International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 12 Issue 3 ǁ March 2024 ǁ PP. 26-34

Exhaust Temperature Control Method to Achieve Non-Overheating Throttling Control at the Evaporator Outlet

Qianjun Ma[1*], Shiji Zong[1], Hongwei Guo[1], Xiao Li[1]
[1]*School of Environment and Architecture, University of Shanghai for Science and Technology, Shanghai, China*
[*]*Corresponding author: Qianjun Ma*

Abstract:
The purpose of this article is to study the influence of the refrigerant state at the outlet of the evaporator on the heat transfer capacity and system performance under low temperature conditions. A control method for controlling the refrigerant at the outlet of the evaporator not to overheat with the exhaust temperature as an indirect control objective is proposed and its feasibility is verified. This study established a low-temperature evaporator testing system and studied the variation of evaporator capacity parameters and system performance parameters with the dryness and overheat at the evaporator outlet under low-temperature conditions. Research has found that when the outlet dryness of the evaporator is between 0.9 and 1, the heat transfer capacity and system performance of the evaporator are better than those of the overheated section. Moreover, the outlet state of the evaporator can be controlled in a small amount of liquid state by the exhaust temperature control method, and at this time, the parameters such as heat exchange capacity, total heat exchange coefficient and system COP of the evaporator reach the maximum.
Key words: *evaporator outlet state, no overheat degree, exhaust gas temperature, heat exchange capacity.*

Date of Submission: 25-02-2024 Date of acceptance: 05-03-2024

I. Introduction

In dry evaporative refrigeration systems, overheat control is the most common throttling control method. During the operation of a dry evaporative refrigeration system, the overheat at the outlet of the evaporator is related to the reheat after evaporation. The presence of overheat indicates that the refrigerant has completely evaporated in the evaporator and entered an overheated state. But when the overheat at the outlet of the evaporator is too low, it is easy to have liquid at the outlet, that is, the outlet is in a two-phase state. Once this state is entered, the overheat remains zero, and the overheat control will be ineffective. Therefore, in the overheat control system of a dry evaporator, the set value of overheat is generally around 5-7 ℃, which contradicts the efficient operation of the evaporator[1]. The existence of overheat at the evaporator outlet reduces the heat transfer area of the two-phase section and weakens the heat transfer performance; On the other hand, the refrigerant in the overheated section not only has a small heat transfer coefficient, but also gradually increases the refrigerant temperature, resulting in a smaller heat exchange temperature difference, resulting in limited heat exchange in the overheated section and occupying a large amount of heat exchange area[2]. At the same time, if the overheat of the refrigerant on the outlet side of the evaporator is too high, it will increase the discharge temperature of the compressor and affect its operational reliability. Therefore, in the overheat control of evaporators, there is a structural contradiction between the necessity of overheat control and the impact of heat exchangers on heat transfer capacity[3].

Theoretically, at the inlet of the heat exchanger, the refrigerant is in a bubbly flow state. Currently, as the refrigerant does not fully reach saturation, the heat transfer inside the tube mainly relies on convective boiling heat transfer[4]. When the heat transfer process is halfway through, the dryness of the refrigerant gradually increases, and phase change heat transfer occurs while generating many bubbles to enhance the disturbance, thereby enhancing the heat transfer effect. As the heat transfer process progresses, when bubbles aggregate to form blocky or filmy structures, they hinder the heat transfer between the tube wall and the refrigerant, greatly weakening the heat transfer effect and causing a slight decrease in the total heat transfer coefficient. At the end of the heat exchange, almost all the refrigerant inside the tube is gaseous, and the heat transfer coefficient inside the tube suddenly decreases. At the same time, the heat transfer outside the tube deteriorates, and the total heat transfer coefficient rapidly decreases [5]. Therefore, a reasonable and good control method should increase the heat transfer length of the two-phase section of the evaporator as much as possible, control the refrigerant state at the outlet of the evaporator within a reasonable range, thereby improving the heat transfer coefficient in the tube and enhancing the heat transfer capacity of the evaporator. For refrigerants, the heat transfer coefficient of the refrigerant in the two-phase zone of the evaporator is high, while the heat transfer coefficient of the refrigerant in the overheated zone is low. The boiling heat transfer coefficient in the two-phase zone is much higher than the heat transfer coefficient in the overheated zone. Therefore, controlling the evaporator outlet state without overheat is the best control method[6]. However, it is difficult to control the refrigerant overheating state, because when the evaporator outlet enters the overheating state, the refrigerant state at the evaporator outlet cannot be measured, and it is impossible to judge the specific liquid carrying situation at the evaporator outlet according to the overheating degree[8]. To solve this problem, this paper puts forward a control method of refrigerant overheat at evaporator outlet: the exhaust temperature is used as an indirect control target to calculate the liquid dryness of refrigerant at evaporator outlet. This control method is introduced in detail, and the refrigeration unit is designed and reformed to control the refrigerant state at the evaporator outlet.

