# EXPERIMENTAL STUDY ON THE TRANSIENT REGENERATION OF MULTI- COAXIAL CYLINDRICAL LAYERS OF CLOTH MATERIAL IMPREGNATED WITH CALCIUM CHLORIDE SOLUTION

دراسة تجريبية على إعادة التركيز الانتقالي لمحلول كلوريد الكالسيوم
محمل على طبقات اسطوانية متحدة المحور مصنعة من قماش قطني

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**خلاصة :**

الطاقة الكهربية المستهلكة في أنظمة تكييف الهواء يمكن ترشيدها وذلك عن طريق التحكم في درجة حرارة ورطوبة الهواء المار بدورة التكييف وذلك باستخدام المحاليل الماصة للرطوبة. وحيث أن الجزء الأكبر من الطاقة المطلوبة و المرتبطة بهذه العملية هي المستخدمة في تسخين المحلول الماص عند درجة حرارة منخفضة لإعادة تركيزه، فان إجراء إعادة تركيز الماص يؤثر بشدة على أداء نظام التكييف ككل. وعليه فان دراسة تأثير المتغيرات المختلفة وعلى الأخص درجة حرارة دخول الهواء , معدل تصرف الهواء والتركيز الابتدائي للماص، على إجراء إعادة التركيز تكون ذات أهمية كبيرة. في هذا البحث المعملي تم استخدام مهد يجمع بين الخواص الجيدة لانتقال الكتلة مع فقد صغير في الضغط الناتج عن سريان الهواء خلاله. يتكون المهد المستخدم من طبقات متعددة من أسطح أسطوانية متحدة المحور و مصنوعة من قماش قطني كحامل لمحلول مجفف من ملح كلوريد الكالسيوم و الماء. باستخدام النتائج العملية تم تقدير كميات المياه المبخرة من المحلول إضافة إلى تغير تركيزه أثناء فترة إعادة التركيز كدالة في ظروف الدخول السابق ذكرها.

تم صياغة معادلات تجريبية لحساب كمية المياه المبخرة كدالة في درجة حرارة دخول الهواء، معدل سريان الهواء و التركيز الابتدائي للمحلول المجفف بالاضافة إلى تركيز المحلول وزمن التجفيف لتساعد في تصميم هذا النوع من المهد.

## ABSTRACT

Desiccant cooling can provide control of temperature and humidity, while at the same time lowering the electrical energy requirement for air conditioning. Since the largest energy requirement, associated with desiccant cooling, is low temperature heat for desiccant regeneration, the regeneration process greatly influences the overall system performance. Therefore, the effect of variables such as air inlet temperature, air mass flow rate and initial desiccant concentration on the regeneration process are of great interest. In the present experimental work a high performance bed that combines good mass transfer characteristics with low pressure drop is used. The bed consists of multi-coaxial cylindrical layers made up of cotton cloth as a holder for liquid calcium chloride desiccant. The accumulated mass of evaporated water as well as the solution concentration during the regeneration period is assessed based on the variables listed above.

The solution concentration and accumulated mass of regenerated water are correlated with air inlet temperature, air mass flow rate and desiccant initial concentration. The functional correlations developed should be useful in the design of such regenerators.

**Keywords:** regeneration, Calcium Chloride bed, cloth material

## INTRODUCTION

Regeneration of aqueous solutions is an important process in open cycle solar space cooling systems. Liquid desiccant cooling can provide control of temperature and humidity, while at the same time lowering the electrical energy requirement for air conditioning. The largest energy requirement associated with the use of desiccant cooling is low temperature heat for desiccant regeneration, and this heat can be provided by solar flat-plate collector

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system or by waste heat However, the auxiliary energy requirement for desiccant regeneration can be large, Öberg and Goswami [1], so that the effectiveness of the desiccant regeneration process greatly influences the overall performance of the desiccant systems. Öberg and Goswami [2] give a more detailed review of liquid desiccant system configurations.

Peng and Howel [3] have modeled the performance of desiccant regenerators. An open surface trickle solar collector regenerator, a glazed trickle solar collector regenerator, and a regeneration chamber containing a finned tube-heating coil were analyzed and compared. The authors concluded that an open solar collector regenerator wasn't practical for hot and humid climates.

Löf [4] proposed a solar space cooling system in which the weak desiccant is regenerated in a chamber by the use of air from a solar collector. The chamber may be a spray tower or packed tower and it could be used for dehumidification purposes also In the spray tower, the solution is sprayed into the air stream by means of a nozzle, which disperse the solution into a fine spray This equipment has the advantage of low air pressure drop but this is offset by a relatively high pumping cost for the solution. Recently, Queiroz et al. [5] have proposed a method for calculating the mass transfer coefficient for dehumidification operation in a spray tower based on the Merkel integral approach. In a packed tower the solution is fed in at the top of the tower and distributed over the packing, through which it falls, by gravity. The packing is designed [6,7] to distribute the liquid over a large surface, thereby providing a large air-liquid contact area. The air enters at the bottom of the tower producing counter-current flow of the two streams There are no moving internal parts. However, power is required to blow the air and to lift the liquid to the top of the tower. The disadvantage of the packed tower is that the air pressure drop through the packing is generally high. However, the packed tower facilitates high mass transfer by providing a large amount of surface area in a relatively small volume. Further, the pressure drop in the liquid circuit is small

