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An Overview on Role of Desiccant Cooling on Human Health

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Abstract

High humidity level of the indoor moist air has adverse effect on human health as it perceived indoor air quality (IOQ). Its major threat is observed as sensory irritation in eyes and respiratory systems due to drastic reduction in humidity sometimes due to overcooling. This overview has reviewed many literatures containing desiccant based alternative cooling as option to vapor compression based traditional cooling in maintaining efficient control over indoor humidity the effects of extended exposure to humidity on perceived IAQ over human health, sensory irritation symptoms in eyes and airways, work performance, sleep quality, virus survival, and voice disruption. As efficient control humidity may positively impact perceived IAQ, eye symptomatology, and possibly human health issues in the hospital mild environment. Amelioration in indoor air humidity level appears to reduce nasal symptoms in patients suffering from obstructive apnea syndrome, while no clear improvement on voice production has been identified, except for those with vocal fatigue. Both either low or high moisture content and perhaps even better relative humidity in range 50-60% prevents the transmission and survival of influenza virus and other bacterial growth in many studies. Maintenance of indoor humidity in above range as one of the IAQ parameter appears to reflect different perceptions among other odour, dustiness and possibly exacerbated by desiccation effect of low air humidity.

Keywords

Desiccant Cooling, Desiccant Dehumidification, Human Health, Humidity Control

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1. Introduction

When indoor air humidity increases it have adverse effect on human health so humidity is an important parameter both in the industrial and residential environment. Moreover, exceptional high value of moisture in indoor air can affect indoor air quality (IAQ) in indoor environments [1-2]. Further to this, causation of perceived sensory reactions ineyes and respiratory system, among top-two reported symptoms, continue to be a puzzle to solve, despite several identified risk factors that influencethe development of eye symptoms have been identified; the risks of symptoms in the upper airways remainlargely unexplained. Furthermore, there is an increasing recognition ofthe impact of humidity, e.g. on virus survival, growth and transmission as well assleep quality, regarding derivation of a safe limit for indoor air humidity. Thus, there is a need for to control theimpact of indoor air humidity on associated health effects as opposed tothe well-known problems associated with moisture-damaged buildings as pointed out the relationshipbetween health, indoor air humidity and pollution is complex and remainsa challenge. Thus, thefocus of this overview is effects in the public domain of perceived IAQ, sensory irritation in eyes and airways, work performance, infection byvirus, sleep quality, and the voice [3].

HVAC (Heating, ventilation and air conditioning) systems

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are used to create a human thermal comfort inside residential and industrial buildings. However, they contribute to a large portion of overall final energy consumption: for example, around 50% of building final energy consumption and 20% of total energy consumption in the United States. This places a strain on the electricity network as well as indirectly contributing to environmental problems such as ozone-layer depletion, air pollution and climate change. Desiccant-based air-conditioning systems can reduce these negative effects, because they can be driven by waste heat, such as the heat discharged from distributed power generation, various co-generators and solar thermal collectors. As such, they require a much smaller amount of electricity to operate. In addition, they do not use chlorofluorocarbon refrigerants, and so do not harm the environment. It is found that the desiccant based dehumidification and cooling technology is still in the early stage of development, since many of the installed systems did not achieve the expected energy savings. Hence, further effort is required to improve overall efficiency. The desiccant component of desiccant-based air-conditioning systems may be based around a liquid-desiccant heat exchanger or a solid-desiccant rotary wheel. Solid-desiccant systems have several advantages over liquid-desiccant systems. These include avoiding potential desiccant loss and contamination of the building supply air due to the carryover of desiccant sorbent into the air streams, and avoiding corrosion issues that arise when using liquid desiccant. Disadvantages of solid-desiccant systems include the need for rotating air seals and the higher temperature of regeneration air. In an air-conditioning system, the desiccant component performs latent cooling, while different combinations of direct evaporative coolers, indirect evaporative coolers, chiller coils or heat recovery devices perform the sensible cooling. Additional components may be present and several different operating cycles are possible [4-9].

