

## Fabrication of Falling Film Liquid Desiccant Air-Conditioning System

Sasapu Venkatesh\*, Rohit Babu V, Bhargav N, Rajesh A, Rambabu M, Handrakanth and Raja Naveen P

Department of Mechanical Engineering, Kaushik College of Engineering, Affiliated To J.N.T.U Kakinada, Visakhapatnam, Andhra Pradesh, India

### Abstract

Increasing of occupant comfort demands are leading to rising requirement for air conditioning, but deteriorating global energy and environment crisis are starving for energy saving and environmental protection. The need to come up with the new energy saving as well as environmental friendly air conditioning systems has been more urgent than ever before.

In hot and humid areas, the liquid desiccant air-conditioning systems based on evaporative cooling was proposed as an alternative to the traditional vapor compression systems due to its advantage in, removing the air latent load, friendly to environment, removing of pollutants from the process air and reduction of the electrical energy. In this project, recent researches and development activities in liquid desiccant dehumidification systems combined with evaporative cooling technologies are surveyed.

Following that, such a liquid dehumidifier is fabricated. In this system,  $\text{CaCl}_2$  salt solution is used for dehumidification of air. Strong solution is internally cooled to minimize heating up of the solution which causes reduction in its absorbing capacity. Evaporative cooling that follows is more effective because dehumidified air flows over cooling water spray. Weak solution is regenerated by an electric heater. Finally air gets cooled and dehumidified. Heating for regeneration can be done using any cheap heat source like waste heat, solar energy.

Direct evaporative cooling gives good effect in dry areas. Its effectiveness is not much in humid areas. To be suitable for such high humidity conditions in this system air is dried first, using  $\text{CaCl}_2$  salt solution. Heat is generated during dehumidification. Cooling water is circulated to absorb this heat. Evaporative cooler also cools the salt solution after it got regenerated by heating.

**Keywords:** Fabrication; Air-conditioning system; Falling film; Liquid dehumidifier; Solar energy; Condenses; Surface, Pump

### Nomenclature

#### Abbreviations

VC: Vapor Compression;

ARI: Air-conditioning and Refrigeration Institute;

COP: Coefficient of Performance;

HVAC: Heating, Ventilation and Air-conditioning;

HX: Heat Exchanger;

RH: Relative Humidity;

WBT: Wet Bulb Temperature [ $^{\circ}\text{C}$ ];

DBT: Dry Bulb Temperature [ $^{\circ}\text{C}$ ]

#### 3.2 Symbols

$m_s$ : Mass flow [kg/min]

$h$ : Specific enthalpy [kJ/kg]

$C_p$ : Specific heat [kJ/kg K]

### Introduction

Liquid desiccants are solutions that have a high affinity for water vapor. This property is the key to creating cooling systems that dehumidify air without over-cooling [1]. Since the 1930s, liquid desiccants have been used in industrial dehumidifiers. The liquid desiccants used in these systems commonly are very strong solutions of the ionic salts lithium chloride and calcium chloride. These ionic salts have the attractive characteristic that the salts themselves have essential zero vapor pressure, and so vapors of the desiccant will not

appear in the air supplied by the liquid desiccant air conditioning. However, zero vapor pressure comes with a price: as with seawater (a chemically similar salt solution), solutions of lithium and calcium chloride are very corrosive. This corrosiveness requires that all wetted parts within the liquid desiccant air conditioning be protected and that no droplets of desiccant are entrained by the supply air.

A desiccant has the ability to dry air without cooling because it forms a relatively strong bond with water molecules (i.e., a stronger bond than that between molecules in pure liquid water). Whereas the heat released when water condenses (i.e., the latent heat of condensation) is approximately 1,000 Btu/lb, more heat typically an additional 50 to 100 Btu/lb will be released when water vapor "condenses" into a liquid desiccant due to the stronger bonds between the molecules [2].

At this point it is important to recognize that a desiccant's ability to dry air decreases as its temperature increases. If a 43% solution of lithium chloride at 80 F were to absorb an amount of water vapor that diluted it to 42%, its temperature would increase to 123 F (assuming the desiccant is not cooled). Whereas the desiccant initially could dry air to 23.2 grains, after increasing in temperature and becoming slightly more dilute its ability to dry air decreases dramatically to 107.6 grains. Most of this loss in drying potential is caused by the increase in temperature:

\*Corresponding author: Venkatesh S, Department of Mechanical Engineering, Kaushik College of Engineering, Affiliated to J.N.T.U Kakinada, Visakhapatnam, Andhra Pradesh, India, Tel: 08977442595; E-mail: [sasapuvnkatesh@gmail.com](mailto:sasapuvnkatesh@gmail.com)

Received June 30, 2016; Accepted July 18, 2016; Published July 30, 2016

Citation: Venkatesh S, Rohit Babu V, Bhargav N, Rajesh A, Rambabu M, et al. (2016) Fabrication of Falling Film Liquid Desiccant Air-Conditioning System. Fluid Mech Open Acc 3: 130.

Copyright: © 2016 Venkatesh S, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

if cooled back to 80 F, the 42% solution of lithium chloride would dry air to 25.7 grains.

