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Performance Evaluation of Internally Cooled Adsorption Solid Desiccant Bed

تقييم أداء مهد إدمصاص صلب مُبرد داخلياً

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KEYWORDS
Temperature - humidity – adsorption – desorption - silica gel – moisture – water – air – flow - desiccant - cooling

الملخص العربي: - يتضمن هذا البحث دراسة عملية لتقييم أداء مهد مكون من مادة صلبة مازة مبرد داخلياً في عمليتي الإدمزاز(Regeneration) والإمتزاز(Adsorption). تتكون تزجة الإختبار من مبادل حراري به زعانف ويحتوي داخله على حبيبات السليكا جل. تم إجراء التجارب المعملية تحت قيم مختلفة من معدل سريان الهواء وأقطار مختلفة من السليكا جل. تتضمن العوامل المقاسة درجة حرارة الماء والهواء والرطوبة النسبية للهواء عند المدخل والمخرج ومعدل سريان الهواء عند المخرج. واعتماداً على العوامل المقاسة من درجة حرارة الهواء والرطوبة النسبية تم حساب معدل إزالة الرطوبة. النتائج أوضحت الآتي: أن التبريد داخلياً يحسن من أداء المهد بصورة ملحوظة وأن عملية الإدمصاص يمكن إجراؤها عند ثبوت درجة الحرارة مع التبريد. التحسين في أداء المهد كان أعلى من 50% بسبب التبريد الداخلي. معدل إزالة الرطوبة ارتفع بشكل كبير جداً في عملية الإدمزاز والإمتزاز. رفع درجة حرارة السليكا جل أثناء عملية الإدمزاز حسن في أداء المهد فبرفع درجة حرارة الماء من 41.5 إلى 63 درجة حرارة مئوية يزداد معدل إزالة الرطوبة من 2.8 جم/ث الي 5.4 جم/ث.

Abstract: - **In the present work، an experimental investigation on the adsorption and desorption operations in an internally cooled solid desiccant bed has been made. Experimental system involves a finned tube heat exchanger containing particles of silica gel, which is tested at different air flow rates and different of particles silica gel. The inlet and exit air temperature and relative humidity, air velocity, the inlet and exit water temperature and water flow rate are measured. Moisture removal rate is calculated. The results show that the internally cooling significantly enhances the performance of desiccant bed and the adsorption process can be done at nearly isothermal process. The enhancement in bed performance can be more than 50% due to internal cooling. Moisture removal rate sharply increases by increasing air flow rate in both adsorption and desorption processes. Increasing the regeneration temperature significantly improves the desorption performance of the bed for example by increasing it from 41.5 °C to 63 °C the moisture removal rate increases from 2.8 g/s to 5.4 g/s.**

1. INTRODUCTION

Recently, desiccant cooling systems receive considerable attention as an effective technology in dehumidification processes. Such systems can be operated by low grade energies like solar energy or waste heat. Reviews on the desiccant systems have been performed [1-3], and vast amount of works such as performance analysis and experimental study of dehumidification rotor [4-7] has been done. Evaluating and predicting the performance of solid desiccant beds are studied by many researchers [8-10]. Several researches studied the performance and using liquid desiccant in air conditioning application [11-13]. The released adsorption heat significantly decreases the performance of the desiccant systems because of the increase of vapor pressure on the desiccant surface. Many investigations are carried out in view to reduce the effect of heat on the bed adsorptivity. Higher air flow rates [14] and a cooling coil in the core of the fluidized bed [15] were proposed to eliminate the effect of adsorption heat. Increasing desiccant material utilization by continuous particle mixing in a fluidized bed was proposed by Hamed et al. [8]. Intercooling the desiccant bed eliminated the effect of the heat of adsorption and increased the desiccant material utilization [16]. However, many theoretical and experimental investigations for internally cooled liquid desiccant dehumidification systems were carried out [17-20].

In this study, solid desiccant bed is internally cooled by a finned tube heat exchanger as shown in Fig. 1 Experimental setup for silica gel bed is constructed, and the performance of the bed in adsorption and desorption modes is investigated.

