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# Experimental study on mass transfer comparison of two liquid desiccants aqueous solutions

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**Abstract.** This paper experimentally studies the mass transfer during the dehumidification/regeneration operation using the hygroscopic material calcium chloride and calcium chloride dehydrate as desiccant. These desiccants are compared on the basis of the same operation conditions. According to the analysis of heat and mass transfer processes, the key influencing factors are relative humidity and regeneration temperature. It can be observed that the $CaCl_2.2H_2O$ is more rapidly diluted than the $CaCl_2$ at the same time during dehumidification, while the $CaCl_2$ solution can be more dried than $CaCl_2.2H_2O$ solution during regeneration. Then the $CaCl_2$ is able to absorb more moisture in the cycle of LDCS system. Also, the obtained experimental results can help to select liquid desiccant.

**Key words**: Mass transfer, Liquid desiccants comparison, Solar desiccant cooling system.

## 1. Introduction

In recent years ozone layer depletion green house effect gases have increased due to the use of the halogenated chlorofluorocarbons (CFC) and hydrochlorofluorocarbons (HCFC) which have been used in the refrigeration and air-conditioning industry. The search for new refrigerants and the adaptation of the existing systems to the alternative refrigerants have created considerable research activities.

Growing demand for air conditioning has caused a significant increase in demand for energy resources. Solar powered cooling is one of the environmentally friendly techniques which may help alleviate the problem.

Conventional closed cycle require heat source temperatures that are significantly higher than the temperatures of corresponding heat sinks. Thus, they have to be operated with high grade heat extracted from natural gas, steam, concentrating solar collectors.

With dramatic climatic changes in recent years, demand for research concerning cooling systems with solar dehumidification is significant. The application of solar energy in cooling systems can reduce energy demand and decrease the use of theses gases (CFC, HCFC). The focus of the directive is on the reduction of environmental impact through changes in product design.

The use of liquid desiccants in an open cycle system is a promising solution for solar assisted air-conditioning. A possible concept for this system is shown in Fig. 1. The area marked in green represents the air-conditioning system; yellow indicates the solar thermal system and blue the building.

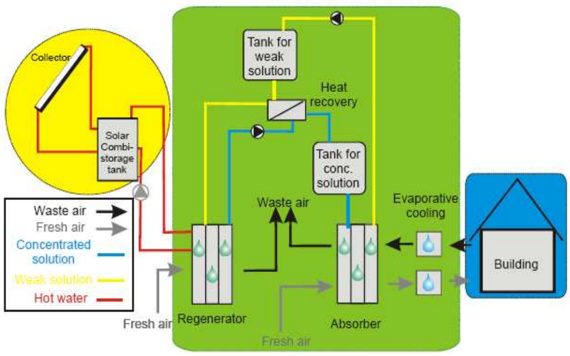


Fig. 1: Design of a solar driven liquid desiccant air-conditioning system (M. Krause) [1].

The main components of this air conditioning open system are the absorber and regenerator. In the absorber, moisture absorbed from the process air stream dilutes the desiccant solution by loading the desiccant with water vapour.

The solution weakened by absorption of moisture is re-concentrated in the regenerator, where it is heated. The heat drives out the moisture and the strengthened solution is returned to the dehumidifier. Liquid desiccant is the salt solution in water and lithium bromide, tri-ethylene glycol, lithium chloride, and calcium chloride are some types of these salt solutions.

Dehumidification using a chemical desiccant was proposed by researchers as a potentially good method to remove the latent load. Compared to solid desiccant systems, liquid desiccant systems are more efficient, easy to install, and have low maintenance costs.

The idea of using a liquid chemical substance (desiccant) for dehumidification was first applied to industrial processes in the early 1930s. Kathabar [2] produced the first cooling and dehumidifying desiccant system in 1937 for a large central system used for an industrial plant.

