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Research of anti-frosting technology in refrigeration and air conditioning fields: A review

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ABSTRACT

Frost formation is inevitable in refrigeration and air conditioning fields. Frosting heavily impacts on the operating efficiency of equipments, and leads to considerable energy consumption for defrosting. This study reviewed anti-frosting techniques in refrigeration and air conditioning fields, including air dehumidification by solid/liquid desiccant, ultrasonic vibration, external electric/magnetic field, surface treatment, etc. Although air dehumidification is an effective method to delay frost formation, the problem of desiccant regeneration prevents this method from practical application. The methods of ultrasonic vibration and external electric/magnetic field are not suitable for large or medium-sized fin-tube evaporator, which result in additional investment and energy input. Besides, the anti-frosting effect of electric/magnetic field is not obvious and needs to be verified by more experiments. However, surface treatment has advantages of high efficient, low cost, environmental protection and practicability. In particular, the superhydrophobic surface shows excellent performance in frosting prevention and defrosting improvement. This is of great significance for energy saving in refrigeration and air conditioning fields. If the strength problem can be further improved by simple preparation methods, it will be a promising anti-frosting technique to deal with the phenomenon of frost formation in refrigeration and air conditioning fields.

1. Introduction

Frost formation is a common and detrimental phenomenon in refrigeration, air conditioning and other cryogenic fields [1–3]. When the surface temperature is below both the dew point of local air and freezing point of water, frosting will happen on the fin-tube evaporator surface in refrigeration equipments. Frost layer can block fin gaps, causing air flow and heat transfer to decrease [4–6]. This eventually decreases the operating efficiency of refrigeration equipments. Besides, frost formation will lead to considerable energy consumption. On the one hand, the electricity consumption of refrigeration equipments increases when running with frosting; on the other hand, defrosting will consume a lot of energy to melt frost layer and evaporate frost melting water. Take air source heat pump (ASHP) as an example. It is well known that ASHP is widely used as cooling and heating sources to provide energy for air conditioning system, due to its advantages of energy saving, environmental protection and flexibility [7–9]. However, frost formation is easily to occur on the cold surface of its fin-tube evaporator when the environment temperature is between −15.0 °C and 6.0 °C and RH > 60%, and the heating capacity can decrease by 30–57% [10]. Moreover, the defrosting energy consumption accounts for more than 12.9% of the heating capacity during a defrosting cycle [11]. Therefore, to ensure the efficient operation of the equipments and reduce the energy consumption caused by frosting, it is significant to develop effective anti-frosting technology.

Understanding the process and mechanism of frost layer growth on a cold surface is the prerequisite to explore effective anti-frosting technology. According to the growth characteristics of frost layer, Hayashi et al. [12] divided frosting process into frost nucleation period, frost layer growth period and frost layer fully growth period. This conclusion now is generally recognized. Wu et al. [13] observed that frosting process generally began with formation and freeze of condensate droplets. And then frost crystals formed on the surfaces of freezing droplets, which finally developed into macroscopic frost layer, as shown in Fig. 1. The frosting process can be described as follows (see Fig. 2) [14,15]. The water vapor in local air firstly forms condensate nucleus on the cold surface (i) and the nucleus grow to condensate droplets (ii-iii). As the temperature of the condensate droplet decreases, it gradually freezes. Then, frost crystals grow on its surface (iv-viii). Frost crystals continue to grow, and gradually form frost layer (ix).

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Nomenclature

T	temperature (°C)
RH	air relative humidity (%)
w	absolute humidity (g/kg)
u	air velocity (m/s)
Q	total heat transfer rate (kW)
$H_{total,\ sen}$	overall heat transfer coefficient (kW/(m^2 K))
A_{out}	heat and mass transfer area on the air side (m^2)
h_{out}	heat transfer coefficient on the air side (kW/(m^2 K))
M_v	mass transfer rate of moisture (kg/s)
q_{st}	adsorption heat (kJ/kg)

Greek symbols

θ	contact angle (°)
θ_a	advancing angle (°)
θ_r	receding angle (°)
$\Delta\theta$	contact angle hysteresis (°)