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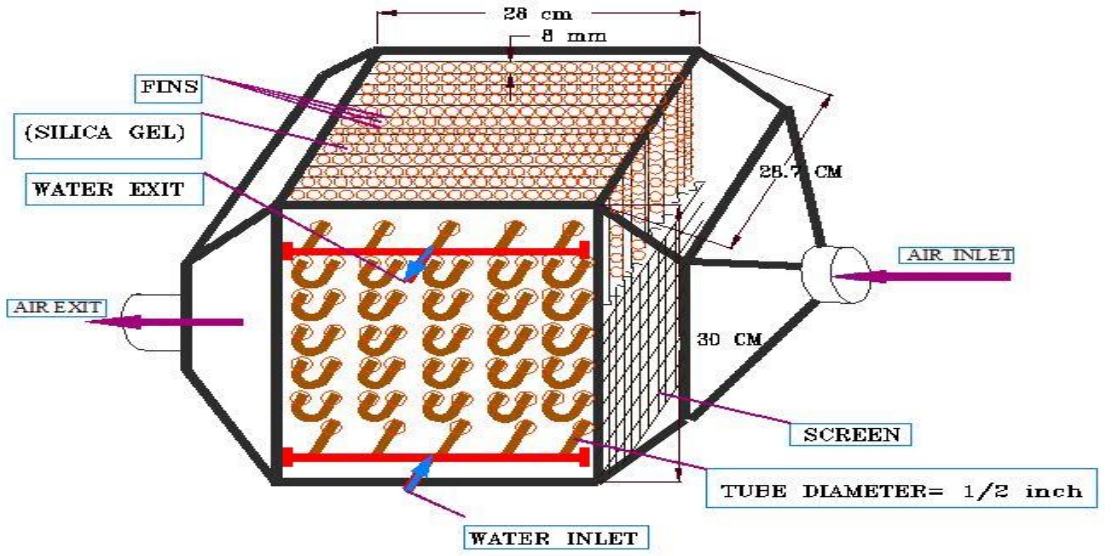
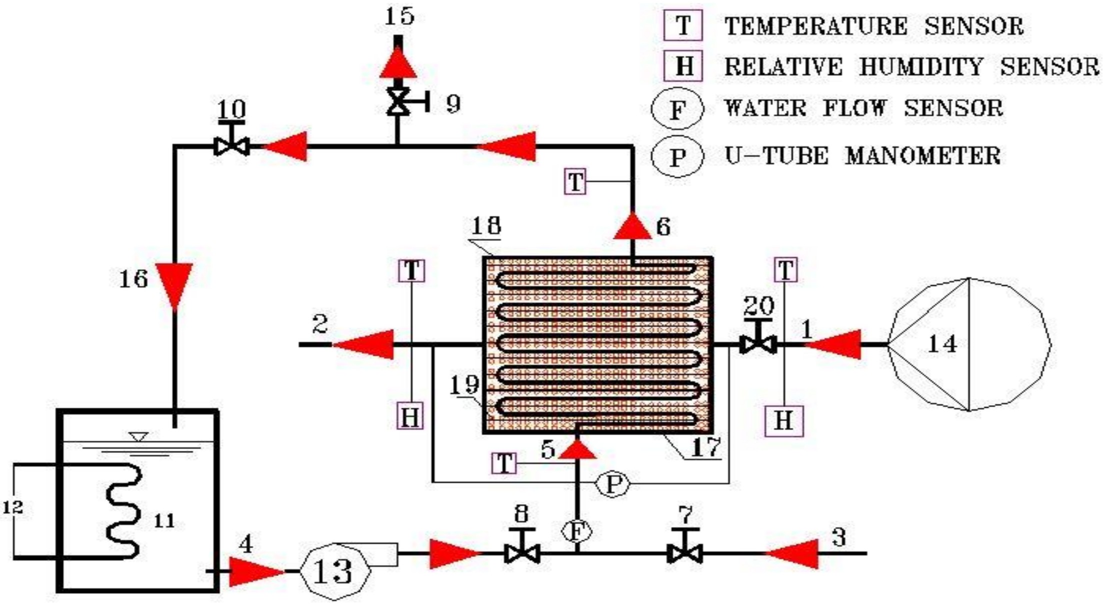


Experimental setup Fig. 1



(1)= Air inlet from blower
(2)= Air outlet from heat exchanger
(3)= Cold water inlet
(4)= Hot water inlet
(5)= Water inlet to heat exchanger
(6)= Water outlet from heat exchanger
(7, 8, 9, 10 & 20)= Control valves
(11)= Water tank
(12)= Electric water heater
(13)= water Pump
(14)= Air blower
(15)= Drain cold water
(16)= Return hot water to tank
(17)= Desiccant bed and heat exchanger
(18)= Silica gel
(19)= Fins

Fig. 2 Flow diagram of the experimental setup.