Several studies have been conducted on the mass transfer in operation of the liquid desiccant dehumidification/regeneration. Al-Farayedi [3] studied the heat and mass transfer between air and liquid desiccant in a gauze type structured packing tower. Three different types of liquid desiccants are compared. It was found that the mixture of calcium chloride and lithium chloride has a significant increase in the mass transfer coefficient compared with the other two solutions.

Mass transfer rate studies were conducted by Li Zhang [4] and dimensionless mass transfer coefficient correlations were obtained for a packed column dehumidifier/regenerator using lithium chloride solution as a liquid desiccant. It was found that, when the air velocity increased from 0.5 to 1.5 m/s, the overall mass transfer coefficient in the structured packing dehumidifier and regenerator varied from 4.0 to 8.5 $g/m^2s$ and from 2.0 to 4.5 $g/m^2s$, respectively.

The study presented by Jaradat [5] designed a plate type cross-flow desiccant based on heat and mass exchanger, built and evaluated as an adiabatic and non-adiabatic absorber and regenerator. The experimental results of supply air dehumidification and cooling show an effective air dehumidification and cooling. The reduction in the supply air humidity ratio, $\Delta\omega$ could reach 4.6 g/kg and a reduction in the supply air temperature, $\Delta T$ of 3.6 K. Desiccant regeneration was possible by using hot water with a temperature started from 55-60 ºC, which suit flat plate solar thermal collectors.

In the present study, experimental equipment is setup for dehumidification/regeneration process. The effects of air parameters on mass transfer of two desiccants are experimentally investigated and analyzed. The results of calcium chloride are compared with those of calcium chloride dehydrate. The experimental results can help in the choice of liquid desiccant.

## 2. Instrumentation and experimental study

The layout of the experimental setup and photograph of the apparatus are shown in Fig. 2. The Conditioning Drying Oven equipment type Memmert HCP 108, with the good overall accuracy was used during absorption and regeneration process. This apparatus includes thermocouples for measure air temperature and relative humidity. The air flow rate is controlled by a valve. The specifications of instrument are listed in Table 1.

Table 1 – Specifications of Conditioning Drying Oven

| Type | MEMMERT HCP 108 |
|---|---|
| Temperature | From 25 °C to 120 °C |
| Relative humidity | From 0 % to 100 %. |

Initially, the air flows over the surface area of the thin layer of desiccant and becomes in direct contact with this desiccant. The air is introduced horizontally into the Conditioning Drying Oven apparatus; and uniformly distributed over its whole surface to achieve the flow conditions while the desiccant solution is placed on plate inside of the apparatus.

Fig. 2. Conditioning Drying Oven

Different experimental tests were carried out. The Calcium chloride desiccant and Calcium chloride dehydrate were used as desiccant. When the partial vapour pressure of process air is higher than that of the desiccant solution at the interfacial area, the moisture of air is then absorbed into the desiccant solution a dehumidification process occurred. On the other hand, when the partial vapour pressure on the air side was lower than that on the desiccant side, a desiccant regeneration process occurred.

## 3. Measurements

Totally, 18 experimental runs were conducted with four test sequences for dehumidification/ regeneration process. The ranges of operating conditions used in dehumidification are presented in Table 2. All data measurements are made where each of them, the climatic conditions were maintained constant. All these data are collected during several days with a time interval of 30 minutes at each test. The measured air and desiccant parameters are used to analyse the process.

A fixed quantity of desiccant was placed on a plate into the Conditioning Drying Oven apparatus. In the dehumidification process the moisture is directly removed from the air by absorbing the moisture by using a strong solution of liquid desiccant. At the surface of plate, moisture absorbed from the process air stream dilutes the desiccant solution by loading the desiccant with water vapour.

Table 2- Experimental measurements: Conditioning Drying Oven

| Parameter | Range | Accuracy |
|---|---|---|
| Air temperature for absorption | 20 to 25 °C | + 0.1 °C |
| Relative humidity | 45 to 90 % | |
| Mass initial of dry salt | 0.1 to 20 g | + 0.001 g |
| Exchange surface diameter | 6.5– 8 – 9 –15 cm | |

Table 3 summarizes the experimental sets; each set consists of four test runs. Experiments are conducted to measure the moisture transfer from air to desiccant during the absorption process. Measurements are carried out at nearly constant ambient conditions.

