Brief introduction of dehumidification technology and research progress

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Abstract. Air humidity is one of the important factors that constitute the human body's thermal comfort. Inappropriate humidity will affect people's comfort and health. With the improvement of people's living standard, people have higher and higher requirements for indoor air quality, and air humidity is important factors that affect air quality. Thus it is an important task to control appropriate air humidity in air-conditioning engineering. This paper will briefly discuss and analyze the existing dehumidification technologies of air conditioning, compare the advantages and disadvantages of various dehumidification technologies, and look into the future research direction.

1. Introduction
In recent years, with the development of the economy and the improvement of people's living standards, indoor air quality has attracted more and more attention, and air humidity is one of the important factors affecting air quality. According to relevant data, people spend 80% of their day indoors, and air humidity is closely related to people's lives. In summer, higher air humidity will make people feel muggy and irritable; in winter, when the air humidity is high, it is easier for the human body to exchange heat with the outdoor air. Excessive heat loss in the body makes people feel cold and depressed. The sick building syndrome caused by the deterioration of the indoor environment greatly affects people's physical and mental health and work efficiency.

Therefore, it is particularly important to deal with the air humidity. Effective measures must be taken to ensure that the air humidity meets the requirements. To meet the hot and humid environment while also guaranteeing IAQ and realizing the safety of the building environment, alternative working fluids without ozone loss and greenhouse effect, and various new air-conditioning systems using low-grade energy have become hotspots and focuses in the air-conditioning field. This article will briefly describe the existing dehumidification technology, introduce the current dehumidification performance of various dehumidification air-conditioning systems, and look forward to future research.

2. Cooling dehumidification

2.1. Cooling dehumidification mechanism and characteristics

Cooling dehumidification is one of the earliest dehumidification methods. The principle is to cool the air to condense water vapor at the dew point temperature, thereby reducing the absolute humidity of the
The cooling source needed for cooling and dehumidification can be either natural, such as well water, or an artificial cold source. The most representative cooling dehumidifier is the refrigeration dehumidifier, which is generally composed of a refrigeration compressor, evaporator, condenser, expansion valve, fan, air valve, and other components. Its workflow is shown in Figure 1.

Figure 1 Schematic diagram of working flow of freezing dehumidifier

1- High-pressure gas;2- High-pressure liquid;3- Low-pressure mixture of gas and liquid;4- Low-pressure gas

Among all dehumidification technologies, cooling dehumidification technology is the earliest developed and most mature technology. Its main features are: the initial investment cost is relatively low; the COP is relatively high; it is reliable, convenient and does not require a heat source, etc. Therefore, this dehumidification technology is currently used most in daily life. It is widely used in national defense engineering, civil air defense engineering, libraries, underground engineering, electronics industry, precision machining, medicine, and agricultural seeds storage and workshops of various industrial and mining enterprises [1].

However, this cooling type dehumidification will cause a large amount of high-grade energy consumption such as electricity, and the refrigerant CFC or HCFC it uses will hurt the ecological environment and the ozone layer. Besides, this type of dehumidification equipment should not be used on occasions where the ambient temperature is too high or too low, and maintenance is troublesome. With the improvement of people's living environment requirements, the negative impact of cooling dehumidification has gradually attracted people's attention, and its application has been restricted. Therefore, it is necessary to seek effective methods to realize the independent control of humidity.

2.2. Cooling dehumidification system

The traditional mechanical refrigeration and air conditioning equipment not only consumes a lot of energy but also causes different degrees of environmental pollution. To emphasize the concept of environmental protection, high efficiency, and energy-saving, Chen [2] proposed the use of 19°C high temperature chilled water for air pretreatment. The results show that the use of high-temperature chilled water can dehumidify air with a temperature of 29°C and relative humidity of 60% or more. The use of high-temperature water pretreatment air can remove 33.85% of the total dehumidification capacity of the system when using traditional air conditioning methods. The dehumidification capacity of the air conditioning system in the later stage is reduced. The chilled water temperature can be appropriately increased, and the efficiency of the refrigeration unit is improved, which has a good energy-saving effect. Yuan [3] designed a set of energy-saving refrigerated dehumidifiers in response to the problems of dehumidification in underground protection projects. This refrigerated dehumidifier has a high dehumidification efficiency. It uses heat recovery to improve dehumidification efficiency. A plate-fin heat exchanger is added between the evaporator and the condenser as cold recovery equipment so that
the humid air entering the dehumidifier is pre-cooled by the plate-fin heat exchanger, and then enters the evaporator to further cool down and dehumidify. Reduce the load of the evaporator and effectively improve dehumidification efficiency. After theoretical calculation and testing, the dehumidification capacity per unit power is increased by 44% compared with the existing equipment.

