

Research Article

Research on Performances of Rotor Dehumidification for Ring Main Unit

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Abstract:

In view of the dehumidification problem of ring main unit, a dehumidification scheme using a small dehumidification rotor is proposed. A small dehumidification rotor device impregnated with polymer adsorbent was designed and manufactured. The experimental device adopts thermal balance calibration, and the error range is less than 3%. In order to further study the performances of the small dehumidifying rotor, the small dehumidifying rotor was tested by changing the regeneration temperature and speed under two air conditions of high temperature and high humidity and low temperature and high humidity. The test results show that it has good dehumidification effect under the two different environmental conditions. After a long time of on-site dehumidification test of the ring main unit, even if the relative humidity outside the ring main unit reaches more than 80%, the relative humidity inside the ring main unit remains below 65%, effectively solving the problem of condensation in the main unit.

Keywords: Dehumidification, Small rotor, Ring main unit, Anti-condensation

1. Introduction

The ring main unit is mainly composed of a sensor layer, a switch main unit layer and a cable layer. The main circuit of the ring main unit needs to work in a completely insulated and sealed environment, and the air circulation is inconvenient. When the surface temperature of the internal parts is lower than the dew point temperature of the air in the main unit, condensation will occur [1-3]. Condensation may reduce the insulation performance of the device, or even cause a short circuit or even burn down the power distribution device. It can be seen that the prevention of condensation is significance to ensure the safe and stable operation of the distribution main unit. Current dehumidification technologies, such as condensation dehumidification, require the air to be cooled below the dew point temperature, while reducing its energy efficiency. At the same time, condensation water will be generated during the condensation process, and needs to be stored or discharged, will have hidden dangers for the safety of the ring network main unit. Based on the principle of adsorption dehumidification, rotor dehumidification can be carried out at any temperature and humidity, and fresh air can also be introduced to provide dry fresh air for the room after dehumidification [4-5]. Compared with condensation dehumidification, rotor dehumidification can be dehumidified without water, and it is more suitable for solving the condensation problem of ring main unit.

The research of anti-condensation technology includes test method and numerical simulation. The anti-condensation effect of temperature control method and humidity control method was studied by experiment. Lu et al. proposed an anti-condensation method to optimize the cabin structure to ensure the tightness and insulation, and set heating and dehumidification functional devices at sensitive locations [6]. Luo et al. studied the dehumidification performance of

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the heater through the temperature difference between inside and outside the control cabinet of the intelligent switching device [7]. Akio Toyoda et al. discovered a humidity-regulating polymer that can be used to prevent telecommunications cable insulation failure due to condensation in overhead terminal closures [8].

The results of numerical simulation can be fitted to the thermal environment parameter formula of the equipment to analyze the influence of wind speed, shape and other factors on the flow field and humidity in the equipment. Patania and Degraciaa carried out theoretical calculation and numerical simulation of heat transfer characteristics of thermal insulation structures respectively, and obtained the empirical formula of heat transfer coefficient of thermal insulation layer based on plate theory [9-10]. Huang et al. established a three-dimensional magneto-thermal coupling model of the high-voltage coaxial GIS bus, and calculated the ohm loss of the bus and the eddy current loss in the housing, but did not calculate the fluid field [11]. Wang et al. calculated the temperature distribution of the conductor and shell of the GIS bus based on the finite element model of heat flow and magnetic field coupling of the GIS bus, but the convection formula still adopted the analytical method [12].

In this study, a small dehumidifying rotor performance test device was designed based on the principle of dehumidification on the premise that the relevant operating parameters and structural parameters of the device could be adjusted. The device is placed in the ring network main unit for long-term operation experiment verification, and the dehumidification effect is analyzed during the continuous performance of the device under conditions of high temperature and high humidity, low temperature and high humidity and long-term operation.