One approach to limiting the impact of the heat released when the desiccant absorbs water vapor is to flow desiccant at a sufficiently high rate that its temperature rise is limited (i.e., in the preceding example, if the desiccant's concentration changed only 0.1 point, its temperature would rise only be 4 F). This approach, which was first used in the liquid-desiccant systems of the 1930s and is still used in many liquid desiccant air conditioning s today, requires that the liquid desiccant is first cooled before it is delivered to the top of a bed of porous contact media. The air that is to be dried then comes in direct contact with the liquid desiccant as the air is drawn through the porous bed. Typically, a ratio of the desiccant-to-air mass flow ratio that is on the order of one will limit the temperature rise of the desiccant [3].

Dehumidifier, regenerator and evaporator are the main components of liquid desiccant air cooling system. The most common technology today for the dehumidifier and regenerator is the packed bed. However, packed beds must work under high desiccant-flow rates to achieve good dehumidification without internal cooling. The main role of the desiccant is to attract water vapor from air; thus, it can be classified as both solid and liquid desiccant. Several types of solid materials can hold off water vapor, e.g., silica, polymers, zeolites, alumina, hydra table salts, and mixtures. Other available liquid desiccants are calcium chloride, lithium chloride, lithium bromide, tri-ethylene glycol, and a mixture of 50% calcium chloride and 50% lithium chloride. These liquid desiccants have common general properties, but their requirements cannot be fully addressed by any single desiccant. These requirements include low vapor pressure, low crystallization point, high density, low viscosity, low regeneration temperature, and low cost. The air is dehumidified by being brought into contact with strong liquid or solid desiccant, after this to provide sensible cooling to dehumidification process, traditional vapor compression, and vapor absorption, direct or indirect evaporative cooler units used. When the solution is weakened by absorption of moisture, it sends direct to regeneration process to release the moisture by using an external heat resources. This is called "reactivating" the desiccant [4]. Thermal energy, at a temperature as low as 40–50°C required for regenerating of the liquid desiccant can efficiently obtained using a heater (Figure 1).

## Literature Review

### Background

Desiccant dehumidification has been studied extensively during the past several years as a way to dramatically reduce energy consumption of a vapor compression cooling cycle. In this type of system, the water vapor is removed from the air as it is routed to the evaporator in an

effort to reduce the cooling load on the air conditioning system. This modified air conditioning cycle, known as a hybrid cooling system , has been shown to help in-crease the coefficient of performance (COP) of the cycle while reducing evaporator and condenser sizes. Analysis of a hybrid system has revealed that the compressor power consumption can be reduced by 25% with an evaporation and condensation area reduction of 34% as compared to a standard vapor compression cycle. Two types of liquid desiccant structures have been studied. The first involves a packed bed design first proposed by Lof in 1955 using a triethylene glycol solution as the desiccant. This design incorporates a porous packing material, sprinklers, and a solution pump. The concentrated liquid desiccant is sprayed over the packing material, which forms a thin film along the bed [5].

Similar to a cooling tower design, the inlet air is forced through the packed bed structure in a counter-flow direction, where the weight of the desiccant enables collection at the bottom of the bed. The packed bed structure has been extensively studied by Factor and Grossman with exit condition predictions using a one-dimensional model. Their analysis included a set of differential equations derived from energy and mass balances along a differential slice of the packed column. A finite difference scheme was used to solve these sets of differential equations, revealing the temperature and humidity profiles along the bed. Along the same lines, Radhwan et al. [6] solved a set of four first-order differential equations based on energy and mass balances along a differential slice. They observed that performance enhancements occur by an increase in height and transfer area of the packed bed. Falling film dehumidification was developed in response to the relatively large pressure drops and occasional inconsistent mixing of a packed bed structure. In addition, the falling desiccant film helps to purify and filter the conditioned air from large organic molecules and prevents the growth of mold, mildew, bacteria, and other airborne microorganisms.

A desiccant is a material that has a strong attraction for water vapor. Desiccants can be classified as either solid or liquid depending on their normal physical state. The strength of a desiccant can be measured by its equilibrium vapor pressure, which increases roughly exponentially with the temperature of the desiccant/water system. It also increases as the desiccant absorbs water. The moisture is absorbed driven by a difference between water vapor pressures of the desiccant at their surface and of the surrounding air [7]. When the vapor pressure at the desiccant surface is lower than that of the air, the desiccant attracts moisture until equilibrium is reached. On the other hand, when the surface vapor pressure is higher than that of the surrounding air, desiccant releases moisture.

Liquid desiccant systems have several advantages compared with solid desiccants:

- Lower pressure drops
- Large energy storage
- Lower regeneration temperature
- Potential to remove a number of pollutants
- Adaptability and flexibility in terms of allowing pumping the diluted solution of small units to a single larger regeneration unit

The performance, cost, size and reliability of a absorber depend on two parameters: desiccant material and matrix geometry. The air dehumidification is generally effected by sprinkling the liquid desiccant from the top of the packing materials and bringing it in contact with

PARAMETER	Vapour compression	Desiccant
Operation cost	High	low
Energy source	Mainly electricity	Low-grade
Control over humidity	Average	Accurate
Indoor air quality	Average	Good
System instalment	Average	Complicate
Energy storage capacity	Mainly not applicable	Good
Installation cost	Low	High
System control	Average	Complicate

Figure 1: Difference between vapor compression and desiccant air conditioning system.

the inlet process air. The desirable characteristics for high-performance liquid desiccant absorbers are:

