Research Progress of Rotary Desiccant Wheel Optimization Technology

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Abstract. The new efficiency dehumidification technology can meet the comfort requirements in the household environment and the relevant industrial dehumidification standards, which is in line with the energy conservation and environmental protection policy. The rotary desiccant wheel is of relatively mature technology, which has advantages of simple equipment, less consumption and environment-friendly. However, there are still several aspects to improve the technology, for example, the improvement in adsorption ability of desiccants, heat and mass transfer performance of the internal dehumidifying device, utilization efficiency of the low-grade energy sources. In this paper, the recent optimization techniques for rotary desiccant wheel systems are summarized. Five aspects of optimization such as development of new composite desiccant, invention of structure of desiccant bed, novel design of circulation system, enhancement of the utilization efficient of low-grade source energy and operation optimum with ambient air condition, are described. This review may provide some reference for the actual application of rotary wheel dehumidification system.

1. Introduction
With people's attention to comfort of living environment and improvement of dehumidification standard in industrial production, new and efficient dehumidification technology has attracted wide attention. The commonly used dehumidification methods include liquid absorbent dehumidification, wheel dehumidification, vapor compression dehumidification, cooling dehumidification, membrane dehumidification, heat pump dehumidification, thermolectric condensation dehumidification and electrochemical dehumidification. Compared with traditional steam compression dehumidification method, liquid absorption dehumidification method can save energy up to 40% and make full use of low-grade heat source. The efficiency of rotary desiccant wheel dehumidification is the same order as that of liquid absorption dehumidification, and it can meet the requirements of miniaturization, low vibration and equipment simplification.

Although there have been many researches on wheel dehumidification technology, there are still some deficiencies, such as low adsorption capacity of dehumidification bed, small heat and component transfer coefficient, and long cycle regeneration period. In order to further improve the dehumidification efficiency, domestic and foreign scholars have carried out a lot of research on new compound dehumidifier, developed dehumidification bed structure with higher efficiency, and optimized the macroscopic circulation system.
2. Overview
Most of rotary desiccant wheel adopts honeycomb structure, which is divided into hygroscopic area (or treatment area) and regeneration area. Two areas are respectively supplied with air to be treated and regeneration air in opposite directions, as shown in Figure 1. As driving device drives wheel to turn slowly, adsorbent which absorbs moisture in the wet air after reaching saturation state in the hygroscopicity area gradually enters regeneration area and is desorbed and regenerated by high temperature air. This process is repeated, so as to obtain dry air steadily and continuously.

3. Main optimization direction

3.1. optimization direction
At present, there are still many deficiencies in rotary desiccant wheel technology, such as poor adsorption capacity of dehumidifier, large heat and mass transfer resistance coefficient of dehumidification device, and low energy utilization efficiency. In order to further improve the performance of rotary desiccant wheel system, domestic and foreign scholars analyzed and optimized new compound dehumidifier, dehumidification bed structure, circulation system, low-grade energy efficient utilization and operation environment.

3.2. New compound dehumidifier
The development of wheel dehumidifier has reached the fourth generation in 2008, and now there are molecular sieve, silica gel, halogen, activated carbon, metal organic framework and other dehumidifying materials[1]. Silica gel is widely accepted due to its low price, good operating stability, wide range of relative humidity, and almost no hysteresis.

Single dehumidifier is limited by its own pore parameters and can only exert maximum ability under specific air conditions, such as silica gel's poor dehumidification ability to low-humidity air. Therefore, various kinds of compound dehumidifiers have appeared, among which common compound dehumidifiers are molecular sieve - silica gel, silica gel - lithium chloride, silica gel - polymer and so on. Dehumidifier is mostly used in coated honeycomb wheel, which can reduce the influence of adsorption heat through heat transfer of fluid. AL-ALILI et al.[2] developed a functional zeolite adsorption material called FAM-Z01. The results show that dehumidification capacity can reach 1.96 ± 0.12 kg/h under given conditions, and humidity fluctuation range can be controlled within 5%. Jia chunxia et al.[3] developed a dehumidifier composed of silica gel and lithium chloride. The research results showed that when the ratio of silica gel and lithium chloride was appropriate, dehumidifying ability of silica gel was significantly enhanced and regeneration temperature was reduced, while dissolution failure of lithium chloride crystals was also solved. Hu et al.[4] also found that dehumidification system using silica-lithium chloride composite dehumidifier can accurately control the humidity.

