



# Experimental Study of the Effects of Silica-gel Bed Thickness on The Regeneration Process in a Desiccant Column

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## Abstract

A desiccant column contains a silica gel as a solid moisture absorbent material had been used in this study, in which the regeneration or desorption process was discussed. The dimensions of the silica-gel column are 30 cm long\*30 cm wide with three thickness of desiccant bed (5,10, &15) cm, respectively. The mass flow rate and the inlet temperature of the regeneration air are 3.72 kg/min and 53 °C respectively. A hot air was obtained using solar air heater in addition to an electric heating unit for temperature control purpose. The results obtained showed that the regeneration period is affected by the bed thickness. so that, increase the bed thickness of silica increased the regeneration period and vice versa. For example, the complete drying process of silica gel from moisture took 21 min with thickness of bed (5 cm), while it took 42 min with thickness of bed (15 cm).

**Keywords:** Desiccant column, Regeneration process, Desorption process, silica-gel.

**الخلاصة:** تم في هذه الدراسة استخدام عمود مجفف الرطوبة والذي يحوي بداخله على حبيبات السيليكا جل الصلبة والتي تعتبر الجزء الأساسي في سحب الرطوبة. حيث سيتم دراسة ومناقشة اجراء إعادة تنشيط وتجفيف عمود المجفف. ان ابعاد عمود السيليكا جل هي 30 سم للطول \* 30 سم للعرض \* مع ثلاث ارتفاعات لسلك طبقة السيليكا وهي (5,10,15 سم) على التوالي. يبلغ معدل التدفق للهواء ودرجة الحرارة عند الدخول لعمود المجفف (3.72 كغم/دقيقة، 53 °C) على التوالي. الهواء الحار المستخدم في الاجراء تم الحصول عليه افتراضيا باستخدام مسخن حراري شمسي وبدلا منه تم استخدام مسخن كهربائي لأغراض السيطرة والتحكم بدرجة الحرارة المستخدمة. ان النتائج التي تم الحصول عليها أظهرت ان فترة إعادة التجفيف تتأثر ب سمك الطبقة. لذلك فان الزيادة في سمك الطبقة يؤدي الى زيادة فترة التجفيف والعكس صحيح. مثال على ذلك، استغرقت فترة عملية تجفيف حبيبات السيليكا بصورة كاملة 21 دقيقة لسلك الطبقة (5سم). بينما استغرقت وقتا وقدره 42 دقيقة لسلك الطبقة 15 سم.

