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Review of defrosting methods

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ABSTRACT

This study reviewed the defrosting techniques applicable for the heating, ventilation, air-conditioning, and refrigeration industry, including passive, active, and system techniques. The passive methods normally use treated surfaces by changing the surface morphology through micro-grooved, anti-frost coating, hydrophilic, hydrophilic, or superhydropholic coating. For passive defrosting techniques, the microgrooved surfaces can improve the drainage of the frost melt effectively. It is generally agreed that the superhydropholic coating can delay the initialization of frosting and provides less water adhesion during defrosting. Yet defrosting performance for hydrophobic surfaces outperforms hydrophilic and uncoated surfaces. Active and system techniques, including electrohydrodynamic (EHD), low-frequency oscillation, and ultrasonic vibration methods, hot gas reverse cycle, electric heater, desiccant dehumidifiers and controlling strategies are reviewed. The EHD defrosting method is proved to be comparatively effective in natural or laminar flow operation. Test results also indicate that utilization of alternative current source is superior to the direct current source. The electrode with negative polarity is better than positive polarity as far as frost accumulation is concerned. The low-frequency oscillation is ineffective in defrosting while ultrasonic vibration provides effective frost removal and can delay the frost growth appreciably. Test results indicate that the ultrasonic oscillation poses considerable positive influence on defrosting either operated continuously or intermittently, in direct contact or not. For system defrosting, the hot gas reverse cycle is comparatively expensive to install but the efficiency, COP, and energy consumption are superior to the other system methods. Desiccants, either solid or liquid, can be employed in association with the system defrosting methods to lower energy consumption. There were various controlling strategies to detect the frost formation and to decide the best time to initiate defrosting. However, many of them were applicable to some specific systems and environments and require further investigations to test the relevant reliability, stability, and repeatability.

1. Introduction

Frost formation is the most detrimental and significant problem that happens on the finned-tube evaporator in air conditioning and refrigerating systems. When the surface temperature is below both water freezing temperature and air dew point temperature, the frost will start to form. In other words, the frost starts to form when the contact happens between the cold surface of the heat exchanger (HX) and the near water vapor in the air due to the temperature difference. Yet the relative humidity (RH) also plays a major effect on the frost formation. Normally the frost growth rate is comparatively slow when RH is less than 40%. But when RH is high with high-temperature difference amid the cold surface and the surrounding air, the growth rate will appreciably increase. Ameen et al. [1] recorded that the frost accumulated significantly when the air temperature falls between −7 °C to 5.5 °C and RH >60%. Initially, the influence of frost on the performance is negligible, but later the frost will start to accumulate more and more and reduce the micro-gap between fins and tubes, see Fig. 1(a–c). As a result, this will affect the whole system due to the partially airflow blockage or full blockage [2]. Yet the contact resistance will reduce the heat transfer rate [3] although the air-side heat transfer coefficient may increase moderately at the beginning [4] stage. This shows the importance of keeping the air flow rate in appropriate situation since the frost formation increases subsequently [5] is highly unfavorable. Notice that a further accumulation of the frost layers may jeopardize heat transfer performance [6,7] and cause a much higher air-side pressure drop (ΔP) [3,8–12] and increase the power consumption at the same time [13], and a typical power increase is in association with fan operation [14,15]. Consequently, the coefficient of performance (COP) or the capacity of the refrigeration system will degrade appreciably and sometimes may even lead to system shutdown [16,17].

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Nomenclature

AIR	air
Al	aluminum
ASHP	Air source heat pump
ASHPWH	Air source heat pump water heater
Cu	copper
BLT	bolt-clamped Langevin-type transducer
COP	coefficient of performance [-]
D	oscillation amplitude [mm]
DB	dry bulb temperature [°C]
DE	desorption
DS	degree of refrigerant superheat
E_m	energy consumption for frost melting [kJ]
EEV	electronic expansion valve
EHD	Electro-hydrodynamics
FPI	fins per inch
f	oscillation frequency [Hz, kHz]
h	hour
HP	heat pump
HPL	high pressure liquid
HX	heat exchanger
min	minute
MRI	frost mass reduction [%]
PCM	phase change material
RH	relative humidity [%]
Q	heat transfer rate [W]
s	second
t	time [min, s]
T_{in}	inlet air temperature [°C]
T_{out}	outlet air temperature [°C]
TES	thermal energy storage
T-H-T	Temperature–Humidity–Time
T-T	Temperature–Time
TXV	thermostatic expansion valve
V	voltageable
W	power
W_{def}	wasted work for defrosting [MJ]
WB	wet bulb temperature [°C]
Y_s	frost thickness [mm]