Dehumidification performance of representative new polymer dehumidifying materials in recent years is shown in Table 1[5]. Obviously, composite materials have higher dehumidification performance value (DCOP) and dehumidification capacity than pure silica gel.
Table 1. Comparison of dehumidification performance of different dehumidifiers.

| Dehumidifier Type | Adsorption bed type | Inlet temperature (℃) | Inlet relative humidity (%) | Regeneration temperature (℃) | DCOP | Dehumidification (g/kg) |
|------------------|---------------------|------------------------|-----------------------------|-------------------------------|------|-------------------------|
| Silica gel       | Honeycomb wheel     | 28                     | 40                          | 100                           | 1.8  | 4.0                     |
| Silica gel + Lithium chloride | Honeycomb wheel | 28                     | 40                          | 100                           | 3.3  | 6.1                     |
| Silica gel + Lithium chloride | Honeycomb wheel | 28                     | 72                          | 100                           | 1.7  | 3.2                     |
| Silica gel + Polyvinyl alcohol | Honeycomb wheel | 28                     | 72                          | 100                           | 2.1  | 1.9                     |
| Activated aluminum | Filling form      | 30                     | 70                          | 25-40                         | 1.1  | 1.7                     |
| Polyacrylic acid + Activated aluminum | Filling form | 16-33                   | 65-78                       | 25-40                         | 3.21 | --                      |
| Polyacrylic acid sodium salt | Filling form | 30                     | 70                          | 50                            | --   | 1.31                    |
|                  | Smear form          | 25-30                  | 75                          | 60                            | 0.45-0.5 | 1.2                    |
| Silica gel + Sodium polyacrylate | Filling form | 16                     | 45                          | 40-50                         | --   | 7.0                     |
| Silica gel + Sodium polyacrylate | Filling form | 30                     | 70                          | 50                            | --   | 2.2                     |

3.3. Structure optimization of dehumidification bed

Desiccant wheel is composed of support carrier, metal flow channel, hygroscopic medium and drive transverse. In order to reduce the weight and cost of wheel, Chung et al.[6] developed a plastic regenerator that can enhance air tightness of wheel. There is a large convective thermal and thermal resistance between dehumidifier and air inside wheel. A large amount of adsorption heat is generated during condensation of water vapor, so internal temperature of wheel gradually increases, and dehumidification efficiency decreases. Goldsworthy et al.[7] developed an internal water-cooled desiccant wheel, which was mainly characterized by coating dehumidifier layer on the side of airflow channel based on the shell and tube heat exchanger. Experimental and numerical simulation results show that dehumidification efficiency of this technology is significantly higher than that of traditional desiccant wheel, and regeneration temperature can be as low as 50℃.

Yadav et al.[8] proposed a wheel model to effectively improve the dehumidification performance, that is, desiccant wheel increases purging purification area. In addition, Yadav et al. also optimized fan angle of purification area, and pointed out that dehumidification performance was better when wheel rotated counterclockwise, and dehumidification efficiency was the highest when fan angle of purification area is 5°.

In order to reduce the energy loss caused by electric heating during wheel regeneration, Yao et al. [9] proposed that ultrasonic technology should be used for dehumidifier regeneration desorption. Ultrasonic wave is a kind of high-frequency elastic wave. It uses its unique high-frequency mechanical
vibration effect to tear liquid water film on the desiccant surface into micron-sized water droplets, and then detach from desiccant surface, which will greatly reduce regeneration energy consuming. In addition, Kubota[10] proposed a method of regenerating wheel by combining hot air and microwave heating. Ultrasonic or microwave regeneration technology is a new and efficient energy-saving regeneration method, but this technology still has shortcomings. For example, ultrasonic transposition is relatively complicated, which will increase processing cost of desiccant wheel, and there is also the problem of ultrasonic leakage.

Circulating fluidized bed dehumidification system is a system with high heat and mass transfer efficiency. Compared with packed bed, Circulating fluidized bed has the characteristics of small pressure drop, uniform physical property of dehumidifier and no driving device. Chiang[11] analyzed adsorption and desorption cycle characteristics of fluidized bed dehumidification air-conditioning system experimentally, and realized that the system can operate continuously and energy-efficiently without external energy application.

