are adsorbed, the humidity is reduced. The electric heater is as an extra heat source for desorption. The research result shows that not only does air humidity decrease, but also air temperature rise for absorbing adsorbing heat. As a result, the frosting problem in the evaporator of the pump is resolved, and the performance coefficient of the equipment is improved in winter.

With the atmospheric pressure decreasing, the partial pressure of the vapor in the moist air declines, which leads to the relative humidity declines and hence results in the effect of restraint frost. Chen et al. [28] investigated the effect of the atmospheric pressure on the frost formation process by visualization experiment under natural convection condition. The results indicate the frost crystal shape transforms from irregular to a columnar type and then to a dendritic type with the atmospheric pressure increasing, what's more, the frost layer turns to