1.1. INTRODUCTION TO DESICCANT COOLING SYSTEMS

Energy conservation has become an area of wide attention due to global energy crisis. Energy consumption of air conditioning systems can be reduced with the application of desiccant based cooling technology. This technology improves indoor air quality and develops environment friendly systems. It provides a tool for monitoring humidity levels for conditioned air places as discussed in Bhatia (2000). Air is dehumidified in desiccant systems in coincidence with conventional air conditioning systems. Desiccant materials are used in desiccant cooling systems to attract the moisture due to vapour pressure difference between air and desiccant solution. People are mostly aware with solid desiccants such as silica gel, activated alumina which are contained within packets in many new products. These desiccants selection are carefully done based on their capability to grasp amount of water, their capability to be regenerated and cost. Desiccant systems contain mainly two processes: dehumidification and regeneration. Vapour pressure of the desiccant is kept lower than the vapour pressure of air passing over it in dehumidification process, therefore, and moisture is absorbed by desiccant materials. In the regeneration process, vapour pressure of the solution is kept more than vapour pressure of the air, hence there is regeneration of the desiccant.

In conventional vapour compression systems, air is cooled below its due point to achieve control of humidity. This method of controlling humidity is ineffective because reheating is required after dehumidification of the air so that air could achieve designed supply temperature before it is to be sent to the conditioned space. The evaporator in the conventional compression system requires working at a lower temperature to fulfill the requirements of latent cooling load. It leads to a lower COP and, therefore, greater energy requirements.

Control of humidity puts an additional load on conventional systems. A number of other techniques are discovered to save high-grade energy. Desiccant
cooling system is one of foremost suitable methods amongst them. Desiccant systems are used efficiently as a complement to conventional vapour compression systems to eliminate latent cooling load. Oberg and Goswami (1998) explained that when humidity and temperature are controlled separately by using desiccant, such system becomes energy saving method and control over humidity is also improved. Desiccant systems are used efficiently as a counterpart to conventional vapour compression based air conditioning systems to eliminate the latent heat of the cooling load. Evaporator in conventional vapour compression system is effective to control the sensible heat load by reducing the temperature of air while latent part of the cooling load is carried by desiccants.

1.2. THERMODYNAMICS OF DESICCANT COOLING TECHNOLOGY

Vapour pressure plays major role in desiccant based cooling systems as shown by figure 1.1. When vapour pressure of air is more than the desiccant solution, the moisture from the air is transferred to the desiccant solution due to vapour difference between air and desiccant solution. This process of transferring moisture from the air to desiccant solution is known as dehumidification.

![Figure 1.1 Vapour pressure versus temperature and water content for desiccant and air (Agarwal et al., 1985)](image)
Vapour pressure of desiccant is increased when moisture is absorbed and its concentration is decreased. Regeneration of the desiccant is required to reactivate it for reuse. When vapour pressure of desiccant is more than the air, moisture from the desiccant is transported to the air and this process is known as regeneration. The moist air is exhausted to the atmosphere and regenerated desiccant is sent back to the absorber for the dehumidification of the air.

1.3. CONVENTIONAL COOLING SYSTEM

The temperature of air is lowered when it passes over a cooling coil in a conventional air conditioning system as explained by Bhatia (2000). The most traditional air conditioner works on the principal of vapour compression refrigeration cycle, known as conventional system. These systems use CFCs/HCFCs as refrigerant and these refrigerants deplete ozone layer. These common systems are based on mechanical closed system where a fixed amount of refrigerant is circulated through evaporator, compressor, condenser and expansion valve as shown in figure 1.2.

![Vapour compression air conditioning system](image)

**Figure 1.2** Vapour compression air conditioning system
In basic operation of vapour compression system, refrigerant enters in the compressor in vapour phase where it is compressed in the compressor, so its temperature as well as pressure becomes high. Then it enters in the condenser which is either water cooled or air cooled, here vapours are cooled and change into the liquid phase. Refrigerant in liquid phase goes through expansion valve where pressure is reduced from condenser to evaporator pressure. As this liquid refrigerant enters the evaporator, it takes heat from the space to be cooled. The refrigerant into vapour state leaves the evaporator and finally it goes to the compressor, thus completing the thermodynamic cycle of simple vapour compression system.

