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EXPERIMENTAL INVESTIGATION ON THE ADSORPTION /DESORPTION PROCESSES USIND SOLID DESICCANT IN AN INCLINED - FLUIDIZED BED

دراسة تجريبية حول عمليتي الامتزاز وإعادة التوليد باستخدام مجفف صلب داخل مهد مميع مائل

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ملخص البحث

يتناول هذا البحث دراسة تجريبية حول عمليات الامزاز (**adsorption**) وإعادة التوليد (**desorption**) لمجفف عبارة عن حبيبات من **السيليكا جل داخل مهد مميع مائل**. و قد تم استخدام أنبوب زجاجي ، للتمكن من الملاحظة البصرية، في وضع يميل على الأفقي بزاوية ٤٥ درجة وتحتوي على حبيبات المجفف . في أثناء التجارب العملية تم تحديد سعة الامتزاز للمهد بطريقة وزنية. في هذه الدراسة تم التعرف على مدى تأثير معدل سريان الهواء الجوي داخل المهد على كل من عمليتي الامتزاز وإعادة التوليد. وقد أمكن مراقبة التغير في شكل الحبيبات عن طريق الملاحظة البصرية وهذا التغير يعبر عن مدى احتواء هذه الحبيبات على بخار الماء الممتز وكذلك درجة جفاف الحبيبات وذلك حيث أن لون الحبيبات يعبر عن محتواها من الماء. ومن خلال تحليل النتائج تبين أن كلا من معدل الامتزاز وإعادة التوليد لحبيبات السيليكا يزداد بصورة ملحوظة (خاصة في إعادة التوليد) مع زيادة معدل سريان الهواء داخل المهد. كما أثبتت التجارب أنه يمكن استخدام هواء مسخن عند درجة حرارة ٩٠ درجة مئوية لإعادة طرد البخار من الحبيبات مرة أخرى مما يسمح باستخدام مصادر حرارية ذات درجات حرارة منخفضة نسبيا لتحقيق هذا الغرض. **كما بينت الملاحظة البصرية أن عمليات الإمتزاز وكذلك إعادة التوليد تتم داخل المهد بصورة متجانسة وهذا يعتبر من أهم مميزات استخدام المهد المائل وكذلك من أهم نتائج الدراسة** حيث أن تجانس احتواء الحبيبات على بخار الماء يزيد من كفاءتها في كل من عمليتي الامتزاز وإعادة التوليد.

ABSTRACT:

This paper presents an experimental investigation on the adsorption and desorption operations in an inclined – fluidized bed using silica gel as the working desiccant. The experimental system involves a circular glass tube containing the particles of silica gel, which is tested at an inclination angle of 45°. The moisture capacity of the bed is measured using a gravimetric technique. Process air at nearly constant ambient parameters (humidity and temperature) and different values of flow rate are used during adsorption. Moisture concentration in the bed is analyzed through visual observation of the color of silica gel particles. Experimental measurements indicate that the regeneration and adsorption rates are highly dependent on the air stream velocity. A satisfactory regeneration rate is confirmed at regeneration temperature as low as 90°C when inclined – fluidized bed is applied. The transient –state moisture transfer rates during adsorption and desorption are presented. Finally,

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observation of the movement and color of the particles in the bed show regular circulation and homogenous distribution of moisture concentration.

Keywords: Adsorption ; desorption; silica gel ; Desiccant ; inclined – fluidized bed.

INTRODUCTION

The use of desiccant cooling and dehumidification systems for building comfort conditioning has increased steadily during the past several years. From the view point of the global environment and energy sources, these systems are considered as a good alternative for air conditioning.

The process of air conditioning composed of air dehumidification through direct contact with a hygroscopic agent, is known and reported by different investigators[1-4]. A comprehensive review and bibliography of solid desiccant technology and air cooling processes can be found in literature [5].

