# Rotary Desiccant-Based Air-Conditioning Systems

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A rotary desiccant-based air-conditioning system is a heat-driven hybrid system which combines different technologies such as desiccant dehumidification, evaporative cooling, refrigeration, and regeneration. This system has an opportunity to utilize low-grade thermal energy obtained from the sun or other sources.

solar energy | air conditioning | hybrid system

## 1. Introduction

According to the International Energy Agency in 2012, HVAC systems in the building sector are the most energy consuming devices, contributing 10–20% of the final energy consumption in developed countries. Thus, the increase in energy efficiency for HVAC systems plays an important role in energy policies worldwide [1]. Providing cooling by utilizing renewable energy, such as solar energy, is one solution to address the energy issues. Desiccant-based solar cooling is one of the most promising methods of utilizing solar energy for the purpose of air conditioning. This system is a combination of dehumidification, refrigeration, cooling with the help of an evaporative cooler, and finally regeneration of the desiccant system by a heat source, in order to provide and maintain the desired room temperature and relative humidity with enhanced efficiency of energy use [2]. So, compared to conventional systems, desiccant-based air conditioning provides efficient control of room temperature along with relative humidity, while consume less electrical energy [3]. Almost all air-conditioning systems essentially handle two kinds of load, namely sensible load and latent load. The sensible load is due to temperature differences, while latent load is due to moisture [4]. Conventional air-conditioning systems do not have any separate arrangements for handling sensible and latent load. Here, the evaporator coil can handle both sensible as well as latent load. When handling latent load in conventional air-conditioning systems, it is necessary to maintain the temperature of the evaporator coil below the dew point temperature of the inlet air. So it is again required to reheat, which implies poorer energy efficiency. In desiccant-based air-conditioning systems, latent cooling is performed by desiccant dehumidification and sensible cooling by evaporative cooling or refrigeration. Thus, a considerable part of expensive vapor-compression refrigeration is replaced by inexpensive evaporative cooling.

The desiccant dehumidification and cooling system (DDCS) is the best alternative for the VC system as it overcomes the traditional system’s disadvantages and is more economical and easily accessible. The DDCS decreases the operational costs and work more significantly when powered by solar energy [5][6][7].

The conventional reheat system not only consumes excess electrical energy because of low energetic efficiencies, but it is also responsible for damaging our environment. These two reasons are responsible for the need to investigate the development of an alternative HVAC system which does not have any adverse effect on our environment, as well as being able to use low-grade sources of energy. Desiccant-based air-conditioning systems utilizing solar energy fulfil both the demands of researcher, so it is one of the most promising choices [8]. Several experimental setups have been built and tested across the world to study the feasibility and effectiveness of using solar-powered solid desiccant cooling systems instead of traditional VC systems. In hybrid systems, both solar-energy- and electricity-driven refrigeration systems are utilized, and progress has been made in making solar energy a primary energy source [9].

## 2. The Desiccant Materials

Desiccants are absorbents which have very high attraction towards water vapor. Desiccants are present either in solid form or in liquid form. Solid desiccants are extremely porous and use chemical adsorption processes in order to adsorb water vapor. Silica gel, activated alumina, synthetic polymers, natural zeolites and molecular sieves are some examples of solid desiccants. For the purpose of dehumidification and cooling Silica gels are used widely [10][11][12][13][14]. Liquid desiccants are commonly very strong solutions of ionic salts. Calcium chloride or lithium chloride, and nearly-organic liquids, such as tri-ethylene glycol are the common examples of liquid desiccants. Some widely used solid desiccants and their properties are discussed in the following sections.

### 2.1. Silica Gel

Because of its very high attraction towards moisture, silica gel is generally used for air-conditioning purposes. It is a naturally available mineral which is nontoxic, as well as odorless. It has a porosity grater then 70%, surface area in the order of 650 $m^2$/g, with pour sizes of 2–3 nm (type A) to 0.7 nm (type B) and a heat-absorption capacity of about 2800 kJ/kg [15]. Some types of silica gel are macroporous whereas some are microporous. Macroporous silica gel gets saturated easily, whereas microporous silica gel can absorb water vapor for a longer time. Some types of silica gel change their color from blue to pink while absorbing water. A regenerated air stream is used for regeneration of silica gel in which absorbed water is removed. The regenerated air temperature generally varies between 90 to 150 °C [16][17].

### 2.2. Activated Alumina

Activated alumina is prepared in thermal processes in which structural properties are controlled by using temperature and duration of the thermal process. Essentially, these are oxides and hydrides of aluminum with a surface area of 150–500 $m^2$/g, pour size of 1.5–6 nm and heat-adsorption capacity of about 3000 kJ/kg. They are used frequently for desiccant dehumidification and cooling applications [18][19].

### 2.3. Molecular Sieves

Molecular sieves, also called synthetic zeolites, are crystalline aluminosilicates prepared in thermal processes. The composition of the ingredient materials and the temperature control the structure and surface features. Synthetic zeolite can hold moisture strongly, and hence is used for different dehumidification and air-conditioning applications [20][21][22][23].