2. Prototype design and main parameter determination

The basic working principle of the rotor dehumidification is shown in Figure 1. The rotor is divided into a hygroscopic zone and a regeneration zone, with an area ratio of 3:1. The treated air enters the hygroscopic zone of the dehumidification rotor, and the water vapor in the air is absorbed by the adsorbent in the hygroscopic zone of the dehumidifying rotor [13-15]. In the process of dehumidification, a large amount of adsorption heat is released, resulting in an increase in air temperature. The treated air becomes low humidity air through the adsorption zone and is sent into the room. The process can be approximated as isenthalpy dehumidification process. When the regeneration air is heated by the electric heater to the regeneration temperature required for dehumidification, it enters the regeneration zone of the rotor for desorption. This process can be approximated as the isenthalpy humidification process. Finally, the hot and humid air is expelled outside.

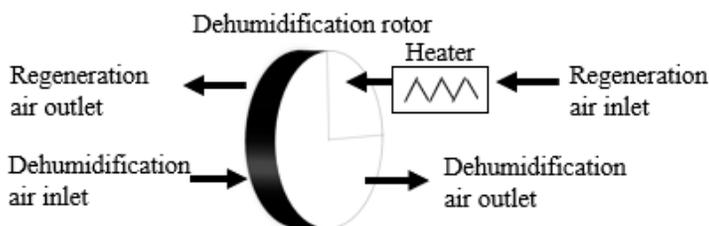


Fig. 1. Working principle diagram of dehumidification rotor.

The structural design is different from conventional dehumidifier design. Due to the limited overall operating power of the ring main unit, the voltage provided to the dehumidifier can only be 12V low voltage, and the supplying power is relatively low. The dehumidifier power must be controlled within 120W. In addition, the ring main unit can place the dehumidifier in a small space, so the device needs to have the characteristics of small size, light weight and low energy consumption. At the same time, the ring main unit is an electrical equipment with high voltage switchgear and power supply unit, and the dehumidification device applied in the ring main unit must ensure the electrical safety of the ring main unit. Compared with common condensation dehumidification, rotor dehumidification is characterized by waterless dehumidification, which can ensure that the dehumidification equipment does not discharge additional water in the ring network main unit, thus ensuring the electrical safety of the ring network main unit. Therefore, the rotor dehumidification is more suitable for dehumidification in the ring main unit. The main part of the dehumidification rotor device is the dehumidification rotor. The dehumidification rotor is mostly a large rotor, which is used for dehumidification work in factories, shopping malls and other scenarios. It is necessary to solve the problem of miniaturization of the dehumidification rotor when it is applied in the ring main unit to prevent condensation. The

difficulty is the sealing of the dehumidification rotor. After the miniaturization of the dehumidification rotor, the sealing problem is particularly important, and the air leakage phenomenon of the small rotor has obvious influence on the performance. In order to solve the sealing problem, a unique three-layer compound sealing ring structure is designed to solve the sealing problem during the running of small rotor. At the same time, the rotor dehumidification needs to use the heater to heat the air in the desorption link, in order to ensure the electrical safety of the ring main unit, the regeneration temperature of the rotor should not be too high, so the polymer rotor with low temperature regeneration characteristics is selected. The advantage of the polymer rotor is that the regeneration performance of the rotor is remarkable at low temperature. In order to ensure the safety of the equipment in the ring network main unit, the energy consumption monitoring device and temperature control device are set up, and the data is collected through the relay and temperature sensor, and the controller is precisely controlled to realize the automatic power off when the power consumption and temperature reach the limit.

The device is mainly composed of unit frame, dehumidification rotor, electric heat pipe heater, speed regulating motor, controller, fans and so on. The power of the electric heat pipe heater is 70W, the power of the supply fan and the exhaust fan are 18W and 6W, respectively, to achieve low power consumption operation. The overall size of the equipment is 400mm×200mm×150mm, as shown in Figure 2.

