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# **Advances in Liquid Desiccant Integrated Dehumidification and Cooling Systems**

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#### **Abstract**

The limitations of vapor compression based conventional systems in terms of substantial energy requirement for its running and environment pollution can arise the need of alternative cooling technology which is not only energy efficient but should be environmental friendly as well. Desiccant cooling is a suitable and cost-effective alternative which provides better thermal comfort conditions. This technology is cost effective, energy efficient, and eco-friendly. It will decrease the dependence on primary energy by an effective utilization of alternative, clean, free, and abundant sources of energy. The desiccant cooling is a thermally operated technology and is mostly used for dehumidification and cooling applications. Desiccant systems can either ant material used. The use of liquid desiccant material is advantageous as these can be regenerated at a lower temperature (60–75°C), which makes the use of low-grade thermal energy resources more feasible. In the present article liquid desiccant cooling systems have been discussed from the prospectus of its recent advancement, future research and development work needed. The pros and cons of the technology have also been discussed in the present work.

#### **Keywords**

COP, Desiccant Cooling, Dehumidifier, Regeneration

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## 1. Introduction

A building's air conditioning load comes from variety of sources such as infiltration, ventilation and occupants. Thermal comfort, energy efficiency, and indoor air quality are the main concerns while designing a heating, ventilating, and air conditioning system for the building. The thermal comfort conditions vary depending on different activities. Generally, in order to provide thermal comfort conditions to the occupants, an air conditioning system should maintain indoor air temperature of 18–26°C and relative humidity of 40%–70%. The latent load is controlled by conventional vapor compression cooling systems by the process of condensation. The air is cooled below its dew point temperature to remove the moisture and then reheated again to desired supply temperature. A considerable amount of energy is wasted during this process of overcooling and

reheating, which lowers the system overall COP. More over process of condensation creates an environment for the growth of harmful fungi and bacteria [1].

The latent load can also be controlled by using some absorbents as used in desiccant cooling systems. A desiccant cooling unit controls the latent and sensible load independently with desiccant dehumidifies controlling the latent load and an evaporative cooler or some other cooling device controls the temperature of supply air. In this way both loads are controlled individually and efficiently. Earlier, these systems were only used for drying applications. But the need of eco-friendly and energy efficient cooling device has introduced the desiccant technology as an alternative cooling.

Although a lot of ideas and efforts have been put for the research and development of liquid desiccant cooling systems but it is relatively at basic level [2].

The use of alternative and renewable energy resources and

\* Corresponding author E-mail address: dbjani@rediffmail.com other environmental concerns are the main driving forces, which are encouraging the researchers and scientists to make this technology more efficient. Keeping in view of the importance and future prospects of this technology many efforts have been made for the development of this technology all over the world [3]. Table 1 shows comparison between traditional air conditioners and liquid desiccant based alternate cooling system.

Table 1. Comparison between conventional central air conditioning system (CACS) and liquid desiccant cooling system (LDDS).

System initial investment	CACS	LDDS
Operation cost	High	Save around 40% of cost
Driving energy source	Electricity	Low-grade energy
Control over humidity	Average	Accurate
Indoor air quality	Average	Good
System installment	Average	Slightly complicate
Energy storage capacity	Bad	Good

Liquid desiccant cooling technology having great number of merits over traditional cooling systems such as no condensation requirement that eliminates growth of fungi or other harmful bacterial growth avoids various health problems to the occupants. This benefit of liquid desiccant cooling can advantageous to many industries such as medicines, food storage, laboratories etc. Merits and limitations of liquid desiccant cooling [6-9] summarized as follows:

- 1. The liquid desiccant can regenerate at ambient temperature, which makes use of freely available low grade energy sources like renewable solar heat.
- 2. The entire unit is small as well as compact.
- 3. It lowers the use of electrical power and has high moisture removal capacity.
- 4. No freezing or frosting occurs at lower temperature as liquid desiccant materials are good antifreeze.
- 5. The latent and sensible heat loads are handled separately and effectively.