- Suitable desiccant properties
- High heat and mass transfer rates
- Low pressure drops
- Small liquid-side resistance to moisture diffusion
- Large contact transfer surface area per unit volume
- Compatible desiccant/contact materials
- Use of common materials and inexpensive manufacturing techniques
- Low heat input for regeneration

### Principle of absorption

The solar cooling technologies are mainly classified into two main groups depending on the energy supply: a thermal/work driven system and electricity (Photovoltaic) driven system. Each group can be classified as the following:

#### Thermal/work driven system

- Absorption refrigeration cycle
- Adsorption refrigeration cycle
- Chemical reaction refrigeration cycle
- Desiccant cooling cycle
- Ejector refrigeration cycle

#### Electricity (Photovoltaic) driven system

- Vapor compression refrigeration cycle
- Thermo-electric refrigeration cycle
- Sterling refrigeration cycle

The absorption cycle is similar in certain respects to the electrically driven vapor compression machines. A refrigeration cycle is operated with the condenser, expansion valve, and evaporator if low-pressure vapor from the evaporator can be transformed into high-pressure vapor and delivered to the condenser [8]. The vapor compression system uses a compressor for this task. The absorption system first absorbs the low pressure vapor in an appropriate absorbing liquid. Embodied in the absorption process is the conversion of vapor into liquid, and since the process is akin to condensation, heat must be rejected during the process (Figure 2).

### Desiccant material

Two essential requirements for comfortable and healthy indoor environments are adequate ventilation and good humidity control. Unfortunately in humid a climate, which includes much of the densely populated regions of the world, it is difficult to meet both these requirements without using a lot of electricity.

The fundamental problem is that a conventional cooling coil (whether using chilled water or direct-expansion refrigerant) cannot effectively meet the latent loads from ventilation on very humid days. All conventional chillers and air conditioners are essentially sensible cooling devices that dehumidify by lowering air temperature below its dew point so that moisture condenses. These systems must run

with a wet cooling coil, and the air that leaves this coil will be close to saturation [9].

The limitation of conventional chillers and air conditioners becomes evident when one tries to use them in an advanced Air Conditioning system. Technologies such as displacement ventilation, chilled beams, and radiate panels can be part of a low-energy air conditioning system that eliminates the fan energy used in a conventional system that re-circulates large volumes of air. However, these advanced systems will not work with a conventional chiller or Direct air conditioner that supplies relatively cold air (e.g., 50 to 55 F) that is saturated with moisture (i.e., 100% $R_h$ ). What is required is a cooling system that supplies drier, but warmer air (Figure 3). Typical supply air conditions for displacement ventilation might be 65 F and 50% relative humidity. This supply air has an absolute humidity of 45.5 grains moisture per pound of dry air (which is equivalent to a humidity ratio of 65 g/kg and a dew point of 46.0 F). Any cooling system that dehumidifies air by reducing its temperature to condense the moisture must first cool air to below 46 F and then reheat the air to 65 F. As shown on the neighboring psychrometric chart, a cooling system that process 6,000 cfm of warm, humid outdoor air must do 54.0 tons of cooling and then 10.8 tons of reheating. This air conditioner is doing 25% more cooling than is required to meet the load. Furthermore, this percent excess cooling becomes much larger during cooler, damp weather, e.g., if it were 70 F and raining, overcooling would be 42% of the required cooling [10].

Liquid desiccants are solutions that have a high affinity for water vapor. This property is the key to creating cooling systems that

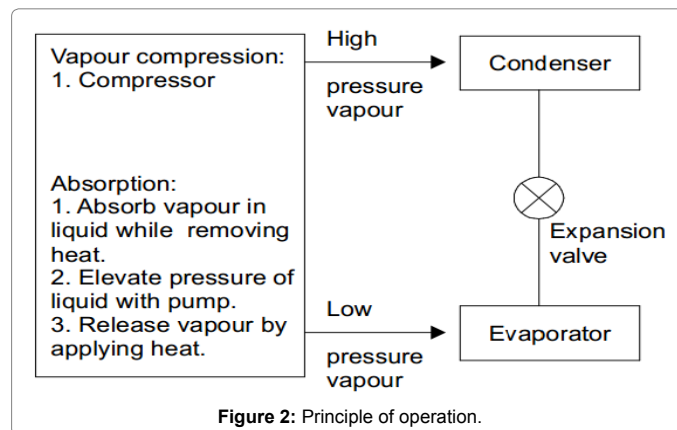


Figure 2: Principle of operation.

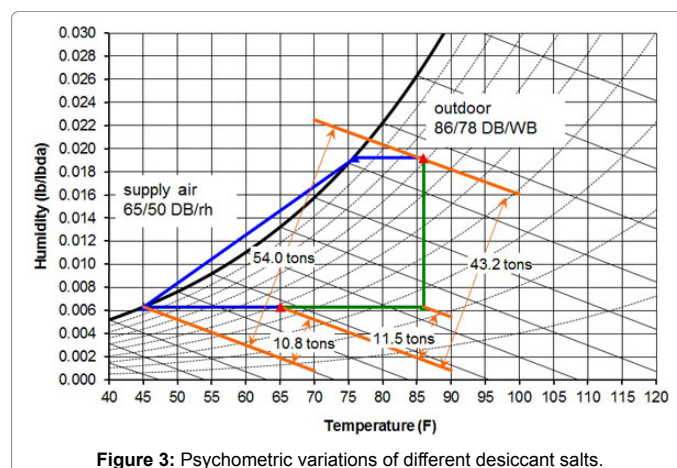


Figure 3: Psychrometric variations of different desiccant salts.



