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Full Length Research Paper

Theoretical investigation on the cyclic operation of radial flow desiccant bed dehumidifier

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In the present work a theoretical investigation of the cyclic operation of the radial flow solid desiccant dehumidifier has been reported. A mathematical model has been developed to predict the effect of air inlet conditions (humidity, temperature and flow rate) as well as bed design parameters on the desiccant bed dynamic performance during cyclic operation. The results show that, lower values of the humidity of process air at bed exit could be attained with increase in regeneration temperature, and desorption time decreases with increase in regeneration temperature. On the other hand, the adsorption time increases with increase in regeneration temperature. Also, it was found that, the adsorption time increases with the decrease in the required degree of dehumidification (w_o/w_i), and the ability of the bed to adsorb the moisture from air increases as the inlet air temperature decreases.

Key words: Adsorption, desorption, silica gel, desiccant, dehumidification, packed bed.

INTRODUCTION

The use of air conditioning and refrigeration is increasing day by day for providing thermal comfort in industrial and residential areas. This technology requires higher energy consumption and is responsible for the emission of CO_2 and other green house gases such as CFCs, HCFCs, which are considered major ozone-depleting gases. Adsorption based systems are promising for providing a safe alternative to CFC-basis refrigeration devices. From this context, adsorption air conditioning and refrigeration systems attain considerable attention as they can be driven either by waste heat sources or by renewable energy sources. From the 1970s, interest in solid-vapor adsorption systems was rekindled in view of their energy saving potential. Many desiccant materials are available, such as silica gel, activated alumina, molecular sieve, alumina gel, etc. However, silica gel, activated alumina and molecular sieve have a higher adsorption capacity (Anonymous, 1978). Of these, molecular sieve requires relatively higher regeneration temperature for 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. This makes these desiccant materials useful for use with solar energy as efficiency of solar collector's decreases with the increase in collection temperature. An investigation on simultaneous dehumidification of silica gel and activated alumina showed that silica gel transfers about 30% more water per unit dry mass than activated alumina, Dupont et al., (1994).

In the present investigation, silica gel has been used as the desiccant material. Silica gels and zeolites have been utilized for dehumidification processes in industrial and residential applications for their great pore surface area and good moisture adsorption capacity. In general, the regeneration temperature for silica gel is less than that of zeolites. Engineers noticed that the operating cost of these types of systems is dependent on the amount of the regeneration energy. An economic analysis on the operating cost of a silica gel bed was reported by Marciniak (1985), and an adsorption performance analysis on the regeneration condition of the other adsorption process was reported by Kamiuto and Ermalina (2002). The sorption of water vapor into a porous sorbent results in the release of the so called ‘‘heat of sorption’’. Accordingly, the temperature of the sorbent particle rises, which reduces its sorptive capacity. Therefore, the heat of sorption has to be removed before a further vapor can be transferred into the sorbent. Thus, the rate of vapor sorption is mainly controlled by both heat and mass transfer mechanisms within the porous

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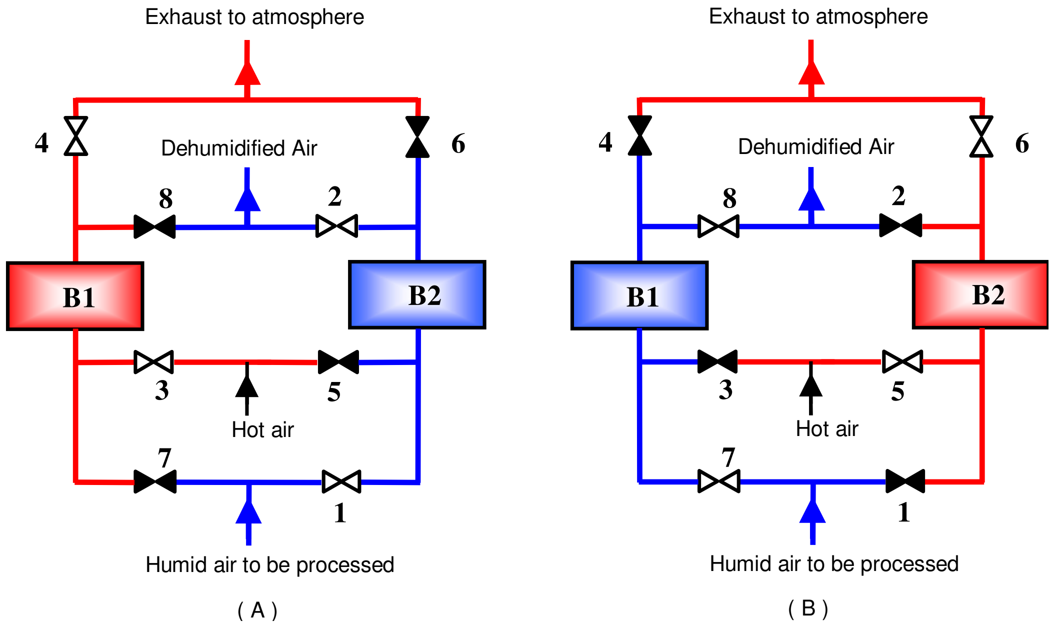


Figure.1 Flow diagram of two-bed adsorption-desorption air dehumidification system packed bed dehumidifier.

bed. The investigation of the combined heat and mass transfer characteristics accompanied with such a sorption process is, therefore, very important in designing and optimizing the operation of sorptive based dehumidifiers. Much research on the solid desiccant dehumidifiers has been accomplished, and many successful, effective mathematical models to predict the heat and mass transfer process in such dehumidifiers have emerged (Pesaran, 1978; Pesaran, 1978; Ahmed, 2002; Paradip, 1998)

Several desiccant dehumidifiers configurations including solid packed bed, rotating horizontal bed, multi-ple vertical bed, rotating honeycomb, fluidized bed, and inclined bed have been investigated for dehumidification purpose (Paradip, 1998; Daou et al., 2004; Ahmed, 2005; Zhang et al., 2001; Elsayed and Chamkha, 1997; National committee of USSR for products control and standards, 1991; Niu and Zhang, 2002; Niu and Zhang, 2002). Most of dehumidifiers working with desiccant packed beds consists mainly of two desiccant beds; one of these beds is working as a dehumidifier and the other undergoes a desorption process. The process air flows through the desiccant bed giving up its moisture to the bed particles. After the bed has become saturated with the moisture, the bed is heated and purged of its moisture for regeneration. Thermal energy that drives the regeneration of the desiccant is added to the process by heating the bed or the reactivation air stream. So, the main driver of the operation mode is the inlet air stream condition. Usually, inlet air stream temperature determines the mode of operation of the desiccant bed. Yang San et al (2002) studied the heat and mass transfer in a packed-bed dehumidification system with humidity damper in which the silica gel particles experience with a significant cyclic temperature variation. In the present study, the cyclic operation of the previously suggested radial desiccant bed Awad et al. (2008), as well as the various operating parameters affecting it has been investigated.

Cyclic operation (System description)

A schematic diagram of the two bed adsorption-desorption air dehumidification system is illustrated in Figure 1. The system consists of two desiccant beds and eight control valves. The two beds exchange the operation mode with the help of control valves. As shown in the Figure (1-A), one of the two beds B1 operates as an adsorber, while the other bed B2 functions as a desorber. During this mode of operation, valves 1, 2, 3 and 4 are kept open while the other four valves 5, 6, 7 and 8 are closed. To exchange the function between the two beds, the valves condition is reversed, as shown in Figure (1-B), that is, valves 1, 2, 3 and 4 are closed and the others are opened. In this case, the bed B2 operates as an adsorber and the second bed as desorber. The operation schedule of control valves is given in Table 1. The heat and mass transfer in the bed is individually analyzed by using a computer program with two different switching control schemes. The first is Equal Adsorption-Desorption Periods Operation (EADPO), and the second is Humidity Controlled Adsorption-Desorption Operation (HCADO).

