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Research Paper

Air source heat pump with water heater based on a bypass-cycle defrosting system using compressor casing thermal storage

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HIGHLIGHTS

- ASHP with water heater using compressor casing thermal storage is developed.
- The total defrosting time and consumption were lower than those of RCD.
- 10 L hot water with a temperature of 30 °C was obtained during the normal heating for 2.5 h.
- The compressor casing temperature was reduced by 4.6 °C.

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ABSTRACT

In this study, the defrosting system of an air source heat pump utilizing compressor casing heat storage combined with a hot gas bypass cycle (ASHP-CCHS-HGBC) was designed. The phase change material for defrosting was selected, the phase change heat storage exchanger was devised, and the ASHP-CCHS-HGBC test system was established. The power consumption, defrosting time, and the influence of the indoor exchanger outlet on the air temperature in the ASHP-CCHS-HGBC method were then compared with those of the reverse-cycle defrosting (RCD) and electric heating defrosting (EHD) methods. Experimental results reveal that the total defrosting time and consumption of the ASHP-CCHS-HGBC method was 100 s and 43.6 kJ, respectively. These values were lower by 10 s (9%) and 12.1 kJ (21.7%) relative to those of RCD. Moreover, the compressor suction temperature was increased by 10.1 °C during defrosting by ASHP-CCHS-HGBC. Under the normal heating operation for 2.5 h, 10 L hot water with a temperature of 30 °C was obtained, the compressor casing temperature was reduced by 4.6 °C. While defrosting, the air temperature of the indoor heat exchanger outlet declined to only 3.3 °C and exerted the least influence on the indoor temperature among those of the three defrosting methods.

1. Introduction

Air source heat pumps (ASHPs) have been applied worldwide in recent decades due to their advantages, such as energy conservation and environmental protection. More than 90% of the world's population resides in areas where ASHPs can operate, and these devices are used to control the indoor thermal environment [1,2]. However, in some areas, during heating by ASHP in winter, the low atmospheric temperature causes the outdoor coil tube to easily accumulate surface frost. The frost layer then reduces the flow channel area and becomes a heat insulator. Ultimately, heat transfer performance degrades and affects heating, even leading to the run-off of the ASHP unit [3–5].

To prevent this, the frost layer requires periodic removal [6–10]. Many studies have been undertaken to solve the problems caused by frosting of outdoor coil which include improving the defrosting performance of the ASHP unit [7,11–13], delaying the frost formation [7,14–16] and the application of more effective defrosting methods [7,17–19].

At present, the reverse-cycle defrosting (RCD) method is the most widely used standard defrosting method for ASHPs [2,7,20]. O'Neal et al. [21] experimentally investigated the transient defrosting performance of a 3-ton (or 3.514 kW) residential ASHP unit by

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Nomenclature

Q_1	theoretical discharged heat of the compressor
Q_2	defrosting power provided by the phase change material
P	compressor rated power
t	period of a heating cycle
m	average mass of water from defrosting
λ	the latent heat of the mixed paraffin
M	mixed paraffin
M_1	solid paraffin
M_2	liquid paraffin
V_m	Volume of mixed paraffin
ρ	density of mixed paraffin

using a thermostatic expansion valve (TEV) and found that the storage exchanger affected the system's dynamic responses. The cycle performance during frosting in an ASHP unit with either a scroll or reciprocating compressor was experimentally studied and compared in accordance with the ANSI/ASHRAE Standard 116-1983 [22]. The results suggested that the ASHP unit that employed a scroll compressor achieved a slightly higher integrated COP and a lower compressor discharge temperature during the frosting and defrosting. Other reported studies aimed to decrease the defrosting period and the associated energy losses. For example, O'Neal et al. [23] considered that increasing the orifice diameter would help decrease the defrosting period. Huang et al. [24] revealed that at the end of RCD operation, the discharge pressure was lower (742.3 kPa) in an ASHP unit under the fan pre-start method than under the normal fan-start method. Results from the dynamic simulation of the RCD operation of an ASHP have also been reported [25,26]. Song et al. [27] conducted experimental investigation on reverse cycle defrosting performance improvement for an ASHP unit by evenly adjusting the refrigerant distribution in its outdoor coil.