dehumidify air without over-cooling. Since the 1930s, liquid desiccants have been used in industrial dehumidifiers

**Different types of desiccants:** The liquid desiccants used in these systems commonly are very strong solutions of the ionic salts lithium chloride and calcium chloride. These ionic salts have the attractive characteristic that the salts themselves have essential zero vapor pressure, and so vapors of the desiccant will not appear in the air supplied by the liquid desiccant air conditioning. However, zero vapor pressure comes with a price: as with seawater (a chemically similar salt solution), solutions of lithium and calcium chloride are very corrosive. This corrosiveness requires that all wetted parts within the Liquid Desiccant Air Conditioning be protected and that no droplets of desiccant are entrained by the supply air.

Proposed a novel method that mixes LiCl and CaCl<sub>2</sub>. In their work, they divided the liquid desiccant into five groups: Group 1 (pure LiCl with mass fraction 39%), Group 2 (mixed LiCl–CaCl<sub>2</sub> solution with mass fraction of 5% for CaCl<sub>2</sub>), Group 3(35% LiCl and 10% CaCl<sub>2</sub>), Group 4 (33% LiCl and 15% CaCl<sub>2</sub>), and Group 5(31.2% LiCl and 20% CaCl<sub>2</sub>). The experimental results show that the fifth groups have the best dehumidification effect [11].

### Desiccant cooling system

Seeking a comfortable living condition is a popular trend today, which leads to the wide-spread of air-conditioner. At present, the most widely used air-conditioner is the vapor compression cooling system, which is driven by electric power. The liquid desiccant air-conditioning system (LDAS) is a novel air-conditioner with good energy saving potential. Compared to the vapor compression cooling system, the liquid desiccant air-conditioning system has attracted more and more attentions in recent years due to its environmentally friendly technology and promising utilization of low-grade thermal energy [12]. The energy consumption of liquid desiccant air-conditioning system mainly relies on the regeneration process of the desiccant solution. In general, the liquid desiccant air-conditioning system is driven by thermal energy, which can be obtained from low-temperature heat sources. As a kind of renewable energy, solar energy can be used to regenerate the desiccant solution for the liquid desiccant air-conditioning system. There are many literatures shared with the investigation of the performance of the solar liquid desiccant air-conditioning system. However, one problem of the solar energy regeneration system is that solar energy will depend on weather conditions, which means that the solar energy regeneration system cannot meet the dehumidification requirements all the time. Therefore, it is necessary to find a new regeneration system for the liquid desiccant air-conditioning system under the condition without plenty of solar energy [13].

**Desiccant dehumidification:** Desiccant dehumidification has been studied extensively during the past several years as a way to dramatically reduce energy consumption of a vapor compression cooling cycle. In this type of system, the water vapor is removed from the air as it is routed to the evaporator in an effort to reduce the cooling load on the air conditioning system. This modified air conditioning cycle, known as a hybrid cooling system, has been shown to help increase the coefficient of performance (COP) of the cycle while reducing evaporator and condenser sizes [14].

### Components Explanation

#### Evaporative cooler

Evaporative cooler is used for evaporation of water to cool a passing

airflow. The airflow passes through either a spray of water droplets or a wetted material. As the airflow comes in contact with the water, water evaporates into the air. If no air is added, the heat required for evaporation will be taken from the sensible heat of the air. The sensible heat of the air and thus its (dry-bulb) temperature will then be reduced. The latent heat of the air will at the same time be increased by the same amount as sensible heat of the air is reduced. The total energy of the air thus remains constant. The change of state of the air towards saturation described on a psychrometric or Mollier chart (Figure 4).

Here we used falling film type Evaporative Cooler. The film is made of Aluminium with a thickness of 0.5 mm. These aluminium sheets are equally spaced with 1.5 inches. The solution is passed through the copper pipe which is turned in the aluminium films. The copper pipe has a maximum outer diameter of 6mm and thickness of a pipe is about 1 mm which makes the inner diameter 5 mm. This copper pipe can also be called as quarter inch or ¼ copper pipes. On aluminium sheet we have punched the hole with a diameter equals to the outer diameter of the copper pipe used. The solution is passed through the copper pipe which is turned in the aluminium films. It is difficult to turn the copper pipe through the holes of aluminium sheets. So we used to bend the copper pipe into two different lengths and welded together after passed through the aluminium sheets. The copper pipe is bended in large ‘U’ shape with a length 23 inches and Small ‘U’ with a length of 1.5 inches. The small ‘U’ shaped copper pipe gets enlarged at its ends diameter to insert in the large ‘U’ shaped copper pipe. These two copper pipes are welded together by using Oxy-Acetylene gas welding with a copper filler rod. In order to spray the solution we used the same size copper pipe for spraying. These copper pipes are arranged horizontally with equal space between them. All these copper pipes are inserted in half inch copper pipe and these are welded together. We punched small holes on the ¼ or quarter inch copper pipe to spray the solution on aluminium films. To make the equal space between the aluminium sheets we used wood. All these aluminium sheets with copper pipe and sprayer make the evaporative cooler [15]. The arrangement of evaporative cooler is shown in the below snapshot (Figure 5).