Solid sorption passes the air through a bed of granular desiccant or through structured packing impregnated with desiccant [6]. Humid air passes through the desiccant, which in its active state has a vapor pressure below that of humid air. Thus vapor pressure differential drives the water vapor from the air onto the desiccant. After becoming saturated with moisture, the desiccant is regenerated by heating, which raises the vapor pressure of the material above that of the surrounding air. With the vapor pressure differential reversed, water vapor moves from the desiccant to the reactivation air, which carries the moisture away from the equipment.

Solid desiccants such as silica gel, zeolites, activated alumina, or hygroscopic salts are generally used to dehumidify moist air, and in such cases, the desiccant is continuously reactivated (regenerated). The basic constituent of the desiccant cooling system is the desiccant bed. The heat and mass transfer characteristics of the bed will no doubt have significant effects on the performance of the cooling system, and should therefore be adequately considered. Adsorption data obtained from the experimental measurements [7] show that the moisture concentration in the bed is highly dependent on the axial distance when packed bed is used for air dehumidification purposes. Desiccant layers at the bed inlet adsorbs moisture faster than the successive layers and this results in unequal distribution of moisture in the bed and consequently the adsorption efficiency of the subsequent layers of the bed decreases.

Fluidizing a bed of solid particles with a gas provides a means of bringing the two into intimate contact and this can be very useful in improvement of the adsorption/desorption characteristics of the desiccant column. Its most important advantage stems from the fact that the solid particles in contains are in continuos motion and are normally very well mixed; the result is that "hot spots" are rapidly dissipated and bed operates in an essentially isothermal manner. Moreover, the fluid-like properties of the gas-solid mixture enable the solid to be transferred without difficulty from one vessel to another a useful feature in cases where the solid is required to take part in two different reactions as part of the same overall process.

The motion of solid particles in a fluidized bed can be influenced by arranging for an uneven distribution of gas flow through the distributor plate. Gross circulation of particles in both two and three dimensional beds by supplying more gas to the outer region of the distributor than the central area [8], (see figure 1). In this way an excess of particles was moved upwards in the bubble wakes in the outer regions while in the center of the bed, due to the relative scarcity of bubbles in that region, particles

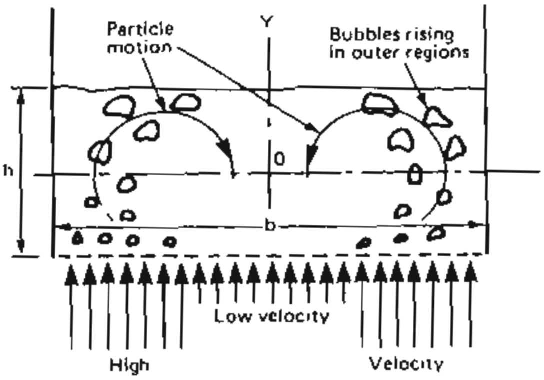

Fig.1 "Gulf Stream" circulation [8]

were moved predominantly downwards. With this arrangement, particles were introduced to circulate continuously in a steady pattern in two circulation cells-the so-called "Gulf stream" circulation. This type of motion is favored particularly in relatively sallow beds. The induced circulation of large particles has been studied [8], using a device

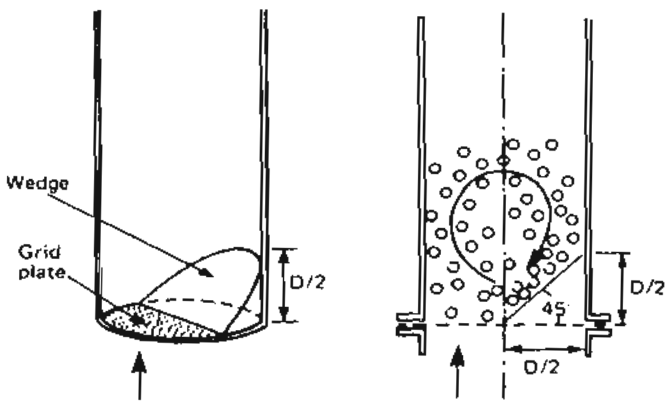

Fig. 2 Whirling bed apparatus [8]

known as a "whirling bed", shown in figure 2. In this system the perforated plate distributor is covered by a 45° angle wedge which serves to return particles, which are effectively de-fluidized in the upper region of the bed, to the grid where they are again carried upwards by the entering air.