3. Liquid absorption dehumidification technique section

3.1. Mechanism and characteristics of liquid dehumidification

The basic principle of liquid absorption dehumidification is to use the partial pressure of water vapor on the surface of the concentrated solution of the dehumidifier to be lower than the partial pressure of water vapor in the humid air. Under the action of the pressure gradient, the water vapor of the moist air is absorbed into the concentrated solution until the partial pressure of the water vapor on both sides reaches equilibrium, and the absorption process ends. The dilute solution after moisture absorption is heated by low-grade energy such as electricity, solar energy, geothermal, industrial waste heat, etc., and sent to the regenerator. Since the partial pressure of water vapor on the surface of the dehumidifying solution is higher than that of air, the water vapor begins to transfer from the liquid phase to the gas phase, thus achieving the regeneration of the dehumidifying solution.

Typical liquid absorption dehumidification devices mainly include dehumidifiers, regenerators, evaporative coolers, heat exchangers, pumps, and other equipment. Figure 2 is the flow chart of a typical liquid absorption dehumidifier [1].

![Flow chart of liquid absorption dehumidifier](image)

Figure 2 Flow chart of liquid absorption dehumidifier

Compared with the traditional cooling and dehumidifying air conditioning system, the liquid dehumidifying air conditioning system has a large dehumidification capacity and a good dehumidification effect. It can absorb some harmful substances such as germs and chemical pollutants in the air, which helps to improve indoor air quality. Only low-temperature heat sources (solar energy, industrial waste heat, waste heat, etc.) of 50 ~ 80°C are required to realize solution regeneration. The ODP and GWP of the dehumidifying liquid used in the liquid dehumidifying air conditioner are both 0, which is environmentally friendly.

However, the liquid absorption dehumidification equipment has a large volume, requires the removal of gas and waste heat, and requires regular maintenance, and the COP of the entire device is also low. Besides, the liquid solution in the liquid absorption dehumidification equipment will corrode metals, and droplets will be generated if the flow rate of the solution is not appropriate. Therefore, the current
liquid absorption dehumidification technology is mainly used in industrial production, and it needs to be further developed for non-industrial applications [4].

3.2. Liquid dehumidification system

Liquid dehumidification air conditioning system is a new type of air conditioning device that can use low-grade heat to drive the air to dehumidify. The use of liquid dehumidification can achieve precise control of indoor air humidity and treat the air humidity to a suitable state. The most important components in the solution dehumidification air conditioning system are the dehumidifier and regenerator. Zhang [5] found that different types of dehumidifier dehumidification efficiency vary widely. A method based on the difference in water vapor partial pressure as the criterion is proposed, and the three types of dehumidifiers of downstream, countercurrent, and cross-flow are theoretically analyzed. It is emphasized that in the actual research and development, the research and design of the dehumidifier must be considered in the entire dehumidification evaporative cooling air conditioning system.

At present, power-driven cooling and dehumidification are widely used in industry, but its main disadvantage is high energy consumption. In these processes, a large amount of low-temperature waste heat is directly discharged into the environment, and a large amount of this waste heat is wasted. Therefore, recycling low-temperature waste heat and generating dry air has great potential for energy saving. Su [6] proposed a new two-stage liquid dehumidification system using a low temperature and heat steps. Use higher temperature heat to generate a strong desiccant solution for use in a primary dehumidifier. Use low-temperature heat to drive a single-effect absorption chiller to provide cooling energy for the secondary dehumidifier. The simulation results show that, compared with the traditional power-driven cooling and dehumidification system, the system can reduce power consumption by 92.29%. The ratio of electricity saving to heat absorption can reach 7.35%. Through the research on the driving force of the dehumidifier, the superiority of the low-temperature heat cascade utilization is further explained, and preliminary economic and environmental analysis is carried out. It provides a new and effective method for deep dehumidification of low temperature and heat for industrial applications.