However, during RCD, the indoor air fan is usually closed to avoid blowing cold air directly into room air and thus affects passengers' thermal comfort. The lack of defrosting heat is a fundamental problem. Furthermore, after defrosting, the indoor coil reaches an extremely low temperature and thereby entails a long time to heat the room coil while heating a room [28,29]. This effect further extends the room heating duration relative to the initial heating time after defrosting. The 4-way valve needs to be reversed twice in a single defrosting cycle, and such frequent reversals may cause mass leakage of refrigerant, and even affect the system's safety [7,30,31].

Some problems are apparent and persistent in the defrosting of ASHPs. One fundamental issue is the shortage of defrosting power, which most obviously manifests as the decreased suction and discharge pressure of a compressor during RCD. As a result, refrigerant flow diminishes, and low defrosting efficiency is achieved. When defrosting for a long time, the indoor environment causes discomfort among the people inside the room. The above shortcoming in RCD must be solved by developing a new defrosting strategy.

Liu et al. [32] presented a new thermal storage defrosting system combined with a bypass cycle, analyzed the feasibility of the thermal storage defrosting system, tested four types of phase change materials, and proposed the operation modes of the overall system. The structure of the heat storage exchangers was designed and optimized. An experimental prototype was set up, and an experimental study was conducted at different defrosting modes. The results showed that the best defrosting mode enhances the defrosting speed by about 50% more than that of the original electric heating model and reduces the defrosting electric power consumption by about 71%. For the ASHP, the compressor exhaust heat is useful heat, so the refrigerator defrosting mode is not suitable for ASHP.

Ooi and Wong [33], estimated that 10%–20% of the total input energy dissipates to the air by convection and conduction of the compressor casing. Meanwhile, Park [34] showed that at least 6.3% of the compressor input energy is converted into casing waste heat and dissipates to the air. In sum, a large heat amount dissipates through the compressor casing into the air for a time period. Therefore, scholars have proposed the use of compressor casing heat storage combined with hot gas bypass cycle for defrosting [7]. To improve the defrosting process and use this waste heat, a novel ASHP unit is developed. The space is heated during the defrosting process using the heat dissipated by the compressor. Experiments using both the RCD method and the novel reverse cycle defrosting (NRCD) method developed in this study are conducted on an ASHP unit of 8.9 kW nominal heating capacity. The experimental results indicated that in the NRCD method, the discharge and suction pressures are increased by 0.33 MPa and 0.14 MPa, respectively, the defrosting time is shortened by 65% while the resuming heating period vanished with the NRCD method, and that the total energy consumption in comparison to RCD method is reduced by 27.9% during the period which is composed of defrosting period and resuming heating period. Moreover, the NRCD method ensured continuous heating during defrosting. The mean temperature difference between the air entering and leaving the indoor coil reaches 4.1 °C during defrosting. Over a test period of 125 min, compared to RCD method, the total heating capacity and input power are increased by 14.2% and 12.6%, respectively. The increase in the system COP is 1.4%.

However, the existing compressor casing heat storage defrosting system only considers the heat storage of the compressor casing during winter [2,7]. In the summer, the outer surface of the heat storage exchanger is covered with heat insulation material; thus, the heat storage exchanger accumulates heat, and the compressor casing temperature rises. The high compressor casing temperature then reduces the cooling COP in the summer, and the lubricant performance cracks. Therefore, scholars must study how to exploit the waste heat of the compressor casing to accelerate defrosting, further improve the comfort under the indoor environment, and ensure normal summer cooling. Compressor casing temperature under long-duration operations needs to study. In summary, this study proposes the use of ASHPs utilizing compressor casing heat storage combined with a hot gas bypass cycle (ASHP-CCHS-HGBC) to achieve indoor comfort in winter and quick defrosting and solve the problems in summer heater power consumption.

2. Heating/refrigeration/defrosting and water-heating cycles

The present study designed a heat storage exchanger to absorb compressor casing waste heat. The heat was stored by the phase change material in the heat storage exchanger and combined with the compressor hot gas bypass cycle for defrosting. During defrosting, the compressor operation cannot be terminated, and the four-