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Review of passive defrosting surface methods in refrigeration systems

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Abstract

The present study reviewed the surface passive defrosting techniques applicable for the HVAC and R industry. There are three main methods of defrosting. The easier one is via on-off defrosting which simply involves periodic on and off of the refrigeration system. It's simple and cheap method but it's not effective. The second defrosting method is via electric resistive heaters. And the same for this method where it's not only expensive but also consumes high energy. The third method of defrosting is by hot or cool gas. In spite of its complexity, the coefficient of performance (COP) in defrosting is better than the other defrosting methods. The previous methods belong to system defrosting techniques.

The surface treatment defrosting classified as a passive technique and it's consider a revolution in this field from long time ago. This study showed that any change on the surface will lead to change on the frost.

The microgroved surface is better than flat surface in the shape, size, melt water retention and in the reduction of frost melt-water retention. Further, the polished baseline is better than unpolished and similar to microgroved in some cases.

Also, the anti-frosting paint proved its ability delay the frost accumulation and reduce the frost weight and thickness. Furthermore, the frost structure coated surface is loose and fragile while it's dense and thick in uncoated surface.

Moreover, the surface geometry and temperature played a high factor on the frost formation and frosting time whereas the surface coatings and water retention played a minor effect.

The microchannel coating heat exchangers outstanding on finned-tube surface in water retention reduction.

The superhydrophobic surface showed a superior on bare, hydrophilic and hydrophobic surfaces in delaying the frost, frost thickness, frost mass, ΔP, total heat transfer, defrosting time, retained water ratio and energy consumption.

Finally, the surface treatment has a good benefits in fighting the frost especially using a superhydrophobic coating due to the effectiveness that shown for it in defrosting.

Keywords: Off cycle defrosting; Electric defrosting, Hot gas defrosting, Passive, Surface treatment, Superhydrophobic.

1 Introduction

1.1 Problem background

Frost phenomenon is the most detrimental and significant problem that happens on finned-tube evaporator in air conditioning and refrigerating systems. This is also applicable for air source heat pump (ASHP) systems. When the surface temperature is below both water freezing temperature and air dew point temperature, the frost will start to form. The relative humidity (RH) also plays major effect on frost formation. When it's less than 40%, the growth rate of the frost is comparatively slow. But when it's high with high difference in temperature between the cold surface and surrounding air, the growth rate will appreciably increase. Ameen et al. [1] recorded that the frost commonly forms when the air temperature between –7 ºC - 5.5 ºC and the RH more than 60%. The accumulation of the frost with time will merge the fin spacing gradually, reducing the effective surface area of heat exchanger. Accordingly, the fin and tube contact resistance will reduce. Then, the air-side heat transfer coefficient will increase tentatively [2]. Subsequently, the frost layers may lead to a retreat in heat transfer performance [3, 4] and a much higher air-side pressure drop [5-7]. Consequently the coefficient of performance (COP) of the refrigeration system will degrade or a drop of capacity is encountered and sometimes may even lead to shut down the system [8, 9].

In order to know how the frost forms, Fig. 1.a illustrates the process of frost growth formation where the frost could be forms directly or subdividing on steps from condensation of water droplets to frost layers passing through ice layer, frost crystals and finally frost branches as in refrigerator and air conditioner.

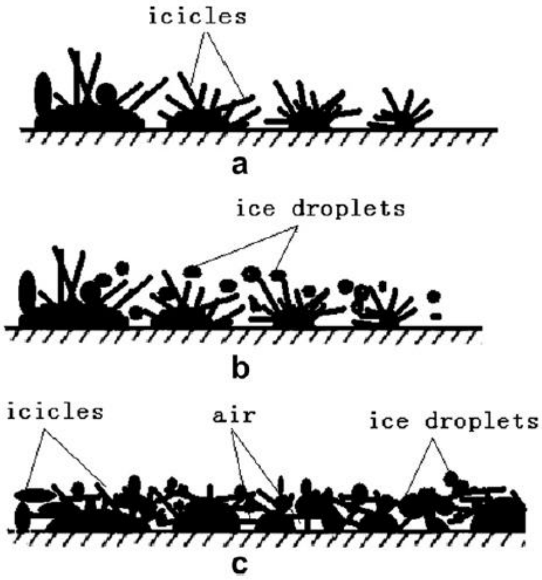


Fig. 1.a The formation and growth of frost layer.

Hayashi et al. [10] divided the frost formation into three steps: frost nucleation (crystal) period, frost layer growth period and frost layer fully growth period. This process approved by Tao et al. [11] and clarified by Li and Chen [12] as shown in Fig. 1.b As well as, in the inset 1 of this figure, the heterogeneous nucleation growth was shown clearly as introduced in Piucco et al. [13]. Later, the thickness and density will increased due to the frost accumulation and water vapor diffusion as in inset 9 in the same figure which can be considered as a porous surface. And they gave a real photography for frost crystal growth on the frozen water droplet surface when they performed their experiment as seen in Fig. 1.c.