2. EXPERIMENTAL SETUP

The experimental test rig consists of : i) the silica gel packed bed ii) finned tube heat exchanger used as internally cooler using cooling water with different flow rates from an infinite sources shown in Fig. 1. iii) Set of manual valves to switch on the bed for adsorption and desorption modes, iv) air blower, v) hot water tank with electric heater. Which undergoes the adsorption process in the desiccant bed. The condition of the inlet air to the bed is determined by measuring the temperature and relative humidity at the air exit. The adsorption test bed is a parallelogram from galvanized steel (30x28.8x28 mm). Two screens are used as flow strainers at the inlet and exit of the silica gel bed. A flow diagram of the experimental test rig is shown in Fig. 2. The inlet and exit air and water temperatures are measured using DS18B20 digital thermometer. The inlet and exit air relative humidity are measured using capacitive hygrometer. Air velocity is measured using hot wire anemometer and water flow rate is measured using peddle wheel flow meter. Measured parameters and equipment uncertainty are listed in table 1

Table (1) Measured Parameters and Equipment Uncertainty

Parameters	Devices	Accuracy	Resolution
Air Velocity	Hot wire	± 0.1 m/s	0.1 m/s
Air dry bulb temperature	DS18B20 digital thermometer	± 0.5 ^{0}C	0.1 ^{0}C
Air relative humidity	Capacitive hygrometer	± 3% RH	0.1 % RH
Water flow rate	Peddle wheel flow meter	± 0.01 kg/s	0.001 kg/s

3. RESULT AND DISCUSSION:

3.1 The Moisture Removal rate:-

The air mass flow rate can be calculated from the following equation,

$$\dot{m}_a = \rho_a A U_m \quad (1)$$

Where U_m is the mean air velocity at the exit which is measured. Then the moisture removal rate can be calculated as follow

$$MRR = \dot{m}_a \, x \, (W_{out} - W_{in}) \quad (2)$$

Throughout this discussion, the effect of the internal cooling on the performance of the desiccant bed is investigated using the experimental data of adsorption and desorption tests for different air flow rates, different cold and hot water flow rates and different sizes of silica gel particles.

3.2 Adsorption mode

The effect of the internal cooling on the exit air temperature, humidity ratio and moisture removal rate in the adsorption mode is shown in Fig. 3.

Figure 3 shows this effect at different cooling water flow rates at $\dot{m}_a$=0.125 kg/s and Fig. 4 at $\dot{m}_a$= 0.02 kg/s, both figures at silica gel particles diameter is 2 mm white color (type A). Generally, by increasing the cooling water flow rates the exit air temperature decreases, the exit air humidity ratio decrease and the removal rate increases. Also from these results, the maximum increase in air exit temperature is about 6 ^{o}C at $\dot{m}_a$= 0.125 kg/s and about 4 ^{o}C at $\dot{m}_a$=0.02 kg/s, moreover air exit temperature decreases at low air flow rate and low cooling water temperature due to the internal cooling so the adsorption process nearly takes place isothermally. Without internal cooling the exit air temperature increases significantly due to the adsorption process. The difference between $T_{a\,out}$ without internal cooling and with internal cooling may reach to more than 20 ^{o}C at low air flow rate. This decrease in $T_{a\,out}$ significantly enhances the adsorption process. Outlet air humidity ratio decreases with internal cooling than without internal cooling and the difference between them reaches more than 5 g/kg. The moisture removal rate (MRR g/s) increases by internal cooling. For the nearly same inlet air humidity ratio the increase in MRR due to internal cooling may be more than 50%.

Figure 5 shows the bed performance at different cooling water flow rates at $\dot{m}_a$= 0.1202 kg/sand silica gel particles diameter is 5 mm yellow color (type B). From the figure, the same trend nearly as 2 mm particles size can be observed. But the effect of internal cooling is not so high because of low inlet air temperature and humidity ratio because of uncontrolled outdoor conditions.