Subscripts

s	surface
a	air
b	brine
in	inlet
ref	refrigerant

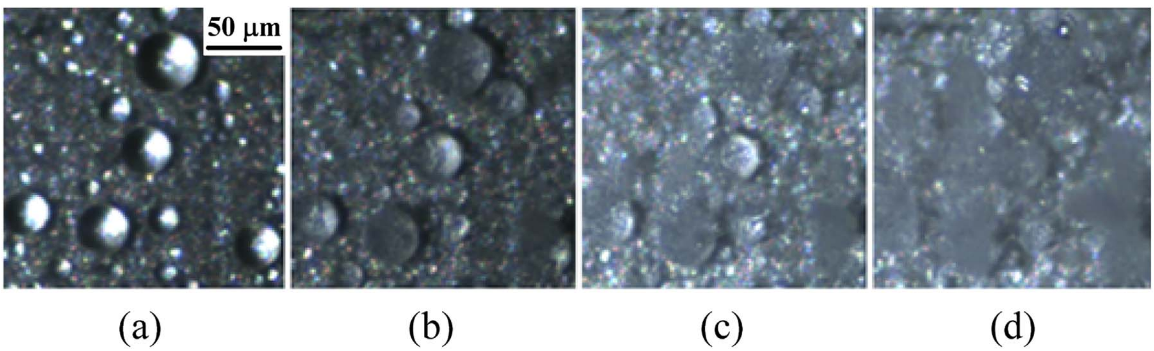

Fig. 1. Visualization of frost formation on cold surface (T_s = − 10 °C, T_a = 12 °C and RH = 75%). (a) Formation and growth of condensate droplets; (b) freezing of condensate droplets; (c) formation and growth of frost crystals on freezing droplets; (d) frost layer growth.

The frost layer growth continues until the supercooling degree of the frost layer surface approach zero. Then, the frost layer stops growing in thickness and the diffusion of water vapor into the porous medium leads to the increase of frost layer density. In conclusion, the frost formation is a phase change process of water vapor in air by means of cold surface. Important parameters that affect frost layer growth on cold surface are air velocity, air temperature and humidity ratio, surface temperature and surface characteristics.

Full understanding of the frosting process on cold surface contributes to exploring effective anti-frosting technology. According to the influence parameters on frost formation, researchers have put forward various anti-frosting techniques, including air dehumidification by solid/liquid desiccant, external electric/magnetic field, ultrasonic vibration, surface treatment, etc. In particular, with the development of various new materials in recent years, the study of surface treatment on restraining frost formation has become a hot topic focused on by researchers worldwide. In this review, the literatures which reported anti-frosting techniques in refrigeration and air conditioning fields were selected to discuss and summarize. And the development of anti-frosting technology was analyzed and research prospect for future study was put forward. This review will help the researchers to achieve an overview and prospect about various anti-frosting techniques in refrigeration and air conditioning fields, and to know the advantage and drawback of using different anti-frosting techniques.

The literatures in this review were reviewed by common method used in most reviews. At first, a guideline for selecting literatures was developed. According to the objective of this review, the literatures, which reported the anti-frosting research in refrigeration and air conditioning fields or applied to the fields potentially, were selected. Then, the appropriate literatures were collected. In order to collect the literatures as soon as possible, the word "frost" was entered in several search engines and databases. And the literatures were selected according to the selecting guideline. Next, the selected literatures were classified according to different anti-frosting techniques. This process was done with the help of CiteSpace software [16,17]. The anti-frosting techniques included air dehumidification by solid/liquid desiccant, external electric/magnetic field, ultrasonic vibration, surface treatment, and other assistant methods. Then, knowledge was achieved by reading these literatures. The literatures were mainly concerned from following four points: (i) what was the frosting condition? (ii) which anti-frosting technique was used? (iii) which stage of frosting process was focused? and (iv) what anti-frosting effect did the study achieved? Finally, combined with our experience in frosting research, conclusions were drawn and research prospect for future study was put forward.

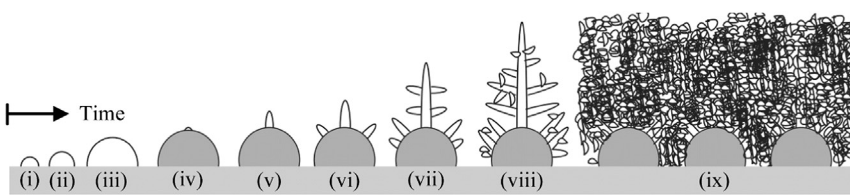

Fig. 2. Schematic diagram of frosting process on cold surface. (i) Condensation nucleation; (ii)-(iii) growth of condensate droplet; (iv)-(viii) growth of frost crystals on surface of freezing droplet; (ix) frost layer fully growth.