Table 1. Operation schedule of control valves and desiccant beds.

Case	Valves		1	2	3	4	5	6	7	8
A	B1	Adsorber	Open	Open	Open	Open	Closed	Closed	Closed	Closed
	B2	Desorber								
B	B1	Desorber	Closed	Closed	Closed	Closed	Open	Open	Open	Open
	B2	Adsorber								

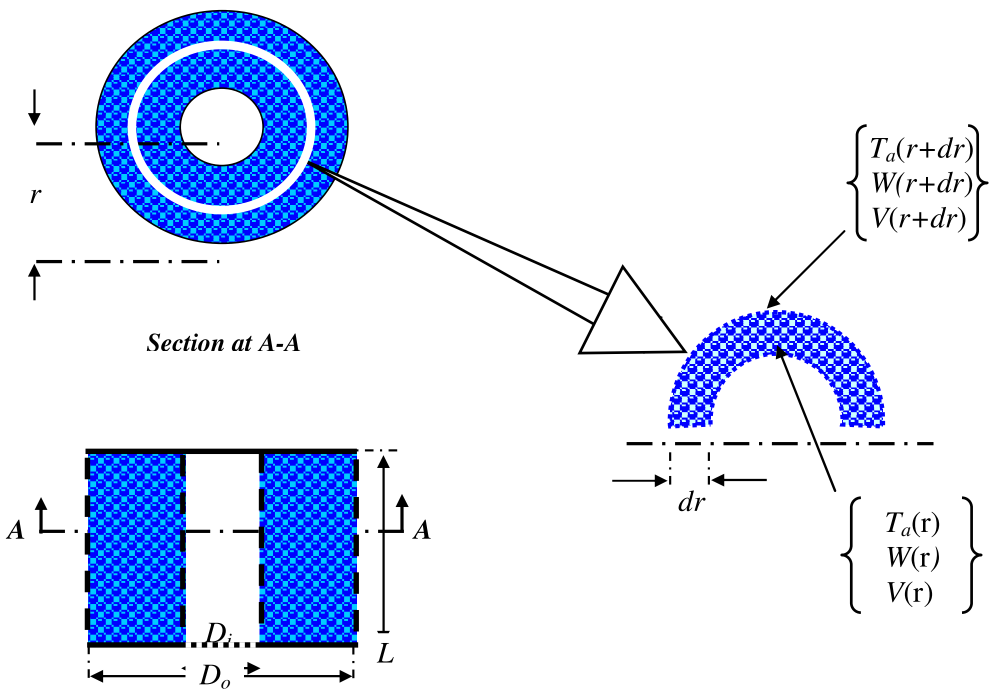


Figure 2. The physical model of the hollow cylindrical packed bed.

Theoretical model

Configuration of the radial flow packed bed dehumidifier, shown in Figure 2, has been experimentally and theoretically investigated in previous study Awad et al. (2008). In this study, a mathematical model for the heat and mass transfer in the radial flow desiccant bed was developed for the adsorption and desorption modes separately. Also, the results was discussed and validated with that of the experimental data, and acceptable agreement was found.

The granules of silica gel in the packed bed have the ability to adsorb moisture from the surrounding air. The process of moisture adsorption on the surface of the silica gel particles releases an amount of heat called heat of adsorption, which results in bed temperature rise. This problem can be treated as a transient heat and mass transfer problem, and the following assumptions will be considered in system analysis; The physical process of adsorption is so fast relative to other slow steps (diffusion within silica gel particles), that in and near the silica gel particles, a local equilibrium exists (Marciniak, 1985). A single film mass transfer coefficient controls the transfer rate between the flowing air and the silica gel particles. The flow direction of air in the hollow cylindrical bed is only radial flow. Heat of adsorption results from the condensation of water vapor in the internal pores in the silica particles, so the heat of adsorption is assumed to be totally generated in the silica particles (Kamiuto and Ermalina, 2002). The heat transfer takes place only by forced convection to the flowing air through the bed, neglecting the conduction heat transfer between the bed particles, so the temperature gradient is a result only of convection heat transfer.

Gas phase moisture balance: Applying the conservation low to the moisture contained in both air and silica gel bed, we have;

$$\frac{\partial w}{\partial r} = -\frac{(1-\varepsilon)\rho_s}{v(r)\rho_a(r)}\frac{\partial q}{\partial t} \quad \text{... (1)}$$

where $v(r)$ is the superficial air velocity (the velocity that would exist if the tube is empty) at radius r, ε denotes the fractional void volume, q is the average composition of the silica gel, expressed as kg of water adsorbed per unit mass of silica gel and ρ_s is the density of dry silica gel in [kg/m^3].

Solid phase moisture balance: An adsorbed moisture balance in the silica gel can also be made using the rate law. Since the silica gel loses no material and generates none, this means that the rate of accumulation equals the rate of moisture transfer to the silica gel. The silica gel balance yields.

$$(1-\varepsilon)\rho_s \frac{\partial q}{\partial t} = ka\left(w - w^*\right) \quad \text{... (2)}$$

Where {*ka*} is the volumetric mass transfer, kg/m^3.sec

Solid phase energy balance: Applying the energy conservation low to the silica gel bed, we have:

$$HA * ka\left(w - w^*\right) = ha\left(T_s - T_a\right) + (1-\varepsilon)\rho_s C_s \frac{\partial T_s}{\partial t} \quad \text{... (3)}$$

Where;

T_s : The temperature of the silica gel in the bed, ^oC

T_a : The temperature of flowing air, ^oC

C_s : Specific heat of silica gel, kJ/ kg.K

C_a : Specific heat of the flowing air, kJ/ kg.K

ha : Volumetric heat transfer coefficient, kw/m^3.K

HA: Heat of adsorption, kJ/kg

Gas phase energy balance: Energy balance for the flowing air through the bed can be expressed as,

$$C_a \rho_a(r) v(r) \frac{\partial T_a}{\partial r} = ha\left(T_s - T_a\right) \quad \text{... (4)}$$

Boundary conditions: The mathematical model of the system consists of Equations. (4), (5), (7), and (8), and the isotherm in Equation (2). In these four partial differential equations we have four unknowns (*w*, *q*, T_s, and T_a). The mathematical model has been solved numerically using finite difference scheme, and the following initial and boundary conditions will be considered:

$q(r,0) = q_o$ (Initial water content of silica gel) ...... … (i)

$T_s(r,0) = T_{so}$ (Initial temperature of silica gel) ...... … (ii)

$w(0,t) = w_o$ (Constant entering air humidity) … (iii)

$T_a(0,t) = T_o$ (Constant entering air temperature) … (iv)

The condition on q implies;

$w^*(0,t) = w^*{}_o$ ... (v)

Auxiliary relations: Based on a survey of the available literature on mass transfer in packed beds, the following relations were used as auxiliary relations;

- Heat and mass transfer coefficients for the gas side in packed beds is presented in Pesaran (1978) by the following relation

$$k = 0.704 Ga \quad Re^{-0.51} \quad kg / m^2\, sec$$

$$h = 0.683 Ga \ C_a \ Re^{-0.51} \quad w / m^2 K$$

Where *Ga* is the air mass flux in, *kg/m^2.sec*, and *Re* is Reynolds number.