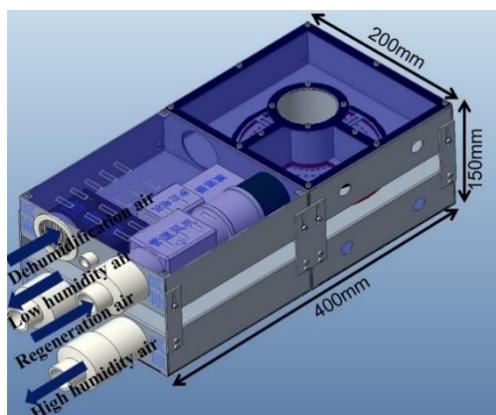


Fig. 2. Prototype design drawing.

The prototype is based on glass fiber rotor matrix, polymer adsorbent impregnated dehumidification rotor, diameter 150mm, thickness 15mm. It has the characteristics of low temperature regeneration. The prototype adopts split structure design, the whole is divided into upper and lower parts, the upper structure has outdoor fresh air inlet and exhaust air outlet, the lower structure has indoor return air inlet and air supply outlet, the rotor is placed in the middle of the upper and lower parts by vertical structure. This arrangement reduces the volume of the equipment to a certain extent, makes the rotor and the device closer to a certain extent under the action of gravity, reduces the problem of air leakage, and the arrangement of the equipment tuyere is more reasonable.

The prototype of the dehumidifier is shown in Figure 3. The supply air volume and exhaust air volume of the overall prototype were corrected through an anemometer. At the same time, temperature and humidity sensors are installed on the four air outlets of the prototype and on the front and rear of the heater to collect and display real-time data. The measurement accuracy of the temperature and humidity sensor and wind speed sensor are $\pm 0.2^{\circ}\text{C}$, $\pm 1\%$, and $\pm 0.05\text{m/s}$ respectively. The overall prototype frame material is made of aluminum alloy profiles, which are lightweight, easy to disassemble and have good anti-corrosion and wear resistance. At the same time, a potholder pad is installed inside the frame for heat insulation, which effectively reduces heat loss during the dehumidification process of the device.

In order to verify the reliability of the experimental data of the prototype, an experimental verification of the heat balance was carried out. As shown in Figure 4, the experimental conditions and test results are: regeneration temperature 35°C , absolute humidity 6g/kg(a) ; the fresh air temperature is the same as the return air temperature, 18.6°C , and the absolute humidity is 6g/kg(a) ; the supply air temperature is 21.3°C and the absolute humidity is 5.52g/kg(a) ; exhaust air temperature is 24.6°C , absolute humidity 8.12g/kg(a) .



Fig. 3. The prototype of the dehumidifier.

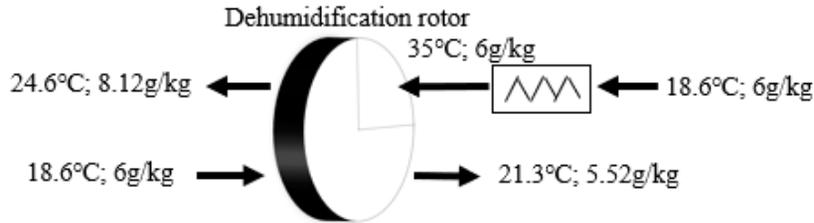


Fig. 4. Experimental data used to verify heat and mass balances.

According to the energy equation, considering the influence of latent heat of phase change, the heat calculation formula is:

$$Q = \dot{m}c_p \Delta T + \dot{m}\Delta wL \quad (1)$$

In the formula: Q - calorimetric, J / s ; \dot{m} - Mass flow rate of air, kg / s ; c_p - Constant pressure specific heat capacity of water, take a value of $1005J / (kg \cdot ^\circ C)$; ΔT - temperature change, $^\circ C$; Δw - Changes in the mass of water, $kg / kg(a)$; L - Latent heat of evaporation of water vapor, its value is $2260 \times 10^3 J / kg$. $\rho_1 = 1.134kg/m^3$ and $\rho_2 = 1.198kg/m^3$.

The measured air volume of air supply, $Q_{a2} = 21.576m^3 / h$. Its mass flow rate, $\dot{m}_2 = \rho_2 \cdot Q_{a2} = 0.00718kg / s$. The regeneration air volume is $5.524m^3 / h$.