The main research contents of this article are as follows:

(1) Clarify the reasons why the refrigerant outlet of the evaporator in a zero-overheat state and a high degree of overheat has a significant impact on the performance of the evaporator, and design a control method to control the refrigerant outlet in a zero overheat state to obtain reasonable and accurate research results.

(2) Use exhaust temperature to control the refrigerant outlet of the evaporator in a zero-overheat state, and experimentally study the effects of different dryness and degree of overheat at the outlet of the evaporator on the heat transfer capability of the evaporator.

II. Methodology

In dry evaporative cooling systems, electronic expansion valves typically control mass flow by using overheating as a control signal. However, due to overheating, this method leads to a decrease in the heat transfer efficiency of the two-phase region of the evaporator. As a way to maximize the effective heat transfer area of the evaporator, the exhaust temperature can be used as an indirect control target to adjust the outlet refrigerant of the evaporator to a slightly liquid state without any overheating[9]. In this way, the refrigerant state at the outlet of the evaporator can be taken as the final control goal, and the exhaust temperature of the compressor can be indirectly adjusted to achieve the final control goal.

2.1 Principle of Evaporator without Overheat Control Using Exhaust Temperature

During the compression process, there is heat loss when the outlet refrigerant from the evaporator enters the compressor[10]. The compression loss mainly manifests as adiabatic compression efficiency within the compressor. Therefore, this study controls the outlet refrigerant of the evaporator to a slightly liquid state without overheat based on the compressor’s adiabatic compression efficiency and actual exhaust temperature. First, the saturated enthalpy values corresponding to saturated gas and liquid states are calculated based on the evaporation pressure[11]. Through the determination of the desired liquid content at the target working condition, the enthalpy and entropy values of the refrigerant at the outlet of the evaporator are obtained. Using the calculated entropy value and exhaust pressure, the theoretical cycle exhaust temperature, which represents the adiabatic compression exhaust temperature, is determined. Finally, the actual exhaust temperature can be obtained by calculating the enthalpy value corresponding to the adiabatic compression exhaust temperature and adiabatic compression efficiency. Different actual exhaust temperatures correspond to different outlet state points. Pressure-enthalpy diagram of isentropic compression cycle is shown in Fig. .