- Heat of Adsorption of silica gel is presented in Jung-Yang et al. (2002) as a function of air specific humidity (*w*) as:

$$HA = 3500.0 - 13400.0 \times q \quad q \le 0.05$$

$$HA = 2950.0 - 1400.0 \times q \quad q > 0.05$$

Silica gel – water isotherm is presented in [17] as;

$$RH^* = S_1 T_s q^2 + S_2 T_s q + S_3 q^4 + S_4 q^3 + S_5 q^2 + S_6 q$$

Where:

RH^* The relative humidity of air in equilibrium with silica gel

T_s The temperature of silica gel particles [^oC]

q The water content of silica gel [kg/kg dry silica].

The regression constants S_1, S_2, S_3, S_4, S_5, and S_6 are given as -0.04031298, 0.02170245, 125.470047, -72.651229, 15.5223665, and 0.00842660, respectively.

RESULTS AND DISCUSSION

In the following subsections, the main concept of cyclic operation is analyzed on the basis of equal time for adsorption and desorption processes, then the various

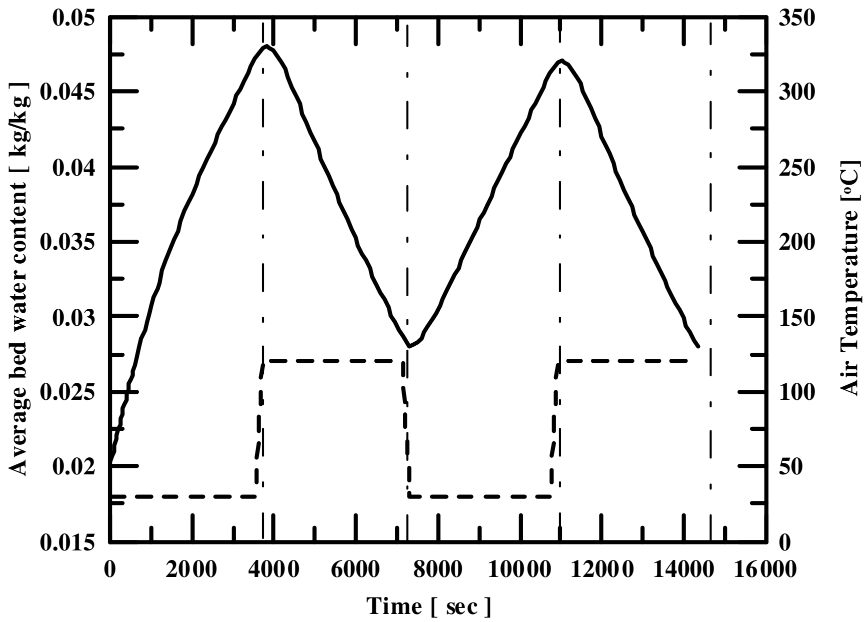


Figure 3. Bed water content with time.

operating parameters affecting the cyclic operation will be discussed.

System operation with EADP scheme

Figure 3 shows the continuous increase and decrease of bed water content during an adsorption-desorption cycle. Inlet air temperature determines the mode of operation of the bed, whereas the air specific humidity is constant at bed inlet. The periodic time of the cycle presented in Figure 3 is 2 h. The cycle starts with adsorption mode for 1 h with subsequent 1 h for desorption. The transient variation of bed water content is shown in the figure. It can be noted that, for the specified period of operation, the rate of increase and decrease of water content in the bed is nearly constant. Also, the maximum and minimum value of bed water content, for the specified conditions, is limited to about 2.8 and 4.8% respectively. It is expected that the limits of water content for a specific cycle is dependent on the bed design parameters and inlet air conditions (temperature and humidity). Figures 4 and 5 demonstrate the parameters of air at bed exit during the cycle. It can be noted that, the step change in inlet air temperature results in rapid increase in humidity ratio and temperature of air at bed exit. The exit humidity ratio of air reaches its maximum value in the desorption mode, and again gradually decreases whereas the heating process continues. When adsorption starts in the succeeding cycle, air exit humidity ratio rapidly decreases to a minimum value which is kept nearly constant for most of the period of adsorption. The air temperature at the bed exit follow that of inlet stream with slight increase during adsorption and decrease during desorption (Figure 4).

The transient variation of the average temperature of the bed is illustrated in Figure 6. The maximum and minimum temperatures of the bed for the conditions shown in the figure are 58.6 and 87.6°C respectively. However, it is expected that these limits of bed temperature are dependent mainly on the period of each mode. Longer period of desorption will increase the higher limit of bed temperature. On the other hand, increase in the adsorption period will decrease the minimum limit of the bed temperature. In the following subsections, the affecting parameters on the system (Regeneration Temperature, Diameter Ratio, and Periodic Time) are discussed.

Effect of regeneration temperature

The regeneration temperature is a key parameter for the desorption process. Figure 7 shows the effect of the regeneration temperature on the bed water content. It is obvious that, the degree of bed regeneration increases with increase in regeneration temperature, which results in lowering the operating range of bed water content, and consequently lowering the exit air humidity. Figure 8 shows the exit air humidity of the dehumidifier for two regeneration temperatures (90 and 120°C). Lower values of the humidity of air at bed exit could be attained with increase in regeneration temperature.

Effect of diameter ratio

Figures 9 and 10 demonstrate the cyclic variation of bed

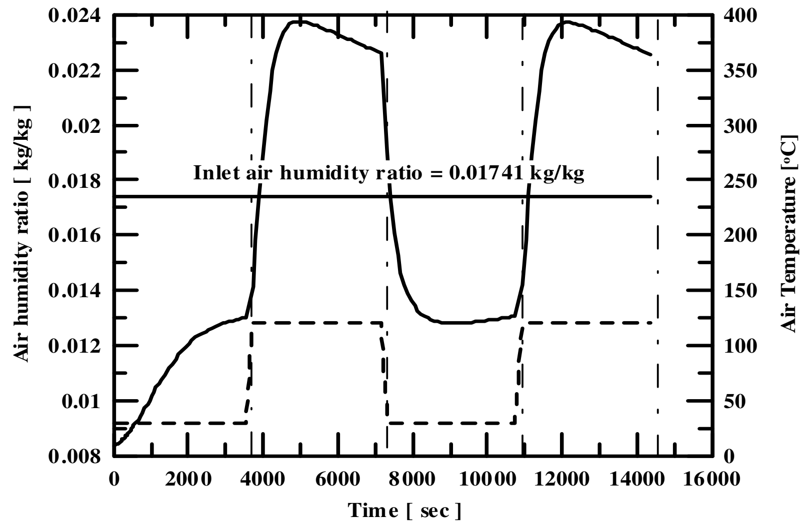


Figure 4. Exit air humidity with time

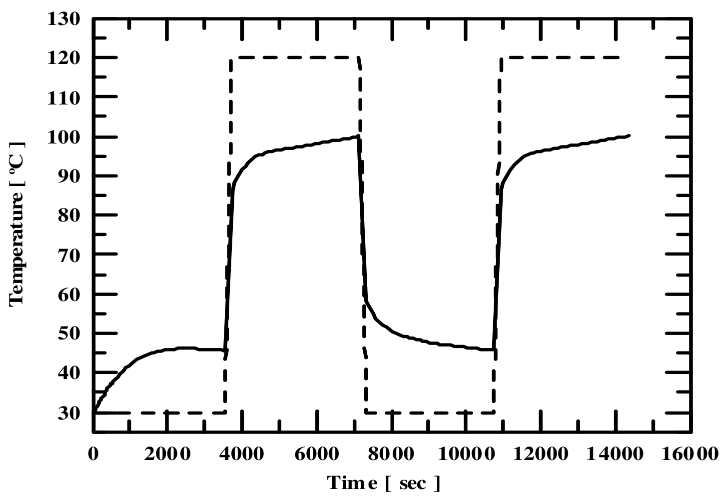


Figure 5. Exit air temperature with time.