For increasing adsorption and desorption efficiency new approaches are highly welcome. An attempt to improve the performance of solid desiccant should include an investigation on the performance of new bed configurations. To the best of our knowledge, inclined bed with desiccant has not been investigated in the literature.

The objective of this experimental study was to investigate the operation of an inclined bed of silica gel in adsorption and desorption modes of operation. In this respect, the article is concerned mainly with the mass transfer aspect. The heat transfer and pressure drop are not considered in this study. Also, it is aimed to obtain experimental data under conditions experienced in solar regenerated desiccant systems (regeneration below 100°C) to quantify the system operation at this condition.

.EXPERIMENTAL STUDY

The experimental test unit was designed to:

- study the adsorption and desorption operation of an inclined fluidized bed for different values of air velocity
- evaluate the effect of bed inclination on the moisture concentration in the bed through the color gradient

The set-up used in the adsorption-desorption experiments for the tilted bed of silica gel is depicted in Fig.3. The apparatus mainly consists of: (1) air blower, (2) air heater, (3) glass tube of 600 mm length and 31 mm diameter (4),(5) inlet and outlet screens, (6) stand to support the test unit. The metal screens has holes about 1mm^2 The bed is inclined during the experiments at an angle of 45° .

The maximum regeneration temperature used in this study was about 90°C; therefore, the results of this study apply to low-temperature applications (waste heat and low – temperature solar-regeneration). Operating conditions and parameters are reported in Table1.

Sorption capacity measurements

The most important property of a desiccant used in humidification and cooling applications is its ability to remove water vapour. This is usually quantified in terms of equilibrium isotherm, i.e., moisture capacity(kilogram moisture removed /kilogram dry desiccant) as a function of relative humidity at a constant temperature. The moisture capacity of the bed was measured by a gravimetric technique. To measure the adsorption capacity, desiccant sample was loaded in the test tube and the moisture gain(during adsorption) or removed (during regeneration) was obtained from the difference of initial and final weight of the desiccant.

Velocity, temperature and humidity of air are measured by a portable anemometer and hygrometer with a multi-function probe, respectively.. The digital hygrometer has a resolution of 0.1°C and 0.1% for temperature and humidity, respectively.

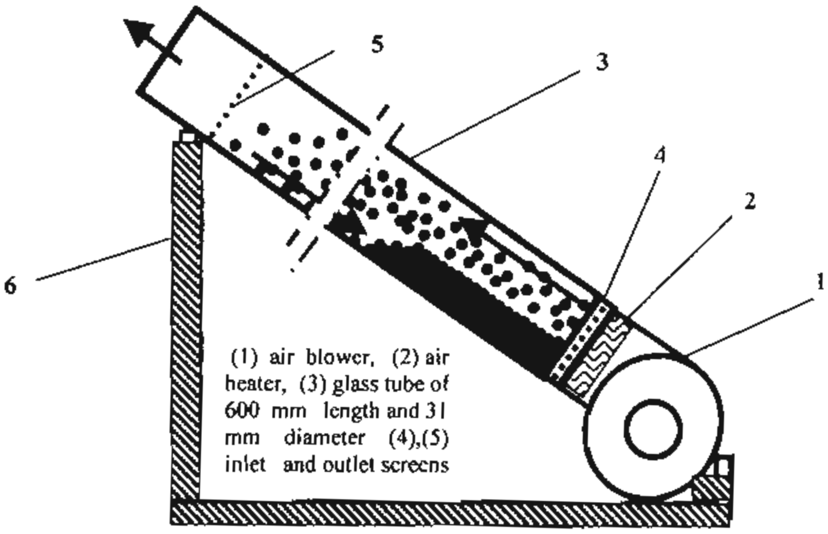

Fig. 3 Experimental set-up

Table 1 Operating conditions and total mass of adsorbed/desorbed water for different values of air velocity during adsorption and desorption operations