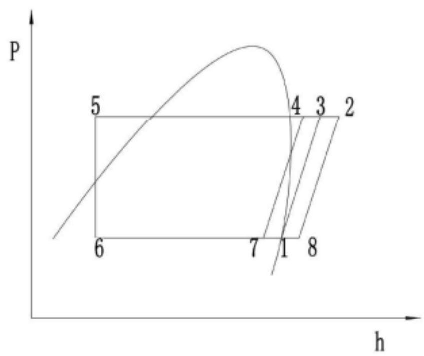

Fig. 1. Isentropic compression cycle pressure enthalpy diagram

Fig. shows the theoretical cycle process of the refrigerant in the liquid state, saturated state and overheated state. The state point 7 ~ 4, point 1 ~ 3 and point 8 ~ 2 is a complete compression without heat loss process. When the evaporator outlet enters the compressor compression from the saturated state point 1, the theoretically calculated exhaust temperature, that is, the isentropic compression exhaust temperature is the temperature corresponding to point 3. When the evaporator outlet is point 7 with liquid state, the exhaust temperature corresponding to the theoretical cycle is point 4. When the evaporator outlet is point 8 overheated, the exhaust temperature corresponding to the theoretical cycle is point 2. The calculation process of exhaust temperature of isentropic compression theory with liquid, saturated and overheated states is as follows. The meaning in the formula is shown in Table.1.

Table.1 The meaning of letters in the formula

Letters in the formula	Meaning
P_e	Evaporation pressure
S_e	Entropy of evaporator outlet
h_e	Evaporator outlet enthalpy
p_c	Condensing pressure
X	Refrigerant dryness
h_d	Enthalpy of isentropic compression exhaust gas
T_d	Isentropic compression exhaust temperature
S	Entropy
h	Enthalpy

The exhaust temperature of isentropic compression theory with liquid state is determined by (1) ~ (4) :

$$S_7 = f(P_c, X_7) \quad (1)$$

$$h_1 = f(P_e, S_1) \quad (2)$$

$$h_4 = f(P_8, S_7) \quad (3)$$

$$T_4 = f(P_e, h_4) \quad (4)$$

The exhaust temperature of isentropic compression theory of saturated state is determined by (5) ~ (8) :

$$S_1 = f(P) \quad (5)$$

$$h_1 = f(P_e, S_1) \quad (6)$$

$$h_3 = f(P_e, S_1) \quad (7)$$

$$T_3 = f(P_c, h_3) \quad (8)$$

The exhaust temperature of the isentropic compression theory in the overheated state is determined by (9) ~ (12) :

$$S_8 = f(P_c, T_8) \quad (9)$$

$$h_8 = f(P_e, S_8) \quad (10)$$

$$h_2 = f(P_c, S_8) \quad (11)$$

$$T_2 = f(P_s, h_2) \quad (12)$$

The exhaust temperature of isentropic compression theory at any point with liquid is determined by (13) ~ (16) :

$$S_e = f(P_e, X) \quad (13)$$

$$h_x = f(P_e, S_e) \quad (14)$$

$$h_1 = f(P_c, S_e) \quad (15)$$

$$T_i = f(P_c, h_i) \quad (16)$$

2.2 Analysis of Calculation Results of Exhaust Temperature Control Methods

Analyzing the performance of refrigeration systems through thermodynamic cycle calculations is an important research method[12]. This article is based on the first law of thermodynamics, ignoring some small influencing factors, thus simplifying the actual refrigeration cycle, and obtaining theoretical data of exhaust temperature under different target operating conditions. The calculation conditions are evaporation temperature of -11 ℃and condensation temperature of 27 ℃

In order to simplify the calculation, this paper makes the following assumptions on the thermodynamic model of the cycle:

(1) The refrigeration cycle is in steady state.

(2) According to the actual engineering experience, the isentropic compression efficiency is 0.7.

(3) No loss before and after the throttle valve.

(4) No heat loss in pipeline and heat exchanger.

(5) The isentropic compression efficiency of the compressor is unchanged when the liquid condition is studied.

Fig. is the theoretical calculation of the relationship between the exhaust temperature and the dryness and overheat of the refrigerant at the outlet of the evaporator. It can be seen from the figure that when the overheat is 5℃, the exhaust temperature is 63.16℃, and when the dryness is 0.93, the exhaust temperature is 39.76℃. Due to the decrease of overheat and dryness at the outlet of the evaporator, the theoretical exhaust temperature gradually decreases and shows a two-stage linear variation law[13]. The theoretical exhaust temperature decreases slightly in the overheated section. When the refrigerant state changes from overheated to liquid, the exhaust temperature decreases abruptly.

