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An Overview on Desiccant Assisted Sustainable Environmental Cooling Technology

Jani Dilip Batukray*

Department of Mechanical Engineering, Government Engineering College, Dahod, India

Abstract

The air conditioner should efficiently control both the sensible as well as latent heat load of building in order to provide necessary indoor thermal comfort. The conventional vapor compression system usually controls the latent load by the process of condensation of water vapor in which air is cooled below its dew point temperature and then reheated again up to the required supply conditions. The conditions where latent load is dominant these two processes i.e. over cooling and then reheating again will increase the consumption of electrical energy and emission of CO_2 remarkably. This increases the temperature on earth further due to global warming. To avoid this wastage of primary energy and emission of harmful gases, desiccant based dehumidification and cooling system is a good alternative to the traditional air conditioning system which is cost effective as well as environment friendly. It can be driven by thermal energy which makes a good use of solar energy which is free as well as clean. In this paper, are view of desiccant based sustainable cooling technology has been presented. The present study is undertaken from variety of aspects including background and need of alternative cooling systems, concept of conventional and desiccant based thermal coolers, system configurations, operational modes, as well as current status of the desiccant based sustainable cooling technology. The review work indicated that the technology of desiccant based cooling has a great potential of providing human thermal comfort conditions in hot and humid climatic conditions at the expense of less primary resources of energy as compared to conventional cooling systems. Various types of desiccant cooling systems have also been introduced in this paper.

Keywords

Dehumidification, Desiccant Cooling, Regeneration, Renewable Energy, Sustainable Cooling

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1. Introduction

While the broader use of energy is essential to developed modern society, most primary sources used today are unsustainableand are accompanied with adverse effects on the environment in form of pollution of land and air both. Approximately 81% of theenergy is supplied by fossil fuels based energy sources which may deplete in near future. The production of energy from uncleansources like fossil fuels has become a key contributor to increasingly concerning environmentalpollution related major issues that include global climate change, acid rain and radioactivewastes. As these environmental threats become more apparent, serious efforts are being made to findinnovative ways to save energy and to increase the energy production capacity byuse of renewable and sustainable sources like as freely availablesolar energy and industrial waste heat. The most energy consuming devices on both the commercial and residential sectors are heating, ventilation and air conditioning units (HVAC) as shown in Figure 1 which used for maintaining indoor thermal comfort [1-5].

* Corresponding author
E-mail address: dbjani@rediffmail.com

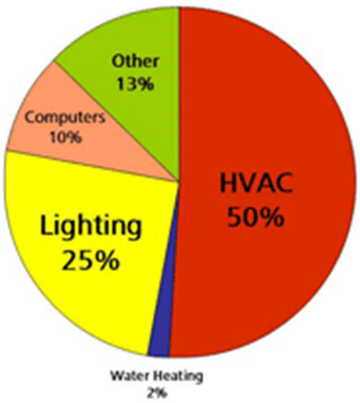

Figure 1. Energy consumption in commercial building.

There are two conventional ways to cool process air: sensibly and latently. To cool sensibly means to reducethe dry bulb temperature (DBT) of the process air. Latent cooling refers to the removal of moisturefrom the conditioned air. In order to promote a healthy indoor environment, HVAC units must control thesensible and latent cooling demand of the building. Indoor air at elevated humidity levels canpromote to the accumulation of bacterial growth inside the building which can be hazardous to theoccupants [6-8]. Oppositely, the indoor air at extremely low moisture level quickly dries the moisture from theoccupant's skin, leading to discomfort to the occupants. The key to promoting a healthy indoor environment is tosupply air with enough humidity to be comfortable but low enough to avoid problems caused byexcess moisture. Therefore, it is important to have efficient control over the humidity level of indoor air; especially inside buildings. The vapor compression cycle used for running the traditional HVAC units can only directly cool the sensibledemand of the process air. In order to accommodate the latent cooling load, the temperature ofthe process air is lowered well below its dew point, allowing water vapor to be removed throughcondensation of conditioned air. The process of sensibly cooling below the air's dew point results ina reduction in humidity as well as overcooling of room supply air. After the temperature of the process air is reduced, the air is thenreheated to meet the temperature desired inside the conditioned space. This process is diagrammatically shown by the red colour line from the state of high temperature to low temperature in the psychrometric chart of figure 2. It takes substantial energy to cool humid air containing excess moisture than it does to cool dry. A desiccant assisted cooling system takes advantage of this concept by first dehumidifying the process air before itis moved into the HVAC where it is cooled sensibly. Effectively, a desiccant system lowers air conditioning energy demand by minimizing its latent cooling load. The ideal cooling of process air bya desiccant powered dehumidification and air conditioning unit is depicted by the blue colour line in the psychrometric chart of figure 2. The dehumidification process of the desiccant cooling is represented by the nearly vertical section of the blue colour line. As the air is dehumidified, it rises in temperature slightly before beingmoved into the conditioning unit. After dehumidification, the process air is cooled sensibly by the traditional cooler to meet the demand of desired temperature of the conditioned space.

