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Experimental investigation of frost issue on various evaporators having different fin types

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ABSTRACT

Frost formation and growth is quite important physical phenomena in evaporators since frost can directly affect both capacity and fan performance. In this study, an in-house-code was programmed to determine frost ratio on evaporator surfaces via an image processing technique. Air inlet temperatures along with pressure drop across the evaporators were monitored and both temperature and pressure breaking points were identified for evaporators with flat, hydrophilic flat and corrugated fins. Evaporator capacities and pressure drops across the evaporators were experimentally measured and compared with theoretical findings. It was revealed that the evaporator with hydrophilic fin was the most suitable selection when entire measured and calculated parameters were considered altogether.

1. Introduction

Frost formation and growth in evaporators have started to capture researchers' attention since the heat transfer capacity of these machines is directly affected by frost formation. Specifically, frost formation on the fins of an evaporator causes capacity reductions because low thermal conductivity frost behaves like an insulator (i.e., thermal resistance) yielding decrease in heat transfer from surfaces of fins and tubes. Besides, once the frost forms and starts to grow on a fin or tube surface, the area where air passes between the evaporator's fins starts to become smaller causing larger pressure drops. This eventually increases pressure requirement and failure of fans becomes unavoidable when the needed defrosting for frost regions is not provided. This undesirable and unavoidable phenomenon can appear in many places such as evaporators of all refrigeration systems, cold storage and warehouse unit coolers. Therefore, investigations on delaying the frosting time by treating the fin surfaces have increased in recent years [1,3,5,11–14]. However, not only surface treatment but also the selection of fin types used at the fin and tube heat exchanger could be effective in terms of delaying frost formation because the contact angle between the cold fin surface and the water droplets, which play an important role on frost formation, must be different among fin types.

Jhee et al. [1] studied the effects of hydrophilic, hydrophobic and bare fin surfaces on the frosting and defrosting behavior. It was highlighted that as the frost density was the highest for hydrophilic surfaces at the early stage of frosting, the lowest was the hydrophobic fin. In addition, they specified that the surface treatment accelerated frost accumulation rather than delaying it. Another study performed by Huang et al. [2] compared hydrophilic and bare fin heat exchangers. According to their experimental study, it was found that not only the bare fin was completely covered by a dense and thick frost layer but also the increase of air pressure drop of the bare fin was higher than the coated fin after 20 min. Kim and Lee [3] investigated hydrophilic, hydrophobic and dual surface treatments in terms of their effects on frost retardation, thermal performance and air pressure drop. As the hydrophilic unit exhibited a thin-film frost layer in the early stages of frost growth, the hydrophobic unit experienced a smaller reduction in the heat transfer rate, with a smaller air-side pressure drop, due to frost retardation. Hence, the hydrophobic heat exchanger provided the best performance under frosting conditions. Liang et al. [4] conducted a dozen frosting experiments on plain-fin heat exchangers by investigating super-hydrophobic, hydrophilic and bare surfaces. They concluded that as the super-hydrophobic heat exchanger showed the best anti-frosting performance, bare heat exchanger showed the worst