A review of selected literature reveals that many investigations into improving the performance of desiccant based air-conditioning systems have been conducted since the 1970s. These include three different desiccant cooling cycles: the ventilation cycle, the recirculation cycle and the Dunkle cycle, which were analysed in. The results revealed that the coefficient of performance (COP) could be improved further by strengthening the performance of the dehumidifier. Two more desiccant cooling cycles were investigated, which were a simplified, advanced, solid desiccant cycle and a direct-indirect, evaporative cooling cycle with a COP higher than 2.0. The feasibility of combining desiccant cooling systems with conventional air-conditioning systems was analysed, which revealed that a desiccant driven by low temperature regeneration air was the key to improving the system's energy performance. In addition to system studies, researchers have also investigated individual components, especially desiccant dehumidifiers. For example, modelling studies of the desiccant wheel used the effectiveness-NTU (number of transfer units) method to predict the moisture removal performance of the desiccant wheel with a high accuracy. Structural studies of the wheel reduced the energy consumed by fans and blowers due to the decrease of drop pressure achieved by redesigning the traditional honeycomb matrix structure; the temperature of the regeneration air for desorption was also reduced. Operating condition studies revealed that wheel rotation speed could significantly influence the performance of the wheel, and that the optimal rotational speed to maximise dehumidification effectiveness depends on the operating conditions. Optimisation studies to improve the dehumidification performance of the desiccant wheel adopted a model predictive control strategy to set a maximum moisture removal capacity for the desiccant wheel. Studies of the heat source used to make regeneration air for the desiccant wheel showed that regeneration air could be made using thermal energy from a micro-cogenerator with a temperature of less than 70°C, while involved heating regeneration air using a solar hot water system [10-11].

The above studies mainly focused on two aspects: (i) improving the efficiency of system (especially for the low temperature of regeneration air), and (ii) improving the dehumidification capacity of the desiccant wheel. Recently, researchers have begun to focus on improving the dehumidification performance of the desiccant component by targeting an isothermal, rather than adiabatic, dehumidification process. An isothermal process has the added benefit of reducing the sensible load on the downstream evaporative components. Some researchers have paid attention to internally cooled, liquid desiccant- based devices to achieve an isothermal dehumidification processes. For example, a one-dimensional numerical model was adopted to analyze the performance of the internally cooled liquid desiccant–air contact units, with the results proving that the dehumidification capacity could improve due to the isothermal process. Model and experimental studies of an internally cooled/heated dehumidifier/ regenerator of liquid desiccant systems used an internally cooled dehumidifier and internally-heated regenerator. Those studies showed that avoiding the adiabatic dehumidification process could offer higher regeneration efficiency for the dehumidifier. Other researchers have focused on the two-stage rotary desiccant cooling system to achieve an isothermal dehumidification process [12-13].

The present review explains the role of desiccant cooling as a green air conditioning technology to provide the fresh air for maintaining required indoor thermal comfort for human hygiene.

2. Effect of Humidity Variations on Human Health

Over the last few decades, the quality of air in indoorenvironments such as houses, apartments, and offices hasbeen extensively investigated both for residential as well as various industrial applications. Field studies have frequentlyfound undesirably high levels of known respiratoryirritants such as nitrogen and sulphur dioxides, hydrocarbons and other particulates which come into existence due to the pollution in airdue to automobiles and known or suspectedcarcinogens such as asbestos, radon, some particulates and formaldehyde etc due to pollution created by industrial waste. In many cases, high indoor levelsof contaminants have been traced to indoor building materials, furnishings, appliances, and human activities [14]. Indoorcontaminant levels can also be exacerbated in tightlysealed energy conserving buildings with minor fresh airventilation rates. Either lowering the sources of pollutantsor increasing ventilation rates, or both, can be usedto reduce or eliminate the levels of these contaminants. Water vapor, usually measured as relative humidity orthe percentage of water vapor held by the air comparedto the saturation level, is not usually considered to be anindoor contaminant or a cause of health problems. In fact, some level of humidity is necessary for comfort. On theother hand, the relative humidity of indoor environments (over the range of normal indoor temperatures of 20 to26°C, has both direct and indirect effects on health andcomfort. The direct effects are the result of the effect ofrelative humidity on physiological processes, whereas theindirect effects result from the impact of humidity onpathogenic organisms or chemicals. This review is primarily concerned with the indirecthealth effects of relative humidity, which are more complexthan the direct health effects and of greater publichealth significance. However, it is worthwhile to brieflydiscuss some of the direct health effects, as these effectsoften lead to solutions such as dehumidification carried out by the desiccant cooling which mayin turn indirectly affect health [15-16].