The mass flow rate of air is calculated as

$$\dot{m} = \rho \cdot Q_a \quad (2)$$

In the formula: \dot{m} - Mass flow rate of air, kg / s ; ρ - Density of air, kg / m^3 .

Therefore, $\dot{m}_1 = \rho_1 \cdot Q_{a1} = 0.00174kg / s$. The heat change of the regeneration process is

$$Q_1 = \dot{m}_1 c_p \Delta T_1 + \dot{m}_1 \Delta w_1 L = (0.00174 \times 1005 \times 10.4 + 0.00174 \times 2.12 \times 10^{-3} \times 2260 \times 10^3) J / s = 26.52 J / s.$$

The heat change of the dehumidification process is $Q_2 = \dot{m}_2 c_p \Delta T_2 + \dot{m}_2 \Delta w_2 L$. Calculate and obtain $Q_2 = 27.27 J / s$.

Comparing the results of Q_1 and Q_2 , it can be seen that the deviation of heat change between the regeneration process

and the dehumidification process is $\left| \frac{Q_2 - Q_1}{Q_2} \right| \times 100\% = 2.76\%$. It can be seen that the experiment has a certain degree of reliability.

3. Performance evaluation indicators

In order to verify the actual dehumidification effect of the device, the device was placed in the field main unit of the ring network main unit under normal use in Chongchuan District of Nantong City for long-term operation experiment verification, and the dehumidification effect was analyzed under two conditions of high temperature and high humidity, low temperature and high humidity during operation.

During the experiment, all the doors of the ring main unit were closed and kept in normal operation [16-19]. The moisture content of the main unit was ignored, and the internal water vapor mainly came from the air condensation in the main unit.

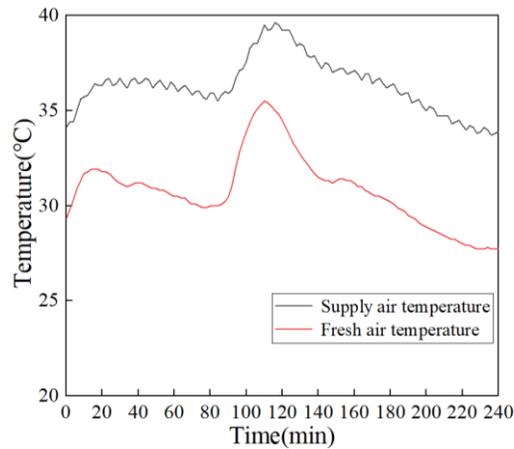


Fig. 5. Temperature changes of supply air and fresh air under high temperature and humidity environment.

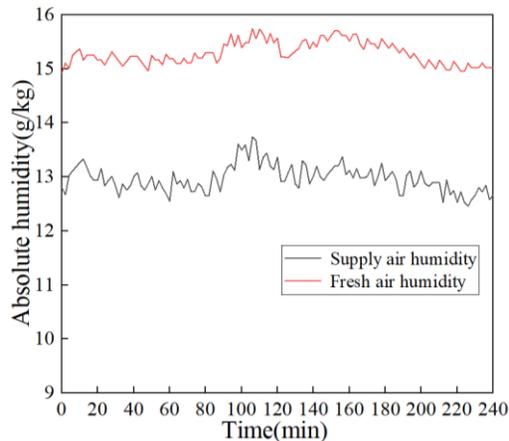


Fig. 6. Humidity changes of supply air and fresh air under high temperature and humidity environment.

During the experiment, the ring main unit is still in normal use. As shown in Figure 5 and Figure 6, the dehumidifier is in a high temperature and high humidity environment, the fresh air temperature is about 30°C. After the work of the rotor dehumidifier, the average dehumidification is 2.31g/kg(a). Therefore, in a high temperature and high humidity environment, the amount of dehumidification removed from the ring main unit in one day is $M = [(Q_{a2} \times \Delta\omega_3 \times \rho_2) / 1000 \times 24] \text{kg} = [(21.576 \times 2.31 \times 1.198) / 1000 \times 24] \text{kg} = 1.43 \text{kg}$. At the same time, the supply air temperature increases by about 5°C compared with the fresh air temperature.

