Review on Solar Powered Desiccant Wheel Cooling System

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Abstract

Nowadays, there is still a big amount of needs in air conditioning system with environmental change and improvement of living standards. However, air conditioning system have already accounted for a large part of energy consumption in the whole society, and then how to effectively increase the energy utilization. Desiccant wheel cooling system operate on the principle of adsorption dehumidification and evaporate cooling. The system adopts natural substance as working fluid and can be driven by low grade thermal energy such as solar energy. Due to this merit, solar powered desiccant wheel cooling system has recognized as one of good alternative to conventional vapor compression air conditioning system and has obtained increasing interest in the past years. This review paper aims to summarize recent research development related to solar powered desiccant wheel cooling system and to provide information for potential application. The cooling potential of the system is based on the performance of the desiccant wheel that removes humidity from outside air to increase the potential of the humidifier.

1. INTRODUCTION

In desiccant cooling systems fresh air is dehumidified and then sensibly cooled before being sent to the air conditioned space. Since this technique works without conventional refrigerants and allows the use of low-temperature waste heat or solar energy [1], it attracted considerable research Attention during the last few years[2–3]. Improved performance of these systems will lower their initial and operating costs and make them a more attractive alternative to existing vapor compression systems. Desiccant dehumidifier is one of the most critical elements of desiccant cooling systems. Typical arrangements of solid desiccant dehumidifiers include slowly rotating partitioned desiccant wheels and periodic packed beds of the desiccant material. There are an increasing number of methods, modes of operation, and system arrangements by which desiccant dehumidifiers can be integrated in air conditioning systems [3]. For example, desiccant cooling systems can be operated in a recirculation mode [4], in ventilation mode [5], Dunkle cycle and wet-surface heat exchanger cycle. Solid desiccant dehumidifiers can be also integrated into radiant cooling systems with energy saving advantages [6]. Desiccant enhanced nocturnal radiation cooling and dehumidification is another interesting application to achieve both sensible and latent heat cooling in hot humid climates [7, 8]. The capacity of building materials to store moisture and thermal energy is used during the day and the desiccant bed removes moisture during the night. The desiccant is regenerated during the day for night time air conditioning. Night purging with natural cold and dehumidified air drawn into structures reduces the daytime air conditioner load and peak demand [9].

In a complete desiccant cycle, the desiccant material undergoes adsorption, regeneration, and cooling processes, see Fig. 1. During the adsorption process, the desiccant extracts moisture from the air until reaching equilibrium with it. The heat of adsorption released during the adsorption process heats the supply air and the desiccant reaches state point B. Reactivation or regeneration of the desiccant material is carried out by heating it to temperatures around 60–90 C using a regenerative air stream, process B to C in Fig. 1. Cooling the desiccant from state point C to state point A reduces its surface vapour pressure so that it can adsorbs moisture again. Reactivation energy and sensible cooling represent the major energy costs of the desiccant cycle. Low values of regeneration temperature allow the use of low cost waste heat and solar energy in the regeneration process. The energy utilized in sensible cooling includes the heat removed from the desiccant (process C to A) and from the outlet supply air to reduce its temperature to the required temperature before introduction into the conditioned space Close examination of the adsorption process (A to B in Fig. 1), shows that the adsorption capacity of the desiccant decreases because of the increase in its water content and temperature.

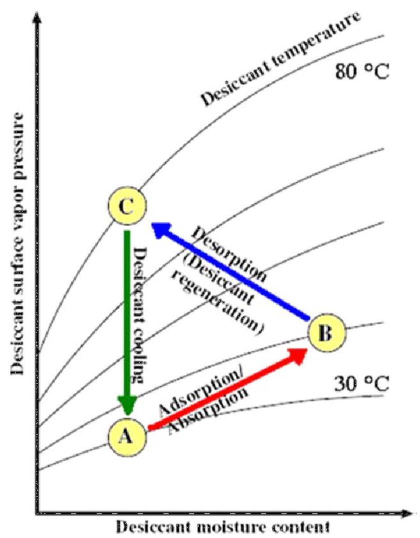

Fig.1: Representation of Desiccant Cycle Processes

2. WORKING PRINCIPLES OF DESICCANT COOLING SYSTEMS

Desiccant systems can be differently designed depending on the considered application, the location where they are installed, adjacent systems producing waste heat, etc. However, every DEC system includes a desiccant dehumidifier, a cooling unit, and a regeneration heat source to regenerate the desiccant. In the following, a general overview of the most common DEC systems is given, followed by a more detailed description of the single components.[11]

2.1 Common Desiccant Cooling System Designs

- **All Desiccant Systems**

  These systems are characterized by the use of desiccant dehumidifiers coupled with direct or indirect evaporative coolers.

- **Hybrid Systems**

  These systems use desiccant dehumidifiers coupled with conventional chillers.

- **Solid Desiccant Systems**

  These systems use solid desiccants.

- **Liquid Desiccant Systems**

  These systems are used liquid desiccants.