Both extremely low and high relative humidity may causesome physical discomfort, as the relative humidity of theair directly affects temperature perception. Very low levelabout below 20% RH may alsocause eye irritation and moderate to high levels ofhumidity reduce the severity ofasthma. Several reports, apparently based on theexperience of physicians with patients who complained ofdryness of the nose and throat during extremely lower relative humidity, have also argued that indoor relative humidity should be kept above 40 to 50% in order to prevent dryingof the mucous membranes and to maintain adequate nasalmucus transport and ciliary activity in human body. These knownor suspected adverse effects of low relative humidity haveled to the widespread use of humidifiers in areas wherecold winters lead to low indoor humidity. Relative humidity also has an important adverse directeffect on health when high humidityis combined withhigh temperatures. This combination reduces the rate ofevaporative cooling of the body and can cause considerablediscomfort due to excessive perspirationand so lead to heat stroke, exhaustion, andpossibly death. Case reports and epidemiological studies reveal thatrelative humidity and humidification equipment can indirectlyaffect the incidence of allergies and infectiousof both relative humidity and humidification equipmenton the population growth and survival of infectious orallergenic organisms such as fungi, protozoans, mites, bacteria and viruses, as well as the probability of effectivecontact (exposure that results in disease or adversesymptoms) with indoor spreading of these organisms in hospitals and houses. These indirect effectsmay partially account for the suspected relationship betweenrespiratory infections and nose or throat irritationand relative humidity In addition, relative humidity affectsthe concentration of noxious chemicals in the air byaltering the rate of offgassing from building materialsand by the reaction of water vapor with chemicals in theair [17]. A review of the available data on the indirect healtheffects of relative humidity shows that these effects donot uniformly increase or decrease in frequency or severitywith a change in relative humidity Instead, for agiven relative humidity, some adverse health effects canbe at a maximum while others are at a minimum [18]. Therelative humidity range for minimizing as many adversehealth effects as possible appears to lie between 35 and50%. The evidence to support this optimum relative humidityrange is presented below Figure 1.

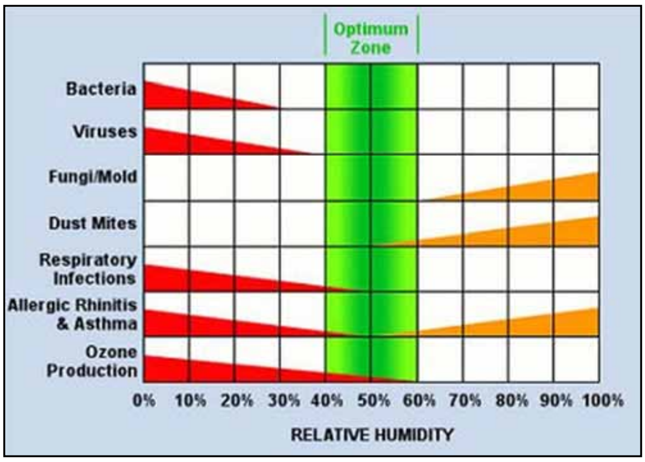

Figure 1. Optimal range of relative humidity for better human health.

