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Energy Saving Optimization for Air Source Heat Pump Air Conditioning System

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Abstract: ***The analysis and optimization of energy saving is not only the problem of energy quantity, but also the comprehensive evaluation of energy quality and quantity. Air source heat pump is an air source, multi-functional space-conditioning unit with water heating function, which can lead to significant energy savings. In this paper, we by using the method of the exergy analysis to get the energy consumption distribution of the air source heat pump air conditioning system and point out the links of large exergy loss in the system and shows that the exergy loss of compressor accounts for 20.5 percent of the unit energy consumption, and the exergy loss of condenser is close to 30 percent of the total energy consumption. Based on these analyses, we put forward some maximum efficiency, energy-saving optimization measures for air source heat pump air conditioning system.***

Keywords: Air source integrated heat pump, Air conditioning system, Exergy analysis.

1. Introduction

An Air Source Heat Pump (ASHP) is an air source, multi-functional space-conditioning unit with water heating function (WH), which generally consists of compressor, condenser, throttle valve, evaporator, as shown in Figure 1. It has an outdoor unit and indoor air handler with air-to-refrigerant heat exchangers (R-AHX) just as a typical heat pump unit. By recovering the condenser waste heat for water heating and by providing dedicated heat pump water heating capability, ASHPs are able to achieve significant energy savings [1].

In air source heat pump air conditioning system (ASHPACS), the heat supply cycle and refrigeration cycle of heat pump are inverse Carnot cycle. Only a four-way reversing valve is added to the refrigeration system of the air conditioner to change the direction of refrigerant flow in winter and summer [3]. Air source heat pump units use indoor and outdoor air as heat and cold sources, without cooling water pumps, cooling water pipelines and cooling towers, rather than a huge cooling water system, especially for water shortage areas. In section 1, we do exergy analysis to discuss the exergy efficiency of ASHPACS. And in section 2, we determine the energy consumption distribution of ASHPACS. Then we put forward some maximum efficiency, energy-saving optimization measures for ASHPACS in last section.

2. Exergy Analysis of ASHPACS

Exergy of a system is the maximum useful work possible during a process that brings the system into equilibrium with a heat reservoir. When the surroundings are the reservoir, exergy is the potential of a system to cause a change as it achieves equilibrium with its environment [2]. Thus exergy is the energy that is available to be used. The greater exergy of the energy, the more parts of energy can be converted into useful work, and shows the higher value and the greater usefulness of this energy. Thus more attention should be paid to saving this kind of energy.

Exergy efficiency is an index to measure the technical or thermodynamic perfectibility for the system or equipment, which denoted by η_e, and defined as

$$\eta_e = \frac{e_q}{e_p}$$

where e_q and e_p are exergy of utilized or proceeds and paid or consumed, respectively. It is clear that the closer the exergy efficiency is to l, the better the thermodynamic perfectibility of the equipment or system is, the smaller the exergy loss is. So by exergy analysis method we can accurately reveal the weakest link in the equipment or system and thus obtain the measures to improve the equipment and save energy.

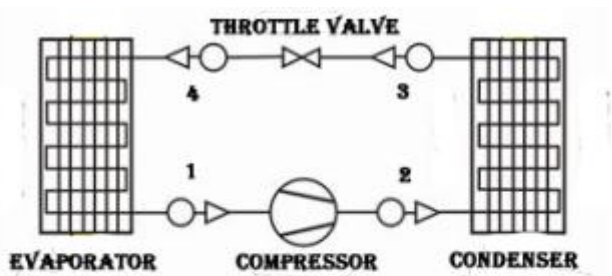

Figure 1: Schematic diagram of air-source heat pump

2.1 Preliminary

By the first and second laws of thermodynamics, the exergy expression of steady working flow is

$$e = (h - h_0) - T_0(s - s_0)$$

Where the subscript 0 denotes the state of the environment; T_0 is the temperature of the environment; h and s are enthalpy and entropy, respectively.

When the working flow changes from state 1 to state 2, the exergy change is as follows:

$$e_1 - e_2 = (h_1 - h_2) - T_0(s_1 - s_2)$$

According to the definition, the exergy is the part of heat quantity q emitted by a heat source at temperature T, which can be converted into a useful work. If the heat source exothermic temperature T unchanged, then

$$e_q = (1 - \frac{T_0}{T})q$$

If the temperature of the heat source decreases from T_1 to T_2 during the exothermic process, the exergy of heat q can be expressed as

$$e_q = [1 - \frac{T_0(\ln T_1 - \ln T_2)}{T_1 - T_2}]q$$

2.2 Exergy Analysis of Air Source Heat Pump

In this section we only gives the exergy analysis of air source heat pump air conditioning system under refrigeration condition. The analysis under heating condition can refer to other relevant literature. For the convenience of analysis, the schematic diagram of air source heat pump is given (see Figure 1). We distinguish four parts to discuss.

A. Exergy Loss of Compressor D_y.

$$D_y = T_0(s_2 - s_1)$$

Where s_1 and s_2 are entropy of inlet and outlet of compressor, respectively.

B. Exergy Loss of Condenser D_n.

As we know that exergy will be lost when refrigerant and cooling medium transfer heat in condenser and the reduction of refrigerant can be regarded as total loss while the heat of cooling medium is not utilized. This means

$$D_n = e_2 - e_3 = h_2 - h_3 - T_0(s_2 - s_3)$$

Where e_2 and e_3 are refrigerant inlet exergy and outlet exergy of condenser working, respectively. h_2 and s_2 are the outlet enthalpy and outlet entropy of compressor working, respectively, and s_3 is outlet entropy of Condenser working.

