Mansoura Engineering Journal

Volume 27 | Issue 2 Article 4

6-1-2021

Absorption/Regeneration Non-Conventional System for Water Extraction from Atmospheric Air.

Ahmed Abd El-Razek Sultan
Department of Mechanical Power Engineering., El-Mansoura University., Mansoura., Egypt.,
aasultan@mans.edu.eg

Recommended Citation
Sultan, Ahmed Abd El-Razek (2021) "Absorption/Regeneration Non-Conventional System for Water Extraction from Atmospheric Air.," *Mansoura Engineering Journal*: Vol. 27 : Iss. 2 , Article 4.
Available at: https://doi.org/10.21608/bfemu.2021.142635

Mansoura Engineering Journal, (MEJ), Vol. 27, No. 2, June 2002.

ABSORPTION/REGENERATION NON-CONVENTIONAL SYSTEM FOR WATER EXTRACTION FROM ATMOSPHERIC AIR

نظام امتصاص/إعادة تركيز غير تقليدي لاستخلاص الماء من الهواء الجوى

AHMED A. SULTAN
Mech. Power Eng. Dept., Faculty of Engineering,
Mansoura University, Egypt. E mail aasultan@mans.edu.eg

خلاصه:

يقدم هذا البحث نظام غير تقليدي لاستخلاص الماء من الهواء الجوي يعمل على مدار ٢٤ ساعة باستخدام نظام مدموج. تم شرح عمل المحطة التي تعمل طبقا للنظام المقترح والذي يعمل بنظام الامتصاص/إعادة التركيز جبريا باستخدام الهواء الجوي المتحرك بسرعات مختلفة خلال برج مدموج كما تم تعريف هذا النظام. البرج المدموج يتكون من عمودين متماثلين تم حشو كل منهما بواسطة مهدين متماثلين. يتكون كل مهد من طبقات راسية من قماش قطني يمكن تشبعه بمحلول ملح كلوريد الكالسيوم بتركيزات مختلفة. تم وضع أنموذج رياضي يعتمد على تجارب عملية للتنبوء بكفاءة النظام تحت ظروف التشغيل المختلفة. وجد من النتائج أن كفاءة النظام ذات قيم عظمى كدالة في زمن الدورة، التركيز النهائي للمحلول، درجة حرارة إعادة التركيز وسرعة تيار الهواء أثناء عملية الامتصاص. كما وجد أن كفاءة النظام القصوى تزيد بزيادة التركيز الابتدائي للمحلول بينما تقل الكفاءة بزيادة سرعة الهواء أثناء عملية إعادة التركيز و/أو زيادة درجة حرارة الامتصاص.

ABSTRACT

The present work suggests a non-conventional method of water production from atmospheric air, on 24-hour basis using a compact system. The operation of the system is described and its efficiency is defined. The system performs under forced convection absorption and regeneration through packed tower. The packed tower consists of two identical columns, each of them is packed with an identical bed. Each bed consists of vertical multi-layers of cloth material impregnated with Calcium Chloride solution of different concentrations. A numerical model, based on the experimental results, has been developed to predict the performance of the system under various operating conditions. The system efficiency is found to have peak values at certain cycle times, desiccant final concentration, regeneration temperature and absorption air stream velocity. It is also found that the maximum efficiency increases with initial concentration and decreases with the increase of the regeneration air stream velocity and absorption temperature.

1. INTRODUCTION

Extraction of water from atmospheric air is considered one of the important methods of fresh water supply, because air, as a source of water, is renewable, clean and exists anywhere.
Several investigators have studied this problem. These investigations can be classified into two main groups. The first group deals with the cooling of air, while the second group studies the absorption-regeneration of the moisture directly from the air.

The extraction of water from atmospheric air can be done by cooling air to a temperature below its dew point, where moisture is condensed. Many investigations [1-5] have studied this method. Wind energy was used [6,7] to circulate atmospheric air through the system condenser in order to separate moisture from it. Another approach for water extraction from atmospheric air is by absorption of water from atmospheric air into solid or liquid desiccant with subsequent separation of water from the desiccant by heating and condensation of vapor [8,9].

Regeneration of an absorbent using solar energy was investigated [10,11]. A comparative study for economical evaluation of the two methods mentioned above shows that the second system is more economic [2]. This comparison was carried out assuming the use of solar energy as the power supply of the two systems, with the use of Li Br absorption cycle for cooling system and applying $Ca Cl_2$ as the working desiccant for absorption-regeneration system.

Accepted June 30, 2002.

An integral desiccant/collector system for production of fresh water from atmospheric air was studied [12]. The system involved absorption of water vapor from ambient air during the night and simultaneous desiccant regeneration and vapor condensation during the day. Description and analysis of the theoretical cycle for absorption of water from air with subsequent regeneration, by heating, was presented in [13]. Theoretical analysis showed that, strong and weak solution concentration limits play a decisive role in the value of cycle efficiency.

The present study was conducted as a part of a full scale project for water extraction from atmospheric air, whose purpose has been to design, build and test a complete system using cloth material impregnated with liquid desiccant. In this work, a non-conventional system applicable for periodically absorption and regeneration processes to extract water from atmospheric air is proposed. A definition of system efficiency based on the heat and mass balance calculations is presented. This work studies also the influence of air initial temperature, initial desiccant concentration and time period on the system efficiency. A suggested lay out of water extraction plant is discussed and experimental data are used to show the effect of different parameters on the cycle efficiency.