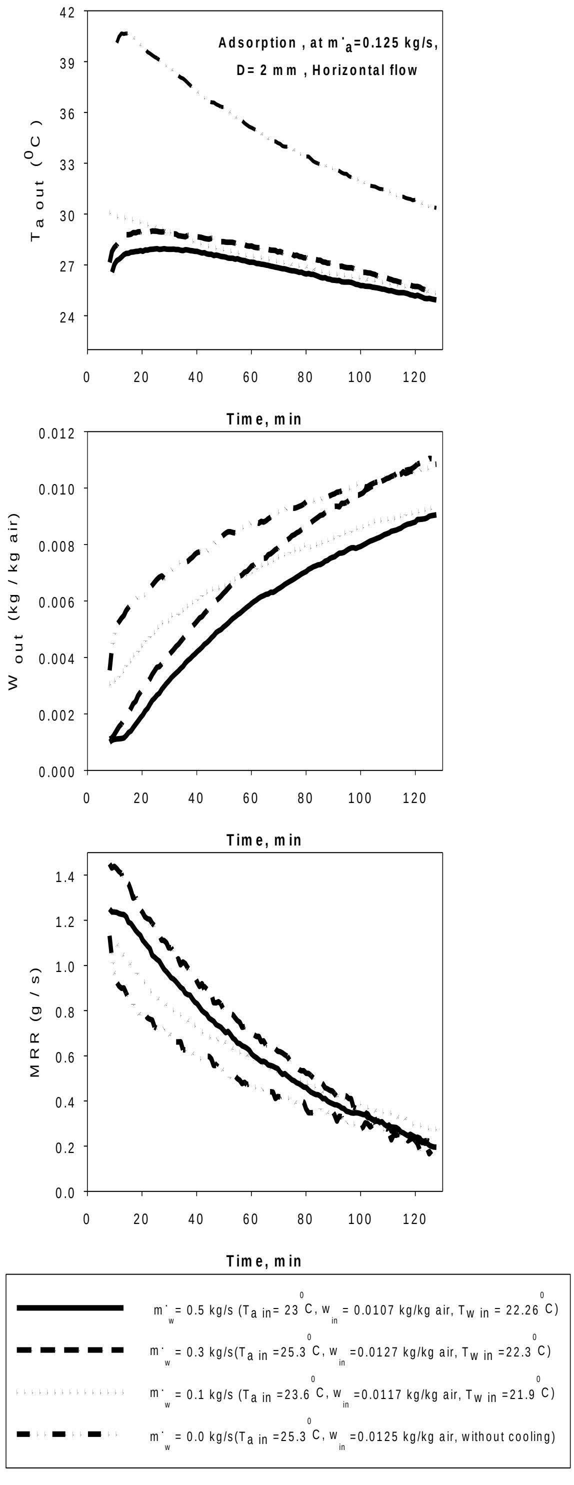


Fig. 3 Exit air temperature, humidity ratio and moisture removal rate for silica gel bed (adsorption mode at $\dot{m}_a$= 0.125 kg/s, D = 2 mm, horizontal flow)

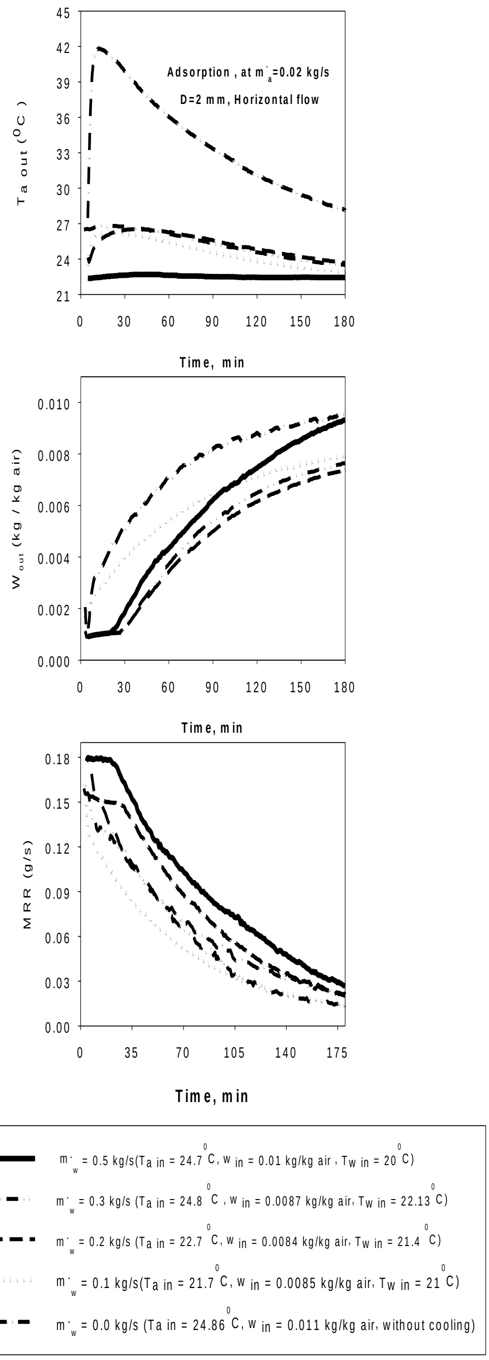


Fig. 4 Exit air temperature, humidity ratio and moisture removal rate for silica gel bed (adsorption mode at ṁa= 0.02 kg/s, D = 2 mm, horizontal flow)