In addition to develop new type of desiccant bed structure, scholars also discusses deeply regenerate desiccant wheel area fan angle, wheel speed, wheel of sealing and non equilibrium air import and export airflow parameter and hot mass transfer efficiency and other factors on dehumidification efficiency. These have provided a wealth of theoretical guidance for the improvement and optimization of desiccant wheel structure.

3.4. Optimization of cycle dehumidification system

The application of the rotary dehumidifier-assisted HVAC system to independently control fresh air temperature and humidity has been fully commercialized. At present, there are five types of widely used systems, namely Pennington cycle, Recirculation cycle, Dunkle cycle, SENS cycle and DINC cycle. Among them, SEN cycle configured in series has the highest thermal efficiency. According to multiple linear regression theory, Sheng[12] established a regression model to evaluate dehumidification performance, and found that regeneration temperature of the wheel and relative humidity of outdoor air had a great influence on the dehumidification performance.

Two-stage or multi-stage wheel system can reduce regeneration temperature of wheel, significantly improve dehumidification efficiency, and increase utilization of low-grade energy. The dehumidification capacity of two-stage rotary desiccant wheel under different heat sources is shown in Table 2.

| Heat sources | \(A_r/A_t\) | \(m_r/m_a\) | \(m_w/m_a\) | Dehumidification capacity (g/kg) | Regeneration temperature (℃) | Process air inlet | Regenerative air inlet |
|--------------|-------------|-------------|-------------|-------------------------------|-------------------------------|------------------|----------------------|
| Heat pump    | 1           | 1.0         | -           | 8.5                           | 44.0                          | 33.0℃, 19.0g/kg | 12.0g/kg             |
| Hot water    | 1           | 1.0         | -           | 4.0                           | 43.2                          | 28.0℃, 11.9g/kg | 19.5g/kg             |
| Hot water    | 3           | 2.6         | 0.4-1.7     | 6.0-9.0                       | 50.0-90.0                     | 35.0℃, 14.1g/kg | 14.1g/kg             |
| Solar energy | 3           | 2.5         | -           | 9.0-12.0                      | 60.0-80.0                     | 26.0℃, 16.0g/kg | 18.0g/kg             |
| Electric energy | 3          | 2.4         | -           | 3.0-15.0                      | 60.0-90.0                     | 37.1℃, 30.3g/kg | 3.6-16.3g/kg         |

Ap/Ar, Area ratio of wheel treatment to regeneration area. \(m_r/m_a\), Regeneration and processing air flow ratio. \(m_w/m_a\), Ratio of water flow to regenerative air flow.

3.5. Solar energy and other low-grade energy application development

In order to alleviate the pressure of energy supply, research on developing and utilizing low grade energy such as solar energy and biomass energy has been paid more and more attention. Solar energy utilization technology has developed to the third generation, that is, the technology of low-temperature
heat recovery and conversion into cold energy and electrical energy, including finned tube dehumidification and multi-stage dehumidification technology. Guo[13] analyzed the dehumidification of solar PV/T heat absorption runner through theoretical calculation and literature review. The results showed that low temperature heat source at 50-60℃ could be utilized efficiently by maintaining low flow rate per unit collector plate area, adopting enamel coating treatment and optimizing hydraulic radius of pipeline. Assadi[14] used TRNSYS software to conduct a series of numerical simulation on the solar wheel dehumidification hvac system, and analyzed performance of various components in the circulatory system. The results show that for an office building with an area of 115m², solar system reduced energy consumption by about 40% compared to mechanical compression refrigeration system, and the energy saving effect was more obvious during the day. Yuki[15], with the support of the Philippine government's energy-saving residential construction project, designed a set of energy-efficient buildings for the comprehensive and efficient use of renewable energy such as solar energy, biomass energy and geothermal energy.

4. Conclusion
In this paper, the main optimization directions of wheel dehumidification system are summarized, including new compound dehumidifier, dehumidification bed structure, circulation system and low grade energy efficient utilization. The results show that dehumidifiers have an important effect on the dehumidification performance. Among them, new composite dehumidifier composed of silica gel and high molecular polymer has excellent dehumidification performance and low regeneration temperature, which has become the direction of many researchers. For the system, the internal water-cooled tubular desiccant wheel can reduce the influence of adsorption heat and realize the constant temperature desiccant process. The dehumidification method of reducing regeneration temperature and improving low grade energy utilization efficiency can also adopt two-stage (or multi-stage) wheel dehumidifier system.

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