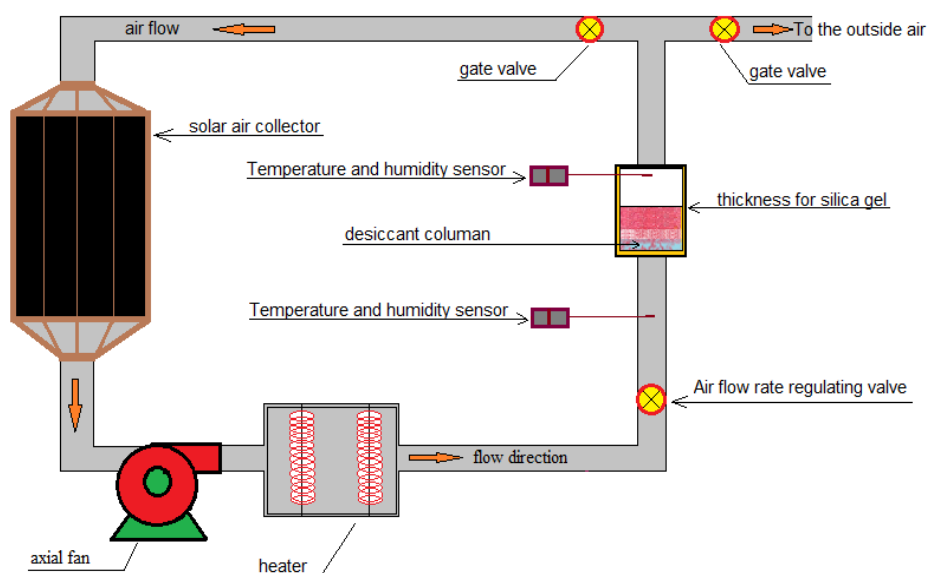
## 1. INTRODUCTION

The phenomenon of physical adsorption has been known for over two centuries and extensively studied over the past couple of decades<sup>[1]</sup>. A significant fraction of the energy in air-conditioned buildings is required for the removal of moisture<sup>[2]</sup>. Desiccant cooling and air dehumidification is a good alternative to the conventional vapor compression system for air conditioning<sup>[3]</sup>. The conventional method for the production of dry air involves cooling air below its dew point temperature, but this method consumes high-grade energy. An alternative method involves the use of desiccants, which can be easily regenerated with the help of solar energy or other low-grade energy<sup>[4]</sup>. To regenerate a desiccant, an ambient air passes through a heat exchanger and air heater. This could bring the regeneration air temperature up to a value that allows the desiccant to be regenerated. The adsorption heat energy released to desiccant particle depends on the mass transfer rate from process air stream to desiccant pores, which heavily depended on the desiccant particle surface due to the moisture partial pressure [5]. Much research on the solid desiccant dehumidifiers has been accomplished, and many successfully effective mathematical models to predict the heat and mass transfer process in such dehumidifiers have emerged<sup>[6]</sup>. The desiccants are natural or synthetic substances capable of absorbing or adsorbing water vapor due to the difference of water vapor pressure between the surrounding air and the desiccant surface<sup>[7]</sup>. The desiccant system consists mainly of a

desiccant dehumidifier, evaporative cooler, and air heater to regenerate the desiccant. The regeneration rate and the regeneration efficiency were greatly affected by the thermal energy, the different initial moisture contents of silica gel and the number of silica gel beds<sup>[8]</sup>. As desiccants can be either solid or liquid, they can be categorized into solid desiccant systems, which include a fixed bed and rotary wheel type, and liquid desiccant system<sup>[9]</sup>. A molecular sieve may require higher regeneration temperature for the desorption, if solar energy is used for regeneration, then a higher regeneration temperature is a disadvantage because an expensive high-performance solar collector needs to be used. On the other hand, silica gel and activated alumina can be desorbed at relatively low temperatures. Silica gel has a higher adsorption capacity can be desorbed at relatively low temperatures<sup>[10]</sup>. The objective of this research is to study the effect of silica gel bed thickness on the desorption process within the silica gel column. To achieve this goal, the experimental test device as shown in Figure (1), was used.

## 2. MODEL DESCRIPTION

Figure (1) shows the test device used in the experiments of this study. It consists mainly of the following items: silica gel column, air solar collector, axial fan, electric air heating unit, in addition to some equipment to control the flow parameters of the regeneration air entering the silica gel column (such as temperature and flow rate).



**Fig.1.** Experimental test device

### 2.1 Characteristics and design of Desiccant column

A hot air at 53 °C was used in the regeneration process in the solid desiccant column. This air can be obtained by using solar air collector in addition to an electric heating unit for the purpose of controlling the air temperature to the required value for the desorption process. The dimensions of the desiccant column are 30 cm long × 30 cm wide × 30 cm height. The hot air is used to regenerate the saturated silica gel enters the drying unit from the lower side and exit from the upper side, as shown in figure (2). The value of regeneration air flow rate was (3.72) kg/min. Sensors of air temperature and air relative humidity, which is defined as “The ratio of the amount of water vapor actually present in the air to the greatest amount possible at the same temperature” were installed at the inlet and outlet sections of the drying unit. The hot air from the electrical heating flows through an axial fan entering the drying unit. Three value of silica gel thickness inside the desiccant column were used in this study (5,10, &15) cm.

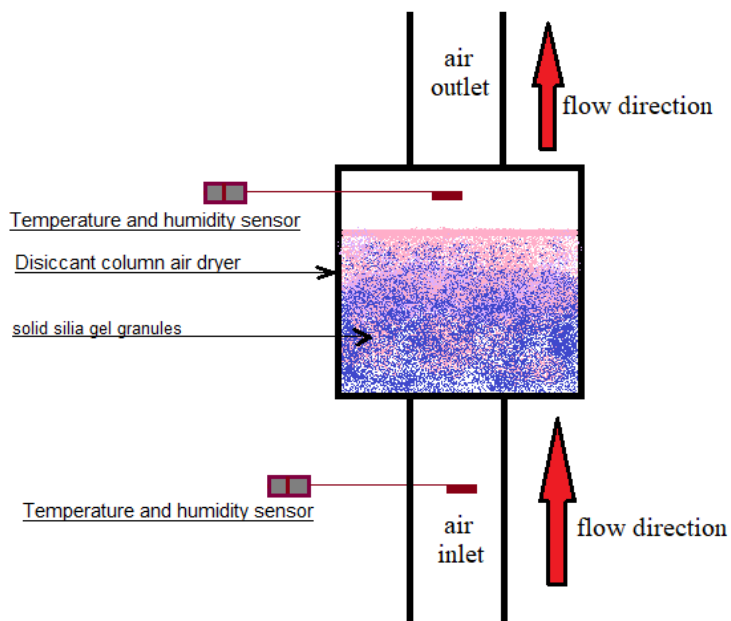


Fig. 2: 2D design of the desiccant column

A Silica gel ( $\text{SiO}_2$ ) is a porous material, granular form of silica, synthetically manufactured from sodium silicate sulfuric acid and activated silica gel which is used as an adsorbent consists mainly of partially hydrated silicon dioxides. It was discovered in 1919 by Walter A. Patrick. Silica gel attracts and holds moisture by capillary condensation and adsorption, it is the highest capacity adsorbent available today. Figure (3) show the silica gel granular. The blue colour represents the dry (moisture free) silica gel, while the pink colour represents moisture saturated silica gel.



