The Application of Liquid Circulation Heat Recovery System

Yuqing Zhao1* and Guoqiang Zhao1
1North China University of Technology, 100144, Beijing, China
*Corresponding author’s e-mail: zyq@ncut.edu.cn

Abstract: This paper analyzes the characteristics of the exhaust heat recovery devices and the air conditioning system of the pharmaceutical factory, and points out that the pharmaceutical factory is more suitable for the liquid circulation heat recovery system. The principle and composition of the liquid circulation heat recovery system are also introduced. The actual engineering case proves that the use of liquid circulation heat recovery system can effectively reduce the fresh air load. Compared with the traditional fresh air pretreatment method, liquid circulation heat recovery system has a short payback period.

1. Introduction

Exhaust air heat recovery technology is an energy-saving method that can reduce the load of fresh air. The exhaust air heat recovery device uses the energy in the exhaust air to preprocess the fresh air [1]. In order for the country to achieve carbon peaking and carbon neutrality on time, it is necessary to rationally use exhaust heat recovery technology to reduce energy consumption.

The air conditioning system of the pharmaceutical factory has the following characteristics: the air conditioning system is relatively concentrated and has a large air volume; the air conditioning system operates continuously throughout the year; the indoor needs to maintain a relatively constant temperature and humidity; the area of the equipment room is limited; in order to maintain the production environment of medicines, most pharmaceutical factories use purifying air conditioning systems, and the fresh air load is the main component of the system. If the exhaust air is directly discharged outdoors, most of the low-grade energy is completely wasted [2]. This article aims to select a suitable exhaust heat recovery device for a pharmaceutical factory and analyze its economy with an actual engineering case.

2. Exhaust air heat recovery technology

2.1 Common heat recovery devices

Exhaust air heat recovery devices have many forms. According to different energy recovery in the exhaust air, the commonly used exhaust air heat recovery devices can be divided into sensible heat recovery devices and total heat recovery devices [3]. Commonly used total heat recovery devices include rotary heat recovery device and plate-fin heat recovery device; commonly used sensible heat recovery devices include liquid circulation heat recovery device and heat pipe heat recovery device [4]. These two kinds of heat recovery devices have their own characteristics: the heat recovery efficiency of the total heat recovery device is relatively high, but the operating cost is relatively expensive, and the equipment covers a large area and the flexibility is relatively poor [5]; the heat recovery efficiency of the sensible heat recovery device is lower than that of the total heat recovery device. The equipment occupies a relatively small space, has no rotating parts, and is relatively safe during operation. It is
widely used in actual projects [6]. According to the characteristics of the air conditioning system of the pharmaceutical factory, it should adopt the liquid circulation heat recovery system.

2.2 Liquid circulation heat recovery system

2.2.1. Principle
Water-air heat exchangers are installed on the fresh air pipes and exhaust pipes of the air conditioning system, and the energy in the exhaust air is transferred to the ethylene glycol solution through the exhaust air heat exchanger. The energy-obtained glycol solution is sent to the fresh air heat exchanger by the circulating pump to preprocess the fresh air, reduce part of the fresh air load, and reduce the energy consumption of the entire system. The schematic diagram is as follows:

![Figure 1. Schematic diagram](image-url)

2.2.2 Composition
The heat recovery system is composed of fresh air heat exchanger, exhaust air heat exchanger, circulating pump and closed expansion tank. The circulating solution is usually water. In order to prevent freezing, a certain proportion of ethylene glycol solution is added to the water to expand the scope of its application, and the appropriate concentration is determined according to the local minimum outdoor temperature.

3. Economics of Liquid Circulation Heat Recovery System

3.1 Winter conditions

\[
Q_W = \frac{cL_x \rho (T_2 - T_1)}{3600} \tag{1}
\]

In the formula: \(Q_W\) is the actual heat recovery in winter, KW; \(c\) is the specific heat capacity of the air, taking an approximate value of 1.01KJ/(kg·K); \(L_x\) is the amount of fresh air entering the fresh air heat exchanger, m\(^3\)/h; \(\rho\) is the density of air, taking an approximate value of 1.2kg/m\(^3\); \(T_1\) is the temperature of the fresh air entering the fresh air heat exchanger, ℃; \(T_2\) is the temperature of the fresh air exiting the fresh air heat exchanger, ℃.

\[
Q_{W_{\text{max}}} = \frac{cL_{\text{min}} \rho (T_3 - T_1)}{3600} \tag{2}
\]