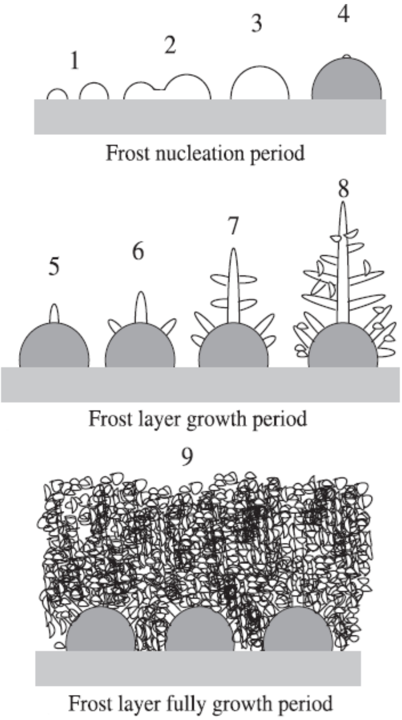


Fig. 1.b Schematic representation of the entire frosting process on cold surface [12].

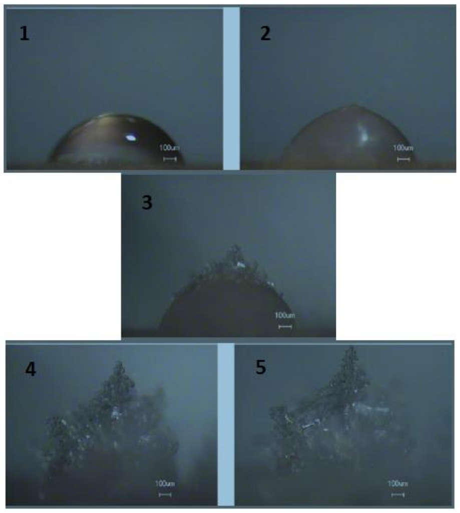


Fig. 1.c The real process photography for frost crystal formation on the frozen water droplet surface [12].

The frost accumulation will obstruct the purpose of cooling system. Therefore, defrosting systems come to solve these problems. There are two main methods for defrosting, passive and active. The first type is related to main system and its components and used to eliminate frosting. But, there are abundant deficiencies in this method like turn off the system for a period of time and water drainage after the frost melt. Then, lose the cooling capacity which means reduce the COP and high energy consumption. Therefore, many researchers tried to solve this by using the second methods although it’s used to reduce the frost.

In this regard, this paper will debate the surface passive technologies with a small view to choose the best one for defrosting.

Nomenclature

T_{in}	inlet air temperature, ºC
T_{out}	outlet air temperature, ºC
ΔP	Air-side pressure drop, [mmAg]
t	time [min]
E_m	energy consumption for frost melting, kJ

Greek symbols

θ	contact angle, º
Δθ	hysteresis contact angle, º
mmAg	iDeltaP pressure drop
τ	Time for frost melting, s

Subscript

COP	coefficient of performance
ASHP	Air source heat pump
RH	relative humidity, %
Al	aluminum
Cu	copper
HX	heat exchanger
MVF	molten volume fraction
s	second
min	minute
h	hour
FPI	fins per inch

2 Surface Treatment

Surface treatment involves any change on the surface characteristics such as the shape, geometry, structure and coating. Huang et al. [14] studied the effect of frosting and defrosting on the performance of a residential ASHP by using different flat, wavy and louver outdoor fin types. Rahman and Jacobi [15-18] investigated the influence of frost melt water drainage on microgroove brass surfaces were fabricated by micro-milling process and compared with flat baseline surface. They noticed significant effects on melt water retention through surface roughness and groove geometry variation and evidently decreasing in frost mass per unit area in the 1st and 2nd frost cycles for the microgrooved samples and drain up to 70% more condensate than flat brass surface.

After that, they [19] conduct an experiment on some of aluminum (Al) and copper (Cu) microgrooved surfaces fabricated by photolithography and wet etching, respectively which means no chemical treatment on the surfaces. They found the difference between these surfaces and flat baseline surfaces in frost formation (methodology), shapes and distribution that consistent with the previous studies on brass samples [15-18]. Fig. 2 shows the water droplets shapes on Al microgrooved (in the orthogonal direction to the grooves) and flat baseline (polished baseline) surfaces. Then, a comparison was done between them in the shape, size and water droplets distribution where the shape and the size of the flat baseline surface were random and big, respectively. But for microgrooved Al surface shape was Longitudinal and the size was smaller than flat surface.