Figure 1.3 Dehumidification and heating Process

Heat load from the air is removed by sensible cooling and latent cooling. Dry bulb temperature of process air is reduced in sensible cooling while moisture is removed the moisture from air during latent cooling. The air is cooled below the dew point temperature in latent cooling. The moisture in air is condensed which perform latent cooling air is carried out below its dew point. The air is then heated to the desired supply air temperature as per design. The whole procedure is demonstrated on the psychometric chart as shown in figure 1.3 and described below.
State 1 to State 2: Moist air is cooled to its dew point temperature.
State 2 to State 3: When air is cooled below its dew point, condensation of the air takes place.
State 3 to State 4: The designed supply temperature of the air is achieved by heating the air.

1.4. TYPES OF DESICCANT DEHUMIDIFICATION SYSTEMS

Air dehumidification is attained by mainly two approaches. Air is cooled below its dew point in first approach as in the case of conventional cooling explained above in section 1.3. Second approach utilizes the principal of sorption by using desiccant materials as explained by Pearson (1993). Desiccants are mainly of two types; liquid desiccant and solid desiccant. Both types of desiccants have great affinity for removing moisture from the air. Heat is released from the desiccant when moisture is removed from the air with the application of desiccant. The air is heated and latent part of heat is converted to sensible heat. This hot air is cooled to desired comfort conditions by heat exchangers or evaporative coolers. Desiccant is reactivated by regeneration process utilizing heat from high grade energy source such as waste heat, natural gas, or solar energy.

The desiccant cooling systems are designed on the bases of desiccant materials to achieve the dehumidification of humid air. Moisture is attracted by two processes in desiccant cooling systems. First process is based upon the principal of adsorption in which moisture from the process air is trapped within the desiccant material itself. Solid materials are mainly used in adsorption process. Second process is based on absorption in which moisture is trapped by a chemical process and desiccant felt a chemical change. Different desiccant materials utilized in desiccant cooling systems are CaCl₂, LiBr, TEG, LiCl, silica gel, activated alumina, titanium silicate and blends of two different desiccants. Kinsara et al. (1996) have studied about different properties and types of the desiccant materials. The main types of desiccant cooling systems are:
• Solid desiccant cooling system
• Liquid desiccant cooling system
• Hybrid desiccant cooling system
• Solar based desiccant cooling system

All types of above mentioned desiccant cooling systems are briefly described in the coming sub-sections.

1.4.1. Solid Desiccant Cooling System

Solid form of desiccant is used as desiccant material in such desiccant cooling systems. These cooling systems utilize dual-column packed-bed dehumidifiers for industrial applications. Solid desiccant in the form of rotary wheel is mainly used in these systems as shown in figure 1.4. The process air enters the desiccant wheel from upper half side and gets dehumidified and becomes hot and dry. Reactivation air is supplied to the dehumidifier from the other side as shown in the figure 1.4. Desiccant wheel is rotated and moisture filled part comes into contact with the hot reactivation air hence moisture from the rotary wheel is removed. The dehumidified hot air is cooled to desired temperature using cooling coil.

Figure 1.4 Solid desiccant cooling system (Chengjuna and Yidab, 2011)
1.4.2. **Liquid Desiccant Cooling System**

Figure 1.5 describes the working of liquid desiccant based dehumidification/regeneration system. Two separate towers are used; one as the dehumidifier and second as the regenerator. The process air is dehumidified in the presence of desiccant solution in the dehumidifier while passing through packing material. Desiccant concentration gets lowered and comes as a weak solution. Weak desiccant solution is then passed through a heat exchanger (regenerative in nature) and supplied to the second tower which acts as a regenerator. Regeneration of weak desiccant solution takes place inside the regenerator and its concentration is increased. The process air after the dehumidifier is carried through heat exchangers and evaporative coolers to attain supply conditions.