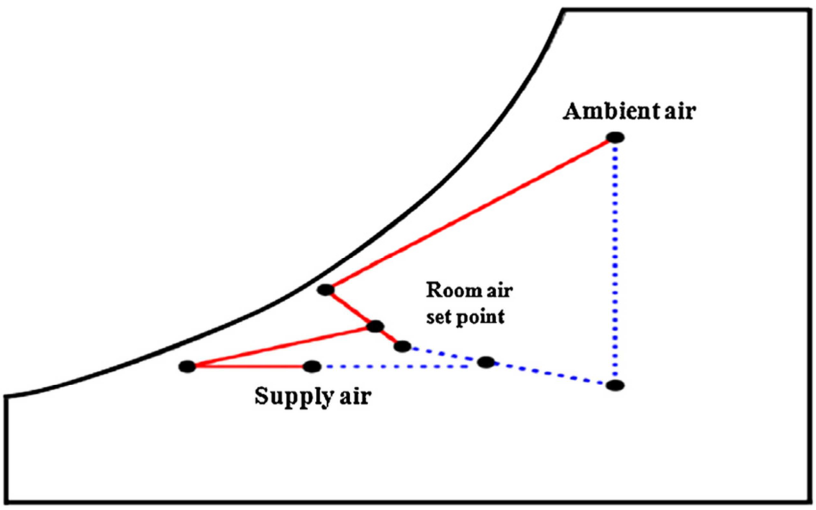

Figure 2. Comparison between VCR cooling (red line) and desiccant cooling (blue line) on psychrometric chart.

It is necessary to control the humidity of air as recirculated air at extremely low relative humidity quickly dries the moisture from theoccupant's skin, leading to discomfort. The key to ameliorate a healthy indoor environment is tosupply air with enough humidity to be comfortable but low enough to avoid problems caused bymoisture. Therefore, it is important to have efficient control over the humidity level of indoorair; especially inside a home.

The comparison between conventional cooling and desiccant cooling can be elaborated in following table 1 [9-14].

Table 1. Comparison between VCR cooling and desiccant cooling.

Parameters	VCR cooling	Desiccant cooling
Operating cost	High	Saves 41-48%
Indoor air quality	Average	High
Effect on environment	Harmful	Eco-friendly
Energy source	Electricity	Low grade heat like waste heat or renewable solar energy
Moisture removal capacity	Average	High

Advantages of desiccant cooling can be summarised as follows:

1. Desiccant cooling systems can be operated by use of low grade thermal energy sources like solar energy.
2. Desiccant cooling system is environmentally friendly as it does not use CFC based refrigerants which are responsible for global warming.
3. Over cooling and reheating of conditioned air supply can be avoided by use of desiccant desorption to control the humidity in air.
4. Leakage is avoided as desiccant cooling system operated nearly at ambient pressure.
5. Less prone to corrosion and wetting the supply duct.

A desiccant cooling system consists of passing humid (and warm) air through a desiccant laden dehumidifier rotary wheel for drying and through a cooler for sensible cooling to provide conditioned air. The desiccant material used in the rotary dehumidifier becomes saturated with water and needs to be regenerated with hot air provided by an energy source (e.g., sun, natural gas, waste heat, or electricity). The cost, efficiency, and durability of a desiccant cooling/dehumidification system depend on those of the components used in the system [15-18].