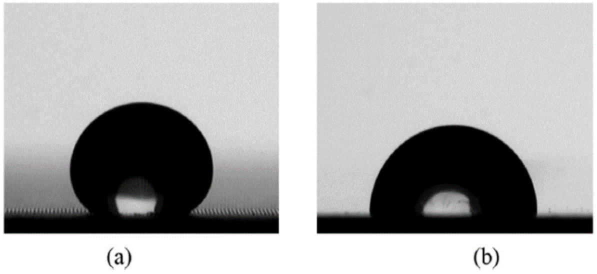


Fig. 2 The difference in the shape of the water droplets on (a) Microgrooved Al surface and (b) Baseline (polished baseline) surface [19].

In the case of melt-water retention, the Al microgrooved surfaces improved the drainage of the frost in all the frost cycles and at different surface temperatures and different RH although the RH doesn’t have that effect on the frost density whereas the flat surfaces increased the frost retention and drainage in the next refrost cycles. On the other hand, the microgrooved surface had about 56% reduction in frost melt-water retention in the 5th cycle as in aluminum polished baseline.

They also measured the frost mass ratio (frost melt-water retention ratio) where it's always less than 0.5 for the microgrooved aluminum surfaces and from nearly 0.4 to 0.88 for the flat baseline surfaces and also here the microgrooved superior on flat baseline surfaces.

Besides that, they pointed to the type of defrosting method which is self-defrosting (no supplied heat) that applied after 45 min from frosting. The self-defrosting can be used with electrical defrosting (supplied heat electrically) as in Zhang and Faghri [20] experiment.

The same results were conducted for the microgrooved Cu samples compared with the baseline elements and the comparison between microgroved Cu surface and baseline element under the same operating conditions was done for condensation and frost formation patterns where the microgrooved Cu showed a good performance in get rid of the condensation water than the polished baseline surface and the same for the frost patterns where its small compared with the other surface which means that the defrost will become easy. The microgrooved aluminum surface is similar to microgrooved brass surfacewith some variations in frost patterns.

From these results, the microgrooved surfaces were more effective in melt-water drainage than flat baseline that lead to lower energy for defrost than flat surfaces and the polished baseline surfaces was better than unpolished one and similar to microgrooved surfaces where the retrained frost melt water for microgrooved was about 30% - 45% and approximately the same for the polished baseline in some cases whilst more than 50% for unpolished baseline surface.

These results were compatible with Sommers et al. [21] results when they cited that the microgrooved hydrophobic surface had 27% water retrained less than baseline surface. And these results approved that the researchers can use the metal surfaces as working materials.

So, the shape or the geometry has a significant effect on defrosting. Because of this, some authors think about upgrade the efficiency of defrosting not only by optimizing the structure of the evaporator fins [22], but also by the surface handling [23].

Others think about adding lateral fins on the tube surface or using internal fins as in Zhang and Faghri [20] model where the experiment was done at low flow rates and thermal conductivity. They got on a 15% increment in thermal energy system performance. Then complete their study by using external radial finned tubes and increasing the fins height [24] and they revealed on an obvious effect on the temperature and an increase in HX molten volume fraction (MVF). By contrast, Lacroix and Benmadda [25] noticed an increasing in solidification rate when they added additional fins.

Other experiments were conducted using anti-frosting paint. Liu et al. [26] prepared a novel anti-frosting paint coated surface and made a comparison with uncoated metallic surface. On the one hand, the frost formation approximately delayed at least 15 min. On the other hand, the thickness and weight of the frost layer reduced by more than 40% compared with Cu surface. As well as, the coated surface stayed without frost when the air relative humidity RH < 60% and cold plate surface temperature > –10 ºC. By contrast, the uncoated surface was covered completely with thick and dense frost layer. Thus, the anti-frosting paint surface optimized the performance of anti-frosting.

Liu et al. [27] complete the first part of experiment. But here, they focus on how the temperature and structure of the surface influence on the frost. In addition, study the effect of coated thickness. The results revealed that the frost crystal growth on the paint coated surface was similar to hydrophobic surface although the paint contained hydrophilic agent in the polymer. The surface temperature of the frost layer in coated surface was lower than uncoated surface in spite of that it's higher than uncoated surface at the beginning. The frost structure had dendritic shape which means loose and fragile structure and this lead to improve the performance of defrosting. Besides to coating thickness that played an important impact in defrosting.

Huang et al. [28] used anti-frosting paint by a spray to coat the HX with thickness of 30 µm. The experiment was done on the hydrophilic paint aluminium coated fins and uncoated aluminium fins. For inlet air temperature (T_{in}) = 2.2 ºC, outlet air temperature (T_{out}) = –0.5 ºC, RH = 90% and recorded per 30 s, the pressure drop (ΔP) was very high for the coated surface at the beginning of the 2nd cycle (2.50 mmAq) with (1.45 mmAq) for uncoated surface due to the reduction of fin gaps. But this changed during the 2nd and 3rd cycles although that the pressure drop still increasing during the 2nd cycle. Moreover, during the 1st cycle, the pressure drop stayed below 30 mmAq for 137 min in coated surface while 80 min in uncoated surface to last. However, T_{out} for both surfaces was convergent. Then, the thermal resistance to the heat transfer was neglected. Finally, the coated hydrophilic fins were free from frost during the whole test unlike the uncoated fins which completely covered by a dense and thick frost layer.

