IJARSCT

ISSN (Online) 2581-9429

International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)

IJARSCT
Impact Factor: 6.252

Volume 2, Issue 1, December 2022

A Progressive Review on Solid Desiccant Cooling Systems

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Abstract: *The different types, applications of thermally activated solid desiccant cooling systems are reviewed in this paper. Particularly when compared to traditional vapour compression systems, solid-desiccant dehumidification has been shown to be a successful approach to remove the moisture from air with comparatively little energy usage. Despite being visually appealing, solar assisted solid desiccant cooling systems have remarkable performance that seem challenging to conventional cooling, according to a thorough evaluation that has been provided by earlier investigations. The solid desiccant dehumidification techniques are covered in detail in this review, along with configurations of related systems. In addition, attention has been given to the theoretical and technological advancements of the regenerator, a crucial part of the solid-desiccant dehumidification system.*

Keywords: COP, desiccant cooling, regeneration, solid desiccants

I. INTRODUCTION

Desiccant cooling systems have drawn a lot of interest in recent years. In humid and hot environments, these systems are viewed as an alternate method of reducing energy usage and greenhouse gas emissions. Researchers show that by switching the energy utilised away from electricity and toward renewable, less expensive fuels and waste energy that are ideal for solar energy, these systems may reduce overall energy usage. The desiccant cooling can be either a perfective supplement to the traditional vapour compression air conditioning technology to attenuate the effects of its drawbacks, or an alternative to it for assuring more accessible, economical, and cleaner air conditioning. Still more importantly, when powered by free energy sources such as solar energy and waste heat, it can significantly reduce the operating costs and increase considerably the accessibility to the air conditioning for the populations in remote areas, especially in developing countries. Desiccants can be used to successfully overcome the latent portion of the cooling load due to their capacity to absorb water moisture. Desiccants may be either solid or liquid, thus they can be divided into liquid desiccant air conditioning systems and solid desiccant air conditioning systems, which include fixed bed type and rotating wheel type. Compared to solid desiccants, liquid desiccants offer several benefits. The liquid desiccant solution, which is utilised to absorb or desorb water vapour from/to an air stream, is the primary working fluid in liquid desiccant air conditioning (LDAC) systems. LDAC systems have been utilised extensively because they are beneficial for managing latent heat load. Due to the difference in water vapour pressure between the surface of the desiccant and the surrounding air, desiccants can either be organic or synthetic materials that can absorb or adsorb water vapour. They can exist in either a liquid or a solid state. Both liquid and solid desiccant systems have benefits and drawbacks. In addition to being flexible in use and having a lower regeneration temperature, liquid desiccant has a reduced pressure drop on the air side. Compact and less prone to corrosion and carryover are solid desiccant. Lithium chloride, triethylene glycol, silica gels, aluminium silicates (zeolites or molecular sieves), aluminium oxides, lithium bromide solution, and lithium chloride solution with water are examples of commonly used desiccant materials. Desiccant components are employed in a variety of technical configurations [1-3]. One common setup uses a wheel that rotates slowly (8–10 revolutions per hour) and is impregnated with or coated with the desiccant, with part of it capturing the incoming air stream while the other section is being regenerated. Another configuration employs solid desiccants packed together to create adsorbent beds that are exposed to the incoming air stream and absorb its moisture. Periodically, these beds must be relocated in the direction of the regeneration air stream before being repositioned in the process air stream [4-5]. To absorb water vapour from the incoming air, liquid desiccants are frequently sprayed into air streams or wetted onto contact surfaces [6-9].

The main flow configurations for solid desiccant dehumidifiers, particularly the effect of nano-particles on liquid desiccants, the different models of the desiccant dehumidifier and finally summarising the recent works on advances in solid desiccant cooling system, are the main topics of the present study's review of solid desiccant air conditioning systems [10-14].