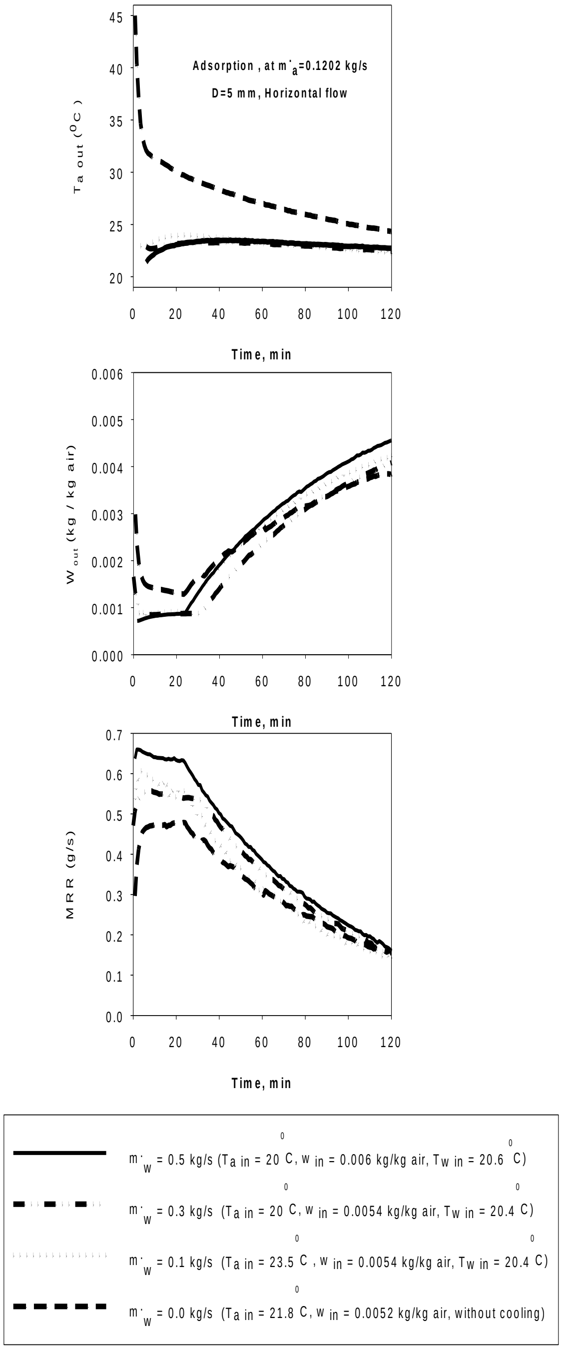


Fig. 5 Exit air temperature, humidity ratio and moisture removal rate for silica gel bed (adsorption mode at ṁa= 0.1202 kg/s, D = 5 mm, horizontal flow)

3.3 Desorption mode

In The effect of the internally heating on the exit air temperature, humidity ratio and moisture removal rate in the desorption mode is shown in Figs. 6-9.

Figure 6 shows this effect at different heating water flow rates at $\dot{m}_a$= 0.125 kg/s and fig. 7 at $\dot{m}_a$= 0.02 kg/s both figures at silica gel particles diameter 2 mm. Figure 8 shows this effect at different heating water flow rates at $\dot{m}_a$= 0.1202 kg/s at silica gel particles diameter 5 mm. From these results, in general, the exit air temperature and humidity ratio increase by increasing water flow rate which leads to moisture removal rate increases. In some cases, the exit air temperature increases and the moisture removal rate decreasing by decreasing the water flow rate this may be because of the different bed moisture content at the beginning of experiments.

Figure 9 shows the effect of heating water temperature on desorption process. By increasing the heating water temperature the exit air temperature increases and the ability of air to absorb water vapor from bed increases which causes the exit air humidity ratio and moisture removal rate increase. By increasing the regeneration temperature from 41.5^{o}C to 63^{o}C the increase in moisture removal rate can be more than 100% at some times.