Along with above mentioned merits, it also has limitations as described below:

- 1. The corrosive nature of liquid desiccant materials can damage the system.
- 2. Mist eliminators are needed as carryover can cause sever health problem to the occupants.
- 3. Larger pumping power is required as to pump large volume of liquid desiccant solution.
- 4. Some liquid desiccant may face the problem of crystallization.
- 5. The initial cost of the system is higher.
- 6. The initial cost for the system is higher.

Many researchers have worked earlier on different combinations of liquid desiccants and packing materials inside the dehumidifier/regenerator in last two decades such as structured packing (rigid cellulose media pads) and try-

ethylene glycol (TEG) to reading the consequence of different design parameters and on the performance of structured packed dehumidifier using TEG as desiccant solution for different packing densities. Furthermore, the performance of structured packed cross flow dehumidification system in terms of moisture removal rate and dehumidifier effectiveness is also studied. The operation of packed tower for regeneration of calcium chloride as desiccant was also investigated. Moreover, the performance of structured packing cross flow desiccant dehumidification system with calcium chloride as desiccant was also evaluated. Many researchers have worked with glycols as desiccant and reported about the formation of mist, especially during regeneration process. Only limited researches are available for CaCl<sub>2</sub> used as desiccant. Vapour pressure of calcium chloride is low and calcium & chloride ions of CaCl<sub>2</sub> are easily separated in water. Thus, it is converted into its ions when released to atmosphere. It is non-volatile and hydrophilic material and it has low possibility of absorption through inhalation and dermal means. So, CaCl2 is mostly chosen as a liquid desiccant by the investigators because of its characteristics and less cost as compared to other salt solutions. The structure packing is selected as desiccant-aircontact equipment in the most of the previous investigations because structure packing shows excellent performance characteristics with relatively low pressure drop, less cost, eco-friendly, long life and high wetting characteristics [10-

So, in the past, most of the investigations were carried out for the liquid desiccant rotary dehumidifiers and no in-depth work is available for analysis of liquid desiccant dehumidifiers. The purpose of this review is to aware the readers about combination of liquid desiccant cooling with other thermal cooling techniques to ameliorate the performance of the system. In this paper, literature survey is made to study the working of the liquid desiccant dehumidifier operating in conjunction with conventional cooling technique considering different constructional features. The design of hybrid system show that better supply air conditions could be obtained to achieve human comfort in

the hot and humid climate with effectiveness of the system largely dependent on air flow rate, regeneration temperature and humidity ratio of the process air. The discussed liquid desiccant cooling system is expected to overcome the disadvantages of conventional vapor compression based cooling in terms of use of electricity and maintaining thermal comfort in hot and humid climatic conditions.

## 2. Advances in Liquid Desiccant

Most of the research on liquid desiccant cooling systems began in the early 1970s. Due to the advantages of high dehumidification capacities and energy storage, many developments are focused on liquid sorption applications. Different modifications have been proposed in to the basic liquid desiccant cooling cycle for its performance enhancement. Some of the developments include inner cooled dehumidifiers, rotary dehumidifiers, membrane type heat and mass exchangers, and

multistage dehumidifiers. The concept of multistage desiccant dehumidification system is developed [4] by combining multiple dehumidifiers in series as shown in Figure 1. Liquid desiccant solution flows from one dehumidifier to other and for better performance cooling is provided between each stage. This new concept overcomes the disadvantage of single-stage dehumidification system. A double-effect liquid desiccant unit with higher concentration gradients can reduce the energy consumption by about 0.06 quads relative to a conventional system in a commercial building. A compact and novel liquid desiccant cooling system is developed [5], which could be installed on rooftop and this reduces the installation cost of the solar collectors. The schematic of the system is shown in Figure 1. This system requires low flooding rates, which avoid the carry over, high-pressure drop, and other problems associated with liquid desiccant dehumidifier requiring high flooding rates. This system has higher COP and produces greater cooling effects with dry air.