Air velocity, m/s	Bed volume, cm^3	Packed bed length, cm	Total mass adsorbed, gm/kg	Total mass regenerated, gm/kg
2.0	43.54	5.77	52.2	76.6
1.5	81.19	10.75	36.8	52.8
1.0	279.26	37	22.2	39.3

Measurements are carried out at nearly constant conditions of process and regeneration air(temperature and humidity). The inlet condition of the process air for different values of air velocity is fixed at 27°C dry bulb temperature and 66% relative humidity. The mass of the bed is recorded with time intervals using a digital balance of .02 gm resolution and 600 gm scale range.

The motion of particles in the bed

The motion of particles in the bed is influenced by the inclination of the tube. With inclination of the tube, uneven distribution of the effect of bed weight on the inlet area is attained. As a result, the bed pressure on the inlet section increases in a downward direction and consequently the resistance to air flow is higher in the lower part of the inlet section of the tube. When the process air is introduced, the upper layers of the particles along the bed is moved upwards with the flowing air stream while in the lower region, due to the effect of gravity, particles move predominately downwards (see Fig.3) . In this way, silica gel particles are introduced to circulate continuously. The bed in this condition can be divided into two regions: the upper region moves upward in fluidized manner, while the lower region can be described as packed bed moving downwards.

RESULTS AND DISCUSSION

To evaluate the effect of process air velocity on the adsorption rate, mass ratio of the bed is plotted versus time as shown in figure 4. The mass ratio is defined as the

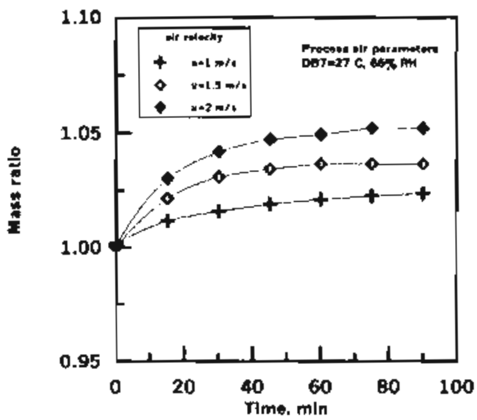

Fig. 4 Effect of air velocity on the adsorption rate

ratio of the instantaneous mass of the bed to the initial mass. As shown in figure, higher rate of adsorptin is attained at air velocity of 2 m/s. The inlet condition of the process air for different values of air velocity is fixed at 27°C dry bulb temperature and 66% relative humidity. The average bed temperature during the adsorption period is about 35°C. As the desiccant bed was near the saturation condition, the increase in the initial mass is limited to about 5%. Cooling of desiccant bed during adsorption could increase this value. The desorption process was carried out at the end of adsorption using regeneration air of 15 gm/kg specific humidity and about 100°C inlet temperature, while the average bed temperature is about 90°C. The desorption period was limited to 15 min. for different values of air velocity. Figure 5 shows that the regeneration rate is highly affected by the air velocity. It can also be expected that, more moisture could be removed by increasing the regeneration period, which means that the mass transfer potential for the specified regeneration condition is higher compared with adsorption.

The change of air humidity during adsorption is evaluated from the experimental measurements and plotted versus time as shown in figure 6. The drop

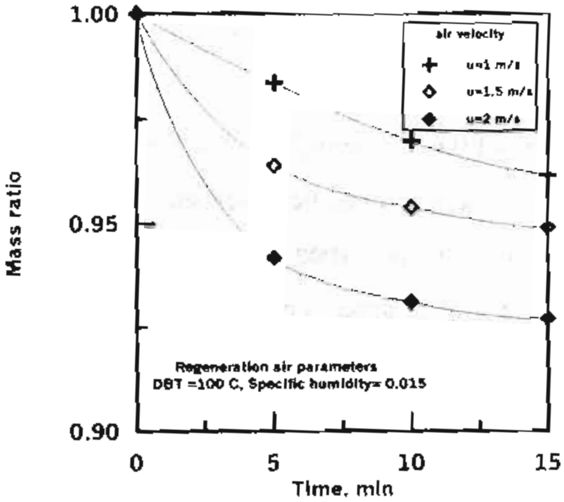

Fig. 5 Effect of air velocity on the desorption rate

in air humidity rapidly decreases with time and reaches zero at the end of adsorption As the mass of desiccant was not equal, the specific humidity of process air has a significant change for lower values of flow rate of air. This of course is due to increase in bed capacity and the increase in bed to air mass ratio.