Greek symbol

δ	frost thickness [mm]
Δθ	hysteresis contact angle
ΔP	Air-side pressure drop [mmAg, Pa]
σ_s	transverse shear force [MPa, Pa]
ΔV	applied voltage [V]
Θ	contact angle [°]
η	efficiency [%]

Fig. 1(a) depicts the schematic of the frost growth formation where the frost could be either formed directly or engendered through condensation of water droplets to frost layers passing through ice layer, frost crystals and frost branches. Hayashi et al. [18] divided the frost formation into three steps, including frost nucleation (crystal) period, frost layer growth period and frost layer fully growth period. Tao et al. [19] had verified the frost formation process which was clarified by Li and Chen [20] as illustrated by Fig. 1(b). Also depicted in the figure, as pointed out by Piucco et al. [21], upon initialization the heterogeneous nucleation growth the thickness and density will increase due to the frost accumulation and water vapor diffusion. Hence the frosted surface can be considered as a porous surface. The actual frost crystal growth on the frozen water droplet surface is shown in Fig. 1(c).

The frost accumulation will impair the heat transfer and impair the system performance. Therefore, defrosting methods are normally employed to tackle these problems where the defrost operation should start before the frost covers more than 45% from the surface to get the higher efficiency from it. There are two main methods for defrosting, namely passive and active. The former uses surface morphology to delay or reduce the frost formation without additional power consumption while the latter requires some additional power input to defrost. In this regard, the aim of the present paper is to provide a thorough review of relevant passive and active defrosting techniques. The active methods being reviewed in this study includes electrohydraulic, oscillation, ultrasonic vibration, and system methods. System methods, such as hot gas bypass, electrical heaters, desiccant dehumidifier, and defrosting controlling strategies will be also addressed in this study. This overall objective of this review will help the researchers to get a quick overview about the variety of defrosting methods, and to understand the potential benefits and drawback of using related defrosting methods.

2. Surface treatment

Surface treatment involves certain change on the surface characteristics such as the shape, geometry, structure or coating. Huang et al. [22] studied the effect of frosting and defrosting on the performance of a residential air-source heat pump (ASHP) by comparing fin surfaces of flat, wavy and louver for the outdoor unit. Their experimental results showed the flat fin had the best thermal performance, followed by wavy and louver fins. The time-average heating capacity, COP and input power for flat fin during frosting cycle were increased by 17.1%, 9.0% and 7.6%, respectively than those for louver fin. Rahman and Jacobi [23–26] investigated the influence of frost meltwater drainage on microgroove brass surfaces which were fabricated by a micro-milling process and was compared with the flat baseline surface. They noticed some significant effects on meltwater retention through surface roughness and groove geometry variation. Test results indicated that frost mass per unit area decreased substantially in the first and second frost cycles for the microgrooved samples and drain up to 70% more condensate than the flat brass surface. They also found that the variation of frost properties becomes repeatable and periodic from the third frosting cycle. Yet using microgrooves on a flat surface could lead to an increase in the frost thickness and a decrease in the frost density in all frosting cycles by about 5–25%.

Rahman and Jacobi [27] further conducted an experiment on aluminum (Al) and copper (Cu) microgrooved surfaces fabricated by photolithography and wet etching, respectively. They found the difference between these surfaces and flat baseline surfaces in frost formation. Basically, the shapes and distribution were consistent with their previous studies on brass samples [23–26]. Fig. 2 shows the water droplets shapes on Al microgrooved (in the orthogonal direction to the grooves) and flat baseline (polished baseline) surfaces. They found that the size and water droplets distribution for the flat baseline surface were random and comparatively large as compared to that of microgrooved Al surface. In the case of meltwater retention, the Al microgrooved surfaces improved the drainage of the frost melt in all the frosting cycles subject to various surface temperatures and different RH, even though the RH does not cast any effect on the frost density. In the meantime, the flat surfaces increase the frost retention and drainage in the subsequent frosting cycles. On the other hand, the microgrooved surface revealed about 56% reduction in frost meltwater retention in the 5th cycle as compared with the baseline of the polished Al surface. They also measured the frost mass ratio (frost meltwater retention ratio), and indicated that the ratio is always less than 0.5 for