Fig.3: Silica gel granules

## 2.2 Heater and Axial Fan in open Cycle with A Desiccant Column

By using the axial fan, an air flow can be obtained for the purpose of regeneration process. The flow rate of this air can be controlled using a regulating valve. The regeneration air is heated to the required temperature for the desorption process of the saturated silica gel, electric air heating unit. Figure 4 shows the desiccant column connecting with the axial fan and air heating unit.

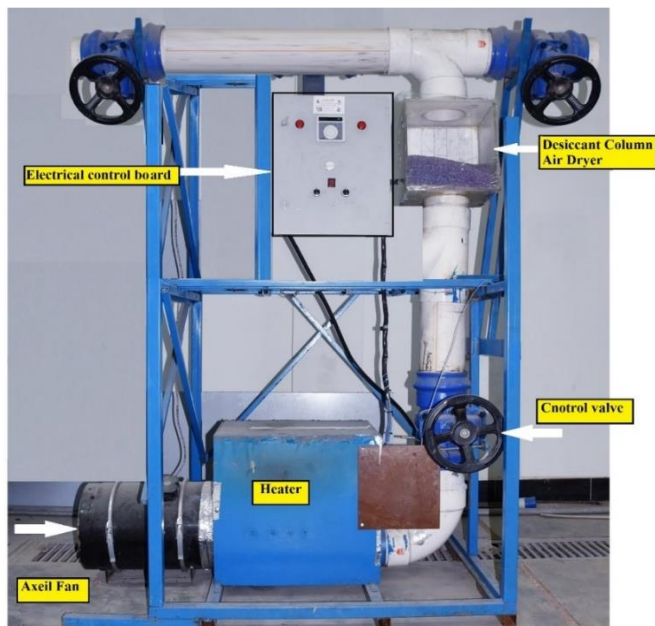


Fig4: Desiccant connected with heater and axial fan

### 3. MEASURING DEVICE FOR EXPERIMENTAL TESTS

Figure (5) display the digital relative humidity-temperature sensor (DHT11) with Arduino (UNO micro-controlled board) that were used to measure the temperature and the relative humidity of the regeneration air entering and leaving the desiccant column. The hot wire device model (GM 8903) as shown in figure (6), was used to measure the velocity of the air entering the desiccant column. Figure (7) illustrate how and where to place these sensors. These devices have been calibrated.

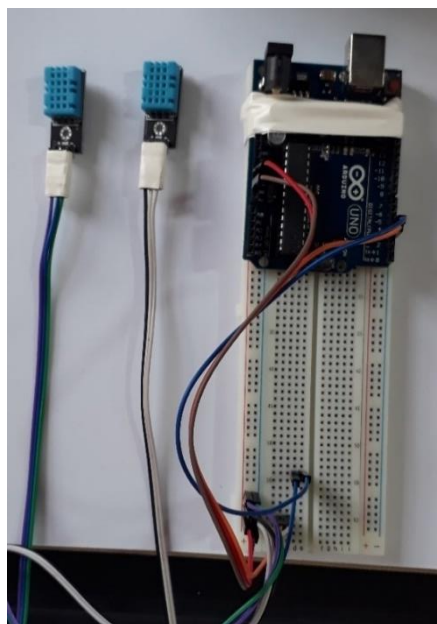


Fig.5: DHT11 sensor with Arduino UNO



Fig.6: Anemometer Device Model (GM8903)



Fig.7: Places of the sensor & the way of recording the reading

#### 4. EXPERIMENTAL CASE STUDY

Three experimental cases were studied (5, 10 & 15 cm), in which the effect of silica gel bed thickness inside the desiccant column on the regeneration period required to release all the moisture content in the saturated silica gel and turn it into a dry state, have been studied. A thickness (height) of silica gel in the first cases was at mass flow rate of 3.72 kg/min and at a temperature of 53 °C.

#### 5. RESULTS AND DISCUSSION

##### 5.1. Results of the first case (thickness of silica gel layer equal 5cm)

Table (1) shows the change in properties of the regeneration air coming out of the desiccant column with time during regeneration process when the thickness of silica gel layer in the column is 5 cm. the properties of the inlet air are the temperature is 53 °C, the flow rate is 3.72 kg/min, and the relative humidity is 19%.