Table 3: Summary of the operation conditions for air dehumidification

| | Air Temperature °C | Relative humidity % | Quantity of desiccant g | Exchange area diameter cm |
|---|---|---|---|---|
| Test 1 | 20 | 95 | 5 | 9 |
| Test 2 | 28 | 92 / 95 | 5 | 9 |
| Test 3 | 20 – 23 | 92 – 95 | 0.1 – 5 | 9 |
| Test 4 | 20 | 95 | 5 | 6.5 - 9 |

An air stream called regeneration air flows through the dilute solution placed into the Conditioning Drying Oven equipment. After, the desiccant solution reaches its suitable regeneration temperature. By this way, the strong solution is then ready to be concentrated and maintained a continuous dehumidification process. Experimental runs were conducted with heating air temperature of 60 – 80 °C, relative humidity 20 – 23 %, and air flow rate is constant.

## 4. Results and Discussion

Experimental runs have been conducted with different parameters. The principal process of the experimental runs is mass transfer between air and desiccant in dehumidification/regeneration tests in order to compare these two desiccants. Samples of the experimental results, at constant values of air parameters are presented to illustrate the transfer of moisture between the air and desiccant. The mass transfer is the core of dehumidification/regeneration process. As shown in fig. 3(a), the mass increases when the $CaCl_2$ absorbs moisture from air and Fig. 3(b) illustrates the regeneration process when desiccant releases moisture. It can be seen that the mass transfer potential decreases with time. This is mainly due to the decrease in vapour pressure on the desiccant surface, during regeneration, and due to vapour pressure rise on the desiccant surface during absorption.

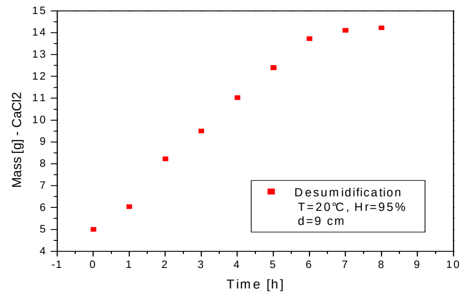


Fig. 3 (a). Absorption process

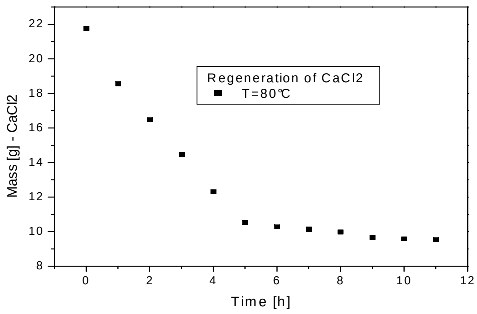


Fig. 3 (b). Regeneration process

To validate the results of mass transfer, an identical experiment was carried out with the same salt and under the similar operation conditions. Fig. 4(a) shows the reproducibility of the absorption process of $CaCl_2$, and Fig. 4(b) shows the reproducibility of the regeneration process of $CaCl_2.2H_2O$, and it can be observed the same results, these curves are superimposed.