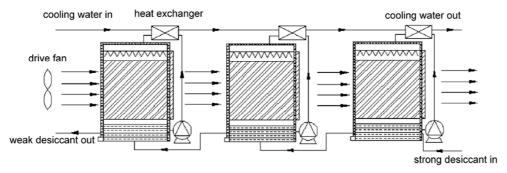


Figure 1. Multistage dehumidifier.

Desiccants use equipments similar to those in chemical industries for liquid gas interactions (e.g. packed beds, spray towers and falling film columns). But these should be designed to handle large process air and low desiccant flow rates. An important consideration in the design of contacting

equipments is that the air pressure drop through the absorber should be as small as possible, while providing large surface areas per unit volume for contact between air and the desiccant. The carryover of desiccant with the air stream is a problem in liquid systems, partly due to drift and to vaporization of some solutions at high temperatures, although there are some systems that claim for zero carryover. In a dehumidification system as shown in Figure 2, the absorber and regenerator are generally linked through a liquid-toliquid heat exchanger to reduce the regenerator residual heat to the conditioner. It pre-cools the warm concentrated solution transferred to the conditioner using the cool dilute desiccant from the outlet of the conditioner. This improves the dehumidifier performance and reduces the heat input to regenerator by 10-15%, thus improving the thermal efficiency of the system. Further improvements are possible by internally cooling the absorber as shown in Figure 2.

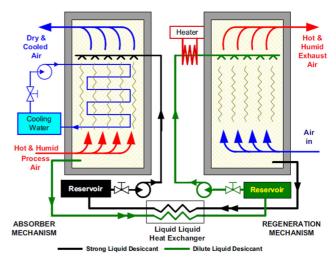


Figure 2. Schematic layout liquid desiccant cooling system.

The performance and development of desiccant cooling systems strongly depends on the used desiccant materials. The thermo-physical properties of these materials affect the performance of the system significantly. The key parameter for the selection of a desiccant material is that it should have the ability to absorb and hold large amount of water vapor. It should be desorbed easily by providing heat input. The properties such as density, vapor pressure, etc. of different desiccant materials can be enhanced by mixing two or more materials together. The mixed desiccants are termed as composite desiccants. Many researchers have studied the properties of composite desiccant materials in order to study their effects on dehumidification performance of the system.

Many efforts have been made for research and development of desiccant materials. CaCl2, Li-Br, SrCl2, and NaSO4 are generally used to mix with silica gel and developed a composite desiccant material with desired properties. SiO<sub>2</sub>·xH<sub>2</sub>O·yCaCl<sub>2</sub> developed as a composite desiccant material by mixing CaCl<sub>2</sub> and silica gel and studied mixture ratio and pore structure. Along with other enhancement, it was found that material can be regenerated in the range of 60-80°C. A composite of silica gel-CaCl<sub>2</sub> and LiCl (lithium chloride) investigated and found that the moisture removal capacity of composite desiccant material has been enhanced and regeneration temperature is lowered. Further, the liquid desiccants should have low vapor pressure, low viscosity and good heat transfer characteristics. The surface tension of liquid desiccant is also important as it directly influences static holdup and wetting of desiccant air contact surface.

## 3. A hybrid Liquid Desiccant Cooling

Desiccant cooling systems are now being successfully incorporated into commercial air-conditioning (HVAC) systems. They are being used either as stand alone units or hybrid units in conjunction with vapor compression systems (VCS) or vapor absorption systems (VAS), the hybrid ones being more in use. Figure 3 shows a hybrid system where the solution chilled by a VCS is passed through the absorber to simultaneously cool and dehumidify the air. In contrast, a hybrid solid desiccant system has to first dehumidify the air in a desiccant wheel and then cool it in a cooling coil. In both the cases the required chemical dehumidification would be less than the stand alone DCS, as no further moisture needs to be added (in an evaporative cooler) to achieve cooling. Further, as the cooling coil is maintained at higher apparatus dew point (ADP) than a stand alone VCS, the overall COP is also high. Waste heat from condenser may also be used for regeneration (part or full) of desiccant. So, considerable energy savings can be achieved by using these systems instead of conventional systems using refrigerated coils alone, especially for high latent load and low humidity applications. Many studies have been carried out using renewable energy sources especially solar energy [18] that tends to increase the energy savings while also increasing the complexity and cost of the unit.