Table1: Experimental outlet data for 5 cm layer thickness

NO.	Time for each recorded (minute)	Temp air outlet C°	RH % outlet	Inlet Moisture content W (kg/kg)	Outlet Moisture content W (kg/kg)	$\Delta w$ (Outlet-Inlet)
1.	1	35	49	0.0171	0.0174	0.0003
2.	3	37	45	0.0171	0.0179	0.0008
3.	6	39	41	0.0171	0.0181	0.0013
4.	9	41	38	0.0171	0.0187	0.0016
5.	11	43	35	0.0171	0.0192	0.0020
6.	14	46	31	0.0171	0.0198	0.0021
7.	17	48	29	0.0171	0.0205	0.0034
8.	19	49	25	0.0171	0.0193	0.0022
9.	21	51	21	0.0171	0.0171	0.0

According to the result in table (1), it could be seen that the time required to complete and finish the regeneration process of silica gel in this experiment was 21 minutes.

By inserting and representing the properties of outlet air on the Psychrometric chart which is defined "Psychrometric charts are complex graphs that can be used to assess the physical and thermodynamic properties of gas-vapor mixtures at a constant pressure. They are often used to assess the properties of moist air", as shown in figure (8), it can be seen that the value of moisture content increase with time until it reached its maximum value (point 7), after that the value begins to decrease until it becomes equal to its value in the entering air after a period of time of 21 minutes. This means that the regeneration air after this period of time did not receive any additional amount of moisture from the silica gel and therefore the silica become completely dry. Thus, according to the results of this case, the regeneration period of silica gel with a thickness of 5 cm took 21 minutes.

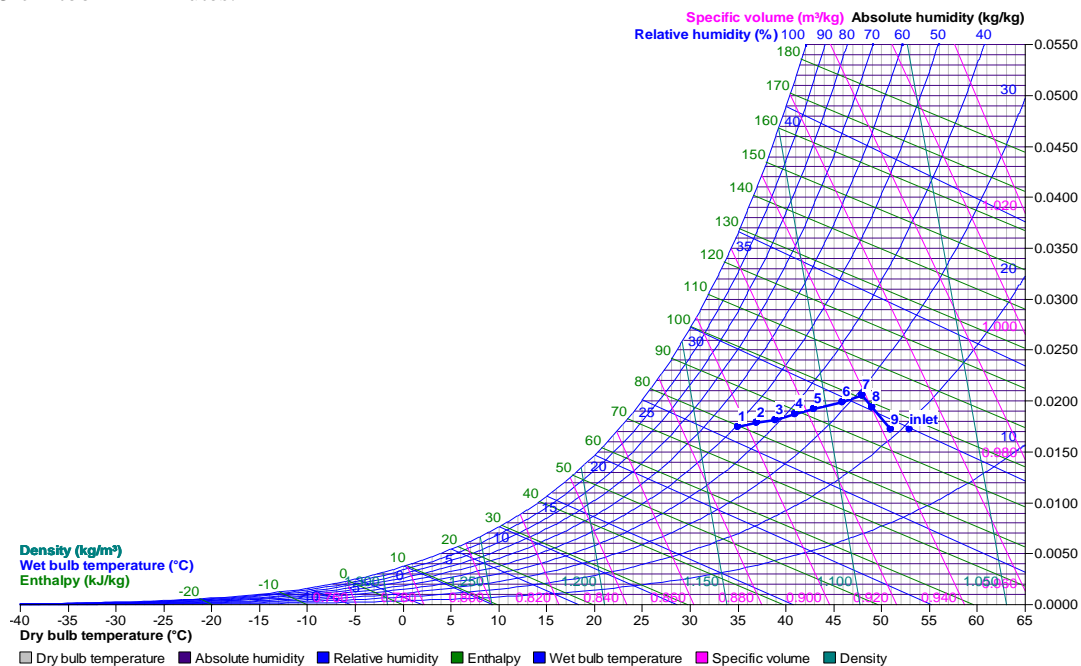


Fig8: Data record on Psychrometric chart

### 5.2. Results of the second case (thickness of silica gel layer equal 10cm)

Table (2) shows the change in the properties of the regeneration air coming out of the desiccant column with time during regeneration process when the thickness of silica gel is 10 cm. The properties of the incoming regeneration air are the same as those mentioned in the previous case.