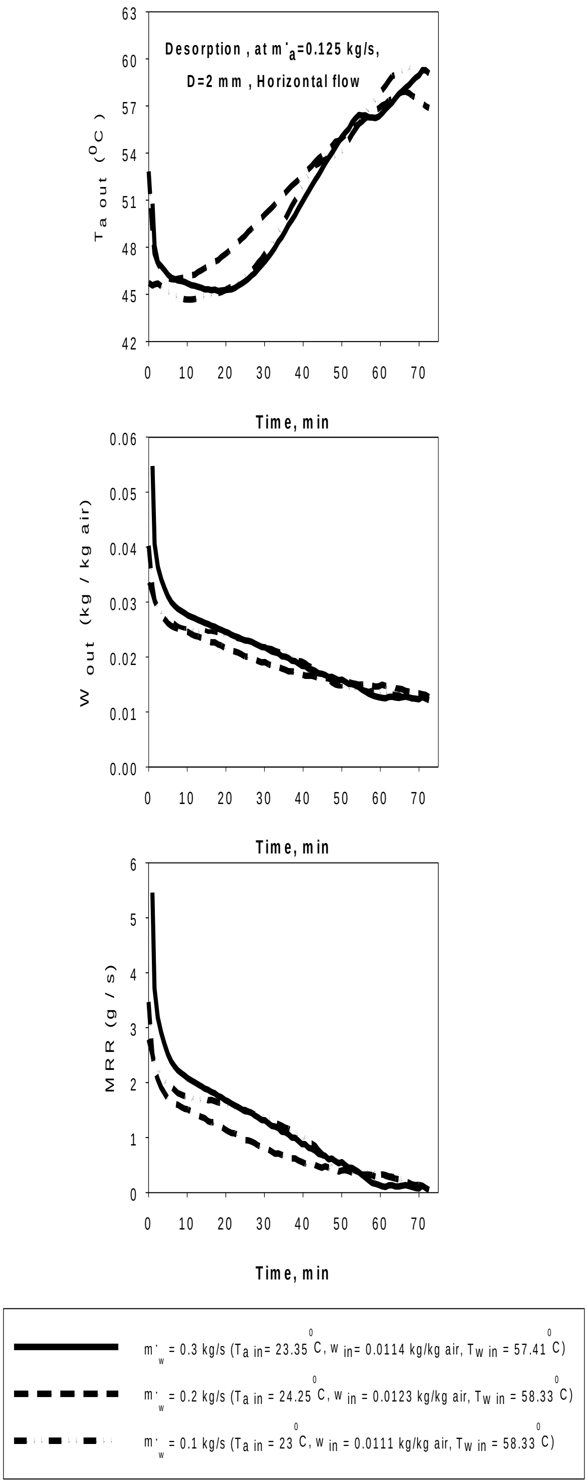


Fig. 6 Exit air temperature, humidity ratio and moisture removal rate for silica gel bed (desorption mode at $\dot{m}_a$= 0. 125 kg/s, D = 2 mm, horizontal flow)