From the Fig.2, it can also be found that when the dryness of the evaporator outlet is less than 0.87, the exhaust temperature stops falling, that is, the exhaust temperature does not decrease infinitely with the increase of the liquid volume but is close to the condensation temperature. Currently, the compressor exhaust has no overheat. If the liquid volume of the refrigerant at the outlet of the evaporator continues to increase, the compressor exhaust may appear with liquid. By comparing the exhaust temperature changes in the overheated zone and the liquid zone[14], it can be found that when there is a small amount of liquid at the outlet of the evaporator, the exhaust temperature is still changing and has a certain degree of exhaust overheat, indicating that it is theoretically feasible to use the exhaust temperature to reflect the outlet state of the evaporator.

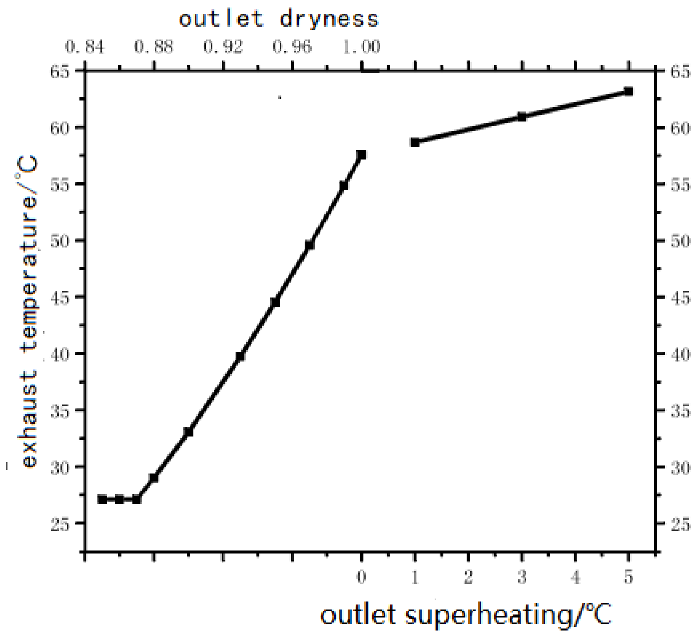

Fig.2. The change of exhaust temperature on the outlet state of evaporator

2.3 Evaporator testing system

This testing system is a low temperature working condition testing system, consisting of a finned tube heat exchanger, a tubular heat exchanger, a plate heat exchanger, a compressor, an electronic expansion valve, and other auxiliary devices. This study adopts R410A refrigeration system. During the operation of the unit, the refrigerant in the evaporator undergoes heat exchange with low-temperature air and vaporizes into overheated gas or no overheated gas is sucked into the compressor. Currently, the compressor is in a state of compression with a small amount of liquid. Controlling a small amount of liquid can prevent adverse effects on the compressor[15]. When the refrigerant does not completely evaporate and enters the compressor, a small amount of liquid will vaporize in the compressor and enter the condenser for heat exchange, The refrigerant after heat exchange is throttled and depressurized by the electronic expansion valve and enters the evaporator to participate in the next cycle[16].

2.4 Experimental conditions

Compressor exhaust temperature reverse pushes evaporator outlet refrigerant state.

Experimental method: Reverse the refrigerant state at the outlet of the evaporator based on exhaust temperature and isentropic efficiency.

Control variables: evaporator outlet dryness 0.95/0.97/0.99, overheat 1/3/5/7.
Test conditions: The experimental conditions for controlling the outlet state of the evaporator using exhaust temperature are shown in Table.2.

Table.2 Experimental conditions for exhaust temperature control methods

Air temperature（℃）	Condensing temperature（℃）	Overheat degree（℃）	Evaporator outlet dryness
-6	27	1/3/5/7	0.95/0.970.99

Measurement parameters: The test data required for using the exhaust temperature control method mainly includes parameters on the unit side, wind side, and water side. Based on the measured experimental data, calculate the actual intake and exhaust enthalpy value, isentropic exhaust temperature enthalpy value, isentropic efficiency, heat transfer, *COP*, total heat transfer coefficient, and other parameters. The specific measurement parameters are shown in Table.3.