Table2: Experimental outlet data for 10 cm layer thickness

NO.	Time for each recorded (minute)	Temp air outlet C°	RH % outlet	Inlet Moisture content W (kg/kg)	Outlet Moisture content W (kg/kg)	Δw (Outlet-Inlet)
1.	1	35	49	0.0171	0.0174	0.0003
2.	3	37	46	0.0171	0.0183	0.0012
3.	6	39	42	0.0171	0.0186	0.0015
4.	9	41	39	0.0171	0.0192	0.0021
5.	12	43	36	0.0171	0.0197	0.0026
6.	17	46	33	0.0171	0.0201	0.0030
7.	21	48	32	0.0171	0.0205	0.0034
8.	24	49	29	0.0171	0.0205	0.0034
9.	27	50	26	0.0171	0.0193	0.0022
10.	30	51	22	0.0171	0.0171	0.0000

According to the results in table (2), it could be seen that the time required to complete and finish the regeneration process of silica gel in these experiments was 30 minutes.

Figure (9) shows the change in the properties of the coming regeneration air time represented on the Psychrometric chart. It is noted from the figure that the values of moisture contain in the incoming and out coming air become equal after 30 minutes, which means that the desiccant process of silica gel with 10 cm thickness is take this period of time.

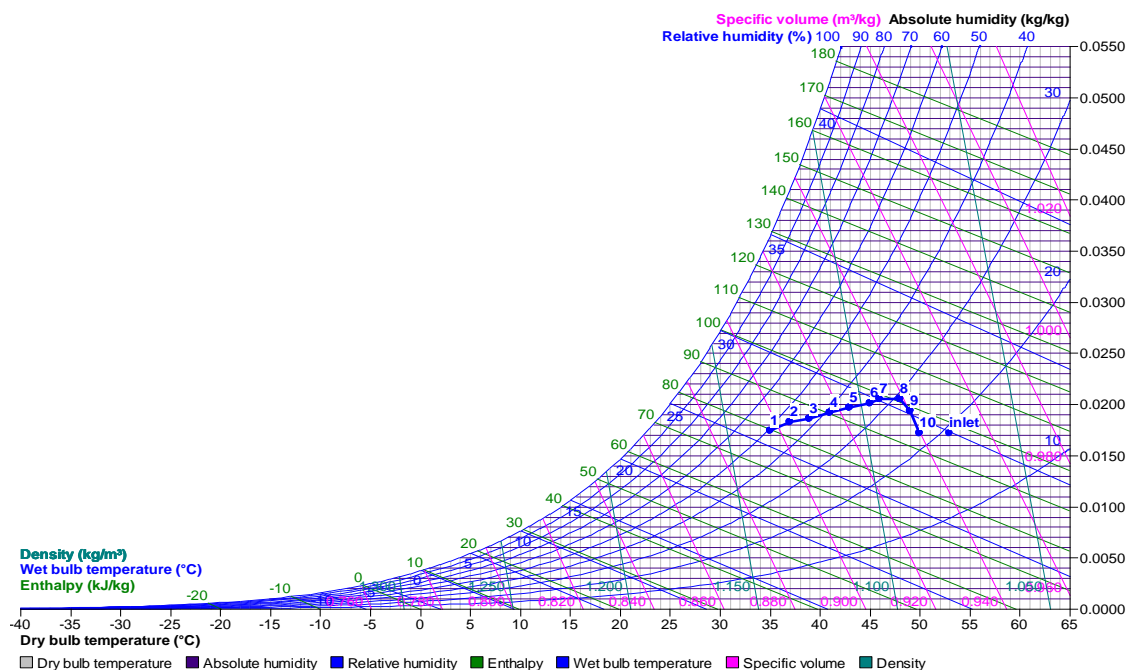


Fig 9: Data record on Psychrometric chart

### 5.3. Results of the third case (thickness of silica gel layer equal 15cm)

Table (1) illustrate the change in the properties of the regeneration air out coming from the desiccant column with time during the regeneration process when the thickness of silica gel bed is 15 cm. the properties of the incoming regeneration air are the same as those mentioned in the previous cases.

Table 3: Experimental outlet data for 15 cm layer thickness

NO.	Time for each recorded (minute)	Temp air outlet C°	RH % outlet	Inlet Moisture content W (kg/kg)	Outlet Moisture content W (kg/kg)	Δw (Outlet-Inlet)
1.	1	36	47	0.0171	0.0176	0.0005
2.	4	38	44	0.0171	0.0184	0.0013
3.	10	39	42	0.0171	0.0186	0.0015
4.	15	40	40	0.0171	0.0187	0.0016
5.	20	42	37	0.0171	0.0192	0.0021
6.	25	44	34	0.0171	0.0196	0.0025
7.	29	46	31	0.0171	0.0198	0.0027
8.	33	48	29	0.0171	0.0205	0.0034
9.	37	49	26	0.0171	0.0193	0.0022
10.	42	51	21	0.0171	0.0172	0.0001

According to the results in table 3, it could be seen that the time requires to complete and finish the regeneration process of silica gel in this experiment was 42 minutes.