Leboeuf and Löf [8] have used a packed tower for reconcentration of lithium chloride solution for an open cycle absorption air conditioning system. Factor and Grossman [9] have studied the packed column as applied to air dehumidification and regeneration in solar air conditioning with liquid desiccants Biswal et al [10] have developed a mathematical model for a packed tower for a solar driven food-processing units Gandhidasan et al. [11] calculated the heat and mass transfer coefficients in a packed tower with a desiccant-air contact system. For this study, aqueous calcium chloride solution is used; ceramic Rasching rings and Berl saddles are used as the packing material They correlated the air phase transfer coefficients with flow rates of air and liquid and the temperature of air, whereas liquid phase coefficients are correlated with rate of air and liquid flow, and the temperature and concentration of the liquid.

Regeneration of lithium chloride in a packed bed was examined experimentally by Lof et al. [12] With the air providing the heat for the regeneration process, this study examined the overall heat and mass transfer coefficients as a function of flow rates and inlet temperatures. Patnaik et al. [13] conducted experiments on a packed bed tower for the regeneration of aqueous lithium bromide. They studied the influence of the type of liquid distribution system on the performance of the regenerator, and presented correlations based on experimental results for the rate of water evaporation as a function of inlet air temperature, humidity, inlet desiccant concentration and flow rate.

Hamid et al [14] and Sultan et al [15] studied experimentally the effect of inlet parameters on the performance of packed tower-regenerator for regeneration of liquid calcium chloride solution. They concluded that the regeneration process was highly dependent on the air inlet conditions, namely, temperature, humidity and flow rate Also, effect of liquid temperature, concentration and flow rate was discussed The obtained data was correlated to estimate the rate of water evaporation (regeneration rate).

Inconvenience and relatively high cost of continuously transporting solid particles as required in steady-state operations frequently make it more economical to pass the fluid mixture to be treated through a stationary bed of absorbent. As increasing amount of fluids are passed through such a bed, the solid absorbs increasing amount of solute, and unsteady state prevails. Analysis of transient heat/ mass transfer and adsorption/desorption interaction cane be found in Ref. [16].

The use of solid adsorbents requires relatively high regeneration temperature, compared with liquid desiccants such as Calcium Chloride and Lithium Chloride. On the other hand, the use of liquid absorbents leads to the requirement of an apparatus, in which continuous transporting of liquid solutions is carried out. However, liquid desiccants can be used in stationary beds when solid porous beds carrying the liquid desiccants are applied. Hamid [17] and Sultan [18], presented theoretical and experimental studies on the transient adsorption characteristics of porous beds. Simplified analytical solutions were presented for the present adsorption systems In the experimental part of these studies, Hamid [17] used porous granules of burned clay as desiccant carrier, while Sultan [18] used parallel multi layers of cloth material, made of cotton knitted fabric, as the desiccant carrier in fixed bed. The granules and cloth material were impregnated with liquid Calcium Chloride solution to form the adsorbing beds Isothermal adsorption of water vapor from atmospheric air was experimentally studied. Transient values of the mass of absorbed water, solution concentration and vapor pressure through the beds were evaluated from the experimental measurements.

In the present work, the performance of regeneration column of multi- coaxial cylindrical layers of cotton knitted fabric with Calcium Chloride as the desiccant solution is investigated, since it provides very large surface area per unit volume, no power consumption for desiccant solution circulation and minimum pressure drop of air across the stationary bed.

## EXPERIMRNTAL SET-UP

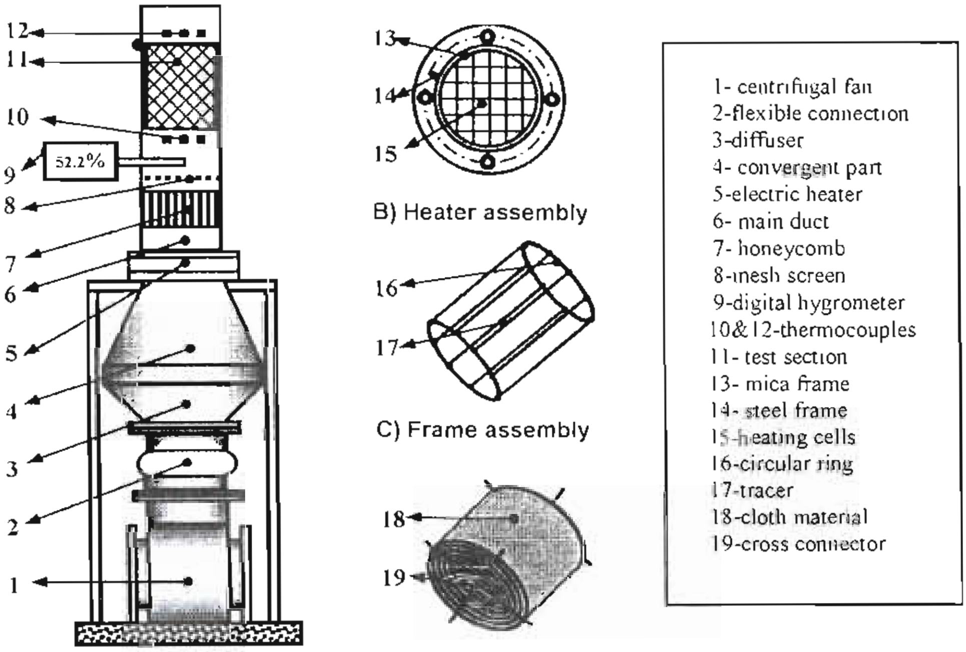
Figure 1 presents the details of the experimental set-up It consists of three main parts: wind tunnel, test section and measuring equipment.