In the south, the hot and humid climate is obvious. Aiming at this feature, Zhang [7] proposed a new type of compressed heat pump driven hollow fiber membrane two-stage liquid dehumidification air dehumidification system. The semi-permeable membrane prevents liquid desiccant droplets from entering the process air. Through a two-stage dehumidification process, the isenthalpic process is transformed into a quasi-isothermal process, and the liquid desiccant reaches its full dehumidification potential. Compared with the single-stage dehumidification system, the two-stage dehumidification system has lower effluent concentration and lower condensation temperature. Under the typical damp and heat conditions in the south, better thermal system performance is achieved, COP can be increased by about 20%, and dehumidification system performance is improved.

The heat pump driven liquid dehumidification device (HPLD) utilizes the cooling capacity of the evaporator and the heat of the condenser and has developed rapidly in recent years. Since the heat of the condenser usually exceeds the heat required for regeneration of the desiccant, the key to improving the performance of these systems is to effectively discharge the excess heat. Zhang [8] analyzed two different waste heat removal methods, adding an air-cooled auxiliary condenser and a water-cooled auxiliary condenser that uses exhaust gas to evaporate cooling water at the inlet and outlet of the regeneration air pipe. The HPLD performance of these processes under different operating conditions was compared. For systems with air-cooled auxiliary condensers, the location of the condenser rarely affects performance: COP is on average about 18% higher than the basic system. The system with a water-cooled condenser performed best among all researched systems: COP was about 35% higher than the basic system.

4. Solid absorption dehumidification technique
4.1. Mechanism and characteristics of solid dehumidification

The principle of solid absorption dehumidification is the same as that of liquid absorption dehumidification, both of which use a desiccant to absorb water vapor in the air. The difference is adsorption is solid desiccant dehumidification using, and desiccant in the process of adsorption of water vapor will release a large amount of heat. To maintain a large adsorption capacity, the desiccant must be cooled during the adsorption process, and energy consumption must be increased. The most typical solid adsorption dehumidification equipment is a rotary adsorption dehumidifier, the main components are a drying runner, a regeneration heater, a dehumidification blower, and a regeneration fan. Figure 3 is a schematic diagram of the structure of a rotary adsorption dehumidifier [9].

![Schematic diagram of the working principle of rotary adsorption dehumidifier](image)

**Figure 3** Schematic diagram of the working principle of rotary adsorption dehumidifier

In the rotary adsorption dehumidification equipment, the moist air and regeneration air are supplied by fans. The rotation of the runner causes the whole equipment to be noisy and requires regular maintenance. The stronger the adsorption capacity of solid desiccant on the runner, the desiccant is more difficult, and the temperature required for regeneration is higher. Even if the regeneration temperature reaches the boiling point of water 100℃ can not desorption, generally need to reach more than 140℃. Although industrial waste heat, solar energy, gas, and other heat sources can be used to regenerate the desiccant, the energy consumption of the whole set of equipment is relatively high, and the outlet temperature of dry air is relatively high due to the influence of regeneration temperature and adsorption heat. If the environment has special requirements, cooling equipment should be added, which also increases energy consumption. Compared with cooling desiccant, runner adsorption desiccant has a lower COP but has a larger handling capacity. Especially for low temperature and low humidity air, it can give full play to its advantages. Therefore, at present, the rotor adsorption dehumidification, and the liquid absorption dehumidification are mainly used in industrial production [3].

4.2. Solid absorption dehumidification system

The solid desiccant dehumidification method such as the wheel dehumidification method is an effective air dehumidification method. This method can avoid cold and heat compensation losses, and can use low-grade heat sources for regeneration. The heat and mass transfer performance of solid runner during dehumidification and regeneration has been studied extensively. Ren [10] used an air source heat pump as a cold and hot source and obtained the dehumidification and condensation dehumidification performance of the solid runner under different conditions through theoretical calculation. The results show that when the dehumidification capacity of the same working condition is the same, the wheel dehumidification has large power consumption and a low exergy efficiency compared with the condensation dehumidification. With the increase of indoor air humidity, the exergy efficiency of both dehumidifiers decreases, while the exergy efficiency of condensation and dehumidification increases more significantly. As the outdoor air humidity increases, the exergy dehumidification performance has
a slight impact, but the dehumidification power consumption increases, resulting in a decrease in exergy efficiency.