#### Dehumidifier

The dehumidifier takes place in a chamber in which airflow of ambient air is forced through counter flowing solution from the bottom towards the top. The solution is cooled to reduce its vapour

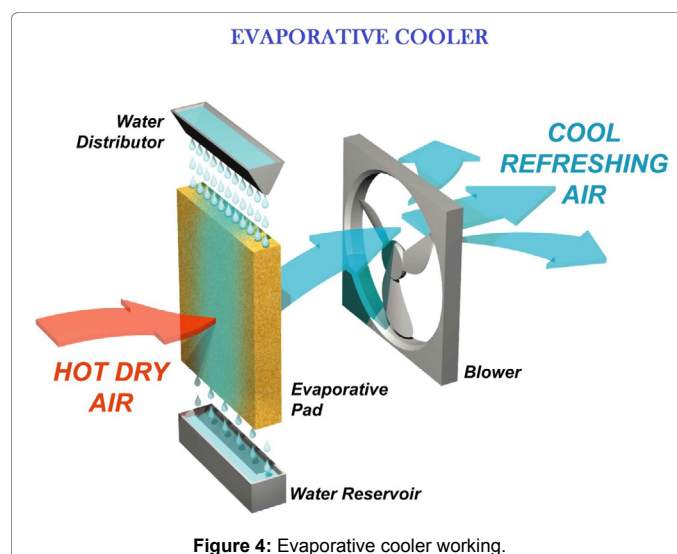


Figure 4: Evaporative cooler working.

pressure, either in a fluid heat exchanger before entering the chamber, by cooling coils inside the chamber, or evaporative with wetted air channels passing through the chamber. As the solution meets the air, water vapour is absorbed by the solution. Several ways of bringing the solution in contact with the air can be used. A rather common method is to spray the solution over a packing. Alternatively it can be sprayed onto wet surfaces, or let onto wet surfaces using overflowing channels above the surfaces or by wicks [16]. The solution then flows down the wet surfaces as a falling film (Figure 6).

### Pumps

Pump is a machine which converts the one form of energy to another form of energy. A pump may be centrifugal or reciprocating. A centrifugal water pump draws water from a lower level and pumps to higher level. Work is required to run the pump and this may be supplied from an external source such as an electric motor or a diesel engine. The water from the tank can be drawn by immersing the pump in it or by suction of water from tank with the pressurized air. Here we used immersed pump with working voltage capacity up to 230 V which can transfer water up to 8 Feet height (Figure 7).

### Heat exchanger

A heat exchanger is a device in which heat is transferred from one fluid stream to another across a solid surface. A wide variety of heat exchangers are extensively used in refrigeration and air conditioning. In most of the cases the heat exchangers operate in a steady state, hence the concept of thermal resistance and overall heat transfer coefficients can be used very conveniently. In general, the temperatures of the fluid streams may vary along the length of the heat exchanger. To take care of the temperature variation, the concept of Log Mean Temperature Difference (LMTD) is introduced in the design of heat exchangers [15]. It is defined as (Figure 8):

$$LMTD = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)}$$

Where

$\Delta T_1$  = the temperature difference between the hot and cold fluid streams at inlets of heat exchangers.

$\Delta T_2$  = the temperature difference between the hot and cold fluid streams at outlets of the heat exchangers.

### Regenerator

The strong desiccant salt solution, after absorbing moisture from air becomes weak solution and absorption capacity decreases. It is to be regenerated by heating to its regeneration temperature about 70°C and made ready for dehumidification. This is done in regenerator; regenerator should provide large contact area in between air and weak liquid at higher temperature moisture transfers from liquid to air. Regenerators may be packed bed type or parallel plate type. A parallel plate type is used in this system. The hot weak liquid from the heater tank is made to fall downwards over the plates by gravity and collected in a tray. While passing over the plates, it gets into good contact with air and gets regenerated and reactivated. The collected strong liquid is sent back to the dehumidifier through a heat exchanger.

### Fans

Fans are extensively used for circulating air through evaporators and condensers and in air conditioning systems. They can be divided into two types: axial and centrifugal. Axial fan blades generate aerodynamic lift



Figure 5: Fabricated evaporative cooler.



Figure 6: Fabricated dehumidifier.



Figure 7: Pump.

that causes the Blades to impart a force on the air, propelling it forward. Low-pressure, high volume propeller fans are used in conjunction with heat exchangers such as evaporators and condensers. They move large quantities of air and generate low pressures. The efficiency is improved by a close fitting inlet Shroud. Some blade types are specifically designed to minimize noise. Other axial types used for circulating air in ducts include vane-axial, which has good downstream air distribution and tube-axial. Fan curves have the volume Flow rate on the x-axis and the pressure development on the y-axis. The fan should be selected as near

to the peak efficiency as possible. When the fan enters the stall region there is a dip in performance due to turbulence and this can cause an increase in noise level.

A fan is a kind of pump which is used for circulating the air through the entire duct system and the conditioned space. It is usually located at the inlet of the air conditioner. A fan essentially consists of a rotating wheel which is surrounded by a stationary member known as housing. The energy is transmitted to the air by the power driven wheel and a pressure difference is created to provide flow of air. The air may be removed by either creating an above atmospheric pressure or below atmospheric pressure. All fans produce both the conditions. The air at inlet to the fan is below atmospheric pressure while at the exhaust or outlet of the above is atmospheric pressure. The air feed into a fan is called induced draft while the air exhaust from the fan is called forced draft. The fans irrespective of the other their type of construction may function as either blowers or exhausters. The blowers discharge air against a pressure at their outlet whereas exhausters remove gases from a space by suction.