3. Use of Desiccant Cooling for Effective Humidity Control

The demand for cooling and air conditioning increasing day by day in the present years due to major climatic change in the atmosphere owing to global warming worldwide. Rise in cooling demand mainly responsible for the substantial energy consumption in high quantity has been recorded. Desiccant cooling system is the best alternative to vapor compression based traditional HVAC system as it provides better indoor air quality and thermal comfort with the minimum consumption of energy by making use of renewable solar energy or industrial waste heat. It is also highlighted in many previous investigations that the desiccant based dehumidification and cooling has proven its feasibility in efficient energy utilization and cost saving in particularly hot and humid ambient conditions. Desiccant cooling system could possibly replace other conventionally used comfort cooling systems such as traditional vapour compression air conditioning system or the evaporative cooling especially in hot and humid climatic conditions [19-20].

With the rapid growth of economy and society, our modern life style and industry consume large amounts of energy for cooling the residential and industrial buildings. According to the latest statistics, energy consumption in air conditioning is estimated to 47% of the whole civil and commercial buildings. Meanwhile, the depletion of fossil fuels and the threat of global warming over the last decades have challenged air conditioning industry to develop new cooling technologies to assist or even replace the conventional air conditioning systems based on VCR. Therefore, numerous alternative cooling technologies have been developed to substitute conventional VC systems, and desiccant cooling is one of them. Compared with other systems, desiccant cooling systems have several significant merits:

1. Desiccant cooling systems can be operated by use of low grade thermal energy sources like solar energy [21].
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 which is available directly from the sun. The cost, efficiency, and durability of a desiccant cooling/dehumidification system depend on those of the components used in the system. The desiccant dehumidifier is a major component in the system. After several years of research, it is well understood that the performance of a desiccant dehumidifier depends strongly on the properties of its desiccant and the geometry of the matrix. Usually, micro porous silica gel has been used as the research baseline desiccant for solar-regenerated desiccant cooling applications. Lithium chloride impregnated wheels, commercially available dehumidifiers, have been used in desiccant cooling systems. Advanced dehumidifiers for desiccant cooling applications should have parallel passage geometries, such as parallel plate or corrugated to be compact and efficient with low pressure drops [22-27].

To the authors' knowledge, there is rare comprehensive summary of these newly developed solid desiccant materials (Figure 2). A type of arrangement is made in which solid desiccants such as silica-gel, molecular sieve etc. are packed to form a sort of adsorbent beds exposed to the incoming air stream which takes up its moisture. The beds are periodically moved in the direction of the regeneration air stream and then returned to the process air stream as shown in Figure 3. Liquid desiccants are often sprayed into air streams or wetted onto contact surfaces to absorb water vapor from the incoming air which latterly like the solid desiccants, regenerated in a regenerator where water vapours previously absorbed is evaporated out from it by heating. To eliminate the overcooling and the reheat, the desiccants can also be coupled with the traditional air conditioning system, thus reducing the equipment size and their costs. Their most frequent use remains, however, their employ with the evaporative cooling. Indeed, the evaporative cooling is the oldest technique of cooling. The desiccant cooling is found more efficient than the conveniently operated conventional air conditioningsubsequent technology has suppressed this old technique. But due to the energy costs and the concerns related toenvironmental harms engendered by the refrigerants used inthis system, the researchers began looking back at the oldcooling technique and trying to solve their main drawbacks. These techniques mainly drawbacks due to the operatinginefficiency in very humid climate, and even for the tropicaland dry climate, their seasonal operating inefficiency (evenin tropical climates, they become inefficient in rainyseasons). Desiccant cooling emerged as a solution to thisproblem. By dehumidifying the incoming air forcing itthrough the desiccants, the evaporative cooler can achievegreater efficiency rather on the dry air stream [28-30].