In Figure 7 and Figure 8, in the low temperature and high humidity environment, the temperature and humidity of supply air and fresh air change gently, and the dehumidifier can still achieve an average dehumidification amount of

2.25g/kg(a). Therefore, in a low temperature and high humidity environment, the amount of dehumidification removed from the ring main unit in one day is 1.40kg. In this working condition, the supply air temperature increases by about 6°C compared with the fresh air temperature.

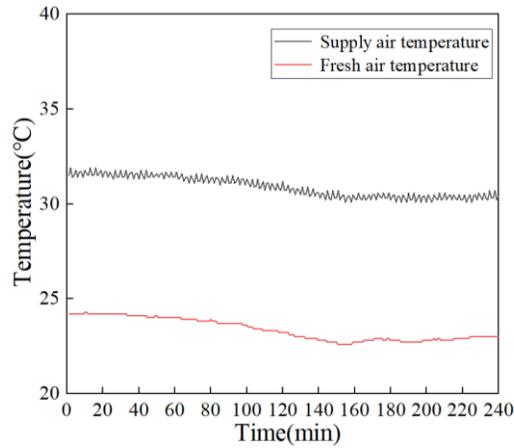


Fig. 7. Temperature changes of supply air and fresh air under low temperature and high humidity environment.

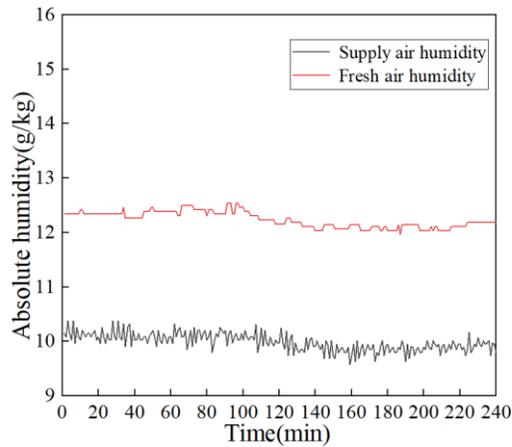


Fig. 8. Humidity changes of supply air and fresh air under low temperature and high humidity environment.

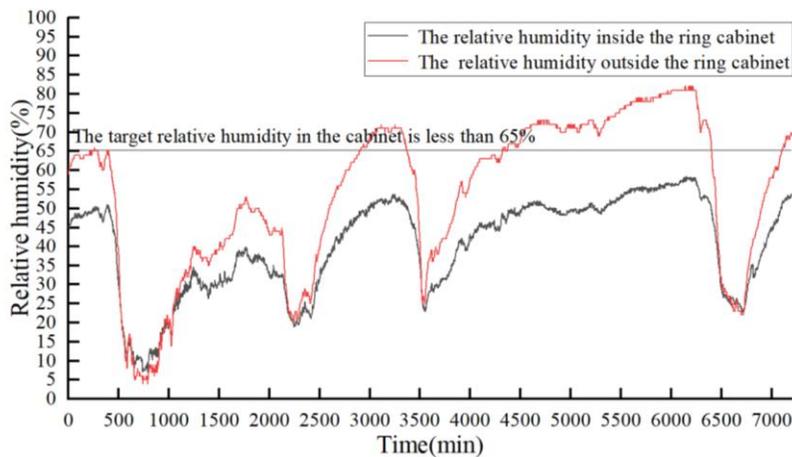


Fig. 9. Internal and external relative humidity diagram of ring main unit in field operation.

As shown in Figure 9, after a long time of on-site dehumidification test of ring main unit, even if the relative humidity outside the ring main unit reaches more than 80%, the relative humidity inside the ring main unit remains below 65%, which effectively solves the condensation problem inside the main unit, ensures the safety of the ring main unit, and verifies the feasibility of the small dehumidification rotor device used to solve the anti-condensation problem of the ring main unit. At the same time, the dehumidification effect of the small polymer rotor dehumidifier at the optimum speed and regeneration temperature difference is verified by comparing the dehumidification before and after dehumidification in the central mesh cabinet in Figure 10.