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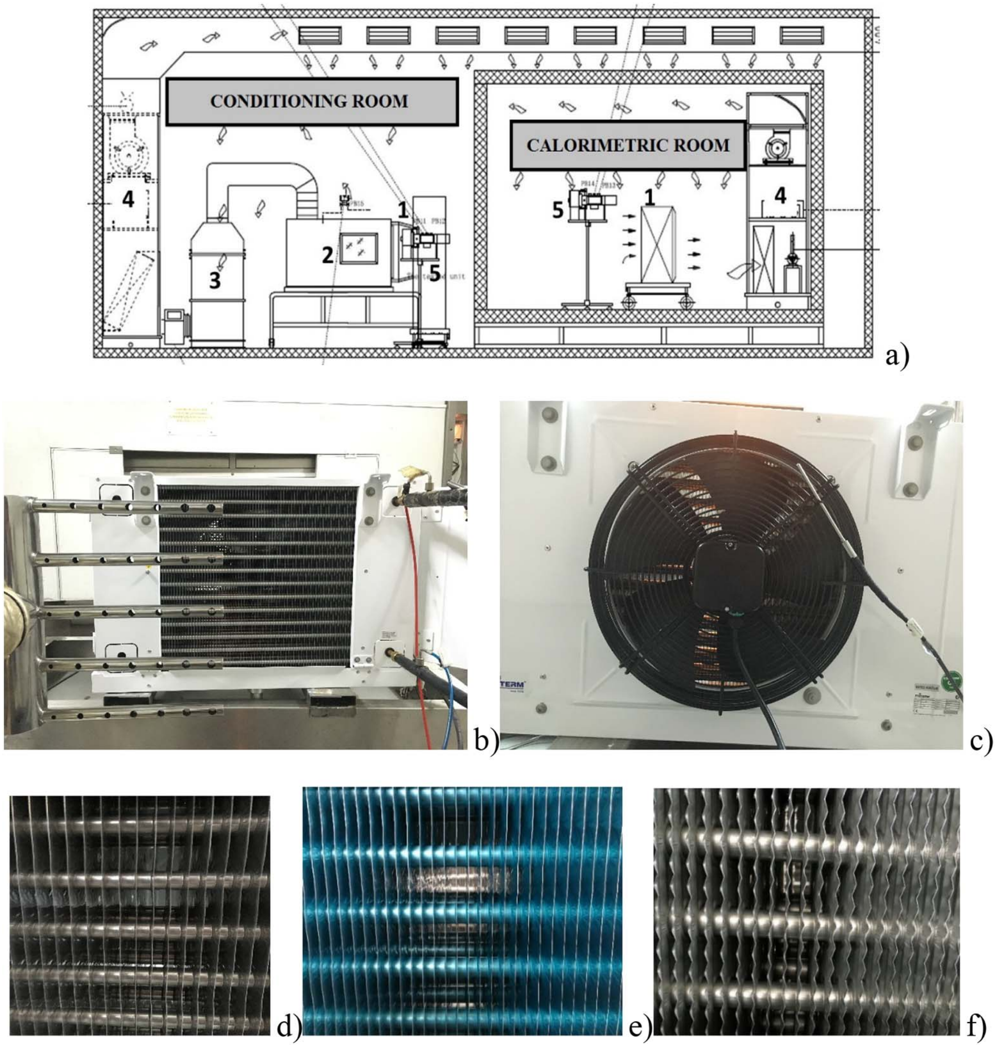

Fig. 1. Test Room (1. Product that is tested, 2. Air receiver room, 3. Flowrate measurement room, 4. Air handling unit, 5. Air sampler) (a); front (b) and back (c) side of the evaporator in the calorimetric room (flat fin); the different type of fin used in the study, flat fin (d), hydrophilic flat fin (e); corrugated fin (f).

Table 1
Dimensional characteristics of the evaporator.

Geometric parameters	Values
Length of evaporator	500 mm
Width of evaporator	517 mm
Number of rows	3
Number of tubes	14
Number of circuits	2
Fin types	Flat, hydrophilic-coated flat, corrugated
Fin thickness	0.2 mm
Fin pitch	6.7 mm
Number of fins	71
Tube thickness	0.32 mm
Tube material	Grooved copper
Tube diameter	12 mm

performance. In another experimental study, Kim et al. [5] examined seed behavior in the early stage of frost formation and the effect of the surface treatments on the frost retardation. They documented surface types based on water contact angles for the frost retardation time. Specifically, water contact angle less than 90° was defined as hydrophilic surface while water contact angle higher than 90° was identified as hydrophobic surface. They also stated that frost retardation time was increased significantly with increasing water contact angle. Xu et al. [6] investigated the performance of three types of microchannel heat exchangers under frost condition, namely samples with louver fins, wavy fins and wavy fins with drainage design. They concluded that as the sample with wavy fin worsened over time within five frost-defrost cycles, the sample with drainage design was quite stable in the same period and exhibited the best performance although total operating time was about 70 min longer when compared with normal wavy fins. Park et al. [7] conducted a study to examine frost behavior and thermal performance between flat and louvered fin heat exchangers. They specified that as the frost layer formation on flat fin was uniform, on louvered fin was rather non-uniform. Moreover, the heat transfer rate of the blocking louver fin sharply decreased. It was noted that the usage of the flat fin heat exchanger could be more advantageous than the louvered fin heat exchanger because the heat transfer rate of the flat fin heat exchanger was higher than the louvered fin heat exchanger after a certain time due to the frosting effect.

On the other hand, when frosting studies with fan effects were considered [15,16], it was realized that these studies mainly focused on the effects of air and refrigerant conditions; for example, air inlet temperature, humidity, tube surface temperature etc. Furthermore, there were not any data available considering the effects of surface treatment on frosting by taking the real fan effect into account. Therefore, understanding the effect of surface treatment and type of fins on frost formation with fan effect consideration is quite important to design more efficient heat exchangers working under frost conditions. In the present study, it was aimed to evaluate performances of flat, corrugated and hydrophilic flat fin unit coolers while maintaining the same frosting test conditions. The changes of heat transfer rates and air pressure drops during test operations were recorded and examined in detail. Moreover, frost thicknesses and blockage ratios at the beginning