NOMENCLATURE

A	Surface area, m^2
B	Cloth Layer width, mm
C	Carnot energy factor [Eq. 9]
Cp	Air specific heat, J/kg K
Dh	Hydraulic diameter [Eq. 5]
f	Friction factor[Eq. 6]
L	Latent heat of water, W/kg
M	Dimensionless mass flow rate of air
m	Air mass flow rate, kg/s
N	Number of cloth layers
P	Friction power, W
Q	Heat energy, W
Re	Reynolds number
S	Mass of desiccant, kg
T	Absolute temperature, K
u	Air velocity, m/s
W	Rate of accumulated mass of vapor, kg/s
w	Mass of regenerated water, kg
X	dimensionless concentration ratio
x	solution concentration, kg/kg

Greek symbols

α	constant
β	constant
ΔP	Pressure drop, pa
η	efficiency
ν	Air viscosity, m^2/s
π	Dimensionless pressure drop
θ	Dimensionless temperature difference
ρ	Air density, kg/m^3
τ	System (cycle) time, s

Subscripts

a	absorption
f	friction
i	Initial or inlet
o	Final or outlet
r	regeneration
sys	system
t	total
v	Water vapor

2. THE SUGGESTED SYSTEM AND ITS OPERATION

A new non-conventional system to extract water from atmospheric air based on absorption-regeneration processes using liquid desiccant is constructed.

2.1.The Suggested Cycle

An absorption-regeneration cycle for a system with cloth material impregnated with liquid desiccants can follow that suggested by Hamid [13] with some modifications. Firstly, the cycle suggested by Hamid [14] consists, as shown in Figure (1), of the following four processes:

-Process 1*-2 is isothermal absorption of water vapor from low temperature moist air.
-Process 2-3* is constant concentration heating of absorbent.

-Process 3*-4 is constant pressure regeneration of absorbent.
-Process 4-1* is constant concentration cooling of absorbent.

Practically process 4-1* can not be performed under constant concentration, because this needs desiccant to be cooled in the absence of air. The strong solution, represented by point 4, with high temperature is cooled due to the heat transfer between the flowing cold air stream and hot desiccant. During cooling period, the desiccant temperature decreases and consequently the cold desiccant with relatively low vapor pressure causes the desiccant to absorb water from cold air stream. As the heat transfer coefficient is high compared to the mass transfer coefficient and due to the small heat capacity of desiccant bed, thermal equilibrium occurs during a small period of time compared to the total absorption time. As a result, process 4-1* must be changed to a process of absorption under varying temperature and concentration that represented by the line 4-1. The position of point 1 and the shape of the line 4-1 depend on the air stream velocity, the heat capacity of desiccant bed and the temperature difference between air stream and desiccant bed at the end of regeneration process (heat transfer parameters).

Also, the weak solution at point 2, the end of absorption process, can not practically follow the constant concentration process 2-3*, for the same reasons mentioned above in describing process 4-1. The process of heating desiccant from absorption temperature, point 2, to the regeneration temperature, point 3, follows the line 2-3 instead of 2-3*. In the same way, the shape of process 2-3 and the position of point 3 on the constant temperature regeneration line depend on the velocity of air stream, the desiccant bed heat capacity and the temperature difference between absorption and regeneration processes (heat transfer parameters).
So the modified cycle, as presented in Fig. (1), consists of the following four processes:

-Process 1-2 is isothermal absorption at low temperature.
-Process 2-3 is variable concentration heating of absorbent.
-Process 3-4 is isothermal regeneration at high temperature.
-Process 4-1 is variable concentration cooling of absorbent.