### *Wind tunnel:*

The present experiments have been carried out with the aid of a low-speed open loop wind tunnel as shown in Figure 1-A.. Room air is sucked in by a double inlet centrifugal fan (1) and pumped to the diffuser (3) through a flexible connection (2). A converging part (4) is connected to the diffuser to obtain a uniform air stream, Afterward, the air passes through a cylindrical duct (6) of 216 mm ( 8.5 inches) diameter. A honeycomb (7) and a screen (8) are provided at the entrance of the cylindrical duct. The electric heater (5) is designed so as to give uniform heat generation across the duct cross section The details of the heater are shown in Fig 1-B. It consists of two circular mica frames (13) 1mm thickness fixed separately on the surface of two circular steel frames (14) of 1 mm thickness. The heating wire is uniformly wounded through the mica frames in the form of parallel lines. The two steel frames are collected together with mica spacer frame in order to have square heating cells (15) as shown in Fig. 1-B.

### *Test section:*

The test section (11) is located at the end of the duct in order to facilitate taking it out and weighing it during the experiments. It consists of aluminum frame covered with cotton cloth layers. Each frame, Fig. 1-C, consists of two circular rings (16) made of aluminum sheet of 3-mm width and 1 mm thickness. Eight aluminum sheets (17) of 3-mm width, 1-mm thickness and 170-mm length are welded on the outer perimeter of the rings to form a cylindrical frame as shown in Fig 1-C The cloth material is wounded around the cylindrical frames to form cylindrical surfaces Seven cloth cylinders (18) of 27, 54, 81, 108, 135, 162 and 189 mm diameters are collected together using two aluminum crosses (19), one at each end, to form the test section as shown in Fig. 1-D. The cloth material is prepared from cotton knitted fabric of total surface area of 0.8075 $m^2$ and a net dry weight of 106.1 gm The cloth material used has a thickness of 1.7 mm under no load conditions [18] The duct portion that contains the test section is well insulated using multi-layers of glass wool insulation of 50-mm total thickness. Two thermocouples are fixed inside the glass wool insulation with a radial distance of 10 mm to estimate the heat lost from the flowing air to the surroundings The monitored temperature difference give a maximum heat lost of about 3 % of the total heat transferred from the flowing air stream to the bed




A) Wind tunnel assembly D) Test section assembly

**Fig 1 Details of the experimental set-up**

## *Measuring equipment:*

The local flow velocity is measured by means of a hot wire anemometer at different locations in the x and y directions at a section just before the test section, and is integrated to get the average air velocity. The power input to the heater is controlled by using an auto-transformer and is monitored using an ammeter and voltmeter. Referring to Fig. 1-A, the air dry bulb temperature at inlet and outlet of the test section is measured by two sets of thermocouples (10&12). Each set consists of nine thermocouples The thermocouples are connected to a digital temperature recorder with a resolution of 0.1 $^oC$ via a multi switch. A digital hygrometer (9), with a resolution of 0.1%, is used to measure the air relative humidity at inlet to the test section. To evaluate the mass of regenerated water from the bed, a digital balance of full scale of 600 gm and 0.02 gm resolution is used. The porosity and thickness of cloth material are taken from the experimental work on the same kind of material reported by Sultan [18]. Air relative humidity and mean dry bulb temperature are used to determine the humidity ratios of air passing through the test section.

### *Experimental Procedure*

Before starting the regeneration experiments, cloth bed is humidified using a cold stream of air at a temperature of 293 K and 57.3 % relative humidity. To ascertain uniform desiccant concentration for the cloth bed, it is turned over during absorption Three groups of experiments are carried out. In the first group, bed initial concentration is 35±0 75 wt%, air velocity is 0.75 m/s and the air inlet temperature is varied from 309.2 K to 325.2 K. In the second group of experiments, bed initial concentration is varied from 20 to 36 wt%, air velocity is 0 75 m/s and air inlet temperature is 316.7±0.5 K. While in the third group, initial concentration is 34.8±0.8 wt%, inlet air temperature is 309 5±0 5 K and air velocity is varied from 0 5 to 3 m/s During the experiments, air inlet velocity, temperature and humidity are recorded with time.