II. SYSTEM OPERATION

There are different configurations to enhance the performance of the solid desiccant cooling namely renewable solar energy in BIPV/T-SDC system as shown in Fig.1 [15-18]. It has the advantages of being simple and having a relatively better thermal coefficient of performance than the dedicated system. Different components of the system namely Desiccant Wheel (DW), Sensible Wheel (SW), Auxiliary Heater (AH) connected to a BIPV/T system and a combination of an Indirect Evaporative Cooler (IEC) and Direct Evaporative Cooler make up the cooling cycle (DEC). A portion of the return air is employed as a secondary stream in the IEC of the DINC cycle, while the remaining portion is combined with the supply air exiting the sensible wheel. As shown in Fig. 1, the supply outside air stream is passed via a rotary desiccant wheel. Its moisture is partially but considerably absorbed by the desiccant material, and the heat of adsorption raises the temperature of the desiccant material, causing a warm and relatively dry air stream to leave at process air side of exit of rotary dehumidifier. The air stream is then cooled in a heat exchanger (heat wheel) and in an evaporative cooler [19-22]. The return air from condition is cooled using an additional evaporative cooler, and the cold air stream acts as a heat sink to chill the supply air in the heat exchanger. When it leaves the heat wheel, its temperature rises as a result. It is now prepared for a supplemental heating to achieve a temperature that is high enough to allow for the regeneration of the desiccant material. A portion of the return air stream (approximately 20%) avoids the heating source to lower the amount of regeneration heat used [23-25].

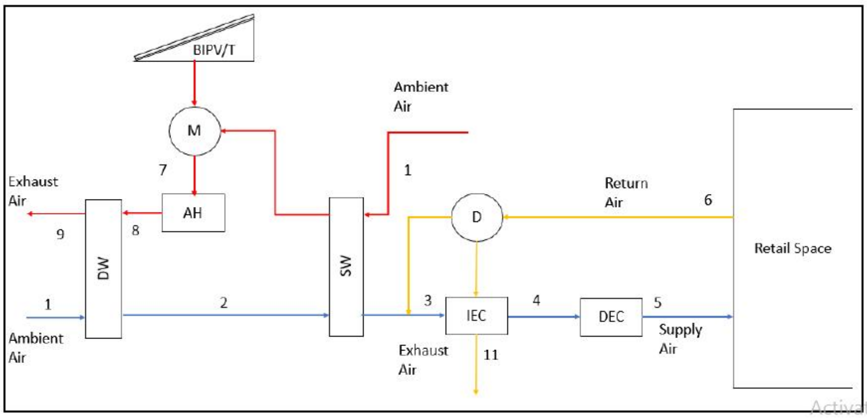

Figure 1: Schematic layout of solar powered solid desiccant cooling system.

III. SOLID DESICCANTS AND THEIR PROPERTIES

There are two types of desiccant cooling systems: liquid desiccant and solid desiccant. Commonly used solid desiccants include zeolite, lithium chloride, lithium bromide, calcium chloride, silica gel, and alumina. A solid desiccant called silica gel is used to dry up external air before it is pumped within a structure. The most important part of desiccant systems is liquid desiccant. The surface vapour pressure is one of the most important factors that affects how much heat and mass move in the dehumidifier among all of its other characteristics. Liquid desiccants are typically nonflammable, odourless, non-toxic, and affordable. Silica gel is used in a variety of desiccant dehumidifiers, including rotating honeycombs, fluidized beds, inclined fluidized beds, and numerous solid packed vertical beds. The rotating honeycomb receives more consistent humidity in process air whereas the solid packed bed can handle significant amounts of moisture. There are benefits and drawbacks to both desiccant dehumidifiers [26-28].

The use of desiccant dehumidification in air conditioning systems to regulate room humidity has received much study. According to the desiccant material, the desiccant dryer may be divided into liquid and solid desiccant, and each has unique properties. In comparison to the liquid desiccant, the solid desiccant has a better water adsorption rate, a simpler structure, and no carry-over danger. The desiccant material's strong water vapour attraction characteristic is used in the dehumidification process to remove moisture from the air. The primary driving force is the difference in water vapour pressure between the desiccant surface and the airflow. Desiccant materials get saturated and lose their capacity to absorb moisture as process air is repeatedly dried out, necessitating a regeneration process. The desiccant unit is often regenerated using thermal energy, which can be produced by solar energy, electrical heaters, electro-osmosis, and waste heat [29-30]. Numerous research have been done to enhance water adsorption capability and lower regeneration temperature in order to improve desiccant system performance by use of advanced desiccant materials (Fig. 2). Composite desiccant materials are the most frequently used in solid desiccant cooling systems in recent studies among the numerous innovative desiccants. Hygroscopic salt is impregnated into the pores of a porous desiccant substance to create them. Silica gels, mesoporous silicate, active carbon, natural rocks, and other conventional porous desiccant materials have the advantages of stable properties and inexpensive cost. The drawback of limited adsorption capacity, however, results in the enormous bulk of SDC units. On the other hand, hygroscopic salts (such as haloids, nitrates, and sulphates, etc.) have a larger capacity for sorption but are unstable, particularly in environments with high humidity ratios because of lyolysis. Desiccant materials may be lost as a result, and dehumidification efficiency may decline. These two types of materials can be traded off well with composite desiccant materials: 1) Physical adsorbent stability and strong hygroscopic salt sorption qualities can be maintained; 2) the deliquescence issue is significantly reduced because dissolved salt can be retained in the pores of its host matrix [31-35].