C. Exergy Loss of Throttle Valve D_i.

Since throttle valve exergy loss equals the difference between the inlet and outlet throttle valves exergy, so

$$D_i = e_3 - e_4 = T_0(s_4 - s_3)$$

Where e_3 and e_4 are inlet exergy and outlet exergy of throttle valve working, respectively, and s_4 is the outlet entropy of throttle valve.

D. Exergy Loss of Evaporator D_f.

$$D_f = |\Delta e_0| - |\Delta e_0'|$$

Where $|\Delta e_0|$ is the exergy loss of working in evaporator and $|\Delta e_0'|$ is the exergy of frozen water. And

$$|\Delta e_0| = |e_1 - e_4| = |h_1 - h_4 - T_0(s_1 - s_4)|$$

Where e_4 and e_1 are inlet exergy and outlet exergy of evaporator, respectively. h_4 and h_1 are the inlet enthalpy and outlet enthalpy of evaporator, respectively, and s_4 and s_1 are the inlet entropy and outlet entropy of evaporator, respectively and thus

$$|\Delta e_0| = [1 - \frac{T_0(\ln T_1 - \ln T_2)}{T_1 - T_2}]q_0$$

Where T_1 and T_2 are temperature of chilled water in and out of evaporator, respectively. q_0 is unit refrigeration capacity of evaporator and $q_0 = h_1 - h_4$.

3. Energy Consumption Distribution of ASHPACS

For a 35kW air source heat pump unit, if the ambient temperature is $30^\circ C$, the inlet and outlet temperatures of chilled water are $12^\circ C$ and $7^\circ C$, respectively. Then some parameters of the heat pump unit are shown in Table 1. The exergy losses of each part are shown in Table 2.

Table 1: Calculation results of air-source heat pump system

State point	Temperature t°C	Pressure p(MPa)	Specific enthalpy $h(kJ \cdot kg^{-1})$	Specific entropy $S(kJ \cdot (kg \cdot k)^{-1})$
1	7.9	0.554120	410.266	1.76078
2	80.9	1.778090	449.748	1.78761
3	36.3	1.778090	244.793	1.15018
4	2.9	0.554120	244.793	1.16221

Table 2: Exergy analysis of air-source heat pump system

Calculation item	Calculation results $kJ \cdot kg^{-1}$	wasted work ratio (%)
Compressor Power Consumption	39.682	100
Compressor exergy loss	8.13	20.5
Condenser exergy loss	11.818	29.8
Throttle valve exergy loss	3.645	9.2
Evaporator exergy loss	4.10	10.32
Total Exergy Loss	27.7	69.82

4. Energy saving measures of ASHPACS

By above analysis, we propose the following measures to save energy for air source heat pump air conditioning system:

(1) Selection of Compressor with High Efficiency and Low Energy Consumption. From the exergy analysis of air source heat pump air conditioning system, it can be seen that the exergy loss of compressor accounts for 20.5% of the energy consumption of the unit, because the compressor is conducting

an irreversible adiabatic compression process. Therefore, compressor energy saving is particularly important in this system. This requires that the compressor with high thermal efficiency, such as screw compressor or or scroll compressor, should be selected in the design of air source heat pump air conditioning system. When the boost ratio is large, two-stage compression should be adopted to reduce the loss. The two-stage compression process is divided into two stages. The gaseous working substance from the evaporator is compressed in the low-level compressor first. When compressed to the intermediate pressure of the intermediate cooler, it enters the intermediate cooler for cooling, and then enters the high-level compressor for compressing to the condensation pressure. Because the two-stage compression adopts the intermediate cooling, the exhaust temperature of the high-pressure stage is not too high, thus reducing the compressor exergy loss.

(2) Selection of Condenser with High Heat Exchange Efficiency. The exergy loss of condenser is close to 30% of total energy consumption, which is mainly due to the large temperature difference between refrigerant and air, so the temperature difference of heat transfer should be reduced. From the heat transfer process, it can be seen that for a certain heat load, in order to reduce the temperature difference, the heat transfer area and coefficient must be increased, and the increase of heat transfer area is limited by the volume and quality of the condenser, so the heat transfer coefficient can only be increased. To increase the heat transfer coefficient, the following measures can be taken: A. to increase the flow rate in the pipe; B. to adopt the threaded tube with high finning coefficient; C. to reduce the thermal resistance of scale and grease scale, or to adopt a new plate heat exchanger to improve the heat transfer coefficient and efficiency, so as to greatly reduce the volume and quality of the pipe.

(3) Super cooling steps for liquid in front of throttle valve. Due to the undercooling of the liquid in front of the throttle valve, the loss of throttle valve accounts for less than 10%. Refrigerant in throttle valve is an irreversible adiabatic throttling process. After undercooling measures are taken, throttle loss can be reduced and thermal efficiency can be improved.

(4) Reducing Heat Transfer Loss of Evaporator. The exergy loss of evaporator is relatively small (10.32%), mainly because of the utilization of refrigerant cooling capacity. The loss of evaporator is also caused by the temperature difference between refrigerant and chilled water. To reduce this exergy loss is also to minimize the temperature difference between refrigerant and chilled water, to improve the heat transfer coefficient, or to adopt a new type of plate heat exchanger.

5. Conclusion

In this paper, we from the point of view of the second law of thermodynamics reveal the quantity and quality of energy usage. It can correctly reflect the performance of the whole air source heat pump air conditioning system and thus we find out the energy saving potential of each part. Compressors and condensers suffer the greatest exergy losses. Therefore, the compressor with high efficiency should adopt to enhance heat transfer, increase heat transfer coefficient and reduce heat transfer temperature difference to reduce condenser loss. At the same time, attention should be paid to improving the surrounding environment of heat pump units.

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Author Profile

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