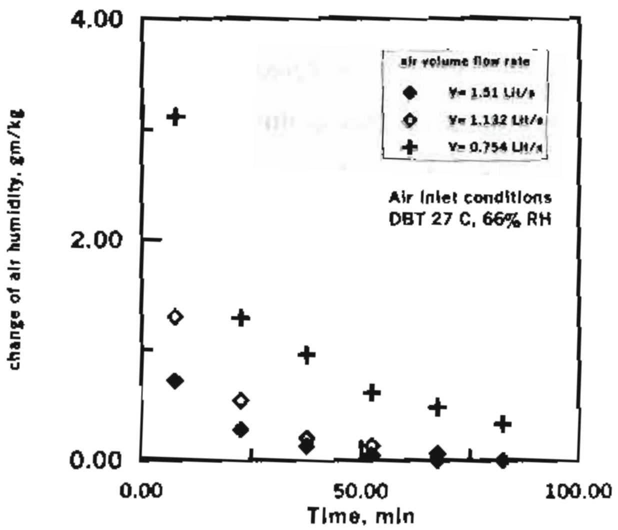

Fig. (6) Change of process air humidity with time for different values of air flow rate

To eliminate the effect of bed mass, the specific moisture adsorbed from air is plotted in figure 7. The specific value of moisture adsorbed is defined as the ratio of the drop of the air humidity to the bed mass in $gm_v/kg_{air}.kg_{bed}$. It can be observed that the specific moisture adsorbed rapidly decreases with time and reaches zero in shorter time for higher values of air stream velocity.

At the specified operating conditions of the experimental tests, the cooling capacity of the system is depicted in figure 8. This cooling capacity is evaluated from the mass of water vapor adsorbed into the bed. As shown in figure, higher values of cooling rate could be obtained at start of adsorption. This value rapidly decreases with time for all the tested values of air speed. However, complete evaluation of system performance must include the fan power consumed , this power is expected to be higher for higher values of process air velocity. It is also expected that increasing the regeneration temperature can enhance the cooling capacity of the bed.

Visual observation

The color of silica gel during experiments gives a good indication to the rate of mass transfer to/from the bed. The degree of darkness in the bed during regeneration increases with time of exposure to the hot air stream. With packed bed operation, a drastic change in color at inlet section can be observed. Also, The gradient of color darkness decreases with bed height, which explain the degree of reactivation (regeneration) in the bed. In inclined bed operation, well mixing and distribution results in homogenous distribution of the color through the bed.

CONCLUSION

The circulation of silica gel particles in an inclined – fluidized bed during adsorption and desorption operations is described and experimentally investigated. The effects of airflow rate on the moistures transfer process is examined for both adsorption and desorption mode of operation. The desorption period is limited to 15 min., whereas adsorption continues to reach near saturation condition in a period of 90 min. The following conclusions can be drawn from the present study:

1- The adsorption rate is highly affected by the Inlet air velocity. An increase in bed mass of about 5% could be attained near saturation condition, when process air of 66% relative humidity and 27°C is blown at velocity of 2 m/s. This value decreases to about 2%, when air velocity decreases to 1m/s.