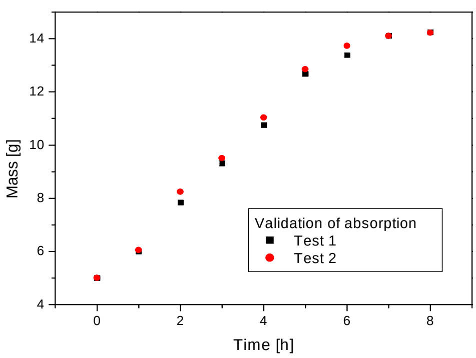


Fig. 4 (a). Validation of absorption process

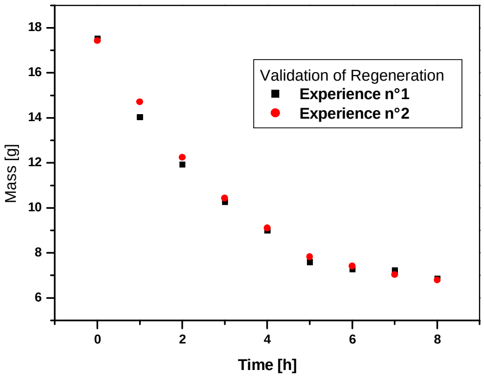


Fig. 4 (b). Validation of regeneration process

## 4. 1. The effect of amount of desiccant

The effect of increasing the initial quantity of desiccant during the absorption process at a fixed air temperature, air flow rate and exchange area is shown in Fig. 5. It can be clearly observed that a higher quantity of desiccant increases the potential mass transfer between the air and desiccant.

In addition, this graph illustrates the evolution of the regeneration process as a function time for the same temperature and exchange area but for two initial masses of solution. It can be observed that the regeneration duration is shorter when the quantity of desiccant used decreases.

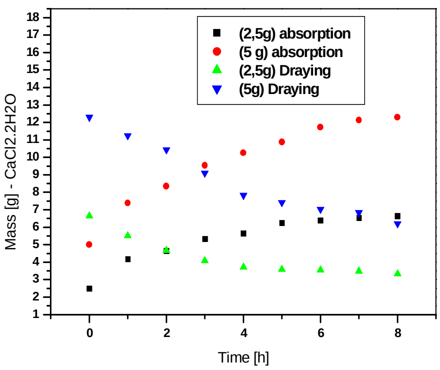


Fig. 5. Effect of quantity of desiccant

## 4. 2. Comparison between two desiccants

In order to compare desiccants $CaCl_2.2H_2O$ and $CaCl_2$ the experiment for absorption/regeneration processes has been carried out, under the similar operating conditions. The following figures show the physical state of these two salts during these processes. It can be seen through Fig. 6(a, b) that the $CaCl_2.2H_2O$ is more rapidly diluted than the $CaCl_2$ at the same time, in the absorption phase. On the other hand, it can be pointed out the appearance of a yellow color at the surface of $CaCl_2$ desiccant but for $CaCl_2.2H_2O$ the color of obtained liquid solution is white color Fig. 6(c, d). In addition, in the final phase of dehumidification process the $CaCl_2$ is more viscous than $CaCl_2.2H_2O$.


Fig. 6(a): $CaCl_2.2H_2O$


Fig. 6(b): $CaCl_2$: absorption

Fig. 6(c): $CaCl_2$ –Yellow color

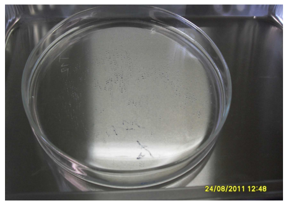


Fig. 6(d): $CaCl_2.2H_2O$: white color

After absorbing, the diluted desiccant is through the solution into the plate. The salt solution swells during regeneration phase and yellow color was observed at the surface Fig. 6(e) and finally the desiccant became concentrated and it looks like a block of hard salt, Figs. 6(f, g). In addition, it can be pointed out that the $CaCl_2.2H_2O$ has become liquid before $CaCl_2$ but during the regeneration phase it was observed the appearance of grain of salt $CaCl_2$ before $CaCl_2.2H_2O$.


Fig.6 (e). Swelling of desiccant

Fig.6 (f). Hard salt

Fig.6 (g). Hard salt

The comparison results of moisture removal express the mass transfer of the dehumidification and regeneration process, which is defined as the moisture variance of the air through these two desiccants. In the dehumidification experimental presented in Fig. 7(a) the absolute difference between these solutions is that the water absorbed by $CaCl_2$ is higher then that absorbed by $CaCl_2.2H_2O$, due to the presence of the water molecules ($2H_2O$) in the latter desiccant. Therefore, the higher mass transfer potential will be the higher moisture removal rate in the same operating conditions.