Table.3 Exhaust temperature control method for measuring parameters

Measuring position	Measurement parameters
Electronic expansion valve side	Electronic expansion valve opening
	Inlet/outlet refrigerant temperature（℃）
Evaporator side	Inlet/outlet refrigerant pressure(*Kpa*)
	Inlet/outlet air temperature（℃）
	Evaporating temperature（℃）
Condenser side	Condensing temperature（℃）
	Exhaust temperature（℃）
Compressor side	Exhaust pressure(*Kpa*)
	Input power(*W*)
Cooling water side	Refrigerant flow rate（m^3/h）
	Inlet and outlet water temperature（℃）
Air side	Inlet and outlet air temperature（℃）

2.5 Experimental operation steps

When conducting experiments on controlling the refrigerant state at the outlet of the evaporator through exhaust temperature control, the overheat control target is the outlet state of the evaporator (the suction state of the compressor)[17]. When testing the working condition of the evaporator outlet with liquid, the dryness of the evaporator outlet is the control target. The experimental operation process is as follows:
(1) Set the temperature of the insulation water tank, adjust the cooling water temperature, and achieve the target condensation temperature.
(2) Adjust the electronic expansion valve to control the refrigerant flow and overheat of the system.
(3) After the system reaches the target low temperature condition and operates stably, adjust the opening of the electronic expansion valve to change the mass flow of the refrigeration system and gradually reduce the overheat. After the overheat condition test, calculate the actual compression efficiency of the compressor according to the measured results.
(4) Based on the measured compression efficiency of the compressor, the relationship between low overheat and dryness in the liquid zone and exhaust temperature is calculated. The opening of the expansion valve is adjusted to control the compressor exhaust temperature to reach the target value, and measurements are conducted for each low overheat and dryness state.

III. Results and discussion

The change of performance parameters with the expansion valve opening is the regulation law for the system during the regulation process in the system, and it is not possible to give a specific change law applicable to the evaporator outlet state affecting the system performance[18]. Therefore, this paper continues to study the impact of the specific state of the evaporator outlet refrigerant on various parameters, providing a reference for improving the heat exchange capacity of the evaporator under low temperature conditions.

3.1 The influence of evaporator outlet state on the total heat transfer coefficient

Fig.3 shows the variation pattern of the total heat transfer coefficient affected by the refrigerant state at the evaporator outlet when using the exhaust temperature control method to control the evaporator outlet state. From the graph, it can be seen that the total heat transfer coefficient gradually decreases with the increase of overheat degree in the overheated section, and the decrease is significant, with a clear trend; When the evaporator outlet is in the liquid zone x=0.9~1, the heat transfer coefficient shows a trend of first increasing and then decreasing as the dryness increases[19]. At a dryness of 0.97, it reaches the maximum value of 318.6$W/(m^2 \cdot ℃)$.Currently, the heat transfer coefficient is 336% higher than that at a overheat of 9.8 ℃.