Figure (10) illustrate the change in properties of out coming regeneration air with time represented on the Psychrometric chart. It is noted that the values of moisture contain of the incoming and out coming regeneration air become equal after 42 minutes, which means that the regeneration process of silica gel with a thickness of 15 cm has taken this period of time.

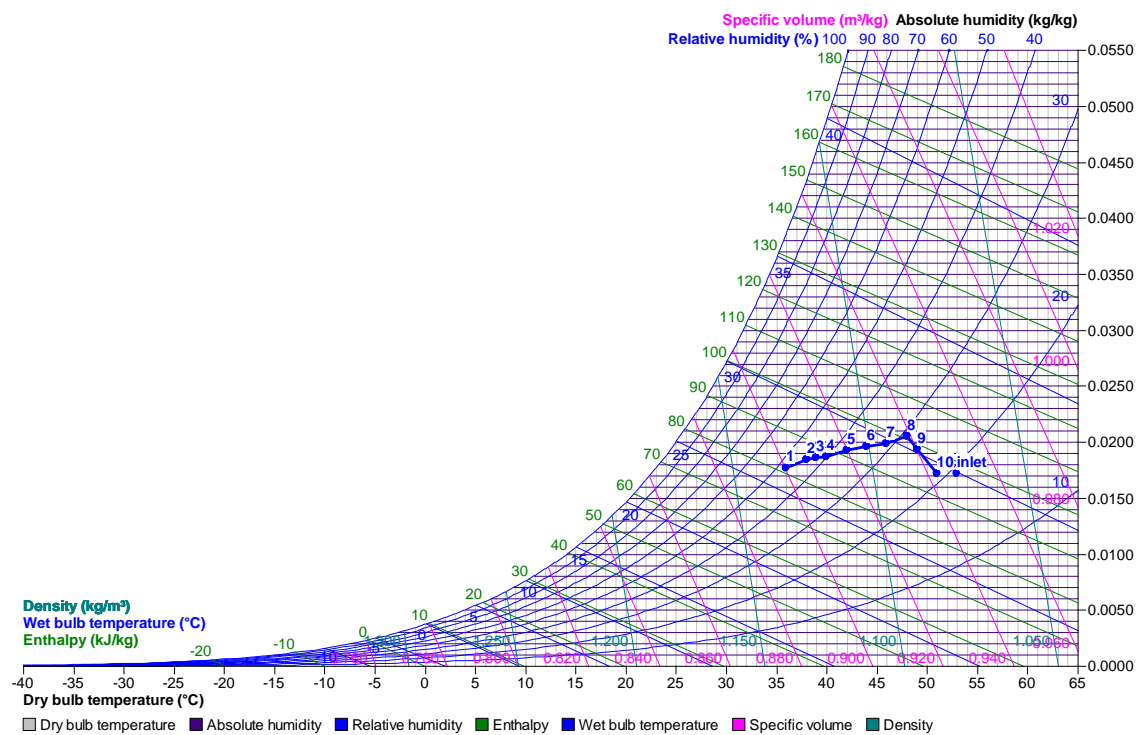


Fig.10: Data record on Psychrometric chart

From the results of the three cases referred to above, the regeneration period of silica gel increases with the increase in the thickness of silica gel bed in the desiccant column and vice versa. The reason for this can be attributed to the fact that the small thickness of silica gel could lead to an increase in the speed of regeneration air inside it, which in turn leads to an increase in both the heat and mass transfer coefficients between them.

## 5.4 Effect of silica gel bed thickness on the regeneration process

The effect of different regeneration bed thickness of silica which are (5, 10, & 15) cm, on the desorption process with inlet air flow rate (3.72) kg/min, and air temperature of about 53 °C has been studied. This effect can be explained as follows:

### 5.4.1 Variation of the moisture content with time

Figure (11) show the variation in the moisture content of the regeneration air leaving the desiccant column with time at different bed thickness of silica gel. The results indicate that the regeneration period, during which all moisture in the silica gel removed, increases with the increase in the height of bed (regeneration period was about 42 minutes with bed thickness of 15 cm, and about 21 minutes with bed thickness 5 cm). the reason for this can be attributed to the increase in the pressure of the silica granular. This can lead to a large amount of moisture will be removed from the silica gel with an increase in the bed thickness size. The transformation of silica gel from a state of complete saturation to a state of complete dryness can be known by changing the colour of silica gel from pink to blue in addition, the difference in the moisture content of the regeneration air at the inlet and outlet of the silica gel column becomes equal to zero.