The conventional air dehumidification methods include moisture condensing method, desiccant-wheel method, and liquid-desiccant method. Among them, the moisture-condensing method, the majority, removes the moisture in the air through the condensation, which is achieved by reducing the air temperature below its dew point temperature (overcooling) and then the cold and dry air is reheated to an acceptable supply temperature. However, this approach inevitably causes energy waste due to overcooling and reheating, and bacteria and mold growth on the cooling coils due to condensate water. The desiccant-wheel as dehumidifier in solid desiccant cooling system consists of solid desiccants such as silica gels, zeolites, and others to directly adsorb water vapor from the air into the small pores inside the desiccant medium. Based on this principle, the desiccant-wheel system can regulate air temperature and humidity separately. Thus, the desiccant-wheel system has an extensive conditioning systems are eliminated. These not only save electricity but also reduce the size of the system if waste energy and solar energy can be used. According to the literature, the solid desiccant regeneration temperature was around 60–100°C. However, the regeneration temperature of the solid desiccant can be relatively higher for sufficient and faster dehumidification [31-33].

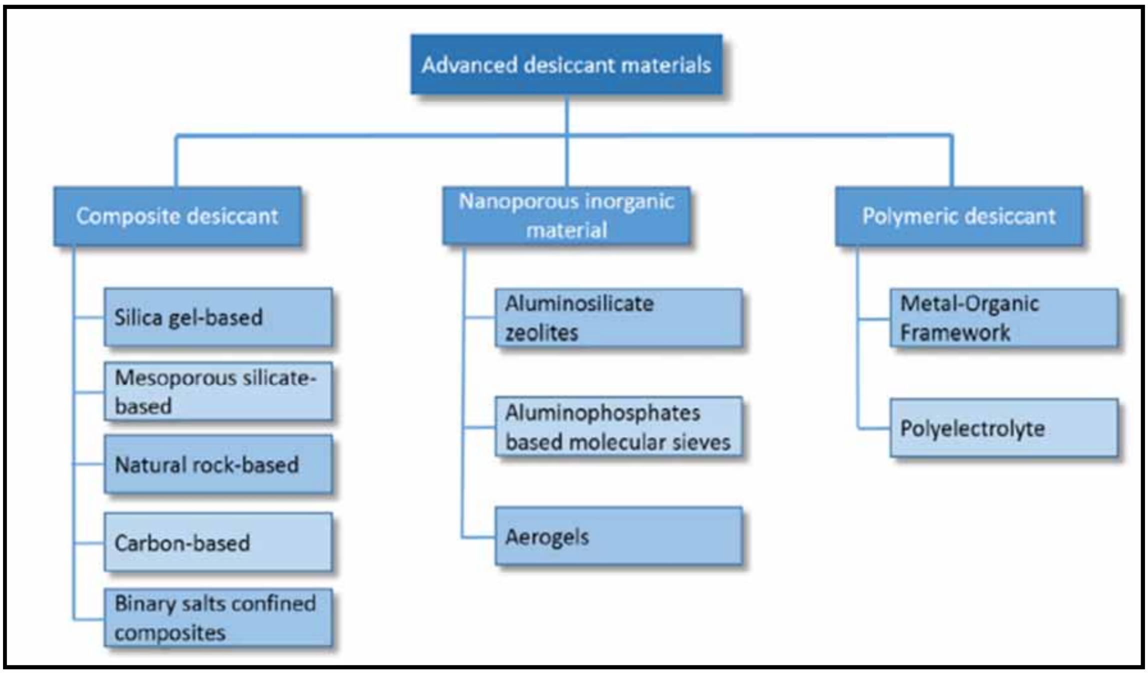

Figure 2. Classification of desiccant materials used in desiccant cooling.