For the defrosting process, the coated fins showed weak resistance against frost because of reducing the hydrophilic ability through the 2nd cycle and the surface still wet during the anti-frosting. This will lead to long defrosting time if compared with uncoated surface. This is unexpected if compared with the results of Liu et al. [26] for hydrophilic polymer paint when they indicated that the frost growth rate can restrain until 3 h with 40% reduction of frost thickness and this made the frost layer baggy or loose which means easy to defrost. Fig. 3.a and Fig. 3.b show the comparison between coated and uncoated heat exchangers with respect to pressure drop in the frosting–defrosting cycles in Huang et al. [28] experiment.

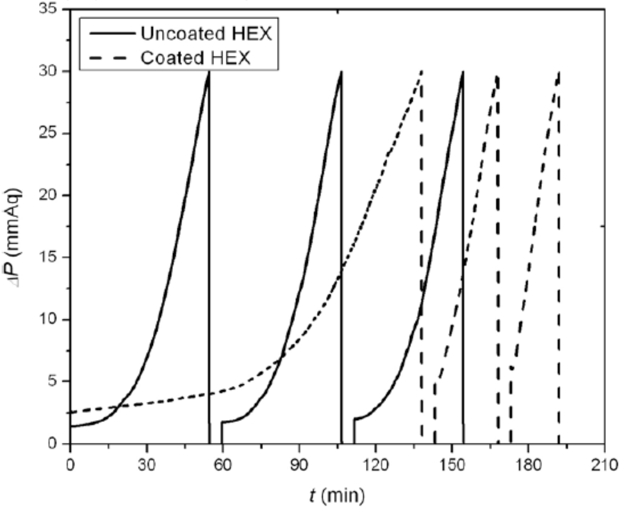


Fig. 3.a The pressure drop for coated and uncoated surfaces [28].

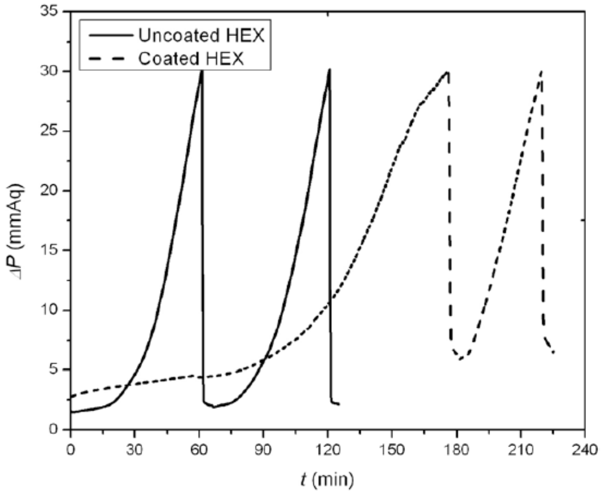


Fig. 3.b The pressure drop for coated and uncoated surfaces [28].

As has been noted and although some unforeseen results from some authors for the anti-frosting paint, most of them deals with its effectiveness in defrosting.

Recently and due to the improvement of materials sector, several researches work on different surfaces such as bare, hydrophilic, hydrophobic and superhydrophobic surfaces, where superhydrophobic surface prepared by sodium hydroxide solution etching method. This is because the importance of surface property on the frosting and anti-frosting systems especially for frost melting time and energy consumption.

In order to measure the wettability degree of the surface, the contact angle θ was found. The contact angle is the angle between the droplet and the surface. As shown in Fig. 4. The surfaces can divided into three types with respect to contact angle. The surface is hydrophilic when $\theta < 90^\circ$, hydrophobic when $90^\circ < \theta < 150^\circ$ and when $\theta > 150^\circ$ and hysteresis contact angle $< 10^\circ$, the surface is superhydrophobic. When the value of θ is small, the surface becomes more wetting. In short, the hydrophilic surface is the wettest surface.

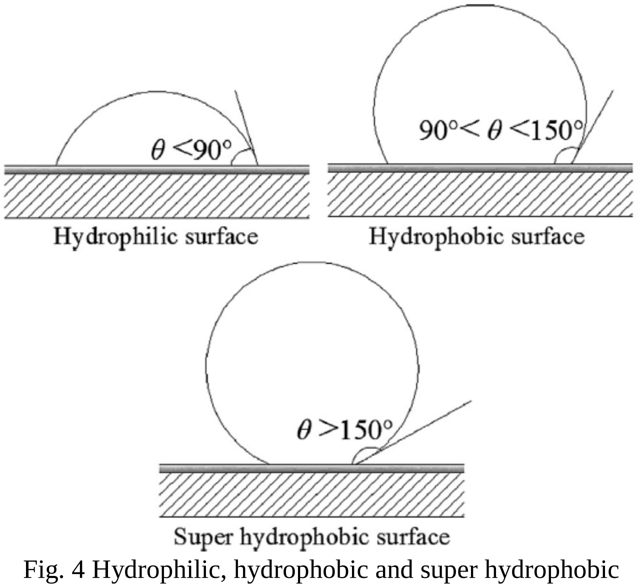


Fig. 4 Hydrophilic, hydrophobic and super hydrophobic surfaces schematic diagram of a droplet [29].