In the desiccant regeneration experiments, the desiccant is heated to the required temperature. The moisture from the desiccant was released when the desiccant came in contact with the regenerating air and finally the obtained desiccant is concentrated. The comparison of regeneration results at the same air flow rate and similar operating conditions are shown in Fig. 7(b). It can be observed that the $CaCl_2$ solution can be more dried than $CaCl_2.2H_2O$ solution. Then the $CaCl_2$ is able to absorb more moisture in the cycle of the LDCS system. In addition, Fig. 7(c) illustrates the comparison of regeneration in function of the effect of temperature. It can be observed that the $CaCl_2$ is regenerated with less temperature 60 °C compared with $CaCl_2.2H_2O$ which is regenerated at 80 °C.

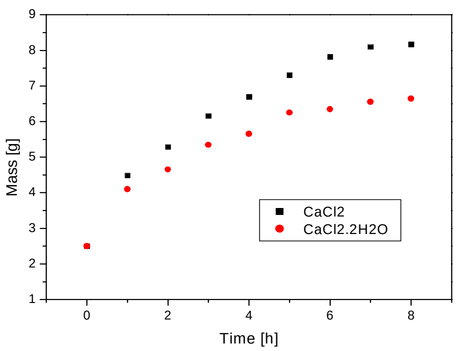


Fig.7 (a). Comparison of absorption

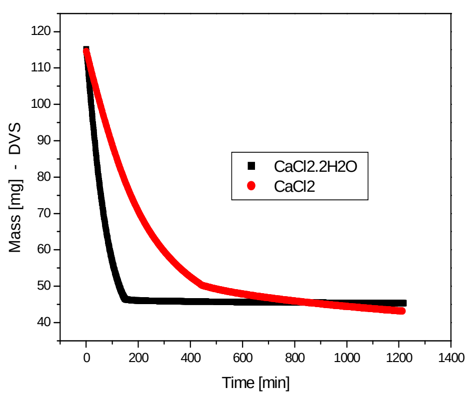


Fig.7 (b). Regeneration at 80°C

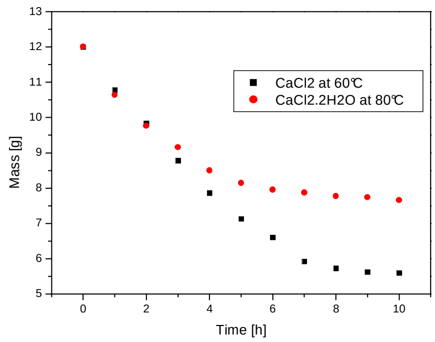


Fig.7 (c). Regeneration at 80° and 60°C

## 5. Conclusion

Conventional air conditioning using (CFC) and (HCFC) refrigerants and having high electrical consumption has a negative environmental impact. The present study aims to eliminate the environment negative impact by using liquid desiccants in the Liquid Desiccant Cooling System; and allows to select the best liquid desiccant according to its properties. One of them is an appropriate alternative for dehumidifying air and for the environment protection. The mass transfer of two liquid desiccants, $CaCl_2$ aqueous solution and $CaCl_2.2H_2O$ aqueous solution, is compared in this paper, including both dehumidification and regeneration processes. The comparison basis of this study is the regeneration temperature, the relative humidity ratio, and the exchange area. At these operating conditions and from the analysis of the experimental data, the following conclusions can be summarized:

(1) In the dehumidification process, the mass transfer potential of $Cacl_2$ solution is better than that of $CaCl_2.2H_2O$ solution in the same desiccant mass flow rate condition due to water molecules present in the letter salt.

(2) In the regeneration process, $CaCl_2$ solution can be more dried than $CaCl_2.2H_2O$ solution, especially in the same operating conditions. Then the $CaCl_2$ is able to absorb more moisture in the cycle of the LDCS system.

(3) Increasing the air regeneration temperature increasing the mass transfer potential, while the period of process is reduced.

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