2. Working of LiquidDesiccant Cooling System

Working of liquid-desiccant system is shown in Figure 3. The conditioner (or absorber) is the component that cools and dries the process air. As shown in this figure, the conditioner is a bed of structured contact media, similar to the corrugated fill that might be used in a cooling tower. Liquid desiccant is first cooled in a heatexchanger and then sprayed onto the contact media. The desiccant flow rate must be sufficientlyhigh to ensure complete wetting of the media, meaning it should be about 5-7gpm per square foot of face area. The process air is cooled and dried as it comes in contact with the desiccant-wettedsurfaces of the contact media.

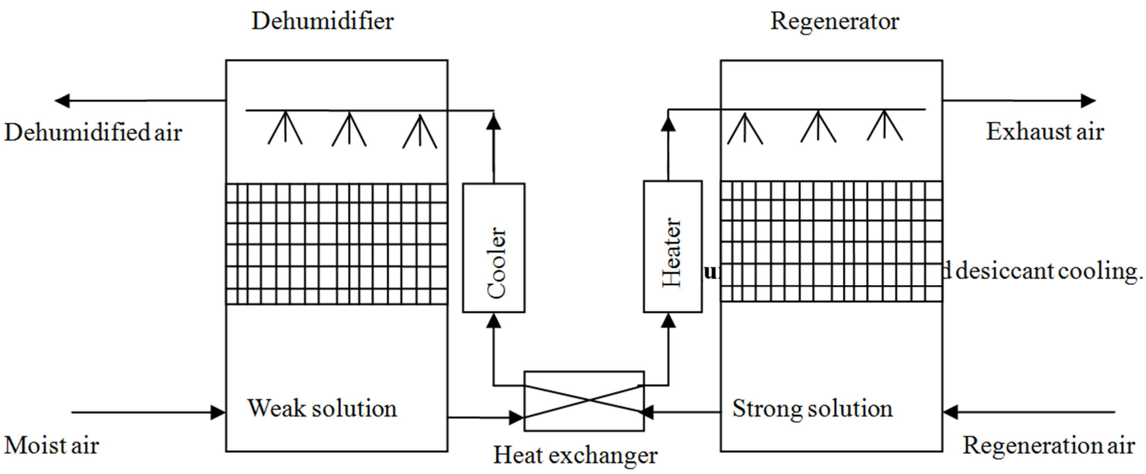

Figure 3. Working of liquid desiccant cooling.

Heat is released as the desiccant absorbs water from the air, butthe high flow rate of the desiccant limits its temperature rise to a few degrees. The regenerator removes the water that the desiccant has absorbed in the conditioner. Thedesiccant is reactivated by first heating it to raise its equilibrium vapor pressure. The hot desiccant, typically between 55-85°C temperature, is sprayed over a bed of random fill. Flooding rates are again sufficiently high to ensure complete wetting of themedia. The hot desiccant desorbs water to the air that flows through the bed. This moisture laden air is typically exhausted to ambient. Both the regenerator and conditioner require droplet filters (also referred to as mist eliminators) to ensure that the desiccant is not entrained in either the supply air to the building or theexhaust from the regenerator. Droplet formation is fundamental to both the spray distributor andthe highly flooded beds of contact media used in industrial equipment. Droplet filters can suppressdesiccant carryover to parts per billion of airflow, but these filters do increase air-sidepressure drops and require maintenance. An interchange heat exchanger (IHX) can be used to preheat the weak desiccant that flows tothe regenerator using the hot, concentrated desiccant that leaves the regenerator. The IHXreduces both the thermal energy use of the regenerator and cooling requirements of the conditioner [19-21].

3. Adsorbents Used in Desiccant Cooling

In a desiccant assisted cooling and dehumidification system, the process air is dehumidified in an adsorption process by a solid desiccant material, and then cooled by evaporative cooling to desired temperature. 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 desiccant dehumidifier used in the system. In order to improve the performance of the overall 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 120°C, considering that waste heat resources in the temperature range of 66-80°C account for 50-80% of the total ones [22-23].