When the contact angle mentioned, the surface energy should be discussed because of its effects on the frost formation

[23, 31-37] where the frost crystal appear weak in low energy surfaces as in cold hydrophobic surface which has big contact angle, whereas the cold hydrophilic surface has a big surface energy with contact angle close to zero as mentioned in Shin et al. [30] who reported that the frost density will be high in the first stages of the frost formation with lower dynamic contact angles.

Some researchers studied the hydrophilic surface, Okoroafor and Newborough [38] found that the frost reduced 10% - 30% when they used polymeric material hydrophilic surface for more than 2 h. Other researchers used a hydrophobic surface [39]. Seki et al. [40] studied the hydrophilic and hydrophobic surfaces and found that frost formation on the hydrophilic surface go faster than on the hydrophobic surface and this discrepancy with Okoroafor and Newborough [38] when they preference thehydrophilic surface than hydrophobic surface in frosting and defrosting performance.

Kim and Lee [36] reported that the time was a minor factor when they studied the behavior of hydrophilic, bare, and hydrophobic surfaces with contact angles 2.5º, 75º, and 142º, respectively under frosting and defrosting processes. The retained water for hydrophilic surface was not significant and smaller than the other surfaces. In addition to high frost density and thin frost layers for hydrophilic surface compared with other surfaces.

Lee et al. [31] studied a domestic refrigerator and reported that under the same operation condition, the frost thickness will be lower for a hydrophilic aluminum surface than hydrophobic surface. But, the frost density for more hydrophobic surface was lower than hydrophilic surface.

These studies for Okoroafor and Newborough [38] and Lee et al. [31] are consistent with a study for Liu and Jacobi [41] when they found that hydrophilic surface had lower condensate and retrained water than hydrophobic surface for a slit-finned-tube heat exchangers.

Liu et al. [37] reported that a superhydrophobic surface with contact angle 162º delayed the frost growth rate for 55 min if compared with plain Cu surface. Further, Jing et al. [42] tested the rigid super hydrophobic surface under frosting and found that it had a good effect on frost layers during defrosting.

New researches were done to make sure from the improvement on the efficiency of the surface treatments. Moallem at el. [43] studied the hydrophilic and hydrophobic surfaces louvered fin microchannel heat exchangers for heat pumps with contact angles less than 5º to 105º range and water retention on frost formation. They conclude that the coated surfaces have a clear effect on the frost growth rate and up to 15% on heat transfer capacity under operating conditions with some differences between them. But, they found that the uncoated louvered aluminium surface had similar heat transfer rate, ΔP and the duration of the frosting cycles. However, the results showed that the frost impact on the pressure drop. Furthermore, the air blockage cause was not the frozen ice.

Moreover, the surface geometry and temperature played a high factor on the frost formation and frosting time whereas the surface coatings and water retention played a minor effect. For frosting time, they found that hydrophobic or highly hydrophobic surfaces increased frosting time. For example, 2 ºC changes in surface temperature will lead to increase the frosting time by more than 80%. In addition to made comparison between dry and wet surfaces which the frosting time for the dry surface was 25% more than the fully wet surface where it’s a 60% for hydrophilic surface.

For a microchannel heat exchangers, Liu and Jacobi [44] reported that the microchannel surface with hydrophilic coating decreased the water retention in opposite of finned-tube hydrophilic surface.

Kim and Lee [45] prepared hydrophilic, hydrophobic, and dual surface nature (hydrophilic and hydrophobic) louvered fin with 14, 16, and 18 FPI (fins per inch) heat exchangers and tested them under frosting-defrosting conditions. The results showed that highest heat transfer rate at 16 FPI at the beginning. But in the next stage, the hydrophobic surface gave less reduction of transfer which means better thermal performance compared to other surfaces that approximately had the same behaviour. Furthermore, the remained water ratio for hydrophobic HX was the highest and without any change on the overall heat transfer rate due to frosting delay, but the lowest one was for the hydrophilic HX and this superior agree with the previous outcomes [31, 38, 41].

Ghaudhary and Li [46] studied the freezing of static water droplets on hydrophilic and hydrophobic surfaces under fast cooling. They found that the time needed to freeze the droplets freeze depends on the droplet temperature and surface wettability. Moreover, the freezing time for small droplets on hydrophobic surface take more time than large droplets on hydrophilic surface.