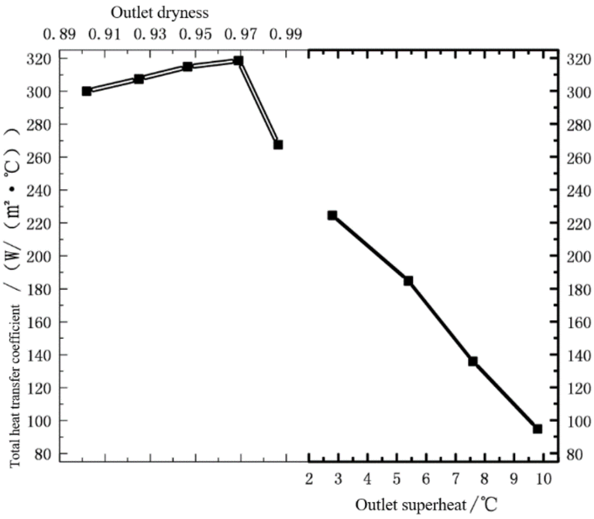

Fig. 3 The variation of heat transfer coefficient with outlet state

3.2 The influence of evaporator outlet state on heat transfer

Fig.4 shows the variation of heat exchange rate with the change of evaporator outlet state when using the exhaust temperature control method for evaporator outlet state. It can be seen that when the dryness of the liquid at the outlet is x=0.901, compared to the conventional overheat at 5-10 ℃, the heat exchange of the evaporator is higher; When the dryness is 0.97, the maximum heat exchange of the evaporator reaches 3254 W. At this point, the heat exchange rate increased by 633W, approximately 24.15%, compared to the heat exchange rate at a overheat of 7.6 ℃.

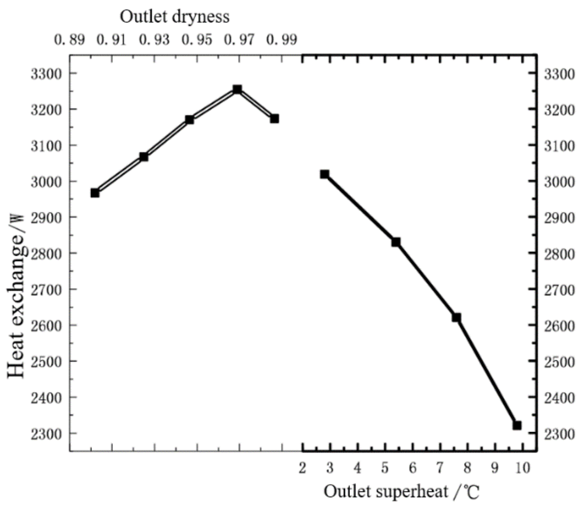

Fig. 4 The change of heat exchange rate of evaporator with outlet state

3.3 The influence of evaporator outlet state on COP

Fig.5 shows the variation of COP with the outlet state of the evaporator when using the exhaust temperature control method. In the overheated zone, the overheat of the refrigerant at the evaporator outlet gradually increases, and the COP gradually decreases. The COP in the liquid zone is greater than that in the overheated zone and reaches its maximum value at a dryness of 0.97. However, COP will not continue to increase with a decrease in dryness but will gradually decrease. When the dryness of the outlet with liquid is at x=0.901, the system performance is better than that of the overheated section at the outlet of 2~10 ℃. Compared with the COP value of controlling the dryness of the outlet with liquid of 0.97 and the conventional COP value of controlling the overheat at around 5 ℃, the COP decreases from 1.94 to 1.72, a decrease of 11.34%. Compared with the liquid zone and the overheated zone, the peak value of COP is 1.94 at a dryness of 0.97, and the minimum COP is 1.42 at a overheat of 9.8 ℃; The trend of COP change in the liquid carrying zone is relatively slow. As the dryness of the liquid carrying zone gradually decreases, COP first increases and then decreases. Throughout the entire change process, the minimum value of COP decreases by 11.47% compared to the maximum value; On the contrary, in the overheated zone, as the degree of overheat increases, COP rapidly decreases, and the maximum value in the liquid zone increases by 36.88% compared to the minimum COP in the overheated zone. The existence of overheat has a negative impact on the performance of the system, and the impact of liquid entrainment at the evaporator outlet on the system performance is much greater than that of overheating at the evaporator outlet.