### *Analysis of the experimental measurements*

In the present analysis, only the mass transfer aspect in the cloth bed is considered The aim of the experimental work is to study the transient variation of desiccant properties during the regeneration process, for different air mass flow rates, air inlet temperatures and initial concentrations of the bed. Another objective is to obtain empirical equations to describe the instantaneous concentration, and mass of regenerated water as a function of the operating parameters

Evaluation of the desiccant parameters, from measurements of mass of regenerated water in the bed is discussed below. Solution concentration ($x_s$) is defined as the ratio of mass of salt $M_{st}$ to the mass of solution $M_s$, which equal the summation of the mass of water $M_w$ and mass of salt contained in the solution, i.e.

$$x_s = M_{st} / M_s, \text{ and} \tag{1}$$

$$M_s = M_{st} + M_w \tag{2}$$

To evaluate the instantaneous value of desiccant concentration $x_{s,t}$ during the regeneration of desiccant in the bed, the following expression can be used.

$$x_{s,t} = x_{s,i} M_{s,i} / M_{s,t} \tag{3}$$

Where the subscripts i and t refer to the initial and instantaneous values of $x_s$ and $M_s$ By knowing the initial concentration of the bed and initial mass of solution, the instantaneous value of concentration can be obtained from the measurement of the mass of absorbed water, using equations (1 and 2) in the following combined form,

$$(1/ x_{s,i}) - (1/ x_{s,t}) = (M_{s,i} - M_{s,t})/ M_{st}, \text{ and} \tag{4}$$

$$M_{s,i} - M_{s,t} = M_{b,i} - M_{b,t} \tag{5}$$

Where $M_{b,i}$ and $M_{b,t}$ are the initial and instantaneous mass of bed, respectively

The vapor pressure ($pv_s$) on the solution surface can be evaluated by knowledge of bed temperature and solution concentration and applying the correlation presented by Sultan . [18] as,

$$pv_s = B(T) + C(T)/ x_s \tag{6}$$

Where B(T) and C(T) are regression constants depending on bed temperature.

Defining the water vapor pressure in air by $pv_a$, the vapor pressure difference between desiccant and air $\Delta pv$ can be calculated as follows:

$$\Delta pv = pv_s - pv_a \tag{7}$$

The transient variation of humidity ratio of air stream flowing through the bed $\omega_t$ can be evaluated as follows:

$$\omega_t = \omega_i + R/G_a \tag{8}$$

Where $\omega_i$ is the air initial humidity ratio, $G_a$ is air mass flow rate and R is the rate of water regenerated, calculated as follows:

$$G_a = \rho_a u_a A_c \tag{9}$$

$$R = W / \Delta t \tag{10}$$

Where, $u_a$ is the air mean velocity measured in cross section just before the test section and W is the accumulated mass of regenerated water, calculated as follows.

$$W = (M_{s,i} - M_{s,t})/ \Delta t \tag{11}$$

*Dimensional analysis*

From the kinetics of regeneration process one can observe that, the accumulated mass of regenerated water W and the solution concentration $x_{s,t}$ depend on air mass flow rate $G_a$, air inlet temperature $T_a$, air inlet humidity ratio $\omega$, solution initial concentration $x_{s,i}$ and vapor pressure difference $\Delta pv$ Adding to these independent parameters the air properties, air standard temperature (288.15 K), mass of bed material, and using the principals of dimensional analysis, the following dimensionless parameters can be obtained:

| | | |
|---|---|---|
| Dimensionless air mass flow rate | $G_D = G_a / D \mu_a$ | (12) |
| Inlet air temperature ratio, | $T_R = T_a / 288\ 15$ | (13) |
| Dimensionless regeneration time, | $\tau = \nu_a t / D^2$ | (14) |
| Mass ratio of regenerated water, | $W_R = W / M_b$ | (15) |
| Initial concentration ratio, | $X_i = x_{s,i} / x_a$ | (16) |
| Instantaneous concentration ratio, | $X_t = x_{s,t} / x_a$ | (17) |

Dimensionless vapor pressure difference, $\pi = \Delta pv / pv_a$ (18)

From the foregoing analysis, the dimensionless output parameters $W_R$ and $X_t$ can be set as a function of $G_D$, $T_R$, $W_R$ and $\tau$

## RESSULTS AND DESCUSSION

The performance of the regenerator may be described by the outlet concentration of the desiccant and the accumulated mass of regenerated water. These are influenced by air flow rate, air inlet temperature and desiccant initial concentration.

