Experimental study on influence of electronic expansion valve opening on performance of water source heat pump unit

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Abstract: The Electronic expansion valve (EEV) has been used as a component responsible for controlling the superheat within the desired limits. In some of these controllers, the control parameters are set at a certain operating point and remain unaltered, even when the operating conditions change. This will lead to a reduction in system performance. In this paper, experiments were carried out to study the effect of EEV opening on the performance of the heat pump unit, and the result revealed that at different inlet water temperatures (13–23°C) the EEV opening had an optimal value: when the inlet water temperature of the source water was lower than 17°C, the COP value of the heat pump unit was the highest with the opening degree of the EEV at 60%, while the COP reached the highest value with EEV opening at 70% when the source water was above 17°C. This study provided a reference for energy-saving operation of water source heat pump units.

1. Introduction
The water source heat pump is based on the principle of the first law of thermodynamics, absorbing the low-grade energy stored in the water, and at the same time the compressor consumes power, and releases heat in the condenser through the system circulation. Since the energy output from the heat pump is always greater than the energy consumed by the compressor, water source heat pump technology can save a lot of energy[1][2].

The performance of the water source heat pump unit is directly related to the temperature of the source water and the components of the system. The opening of the EEV can be precisely adjusted within the range of 10% to 100%, which can adapt to the large flow rate change of the heat pump system. In the heat pump system, the opening degree of the EEV is usually set by supercooling, how to improve the unit performance and the unit operating conditions is the focus of the research[3][4]. There are many studies on the effect of the characteristics of the EEV on the system performance[5][6][7][8], some of them are based on the optimization of control methods, and some are on the research of the unit of a certain refrigerant. For heat pump units with new refrigerant, experimental parameters need to be optimized to achieve higher performance. This paper studied the influence of the change of superheat on the performance of heat pump units through experimental method, and analyzed the effect of water temperature, the EEV opening degree on system performance such as heating, power, and COP. In order to achieve optimal performance of the system, the optimal EEV opening of different water sources is clarified[9].

2. Experimental system and analysis method
The water source heat pump unit used in this experiment is a fixed frequency scroll compressor and the refrigerant adopts the ternary mixed non-azeotropic refrigerant (R1234ze (E)/R134a/R32, quality ratio
17%/33%/50%), the slip temperature is 6.1 °C, the EEV is Danfoss type 034G421, condenser and evaporator are plate heat exchangers. The introduction of the experimental system and error analysis are detailed in the literature[10].

In the experiment, the water inlet temperature range is 13~23°C. When the temperature of the source water reaches a steady state, the refrigerant temperature and pressure of the high-temperature side and low-temperature side and also the water flow rate and water temperature are automatically collected every 3 minutes, and then analyze the average of the three groups of test data. Experiments were performed on four EEVs at 60%, 70%, 80%, and 90%, respectively.

The heating cycle of the thermal system is shown in figure 1. The calculation of COP is shown in Eq. (1), and the heat capacity is shown in Eq. (2). The Equations (3) and (4) is the mass flow rate of the refrigerant. The heating capacity of the heat pump is obtained through the temperature difference and the mass flow rate of the water, as shown in Eq. (5). The power consumption is automatically recorded by the test instrument of the heat pump system. The calculation of energy consumption and COP is shown in Eq. (6) and Eq. (7) respectively.

\[
\text{COP}_{\text{in}} = \frac{h_2 - h_3}{h_2 - h_1} \tag{1}
\]

\[
q_i = \frac{h_2 - h_1}{v_1} \tag{2}
\]

\[
\dot{m} = \frac{c_p\rho \Delta T_{H_20}}{h_2 - h_3} \tag{3}
\]

\[
m_{\text{ref}} = \frac{\eta V_{th}}{v_1} \tag{4}
\]

\[
Q_k = C_p\rho \dot{V} \Delta T_{H_20} = m_{\text{ref}}(h_2 - h_3) \tag{5}
\]

\[
P_{\text{in}} = \frac{Q_k}{\eta} \tag{6}
\]

\[
\text{COP} = \frac{Q_k}{P_{\text{in}}} \tag{7}
\]

3. Experimental results and discussion
In order to compare the differences between the two methods of EEV control, two experiments were conducted. The first one is effect of setting the superheat degree of EEV on system performance, and
the second is the influence of EEV opening on performance of heat pump.

3.1 Effect of setting the superheat degree of EEV on system performance
The opening state of the EEV was set to the state at superheat degree of 3°C. As can be seen from figure 2, the COP of the unit grows with the increase of the source water temperature. When the hot water outlet temperatures were 43°C, 45°C, and 47°C respectively, the unit COP increased by about 30%, 26%, and 20% respectively.

3.2 Influence of EEV opening on performance of heat pump
This section examines the effect of the expansion opening on the parameters such as superheat, supercooling, suction temperature, pressure ratio, heating capacity, power consumption and COP. The opening degree in the experiment was set to 60%, 70%, 80%, and 90%, respectively. The optimal opening degree of the EEV is determined based on the highest COP value.

3.2.1 Influence of EEV opening degree on superheat and supercooling
From figure 3, it can be seen that when the opening degree of the EEV is 60% and 70%, the superheat degree shows a significant upward trend with the increase of the source water inlet temperature, and when the EEV opening degree is 80% and 90%, the increase in superheat is relatively slow. This is because the small opening degree of the EEV results in less flow. After the liquid refrigerant completely evaporates, it is continuously heated by the source water, so that the degree of superheat of the refrigerant is high. When the opening degree of the EEV becomes large, the flow of the liquid refrigerant also becomes large, so the liquid refrigerant cannot quickly vaporize completely in the evaporator, and resulting in a small degree of superheat.

