



Review

Recent progress on desiccant materials for solid desiccant cooling systems



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ABSTRACT

SDC (Solid desiccant cooling) systems have gained increasing interest as an alternative air conditioning technology. Performance of desiccant plays a crucial role in overall performance of the whole system, especially in terms of dehumidification and regeneration capacity. It is desirable to explore desiccant possessing high adsorption capacity and good regeneration ability. Thus, this review summarizes recent researches and developments on novel solid desiccant materials that can be adopted in SDC systems. The materials include composite desiccants, nanoporous inorganic materials and polymeric desiccants. Adsorption isotherms are concluded and compared. Regeneration ability is also considered for full use of low grade thermal energy. Results show that by proper selection of host matrix and immersed salts, composite desiccants have improved capacity of dehumidification and regeneration. Besides, a good balance can be reached between regeneration and adsorption capacity by tailoring textural properties of nanoporous inorganic materials. For polymeric desiccants, especially MIL type (materials of Institute Lavoisier Frameworks), further progress in adsorptive dehumidification will be anticipated. Though some novel materials approach requirements for SDC systems, no material currently available can perfectly satisfy all the required demands. In this case, more intensive researches in the field of development and evaluation of advanced materials are still required.

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1. Introduction

With the rapid development of economy and society, our modern life and industry consume large amounts of energy for cooling. According to the latest statistics, energy consumption in air conditioning is estimated to 45% of the whole civil and commercial buildings [1]. Meanwhile, the depletion of fossil fuels and the threat of global warming over the last decades have challenged air conditioning industry to develop new cooling technologies to assist or even replace the conventional VC (vapor compression) systems. Therefore, numerous alternative cooling technologies have been developed to substitute conventional VC systems, and SDC (solid desiccant cooling) is one of them. Compared with other systems, SDC systems have several significant merits [2–4]:

- (1) SDC systems can be driven by low grade thermal energy, such as waste heat or renewable energy sources (i.e. solar

energy, geothermic energy and etc.), thus have a large energy saving potential.

- (2) Water is used as a refrigerant and most of the desiccant materials such as silica gels and zeolites are also environmentally friendly.
- (3) Desiccant materials provide an effective and economical way for dehumidification.
- (4) SDC systems can be able to handle air with extremely low dew-point temperature (i.e. $-40\text{ }^{\circ}\text{C}$), while that of a traditional VC system is only $4\text{ }^{\circ}\text{C}$.
- (5) Conventional VC air conditioning systems usually cool the process air down below its dew point to treat latent heat, bringing about great energy waste by subsequent reheating. Nevertheless, SDC systems can solve this problem by treating latent and sensible heat loads independently.
- (6) SDC systems are less subject to corrosion when compared with liquid ones.

In the past decades, extensive researches have been carried out on SDC systems, including development of mathematical simulation [5–7], investigation of advanced desiccant materials [8–10],

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and optimization of cycles and systems [11–13], etc. Works regarding simulation, cycles and systems have been reviewed by the researchers [14,15] in past few years. Desiccant materials play a crucial role in the SDC units since their characteristics (adsorption isotherms and regeneration temperature etc.) impact the performance of SDC systems significantly [16]. Silica gels and zeolites are the widely adopted desiccant materials in SDC systems. Recently, with the development of material science, several new types of solid desiccants are developed and investigated. Meanwhile, numerous ongoing researches have been directed at the preparation of advanced materials with improved water adsorption properties, regeneration capacity and long-term stability.

To the authors' knowledge, there is rare comprehensive summary of these newly developed solid desiccant materials. Therefore, in this paper, recent emerging researches relevant to the development of high-performance desiccants are overviewed. Their characteristics and possible applications in SDC systems are also compared and discussed. In the end, major conclusions and perspectives towards further endeavors are summarized.

2. Performance indices to evaluate solid desiccant materials

In an SDC system, the process air is dehumidified in an adsorption process by a solid desiccant material, and then cooled by evaporative cooling to desired temperature [2,17,18]. To reuse the desiccant, water vapor adsorbed is driven off through a regeneration process. This process is realized by heating from thermal energy such as electricity, waste heat, or renewable energy. Thus, adsorption and regeneration performance of the desiccant material can greatly affect dehumidification of the SDC system. In order to improve the performance of the system, the desiccant is expected to have large water adsorption capacity at a defined adsorption temperature and be easily-regenerated at a relatively low regeneration temperature. Besides, it is expected that the regeneration temperature is less than 100 °C, considering that waste heat resources in the temperature range of 40–99 °C account for 70–80% of the total ones [19].