The exchange of water vapor between air and desiccant depends on the relative magnitude of water vapor pressure in the air and at the surface of the desiccant. When calcium chloride solution is brought into contact with air with a given water vapor partial pressure, as shown in Fig. 2, water will be transferred from the air to calcium chloride solution that has a temperature below $T^*$ and in the reverse direction for calcium chloride solution temperatures greater than $T^*$. Thus, for regeneration to occur the vapor pressure of the desiccant must be higher than the partial pressure of water in the air. In other words, the driving force for regeneration is the difference between the partial pressure of the water in the air and the water vapor pressure on the desiccant surface

### *Temperature distribution*

The bed temperature in all experiments, of course, equals the ambient temperature just before starting the heat and mass transfer process between air stream and desiccant bed. In other words the bed temperature is lower than the inlet temperature of the hot air stream at the beginning of the regeneration process. Because it is difficult to fix therocouples inside the cloth layers of the bed, due to their small thickness, the temperature of the bed can not be measured. But it can be calculated applying a heat balance between the bed and the flowing through it hot air, assuming no heat lost to the surrounding, as follows

Heat lost from hot air = heat gained by the bed + heat of evaporation of regenerated water, i.e.

$$G_a\, cp_a\, (\Delta T)_a\, \Delta t = (M_c\, cp_c + M_f\, cp_f + M_s\, cp_s)\, (\Delta T)_b + W\, L \quad (19)$$

Where, subscripts a, c, f, s and b refer to air, cloth material, frame material, desiccant solution and bed respectively While L denotes the latent heat of water taken at the arithmetic mean temperature of the ambient and the hot air entering trough the bed From the above equation one can calculate the bed mean temperature as a function regeneration time.

As a result of the small heat capacity of the desiccant bed, its temperature increases sharply during a small time interval from the beginning of the regeneration process, and consequently the outlet temperature of the hot air stream decreases sharply at the beginning of the process due the transient heat transfer between it and the desiccant bed Increasing the regeneration rate, the rates of change of both air outlet temperature and bed temperature decrease with time until they reach nearly constant values at a certain time. In other words, the mean temperatures of air and bed increase with time and reach their maximum value at a certain time Figure 3 shows the variation of the mean temperatures of air and desiccant with time for a sample of experiments performed in the present study, which supports the foregoing discussion Also, It can be concluded that any increase in the inlet temperature of hot air stream increases its mean temperature and consequently increases the mean temperature of the desiccant bed.

*Effect of regeneration time*

The variations of the dimensionless vapor pressure difference $\pi$, dimensionless mass of regenerated water $W_R$ and solution concentration ratio $X_t$ for different parameters are shown in Figures 5-13. From the over view of these figures, one can observe that $W_R$ and $X_t$ increase with time as a result of the mass transfer between desiccant bed and air stream flowing through it. The dimensionless vapor pressure difference $\pi$ increases rapidly through a relatively small period of time, relative to the total regeneration time, until it reaches a maximum value and then decreases with further increase in time until it reaches nearly zero at the end of the regeneration process. This trend of variation may be explained as follows

Referring to the temperature-pressure-concentration diagram of calcium chloride water solution, developed from the data of Ref [19], presented in Fig 4, It is seen that, the vapor pressure on the desiccant surface increases with desiccant temperature and decreases with the increase of desiccant concentration. The resultant of these two effects depends on the rate of change of each of them. Referring to Figure 3, one can observe that the desiccant mean temperature increases rapidly through a small period of time from the beginning of the regeneration process Further increase in time increases desiccant mean temperature until it reaches a maximum value, in general less than the mean temperature of the flowing air stream, and then remains nearly constant to the end of the process. As a result the vapor pressure on the desiccant surface increases rapidly until it reaches its maximum value, at a certain temperature-concentration combination. Further increase in time leads to an increase in the desiccant concentration with nearly constant value of desiccant mean temperature, and consequently the vapor pressure decreases with time as shown in Fig 4 As the water vapor pressure in the air is nearly constant, due to the nearly constant humidity ratio, the dimensionless vapor pressure difference follows the same trend of variation of the vapor pressure on the desiccant surface as shown in Figures 5 , 9 and 13

*Effect of air inlet temperature*

Increasing air inlet temperature increases bed temperature and consequently increases vapor pressure on the desiccant surface, and hence, there is an increase in the dimensionless vapor pressure difference between the desiccant and the air, as shown in Fig 5. As the potential for mass transfer increases with air inlet temperature, the desiccant evaporates more water to the air, hence, the dimensionless accumulated mass of regenerated water increases as shown from Fig. 6. The increase in accumulated mass of regenerated water leads to an increase in the desiccant concentration ratio as shown in Fig. 7.

*Effect of desiccant initial concentration*

Increasing the initial concentration of the desiccant decreases the water vapor pressure on the surface of the desiccant, and this in tern decreases the vapor pressure difference between desiccant and air at constant air humidity ratio as shown from Fig. 8. As a result of decreasing the vapor pressure difference the amount of regenerated water decreases as shown from Fig. 9 Figure 10 indicates the relation between desiccant concentration during regeneration period and the regeneration time It is seen from the figure that desiccant concentration increases with initial concentration of the desiccant This is because of the increasing mass of regenerated water during the regeneration period and the increased initial concentration.