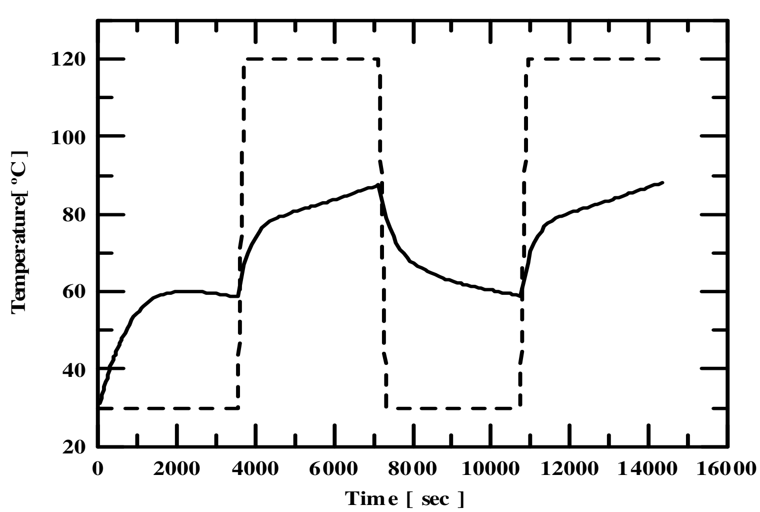
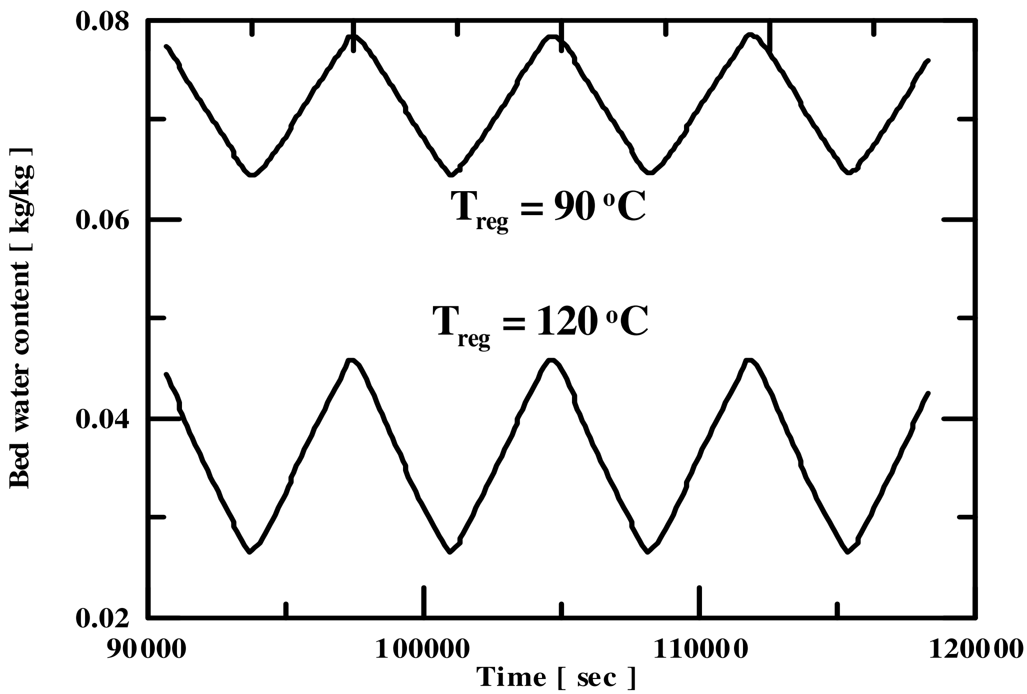
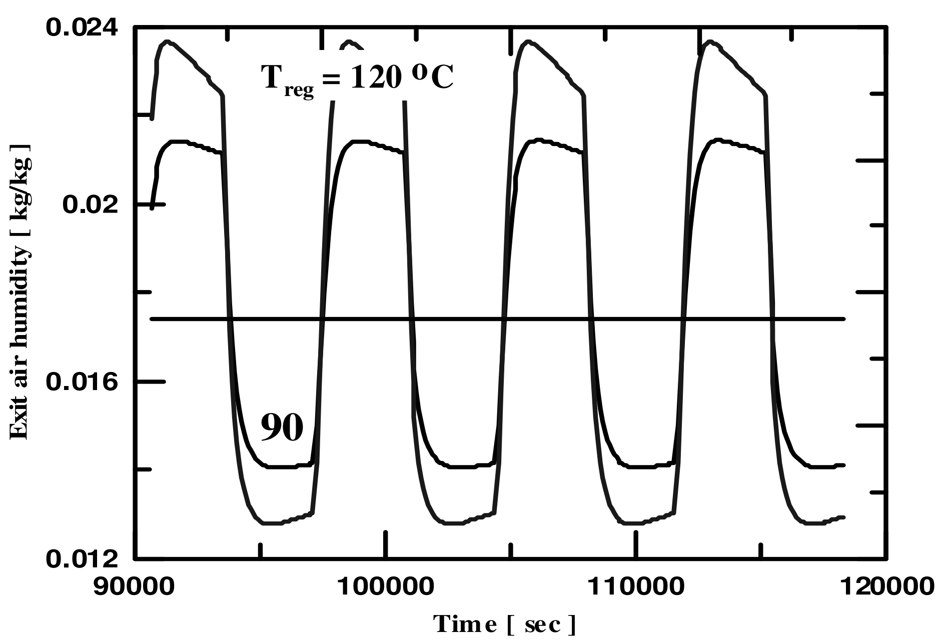


Figure 6. Average bed temperature with time.



PT = 3600 sec, T_a = 30 °C, RH = 65 %, D_i = 5 cm, D_o = 13.5 cm, L = 40 cm, Flow=6 L/sec

Figure 7. Bed water content with time at different values of regeneration temperature.



PT = 3600 sec, T_a = 30 °C, RH = 65 %, D_i = 5 cm, D_o = 13.5 cm, L = 40 cm, Flow=6 L/sec

Figure 8. Exit air humidity with time at different values of regeneration temperature.

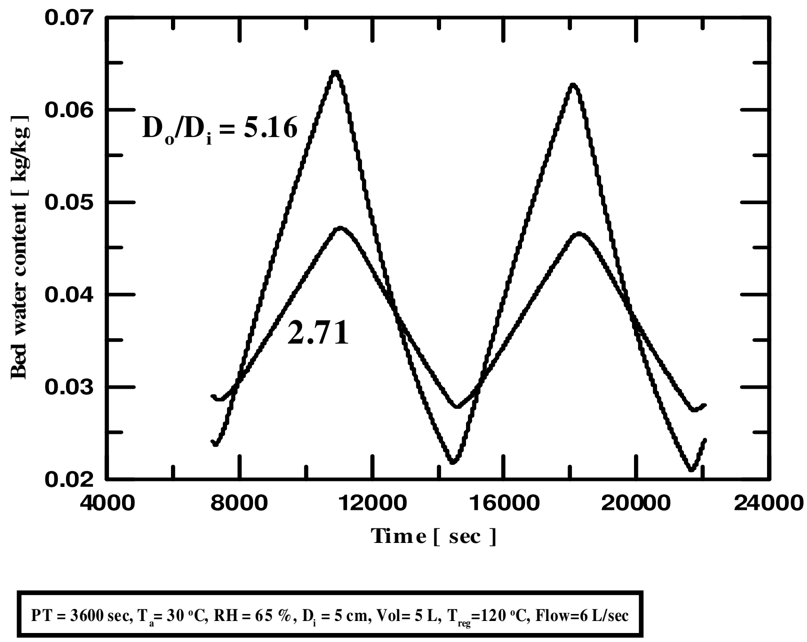


Figure 9. Bed water content with time at different values of bed diameter ratio.

