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New frost property correlations for a flat-finned-tube heat exchanger

H.M. Getu, P.K. Bansal*

Department of Mechanical Engineering, The University of Auckland, Private Bag 92019, Auckland, New Zealand

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ABSTRACT

This paper discusses the fundamentals of experimental techniques for frost measurements and presents unique frost property correlations that are developed from experiments on a lab-scale flat-finned-tube heat exchanger. A multilinear regression analysis was employed on air inlet temperature and humidity ratio, frost-coil interface temperature, refrigerant inlet temperature, and Reynolds and Fourier numbers. This resulted in the development of mathematical expressions for frost thickness, density, thermal conductivity and air pressure drop across the heat exchanger. The newly developed correlations will be useful for better prediction and control of defrost periods and duration for medium-temperature (−10 °C) air coils.

1. Introduction

When a moist air passes continuously over the cold surface of a heat exchanger having a temperature below the dew-point temperature of the moist air, the water vapor in the air will condense on the heat exchanger surface. If the surface temperature is greater than the water freezing temperature but less than the dew-point temperature of the moist air, the condensed water vapor continuously drains along the heat exchanger surface. However, if the surface temperature is below both the water freezing temperature and the dew-point temperature of the moist air, the transferred water vapour may either condense and then freeze, or desublimate (vapour-to-ice) on the cold surface. As a result, frost forms on the surfaces of air coils, thereby resulting in the reduction of heat transfer rate and blockage of the air passage.

Frost formation phenomenon consists of three stages according to Iragorry et al. [1] and Tao et al. [2]. The first stage is called dropwise condensation, during which the condensing droplets in a subcooling state form on the cold surfaces and all of the coalescent droplets turn into ice particles after a critical time (t_c) is reached. The second stage is the solidification and tip-growth of frost. This process continues until a transitional time (t_f) is reached. The last stage is the densification and bulk-growth of frost. During this stage, the frost shows homogeneous and porous characteristics. A literature review on several frost experiments conducted on flat surfaces with temperature ranging from (−) 15 °C to (−) 40 °C showed that frost density and frost thermal conductivity decreased with a decrease in temperature as reported by Getu and Bansal [3]. Frost growth on air coils decreases the capacity of the air coils that are rated at either normal or dry air conditions. Therefore, in order to operate, for instance, a supermarket refrigeration system under a required condition, different defrosting mechanisms must be devised. Precise prediction and control of defrosting periods and duration requires an in-depth understanding of the frost formation process, the operating conditions of the refrigeration system and its interaction with ambient conditions.

Many researchers have used different experimental techniques to develop correlations, especially empirical ones, for calculating properties of a frost layer growing on a cold flat surface. The frost properties such as frost density, frost thickness and frost thermal conductivity are expressed in terms of the surface type, position, surface temperature, frost/air interface temperature, air temperature, air velocity, and air humidity ratio. Mao et al. [4] determined the frost local density by collecting frost over a period of time, measuring the frost thickness, and removing and weighing the frosted aluminum disks (32 mm diameter by 0.5 mm thick). The frost thickness was measured following Besant et al. [5], where an apparatus was used consisting of a helium-neon laser beam light source, a light attenuating filter, and a precision light meter. Mao et al. [6] then developed a correlation for frost density as a function of time, distance from the leading edge, cold plate temperature ratio, humidity ratio, and Reynolds number. Lee and Ro [7] used

* Corresponding author. Fax: +64 9 373 7479.
E-mail address: p.bansal@auckland.ac.nz (P.K. Bansal).

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