Here we used axial flow propeller fans. A propeller type of axial flow fans consists of a propeller or blades on a rotor which operates within a mounting blade. The design of the blade surrounding the wheel is important because it prevents the air discharged from being drawn backward into the wheel around its periphery. The propeller fans are used only when the resistance of air movement is small. They are used for the radiator fans, air ducts, etc. we get these axial flow fans from Santo Xing car radiators. These actually work with 12 Volts with a maximum 2000 rpm. This fan is a 12 inch outer diameter of housing. The rotor mainly consists of 13 blades which mainly increase the flow of air (Figure 9).

### Salt solution

The main role of the desiccant is to attract water vapour from air; thus, it can be classified as both solid and liquid desiccant. Several types of solid materials can hold off water vapour, e.g., silica, polymers, zeolites, alumina, hydra table salts, and mixtures. Other available liquid desiccants are calcium chloride, lithium chloride, lithium bromide, triethylene glycol, and a mixture of 50% calcium chloride and 50% lithium chloride. These liquid desiccants have common general properties, but their requirements cannot be fully addressed by any single desiccant. These requirements include low vapour pressure, low crystallization point, high density, low viscosity, low regeneration temperature, and low cost. The air is dehumidified by being brought into contact with strong liquid or solid desiccant, after this to provide sensible cooling to dehumidification process, traditional vapour compression, and vapour absorption, direct or indirect evaporative cooler units used. When the solution is weakened by absorption of moisture, it sends direct to regeneration process to release the moisture by using an external heat resources. This is called "reactivating" the desiccant. Proposed a novel method that mixes  $\text{LiCl}$  and  $\text{CaCl}_2$ . In their work, they divided the liquid desiccant into five groups: Group 1 (pure  $\text{LiCl}$  with mass fraction 39%), Group 2 (mixed  $\text{LiCl}$  -  $\text{CaCl}_2$  solution with mass fraction of 5% for  $\text{CaCl}_2$ ), Group 3 (35%  $\text{LiCl}$  and 10%  $\text{CaCl}_2$ ), Group 4 (33%  $\text{LiCl}$  and 15%  $\text{CaCl}_2$ ), and Group 5 (31.2%  $\text{LiCl}$  and 20%  $\text{CaCl}_2$ ). The experimental results show that the fifth groups have the best dehumidification effect [16].

Here we used calcium chloride ( $\text{CaCl}_2$ ) as a desiccant liquid which is easily available in market. This liquid  $\text{CaCl}_2$  solution is converted into solid form like powder, by exposing this  $\text{CaCl}_2$  solution to suns radiation or by heating  $\text{CaCl}_2$  solution to certain temperature. By mixing

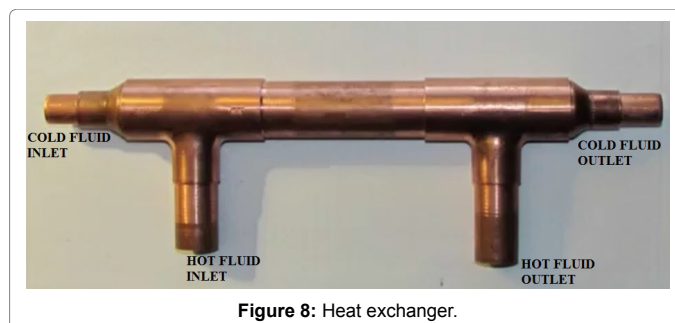


Figure 8: Heat exchanger.

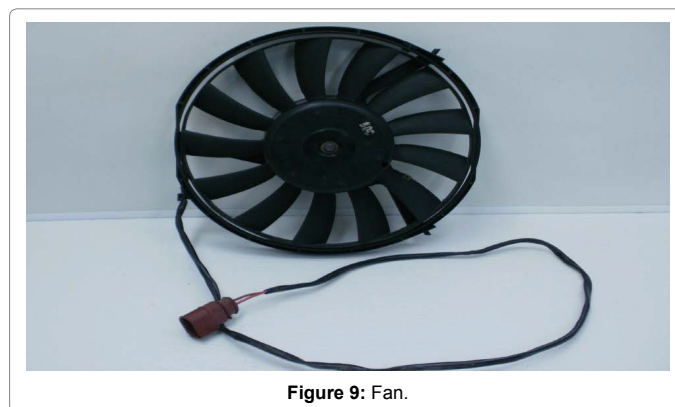


Figure 9: Fan.

this  $\text{CaCl}_2$  powder to water we will get the previous  $\text{CaCl}_2$  solution. The concentration percentage of a salt solution is mainly depends on the amount of  $\text{CaCl}_2$  powder dissolved in water. For 1 kg  $\text{CaCl}_2$  powder we used to mix 4 litres of water in it to get 30% concentration percentage. The air is passed over chemicals which have an affinity for moisture. As the air comes in contact with these chemicals, the moisture gets condensed out of the air and gives up its latent heat. Due to the condensation, the specific humidity decreases and heat of condensation supplies sensible heat for heating the air and thus increasing its dry bulb temperature.