In previous years, some composite desiccant materials were used for adsorption cooling. Results revealed that the use of composite adsorbents improved both water adsorption quantity and COP (coefficient of performance), indicating that composite adsorbents had considerable promise in adsorption cooling. Due to these benefits, composite materials made of various host matrix and confined salts have made greater progress in much more recent years [36-37].

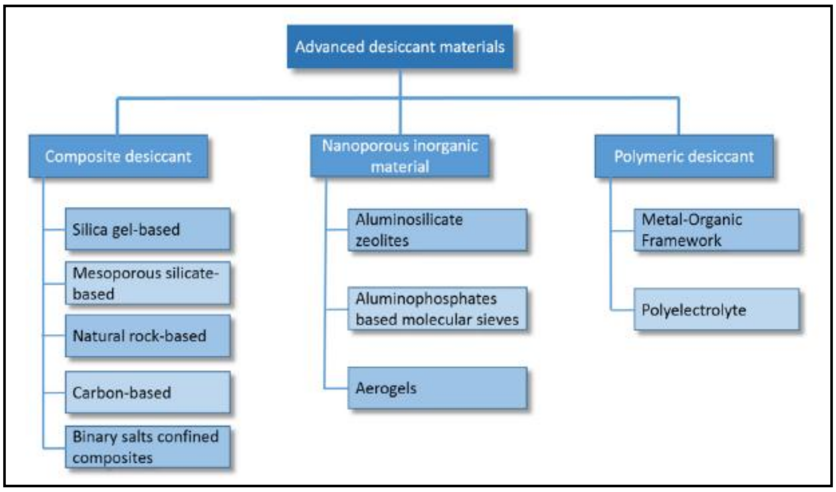

Figure 2: Classification of advanced solid desiccant materials.

IV. RECENT DEVELOPMENT AND FUTURE SCOPE

To improve performance of system hybrid cooling system developed (Fig.3) in which the integrated heat pump's condenser serves as the sole heat source for the regeneration process. In this setup, the evaporator produces cooled water, which is then kept in a chilled water tank. To cool process air from the environment, chilled water is piped to pre-cooling and cooling coils. An additional condenser installed outside the air handling unit can be used in the integrated heat pump sub-system to exhaust extra condensation heat into the environment and prevent the compressor from being overloaded owing to higher condensation temperatures during the refrigeration cycle. The solid desiccant wheel is heated by the return air stream, which also absorbs heat from the condenser inside the air handling unit. As a result, the solid desiccant has a higher vapour pressure than the air stream. The air stream expels the moisture from the solid desiccant into the surrounding area. The regeneration process is the process of removing moisture from the desiccant wheel using more heat from the return air stream [38-41].

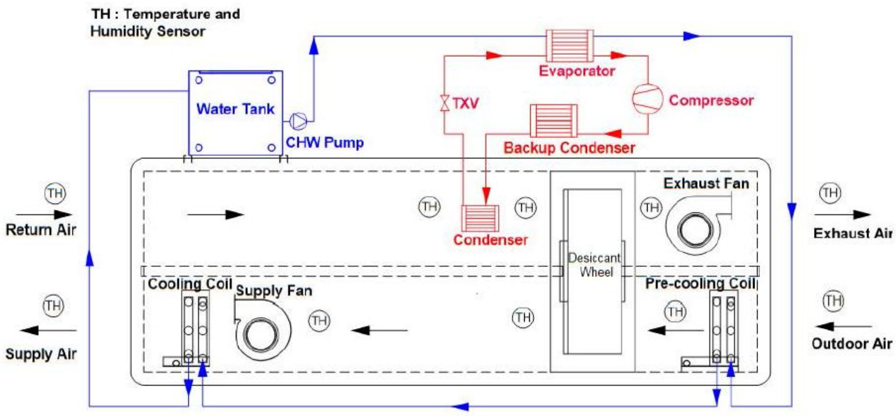

Figure 3: Solid desiccant vapour compression hybrid air conditioning system.