![Figure 1.5 Liquid desiccant cooling systems](image)

1.4.3. **Hybrid Desiccant Cooling System**

Hybrid type cooling systems consist of two cooling systems as shown in figure 1.6. First cooling system is desiccant cooling system which takes care of the latent cooling load and second is vapour compression based cooling system which handles sensible part of cooling load. Desiccant solution cooled by a vapour compression
based system is supplied to the dehumidifier where cooling as well as dehumidification takes place at same time. The coefficient of performance is high in hybrid cooling systems because cooling coil is retained at greater apparatus dew point. Hybrid cooling systems are energy saving systems because heat released from condenser is used for desiccant regeneration.

Figure 1.6 Hybrid desiccant cooling system (Jain & Bansal, 2007)

1.4.4. Solar Based Desiccant Cooling System

Figure 1.7 shows the working of solar based liquid desiccant system, where solar energy is used for regeneration of the desiccant. These systems are similar to the liquid desiccant cooling systems with solar heaters arrangement for weak desiccant. Researchers (Oberg and Goswami, 1998a; Chengjuna and Yida, 2011) studied solar based desiccant dehumidification system and promised energy saving units.
1.5. BENEFITS OF DESICCANT COOLING TECHNOLOGY

Desiccant cooling technology has a number of benefits comprising less use of high grade energy, utilizing waste heat or renewable energy, no usage of chlorofluorocarbon, and improves quality of indoor air. Bhatia (2000) discussed that when the level of specific humidity is high and better control of the humidity is required, desiccant based technology must be considered. This technology is advantageous to meet high electricity demand during peak hours.

The advantages of desiccant based systems are discussed by Davanagere et al. (1999). Leading advantage is possibility of independent control of humidity and temperature in these systems. Desiccant unit controls humidity and conventional cooling system controls temperature. Operating cost of desiccant cooling system is low as compared with conventional cooling systems because desiccant based systems can use waste heat, natural gas or any other low grade energy.
Desiccant systems are ecofriendly because such systems do not use chlorofluorocarbon and ozone depletion potential is zero. Indoor quality of the air can be improved by using suitable levels of fresh air and reduced levels of air borne bacteria. Chemicals may also be used with liquid desiccants for treatment of air. Desiccant solution in the liquid desiccant cooling system can be pumped easily from one place to another and it is possible to attach numerous small desiccant dehumidifiers to a larger regeneration unit which is especially beneficial in large buildings. Using a liquid desiccant also enables more efficient heat transfer since highly efficient liquid-liquid heat exchanger is employed in liquid desiccant cooling systems.

1.6. APPLICATIONS OF DESICCANT COOLING SYSTEM

Desiccant dehumidification systems have been used effectively for several years in institutional and industrial applications [(Bhatia (2000), Elsarrag (2006)]. Utilization of such systems has also been started for commercial applications. Different areas of applications of desiccant cooling systems are supermarket, ice rinks, hotels, hospitals, offices, theaters and restaurants etc.

This technology will mostly be used in future because of lower cost and improved air quality. The air conditioning mass market needs more perfection in efficiency and reliability, decrease in size of the system and lesser cost. Investments in advance research and development in materials, constituents, and schemes are required which can be justified seeing the potential of the desiccant base cooling systems.

A few of the above mentioned applications of liquid desiccant systems are discussed below:

1.6.1. Supermarket

The conventional air conditioning methods have a tendency to cycle on and off. Due to this reason specific humidity inside the building gets increased and frost is also formed. A conventional air-conditioning system is not able to handles both loads
efficiently. A liquid desiccant dehumidification system is used in supermarkets which controls the humidity independently with decreasing better dry bulb temperature.

### 1.6.2. Hotels and Restaurants

Generally hotels and restaurants have problems of mold, mildew and musty orders in humid seasons. Wallpapers and carpets of hotels and restaurants are removed in the presence of humid air because moisture is stuck on the back faces and origins mold and mildew on these surfaces. Therefore, air humidity should be controlled under 60% specific humidity to evade the development of mold and mildew. The desiccant dehumidification system eliminates the problem of mold, mildew in hotels and restaurants.

