

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization, Volume 2, Special Issue 1, December 2013

Proceedings of International Conference on Energy and Environment-2013 (ICEE 2013)

On 12th to 14th December Organized by

Department of Civil Engineering and Mechanical Engineering of Rajiv Gandhi Institute of Technology, Kottayam, Kerala, India

**EXPERIMENTAL ANALYSIS OF A LIQUID DESICCANT DEHUMIDIFIER
USING AQUEOUS CALCIUM CHLORIDE SOLUTION**

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ABSTRACT

In this paper an experimental analysis of a hybrid liquid desiccant dehumidifier system is conducted. Dehumidification of air is effected in a packed column packed with random packing in which air and the desiccant solution flow in a counter flow manner so as to exchange heat and moisture and after heat and mass transfer it is circulated through the regenerator where it is re-concentrated. The desiccant chosen for the analysis is aqueous solution of calcium chloride. The packed bed consists of polypropylene intalox saddle. After dehumidification the desiccant is regenerated in an absorber of similar construction as the dehumidifier. The effect of different operating variables on performance of both dehumidifier and regenerator are studied. The parameters studied are the effect of mass air flow rate, air inlet temperature, and desiccant inlet temperature. The practicability of additional dehumidification of supply air by the desiccant loop of the hybrid system is demonstrated.

1. INTRODUCTION

In recent years ozone layer depletion green house effect gases have created considerable concern. The fully halogenated chlorofluorocarbons (CFC) which have been in use in the refrigeration and air-conditioning industry for about 65 years have been found to cause ozone layer depletion and global warming. The search for new refrigerants and the adaptation of the existing systems to the alternative refrigerants have created considerable research activities. Efforts have also been devoted to the developments of alternate methods of refrigeration and air-conditioning. One of the main disadvantages of the vapor compression systems is that providing dehumidification requires air to be cooled below its dew point temperature in most cases it results in an air temperature that is colder than that required for meeting the sensible load. Conventional vapor compression systems which operate on closed cycle using electricity have reached their limits after years of research and development. The combination of a conventional air conditioning system with a desiccant system to reduce the sensible load and latent load results in a hybrid system which controls both the temperature and the humidity ratio within comfort range. With desiccant cooling

system, independent control of air temperature and humidity impossible, enabling better humidity control. Desiccants can be classified into mainly two types—solids and liquids. The liquid desiccant has a vapour pressure lower than that of water at the same temperature and the air passing over the solution approaches this reduced vapour pressure and is dehumidified. Vapour pressure of a liquid desiccant is directly proportional to its temperature and inversely proportional to its concentration. As the desiccant content in the mixture increases its vapor pressure decreases. This pressure difference allows the desiccant solution to absorb moisture from air whenever the vapour pressure of air is greater than that of the desiccant solution. Out of the many liquid desiccants available viz aqueous solution of Lithium chloride, Calcium chloride, Ethylene glycol. Generally liquid desiccants are found to have many advantages over the solid ones. Firstly the regeneration temperature required for liquid desiccants are lower than for that of solid desiccants. Secondly the pressure drop through a liquid desiccant system is smaller than the pressure drop through a solid desiccant wheel. Thirdly liquid desiccants can be used as a heat transfer medium in heat exchanger which enables pre-cooling or preheating whenever required. Fourthly during the dehumidification process scrubbing of air stream takes place which provides a cleansing action and it inhibits microbial growth [1]. Finally another major advantage of this system is that energy is stored as chemical energy rather than thermal energy. Out of the different contactors for effecting heat and mass transfer many methods are adopted namely sprayed coil arrangement, spray chambers and packed bed towers. From the point of view of heat and mass transfer packed bed towers are more effective since they provide large rate of heat and mass transfer per unit volume and hence a compact design is possible. In this paper a packed tower operated in a counter flow arrangement is used in which the cool strong desiccant is sprayed from the top and distributed into the tower which then trickles down through the tower in a thin film covering the packing surface.