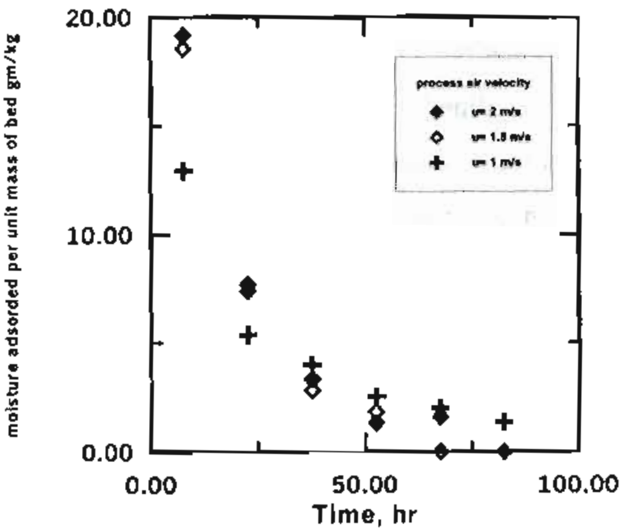

Fig 7 Transient variation of relative value of moisture adsorbed per unit mass of bed material for different values of air velocity

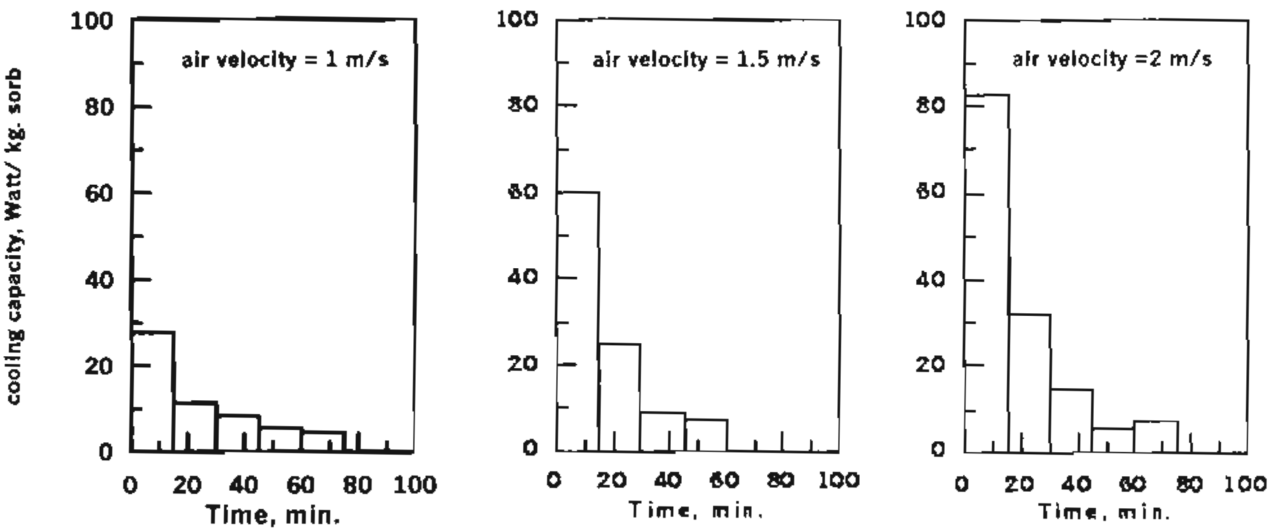

Fig.8 Average value of cooling capacity versus time during adsorption at different values of process air velocity

2- The regular circulation of silica gel particles in the inclined tube and homogenous moisture concentration in the desiccant, which can increase the rate of moisture transfer to/or from the bed has been observed.

3- Regeneration temperature as low as 90°C demonstrates the possibility of using solar energy for desiccant reactivation when inclined-fluidized bed is applied.

4- Cooling capacity as high as 80 Watt / kg desiccant could be obtained at the beginning of adsorption , when the air stream velocity reaches 2 m/s. However, this value decreases to about 30 Watt/ kg desiccant when the air velocity is 1 m/s.

Finally, Further investigation to evaluate the effect of system long-term operation on the performance of silica gel particles is recommended. Also, quantitative analysis of the heat and mass transfer properties in the fluidized bed as well as quantitative description of the degree of darkness will be the subject of a further coming study.

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