### 1.6.3. Ice Rinks

An ice arena has a great deal of humidity, but the cooling coil has to cool below the freezing point. In such environment, desiccant dehumidification plays a major role to improve ice quality by preventing the rust and mildew. It also stops the development of fog in ice rinks.

### 1.6.4. Hospitals

Hospitals require flexible temperature range and humidity controls in operation theaters. The rise in humidity causes condensation on the walls and ceilings, creates potentially hazardous conditions and patient discomfort. Here the liquid desiccant dehumidification technology sustains a fresh, controlled temperature and humidity level for the required comfort. It works as an air scrubber to eliminate and counterbalance air-borne bacteria, viruses, mold and allowing both patients and staff to enjoy clean air and comfort.
1.6.5. **Schools and Theaters**

Classrooms in school’s building struggle with a musty odor and high humidity. Such an environment can be potentially harmful to students and staff. Thus desiccant dehumidification technology controls the odor and high humidity and provides an environment where students and faculty feel additional comfort with dry and clean air.

1.6.6. **Candy and Sugar**

Candy and sugar applications require uniform sugar coating which is affected by the condensation and the presence of moisture in the air. This problem is tackled by desiccant dehumidification technology by eliminating frost and sticking of products to equipment, thus preventing clogged equipment.

1.6.7. **Pharmaceutical Plants**

The pharmaceutical plant's saline compression area required precise, maintained conditions of temperature of about 24°C and relative humidity of about 50% on the production floor. This could be achieved with conventional cooling and dehumidification but that would not be economical. Thus the desiccant dehumidification is a cost-effective solution for the air treatment. It supplies treated air to the compression room and adjacent spaces after mixing it with the bypass air stream. It eliminates the need for special refrigeration to achieve desired humidity. It also helps in utilizing a chemically stable effective biocide which does not vapourize.

1.6.8. **Water Treatment Plants**

Water treatment plants are often affected by condensation, rusting and deterioration of pipe lines, thus insulation of the pipe lines is required to avoid rusting. The desiccant dehumidification technology eliminates condensation, stops rusting and deterioration. Therefore, this technology removes the necessity to insulate piping.
1.6.9. **Plastic Molding**

The plastic molding process requires dehumidification to achieve high productivity and desiccant dehumidification technology is used effectively. It increases production rate, reduces imperfection and rejection rate. It prevents condensation on molds, eradicates corrosion and increase the lifetime of molding apparatus.

1.7. **ORGANIZATION OF THE DISSERTATION**

Chapter 1 briefs the introduction to the desiccant cooling system with its types, benefits and applications. Thermodynamics of the desiccant cooling system is also given in this chapter.

Chapter 2 describes the literature review of different liquid desiccants and packing materials used by researchers in desiccant cooling systems. A brief study on the performance parameters of the desiccant cooling system is presented with the review of different experimental and simulation studies on the absorber and regenerator. Based upon the conclusive remarks of literature survey, looking the unexplored gap, a suitable combination of desiccant & packing material and flow of the air & desiccant solution have been identified. Correspondingly problem formulation and objectives of the current research work have been devised.

To fulfill the objectives of the current research work, an experimental set-up has been fabricated, whose complete details are given in chapter 4. As detailed methodology, experimental set up working for the dehumidification of the air in the absorber and regeneration of the desiccant in the regenerator is explained in the chapter with specifications of measuring instruments and details of components.

Experimental observations and results of the absorber and regenerator are discussed in chapter 5. The effect of each inlet parameter on the outlet and performance parameters for both main components are presented in graphical form and relevant discussion is provided. Current experimental results are compared with the results available in the literature at the end of this chapter.

Chapter 6 describes a simple mathematical model for the preliminary design of an air dehumidification and regeneration processes have been developed. Taking
control volumes of the absorber and the regenerator, mass and energy balance equations have been derived for both the components. Simulations of the absorber and regenerator have been carried out with Warner technique and simulated results are compared with experimental results. Deviation among predicted and experimental variations is also mentioned at the end of the chapter.

The major conclusions emerging from the present work have been summarized in the chapter 7 of the dissertation and a few suggestions for future scope of the research in this field have also been proposed.