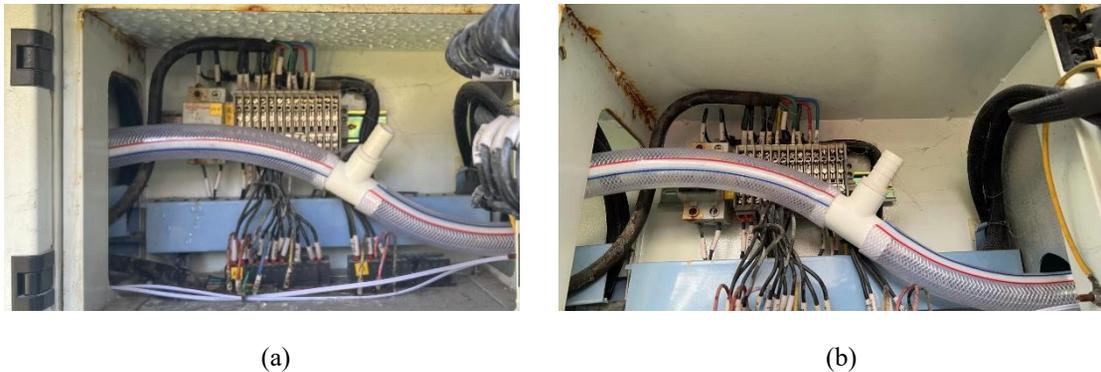


Fig. 10. Inside ring cabinet before dehumidification (a) After dehumidification (b)

4. Conclusions

In this paper, the dehumidification system requirements of ring network main unit are designed, manufactured and the performance test of the small rotor dehumidification prototype is completed. The small rotor is applied to the dehumidification of ring network main unit, which can realize the dehumidification under the premise of minimizing energy consumption.

Through the long-term field operation experiment test of the ring network main unit, the two environmental conditions of high temperature and high humidity, low temperature and high humidity during operation were analyzed. The dehumidification capacity of the device was the strongest under high temperature and high humidity condition, and the effective dehumidification capacity reached 2.27g/kg(a). Under low temperature and high humidity conditions, the effective dehumidification was 2.25g/kg(a) respectively. At the same time, through the long-term operation experiment of the ring network main unit, the relative humidity in the ring network main unit is kept below 65% after dehumidification, which effectively solves the problem of condensation in the main unit. The operation test results of the device verify the dehumidification effect of the small polymer rotor dehumidifier, and the device has the ability to control the high humidity environment in the field of anti-condensation dehumidification and dehumidification of the ring main unit.

The future focus of work will mainly be on deep technical optimization and functional improvement of existing devices, aiming to enhance their performance stability, operational convenience, and user experience. We will consider commercializing it and pushing it to the market to meet the needs of our customers.

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Nomenclature

- Q Calorimetric, J/s
- Q_1 The heat change of the regeneration process
- Q_2 The heat change of the dehumidification process

\dot{m}	Mass flow rate of air, kg/s
\dot{m}_1	The mass flow rate of the regeneration process
\dot{m}_2	The mass flow rate of the dehumidification process
c_p	Constant pressure specific heat capacity of water, take a value of $4196 J / (kg \cdot ^\circ C)$
ΔT	temperature change, $^\circ C$
Δw	Changes in the mass of water, g/kg(a)
Δw_1	The moisture content difference between exhaust air and return air
Δw_2	The moisture content difference between fresh air and supply air
L	Latent heat of evaporation of water vapor, its value is 2260kJ/kg
Q_a	air volume, m^3 / s
Q_{a1}	The air volume of the regeneration process
Q_{a2}	The air volume of the dehumidification process
M	Moisture mass, kg
ρ	Density of air, kg/m^3
<i>Subscripts</i>	
1	Regeneration process
2	Dehumidification process

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