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The application of photo-coupler for frost detecting in an air-source heat pump

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Abstract

This experimental study is carried out to investigate reliability and effectiveness of a new method of using photo-coupler for detecting frost formation in an air source heat pump, and further to determine the most efficient initiation point of the defrost cycle. This new method of using photo-coupler as a frost sensing device is evaluated by comparing its performance with conventional time control defrost system in which defrost cycle is set to start at predetermined interval, e.g. about at every 1–1.5 h. Results indicate that overall heating capacity of photo-coupler detection method (case IV) is 5.5% higher than that of time control method. It is also shown that for maximum efficiency the defrost cycle must be initiated before the frost build-up area exceeds 45% of total front surface of the outdoor coil.

Keywords: Heat pump; Air-air; Experiment; Growth; Frost; Process; Optical

Application d'une méthode à couplage optique pour la detection de la formation de givre dans une pompe à chaleur air-air

Mots clés : Pompe à chaleur ; Air-air ; Expérimentation ; Croissance ; Givre ; Procédé ; Optique

1. Introduction

Fossil fuels and low-efficiency electrical equipment are still being in use for heating during the winter season. However, efficient energy utilization is getting very important due to environmental and energy problems such as global warming and the depletion of fossil fuels. In this regard, a high thermal efficiency heat pump has been proposed as a new heating apparatus. Especially after the oil shock of the early 1970s, there has been more research and technical development for smaller, quieter, and higher efficiency heat pump systems.

One clear advantage of a heat pump is that it can provide heating or cooling from one machine without any major modification. When the air-source heat pump is operating in the heating mode, refrigerant is evaporating in the outdoor oil. If the temperature of the coil falls below 0 °C, frost will begin to form on the coil. Eventually, the frost can build up enough on the coil to restrict the air passing through the coil,

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Nomenclature

c_p	specific heat at the constant pressure (kJ/kg K)
h	enthalpy (kJ/kg)
m	mass flow rate (kg/s)
ps	photo sensor
q	volumetric flow rate (m^3/min)
Q	heat transfer rate (kW)
t	temperature (K)
v_n	specific volume of the air (m^3/kg)
W	power (kW)
x_n	absolute humidity (kg/kg)

Subscripts

r	refrigerant
a	air
i	inlet
o	outlet

reducing efficiency. The frost will also act as an insulator on the finned surface and reduce heat transfer, thus reducing coil efficiency even further. Therefore, the heat pump requires an auxiliary heat source and its use is restricted by local climate [1].

The frost of the outdoor coil degrades the thermal performance of the heat pump by reducing airflow area as a result of the blockage caused by the layer of frost, and building up an insulating layer over the coils, being unable to absorb heat from the outdoor coil. There are several methods to eliminate and stop frost from forming in the outdoor coil [2]; the hot gas method, the electrical heater method, the cycle reversing method, and the coil spray method. Of these methods, cycle reversing is the standard heat pump defrosting method. To defrost efficiently, the method used to start and stop the defrost cycle must be accurate. Unless there is exact timing, there will be waste of energy while defrosting [3]. Along with defrosting method, there are several popular frost detection and control methods; temperature control, air-pressure control, time–temperature control, and time control. The temperature control method uses the difference between the outdoor air temperature and the temperature of the refrigerant in the coil. The air-pressure control method detects the air-pressure drop across the outdoor coil. The time–temperature control method checks coil temperature at predetermined intervals. The time control method defrosts the outdoor coil automatically after a predetermined amount of running time. Most heat pump adopts the time control method due to its simplicity, though it has a less reliable for frost detection.

Previous work on an outdoor coil's frosting has been conducted over the three main areas; (1) the mechanism of frost formation and growth at the coil (2) the effects of frost formation and growth on a finned tube heat exchanger's performance (3) the effective methods of delaying frost and defrosting.

Hayashi et al. [4] characterized the frost formation into three stages; (i) crystal growth period, (ii) frost layer growth period and (iii) frost layer full growth period. Yonko et al. [5] reported that the thermal conductivity of frost varies with its density from frost formation on flat plates. Jones et al. [6] studied frost formation on flat plates and found that increase of relative humidity of ambient air increases the frost formation rate, while increasing the air velocity decreases the frost formation rate. During the defrost period, O'Neal et al. [7] examined a variety of parameters including the power consumption, the refrigerant flow rate, the pressure and temperature, etc. Furthermore, in 1991, they [8] carried out many defrost tests to decrease the defrost time and losses. According to their results, increasing the orifice diameter (expansion device) contributed to the decrease in defrost time. Nutter and O'Neal [9] studied the effects of the accumulator of suction line on the frost/defrost performance of an air-source heat pump with a scroll compressor. Their results showed that removal of the accumulator produced a 10% reduction in defrost cycle time and a 2% reduction in the integrated cyclic coefficient of performance (COP). Watters and O'Neal [10] tested two three-row heat pump evaporators to determine whether fin staging would slow frost growth and improve heat pump frost/defrost performance. One of the coils used for the test is a base coil which has a uniform fin density of 8 fins per centimeter [FPC], and the other one is a staged coil which has fin spacings of six FPC, eight FPC and 10 FPC on the front, second, and third row, respectively. They found that the COP of the staged coil was 8.7% lower than that of the base coil at 95% relative humidity and 1.7 °C, but its defrost cycle time could be shortened from 6 to 30% depending on airflow. Jhee et al. [11] found that the heat exchanger with a hydrophobic surface treatment was more effective in the defrost efficiency and time than that with a hydrophilic surface. Kondepudi et al. [12] investigated the times for evaporator frosting with and without solid desiccant placed in the air stream, and found that the use of desiccant significantly reduced the rate of evaporator frosting. Forest [13] evaluated the use of polymer coatings to reduce the surface energy, which resulted in reduced ice adherence force. Wu and Webb [14] investigated frosting on both hydrophobic and hydrophilic surface and found that a hydrophilic coating is probably preferable.

In this study, it is examined the feasibility of using a kind of photo sensor, the photo-coupler, as the frost detection device for an air-source heat pump. The photo-coupler is composed of an emitter and receiver installed on the outdoor coil and the change of their output voltage is measured according to the frost growth. Test results indicate the very