The desiccant materials either adsorb or absorb according to its solid or liquid which attracts moisture. These materials are used in place where low dew point for dehumidification of air is required. The strength of desiccant materials can be measured by its equilibrium vapor pressure, which is water vapor pressure that is in equilibrium with desiccant material. Some other parameters which indicate desiccant materials performance are:

1. Energy storage density.
2. Temperature for reactivation.
3. Availability.
4. Cost.
5. Desorption temperature.

A good desiccant should have the following properties:

1. Large saturation absorption capacity.
2. Low regeneration temperature.
3. Low viscosity.
4. High heat transfer.
5. Non-volatile.
6. Non-corrosive.
7. Odourless.
8. Stable.
9. Inexpensive.

Characteristics of the adsorbate play an important role in adsorption. Description aboutsome important desiccant materials used in desiccant cooling are described as follows:

i. Silica gel

One conventional adsorbent for dehumidification is silica gel. Silica gel physically adsorbs moisture from air into its internal pores. The adsorption and desorption characteristics of different silica gels may vary based on their manufacturing procedures. The variable adsorption performance suggested that the textural properties of silica gel played a significant role in dehumidification. Silica gel has very high moisture adsorption capacity because of its micro-porous structure of internal interlocking cavities, which provide a high internal surface area. Silica gel interacts with H_2O through the significant amount of surface via hydrogen bonding interactions. The significant number of active sites makes silica gel a promising material for air dehumidification at high humidity. However, due to the mild hydrogen bonding between OH groups and H_2O, silica gel is not suitable for deep dehumidification. It should also be pointed out that the adsorption capacity of silica gel decreases with an increase in adsorption temperature due to its weak physisorptive nature. Silica gel is not susceptible to structural damage in a mild regeneration condition, but a loss of surface silanol groups for moisture adsorption occurs at a high regeneration temperature.

ii. Activated carbon

Activated carbon is one of the most important adsorbents dominating the commercial use of adsorption. Taking advantage of porous materials with very high surface areas and large pore volumes, activated carbon and carbon-based materials have been studied for adsorption dehumidification. The textural properties of activated carbon vary with the carbon sources and activation methods. The hydrophobic nature of the perfect graphene structure in some activated carbon shows a low adsorption capacity of H_2O at low relative pressures of water vapor. However, it is worth noting that the surface chemical properties of activated carbon, including surface functional group types and density, can be modified by different activation processes at variable conditions. With the modification of activated carbon with silica for a more hydrophilic surface, a significantly improved adsorption capacity was reported.

iii. Zeolites

Zeolites play an enabling role in deep dehumidification. Zeolites that are in commercial use for air dehumidification today are types A, X, and Y. Zeolites possess special adsorption properties due to their unique surface chemistry and crystalline pore structures Zeolites can achieve low dew points or deep dehumidification of air due to the strong zeolite–H_2O interaction. However, the regeneration of zeolites at low temperatures is difficult because the bond of water molecules with Al cation sites in the zeolite is quite strong. In previous study it is observed, a heat of adsorption of zeolite adsorbents up to 50% greater than the latent heat of vaporization was reported, which indirectly suggested that a high desorption energy is required for regeneration. Therefore, one of the drawbacks of using zeolites as the dehumidification adsorbent is the energy-intensive regeneration due to the required high desorption temperature.

iv. Metal foam

As a kind of porous media, metal foam has drawn extensive attention as desiccant material for the low density and special thermal, mechanical, and acoustic properties. Particularly, the heat transfer performance of metal foam has been studied widely by a number of researchers. Large-size pore diameter and high porosity are the main structural features of metal foam, and the porosity of common metal foam can reach 45–80%. Metal foam can be classified as open-cell and closed-cell foam. But open-cell metal foams are used more widely than closed-cell metal foams, as the former have high specific surface area, relatively high thermal conductivity and abundant flow path. If the substrate of desiccant wheel is made of open-cell metal foam, the dehumidification performance of the desiccant wheel will be considerable.

