

A NOVEL PCM BASED REVERSE CYCLE DEFROSTING METHOD FOR AIR SOURCE HEAT PUMPS

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Abstract: The most widely used standard defrosting method for air source heat pumps (ASHPs) is reverse cycle defrosting. However, the fundamental problem of this method is that there is insufficient heat available during defrosting. This consequently leads to a poorer operating performance, reduced indoor thermal comfort for occupants and a poorer system reliability, etc. In order to solve this problem of insufficient heat and a number of its associated operational problems, in the paper a novel thermal energy storage (TES) based reverse cycle defrosting method for ASHPs using phase change material (PCM) was presented. The schematics, operation modes and control strategy of ASHP using the TES defrosting method developed were introduced. The experimental results indicated that the novel reverse defrosting method solve a number of problems including a longer defrosting time and a poorer system reliability and etc. existing in current ASHP.

Key Words: *air source heat pumps, thermal energy storage, phase change material*

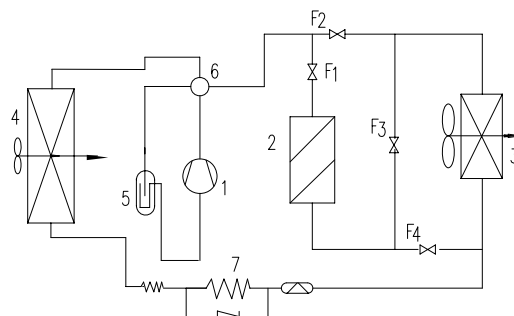
1 INTRODUCTION

When an ASHP operates at air temperature below freezing point of water, frost formed on ASHP's outdoor unit's coil surface reduces the airflow passages area and acts as a thermal insulator, leading to the performance degradation for the outdoor coil, even the shutdown of the unit. Currently, the most widely used standard defrosting method for ASHP is reversed-cycle defrosting (Ding et al.2004). When reversed-cycle defrosting starts, its indoor supply air fan is normally switched off. Therefore, the energy available for defrosting is basically from indoor coil metal and the input work of compressor, for there is an insignificant amount of energy available from indoor air because of a very small airside convective heat coefficient resulted from de-energized indoor fan during defrosting. When there is no heat to be absorbed from the coil metal, evaporating temperature drops significantly, and then an ASHP may shut down due to low-pressure cut-off or wet compression may take place, requiring more power input, and possibly damaging compressor consequently. Insufficient heat available during defrosting is currently a fundamental problem for reversed-cycle defrosting, with which a number of operational problems during defrosting for ASHPs are associated, including a prolonged defrosting time and the risk of a lower indoor air temperature inside a heated space as no heating is provided during defrosting, etc.

The previous limited related studies available in the open literature concentrated on the dynamics of reversed-cycle defrosting (O'Neal et al 1989; Krakow et al 1992; Krakow et al 1993) and on the effects of ASHPs's components such as a throttle regulator and

accumulator, etc. (Nutter et al 1996; Payne et al 1995; Liu et al 2003; Huang et al 2004) on defrosting performance. However, no previous studies on resolving this fundamental problem of insufficient heat available during reversed-cycle defrosting for ASHPs have been found. In this paper, a novel TES based reversed-cycle defrosting method for space heating ASHPs was presented, so as to solve this fundamental problem of insufficient heat and a number of its associated operational problems for ASHPs in the defrosting process.

2 THE PRINCIPLE OF THE TES BASED DEFROSTING SYSTEM



1- Compressor; 2-PCM based heat exchanger; 3-Indoor coil; 4-Outdoor coil; 5-Suction line accumulator ; 6-Four-way valve; 7-Capillary tube ; F1~F4 -Valve;

Figure 1: Schematics of the TES based reversed-cycle defrosting ASHPs

Fig.1 shows the schematics of the TES based reversed-cycle defrosting ASHPs prototype. Compared with traditional ASHPs, a PCM based heat exchanger (PCM-HE) filled with PCM is added to the system and this system can be operated in different modes such as space heating and heat storage and defrosting modes by opening or closing valves F1-F4.

2.1 The Operating Modes of ASHP Prototype

Table 1 shows the state of valves when the system operates in different modes.

Table 1; Operating modes and state of valves

Valves	F1	F2	F3	F4
Normal heating mode	close	open	close	close
Sole heat storage /defrosting mode	open	close	close	open
Series heat storage/defrosting mode	open	close	open	close
Parallel heat storage/defrosting mode	open	open	close	open

2.1.1 Heat storage mode

Generally, an ASHP operates at part load for most of its operating time, therefore excess heat is available in addition to the heat used for space heating. This part of excess heat efficiently obtained by heat pump can therefore be stored in the PCM-HE.