Solid desiccant material refers to the material which can adsorb water vapor in moisture air and be regenerated at relatively high temperature. Up to now, it can be classified into two main categories: 1) substances with porous structure, such as activated alumina, silica gels, zeolites and so on; these materials realize the adsorption based on water vapor pressure differences between pores within the desiccant material and surrounding air. A physical process occurs in the adsorption phase. 2) Substances that can form solid crystalline hydrate, such as LiCl, CaCl₂, LiBr and etc. A hydration reaction always occurs within these materials [20].

Adsorption isotherms can be utilized to evaluate both dehumidification and regeneration capacity of desiccant materials. It presents the affinity for water vapor with respect to different water vapor pressure and temperature [21]. Fig. 1 shows six main types of water adsorption isotherms based on the classification of IUPAC (International Union of Pure and Applied Chemistry). Type I represents very hydrophilic materials with a steep increase of water at very low relative pressure (P/P_0 ¹). Substances with isotherm shapes of type II or IV are also classified as hydrophilic materials. For these materials, considerably high water adsorption capacities are measured at low and middle P/P_0 . Additionally, hydrophilic materials include those exhibiting the unusual step-like type VI isotherm. In contrast, materials with type III isotherms are recognized as hydrophobic or low hydrophilic, showing low water

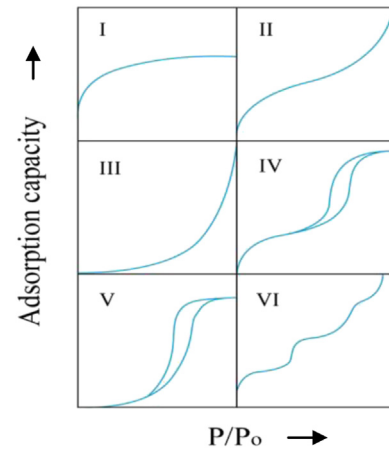


Fig. 1. Classification of the isotherm types according to IUPAC.

adsorption at low P/P_0 and a sudden increase of water adsorption at high P/P_0 . Same with type III isotherm, type V isotherm also shows a low water adsorption at low P/P_0 . However, a sigmoidal or S-shaped curve at middle or high P/P_0 is observed, indicating a sudden increase of water adsorption between narrow P/P_0 .

The optimal desiccant material for an SDC system should have type V isotherm. This is because materials possessing types I, II or IV isotherms are more difficult to regenerate as they are more hydrophilic and have higher water adsorption amount at low P/P_0 . Besides, water adsorption occurs at too high P/P_0 for materials possessing type III isotherm [22]. Combined with practical adsorption and regeneration processes, ideal adsorption and desorption isotherms on water vapor are anticipated to meet the following requirement: 1) for adsorption process, saturated water adsorption is expected at medium P/P_0 (≤ 0.5); 2) at regeneration part, water adsorbed is anticipated to be fully desorbed at relatively higher P/P_0 (≥ 0.6).

In addition to the performance indices of high water adsorption quantity (g water vapor/g desiccant) and good regeneration ability, appropriate desiccant materials should also possess other characteristics like long-term stability, nontoxicity, proper cost and etc. [14,23]. This paper mainly focuses on the comparison of thermodynamic performance between different desiccant materials. Other characteristics such as textural properties and stability will also be described if involved in the literature.

In the following chapters, newly developed desiccant materials that can be candidates in SDC systems will be classified into three main categories, namely, composite desiccant, nanoporous inorganic material and polymeric desiccant, as shown in Fig. 2.

3. Composite desiccant

Among the various kinds of novel desiccants, composite desiccant materials are the most frequently utilized in SDC systems in researches in recent years. They are formed by impregnating hygroscopic salt to the pores of porous desiccant material as a host. Conventional porous desiccant materials such as silica gels, mesoporous silicate, active carbon, natural rocks and so forth, have the advantages of stable characteristics and low cost. However, the disadvantage of low adsorption capacity leads to huge size of SDC units. On the other hand, hygroscopic salts (i.e. haloids, nitrates and sulphates, etc.) possess higher sorption capacity, but they are not stable especially under high humidity ratio due to lyolysis (the appearance of wetting, followed by that of liquid solution, which often takes place after the formation of solid crystalline hydrate).

¹ P_0 is the saturated vapor pressure at adsorption temperature and P is the vapor pressure.

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