Investigation on Exergy in The Process of Heat Exchanger Defrosting

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Abstract. Excellent thermodynamics performance of heat exchangers plays a vital role in the effective operation of the air source heat pump (ASHP). However, the growing process of frost on the surfaces of the heat exchanger in winter could always affect the thermodynamic performance of the heat exchanger, which has attracted a great deal of attention over the past years. Moreover, the exergy analysis based on the second law of thermodynamics of the heat exchangers in the frosting condition has not been investigated before. In the present paper, exergy analysis of air-side heat exchanger was experimentally investigated. The experimental results show that exergy destruction would reach the minimum. The system has the lowest peak of energy utilization. This study is particularly useful for the design of optimal defrosting condition for heat exchangers of ASHP in winter.

1. Introduction
The air source heat pump (ASHP) is a device to deliver the energy from an airstream at high temperature or humidity to an airstream at low temperature or humidity using small amount of high-grade electric energy. Ambient air is used as the heat source for the ASHP [1], since ambient air is considered as inexhaustible and huge reserves of low quality energy and renewable resource. Due to the consideration of pollution in the environment, and the world's requirements to use renewable energy and more energy efficient energy usage, ASHP has been greatly and widely developed and used for buildings [2]. However, conventional problems created by the accumulation of the frost layer on the fin surface of the heat exchanger are the reduced the coefficient of performance (COP) [3] and the heat transfer rate. These would lead to the frosting becoming the main problem for the ASHP technology.

Lots of literatures show that the defrosting strategy [4] and defrosting control [5] under frost conditions of the heat exchanger in the winter. These studies were based on different types [6], different structures [7] and different defrosting control methods [8]. In these studies, only the study of the thermodynamic properties of the refrigerant side was made. In addition, some of the simplifying assumptions considered in these studies are not realistic in practice. For example, many studies do not consider the actual operating conditions. [9-12] However, in the actual operation process, the thermodynamic performance of the air-side heat exchanger is simultaneously affected by the latent heat and the sensible heat, which is a continuously changing process. What is more, air is the heat source of the ASHP, so a comprehensive experimental analysis on the air side and the refrigerant of heat exchanger on frost condition is essential. However, little is known about the thermodynamic
properties of the two side of the heat exchanger under the frost conditions in winter in a lot of the published literature. According to the author’s knowledge, there is no direct study available in the literature on the analysis of the air side of the heat exchanger under frost conditions. Therefore, in order to improve the thermodynamic performance of the heat exchanger and reduce its energy destruction, it is indispensable to study the effects of critical parameters on the system performance and the analysis of the exergy of the evaporator under frost conditions. In an attempt to fill these breaches, a detailed and accurate mathematical model to analyze the performance of the heat exchanger under different actual operating conditions has been developed. In this study, exergy analyses were conducted in order to find the optimal defrosting control condition of the evaporator in winter operating conditions, to achieve efficient operation of the ASHP.

2. Experiment system

2.1. Experimental Instruments

![Image of experimental setup]

**Fig. 1 Schematic diagram of heat exchange performance test bench**

An experimental test setup was built in order to measure the thermodynamics performance of heat exchanger. The main components of the experimental system are illustrated in Fig. 1. The experimental system is composed of the test system, the auxiliary heat pump unit, humidifier and electric heater. Temperature and humidity regulation of constant temperature and humidity chamber was done using the heat exchanger of the test system and the auxiliary heat pump unit, humidifier and electric heater.

3. Mathematical model

3.1. The exergy analysis model of the evaporator

The general form of the exergy destructon is as follows:

\[ \Delta E_x = T_e \Delta S \]  \hspace{1cm} (1)

Operating parameters that were kept constant for the present study are shown in Table 1.
Table. 1 Reference operating parameters of the systems.

| Item   | Ambient air temperature (°C) | Relative air humidity (%) | Air velocity (m/s) | Outdoor air temperature (°C) |
|--------|------------------------------|---------------------------|-------------------|-------------------------------|
| Case1  | 3                            | 97                        | 1.5               | 18                            |
| Case2  | 0                            | 92                        | 1.5               | 17                            |
| Case3  | -3                           | 88                        | 1.5               | 18                            |

4. Results and discussions

4.1. Variations of temperature difference and pressure drop with time

There are two essential factors that could influence the entropy difference. These are: temperature difference and pressure drop. From Fig.2, the temperature difference is decreased with time, but the pressure drop is the reverse of this trend. The change in temperature difference is more intense in pressure drop. The main reason is that the water vapour in the air condenses into frost on the surface of the fin. As the frost layer continues to thicken, the heat absorption of the refrigerant would become reduced, but the air pressure differential would increase as the air flows through the gradually decreasing passage. Therefore, the air temperature difference and air pressure differential would change in the opposite direction.

![Fig. 2 Variations of temperature difference and pressure drop versus time](image1)

4.2. Variations of entropy generation with time

Fig. 3 shows the curve of entropy generation with time during the condition of frosting. The figure shows the entropy generation gradually decline initially and then increase with time. This mainly due to this trend can be explained as follows. The entropy generation is a function of entropy flow and entropy difference. The entropy flow and entropy difference are a function of temperature difference and pressure drop respectively. So entropy flow shows a trend of decreasing with time, but entropy difference show an opposite trend as the trend of the temperature difference and pressure drop with time. The inflection points occurred at 382 min, 69 min, 77 min, 158 min, and 257 min, respectively. Meantime, the entropy generation and the system irreversibility degree reach the minimum.

![Fig. 3 Variations of entropy generation with time](image2)
4.3. Variations of exergy destruction with time

Fig. 4 shows the variation of exergy destruction in terms of time. By increasing the time, the exergy destruction declines initially and then increase as in the entropy generation. Similarly, inflection points also occurred at 382 min, 69 min, 77 min, 158 min, and 257 min respectively. The general reasons in exergy destruction with time can be explained by mechanisms as follows. According Eq. 1, the exergy destruction is a function of entropy generation. The inflection points are also the minimum exergy destruction which is the optimum defrosting conditions.

![Exergy Destruction Graphs](image)

Case 1 $T_{a1}=3 \, ^{\circ}C \phi=97\%$  
Case 1 $T_{a1}=0 \, ^{\circ}C \phi=92\%$  
Case 3 $T_{a1}=-3 \, ^{\circ}C \phi=88\%

Fig. 4 Variations of exergy destruction with time

5. Conclusion

The key findings from the exergy analysis are described as below:

1. The temperature difference and pressure drop show an opposite trend with the accumulation of the frost layer. This performance is due to the fact that the temperature difference has a decline trend caused by the decrease of the heat absorption of the refrigerant and a decline in the pressure caused by the increase blockage of air flow passages.

2. The obtained entropy generation shows an initial increasing trend and then decline with time. The entropy generation analysis determines the system irreversibility degree reach the minimum.

3. In the results obtained from the experimental system for the evaporator, the least exergy destruction value was obtained because of an initial decline and then increasing trend with time. The definition of the optimum defrosting conditions is the most suitable solution to start defrosting when the minimum exergy destruction occurred in the heat exchanger.

The results of this study provide an available measure for the general calculation and determination of the optimum defrosting conditions for the heat exchanger. That is, the minimum exergy destruction is acquired with the time, which is the optimum defrosting conditions.

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