Wang and Kwon et al. [47] prepared a hydrophobic surface by aluminate coupling agent. The static contact angle of Al hydrophobic was 147º. By static and dynamic contact angles, the experiment conducted on hydrophobic and neat Al surfaces.

For frosting, they found that the hydrophobic coating surface had significant impact on frost growth rate by restrain it. In addition to delay the time for frost accumulation for 60 min when compared to neat Al surface as shown in Fig. 5.

For defrosting, the results pointed to high performance in restrain the frost by reducing the water droplet condensation for hydrophobic coated surface at low temperature.

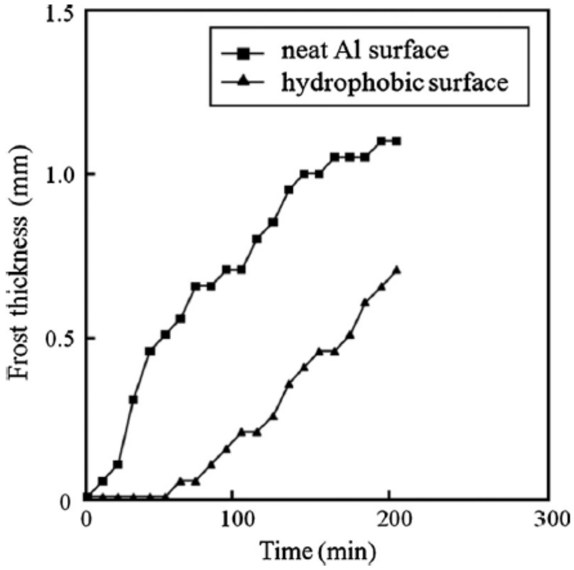


Fig. 5 Relationship between frost thicknesses and time during the frost growth process on coated hydrophobic and neat Al surfaces [47].

Wang et al. [48] performed an experiment on bare, hydrophilic and superhydrophobic finned-tube heat exchangers and they indicated a high heat transfer performance and low ΔP during frosting for superhydrophobic and a 17.1% frost thickness, 28.8% frost mass less than bare surface. Further, forming a few small spherical droplets for superhydrophobic fins due to retrained water and slow growth speed of the frost layer that will contribute in reduce the melting time and energy consumption if compared with thin water film on bare and hydrophilic surfaces due to the strong wettability of them. Then, the superhydrophobic surface has the best anti-frosting efficiency performance.

On the one hand, the authors made a comparison between the three surfaces in frost thickness, frost mass, ΔP and total heat transfer as illustrated in Table 1.

Table 1 A comparison between bare, hydrophilic and superhydrophobic surfaces for frosting

Surface	Bare	Hydrophilic	Superhydrophobic
Frost thickness (mm) ***(For 20 min***)	0.82	0.75	0.68
Frost mass (kg) (For 80 min)	0.302	0.267	0.68
Pressure drop (ΔP)	Very high	In the middle	Very low
Total heat transfer (kJ)	2437.7	2667.9	3047.2

It is clear that the superhydrphobic had the lowest frost thickness and frost mass compared with other surfaces. Further to lowest ΔP and highest heat transfer in a percentage 25.0% and 14.2% more than bare and hydrophilic surface heat exchangers, respectively.

On the other hand, the authors reported the effect of defrosting for each surface and made a comparison between them. Table 2 demonstrates this comparison.

Table 2 A comparison between bare, hydrophilic and superhydrophobic surfaces for defrosting.

Surface	Bare	Hydrophilic	Superhydrophobic
Melting time (s)	147	128	107
Energy consumptions (kJ)	0.302	0.267	0.68
Retained water mass (kg)	0.076	0.074	0.039

From Table 2 the superhydrophobic surface had lowest melting time by 27.2% compared with bare surface. Besides that, it had lowest energy consuming. Then, this will lead to decrease the heating capacity of frost melting. Moreover, a minimum retained water with 48.7% and 47.3% less than the other surfaces as shown in Fig. 6.a and Fig. 6.b.

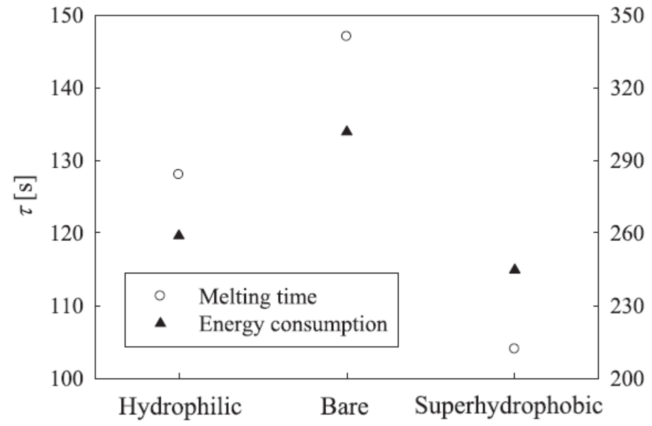


Fig. 6.a Time and Energy consumption for frost melting [48].