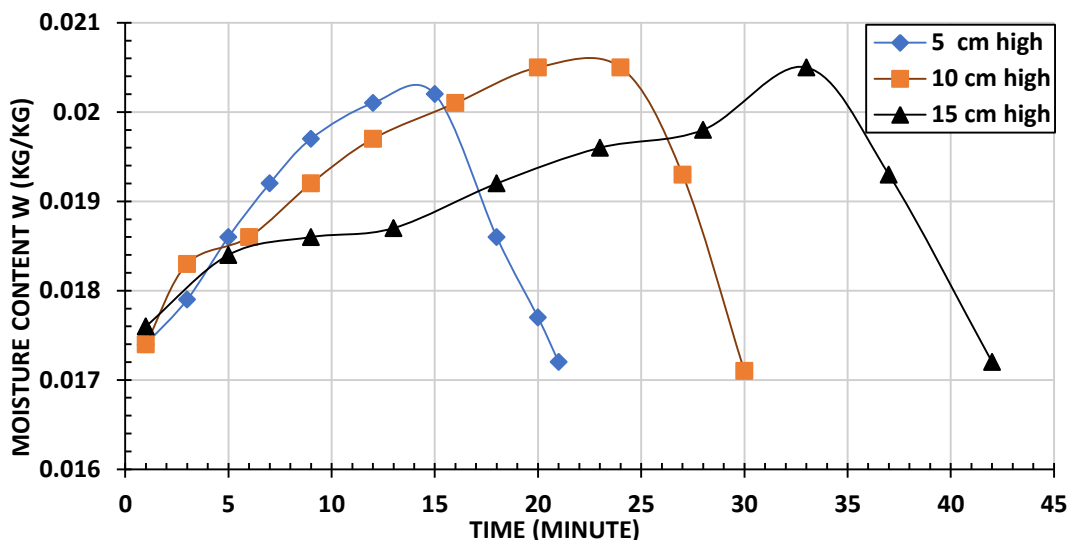


Fig.11: Moisture content w (kg/kg) with time

### 5.4.2 Variation of the temperature with time

Figure (12) show that the variation in the temperature of the outlet regeneration air with time at different bed thickness. It is noted from the figure that at the beginning of the regeneration period, the temperature of the air leaving the unit is lower than that at the entering of the unit. The reason for this can be attributed to the fact that the air will lose part of its sensible heat in heat exchange with cold silica gel during this time of the regeneration period (silica is at a temperature approximately equal to that of the ambient temperature). The temperature of the air leaving the unit begins to rise gradually with time until at the end of the regeneration period it becomes approximately equal to the temperature of regeneration air entering the unit.

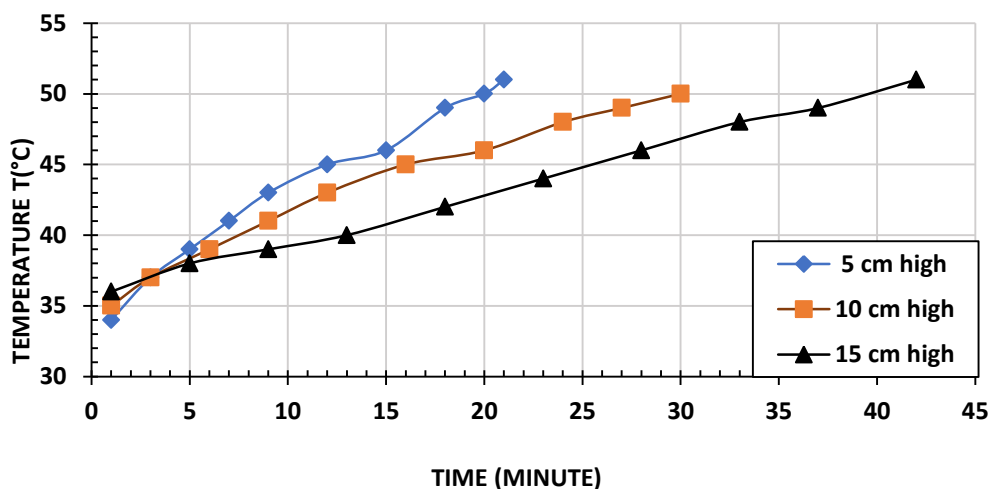


Fig.12: Temperature t(°C) with time

### 5.4.3 Variation of the relative humidity with time

Figure (13) represents the change in the relative humidity of the regeneration air leaving the desiccant unit with time. At the beginning of the regeneration period, the temperature of the air leaving the desiccant unit is low because the air loses part of its sensible heat for heating the silica gel. After a period of time the air temperature begins to rise, which leads to a decrease in the relative humidity, until the end of the regeneration period is reached the relative humidity of the exit air becomes approximately equal to its value at the entering of the desiccant unit.