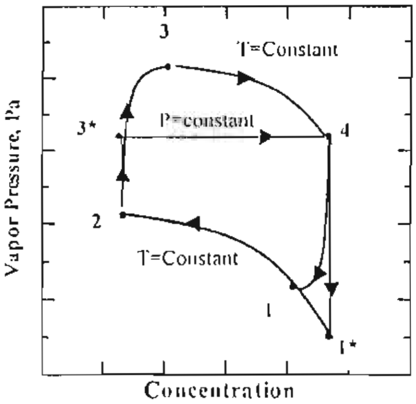

Fig. (1) Improved Cycle

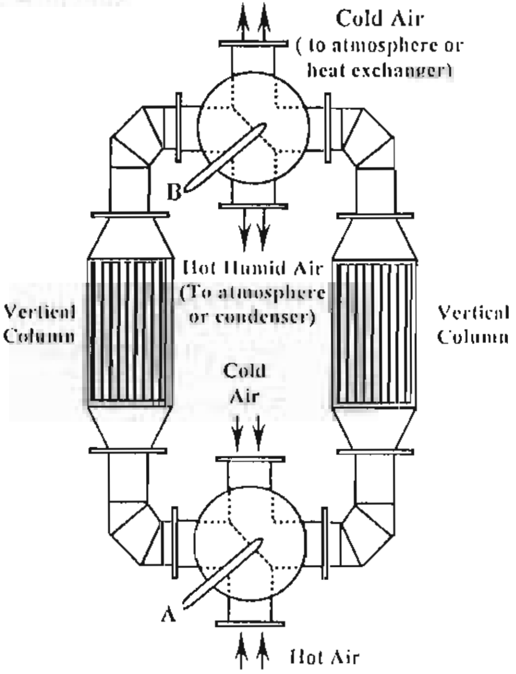

Fig. 2 Layout of the water extraction system

2.2. System Description.

The design of the system of water extraction from atmospheric air, by subsequent absorption and regeneration through a desiccant bed, must be simple, efficient and cheep. The suggested system is so design to satisfy these advantages. The system layout is illustrated in Fig. (2). It consists of two identical columns, the dimensions of which are 180x180 mm and holds one of two identical beds. The inlets and outlets of each column are connected to two four-way valves A and B respectively. The function of valve A is to direct the flow of hot and cold air streams periodically through the two columns. This process permits the bed of the two columns to change their functions periodically from absorption to regeneration. The function of valve B is to direct the exhaust air from the absorber to the atmosphere, and the hot humid air from the regenerator to the system condenser. The hot water vapor carried out with the hot humid air from the regenerator is cooled and condensed using an air cooled condenser, not shown in Fig. 2. In order to enhance the efficiency of the system, the cold air from the absorber can be used to cool the hot humid air from the regenerator via an air-to-air heat exchanger, not shown in Fig. (2).The packing of each bed consists of 13 vertical cloth layers of 17.5 mm width and 17.5 mm height. The cloth layers are made of 1.5 mm thickness cotton knitted fabric with total surface area of 0.7962 m^2. More details about the packing are given in Reference [14].

3.THEORETICAL ANALYSIS

Practically speaking, all desiccant operates by the same mass transfer mechanism of water vapor or moisture under the difference between the water vapor pressure at their surface and that in the surrounding air. When the vapor pressure at the desiccant surface is lower than that of the air, the desiccant attracts moisture. When the surface vapor pressure is higher than that at the surrounding air, the desiccant releases moisture.

As the moisture content of the desiccant rises, so does the vapor pressure at its surface. At a certain point, the vapor pressure at the desiccant surface is the same as that of the air, the two are in equilibrium. Then moisture can not move in either direction until some external force changes the vapor pressure at the surface of the desiccant or in the air. Both higher temperature and increased moisture content increases the vapor pressure at the surface. When the surface vapor pressure exceeds that of the surrounding, moisture leaves the desiccant, the process called regeneration. After the heat regenerates the desiccant, its vapor pressure remains high, so that it has very little ability to absorb moisture. Cooling the desiccant reduces its surface vapor pressure so that it can absorb moisture again.

3.1.Absorption/Regeneration Properties

The absorption/regeneration equilibrium relations of Calcium Chloride, which is used as the working absorbent in this study, are correlated for computer calculation purposes. An attempt is made to correlate the data presented by Sultan [11,14] in order to facilitate the calculation of the outlet concentration of the absorption and regeneration processes as a function of the time and other parameters that affect these processes. In these correlations the outlet concentrations are set as functions of desiccant initial concentrations, air inlet temperatures, air inlet mean velocities and the time of the processes as follows:

$$x_0 = 2.59\times10^{-3}\, \tau_a^{-0.059}\, u_a^{-0.0304}\, T_a^{1.075}\, x_i^{0.781}, \qquad (1)$$

$$0.5 \le u_a \le 3,\ \ 300 \le T_a \le 350, \quad 0.2 \le x_i \le 0.5$$

$$x_i = 3.37\times10^{-12}\, \tau_r^{0.0917}\, u_r^{-0.028}\, T_r^{4.45}\, x_0^{0.695}, \qquad (2)$$

$$0.5 \le u_r \le 3,\ \ 300 \le T_r \le 350 \text{ and } 0.2 \le x_o \le 0.5$$

Where subscripts a and r refer to absorption and regeneration respectively and subscripts i and o refer to initial and final concentrations through the absorption column respectively and vice versa through regeneration column.
Equations (1) and (2) predict the values of outlet concentrations for absorption and regeneration with a standard deviation of 10%. These two equations can be used to evaluate the operating limits of the system for a given condition, and can also be applied for a parametric study to evaluate the effect of various operating parameters on the system performance.
For the absorption process, the final concentration at which absorption ends (x_o) depends on the vapor pressure in the atmosphere and the absorption temperature and nearly equals the solution concentration at equilibrium with air. For the regeneration process, the final concentration at which regeneration ends (x_i) depends on the regeneration temperature and desiccant vapor pressure in order to avoid crystallization of the desiccant solution. This value equals the initial concentration of the absorption process

3.2 System Efficiency

The efficiency of the suggested system depends on the energy consumption, which depends on air velocity and air inlet temperature as well as the concentration difference during the absorption/regeneration process. Increasing air velocity increases the energy added to forced air streams. Also heating or cooling of air increases the energy consumption of the system. The power consumption due to airflow through the system can be calculated as:

$$P_a = m_a \, \Delta p_a / \rho_a \text{ and } \quad P_r = m_r \, \Delta p_r / \rho_r \qquad (3)$$

Where, ρ and m are the density and mass flow rate of air respectively. Δp is the pressure drop of air through the system, which can be calculated for the absorption and regeneration columns respectively as follows:

$$\Delta p_a = f_a \, \rho_a \, z \, u_a^2 / 2 \, Dh \quad \text{and} \quad \Delta p_r = f_r \, \rho_r \, z \, u_r^2 / 2 \, Dh \qquad (4)$$