When heat storage is needed (the temperature of PCM is lower than the melting point), 3 heat storage modes (sole heat storage mode, series heat storage mode and parallel heat storage mode) can be realized. To what extent the heat supply to the room and heat storage will be affected depends on the heat storage mode and the required heat from indoor space.

2.1.2 Defrosting mode

When defrosting is necessary, 3 defrosting modes (sole defrosting mode, series defrosting mode and parallel defrosting mode) can be realized by opening or closing valves F1-F4. In defrosting mode, the refrigerant exiting the capillary tube flows through the PCM-HE which actually acts as an evaporator during defrosting. The energy stored in PCM-HE previously is discharged and used in the outdoor unit for defrosting. In different operating modes, the defrosting time and the recovering heating time for the system may be different.

2.2 PCM-HE

With an appropriate PCM-HE, a quick defrosting process may be accomplished, and the risk of having a lower indoor air temperature and shutdown of ASHP during defrosting may be eliminated. Thus it is an important issue to size a PCH-HE and choose appropriate PCM in this system. A PCM-HE should be able to store enough thermal energy for defrosting, therefore under-sizing should be avoided. However, over-sizing may not be accepted because of limitation of actual space. As to the PCM, to maximize the heat transfer between refrigerant and PCM and make sure the practical use of PCM-HE, PCM should have following properties. Firstly the PCM should have high conductivity and high latent heat of fusion per unit mass Secondly, the PCM should have appropriate melting temperature (30°C around), which is neither much lower than the condensate temperature nor much higher than the evaporate temperature. Thirdly, PCM should have some other superior properties such as the stable chemical stability, non-toxicity and no corrosion to the pipes.

3 EXPERIMENTS AND RESULTS DISCUSSION

3.1 Case Study

Figure2 shows a schematic diagram of the experimental setup. The test facility consisted of three major parts: the test heat pump prototype, psychrometric room, and data acquisition system. The outdoor coil is placed in a psychrometric room (312×310×214cm). The temperature in the room is controlled by a natural cooling system, a glycol-water solution heating water tank with a capacity of 4000W and an adjustable infrared heater with a capacity of 800W. Humidity is controlled by adjusting two ultrasonic humidifiers with a capacity of 300g/h. The test heat pump prototype was a separate heat pump unit, with a 2300W nominal cooling capacity.

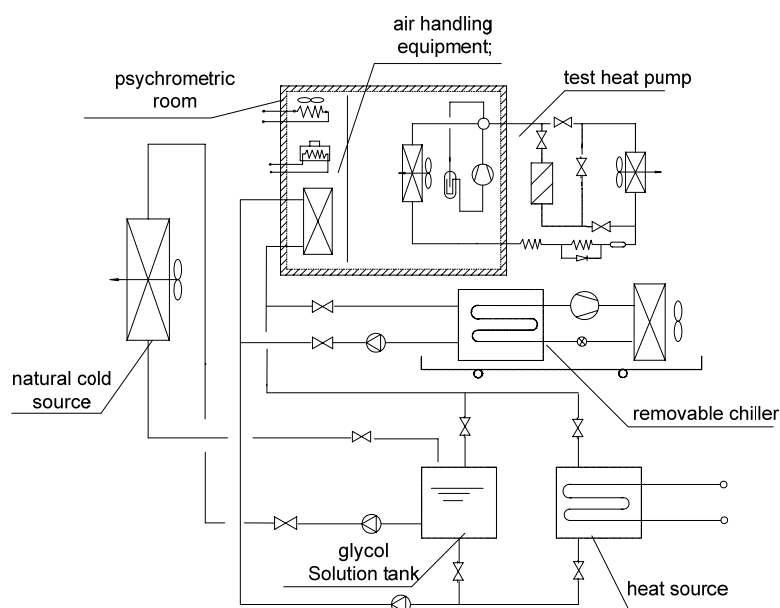


Figure2: principle of TES based reversed-cycle defrosting for ASHPs

The PCM-HE is designed as a thermally insulated shell-and-tube storage unit with the PCM on the shell side and the refrigerant being circulated inside the tubes. In this system, the PCM-HE is composed by inner heat storage coil and two cylinders made of organic glass, which are set together, as Figure3 shows. The PCM-HE has an outer diameter of 262mm and an inner diameter of 200mm and is 242 mm high. The PCM filled the PCM-HE is the compound of $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$, BaI_2 and $\text{Ba}(\text{OH})_2$. The Spiral coil in the double-cylinder is 12.38 m long. In order to make sure there is no heat lost from the PCM-HE, the PCM-HE is wrapped by high-pressure polyethylene film.