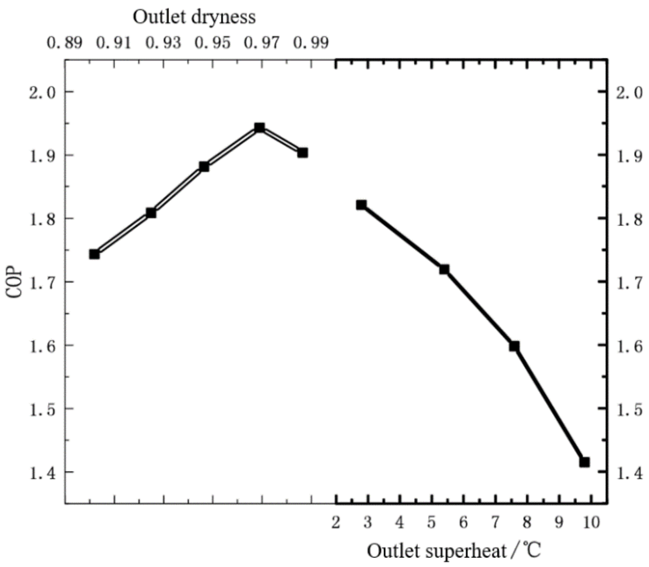

Fig. 5 COP changes with export status

In this chapter, the theoretical analysis idea is verified by experiments, and the feasibility of the control method of controlling the overheat of evaporator outlet by exhaust temperature is verified by experiments. This method can better realize the overheat of evaporator outlet refrigerant. At the same time, the relationship between exhaust temperature and evaporator outlet state, the relationship between the opening of electronic expansion valve and exhaust temperature and overheat degree, and the relationship between the single point state of evaporator outlet and evaporator heat exchange capacity, total heat exchange coefficient, COP and other parameters are analyzed in detail. It is found that the evaporator capacity when the evaporator outlet is in liquid state is much greater than that in overheated state.

IV. Conclusion

The purpose of this paper is to study the influence of the outlet refrigerant state of the evaporator on the heat exchange capacity of the evaporator and the performance of the system under low temperature working conditions and put forward a method to control the outlet state of the evaporator by taking the exhaust temperature as an indirect control target. The experimental results are as follows:

(1) There is a non-overheat boundary opening line during the adjustment process of the electronic expansion valve, which is the boundary between the outlet overheat state and the outlet liquid state. On the left side of the opening line is the adjustment of the outlet overheat section, and on the side of the opening line is the adjustment of the outlet with liquid section. When passing through the opening line, there will be a sudden change point in the exhaust temperature, overheat, and other parameters. The sudden change point in the exhaust temperature can be used as the target point for exhaust temperature control.

(2) When the exhaust temperature is used to control a small amount of liquid at the evaporator outlet, the influence on the total heat transfer coefficient is very significant. When the evaporator outlet is in the liquid zone x=0.90~1, the heat transfer coefficient shows a trend of first increasing and then decreasing with the increase of dryness. At a dryness of 0.97, it reaches the maximum value of 318.60W/(m^2·℃), and at this time, the heat transfer coefficient increases by 336% compared to the heat transfer coefficient at a overheat of 9.8 ℃. It is proved that this method can significantly improve the total heat transfer coefficient.

(3) When the exhaust temperature is used to control a small amount of liquid at the evaporator outlet, the heat exchange capacity and COP are greatly improved. The change trend of heat exchange capacity and COP is almost the same, and it rises first and then falls in the whole process of export state reduction. When the outlet dryness is x=0.97, the heat exchange capacity of the evaporator reaches the maximum, and the heat exchange capacity is 633W higher than that at the overheat of 7.6℃, about 24.15%. The COP reaches a peak of 1.94 at x=0.97, and the minimum value of COP is 1.42 when the overheat is 9.8℃, and the minimum value of COP decreases by 11.47% compared with the maximum value.

Acknowledgement

This work has received support from a laboratory of a certain company in Shanghai. Thank you for the help of all participants in the experiment. The experiment described in this article was conducted in a professional laboratory, and it is declared that all authors have no conflicts of interest.