Where z and u are the bed height and air mean free stream velocity respectively.
The hydraulic diameter Dh of the absorption and/or regeneration columns is presented as four times the volume of air flow divided by the total wetted surface area,

$$Dh = 2(b - Nt)/(N + 2) \qquad (5)$$

Where b and t are cloth layer width and thickness respectively and N is the number of cloth layers.
The friction factors f_a and f_r for air flows through absorption and regeneration columns respectively can be set as functions of Reynolds number of air flow in the following form.

$$f_a = \alpha \, Re_a^{\beta} \quad \text{and} \quad f_r = \alpha \, Re_r^{\beta} \qquad (6)$$

Where α and β are constants and can be calculated from the experimental results. The Reynolds numbers are defined by,

$$Re_a = u_a \, Dh / \nu_a \text{ and } Re_r = u_r \, Dh / \nu_r \qquad (7)$$

Where, ν is the viscosity of air.
The heat equivalent to energy added to air streams during absorption and regeneration processes can be evaluated by dividing the friction power by Carnot energy factors C_a and C_r.

$$Q_f = P_a / C_a + P_r / C_r \qquad (8)$$

Carnot energy factors C_a and C_r depend on air inlet temperature during absorption T_a and regeneration T_r respectively and the ambient air temperature T_0. Consequently Carnot energy factors can be expressed as,

$$C_a = (T_o-T_a)/T_o \quad \text{and} \quad C_r = (T_r-T_o)/T_r \tag{9}$$

The energy required for heating and cooling air streams in the regeneration and absorption columns respectively can be calculated from the following equations,

$$Q_r = m_r\, Cp_r\, (T_r - T_o) \quad \text{and} \quad Q_a = m_a\, Cp_a\, (T_o - T_a) \tag{10}$$

Where, m, Cp and T are the air mass flow rate, specific heat and absolute temperature respectively. Subscripts a, r and o refer to absorption, regeneration and ambient conditions respectively.

The total energy required for the process of water extraction from atmospheric air through absorption/regeneration columns is calculated as,

$$Q_t = Q_f + Q_r + Q_a \tag{11}$$

Substituting from Eqs 3, 8 and 10 in Eq 11 yields,

$$Q_t = m_r\, Cp_r\, (T_r - T_o) + m_a\, Cp_a\, (T_o - T_a) + m_a\, \Delta p_a /(\rho_a\, C_a) + m_r\, \Delta p_r / (\rho_r\, C_r) \tag{12}$$

As the purpose of this study is to produce water from atmospheric air, the useful heat Q_v will be assumed equal to the latent heat of regenerated water vapor (L_r) at the corresponding regeneration temperature T_r multiplied by the mass of regenerated water vapor w, i.e.,

$$Q_v = w\, L_r / \tau \tag{13}$$

Knowing the desiccant concentrations at the beginning and end of the regeneration process (x_o and x_i) and the initial mass of desiccant solution before the regeneration process S_o, one can evaluate the mass of the regenerated water vapor as follows,

$$w = (x_i-x_o)\, S_o / x_i \tag{14}$$

Substituting w in Eq. (13) we get,

$$Q_v = (x_i-x_o)\, S_o\, L_r / (\tau\, x_i) \tag{15}$$

The system efficiency is defined as the ratio of useful heat Q_v and the total heat used to produce the water with this system, i.e.,

$$\eta_{sys} = Q_v / Q_t \tag{16}$$

Substituting from Eqs 12 and 15 in Eq. 16 we get,

$$\eta_{sys} = \{ (x_i-x_o)\, S_o\, L_r / (\tau\, x_i)) \} / \{ m_r\, Cp_r\, (T_r - T_o) + m_a\, Cp_a\, (T_o - T_a) +$$
$$m_a\, \Delta p_a /(\rho_a\, C_a) + m_r\, \Delta p_r / (\rho_r\, C_r) \} \tag{17}$$

However, it is convenient to express the system efficiency in terms of dimensionless form. This form can be set as.

$$\eta_{sys} = 1 / \{X_r (M_r \theta_r + M_a \theta_a + M_a \pi_a / C_a + M_r \pi_r / C_r)\} \qquad (18)$$

The above used dimensionless parameters are defined as follows,

Dimensionless concentration ratio, $X_r = x_i /(x_i - x_o)$ (19)

Dimensionless air mass flow rates, $M_a = m_a \tau / S_o$ and $M_r = m_r \tau / S_o$ (20)

Dimensionless temperature differences, $\theta_r = Cp_r(T_r - T_o)/L_r$ and $\theta_a = Cp_a(T_o - T_a)/L_r$ (21)

Dimensionless pressure drops, $\pi_r = \Delta p_r / (\rho_r L_r)$ and $\pi_a = \Delta p_a / (\rho_a L_r)$ (22)

4. SYSTEM PROCEDURE

In order to describe completely the system procedure, the handling of it is divided into two kinds, operation procedure and calculation procedure.