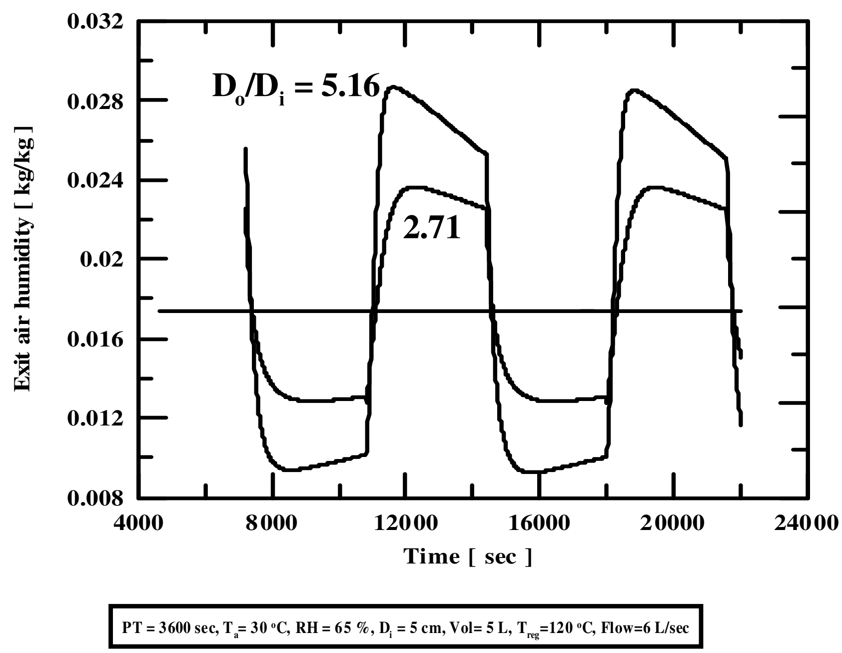


Figure 10. Exit air humidity with time at different values of bed diameter ratio.

water content and humidity of air at exit, respectively. It can be observed that increasing the diameter ratio results in higher operating range of bed water content and higher degree of dehumidification.

Effect of periodic time (PT)

It is interesting to evaluate the effect of periodic time on the performance of the system during cyclic operation. Figures 11 and 12 show the exit air humidity and bed water content, respectively. It can be observed that operation with longer periodic time results in increase in the operating rang of bed water content. Also, as a result the exit air humidity slightly increases. It can be stated here that, the periodic time should be selected according to the range of dehumidification degree required in

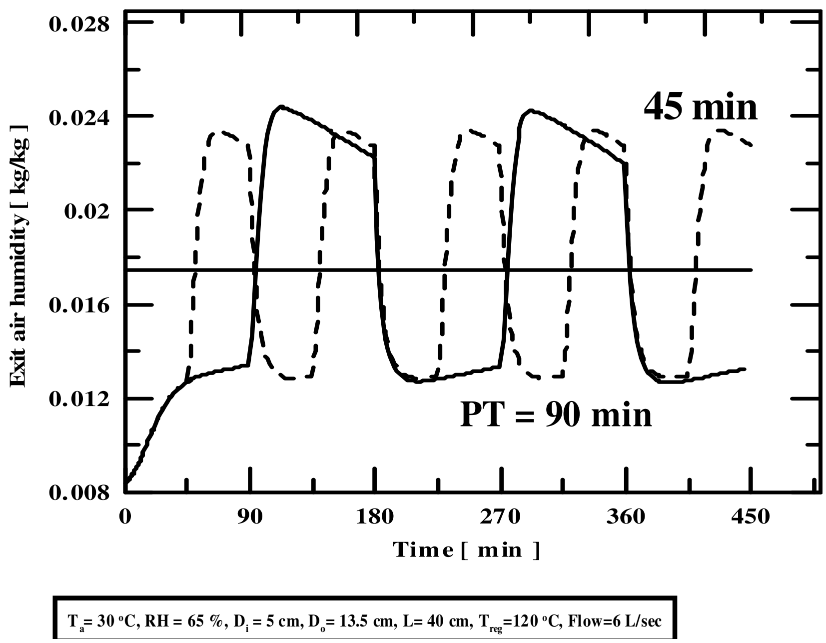


Figure 11. Bed water content with time at different values of periodic time.

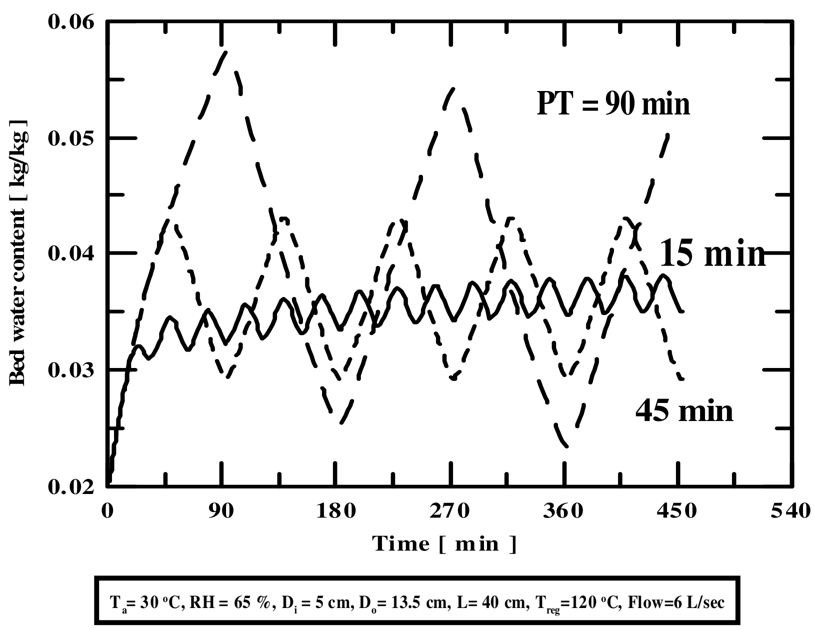


Figure 12. Exit air humidity with time at different values of periodic time.

accordance with the regeneration temperature and diameter ratio.