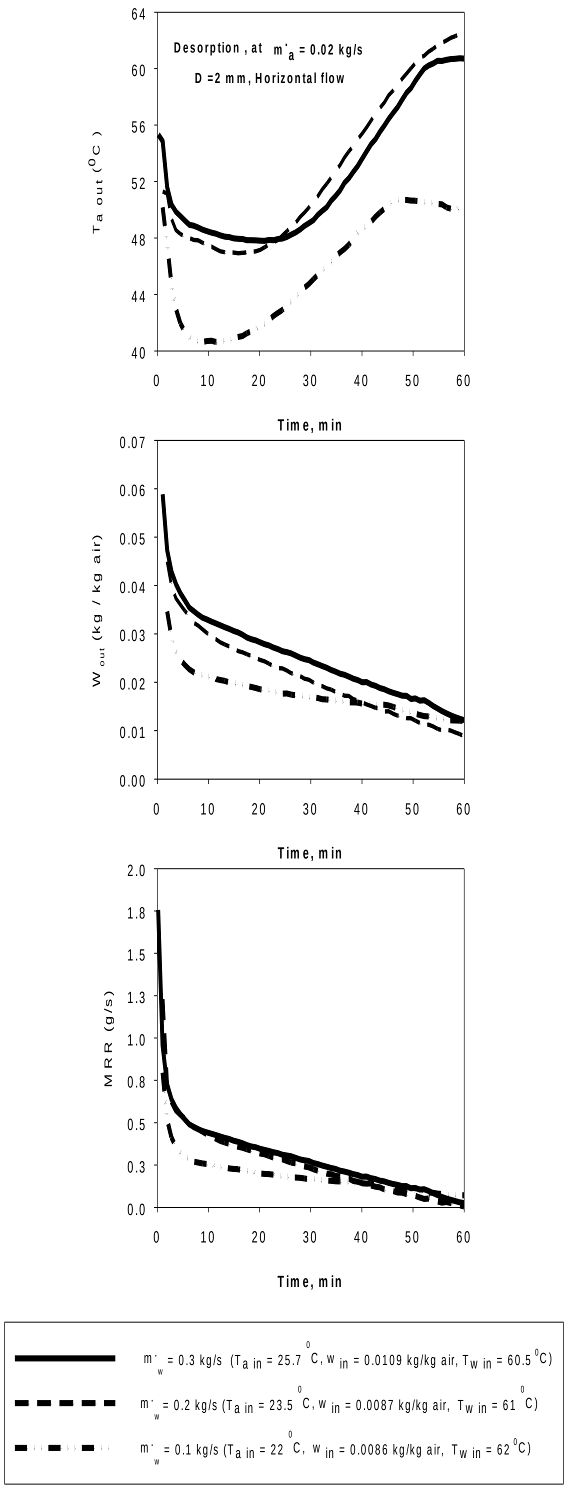


Fig.7 Exit air temperature, humidity ratio and moisture removal rate for silica gel bed (desorption mode at $\dot{m}_a$= 0. 02 kg/s, D = 2 mm, horizontal flow)

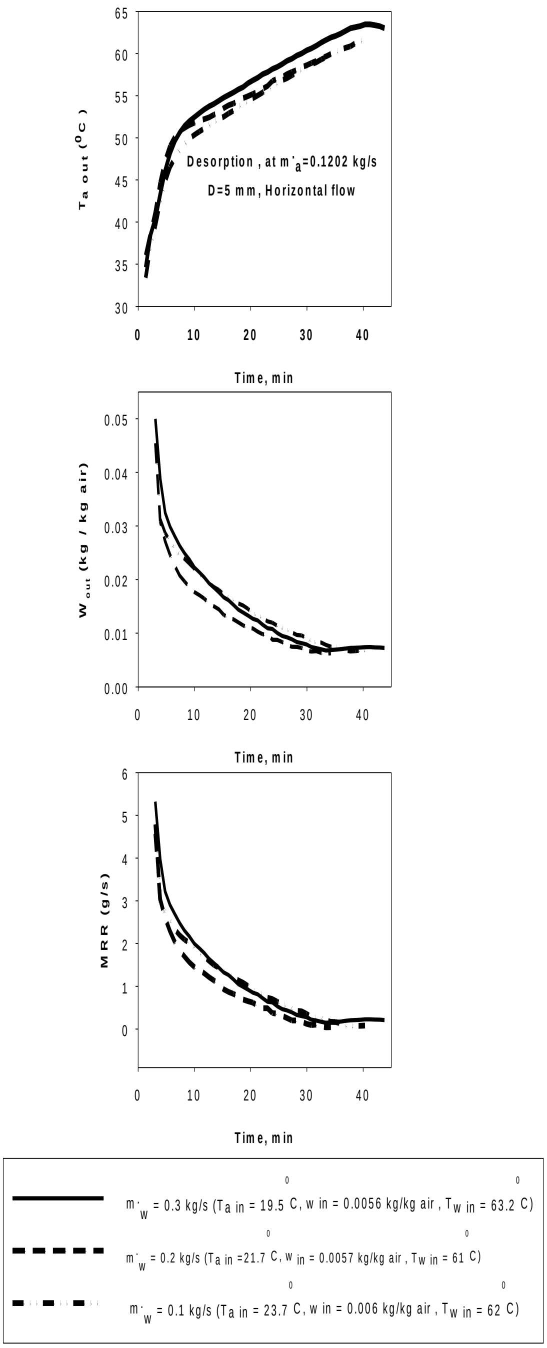


Fig. 8 Exit air temperature, humidity ratio and moisture removal rate for silica gel bed (desorption mode at $\dot{m}_a$= 0. 1202 kg/s, D = 5 mm, horizontal flow)