4.1 Operation Procedure

At the beginning of a cycle, valve A is switched to direct the cold air to the right bed and the hot air to the left one. While valve B is switched to direct the dehumidified cold air to the atmosphere, or to a heat exchanger, and hot humidified air to the atmosphere, or to the condenser. Following adsorption for a pre-specified time period, valve A is switched to direct cold air to the left bed and hot air to the right one. While valve B is switched to direct the cold dehumidified air to the atmosphere, or to the heat exchanger, and the hot humidified air to the atmosphere, or to the condenser. The two beds are subjected to repeated absorption and regeneration cycles by switching valves A and B to the appropriate position. Because of this arrangement, the desiccant always has the same initial and final concentrations from one cycle to another. Similarly, the inlet temperatures of air for absorption and regeneration processes could be maintained at the same value in all cycles.

The air flow rate can be varied from 0.019 to 0.115 kg/s that provided a mean velocity in the range 0.5 to 3 m/s. In commercial units, a face velocity in the range of 1.32 to 3.05 m/s is generally used. The desiccant concentration ranges from 20 to 50 percent for absorption and regeneration can be used in the system. The effect of a parameter is studied by varying one parameter at a time while other parameters are kept constant.
Note that the amount of water absorbed during the absorption process should be equal to the amount of water regenerated during the regeneration process. The maximum regeneration temperature used in this work can be set equal to 50 °C, while the minimum absorption temperature can be set equal to 17 °C.

4.2 Calculation Procedure

First of all, the following restrictions must be taken into consideration in calculating the system efficiency:

1-As absorption and regeneration are interrelated, the time periods of both processes must be equals, i.e. $\tau_a = \tau_r = \tau$
2-In order to reach a steady state operation, the moisture transfer of both absorption and regeneration processes must be equal. Also solution concentration at the end of absorption period must be equal to solution concentration at the beginning of regeneration period and vice versa.
3-The air mass flow rate (air velocity) for regeneration must be as low as possible in order to decrease the energy required for moisture condensation.

Using the aforementioned restrictions, the calculation procedure can proceed as follows:

1-Assume air mass flow rate for absorption m_a and for regeneration m_r
2-Assume initial concentration for absorption x_i, absorption time period τ and air inlet temperature for absorption T_a.
3-Calculate the final concentration for absorption x_o from Eq. 1.
4-take initial concentration for regeneration equals the final concentration for absorption x_o and vice versa.
5-Knowing the regeneration time ($\tau_a=\tau_r=\tau$) and the regeneration air mass flow rate m_r one can calculate the initial air temperature for regeneration T_r from Eq. 2.
6-Knowing the air mass flow rate, air inlet temperature, time period and initial and final desiccant concentrations for absorption and regeneration respectively, the efficiency of the system can be calculated using equations 18 to 22 .

5. RESULTS AND DISCUSSION

The system suggested in this work consists of periodically absorbing/ regenerating columns. Each column consists of identical bed made of vertical multi layers of cloth material impregnated with calcium chloride solution of different initial concentrations. The main aim of this work is to study the effect of the air inlet temperature and air mean velocity through both absorption and regeneration columns, on system efficiency. Also the effect of initial and final concentrations and cycle time on the system efficiency are discussed.

5.1 Effect of Cycle Time

The results of calculation of system efficiency for different discussed parameters are demonstrated in Figs. (3-16). From the over view of these figures it can be observed that, the system efficiency increases with time until it reaches maximum value at certain time and then decreases with further increase in time. The peak value of system efficiency depends on the different parameters discussed in this work. This can be explained as follows:

The driving force for absorption, as well as, regeneration is the difference in water vapor pressures in air and at the desiccant surface. This pressure difference changes with the desiccant concentration, which changes with the cycle time at constant air properties. Successive change in the desiccant concentration changes the pressure difference and consequently changes the absorption and regeneration rates. The accumulated mass of absorbed or regenerated water increases with cycle time. But the rate of increase of accumulated mass of water vapor increases with time up to a maximum value at certain time and then decreases with further increase in time as shown in Fig. (3). One can conclude that the system efficiency follows the same trend as the change in the rate of increases of accumulated mass of water vapor at constant other operating parameters. This is because the total energy added to the system depends on other operating parameters, which are kept constant.

5.2 Effect of Ambient Temperature

As already known, ambient temperature widely changes depending on climatic conditions allover the planet. This change in ambient temperature affects the value of Carnot efficiencies and energy added to the system through absorption and regeneration periods. In order to show the effect of ambient temperature on the system efficiency, different values between absorption and regeneration temperatures are used in the calculations with constant other parameters. Figure (4) shows the relation between ambient temperature and both Carnot energy factors and the air temperature differences through absorption and regeneration columns. It is seen from the figure that, increasing ambient temperature decreases the temperature difference of air stream through the regeneration column and, in the same time, increases the temperature difference of air stream through the absorption column. Also, increasing ambient temperature increases Carnot energy factor for regeneration column and, in the same time, decreases Carnot energy factor for, absorption column. As a result the heat energy added to the absorption column increases while the friction energy decreases with the increase of ambient air temperature. Also the heat energy added to the regeneration column decreases while the friction energy increases with the increase of ambient temperature. So the total energy consumption in the system is independent of ambient temperature and so does the system efficiency as shown in Fig. (5).