In the formula: \(Q_{W_{\text{max}}}\) is the maximum possible heat obtained under winter conditions, KW; \(c\) is the specific heat capacity of the air, taking an approximate value of 1.01KJ/(kg·K); \(L_{\text{min}}\) is the smaller of the fresh air flow and exhaust air flow m\(^3\)/h; \(\rho\) is the density of air, taking an approximate value of 1.2kg/m\(^3\); \(T_1\) is the temperature of the fresh air entering the fresh air heat exchanger, ℃; \(T_3\) is the temperature of the exhaust air entering the exhaust heat exchanger, ℃.
In the formula: $\eta_w$ is the sensible heat efficiency of heat recovery in winter.

\[ \eta_w = \frac{Q_w}{Q_{w,\text{max}}} \tag{3} \]

3.2 Summer conditions

\[ Q_s = \frac{cL_p\rho(T_3 - T_4)}{3600} \tag{4} \]

In the formula: $Q_s$ is the actual heat recovery in summer, KW; $c$ is the specific heat capacity of the air, taking an approximate value of 1.01KJ/(kg·K); $L_p$ is the exhaust air volume entering the exhaust air heat exchanger, m$^3$/h; $\rho$ is the density of the air, taking an approximate value of 1.2kg/m$^3$; $T_3$ is the temperature of the exhaust air entering the exhaust air heat exchanger, °C; $T_4$ is the temperature of the exhaust air exiting the exhaust air heat exchanger, °C.

\[ Q_{s,\text{max}} = \frac{cL_{\text{min}}\rho(T_1 - T_3)}{3600} \tag{5} \]

In the formula: $Q_{s,\text{max}}$ is the maximum possible heat obtained under summer conditions, kW; $c$ is the specific heat capacity of air, taking 1.01KJ/(kg·K); $L_{\text{min}}$ is the smaller of the fresh air flow and exhaust air flow m$^3$/h; $\rho$ is the density of air, taking an approximate value of 1.2kg/m$^3$; $T_1$ is the temperature of the fresh air entering the fresh air heat exchanger, °C; $T_3$ is the temperature of the exhaust air entering the exhaust air heat exchanger, °C.

\[ \eta_s = \frac{Q_s}{Q_{s,\text{max}}} \tag{6} \]

In the formula: $\eta_s$ is the sensible heat efficiency of heat recovery in summer.

4. Case analysis of liquid circulation heat recovery system

Take the liquid circulation heat recovery system of a pharmaceutical factory in Shanghai as an example for calculation and analysis.

- The total fresh air volume of the pharmaceutical factory is 89500m$^3$/h, and the total exhaust air volume is 86200m$^3$/h. The heat exchangers of the heat recovery system use copper sleeve fins to enhance heat transfer.
- In winter conditions, the calculated temperature of the air conditioner is -2.2°C and the relative humidity is 38%; the exhaust temperature is 22°C and the relative humidity is 50%. Under summer conditions, the exhaust air temperature is 20°C and the relative humidity is 50%. For the convenience of calculation, the sensible heat efficiency of heat recovery is 50%. The system uses 20% ethylene glycol solution by mass.
- The purifying air conditioning system of the pharmaceutical factory runs 24 hours. In winter conditions, when the outdoor temperature is less than 14°C and in summer conditions, when the outdoor temperature is greater than 26°C, heat recovery can be generated. The flow rate of the glycol solution will be adjusted according to the change of the fresh air temperature in order to achieve a stable operating state.
- The operating parameters of the system are shown in Table 1 and Table 2.
Table 1. Variable operating conditions in winter parameters

| $T_1$ (°C) | $T_2$ (°C) | $Q_W$ (KW) | $Q_{W\max}$ (KW) |
|------------|------------|------------|------------------|
| -2.20      | 9.45       | 351.15     | 702.30           |
| 0.00       | 10.59      | 319.23     | 638.45           |
| 2.00       | 11.63      | 290.21     | 580.41           |
| 4.00       | 12.67      | 261.19     | 522.37           |
| 6.00       | 13.71      | 232.17     | 464.33           |
| 8.00       | 14.74      | 203.14     | 406.29           |
| 10.00      | 15.78      | 174.12     | 348.25           |
| 12.00      | 16.82      | 145.10     | 290.21           |
| 14.00      | 17.85      | 116.08     | 232.17           |

Table 2. Variable operating conditions in summer parameters

| $T_1$ (°C) | $T_4$ (°C) | $Q_S$ (KW) | $Q_{S\max}$ (KW) |
|------------|------------|------------|------------------|
| 34.40      | 27.20      | 208.95     | 417.90           |
| 32.00      | 26.00      | 174.12     | 348.25           |
| 30.00      | 25.00      | 145.10     | 290.21           |
| 28.00      | 24.00      | 116.08     | 232.17           |
| 26.00      | 23.00      | 87.06      | 174.12           |

- The outdoor meteorological data adopts the annual temperature frequency data of Shanghai's typical meteorological year in the "Special Meteorological Data Set for Thermal Environment Analysis of Chinese Buildings" [7], and uses 2°C as the temperature frequency band. The heat recovery amount is calculated hourly, and the calculation results are shown in Table 3.