References

[1]. Haijun Li, Zhonglai Zhang, Zhiyong Su, et al. Influence of Electronic Expansion Valve on the Refrigeration Performance of Air Conditioner for Coaches [J]. Cryogenics and Superconductivity, 2020, 48(09): 54-59.
[2]. Shuang Tu, YingChao Li, Zuowei Yang, et al. Thermal Performance Investigation of 315 kW Organic Rankine Cycle Experimental Prototype Evaporator [J]. Dongfang Turbine, 2023(03): 32-36.
[3]. Chunlei Liu, Xue Bai, Ruxin Wang, et al. A method for obtaining the overheat of evaporators and software design [J]. Journal of Hebei Institute of Architecture and Engineering, 2018,36 (02): 55-58+87.
[4]. Shaohua Zhou, Feilong Zhan, Guoliang Ding, et al. Experimental study and noise reduction measures of flow noise in short pipe throttle valves [J]. Journal of Chemical Engineering, 2023,74 (S1): 113-121.
[5]. Beghi A, Cecchinat L. A simulation environment for dry-expansion evaporators with application to the design of autotuning control algorithms for electronic expansion valves[J]. International Journal of Refrigeration,2009,32(7):1765-1775.
[6]. Zhongyang Yu, Leren Tao, Chaoyang Yuan. Research on the suction liquid problem of compressors in air source heat pump systems [J]. Thermal Power Engineering, 2018,33 (03).
[7]. Lihao Huang, Leren Tao, Hong Tao, et al. Experimental study on the control of exhaust temperature of variable frequency compressors using electronic expansion valves [J]. Thermal Science and Technology, 2009,8 (04): 361-365.
[8]. Hong Tao, Leren Tao, Zhigao Zheng, et al. Experimental study on thermal measurement of evaporator outlet state [J]. Journal of Engineering Thermophysics, 2009,30 (11): 1920-1922.
[9]. Ruzaburo YAJIMA, Atsushi YOSHIMI.PIAO Chuncheng,et al.Measures to reduce the discharge temperature of R32 compr essor [J].Refrigeration and Air-conditioning,2011,11(2):60-64.
[10]. Huan Su. Thermodynamic optimization and inversion method research on the condensation heat recovery process of air conditioning [D]. Hunan University, 2018.
[11]. Ruidong Yan, Junye Shi, Jiangping Chen. Experimental study on the effect of evaporator outlet overheat on the performance of automotive air conditioning [J]. Journal of Refrigeration, 2014,35 (03): 86-89.
[12]. Binbin Yu, Dandong Wang, Jiangping Chen. The effect of outlet overheat on the performance of CO2 microchannel evaporators [J]. Journal of Refrigeration, 2018,39 (03): 31-38.
[13]. Pr Zhang, Laiyun Lu, Kaihua Guo. Performance analysis of low-temperature mixed refrigerant cycle multi-stream heat exchanger [J]. Cryogenic Engineering, 2012 (05): 46-50.
[14]. Lihui Yang, Leren Tao, Fangqin Li, Lemin Wang, and Fan Lina. The effect of a small amount of suction liquid on the performance of refrigeration systems in compressors [J]. Journal of Refrigeration, 2014,35 (05): 83-87.
[15]. Ning Zhang, Lu Sha, Hao Guo. Research on the overheat control technology of electronic expansion valves [J]. Refrigeration, 2013,32 (02): 15-18.
[16]. Elliott MS,Rasmussen B P.On reducing evaporator overheat nonlinearity with control architecture[J].International Journal of Refrigeration,2010,33(3):607-614.
[17]. Haitao Hu, Guoliang Ding, Wenjian Wei, et al. Heat transfer characteristics of R410A oil mixture flow boiling in a 7 mm horizontal straight tube II. Correlation formula [J]. Journal of Shanghai Jiao Tong University, 2007 (10): 1638-1642.

[18]. Chao Wang, Leren Tao, Chao Wu, et al. Comparison of the effects of R32 and R22 overheat on the refrigeration system of rotary compressors [J]. Journal of Refrigeration, 2016,37 (04): 81-86.
[19]. Klein, S.A., D.T.Reindl,and K.Brownell, Refrigeration system performance using liquid-suction heat exchangers. International Journal of Refrigeration,2000.23(8): p.588-596.