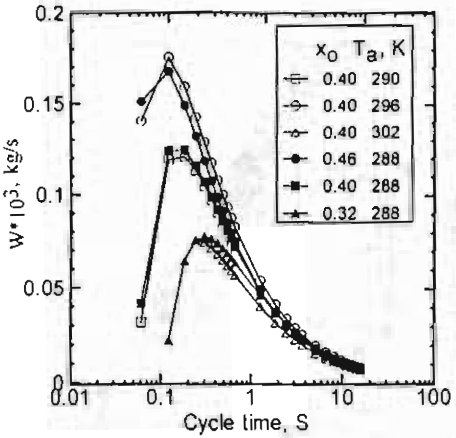

Fig. (3) Effect of cycle time, absorption temperature and final concentration on the rate of accumulated water vapor (W).

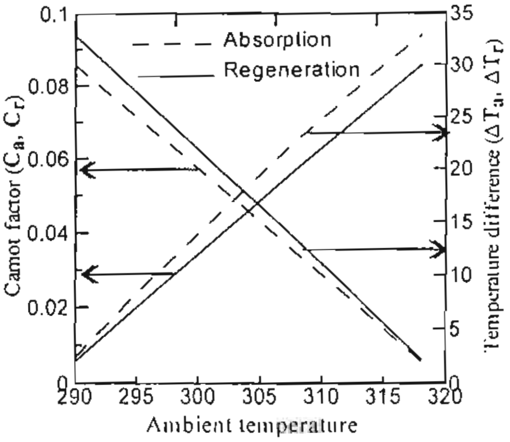

Fig.(4) Carnot factor and temperature difference versus ambient temperature.

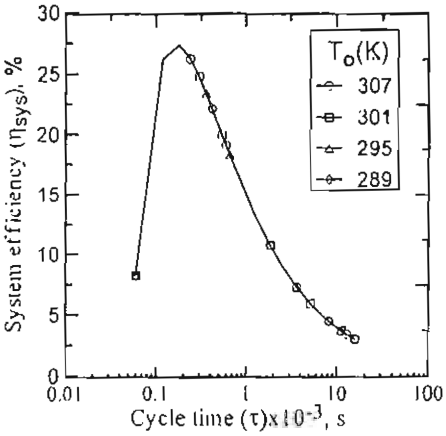

Fig (5) Effect of cycle time and ambient temperature on system efficiency.

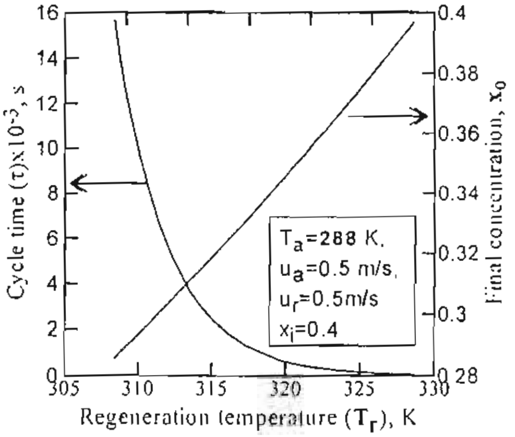

Fig. (6) Regeneration temperature versus cycle time and final concentration.

5.3 Effect of Air Stream Temperatures

The relation between the regeneration temperature and both final concentration and cycle time are shown in Fig. (6). While Fig. (7) indicates the effect of the regeneration temperature on the system efficiency. It is seen from Fig. (6) that the increase of regeneration temperature increases the final concentration and decreases cycle time. This is because increasing the regeneration temperature increases the regeneration rate and consequently increases the final concentration at constant cycle time or decreases the cycle time at constant final concentration.

It is observed from Fig. (7) that the system efficiency has a peak value with respect to the regeneration temperature. This is because increasing the regeneration temperature increases the regeneration rate and the energy added through the regeneration period. Increasing the regeneration rate increases the system efficiency while increasing the energy added to the system decreases the system efficiency. This makes the system efficiency increases or decreases with the regeneration temperature through cycle time.

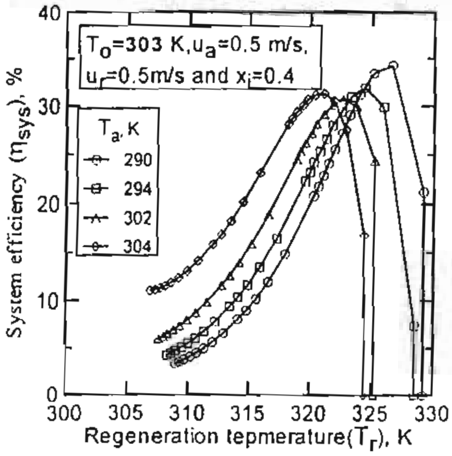

Fig.(7) Effect of regeneration temperature on the system efficiency at different absorption temperatures.

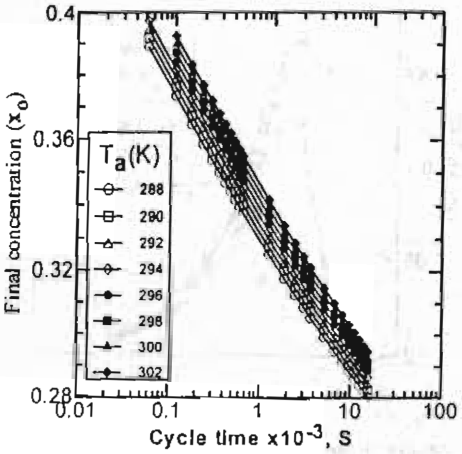

Fig.(8) Final concentration versus cycle time at different absorption temperatures.