A liquid desiccant cooling system often consists of many different components, such as dehumidifier a regenerator, an evaporative cooler, heat exchangers, and so on. In the dehumidifier the surface vapour pressure of the concentrated liquid desiccant with lower temperature lower than that of processed air, and so that the mass (water) transfer is from the processed air to the desiccant after the dehumidification process, the desiccant solution is diluted and then pumped out to the regenerator where the surface vapour of the diluted liquid desiccant with high temperature is higher than that of the sweeping air. Thus, the mass (water) transfer is form desiccant to processed air, and then the weak solution is concentrated. The surface vapour pressure between the liquid desiccant and air is the driving force for the mass transfer. Thus, the diluted solution flowing out to the dehumidifier is preheated to increase its surface vapour pressure to improve the desiccant regeneration. The heat for the preheating process can be obtained by low grade heat sources, such solar as solar energy, waste heat, and so on.

### Heater

A heater is an object that emits heat or causes another body to achieve a higher temperature. In a house hold or domestic setting, heaters are usually appliances whose purpose is to generate heating (i.e., warmth). Other types of heaters are Ovens and Furnaces.

These systems also contain either duct work for forced air systems



or piping to distribute a heated fluid to radiators to transfer this heat to the air. The term radiator in this context is misleading since most heat transfer from the heat exchanger is by convection, not radiation. The radiators may be mounted on walls or installed within the floor to give floor heat [17]. An electric heater of capacity 1000 W is used for regeneration. A regulator is used for regulating its heating capacity (Figure 10).

### Explanation of System Process

Evaporative cooling is effective in hot and dry climates whereas in hot and humid climates. Increased humidity adds up to the existing discomfort. So evaporative cooling is unsuitable for humid climates. Dehumidification and cooling are required for this kind of climates. In conventional vapor compression system, both cooling and dehumidification process occurs simultaneously by cooling the air to a very low temperature essentially below dew point temperature which is very energy consuming. In desiccant humid dehumidification and cooling are handled separately.

In this system,  $\text{CaCl}_2$  salt solution is circulated and made to fall over parallel plates, so that gets into contact over a large area during which the moisture in air is absorbed by solution. The absorbing moisture form air, the strong solution becomes weak solution and is unable to absorb any moisture from air to reactive it, it is regenerated by heating it and taken into contact with outside air so that the moisture in the weak solution gets absorbed by air so that the solution again becomes strong and is re-circulated for reuse. Moisture transfer occurs from air to solution. When solution is at low temperature it will be in reverse when solution is hotter than air that depends on vapor pressure of both. For regeneration, the electrical with control is used [18].

During dehumidification the latent heat of condensation of water vapor in air that got absorbed by the solution heats up the desiccant solution and results in reduction its absorbent capacity. For that reason, copper coil with cooling water circulated inside are provided with parallel plates to absorb the heat of absorption.

The regenerated solution is hot and it must be cooled before it enters the dehumidifier. For this it made to pass to copper coils with a number of passes though the evaporative cooler to get cooled. The heat exchanger is provided in between regenerator and dehumidifier to improve the efficiency by cooling the solution flowing to dehumidifier and heating the solution flowing to heat rank. The concentric tube heat exchanger is used.

Finally, evaporative cooler is used to cool the dehumidifier air the changes in the condition of air can be represented on psychometric chart.

During the dehumidification process 1-2 air undergoes reduction in humidity at almost the same temperature. Chemical dehumidification accompanies increase in temperature. But cooling water circulated absorbs the heat prevents heating up of air. In evaporative cooler, 2-3 air undergoes cooling and humidification. The net result is 1-3 cooling and dehumidification that improves comfort (Figure 11).

### Results and Discussion

Outside air	DBT	=	32°C
	WBT	=	28.5°C
	RH	=	80%
Processed air	DBT	=	25°C

$$\text{WBT} = 21^\circ\text{C}$$

$$\text{RH} = 70\%$$

By passing the air through this system, air is first dehumidifier without much increase in temperature later when it passed through the evaporative cooler there is reduction in temperature with a slight increase in humidity the net change in the condition of air is reduction in temperature when reduction in specific humidity, both increase the feeling of comfort.

This system overcomes the difficulty with evaporative cooler increased humidity with cooling, which makes it unsuitable for hot and humid climates, by dehumidifying the air first below it is evaporative cooled. Heating effect of dehumidification process is compensated by cooling water circulation. Evaporative cooling became more effective by dehumidification with cooling (Figure 12).

### Conclusion

In this project a dehumidifier – evaporative cooler is fabricated. Evaporative cooling is made more effective by using salt solution for dehumidification.