Table 3. Annual heat recovery

| $T_1$ (°C) | days | $Q$ (KW) | $W$ (KW) | $Q_1$ (KW) |
|------------|------|----------|----------|------------|
| winter     |      |          |          |            |
| -2.2       | 6    | 351.15   | 10.00    |            |
| 0          | 10   | 319.23   | 10.00    |            |
| 2          | 10   | 290.21   | 10.00    |            |
| 4          | 16   | 261.19   | 10.00    |            |
| 6          | 19   | 232.17   | 5.00     | 367363.07  |
| 8          | 20   | 203.14   | 5.00     |            |
| 10         | 20   | 174.12   | 5.00     |            |
| 12         | 25   | 145.10   | 5.00     |            |
| 14         | 30   | 116.08   | 10.00    |            |
| summer     |      |          |          |            |
| 34.4       | 2    | 208.95   | 10.00    |            |
| 32         | 8    | 174.12   | 10.00    |            |
| 30         | 20   | 145.10   | 10.00    | 623234.95  |
| 28         | 40   | 116.08   | 10.00    |            |
| 26         | 30   | 87.06    | 10.00    |            |
| sum        | 256  | 990598.02|          |            |

(6) Calculation of return on investment

In order to maintain the indoor environment, the pre-cooling and pre-heating process of fresh air is necessary. If the liquid circulation heat recovery system is not used, other methods need to be used to achieve the same effect. The traditional method is to use chillers for pre-cooling in summer and steam to pre-heat in winter. The calculation parameters and results are shown in Table 4.
Table 4. Return on investment

| period           | Traditional way | liquid circulation heat recovery system |
|------------------|-----------------|-----------------------------------------|
| Q (KW)           | winter          | summer                                  |
|                  | 367363.07       | 623234.95                               |
| price (yuan/KW)  | 0.31            | 0.9                                     |
| efficiency       | 0.8a            | 3                                       |
| operating expenses (yuan) | 142353.19 | 186970.49                              |
| total Operating expenses (yuan) | 329323.67 | 74131.59                              |
| initial investment cost of equipment (yuan) | 150000b | 480000c |  

* The steam is calculated at an ultra-high efficiency of 0.8. In reality, the efficiency is generally around 0.6.
*a The initial investment cost of steam piping equipment and 3 air source heat pumps is 150000 yuan.
b The initial investment of the liquid circulation heat recovery system includes the estimated installation cost, and the total estimated price is 480000 yuan.

5. Conclusion

- According to the characteristics of the air conditioning system of the pharmaceutical factory, it is more suitable for the liquid circulation heat recovery system.
- The initial investment of the traditional pretreatment method is about 150000 yuan, and the annual operating cost is about 329323 yuan, while the initial investment of using the liquid circulation heat recovery system is close to 480000 yuan, and the annual operating cost is about 74131 yuan. Compared with the traditional method, the use of the liquid circulation heat recovery system requires an additional investment of 330000 yuan. The annual cost of the system is 255192 yuan. The cost of the investment can be recovered in about 1.4 years. Therefore, it is more suitable to adopt a liquid circulation heat recovery system.

References

[1] Zhongshi Wei. The heat recovery performance analysis and energy saving research of heat pipe heat recovery air conditioning system [D]. Hefei: Anhui University of Architecture, 2017:2-3.
[2] Feng Pan, Chuanxue Song. The application of heat pipe heat recovery device in DC air conditioning system [J]. HVAC, 2007, 37(1): 80-82.
[3] Weidong Yan, Chu Tong, Xu Han, et al. The experimental study and energy-saving analysis of a new-type runner full heat recovery fresh air unit[J]. Refrigeration and Air Conditioning, 2018, 32(2): 85-90.
[4] Hong Li, Huiliang Lian, Jing Li. The economy and application of heat recovery system[J]. Refrigeration and Air Conditioning, 2010, 24(5): 97-100.
[5] Jin Wang, Zhen Li, Yuan Yuan, et al. The fresh air treatment system combining liquid dehumidification and exhaust heat recovery[J]. HVAC, 2013, 43(1): 109-112.
[6] Zhengyu Shao, Min Liu, Ying Li, et al. The waste heat recovery from the exhaust air of a tobacco factory in the area of hot summer and cold winter[J]. HVAC, 2013, 43(2): 87-90.
[7] Meteorological Data Room, Meteorological Information Center, China Meteorological Administration, Department of Building Technology and Science, Tsinghua University. Special meteorological data set for thermal environment analysis of buildings in China [M]. Beijing: China Construction Industry Press, 2005.