The regeneration temperature and final concentration as a function of cycle time are shown in Figs. (8 and 9) at different absorption temperatures. It is concluded from these figures that the increase in cycle time, at constant absorption temperature, is followed by a decrease in final concentration and regeneration temperature as discussed earlier. The figures show also that the final concentration increases with the absorption temperature, while the regeneration temperature decreases with the increase of absorption temperature at constant cycle time. This may be due to the decrease of the absorption rate with the increase of the absorption temperature at the same time. Also increasing the final concentration needs higher regeneration temperature to perform regeneration of absorbed water during the same period of time.

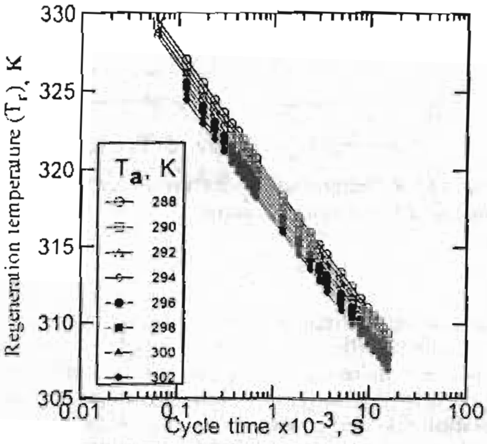

Fig. (9) Regeneration temperature versus cycle time at duifferent absorption temperatures.

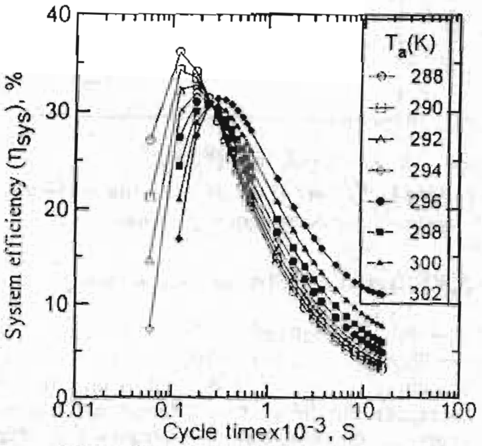

Fig. (10) Effect of cycle time and absorption temperature on system efficiency.

The relation between the system efficiency and the absorption temperature is illustrated in Fig. (10). It is seen from the figure that the peak value of the system efficiency increases with decreasing the absorption temperature. The cycle time, as shown from Fig. (10), can be divided into two periods, through the first period of time, the system efficiency increases with decreasing the absorption temperature, while, the system efficiency decreases with the absorption temperature through the second period of time. This trend may be because, the regeneration temperature decreases with the increase of the absorption temperature and as a result, the system efficiency increases. But increasing the absorption temperature decreases the accumulated mass of water and consequently decreases the system efficiency. These two effects on system efficiency make it to increase through the first period and decreases through the second period of cycle time.

5.4 Effect of Desiccant Concentration

Increasing the cycle time at constant initial concentration decreases the final concentration as shown in Fig. (11). Decreasing the final concentration at constant initial concentration increases the desiccant vapor pressure and consequently decreases the desiccant temperature needed for regeneration as shown in Fig. (12). Increasing the initial concentration at constant cycle time increases the final concentration and increases the regeneration temperature as shown in Figs. (11 and 12).

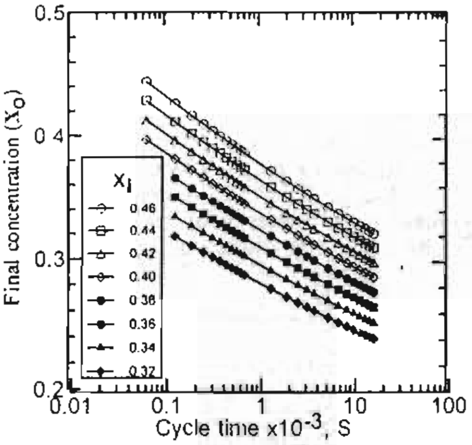

Fig.(11) Final concentration versus cycle time at different initial concentration.

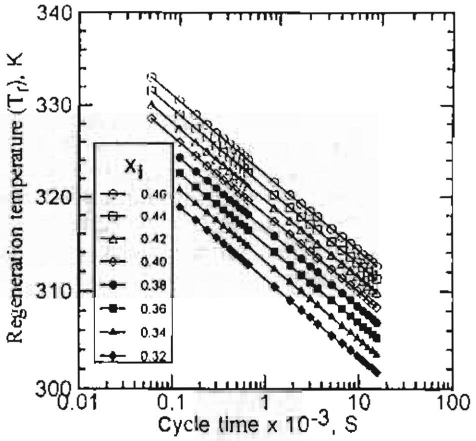

Fig.(12) Regeneration temperature versus cycle time at different initial concentration.