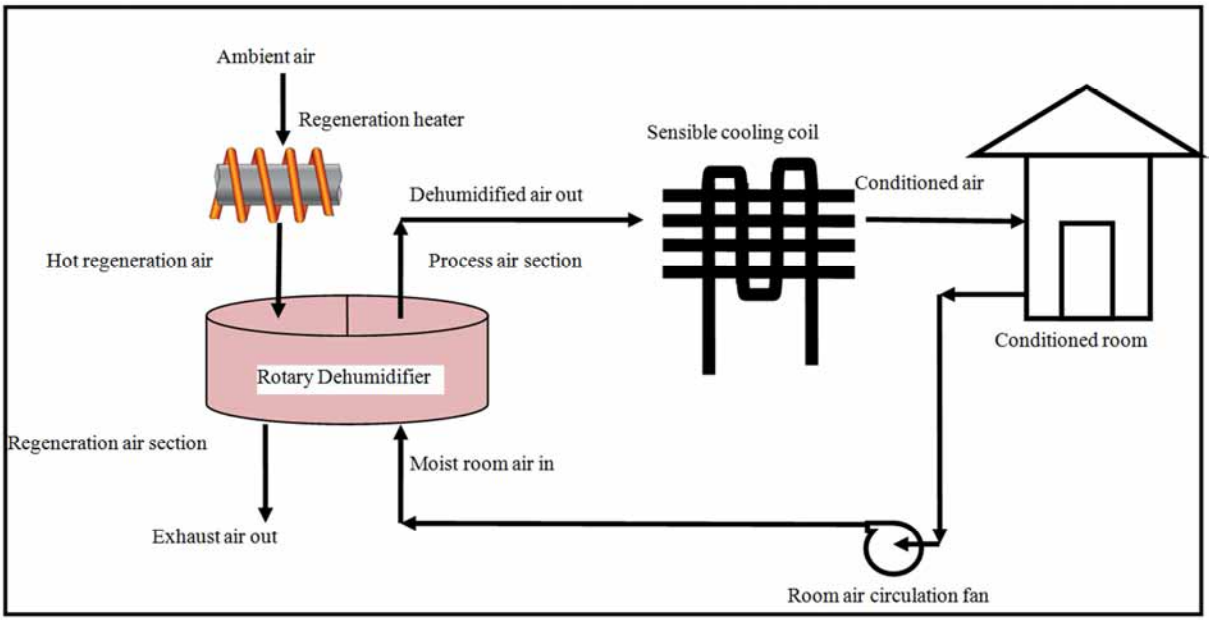

Figure 3. Working of desiccant cooling system.

Liquid desiccant cooling technology have many advantages over the 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 [34]. This benefit of liquid desiccant cooling can advantageous to many industries such as medicines, food storage, laboratories etc. Merits and limitations of liquid desiccant coolingsummarized 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.

4. Role of Desiccant Material in Effective Dehumidification

In general, the bulk of a rotary desiccant wheel dehumidification system is a cylindrical rotary wheel, which is obtained by rolling up the corrugated porous fiber sheet coated with desiccant. During the forming process of the corrugated porous fiber sheet, two pieces of long flat porous fiber sheets are prepared. One piece of flat porous fiber sheet is processed to corrugated shape in a corrugating machine. Then it is bonded to the other crude one to maintain the corrugated shape. In the cylindrical rotary wheel, a large number of parallel channels are obtained, and the cross section shape of single air channel is a sinusoidal shape, as shown in Figure 4. Usually, the main raw materials used as substrate are porous ceramic fiber paper and glass fiber paper. In the rotary desiccant wheel dehumidification system, when the process air or regeneration air passes through the air channels of desiccant wheel, they will conduct heat and mass exchange with the desiccant and substrate. So the dehumidification and regeneration efficiency of the desiccant wheel are affected by the performance of the heat and mass transfer in the air channels. To get deep insight into dehumidification performance of desiccant wheel, single air channel should be selected as an object [35-36].

From the earlier researches, it can be seen that cross-section shape of air channel in a conventional desiccant wheel is usually sinusoidal, and thermo-physical property of substrate materials has a great effect on the dehumidification performance of desiccant wheel. Some researchers have attempted to study the effect of various cross-section shapes of air channel and substrate materials on the dehumidification performance. Because of desiccant wheel having a requirement for suppleness of substrate materials, non-rotary solid desiccant dehumidification systems are selected as an alternative [37].