*Effect of air mass flow rate*

Since increasing air flow rate results in an increase in mass transfer coefficient between desiccant bed and air stream, it consequently results in an increase of mass of regenerated water, as shown from Fig. 11 Increasing the accumulated mass of regenerated water increases the desiccant concentration ratio as shown in Fig. 12. Any increase in desiccant concentration leads to a decrease in the water vapor pressure on the desiccant surface, see Fig 4, and therefore, the vapor pressure difference decreases with the increase of air mass flow rate as seen from Fig. 13 One can observe from this group of figures that the air mass flow rate has a small effect on the regeneration process compared to other inlet parameters

## CORRELATIONS

In order to facilitate using the experimental results obtained in the present work in designing similar regeneration columns, the obtained data is correlated by use of statistical analysis [20] to estimate the values of accumulated mass of regenerated water and the instantaneous concentration of the desiccant from values of inlet parameters that influence the regeneration process

The regression equations obtained from the experimental data are,

$$X_t = 2.0016\,\tau^{0.0853}\,G_D^{-0.016}\,T_R^{-9.33}\,X_i^{0.9927}, \qquad (20)$$

$$W_R = 0.00866\,\log(0.196\,\tau)\,G_D^{0.0988}\,T_R^{25.44}\,X_i^{-1.356} \text{ and} \qquad (21)$$

$$605.5 \le G_D \le 3632.9, \quad 1.072 \le T_R \le 1.1284 \text{ and } 0.4739 \le X_i \le 0.84557$$

Figures 14 and 15 show the plots of the dimensionless regeneration time and the experimental values of dimensionless accumulated mass of water and dimensionless solution instantaneous concentration presented in the following modified forms respectively,

$$(\text{Modified } W_R) = W_R\,G_D^{-0.0988}\,T_R^{-25.44}\,X_i^{1.356} \text{ and}$$

$$(\text{Modified } X_t) = X_t\,G_D^{0.016}\,T_R^{9.33}\,X_i^{0..9927}$$

Lines representing equations 20 and 21 are also included in the above figures. The experimental values of $X_t$ and $W_R$ are found to agree with the above equations within ±25% and ±20 % respectively.

Using the above two equations, one must keep in mined that $X_t$ equal unity at the end of the regeneration process So substituting with $X_t = 1$ in equation 20 enables calculation of the maximum regeneration time $(\tau)_{max}$ as a function of $G_D$, $T_R$ and $X_i$. Using equations 20 and 21 one can calculate $X_t$ and $W_R$ at any regeneration time in the range $0 < (\tau) \le (\tau)_{max}$

## CONCLUSIONS

An experimental apparatus has been constructed in order to investigate liquid desiccant behavior in bed consisting of multi-coaxial cylindrical layers made up of cotton knitted fabric impregnated with calcium chloride solution. The different design parameters affecting the performance of the present regenerator have experimentally investigated It is found that the change in calcium chloride concentration across the regenerator and the accumulated mass of regenerated water are strong functions of inlet air temperature and bed initial concentration, and weak functions of air mass flow rate. Based on the experimental results correlations are presented for the effect of different parameters on desiccant concentration and accumulated mass of regenerated water Predicted values by these correlations are generally in fair agreement with the experimental results, and should be useful for design purposes.

Experimental results are also presented graphically provide insight into the influences of different parameters on regeneration performance.

## NOMENCLATURE

| | |
|---|---|
| A | Regeneration area $m^2$ |
| b | barometric pressure, mm Hg |
| B(T) | temperature dependent constant of Eq 6 |
| C(T) | temperature dependent constant of Eq. 6 |
| cp | specific heat, J/kg K |
| D | hydraulic diameter, m |
| G | mass flow rate, kg/s |
| $K_G$ | mass transfer coefficient, kg/$m^2$s |
| L | latent heat of water, J/kg |
| M | mass, kg |
| Pv | vapor pressure, Pa |
| R | regeneration rate, kg/s |
| T | temperature, K |
| t | time, s |
| u | velocity, m/s |
| V | volume, $m^3$ |
| W | accumulated mass of regenerated water, kg |
| x | solution concentration, kg/kg |
| X | Solution concentration ratio |

### Greek symbols

| | |
|---|---|
| $\Delta M$ | mass difference, kg |
| $\Delta pv$ | Vapor pressure difference, Pa |
| $\Delta T$ | temperature difference, K |
| $\varepsilon$ | porosity |
| $\nu$ | kinematic viscosity, $m^2$/s |
| $\pi$ | Dimensionless vapor pressure difference |
| $\tau$ | dimensionless time |
| $\omega$ | air humidity ratio, kg water /kg air |

### Subscripts

| | |
|---|---|
| a | air or at equilibrium with air |
| b | bed |
| c | cloth material or cross section |
| D | dimensionless |
| f | frame |
| i | initial |
| s | solution or surface |
| st | salt |
| t | instantaneous |
| w | water |
| $\Delta t$ | time interval |