With the continuous maturity of the runner dehumidification technology, Chen [11] optimized the runner dehumidification system and explained the five optimization aspects of the new compound dehumidifier, dehumidification bed structure, circulation system, low-grade energy-saving utilization, and operating environment. The practical application of the wheel dehumidification system provides reference. Tu [12] analyzes and compares the heat and mass exchange processes of different solid dehumidification methods. The paper introduces the working principles of three solid dehumidification devices, solid dehumidification runner, heat pump type internal cooling solid dehumidification bed, and multi-stage solid dehumidification device combined with heat pump. It established a corresponding heat and mass transfer model and verified the accuracy of the model through experiments. The multi-stage dehumidification system is an effective way to improve the performance of the dehumidification system. It can greatly reduce the required regeneration temperature and make it possible to use the waste heat of the heat pump. Tu [13] analyzed the performance of a two-stage dehumidification wheel system driven by a heat pump. The dehumidifying wheel model and heat pump system model are used to predict the system performance. The influences of compressor power input, heat transfer area distribution between evaporator and condenser, impeller speed, and air inlet parameters after treatment on system performance are studied. An improved system that uses an indirect cooler to recover cooling capacity from the indoor exhaust air is proposed. Compared with the original system, its cooling capacity is increased by 15%.

5. Progress of new dehumidification technology

Although traditional dehumidification technology is widely used, it also has some shortcomings. Among them, liquid dehumidification and air dehumidification have attracted much attention due to its fluidity. When fresh air is dehumidified, it is directly in contact with salt solutions such as lithium chloride solution. There is a potential risk that droplets may be entrained in the airflow and transported to the air conditioner by the dehumidified air. These liquid droplets are quite corrosive and harmful. Therefore, Zhang [14] proposed a new type of dehumidification system—hollow fiber membrane-based liquid dehumidification air dehumidification system. Using hollow fiber membrane modules to achieve liquid dehumidification and air dehumidification. The air is dehumidified by the liquid in a non-contact way, which prevents corrosion problems and is convenient for practical engineering applications.

Membrane dehumidification is an emerging dehumidification technology, and the research progresses rapidly now. Thuan Duc Bui [15] developed a cheap, thin, and highly stable metal-supported hydrophilic polyvinyl alcohol (PVA)/lithium chloride (LiCl) composite film. The film is thin, stable in physical and chemical properties, has high water vapor permeability and selectivity, and is suitable for dehumidification under high humidity conditions. Humidity is one of the important objects of cultural relic preservation and electronic product operation environment control. The existing traditional dehumidification technology has high energy consumption and poor reliability. Lu Dawei [16] elaborated on three new types of dehumidification technologies: condensation heat recovery type refrigeration temperature regulation dehumidification technology, electroosmosis regeneration solid dehumidification technology, and ionic liquid dehumidification technology. It provides high-efficiency dehumidification technical solutions for the humidity control of cultural relics preservation and electronic product operation.

6. Conclusion

The air humidity treatment process is an important part of the air conditioning system. Improving its energy efficiency is an important way to realize the energy-saving operation of air-conditioning systems, and it plays an important role in meeting the needs of building environment control and regulation. How to improve and improve the performance of the actual air humidity treatment process is also an important part of the current building energy conservation business. In the face of future development needs, continuous optimization and development based on traditional dehumidification, and continuous
integration of multiple dehumidification technologies. Practice the concept of environmental protection and energy-saving, make good use of low-grade heat sources (such as solar energy, heat pump waste heat, etc.) to improve system performance. The research and development of new dehumidification technologies will also become an important topic in the future energy field and environmental development. Combining the development and research progress at home and abroad, according to the actual situation and characteristics, we have developed efficient dehumidification technologies and solutions. The research and development of new dehumidification technology should also become an important subject in the future energy field and environmental development. In combination with the development research progress at home and abroad, efficient dehumidification technology and scheme should be developed according to the actual situation and characteristics.

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