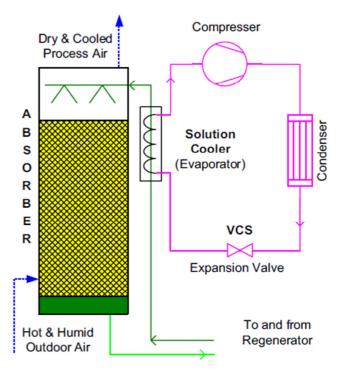


Figure 3. Liquid desiccant VCR hybrid cooling.

## 4. A Solar Powered Liquid Desiccant Cooling

The heat energy is used as input energy source in the regenerator of liquid desiccant cooling system; this heat can come from different sources such as solar [19-22], biomass waste heat, or other low-grade energy source. The amount of required energy input is a very important parameter as it will define the size of regenerator and overall performance of the system. Several investigations had been carried out for the regeneration of liquid desiccant cooling systems. The regenerator with packed bed configuration is mostly used for regeneration of liquid desiccant solution. These operate similar to packed bed dehumidifier but packed media is flooded with hot desiccant solution with air flowing across or through the packed bed. In this way water is taken by the flowing air and regenerated desiccant solution can be used in dehumidifier again. As of packed bed dehumidifier, a packed bed regenerator also requires high-flow rate of desiccant solution. This will require high pumping power, which correspondingly reduces the overall performance of the system. The high-flow rate will also cause droplet carry over. To overcome this limitation, an internally heated regenerator can be used instead of packed bed regenerator. Internally heated regenerator reduces the pumping power and overcome the problem of desiccant carry over. A liquid desiccant cooling system, can also utilize freely available low-grade

solar energy effectively. The system was called as dehumidifier–evaporator–regenerator cycle and is shown in Figure 4. It operates at atmospheric pressure. The results of simulation show that with a cooling capacity of 21.5 kW, the system can achieve a COP of 0.43.

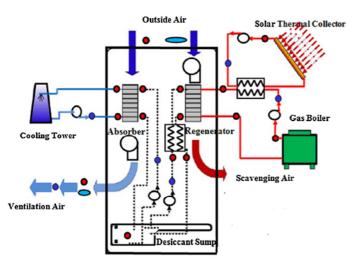


Figure 4. Solar powered liquid desiccant cooling.

### 5. Future Needs

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:

- 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.

Research and development of liquid desiccant cooling system 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.

## 6. Conclusions

The present study depicts the progress related to the liquid desiccant cooling technology along with its advantages offered by this innovative cooling technology. For better understanding the basic working principle has been discussed. The main things can be summarized as follows:

- The liquid desiccant materials have low viscosity, which reduces the required pumping. Low regeneration temperature makes these materials more suitable for the application of low-grade energy resources.
- 2. The carryover is the problem faced in liquid desiccant cooling system in past. Different developments have been made to overcome this problem such as the use of rotary liquid desiccant dehumidifier, membrane heat exchanger, inner cooled dehumidifier, and multistage dehumidification.
- 3. Different composite desiccant materials have also been develop to overcome their corrosive nature and to obtain desired sorption properties.
- 4. As liquid desiccant cooling has the ability to control latent and sensible load independently, different advancements have been made in cooling unit used for the control of sensible load. Such as the development of evaporative coolers. Indirect evaporative coolers have been introduced, which cool the air without adding moisture to it.

The use of solar energy as input heat source is a successful option for this technology as cooling load demand follows the same profile as solar radiation. Different hybrid combination of liquid desiccant with conventional cooling systems such as vapor compression has been developed recently. More research should be conducted on other innovative hybrid liquid desiccant cooling systems integration, taking into consideration the associated investment costs. The development in liquid desiccant technology is in progress 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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