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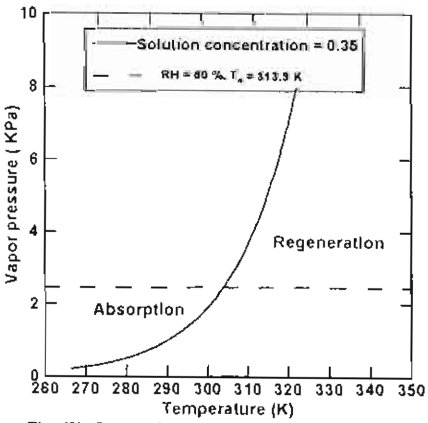


*Fig. (2) Comparison of water vapor pressure in the calcium chloride solution and vapor partial pressure in the ambient air.*

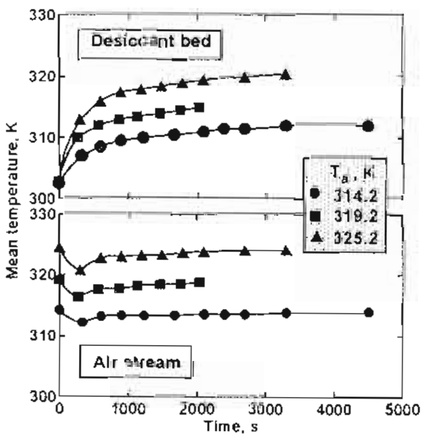


*Fig (3) Variation of air and desiccant temperatures with time for different inlet temperatures of air.*

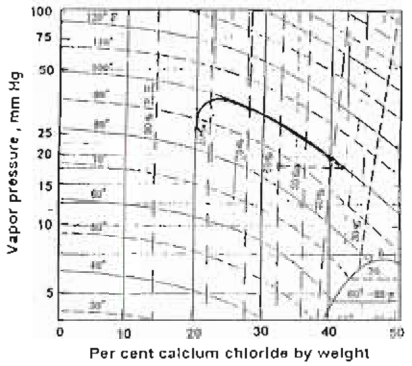


*Fig. (4) Temperature-pressure-concentration diagram of saturated calcium chloride-water solutions.*

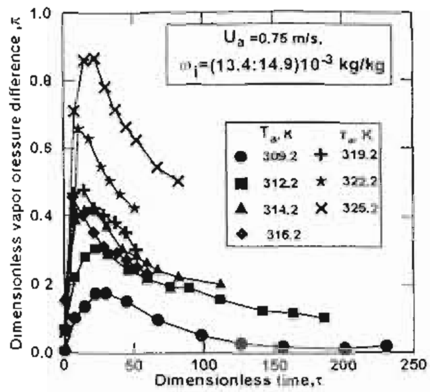


*Fig (5) Variation of dimensionless vapor pressure difference with dimensionless time for different air tepmeratures.*

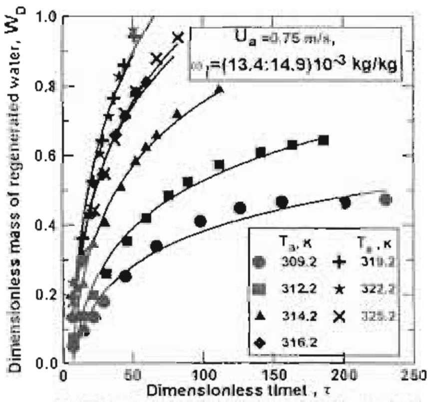


*Fig (6) Variation of dimensionless mass of regenerated water with dimensionless time for different air tepmeratures.*

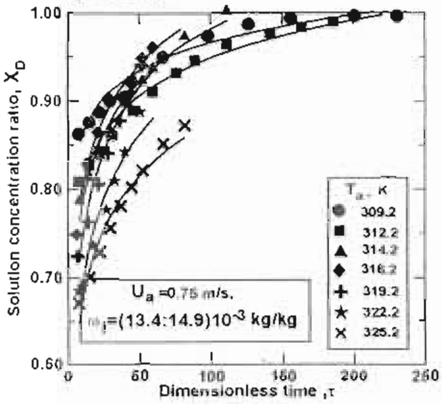


*Fig (7) Variation of solution concentration ratio with dimensionless time for different air tepmeratures.*

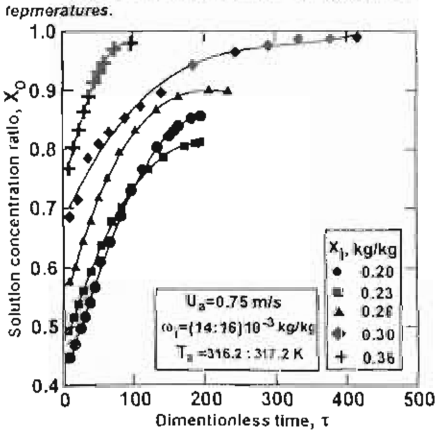


*Fig (8) Variation of solution concentration ratio with dimensionless time for different masses of salt.*