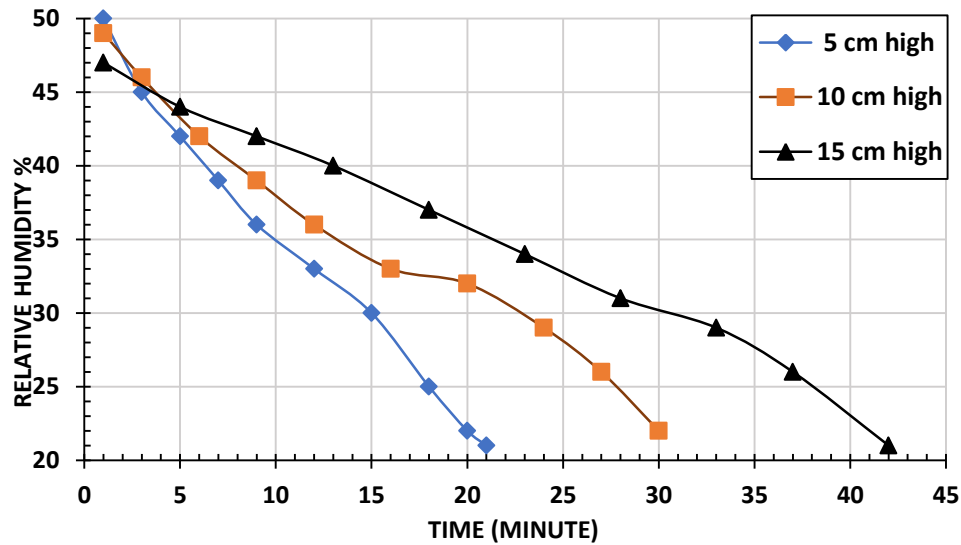


Fig.13: Relative humidity % with time

#### 5.4.4 Variation of the Enthalpy with time

Figure (14) represents the change in the enthalpy which is defined "A property of a thermodynamic system, and it is the sum of the system's internal energy and the product of its pressure and volume" of regeneration air leaving the unit with time. It is noted from the figure that the enthalpy value of the air is low at beginning of the regeneration period because the air temperature at this time is low as a result of heating silica gel. The heat content (enthalpy) of the air begins to rise with time due to of the increase in the air temperature as well as the increase in the amount of moisture it contains, which is gained from silica gel until reaching the highest value near the end of the regeneration period, after which the enthalpy begins to decrease due to the decrease in the moisture content of the air after this limit as it is clear in the figure.

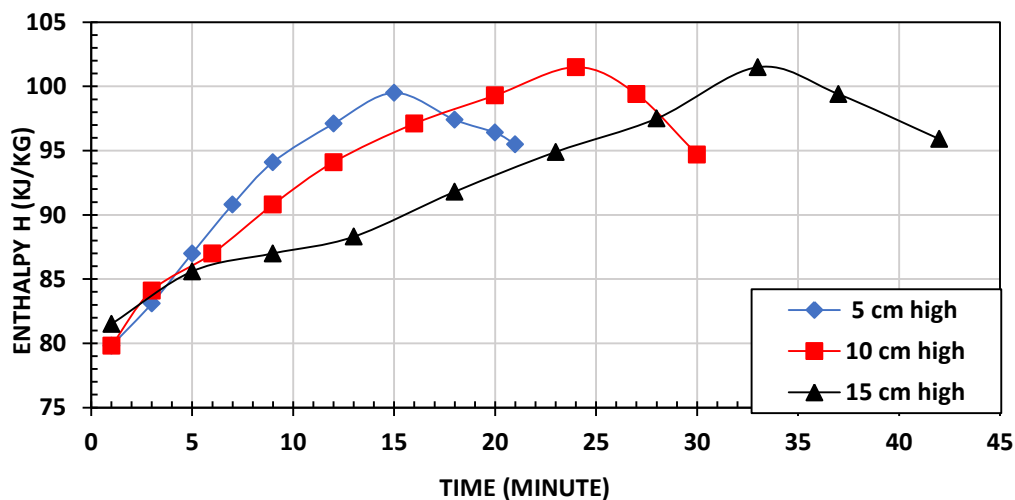


Fig14: Enthalpy H (kJ/kg) with time

## 6. CONCLUSION

From the results obtained, the following conclusion can be summarised:

- The period of complete regeneration of silica gel saturated with moisture increase significantly with an increase in the bed thickness of silica gel.
- The end of the silica gel regeneration process arrived when the difference in the moisture content of the regeneration air between the entry and exit section of a desiccant unit became equal to zero.
- The silica gel regeneration air temperature of about 53°C, which was obtained from the use of an air solar collector, was sufficient to perform a complete regeneration of the silica in a reasonable period.

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