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A novel defrosting control method based on the degree of refrigerant superheat for air source heat pumps

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ABSTRACT

When an air source heat pump (ASHP) unit operates for space heating at a frosting environment, periodic defrosting is necessary to maintain a high system performance. To defrost efficiently, it is necessary to find an effective defrosting control method. In this paper, an experiment was carried out on an ASHP unit with a capillary tube as a throttle device, under simulated frosting and defrosting conditions using time control defrosting method, and the experimental results are firstly presented. Secondly, a novel defrosting control method based on the degree of refrigerant superheat (DS) is reported. To validate the novel defrosting control method, a further experiment was conducted on another ASHP unit with an electronic expansion valve (EEV) as a throttle device, under simulated frosting and defrosting conditions. The experimental results demonstrated that when applying the novel defrosting control method, defrosting was initiated before the operating performances of ASHP unit rapidly deteriorated, which was more reasonable.

Nouvelle méthode de régulation du dégivrage fondée sur la surchauffe du frigorigène, pour une pompe à chaleur aérothermique

Mots clés : méthode de régulation du dégivrage ; frigorigène ; surchauffe ; pompe à chaleur ; aérothermique ; expérience

1. Introduction

ASHPs have been widely used in recent decades, due to the advantage of high energy efficiency (Nishimura, 2002). However, when an ASHP unit operates for space heating at an ambient environment of low temperature and high humidity in winter, frost will appear on its outdoor coil surface. Over the time, frost accumulation on coil surface reduces the airflow

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Nomenclature

DS	degree of refrigerant superheat, °C
DS_i	DS at time i, °C
DS_{m_i}	time average of DS from initiation to the time point i, °C
F_i	fluctuation of DS at the time point i
i	time point, s
I	integral of fluctuation of DS
n	number

passages and acts as a thermal insulator, thus increasing the heat transfer resistance and reducing the coil's efficiency (Dong et al., 2012; Yang and Lee, 2005; Yao et al., 2004), and leading to the shutdown of the ASHP unit (Yang et al., 2006; Kondepudi and O'Neal, 1990, 1991).

To ensure the safe and efficient operation of an ASHP unit, frost must be removed from its outdoor coil surface. Currently, defrosting methods such as hot gas bypass (Hewitt and Huang, 2008; Byun et al., 2008) and reverse-cycle defrosting (Huang et al., 2009; Hu et al., 2010) are widely used. To minimize both the energy use for defrosting and the disturbance to indoor thermal comfort (Baxter and Moyers, 1985; Qu et al., 2010), the time points to initiate and terminate a defrosting operation must be as accurate as possible.

Various frost detection and defrosting control methods have been developed and used. Currently, time control is the most widely used control method. An ASHP controlled by this method would start defrosting automatically after a predetermined duration of heating/frosting operation. Such a method is adopted in most ASHPs system due to its simplicity, although its reliability is questionable. For example, it was reported that 27% of defrosting operations under time control were conducted when there was less or no frost on outdoor coils (He and Liu, 2004), damaging ASHP units and wasting energy (Han et al., 2006). Other control methods include the temperature difference control which is based on the temperature difference between outdoor air and evaporator surface (Buick et al., 1978), and the pressure difference control which is based on the air pressure drop across an outdoor coil. Moreover, the artificial intelligence techniques (Datta et al., 1999), artificial neural network (Datta and Tassou, 2002), fan power sensing (Muller, 1975), and measuring ice thickness (Byun et al., 2006) have been also used for frost detection and control. In general, except the time control method, no other single control method has gained wide acceptance due to the complexity of sensing methodology, reliability and cost (Xiao et al., 2010; Lawrence and Evans, 2008).

Frost formation on outdoor coil surface is essentially a complex transient process involving spatial and time variations of heat and mass transfer, which depends on the outdoor environment and the outdoor coil characteristics such as its surface properties and structure. Therefore using only one or two out of many operating parameters on the air side that affect frost formation as a defrosting control method is not considered reasonable (Xiao et al., 2009). On the other hand, frosting also affects the operating performances on the refrigerant side of an ASHP unit, such as suction temperature and pressure, condensing temperature, COP and the DS, etc. Therefore, the operating parameters on the refrigerant side in an ASHP unit may be used to detect the frost growth on its outdoor coil surface and determine the initiation of a defrosting operation.

For an ASHP unit, as frost forms on its outdoor coil surface, the heat transfer between outdoor air and the low-temperature refrigerant deteriorates due to the increased heat transfer resistance and reduced air flow rate. Therefore, the refrigerant dry-out point of a frosted outdoor coil moves to near the outlet, resulting in a larger two-phase region and a smaller superheated region in the outdoor coil (evaporator), and hence a reduced DS at outdoor coil outlet. When the DS decreases to below its minimal stable value, it will decrease rapidly and thus reduce the safety and efficiency of the ASHP unit (Chen et al., 2008, 2002). Therefore, the variation in DS can directly reflect the frost growth on outdoor coil surface and may then be used as a parameter to initiate a defrosting operation.

The present study focused on developing a novel defrosting control method based on DS for ASHP units. Firstly, frosting and defrosting experiments were carried out on an ASHP unit (the first ASHP unit) having a 2.5 kW heating capacity and with a capillary tube as a throttle device. Time control defrosting method was used, and a frosting time duration of 120 min was set before defrosting was initiated. Based on the experimental data obtained, the novel defrosting control method was developed. To validate the novel defrosting control method, a further experiment was conducted on another ASHP unit (the second ASHP unit) having a nominal 6.5 kW heating capacity and with an EEV as a throttle device, where a frosting time duration of 130 min was set. The experimental results demonstrated that if adopting the novel defrosting control method, defrosting should be initiated at 101 min and 115 min, respectively for the two experiments. Although they were close to 120 min and 130 min adopted in the time control defrosting method, they were more reasonable as defrosting was initiated before the operating performances of ASHP units rapidly deteriorated.

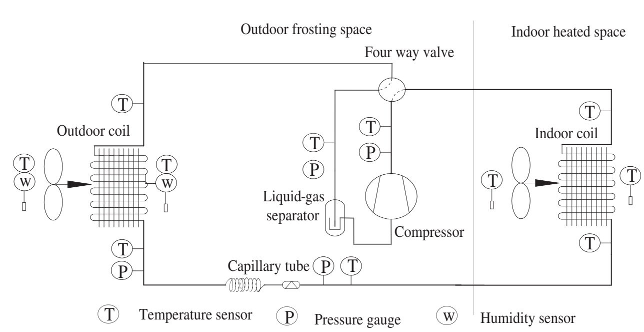

Fig. 1 – Schematics of the experimental setup of the first ASHP unit.