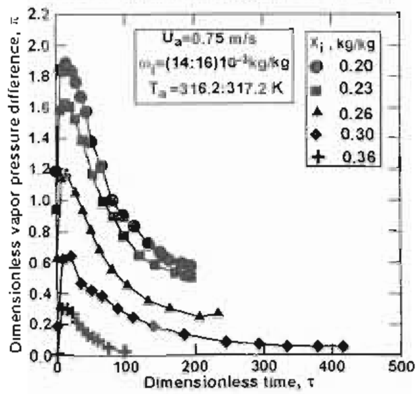


*Fig (9) Variation of dimensionless vapor pressure difference with dimensionless time for different masses of salt.*

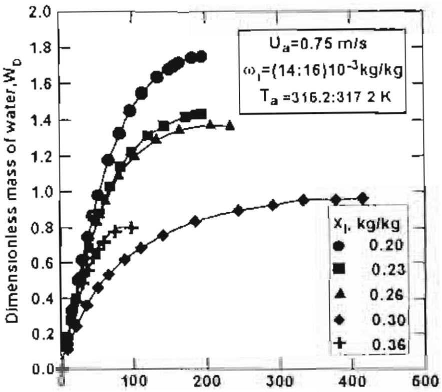


*Fig (10) Variation of dimensionless mass of accumulated water with dimensionless time for different desiccant inlet concentrations.*

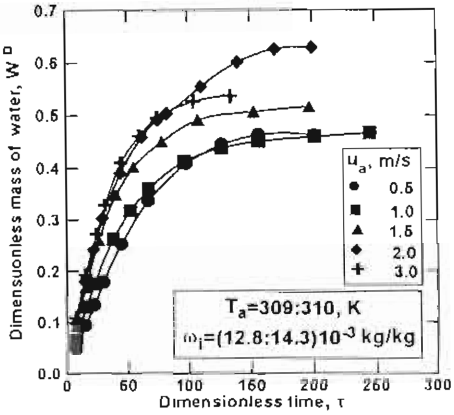


*Fig (11) Variation of dimensionless mass of water with dimensionless time for different air velocities.*

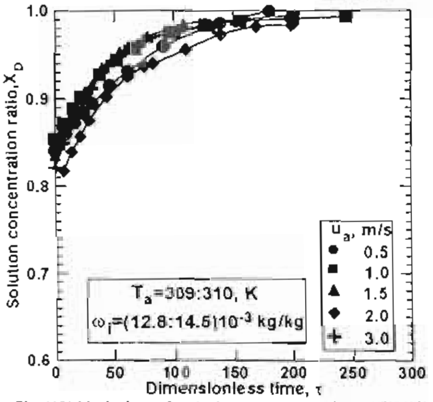


*Fig (12) Variation of solution concentration ratio with dimensionless time for different air velocities.*

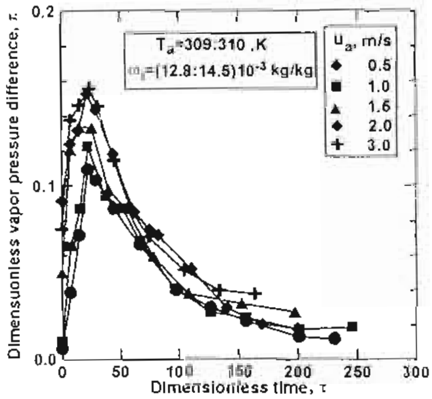


*Fig (13) Variation of dimensionless vapor pressure difference with dimensionless time for different air velocities.*

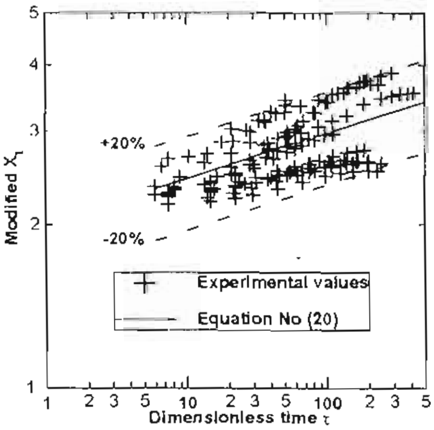


*Fig. (14) Agreement between equation 20 and modified dimensionless desiccant concentration*

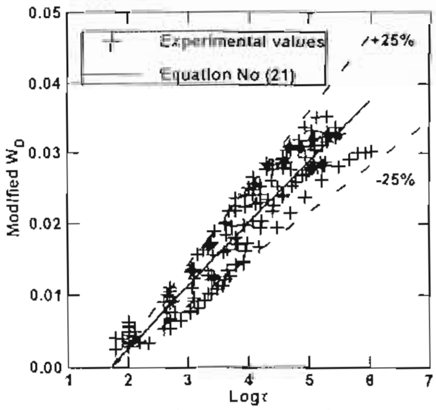


*Fig. (15) Agreement between equation 21 and modified ratio of accumulated mass of regenerated water*