The temperature and humidity in the psychrometric room were collected by TES-1360 thermometer-hygrometer with an error of 3%. Other temperatures were collected by a WJK-Multi-Channel data acquisition recorder. The sensors were copper constantan thermocouples with an error of $\pm 0.3^\circ\text{C}$. The relative error of manometer over the effective measurement range of 2.0MPa was $\pm 0.25\%$.

In this paper, parallel defrosting mode and traditional defrosting were studied. In the process of defrosting, the air temperature in the psychrometric room was kept -2.0°C and the humidity was 85%. The temperature the out door coil worked at is 17.0°C .

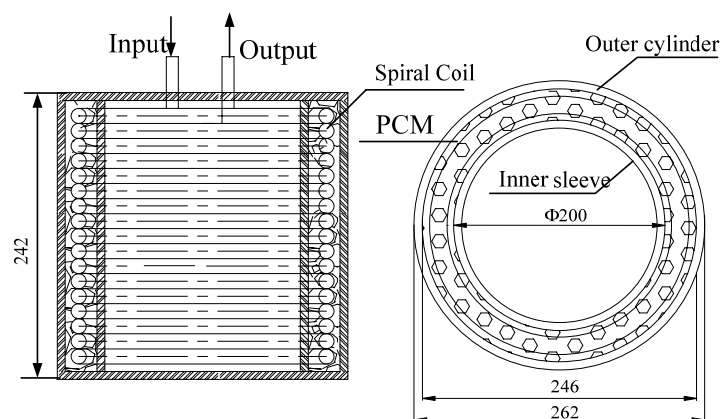


Figure 3: Sketch of structure of Phase Change Material Thermal Energy Storage Canister

3.2 Results And Discussion

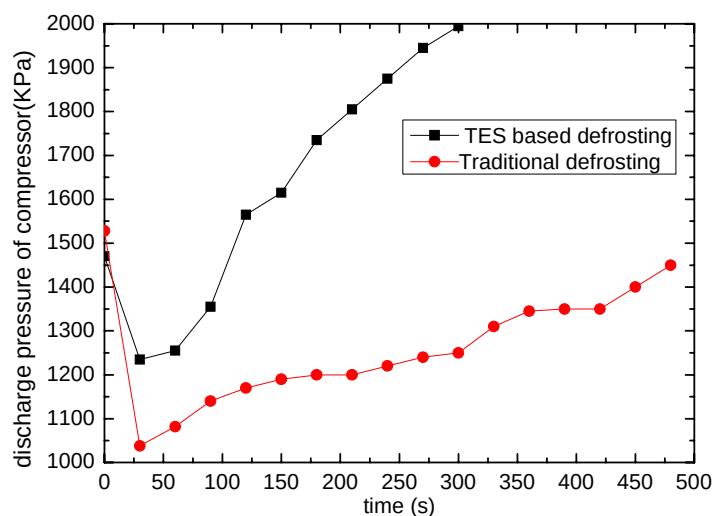


Figure 4: Comparison of Discharge Pressure of Compressor between TES Based Defrosting and Traditional Defrosting

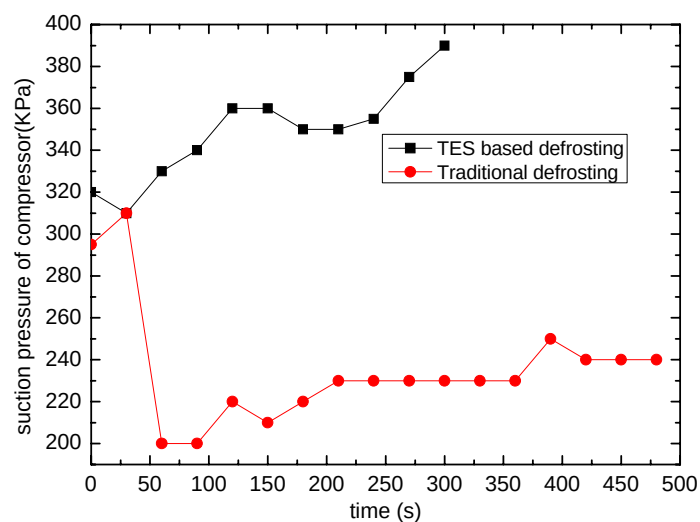


Figure 5: Comparison of Suction Pressure of Compressor between TES Based Defrosting and Traditional Defrosting