The condition of air changed towards comforts conditioned by reducing temperature and humidity, which are handled separately by salt solution and cooling water. In conventional vapor compression system cooling and dehumidification occurs simultaneously which

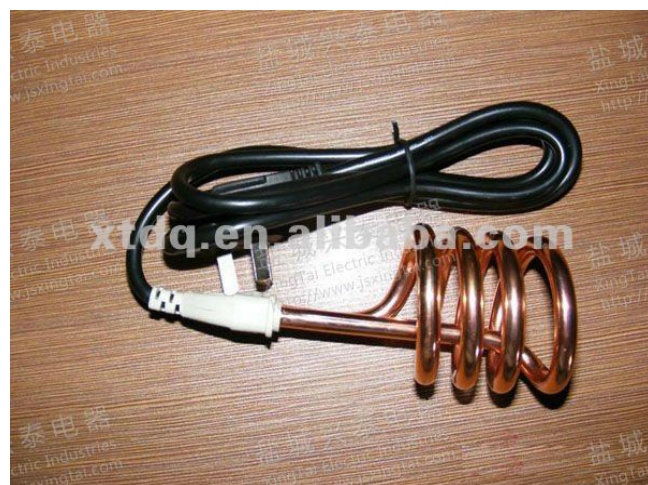
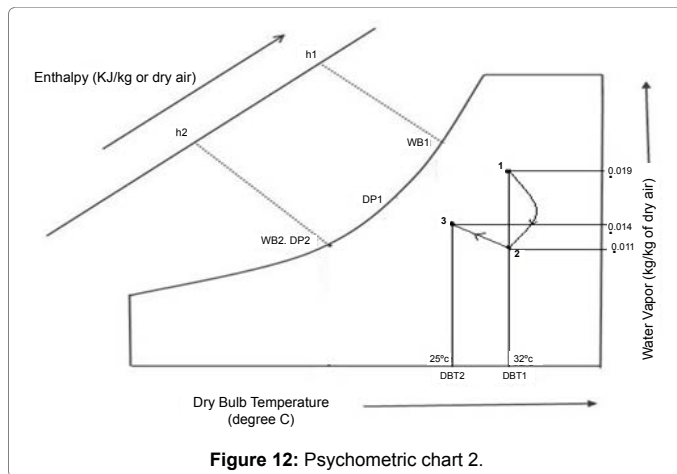


Figure 10: Heater.



Figure 11: Falling film desiccant air conditioning system.



remains very low temperature below dew point temperature which increases power consumption.

Power consumed by heater is the only major part of power consumption. Although it is not very low compared to power consumed by compressor motor, heating can be done by any other cheap sources like waste heat, solar thermal collector etc. Cost of manufacturing is lowered compared to conventional vapor compression system.

The salt solution used is not harmful to environment whereas most refrigerant used in vapor compression systems are harmful to environment. This system is bulky and not very easy to handle.

## References

- Ahmad AP (1993) A review of desiccant dehumidification technology. Energy Efficient Humidity Control for Commercial and Institutional Buildings Conference, New Orleans, Louisiana.
- Mario HE, Ghali K, Ghaddar N (2014) Effective desiccant dehumidification system with two-stage evaporative cooling for hot and humid climates. Journal of Energy and Buildings 68: 329-338.
- Halliday SP, Beggs CB, Sleight PA (2000) The use of solar desiccant cooling in the UK: A feasibility study. Appl Therm Eng 22: 1327-1338.
- Ying S, Yufeng Z, Deng N, Fang L, Jinzhe N, et al. (2013) Experimental analysis on performance of high temperature heat pump and desiccant wheel system. Energy and Buildings 66: 505-513.
- Khalid A (2007) Experimental investigation and mathematical modeling of a low energy consuming hybrid desiccant cooling system for the hot and humid areas of Pakistan. NED University of Engineering & Technology, Karachi.
- Ge TS, Dai YJ, Wang RZ, Li Y (2013) Feasible study of a self-cooled solid desiccant cooling system based on desiccant coated heat exchanger. Journal of Applied Thermal Engineering 58: 281-290.
- Cheng Q, Xiao-Song Z (2013) A solar desiccant pre-treatment electro dialysis regeneration system for liquid desiccant air-conditioning system. Journal of Energy and Buildings 67: 434-444.
- Cheng Q, Xiao-Song Z, Xiu-wei (2013) Performance analysis of a new desiccant pre-treatment electro dialysis regeneration system for liquid desiccant. Energy and Buildings 66: 1-15.
- Terry RP, McClain (1985) Promising advances in desiccant cooling. Department of Energy's Solar Buildings Conference, Washington, D.C.
- La D, Dai Y, Li H, Li Y, Kiplagat JK (2010) Experimental investigation and theoretical analysis of solar heating and humidification system with desiccant rotor. SJTU, Shanghai.
- Henning HM (2007) Solar assisted air conditioning of buildings-an overview. Appl Thermal Eng 27: 1734-1749.
- Pesaran AA, Penney TR, Czanderna AW (1993) Desiccant Cooling: State-of-the-Art Assessment. National Renewable Energy Laboratory, Colorado.
- Hofmann P (2012) Lecture Notes on Surface Science. Cole-Parmer India Pvt. Ltd, India.
- Dai J, La D, Li Y, Wang R, Ge T (2010) Technical development of rotary desiccant dehumidification and air conditioning: A review. Renewable and Sustainable Energy Reviews 14: 130-147
- Esser P (2010) Principles in adsorption to polystyrene. Thermo Fisher Scientific Inc.
- Sopian K, Al-abidi AA (2013) Historical review of liquid desiccant evaporation cooling technology. Journal of Energy and Buildings 67: 22-33.
- Mei VC, Chen FC, Lavan Z, C-Jr RK, Meckler G (1992) An assessment of desiccant cooling and dehumidification technology. Martin Marietta Energy Systems, INC. U.S.
- Daou K, Wang RZ, Xia ZZ (2006) Desiccant cooling air conditioning: a review. Renewable and Sustainable Energy Reviews 10: 55-77.