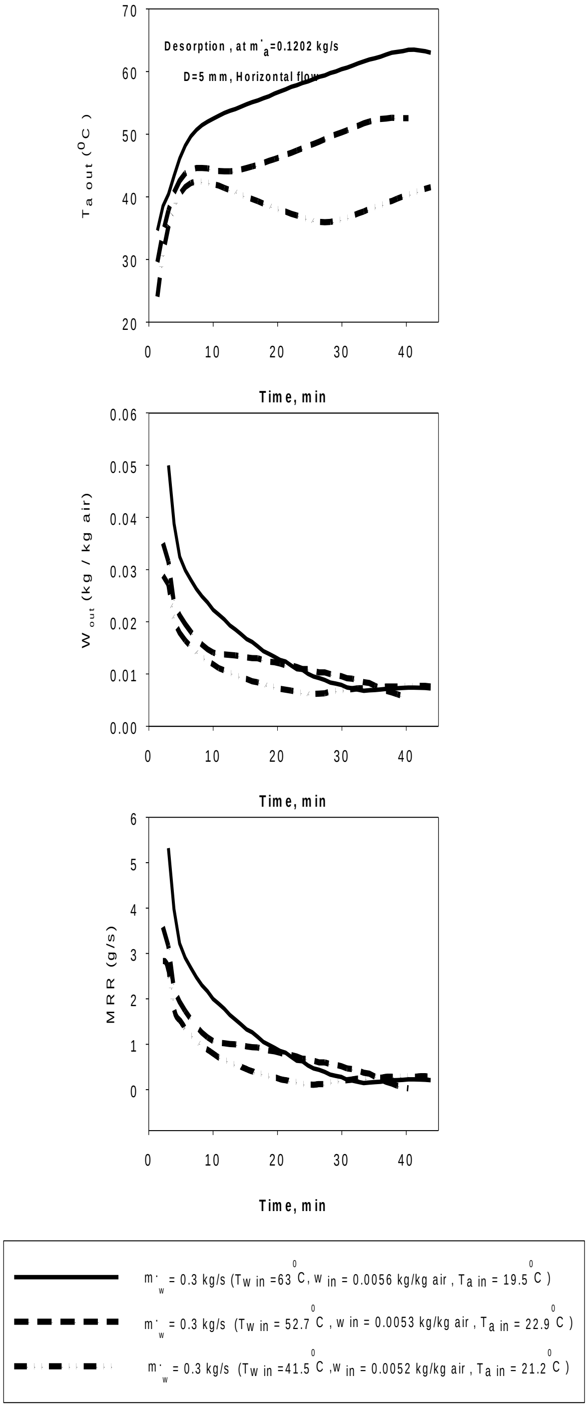


Fig. 9 Exit air temperature, humidity ratio and moisture removal rate for silica gel bed (desorption mode at $\dot{m}_a$= 0. 1202 kg/s, D = 5 mm, horizontal flow)

5. CONCLUSION

1- The maximum increase in air exit temperature is about 6 ^oC at $\dot{m}_a$= 0.125 kg/s and about 4 ^oC at $\dot{m}_a$= 0.02 kg/s, moreover air exit temperature decreases at low air flow rate and low cooling water temperature due to the internal cooling so the adsorption process nearly takes place isothermally.

2- It was found that the moisture removal rate rises with increase cooling water flow rate. On the other hand, the exit air temperature decreases as the cooling water flow rate increases. However the humidity ratio decreases with higher value of cooling water flow rate. This means that the dehumidification is improved with increasing the cooling water flow rate through the bed. The enhancement in bed performance can be more than 50% due to internal cooling.

3- It was found that the moisture removal rate decreases with decreasing the process air flow rate.

4- Through the study it was observed that the desorption process takes place more rapidly than the adsorption one and enhances significantly by increasing the regeneration temperature for example by increasing it from 41.5 °C to 63 °C the moisture removal rate increases from 2.8 g/s to 5.4 g/s.

5- (5) Regeneration temperature less than 60°C are sufficient to regenerate the bed at the specify experimental outdoor conditions.

6. NOMENCLATURES

A	The cross section area of desiccant bed exit (m^2).
D	The diameter of desiccant particles (mm).
$\dot{m}_a$	The air mass flow rate (kg/s).
$\dot{m}_w$	The water mass flow rate (kg/s).
MRR	The moisture removal rate (g/s).
U_m	The exit air means velocity (m/s).
$T_{a\,in}$	The inlet air temperature (°c).
$T_{a\,out}$	The exit air temperature (°c).
$T_{w\,in}$	The inlet water temperature (°c).
W_{in}	The inlet air humidity ratio (kg water vapor / kg dry air).
W_{out}	The exit air humidity ratio (kg water vapor / kg dry air).
ρ_a	The density of air (kg/m^3).

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