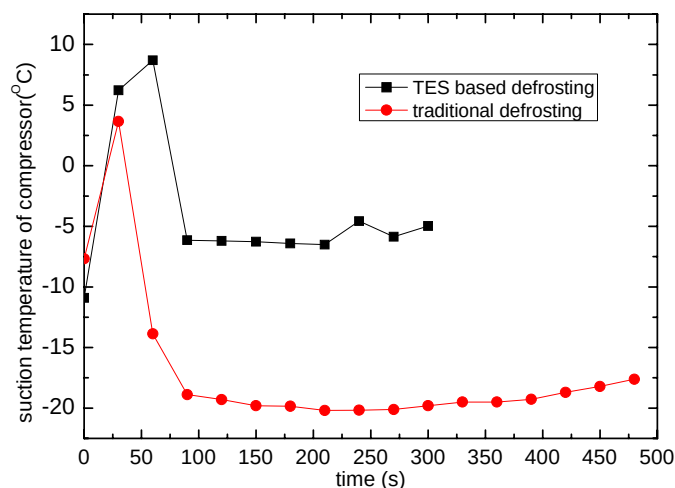


Figure 6: Comparison of Suction Temperature of Compressor between TES Based Defrosting and Traditional Defrosting

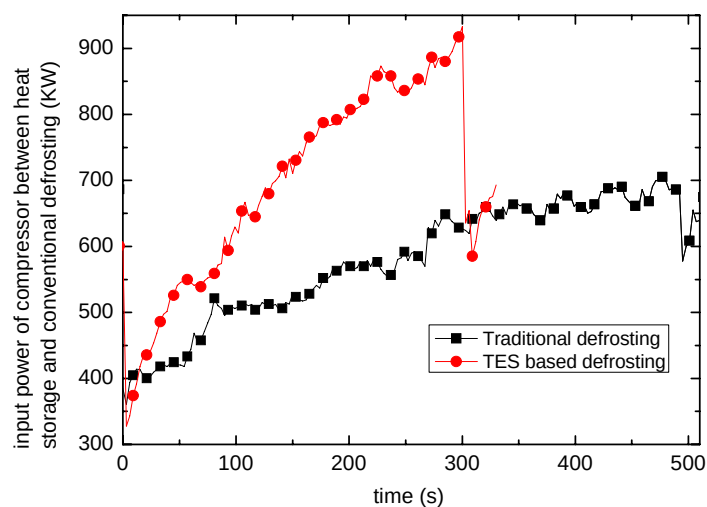


Figure 7: Comparison of Input Power of Compressor between TES Based Defrosting and Traditional Defrosting

1 From Figure 4, it can be found that the discharge pressure of compressor using TES based defrosting method was higher than that of conventional defrosting. Even the smallest discharge pressure difference appeared at the start of defrosting is about 200KPa. Although both of the discharge pressure increased, the discharge pressure difference increased with time.

2 Figure 5 shows that compared with conventional defrosting, TES based defrosting method has higher compressor suction pressure. The suction pressure in traditional way is between 200~250 Pa, which can easily cause shut down of compressor, while TES based defrosting has suction pressure between 310~390 Pa. So TES based defrosting may be more helpful for the system to avoid shut down of compressor because of the low suction pressure in the process of defrosting.

3 From Figure 6, it can be found that in the process of defrosting, because of the PCM-HE, the suction pressure of compressor in TES based defrosting method was about -5°C, about 15 °C higher than that of conventional defrosting. This can be helpful for the system to avoid poor indoor thermal comfort for occupants and to shorten the time for heating recovering.

4 Figure 7 indicates that input power for both TES based defrosting and conventional defrosting increase quickly. Compared with conventional defrosting, although the input power of TES based defrosting is higher and increased much more quickly, the defrosting time is shorter than conventional defrosting. So it is found that TES based reverse cycle defrosting consume less power because of the PCM-HE.

4 CONCLUSIONS

The compressor using TES based reversed-cycle defrosting method has higher discharge pressure, suction pressure and suction temperature than that using traditional reversed-cycle defrosting method, which eliminates a series of problems including a longer defrosting time, a reduced indoor thermal comfort for occupants and poor system reliability. Besides, although the input power of compressor in TES based defrosting is higher, the defrosting time can be shorten effectively, which can help increase an ASHP's energy efficiency.

ACKNOWLEDGEMENT

The project was financially supported by National Natural Science fund of China (Grant No.50606007), and the Hong Kong RGC (Grant No. B-Q05R.)

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