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Review on substrate of solid desiccant dehumidification system

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ABSTRACT

Desiccant wheel dehumidification air conditioning system makes full use of the principle of desiccant dehumidification and evaporative cooling. Besides desiccant material, the substrate also plays an important role in improving the dehumidification performance of a rotary desiccant wheel. The objective of this paper is to present the state of the art of substrate, and then provide guidelines for the choice and further research work of substrate. It is found that the substrate of a rotary desiccant wheel usually is porous ceramic fiber paper or glass fiber paper. To improve the dehumidification capacity of rotary desiccant wheel dehumidification system, substrate with high porosity and high thermal conductivity should be selected. Taking into account both dehumidification capacity and pressure drop, sinusoidal air channel is a good choice for rotary desiccant wheel. The review of non-rotary solid desiccant dehumidification system reveals that substrate plays an important role in dehumidification processing and porous fiber paper is the best choice for substrate of rotary desiccant wheel. Short service life and poor adsorption performance are the main drawbacks of existing desiccant wheels. The match for substrates and desiccant materials has not been understood deeply. In the future, revealing the nature of the effect of substrate on the dehumidification performance may be the main work to fill in these blanks.

1. Introduction

With the improvement of people's living standard and the attention to health condition, human beings put forward higher quality requirements for their work and living environment. More fresh air is introduced into indoor room, it needs to be cooled and dehumidified in hot and humid regions to meet people's comfort. In addition, some of modern production workshops, for example factories of powder, lithium battery, and pharmaceutical equipment, require constant low humidity [1,2]. The conventional method for space cooling and dehumidification is mainly using vapor compression refrigeration (VCR) system. This system can cool process air below dew point and remove water vapor from moist air [3,4], and then the processed air is reheated as supply air which meets the requirement of advance design. This approach consumes a lot of high-grade electrical energy [5] and causes the environment problems [6,7].

The desiccant wheel dehumidification air conditioning system operates on the principle of desiccant dehumidification and evaporative cooling. When moist air as process air passes through desiccant wheel, the water vapor within process air is adsorbed by desiccant materials because of the partial pressure difference of water vapor between process air and solid desiccant materials. Meanwhile, the temperature of process air rises due to the released adsorption heat. Then an evaporative cooler is adopted to cool the air with increasing the humidity ratio. Namely, the desiccant wheel removes water vapor from process air and converts latent load into sensible heat load simultaneously, and a following evaporative cooler reduces the temperature of the supply air with increasing humidity. It can be found that desiccant wheel realizes independent control of the sensible and latent load, and then overcomes the super-cooling and reheating problems of VCRs. Instead of conventional electrical power for producing the regeneration air, solar assisted desiccant wheel dehumidification air conditioning system has been widely applied [5,8,9], which uses solar energy producing hot air to regenerate desiccant wheel. Solar assisted desiccant wheel dehumidification air conditioning system is a promising alternative to making full use of renewable energy, and the rotary desiccant wheel is the key component of the system. This system can cut down carbon dioxide emissions to surrounding and save much high-grade electrical energy [10]. So the desiccant wheel dehumidification air conditioning system has the characteristics of environmentally friendly and energy-saving.

Due to the merits of the desiccant wheel dehumidification air conditioning system, lots of works [11–20] have been conducted on such systems in past few years. In terms of mathematical model, Kang et al. [11] obtained an explicit analytic solution to heat and mass transfer in a desiccant wheel with a simplified model. Ge [12] made a review on different kinds of mathematical models for desiccant wheel. However, the dehumidification performance of such systems has not been studied

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and discussed deeply. Koronaki et al. [13] established a 1-D gas side resistance model to predict the performance of the desiccant wheel. The simulation results indicated that the dehumidification performance of the counter flow wheel design is higher than the co-current one. Goodarzia et al. [14] investigated the effect of the temperature of process and regeneration air, humidity ratio, air flow rates, and wheel speed on the performance of solid desiccant wheel. Mandegari et al. [10] established a two-dimensional unsteady state mathematical model to analyze the effect of purge angle on energy and dehumidification performance of desiccant wheels. For experiment aspect, Kang et al. [15] experimentally investigated the dehumidification performance of three polymer desiccant wheels with different wheel thicknesses and different desiccant contents. Zendehboudi et al. [16] investigated the effect of supply/regeneration section area ratio on the performance of desiccant wheels experimentally. The regeneration temperature of many rotary desiccant wheel dehumidification systems exceeds 80 °C [21–25], which limits the wide application of desiccant wheel. To make the rotary desiccant wheel dehumidification system can be driven by solar energy or industrial waste thermal energy, the regeneration temperature should be reduced. Li et al. [26] and Ge et al. [27] came up with a two-stage desiccant wheel to reduce the regeneration temperature. Narayanan et al.[28] developed a non-adiabatic desiccant wheel, which has a low regeneration temperature of 60 °C. Goldsworthy and White [29,30] conducted an investigation on an internally water cooled desiccant wheel. This kind of desiccant wheel has a low regeneration temperature of 50 °C. The reviews on the type and running mode of rotary desiccant wheel dehumidification system driven by solar power and heat pump have been conducted systematically. Jani et al. [5] summarized the progress and variation in solid desiccant cooling system configuration. Many researchers have proposed heat pump assisted rotary desiccant wheel dehumidification systems [31–34]. Ge [8] reviewed research developments on the solar powered rotary desiccant wheel cooling system. The regeneration processes are mainly considered to study the feasibility of such systems under different climates and energy saving. Sultan et al. [35] comprehensively reviewed three kinds of solar thermal driven desiccant air-conditioning (DAC) systems. Compared to solar single-stage desiccant dehumidification system, solar two-stage desiccant dehumidification system has the advantage of lower regeneration temperature and higher moisture removal capacity, which contributes to high system COP. As a matter of fact, the dehumidification performance cannot obtain improvement further only by optimizing the rotary desiccant wheel dehumidification system. So the dehumidification performance of desiccant materials and the properties of substrate should be considered to improve the overall performance of the rotary desiccant wheel dehumidification system. Many researchers concentrated on improving adsorption capacity of desiccant materials.