v. Calcium Chloride

Calcium chloride is a typical ionic halide which serves calcium ion in aqueous solution and at room temperature it is a solid. It is generally produced by direct reaction of limestone with hydrochloric acid but in large quantities it is produced as a by product of solvey process. It has a boiling point temperature of 1395°C with 2.15 g/cc density.

vi. Lithium Chloride

Lithium chloride is an ionic salt that is widely used in air-conditioning systems. It has better hygroscopic properties and amazing solubility of about 83g/100 ml at 20°C in polar solvents. It has a boiling point temperature of 1382°C with 2.068 g/cc density. The crystallization line of LiCl-H_2O solution is an increasing mass fraction of Li-Cl and reducing water content

vii. Composite adsorbents

Composite materials are generally formed by the impregnation of hygroscopic salts into the pores of the host, i.e., a porous desiccant material in this case. The hygroscopic salts (nitrates, sulphates and haloids etc.) possess high water adsorption characteristics but they are unstable at higher humidity ratios due to lyolysis, so porous desiccant materials with stable characteristics like silica gels, activated carbon, mesoporous silicates and natural rocks are used as host material. Previously investigated some composite desiccants for cooling applications and reported that the composite desiccants achieved high COP as well as water adsorption characteristics. A number of composite desiccant materials have been developed in the past few years to improve the performance. The results showed that the composite desiccant materials have lower desorption temperature. About 78% of desorbed water could be desorbed from these composite desiccant materials at a temperature between 60 and 90°C [24].

4. Future Needs

The limitation faced by desiccant system is availability of regenerating heat to regenerate desiccant material. But the use of solar energy and waste heat for regeneration of desiccant material will make the system more economical. The use of desiccant system can solve lot of environmental problems well, as it can also minimize the high demand of electrical energy for conventional air-conditioning system and poor indoor air quality [25-26]. Although a number of developments had been made in liquid desiccant cooling technology but a number of steps still need to be taken in order to make this technology more market accessible. Some of future research and development needs are:

1. Cost-effective, noncorrosive, and nontoxic liquid desiccant materials need to be developed. These materials must have relatively low surface tensions so that they can easily wet the surface of the dehumidifier and regenerator.
2. The desiccant materials should have less viscosity so that required pumping power can be reduced. Also these materials should be stable.
3. The effectiveness of regenerator needs to be improved using several approaches including multiple-effect boilers and vapor compression distillation. Different alternative energy sources should be utilized for regeneration purpose.
4. Surface enhancements extended surfaces such as fins should be used to modify the design of dehumidifier and regenerator for better heat and mass transfer.
5. Technology development in terms of software for modeling, Zero carry-over design, new sorption materials etc.
6. Performance map should be carried out for the types of

desiccant used under different environmental and operational conditions

7. Some problems in desiccant system such as pressure drop in solid desiccant and carryover of liquid desiccant by air stream may be eliminated or reduced by optimization of the design of desiccant system. The design optimization of desiccant system will enhance the potential from the technical and energy saving point of view.
8. The use of composite desiccant materials may improve the moisture adsorption capacity of the material.

Research and development of desiccant used in the field of air conditioning requires more efforts from experts in the area, which are familiar to these systems. Design activities need to be developed to make this technology accessible to all people in different parts of the worlds.

5. Conclusions

In desiccant assisted air conditioning, which can be driven by low grade heat, is considered as a promising method for assuring clean and economical air conditioning. The main objective for using desiccant materials is to remove latent heat in predetermined cycles. To find the optimal desiccant, a comprehensive comparison of water adsorption quantity and regeneration ability between different desiccants mentioned has been explained in the article. For instance, composite desiccant materials have improved water adsorption capacity with the support of impregnated salts. Moreover, by proper selection of host matrix and immersed salts, i.e. clay/chlorine salt composite materials, regeneration temperature as low as 50°C can be achieved. In addition, a good balance can be reached between the regeneration and water sorption capacity by delicately tailoring textural properties of nano-porous inorganic materials. For polymeric desiccants together with the development of material science and help of molecular simulation, a large step forward practical application in adsorptive dehumidification will be anticipated. The development in desiccant technology is in progress in terms of its desiccant materials and it has attaining stability in the market. It appears to be reliable, safe, and environmental friendly according to the needs of our society.

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