## 2.4. Advanced Desiccant Material

These are the newly developed desiccant materials, such as composite desiccant and polymeric desiccant, with better properties that can be used in place of common desiccant materials.

### 2.4.1. Polymer Desiccants

Essentially, a polymer is a substance made up of macromolecules. In comparison with silica gel, polymer desiccants enable 2–3 times greater sorption capacity [24]. Polymer desiccant gives a better result when used in a condition of higher relative humidity and low regeneration temperature [25]. Synthetic polymers can be used as advanced desiccant materials because they are capable of adsorbing up to 80% of their own weight in water and have the potential of being adjusted to realize desired water adsorption isotherms.

### 2.4.2. Composite Desiccant

Composite Desiccant is made by infusing hygroscopic salt into the porous desiccant material. The development of composite desiccants such as silica-gel- and haloids-based composite materials not only increases the dehumidification capacity of silica gel, but also minimizes the problem of corrosion with haloids. At the same time, regeneration temperature is considerably decreased, thus enabling the usage of lower-grade heat sources. A composite desiccant wheel can remove approximately 50% or more moisture from air than a conventional wheel [26].

# 3. Working Principles of Rotary Desiccant-Based Cooling Systems

In rotary desiccant-based air-conditioning systems, latent cooling is performed by desiccant dehumidification and sensible cooling is performed by a low-cost evaporative cooler. So, it is a combination of the dehumidification of the process air by passing it through the rotary desiccant wheel followed by cooling of the dehumidified air to the required indoor conditions. This system is made continuous by a regeneration process in which heated regeneration air is made to flow through the desiccant wheel so that the water vapor which is accumulated from the process air is removed and the wheel is made available to absorb water vapor from the process air in the next cycle. Therefore, the desiccant cooling system mainly contains three components: the desiccant dehumidification system, the cooling system, and the regenerative heating source.

## 3.1. The Rotary Desiccant Dehumidification System

The principle of rotary desiccant dehumidification is shown in **Figure 1**. A process in which a fresh-air stream is dehumidified while flowing through a rotary desiccant wheel is known as desiccant dehumidification, and since air is also heated during the process, it is shown as a dehumidification and heating process on the psychometric chart. There is another type of air stream, known as regeneration air, which is first heated and then made to flow through the wheel to drive off the absorbed moisture from the desiccant. Consequently, the regeneration air is humidified and cooled. This process is known as regeneration of the desiccant wheel.

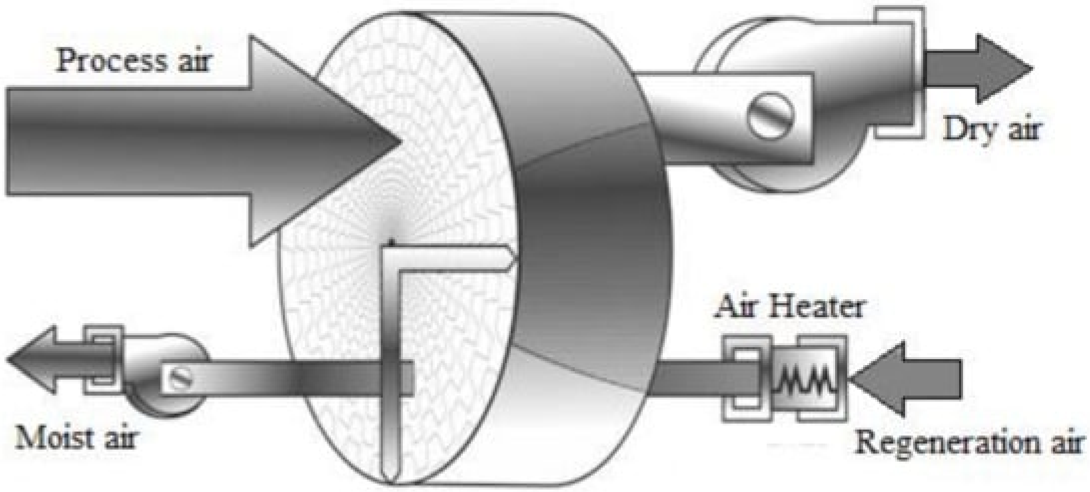


**Figure 1.** Rotary Desiccant Dehumidification System.

### 3.2. The Cooling System

The cooling system is mainly used to handle sensible load. Generally, an evaporative cooling system or cooling coil of a traditional vapor-compression system are used for this purpose. With the implementation of a desiccant wheel, a number of heat exchanges are also used to preliminarily cool the dry and warm air stream after the desiccant wheel with the help of cabin and ambient air, before it is further cooled by an evaporative or traditional cooling unit.

### 3.3. The Regenerative Heating Source

An energy source is required in order to increase the temperature of regeneration air which can supply the necessary thermal energy for removing the moisture absorbed during the sorption phase from the desiccant wheel. A variety of possible energy sources such as an electrical heater, gas heating system, waste heat from different sources, and solar energy are generally used as a regeneration energy source for desiccant wheel.

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