The Effect of Favourable and Unfavourable Frost on Air Cooling Coil Performance

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ABSTRACT

The most common type of air cooling coil used in the refrigeration industry is the finned tube heat exchanger. The performance of such coils can be greatly hindered by frost formation, which will occur when the coil surface temperature is both below the dewpoint of the air passing over it, and below 0°C. Frost reduces performance, both through the increased thermal resistance of the frost layer, and by reduction of the air flow through the coil.

Whilst frosting on coils is influential on performance, there is comparatively little information available on the performance of finned tube heat exchangers under frosting conditions. Smith (1989) has proposed an "unfavourable" frost formation theory. The theory states that unfavourable frost formation occurs when the line representing the temperature and humidity of the air passing through the coil, crosses the saturation line of the psychrometric chart. This criteria is more likely to occur under conditions of high relative humidity, low sensible heat ratio (*SHR*), and/or high refrigerant-to-air temperature difference (*TD*). Under unfavourable conditions it is suggested that the frost will be of particularly low density, which would cause coil performance to decline to a much greater extent for the same total frost accumulation, than under "favourable" frosting conditions.

The objectives of this study were to measure the change in performance of a cooling coil under frosting conditions, and to assess the validity of the unfavourable frost formation theory.

A calorimeter style coil test facility was used, that allowed coil performance to be measured as frost accumulated in a manner consistent with coil operation in industrial practice (i.e. declining air flowrate and a wide range of *SHR's*). The data collected supported the concept of unfavourable frost formation with a more rapid decline in performance for operation with low *SHR*, than that at high *SHR*, for the same total frost accumulation. Some recovery of coil performance was observed when operation at low *SHR* (with rapid performance deterioration) was followed by a period of high *SHR* operation.

Equations were developed that allowed the theoretical conditions for the formation from favourable to unfavourable frosting to be quantified. The measured change in the rate of coil performance deterioration with frost buildup was dependent on air and coil conditions, in a manner consistent with these equations. The transition between favourable and unfavourable frost formation appeared to be related to the lowest temperature on the coil surface rather than the mean surface temperature. Satisfactory predictions of frost formation types were obtained by using the refrigerant evaporation temperature as an approximation to the lowest coil surface temperature.

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1 INTRODUCTION

The preservation of perishable food items for storage, transport, and distribution to the consumer is important, especially with seasonal production of many products, and international trade now being common place. Refrigeration is a common method of food preservation. Cost-effective refrigeration is particularly important to New Zealand, as a country whose economy is highly dependent on exports of primary products.

The most common refrigeration systems used are mechanical vapour compression units, with air as the heat transfer medium between the cooling refrigerant and the product. Air cooling coils are one of the key components used in such a system. The cooling coil, and associated fans, have two main purposes:

- provide the rate of heat transfer necessary to maintain the desired air and product temperatures, and
- provide the desired air movement through the coil, around the application, and over the product.

In some applications an additional role of maintaining the desired relative humidity of the air is also required.

Operation below 0°C can result in frost formation on the coil surface. Frost formation reduces coil performance through both insulation of the coil surface and reduced airflow through the coil. The coil must be periodically defrosted when performance becomes inadequate. All of these factors result in additional operating and capital costs for the refrigeration system, and potential disruption to the continuous operation of the application.

Prediction of the effect of frost on coil performance is important for cost-effective coil, and refrigeration system, design and operation. Although the mechanism of frost growth has been extensively researched, and good models for dry coil performance are available, there is comparatively little information on the effects of frost on air cooling coil performance. A better understanding of the factors affecting frosted coil performance will enable costs to be minimised and plant performance to be optimised. This would represent an important step in achieving a cost-effective refrigeration system. This study into the effect of frost on air cooling coil performance is therefore clearly justified.