2.2 Desiccant Dehumidifiers

Sorption is the fundamental process distinguishing DEC systems from conventional cooling- based dehumidification systems. Sorption refers to the binding of two different substances, one attracting the other. The attracting materials are called sorbents, and they have the ability to attract and hold other gases or liquids that are called sorbates. Desiccants are a subset of sorbents with a particular affinity for water. Nearly any material shows an affinity with water, attracting and holding water up to a certain percentage of its dry weight. However, desiccants used as dehumidifiers in air treatment processes include those materials for which this percentage is particularly high, approximately between 10% and

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1200% of their dry mass in water, depending on the type (e.g. solid or liquid desiccant) and the air humidity content, [6]. Desiccants are able to attract moisture even if the air is already quite dry, contrarily to other materials. There are two different sorption processes involving the attraction and capture of moisture by desiccants, which usually differ depending on whether the desiccant undergoes or not a chemical change during the process:

- **Adsorption**

  This process does not involve a chemical change in the desiccant but only bonding at its interface with the adsorbed water vapour. The types of bonding that can occur are ionic, covalent, or metallic. The nature of the bonding depends on the species involved in the adsorption process.

- **Absorption**

  This process involves a chemical change in the desiccant. In fact, molecules undergoing absorption are taken up by the volume of the desiccant, and not by its surface. To understand how desiccants dehumidify the air, it is important to analyze the thermodynamic processes involved. The functioning principle of all desiccants is the same: the attraction of moisture from humid air is driven by the difference between the water vapour pressure at the desiccant surface and in the adjacent air stream. Desiccants attract moisture when the vapour pressure at their surfaces is lower than in the humid air and vice versa.

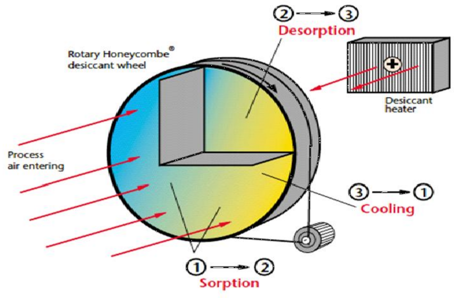
2.3 Solid desiccant

Adsorbents do not undergo chemical changes but they attract and hold moisture on their surfaces. This implies that, larger the desiccant-air contact surface is, higher is the maximum amount of moisture that can be adsorbed as a percentage of the desiccant dry mass. Therefore, solid desiccants have not a compact structure but they are characterized by an extremely high ratio between their internal surface area and their mass. This means that the volume of solid desiccants contains an extremely high number of capillaries, to increase the contact surface. The adsorbed moisture is mainly contained into the capillaries by condensation, and the majority of the surface area that attracts water vapour molecules is in the crystalline structure of the desiccant. Since solid desiccants attract moisture in the vapour phase, without any condensation of liquid on the desiccant surface, they can continue dehumidifying the air even when its dew point is below freezing, differently from all the others cooling-based dehumidification system.

The most common commercial adsorbents are:

- Silica gels
- Zeolites
- Synthetic zeolites (also called molecular sieves)
- Activated aluminas
- Carbons
- Synthetic polymers systems

Adsorbents used for air conditioning applications require a continuous reactivation process to work properly. Two different air streams (process and regeneration) are used to operate these dehumidifiers. The most common type of continuously regenerated solid desiccant dehumidifiers are desiccant wheels. These components are constituted of finely divided grains of desiccant material, impregnated into a support structure.



(a) Functioning scheme of a desiccant wheel, [7]

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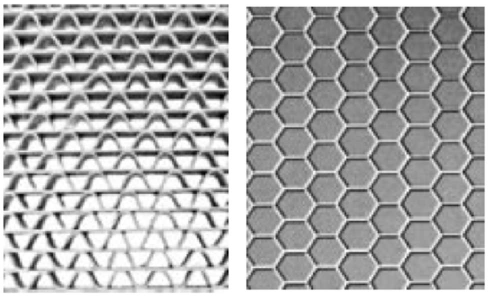

(b) Possible geometries of the flutes

Fig.2: Characteristics of a Typical Desiccant Wheel

3. THE REGENERATION HEAT SOURCE

Different energy sources and technologies can be adopted to supply the necessary amount of heat at the required regeneration temperature. An important distinction has to be done between different regeneration system types:

- Hot water is used to provide heat to the regeneration air stream. Examples of suitable technologies are boilers, solar heating systems, geothermal heat pumps, and heat recovery from closed systems.
- The regeneration air stream is directly heated without the use of a secondary fluid. Examples of suitable technologies are electric resistances and solar air heating systems.

4. CONCLUSION

Solar powered rotary desiccant cooling system has become a good alternative to conventional vapor compression system, and lots of investigations have been conducted to evaluate performance of the system. These work scan be divided into two groups : separate solar rotary desiccant wheel cooling system and hybrid system. Within the first group, researches can be subdivided based on different solar collector system. And within the second group, hybrid system can be classified by whether conventional VCS is adopted.[12]

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