Different packings made of various materials and sizes are generally used in the construction of packed beds. Out of these the usually used ones are flexi rings, berl saddles, intalox saddles, raschig rings [2]. These constitute the random packings. Although these random packings provide large area in a relatively small volume, the air pressure drop through the packing is large. The regenerator is used to re-concentrate the weak desiccant during the cycle operation. In this paper the packing used is 1 inch polypropylene intalox saddle. Yadav [3] simulated a hybrid desiccant cooling system comprising the traditional vapour compression air conditioning system coupled with a liquid desiccant dehumidifier which was regenerated by solar energy. The study suggested that, when the latent load constitutes 90% of the total cooling load, the system can generate up to 80% of energy savings. Dai et al. [4] conducted a comparative study of a standalone VCS, the desiccant associated VCS, and the desiccant and evaporative cooling associated VCS. The authors found an increase of cold production by 38.8–76% and that of COP by 20–30%. Mazzei et al. [5] compared the operating costs of the desiccant and traditional systems using the computer simulation tool and predicted operating cost savings of about 35% and a reduction of thermal power up to 52%. In the case where the desiccant would be regenerated by waste heat, the authors projected operating costs savings reaching up to 87%. They also found that cost savings and cooling power reduction increased when the indirect evaporative cooling is used in conjunction with desiccant dehumidification. Henning et al. [6] conducted a parametric study of a combined desiccant/chiller solar assisted cooling systems and showed not only their feasibility but also the primary energy savings of up to 50% with a low increased overall costs. Sanjev et al. [7] studied theoretically and experimentally a liquid desiccant cooling system made of a falling film tubular absorber and a falling film regenerator. Fathalah et al. [8] studied a heat recovery system. The system studied was a solar energy driven LiBr–H₂O absorption cooling machine. The heat was recovered from the condenser of the machine and added to the driving solar energy. The coefficient of performance was raised 1.2 times, hence 58% higher than that for the absorption machine alone. Arshad [9] undertook the study of a mathematical model of a liquid absorber (dehumidifier).

2. EXPERIMENTAL FACILITY AND PROCEDURE

A schematic of the experimental facility is shown in the Figure 1. The system consists of two packed towers meant for absorption and dehumidification. The construction of both towers is identical. The towers are made of fiber reinforced plastic (FRP) and it has a constant height of 100cm. Packing is done using polypropylene intalox saddle of specific surface area $207 \text{ m}^2/\text{m}^3$ for a height of 28 cm. Beneath both the towers a collection tank each for storage of the liquid desiccant has been provided. The arrangement for the tanks is such that heated desiccant is sprayed on to the regenerator and cool desiccant is sprayed on to the absorber. In the absorber moisture is absorbed from the incoming air stream, the driving forces being the vapour pressure difference and the temperature difference responsible for heat transfer, so that cooling and dehumidification takes place. From the absorber the desiccant falls into a collection tank where it is heated to a an elevated temperature so as to increase its vapour pressure and this heated desiccant is sprayed on to the regenerator where the moisture is transferred into the air stream. For achieving this two 2KW immersion type heaters along with a digital temperature controller for achieving the desired desiccant temperature is used. A PT100 sensor (fig 3) is used to sense the temperature of the heated desiccant. The other tank is cooled using a vapor compression system. In the towers, the desiccant and air flow in a counter current manner. Desiccant is sprayed on to the packing and air moves upward through the packing. For obtaining the airflow blowers of capacity of $2.2 \text{ m}^3/\text{min}$ are installed in the exit of the two towers.



Fig:1 Experimental set up

Two centrifugal pumps each which have a maximum discharge of 800 liters /hour are used for pumping the desiccant into the two towers. In order to vary the inlet air relative humidity and temperature an electric heater is used which is made of Tungsten and is wound in a manner concentric to the inlet pipe which has a diameter of 4 inch made of GI. Glass wool is used to insulate the heater from the pipe for minimizing heat loss. The heat flux of the heater is controlled using a rheostat. Desiccant is distributed into the towers by means of an E-shape distributor made of PVC pipes and it trickles down through the packing to the outlet which is situated at the bottom. Demister pads are placed at the top of the two towers to eliminate desiccant carry over through the air stream. The specifications of the measuring devices used are given in Table 1.

Once steady state conditions are attained the different measurements viz inlet and outlet temperature of the desiccant and air, using calibrated T type thermocouples, inlet and outlet air relative humidity using digital capacitive probe hygrometer inlet and outlet desiccant concentration are measured. In the

measurement of concentration of desiccant, weight of a known quantity (100ml) of the desiccant is taken whereby its density is calculated and along with its temperature, the concentration is calculated using the correlation developed by Manuel R. Conde [10]. These readings are taken for both the absorber and regenerator simultaneously. Once these readings are obtained, for the dehumidifier the moisture removal rate is calculated and the effect of the different variables namely air inlet temperature, desiccant inlet temperature solution to air flow ratio. Similarly the moisture absorption rate in the regenerator is also calculated and the effect of the above mentioned parameters are studied. For studying their effect, one variable is changed keeping all others at their mean values and their effects are studied for both absorber and regenerator.