Humidity controlled adsorption-desorption operation

In order to operate an adsorption-desorption air dehumidification system in a humidity controlled mode, the exit humidity of air determines the mode of operation of the bed. When the bed operates in adsorption mode, the maximum limit of the exit air humidity switches off the dehumidification process for this bed and the mode is reversed to desorption. On the other hand, during desorption process, air humidity at bed exit decreases gradually with time. Defining a minimum limit for air humidity at bed exit during desorption can be used as a control parameter to switch off the desorption mode and

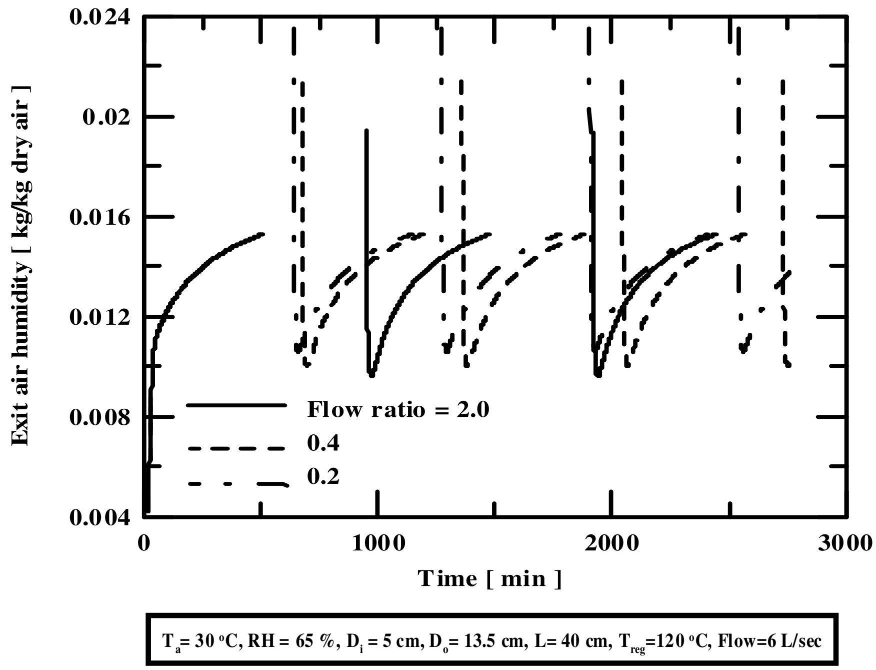


Figure 13. Exit air humidity with time at different values air flow ratio.

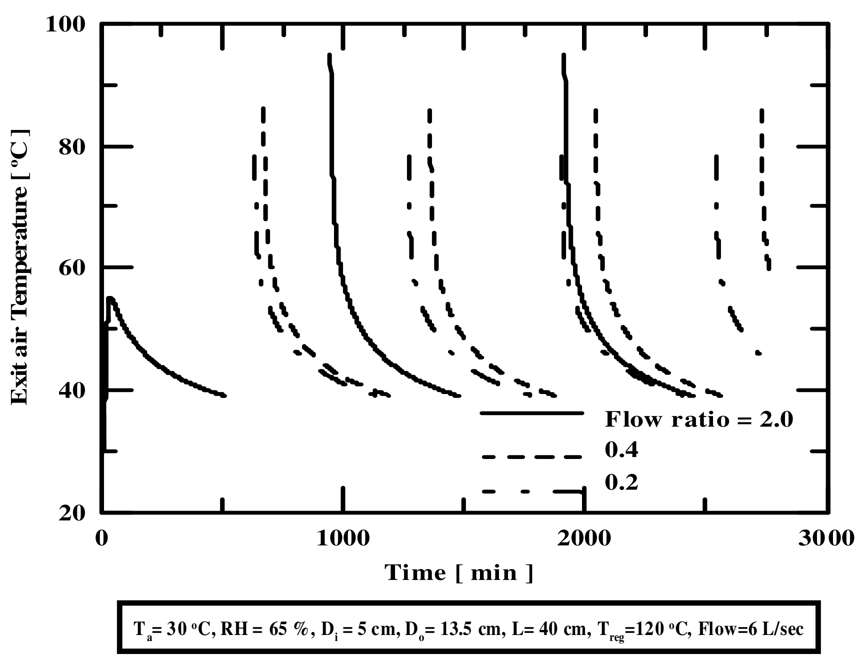


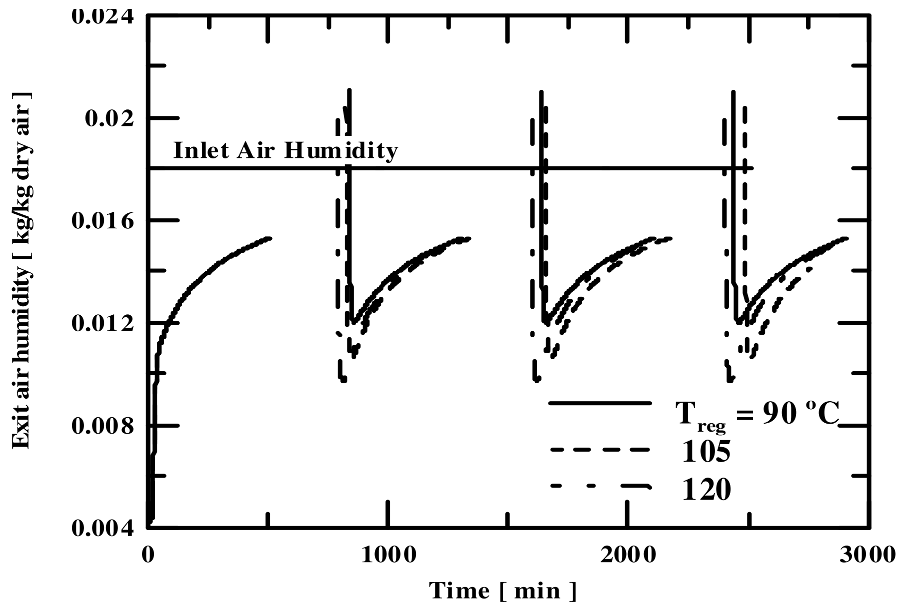
Figure 14. Exit air temperature with time at different values air flow ratio.

start adsorption.

To study the system operation under the condition of exit humidity control, the periodic time is expected to be dependent on the air inlet parameters as well as the setting limits of the air exit humidity. Moreover, the adsorption and desorption periods may have unequal values. The driving parameters for the system, in this case, are the process and desorption air conditions (humidity, temperature and flow rate). In the following analysis, effect of these parameters will be demonstrated.

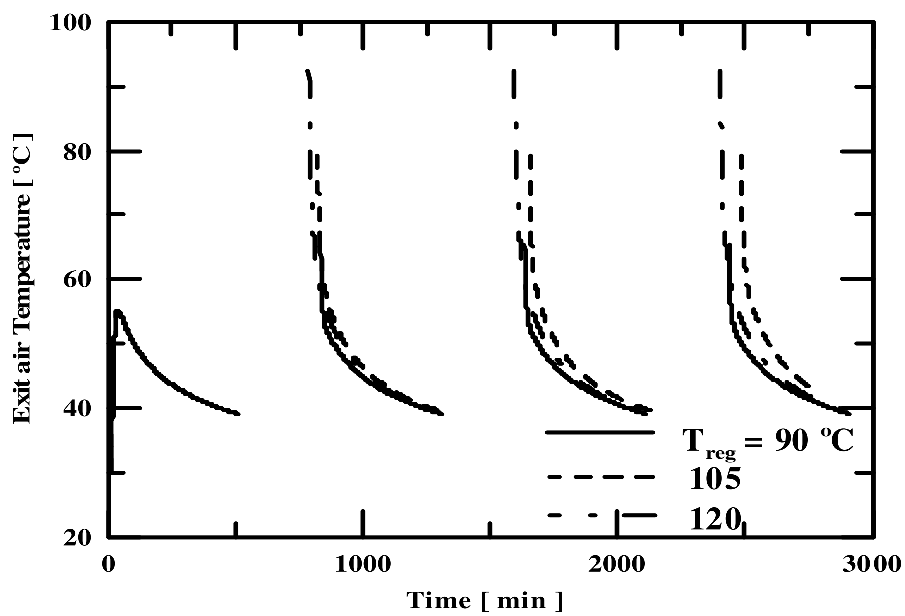
Effect of desorption air parameters

Figure 13 and 14 show the transient variation of process



T_a= 30 °C, RH = 65 %, D_i = 5 cm, D_o= 13.5 cm, L= 40 cm, Flow Ratio =1, Flow=6 L/sec

Figure 15. Exit air humidity with time at different values of regeneration temperature.