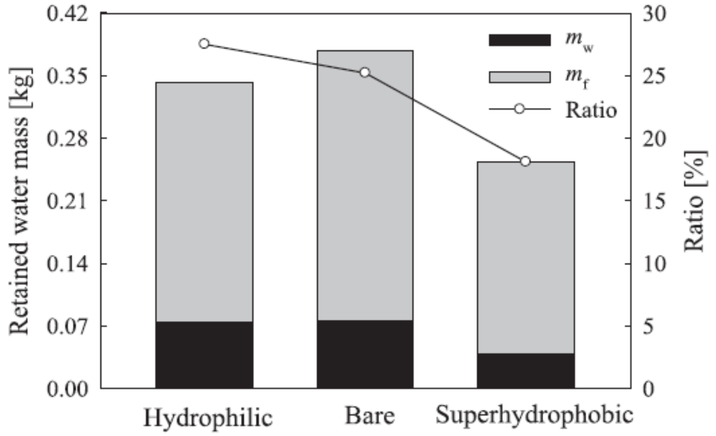


Fig. 6.b Retained water mass for every surface [48].

The ratio of the retained water mass to the entire mass of frost layer for bare, hydrophilic and superhydrophobic in Fig. 6.b was 27.5%, 25.2% and 18.1%, respectively. Krakow et al. [49, 50] reported that the defrosting process for ASHP is divided into four stages, which are preheating, melting, evaporation and dry heat. And here for superhydrophobic surface, the least retained water can be reducing the evaporation energy consumption. In a word, ameliorate defrosting efficiency.

With respect to defrosting process, Dopazo et al. [51] subdivided it into six periods, which are preheating, tube frost melting start, fin frost melting start, air presence, tube-fin water film and dry-heating.

Furthermore, there is a force called capillary force, this force generates when the droplets start to depart from the vertical fin surface under the effect of gravity, then this force produces against it in the opposite direction depending on surface characteristic, including the wettability and glutinousness [52] where the gravity force should be higher that the capillary force to let the droplets fall down from the surface. Otherwise, they will stay on it. For the superhydrophobic surface, the large droplets drop down easily while the small droplets retain on the surface due to small capillary force of the superhydrophobic surface.

Also Wang et al. [53] studied the effect of frosting/defrosting on bare, hydrophilic and super hydrophobic aluminium surfaces on liquid behaviours in ASHP system. They indicate that the super hydrophobic had the best performance in condensate the droplets lastly compared with hydrophilic surface or bare surface which condensate the droplets firstly. The superhydrophobic surface retained water mass decreased by 65.63% and 79.82% compared with other surfaces. These from the retained water mass were its 0.064 g, 0.109 g and 0.022 g for bare, hydrophilic and super hydrophobic surfaces, respectively. In addition to 63%, 91% and 15% for the fraction of surface covered area. This means that the effects of surface characteristics on time, shape and density of droplets condensation, were significant. Moreover, a good performance of superhydrophobic surface for the molten water retention in defrosting process. In brief, the superhydrophobic surface showed good results in restrain frosting and improving defrosting efficiency.

Liang et al. [29] performed an experiment in frosting and defrosting processes on four surfaces. Bare and hydrophilic surfaces where extracted from ASHP finned-tube heat exchangers. In addition to, hydrophobic surface and super hydrophobic surface that prepared by sodium hydroxide solution etching method. The relative humidity in this experiment was 63% and the frosting temperature was –10 ºC over 60 min frosting time where the defrosting temperature was 50 ºC. The contact angle (θ) and the hysteresis contact angle (Δθ) for the bare, hydrophilic, hydrophobic and superhydrophobic surfaces (θ, Δθ) were (98º, 36º), (15º, 140º), (137º, 19º) and (160º, 5º) respectively. Table 3 shows a comparison between surfaces in frost layer height, frost melting time, diameter of the retained droplets and mass of the retained water.

Table 3 A comparison between bare, hydrophilic and superhydrophobic surfaces for frosting.

Surface	Bare	Hydrophilic	Hydrophobic	Superhydrophobic
Frost layer height (mm) ***(For 60 min)***	1.62	1.70	1.36	0.99
Frost melting time (s)	25	36	23	22
Retained droplet diameter (mm)	1.80	-	1.12	0.12
Retained water mass (g)	0.091	0.109	0.065	0.022

From the results of researchers and if compared superhydrophobic surface with bare surface, the frost layer height of superhydrophobic fin decreased 38.89%. It's also decreased for the retained water mass on the super hydrophobic by 75.82%, 79.82% and 66.15% compared to other surfaces which considered the lowest one with 0.022 g and these results agree with Wang et al. [53] results especially with results that related to bare surface which contradict Wang et al. [48] outcomes and the same thing for the the retrained water as in Jhee et al. [54] study when they revealed that the amount of retained water on the aluminum bare surface was more than hydrophilic and hydrophobic treated surfaces that mean lower ability of the bare surface in frost retarding.