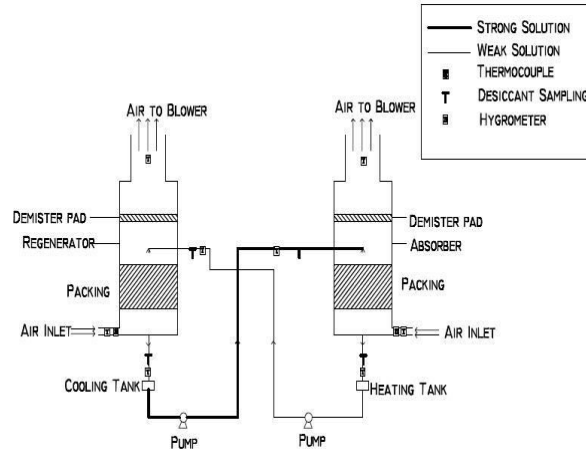


Fig 2 Schematic of the experimental setup



Fig : 3 Instrumentation

3.RESULTS AND DISCUSSION

The objective of the study is to analyze the hybrid system for dehumidification and regeneration processes and the factors affecting them. The parameters studied are the desiccant inlet temperature ,Air inlet temperature ,mass air flow rate. The specifications of the various measuring devices used in the investigation is shown in table 1.

Devices	Type	Accuracy	Operating Range	Fluid
Thermometers	T-type Thermocouples	0.5°C	-200 to 350 °C	Air and Liquid
Hygrometer	Capacitive probe	±2% RH	0 to 100% RH	Air
Air Flow meter	Vane type Anemometer	±2%	0 to 30 m/s	Air
Weiging machine	Electronic weighing balance.	0.001 g	0 to 300 g	Liquid

Table 1

The results are discussed in the following sections.

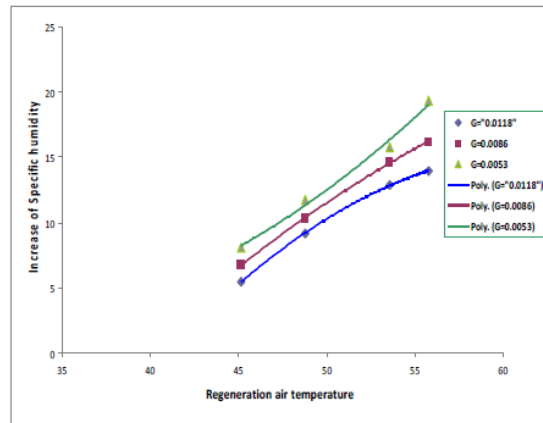


Fig 4 Effect of regeneration temperature on humidity reduction (regenerator)

Figure 4 shows the effect of the regenerator air *temperature on the humidification of air in the regenerator*. As the regeneration air temperature increases, moisture absorbing capacity of air increases. Solution also gets heated up and consequently its vapour pressure becomes higher, compared to that of the regeneration air. This results in enhanced humidification of regeneration air.

When mass air flow rate(G) decreases keeping desiccant flow rate a constant then ,humidification of air stream increases.

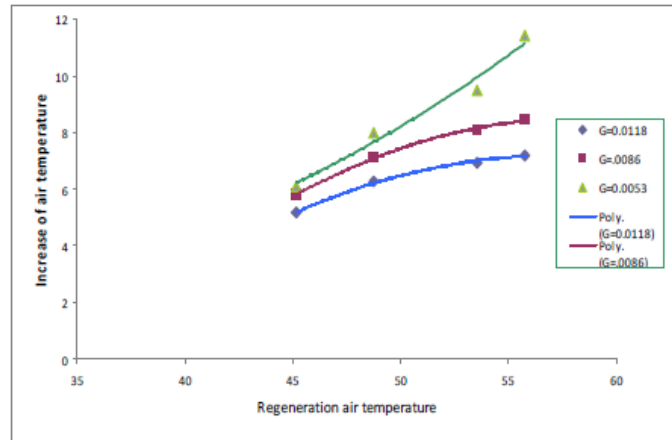


Fig 5 Effect of regeneration temperature on temperature increase

Figure 5 shows that as the temperature of the regenerator air increases, the exit temperature reduction also increases in regenerator indicating that more heat is utilised to regenerate the solution. It is seen that, as the regenerator air temperature increases, the moisture holding capacity of air increases, there by absorbing more moisture from the solution. Similarly as air flow rate (G) decreases keeping desiccant flow rate, the solution will supply more moisture to the air thereby enhancing the humidification of the regenerator air which explains the temperature reduction at the exit of the regenerator.