T_a= 30 °C, RH = 65 %, D_i = 5 cm, D_o= 13.5 cm, L= 40 cm, Flow Ratio =1, Flow=6 L/sec

Figure 16. Exit air temperature with time at different values of regeneration temperature.

air exit humidity and temperature, respectively. This analysis is carried out under different conditions of flow ratio. The flow ratio is the ratio of process air to desorption air. It can be seen that, required time for desorption process decreases as the flow ratio decreases. Figure 14 shows that, the exit air temperature decrease with increase in flow ratio.

The effect of regeneration air temperature is illustrated in Figures 15 and 16. It can be observed that desorption time decreases with increase in regeneration tempera-

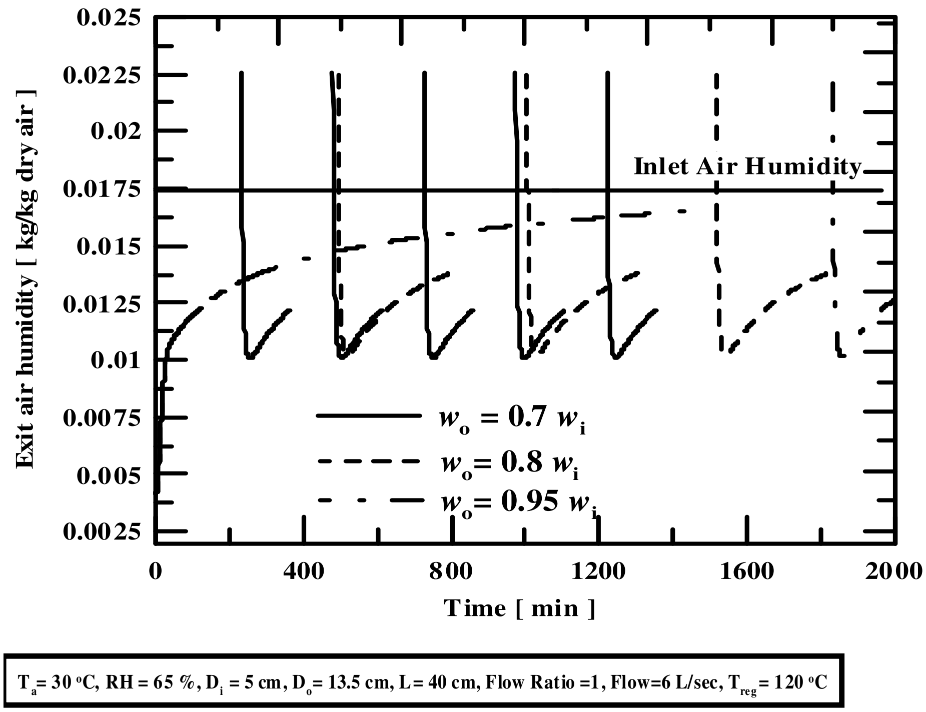


Figure 17. Exit air humidity with time at different values of (wo/wi).

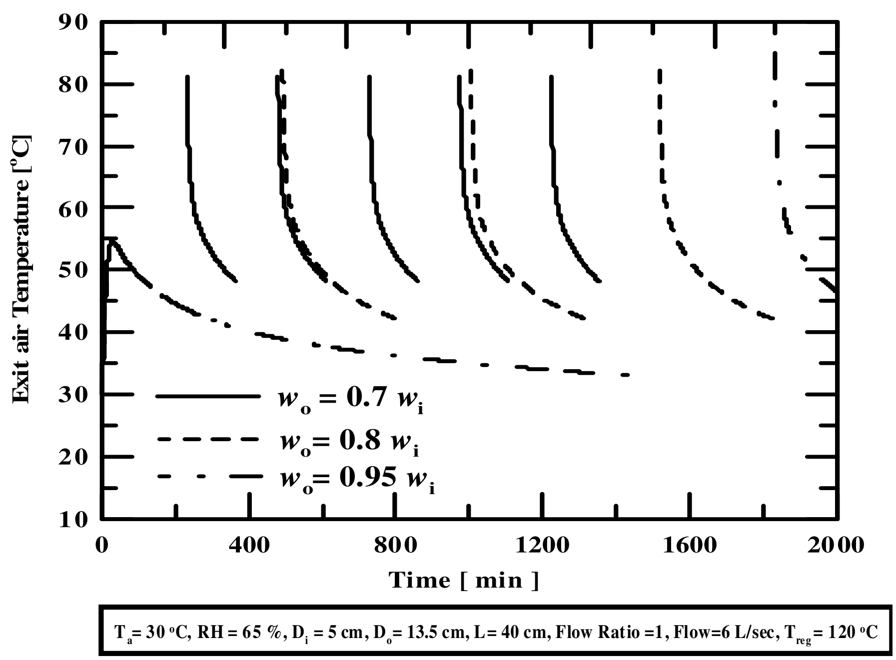
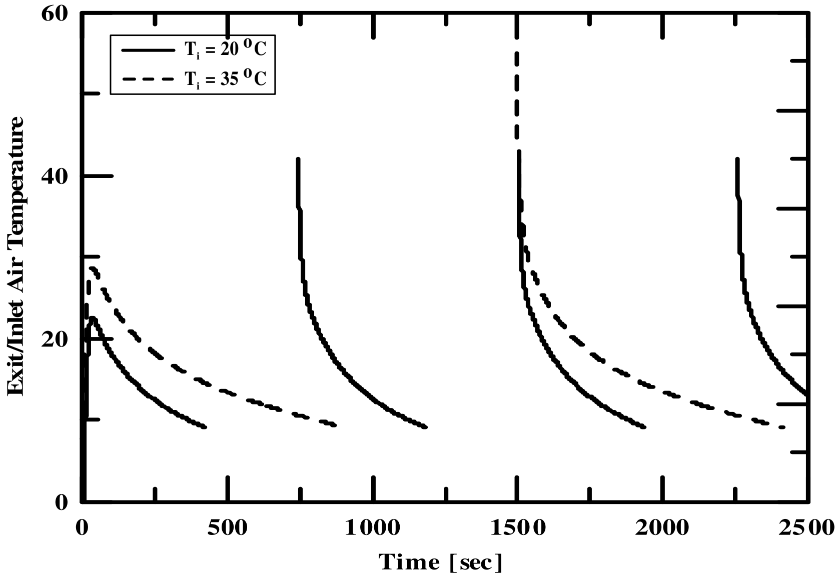