The properties of different kinds of desiccant materials have been widely investigated in the previous literature [3,36–42]. Hu et al. [3] compared dehumidification performance of fin-tube heat exchangers coated by silica gel and silica gel-lithium chloride composite desiccant. The experiment result showed that composite desiccant has a higher dehumidification capacity than silica gel (increased by 107%) under the same experiment conditions. Chua [36] studied three kinds of composite desiccants—silica gel-calcium chloride, silica gel-lithium chloride, and silica gel-polyvinyl alcohol. The composite desiccant materials combine more merits of silica gel and halides or polymers, and exhibit expected characteristics of high moisture removal capacity and high regeneration capacity. Except this, a mountain of work on review or summary of desiccant materials has been done by Zheng [43]. For the fact that every type of desiccant material has its advantages and drawbacks, only one single type of desiccant material may not meet the requirements of specific dehumidification or production process in some cases. In real work, many kinds of desiccant materials with different types of adsorption isotherm are chosen according to the specific environmental conditions and desired requirements.

A brief review of these literature can indicate that most of the researchers mainly focus on cycle systems, mathematical models, and desiccant materials. In reality, substrate plays an important role in improving the performance of rotary desiccant wheel dehumidification system. For one thing, in a rotary desiccant wheel, the substrate not only offers support for desiccant materials but also affects the heat and mass transfer process and coating rate. Those have an important effect on overall performance of the rotary desiccant wheel dehumidification system. For another, the match for substrates and desiccant materials is also important and should be considered especially. However, the composition, porous structure, thermal properties, mechanical strength, and fabrication techniques of the substrate receive little concern in the existing literature. To the authors' knowledge, there is no summary of substrates of rotary desiccant wheel dehumidification system. So the objective of this paper is to present the state of the art of substrate, and then provide guidelines for the choice and further research work of substrate. For reviewing the state of art of substrate, dehumidification systems are divided into rotary desiccant wheel dehumidification system and non-rotary solid desiccant dehumidification system.

2. Rotary desiccant wheel

In general, the bulk of a rotary desiccant wheel dehumidification system is a cylindrical rotary wheel, which is obtained by rolling up the corrugated porous fiber sheet coated with desiccant. During the forming process of the corrugated porous fiber sheet, two pieces of long flat porous fiber sheets are prepared. One piece of flat porous fiber sheet is processed to corrugated shape in a corrugating machine. Then it is bonded to the other crude one to maintain the corrugated shape. In the cylindrical rotary wheel, a large number of parallel channels are obtained, and the cross section shape of single air channel is a sinusoidal shape, as shown in Fig. 1. Usually, the main raw materials used as substrate are porous ceramic fiber paper and glass fiber paper.

In the rotary desiccant wheel dehumidification system, when the process air or regeneration air passes through the air channels of desiccant wheel, they will conduct heat and mass exchange with the desiccant and substrate. So the dehumidification and regeneration efficiency of the desiccant wheel are affected by the performance of the heat and mass transfer in the air channels. To get deep insight into

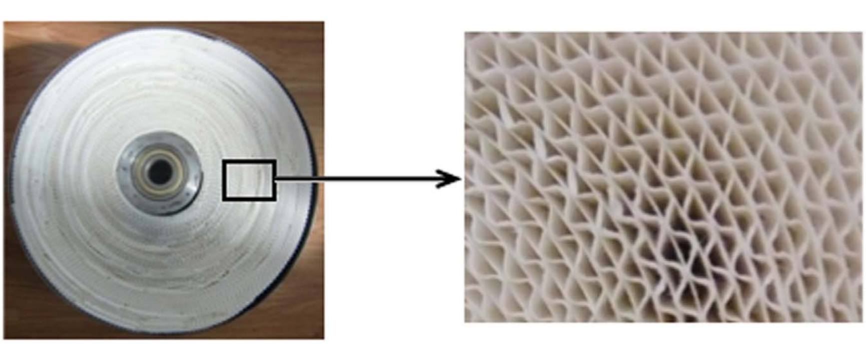

Fig. 1. A complete desiccant wheel.