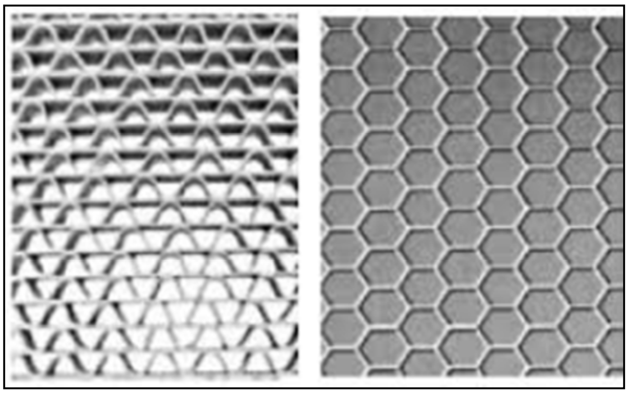

Figure 4. Geometry of desiccant material in rotary dehumidifier.

The liquid desiccant cooling use component similar to those in solid desiccant cooling but it operates on desiccant in liquid state (e.g. packed beds, spray towers and falling film columns). These should be designed to handle large process air and low desiccant flow rates. An important consideration in the design of contactingequipments 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 5 the absorber and regenerator are generally linked through a liquid-to-liquid 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 12-17% [38], thus improving the thermal efficiency of the system. Further improvements are possible by internally cooling the absorber.

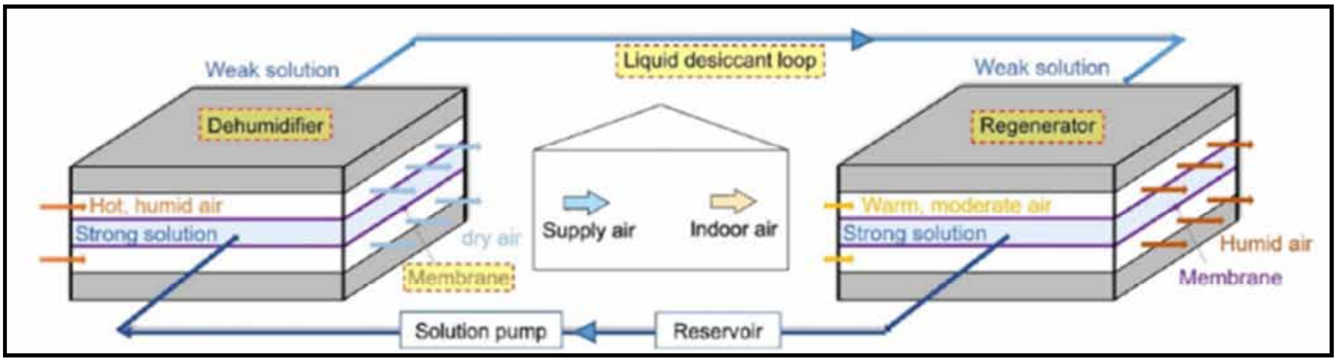

Figure 5. Liquid desiccant loop.

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 [39-40]. 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.

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 [41-42]. 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. Odour less.
8. Stable.
9. Inexpensive.

5. 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 [43-48]. 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.

6. Conclusions

The adverse health effects of higher relative humidity concentration may begrowing in importance as a result of the continuing constructionof energy efficient sealed buildings cooling and efficient moisture control with lowfresh air ventilation rates. The high fresh air ventilationrates found in older leaky buildings may dilute the concentrationof pathogens, allergens and noxious chemicalsin the indoor air and thus offset some of the health problemsassociated with relative humidity In contrast, energy-conserving buildings require the careful maintenanceof good indoor air quality through maintaining, among other factors, optimum relative humidity levels inorder to minimize potential health problems. As conclusion of this overview, the need for a lower limit for longterm indoor air humidityrange can be deduced, but further research is needed to gain deeper knowledge about theeffects of low indoor air humidity. This knowledge will help to save a lot of technicalexpenditure as well as energy for indoor air conditioning. Use of desiccant cooling in maintaining and controlling relative humidity as environmental thermal control 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. 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 to maintain good health.

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