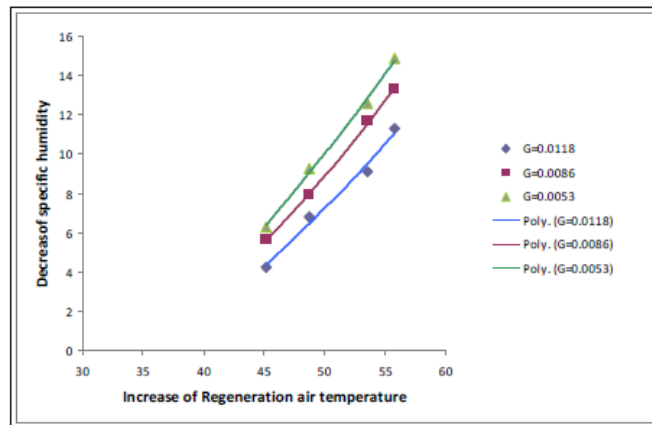


Fig 6 Effect of regeneration temperature on humidity decrease in the absorber

Figure 6 shows that, as the regeneration air temperature increases, the dehumidification rate in the absorber also increases. This is because when the regenerator inlet air stream is heated its moisture holding capacity is increases and subsequently the desiccant which comes into contact with the air also is heated up. This increases the vapor pressure gradient between the air stream and the solution and consequently regeneration increases leading to higher solution concentration at the exit of the regenerator. In the absorber, this strong solution could absorb more moisture which explains the increased dehumidification. When mass air flow rate (G) decreases keeping desiccant flow rate a constant, dehumidification is reduced in the absorber.

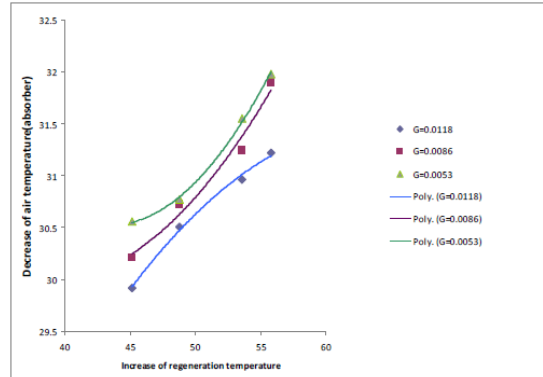


Fig 7 Influence of the regenerator air temperature on absorber air humidity change.

Fig 7 illustrates the influence of the regenerator air temperature on absorber air humidity change. Moisture removal rate increases with the increase in regeneration.

II. Effect of desiccant inlet temperature:

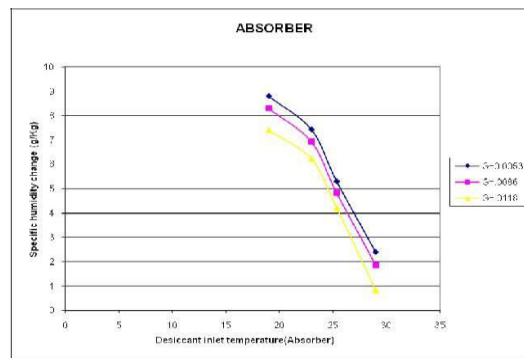


Fig 8 Effect of Desiccant inlet temperature on humidity decrease in the absorber.

The effect of desiccant inlet temperature (cool and strong) to the absorber is analysed for different air mass flow rates (G_a) (fig 8). During the experiment desiccant flow rate was kept a constant. As the inlet temperature of the desiccant (absorber) increases, the dehumidification reduces in the absorber, indicating the reduction in moisture removal capacity. The figure also shows that dehumidification in the absorber increases as air flow rate increases for any process desiccant inlet temperature.

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