A certain degree of supercooling in refrigerant can increase the unit heating capacity of the system, however, when the degree of supercooling increases to a certain extent, the impact on the heating capacity will not increase anymore. As can be seen from figure 4 that when the EEV opening is 80% and 90%, the degree of system supercooling increases with the rising temperature of the source water, and the degree of supercooling is between 2.6–4°C and 1.6–2.2°C respectively; when the opening degree of the EEV is 60% and 70%, the degree of supercooling tends to decrease with the increase of the source temperature, in addition, a steep drop trend occurred at 60% opening degree. Comparing figure 3 and figure 4, it can be seen that under the same EEV opening degree, the degree of supercooling and superheat have opposite relationship with the increase of the temperature of the source water, that is, the degree of superheat increases as the temperature of the source water increases, but the degree of supercooling is not the same. This will result in different changes in the performance of the system.
3.2.2 Effect of EEV opening on system performance

(1) Heating capacity The relationship between the heating capacity and temperature of the source water is plotted in Figure 5 for different opening degree. It is evident that the heating capacity is lower when the EEV opening is 90%. It can also be seen from figure 5 that at different opening degrees of the EEV the heating capacity of the system shows an upward trend with the rising temperature of the source water. This is because when the evaporating temperature is increased, the specific volume of the suction is reduced, according to the Eq. (4), the mass flow rate of the refrigerant is increased, and thereby the heating capacity is increased. However, due to the different opening degree of the EEV, the increase in heating water shows a large difference as the temperature of the source water increases. When the EEV is at 90%, the supercooling is between 1.6-2.2°C, and this lead to the heat of the refrigerant is not fully released, so that the improvement of the heating capacity of the system is small; when the EEV opening degree is 60%, the supercooling is 3-3.6°C, excessive refrigerant fluid in the condenser causes the reduction of the heating capacity.

(2) Compressor power consumption The changes in suction pressure, pressure ratio and compressor power consumption with the opening of the EEV are shown in Figures 6, 7, and 8 respectively.

As can be seen from Figure 6, the suction pressure of the compressor grows with the opening degree
of the EEV. Figure 7 shows that the pressure ratio of the compressor shows a decreasing trend with the increase of the opening degree of the EEV and the inlet source water temperature. The influence of the opening degree of the EEV on the power consumption of the compressor is reflected in two aspects, on the one hand, when the opening degree of the EEV becomes larger, the flow rate of the refrigerant will increase, according to Eq. (6), the power consumption of the compressor increases; on the other hand, as the opening degree of the EEV becomes larger, the degree of superheat and the pressure ratio gradually decrease, the enthalpy difference between exhaust and suction gas is reduced, according to the Eq. (6), the compressor power consumption will be reduced. The combined effect will make the compressor power consumption show different trends with the change of the opening degree of the EEV.

(3) COP

The relationship between the heating capacity of the system and EEV opening is shown in figure 10. The COP value of the heating system shows a significant upward trend with the increase of the source water inlet temperature, and the overall COP value is lower when the EEV opening is 90%. When the source water temperature is in the range of 13-17°C, the COP value is the highest with the opening degree of 60%; when the source water temperature is in the range of 17-23°C, the COP value is the highest with the opening degree of 70%. This is result of the combined effects of the refrigerant flow rate, pressure ratio, power consumption, superheat, and compressor efficiency. Therefore, a suitable configuration of the opening of the EEV with the water source can improve the performance of the system.

Taking the inlet source water temperature of 16°C and 21°C as examples, the trend of COP with the EEV opening was investigated. COP changes with the opening of the EEV as shown in figure 10, when the source water temperature is 16°C, the optimal opening of the EEV is 60%; and when the source water temperature is 21°C, the optimal opening of the EEV is 70%.
Comparing the method of setting the degree of supercooling (as seen in figure 2.) and setting the opening degree of the EEV, the relationship between COP and the temperature of the source water is shown in figure 11. COP1 represents system COP using the method of setting the superheat degree of EEV, and COP 2 represents system COP using the method of setting EEV opening. In the curve of COP2, when the source water inlet temperature is between 11℃ to 20℃, the EEV opening degree is at 60%; when the source water inlet temperature is above 16℃, the EEV opening degree is at 70%. It can be seen that the COP with the second method is about 5%-11% higher than that of the first one.

4. Conclusion
In this paper, an experimental study has been conducted on a water-source heat pump unit with EEV for the preparation of 45℃ hot water. The heat pump unit used a new type of ternary mixed refrigerant (R1234ze(E)/R134a/R32, mass ratio of 17%/33%/50%), and the compressor was a fixed frequency scroll type. The experimental source water temperature range was 13-23℃. The following conclusions were obtained through experimental research:

1) Within the experimental temperature range, when the EEV opening was smaller, supercooling and superheat showed the opposite trend with the increase of source water temperature. When the EEV opening was larger, the superheat and the supercooling showed different trends.

2) When the water temperature of the source water was in the range of 13-17℃, the COP value was
the highest with the EEV opening degree at 60%, and when the water temperature of the source water was in the range of 17-23°C, the COP value was the highest with the opening degree of the EEV at 70%.

3) By analyzing the influence of two control methods on COP, it was found that the method of adjusting the opening degree of the EEV was about 5% to 11% higher than that of the method of setting the degree of superheat. If the EEV adopts the method of controlling the degree of superheat, then in the working process of the system, the degree of superheat control shall be adopted according to the change of the temperature of the water source so as to ensure that the system is always in an optimal state.

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