The longevity and life cycle cost of the materials utilised are now limiting the cost-effective implementation of numerous new renewable energy conversion technologies. There is a critical need for desiccant material research and sorption performance degradation investigations. Understanding and quantifying the processes by which typical desiccants degrade as well as developing new material possibilities for enhancing sorption kinetics and, consequently, the mass transfer in solid desiccant geometries are all part of fundamental materials research. The ideal outcome is to find a material that is both affordable and performs well in the temperature range that is specific to a solar regenerated desiccant dehumidifier. The sorption capacity, the heat of sorption, the rate of sorption at or near the desiccant bed temperature, the rate of vapour evolution at a higher temperature, and the cyclic repeatability of the sorption quantity and rates are significant criteria for the solid desiccant material [42-44]. The binding energy can be calculated from sorption isotherms and used to estimate the rate of desorption from the surface. Calculations of the rate of evolution from the solid can theoretically be made and compared to experimental findings, as can the rate of diffusion through the porous medium. Although there are a lot of sorption data for potential desiccant adsorbent materials accessible in the literature, these data have not been analytically examined to find out what maximum rates of water vapour evolution are feasible at very low driving potentials. The outcomes of this research are specifically intended to develop a novel desiccant material for use in cooling devices that burn gas. We are aware that intra-particular diffusion and pore volume diffusion can both lower sorption rates in different geometries. Recent studies conducted on solid desiccants have sought to validate analytical models of this mechanism. In the past, volumetric and scanning electron microscopy (SEM) methods were utilised to provide a rudimentary understanding of the basic sorption processes. It is not possible to evaluate the potential of polymeric materials intended for and used as desiccants due to a lack of sufficient experimental data. The clear untapped opportunities for advancing scientific knowledge and information on potential water-desiccant materials, as well as the justification for any potential adsorbent modifications, have led to the development of form of the desiccant materials, quantification of performance of fundamenta1 geometries with desiccants attached, including total desiccant geometries, vapour flows, and heat and mass exchange characteristics in these geometries, sorption hysteresis, and effects of desiccant material contamination/degradation. Recent quantitative findings utilising field samples of silica gel generated by gas and electric sources show the material's capacity evolves over time. Researching new material combinations with a low heat of adsorption and less diffusion resistance to measure and fine-tune the equilibrium properties of regular density silica gel, molecular sieve, and one type of manganese dioxide under temperature and humidity conditions resembling those that occur during solar desiccant cooling system operations [45-47].

It was discovered that using a hybrid solid desiccant cooling systems might boost cooling capacity by 40–60% while reducing overall power usage by 20–30%. A two-stage rotating desiccant cooling/heating system powered by evacuated glass tube solar air collectors demonstrate that the main benefit of the two-stage desiccant cooling system was that moisture removal in hot and humid environment conditions reached 6.68-14.43 g/kg. Significantly increased indoor comfort can be achieved with solar heating and desiccant humidification [48-51]. Particularly in hot and humid areas, a solar hybrid SDCS is an excellent replacement for conventional vapour compression air conditioning systems because solar energy can lead to energy savings of between 40 and 45 percent. In solar SDCS systems, stated regeneration temperatures of hot water in the range of 54.3° C to 68.3° C can be attained via modelling [52-58].

V. CONCLUSION

The number of previous studies focused on performance enhancement by the novel solid desiccant cooling systems is progressively growing today. These investigations support the possibility of using solid desiccant cooling as an alternative to conventional air conditioning. Additionally, it is crucial to design and choose the appropriate desiccant in a way that is more energy-efficient, environmentally friendly, and cost-effective as this cooling technology is developed. The recommendations and difficulties raised here indicate the lines of inquiry for further study. More thorough research on the creation and assessment of sophisticated materials is still required to move forward.

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