These are stupendous results for hydrophilic surface. The hydrophilic surface had the highest height frost layer. So, it needs more heat capacity for melting and this will lead to longest frost melting time. The same was for retained water mass and this is because of the strong wettability of the surface where the retained water formed a thin water film. Because of that, they cannot measure the maximum retained droplet diameter of this surface.

Fig. 7.a and Fig. 7.b clarified that the frost melting time and the maximum droplet diameter, retained water mass that decreasing with increasing contact angle or with hysteresis contact angle decreasing.

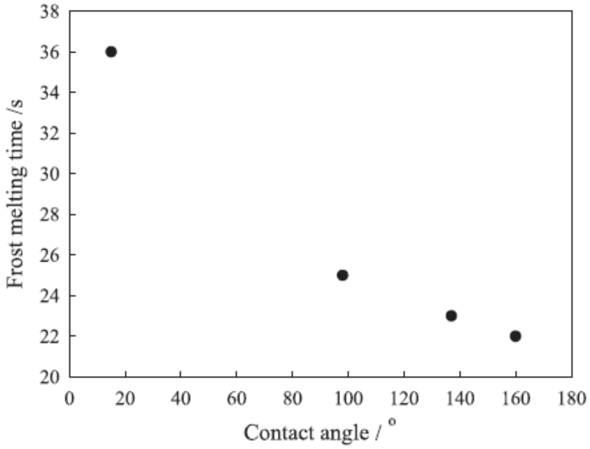


Fig. 7.a Relation between frost melting time and contact angle [29].

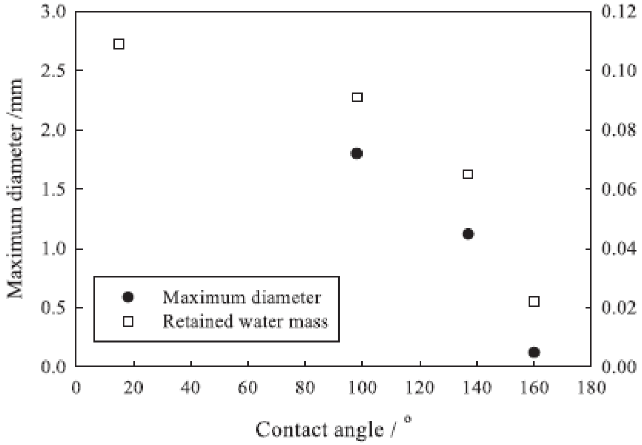
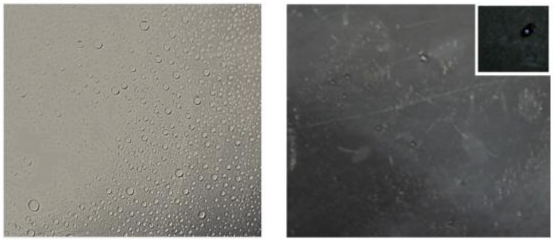


Fig. 7.b Relation between maximum retained droplet diameter, retained water mass and contact angle [29].

Finally, the energy consumption for evaporation will decrease with decreasing of retained water mass. What is more, the energy consumption needed for frost melting and evaporation was almost one to eight. This is clear from Fig. 7.c which the superhydrophobic that looks dry. Consequently, the efficiency of defrosting will improve.

Hydrophilic fin Bare fin



Hydrophobic fin Super hydrophobic fin

Fig. 7.c Retained water on each surface [29].

Based on the present review of surface treatment and ultimately, the superhydrophobic surface approved its ability against frost and out performed on the other surface treatments.

3 Conclusions

The present study reviewed the surface passive defrosting techniques applicable for the HVAC and R industry. The surface treatment consider a revolution in this field from long time ago. This study showed that any change on the surface will lead to change on the frost. In conclusion:

1. Microgroved surface is better than flat surface in the shape, size, melt water retention and in the reduction of frost melt-water retention. Further, the polished baseline is better than unpolished and similar to microgroved in some cases.
2. The anti-frosting paint proved its ability delay the frost accumulation and reduce the frost weight and thickness. Furthermore, the frost structure coated surface is loose and fragile while it's dense and thick in uncoated surface.
3. The surface geometry and temperature played a high factor on the frost formation and frosting time whereas the surface coatings and water retention played a minor effect.
4. The microchannel coating heat exchangers outstanding on finned-tube surface in water retention reduction.
5. The superhydrophobic surface showed a superior on bare, hydrophilic and hydrophobic surfaces in delaying the frost, frost thickness, frost mass, ΔP, total heat transfer, defrosting time, retained water ratio and energy consumption.

Finally, the surface treatment has a good benefits in fighting the frost especially using a superhydrophobic coating due to the effectiveness that shown for it in defrosting.

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