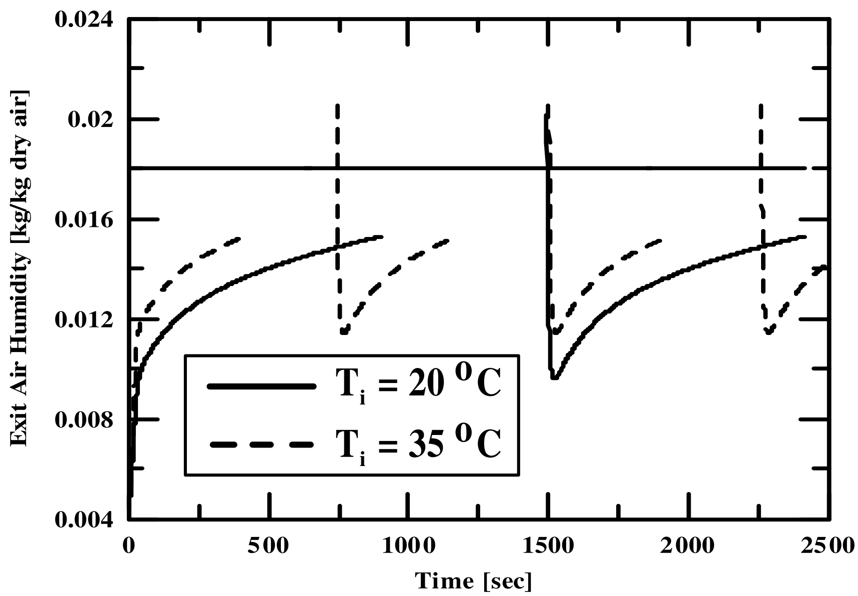
Figure 18. Exit air temperature with time at different values of (wo/wi).

ture, on the other hand, the adsorption time increases with increase in regeneration temperature. Figures 17 and 18 shows that, the adsorption time increase with decrease in the required degree of dehumidification (w_o/w_i). Exit air humidity and temperature of process air for various required degree of dehumidification are shown in Figures 17 and 18, where the degree of dehumidification is the ratio of exit to inlet air humidity ratio.



wo=0.85wi, T_{reg} =120 °C, RH = 65% , D_i =5cm, D_o = 13.5 cm, L = 40cm, FR = 1, $Flow_{Reg}$ = 6 L/sec

Figure 19. Exit air humidity with time at different values of inlet air temperature.



wo=0.85wi, T_{reg} =120 °C, RH = 65% , D_i =5cm, D_o = 13.5 cm, L = 40cm, FR = 1, $Flow_{Reg}$ = 6 L/sec

Figure 20. Exit air temperature with time at different values of inlet air temperature

Effect of process air inlet temperature

As discussed before, the adsorption of water vapor on the surface of desiccant particles results in release the so-called heat of adsorption, also, the desiccant particles have just passed a thermal desorption process. So, it is expected that the bed is hot in the start of the second cycle (adsorption process). Consequently, the heat is convectively transferred to the process air and its temperature rises. As shown in Figures 19 and 20, the ability of the bed to adsorb the moisture from air increases as the inlet air temperature decreases, that can be illustrated as a result of the cooling mechanism made by the flowing process air.

Conclusions

A theoretical model to predict the heat and mass transfer process of radial flow of moist air in a desiccant bed has been presented. The model results were used to illustrate the cyclic operation of the desiccant bed. Also, the model results were used to investigate the effects of various operating parameters on the cyclic operation of the radial flow bed. Finally, the effect of ambient parameters on the cyclic operation timing was illustrated. The following conclusions can be summarized.

1. Lower values of the humidity of process air at bed exit could be attained with increase in regeneration temperature.
2. Increasing the diameter ratio results in higher degree of dehumidification.
3. Desorption time decreases with increase in regeneration temperature. On the other hand, the adsorption time increases with increase in regeneration temperature for a specified exit condition of process air.
4. The adsorption process time increases with the decrease in the required degree of dehumidification (w_o/w_i).
5. The ability of the bed to adsorb the moisture from air increases as the inlet air temperature decreases.

REFERENCES

Ahmed MH (2002). “Theoretical and experimental study on the transient adsorption characteristics of a vertical packed porous bed”, Renewable Energy, 27: 525-541.

Ahmed MH (2005), “Experimental investigation on the adsorption/ desorption process using solid desiccant in an inclined-fluidized bed”, Renewable Energy, pp. 1-9.

Anonymous (1978). Development of Solar Desiccant Humidifier. Technical Progress Report, 78:14957-1, Air Res. Manufacturing Company of California.

Awad MM, Ramzy KA, Hamed AM, Bekheit MM (2008) “Theoretical and experimental investigation on the radial flow desiccant dehumidification bed”, Appl. Thermal Eng., 28: 75–85.

Daou K, Wang R.Z, Xia ZZ (2004). “Desiccant cooling air conditioning: A Rev.”, Renewable Sustainable Rev., pp. 1-23.

Dupont M, Celestine B, Nguyen PH, Merigoux J, Brandon B (1994). Desiccant solar air conditioning conditioning in tropical climates: I-Dynamic experimental and numerical studies of silica gel and activated alumina. Solar Energy, 52: 509-517.

Elsayed MM, Chamkha AJ (1997), “Analysis and performance of radial flow rotary desiccant dehumidifiers”, Solar Energy Eng., 119: 35-43.

Kamiuto K, Ermalina SA (2002). Effect of desorption temperature on CO2 adsorption equilibria of the honeycomb zeolite beds, Appl. Energy 72: 555–564.

Jung-Yang S, Cheng-Chin N, Sheng-Hsiang H (2002). “Validity of solid-side mass diffusivity in simulation of water vapor adsorbed by silica gel in packed beds”, Int. J. Thermal Sci., 41: 41–49.

Marciniak TJ (1985). Solid desiccant dehumidification systems for residential applications, Gas Res. Inst., Chicago, Ill, NTIS Document No. PB85-198489.

Niu JL, Zhang LZ (2002). “Effects of wall thickness on the heat and moisture transfer in desiccant wheels for air dehumidification and enthalpy recovery” Int. Comm. Heat and Mass Transfer, 29: 255-268.

Niu JL, Zhang LZ (2002). “Performance comparisons of desiccant wheels for air dehumidification and enthalpy recovery”, Appl. Thermal Eng. 2002, 23, , 1347–1367.

Paradip M (1998). “Heat and mass transfer in composite desiccant pore structures for dehumidification”, Solar Energy Eng., 62: 1-10.

Pesaran AA (1978). “Moisture transport in silica gel packed beds-I. Theoretical study”, Int. J. Heat Mass Transfer, 30: 1037-1049.

Pesaran AA (1978). “Moisture transport in silica gel packed beds-II. Experimental study”, Int. J. Heat Mass Transfer, 30: 1051-1060.

National committee of USSR for products control and standards (1991). “Properties of materials and substances - air and its main components”, standard tables, In Russian, Moscow.

Zhang HF, Dai YJ, Wang RZ (2001). “Parameter analysis to improve rotary desiccant dehumidification using a mathematical model”, Int. J. Thermal Sci., 40: 400–408.

Nomenclature

A	Air flow area , m^2	*r*	Radius of layer, m
A	Area per unit bed volume , m^2/m^3	*T* Temperature, ˚C	
C	Specific heat, kJ/kg.K	*t*	Time, sec
D	Bed diameter, m	*v*	Air flow velocity, m/sec
D	Particle diameter, m	*w*	Air humidity ratio, kg/ kg dry air
dH	Rate of heat generation, kJ/sec	**Greek symbols**	
dR	Adsorption/desorption rate, kg/sec	ε Bed porosity	
Dr	Control volume depth, m	ρ Density, kg/m^3	
FR	Air flow ratio	**Super scripts**	
Ga	Air mass flux, kg/m^2.sec	* At equilibrium with bed condition	
HA	Heat of adsorption, kJ/kg	**Subscripts**	
H	Heat transfer coefficient, W/m^2.K	*a* Air property	
K	Mass transfer coefficient, kg/m^2.sec	s Silica gel property	
L	Bed thickness, m	*v* Vapor property	
PT	Periodic time, sec	ads Adsorption	
Q	Bed water content, kg/kg dry gel	reg Regeneration	
Re	Reynolds number	i Inlet properties	
RH	Air relative Humidity	o Exit properties	