Figure (13) represents the effect of the cycle time on the system efficiency at different initial concentrations and constant other parameters. Increasing the initial concentration increases the regeneration temperature and as a result the system efficiency decreases. From the other hand, at the same cycle time, increasing inlet concentration increases the absorption rate, which increases the system efficiency. Also increasing the cycle time, the rate of increase of accumulated mass of water decreases which decreases the system efficiency. The above-mentioned trends make the system efficiency have peak values, as discussed earlier, depending on the initial concentration. In the same time, this makes the system efficiency to increase with the initial concentration through certain periods of cycle time and decreases with increasing the initial concentration during the rest of cycle time, as shown in Fig. (13). At constant operating parameters, the final concentration of any cycle decreases with the increase of cycle time as discussed above, see Fig. (6). Therefore, the relation between the final concentration and the system efficiency must follow the same function of the system efficiency and cycle time. This means that, the system efficiency increases with the decrease of final concentration up to a maximum value and then decreases with further decrease in final concentration as demonstrated in Fig. (14). The peak values of system efficiency and the corresponding cycle time depend on the values of operating parameters.

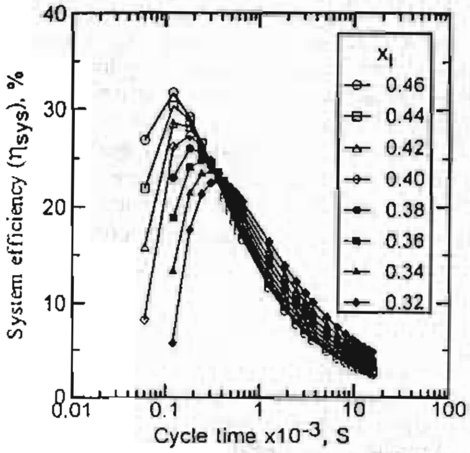

Fig.(13) Effect of cycle time and initial concentration on system efficiency.

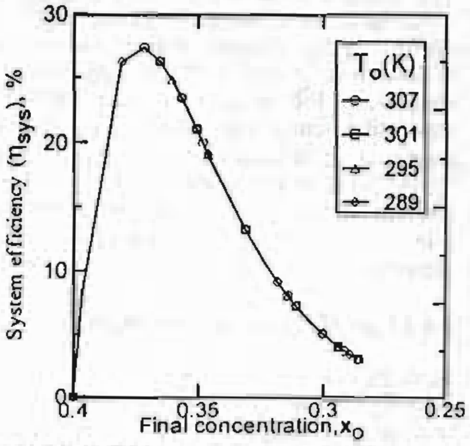

Fig.(14) Effect of final concentration on system efficiency at different ambient temperature.

5.5 Effect of Air Stream Velocity

Increasing the air stream velocity in the absorption column increases the rate of absorption and in the same time increases the energy added to air stream and the power required to move it through the bed. So this increases the amount of the absorbed water and in the same time increases the total energy required for the absorption process. As a result the efficiency of the system increases with air velocity up to a maximum value at air velocity nearly equal to 1.0 m/s and then decreases with further increase in air velocity. Figure (15) illustrates the relation between the system efficiency and cycle time for different values of air velocity. The figure shows that, system efficiency has maximum values at certain times depending on the air velocity at constant other parameters.

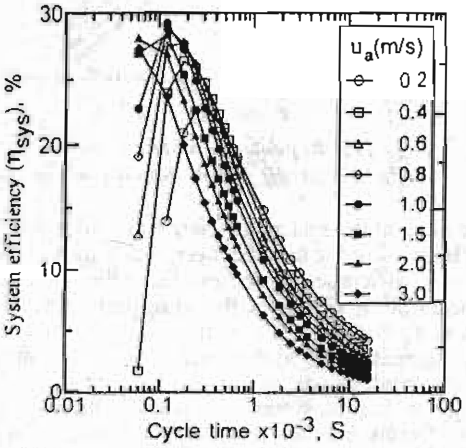

Fig.(15) System efficiency versus cycle time at different regeneration column air velocity.

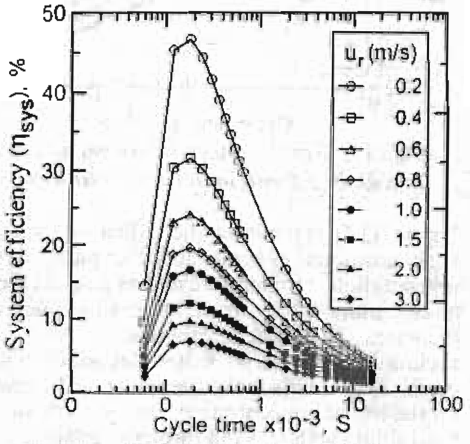

Fig.(16) System efficiency versus cycle time at different absorption column air velocity.

In order to show the effect of air stream velocity in the regeneration column, the system efficiency is calculated for air velocities in the column ranging from 0.2 to 3 m/s, while other parameters are kept constant. The results of these calculations are demonstrated in Fig. (16) as a relation between the system efficiency and cycle time. It is observed from the figure that, the system efficiency and its maximum value decreases with increasing air velocity through the bed. As the air velocity increases the total energy added to the air stream increases, while the mass of regenerated water is constant because it equals the mass of absorbed water, which depends on the air velocity through the absorption column. This decreases the efficiency of the system with increasing the regeneration air velocity.

6. CONCLUSIONS

Analysis of the operation of the absorption/regeneration system for water extraction from atmospheric air, in the forced convection mode, has been developed. . The system efficiency is defined in terms of the system design parameters. Also the effects of air temperature, air stream velocity and initial and final concentrations through the absorption and regeneration columns on the system efficiency have been well defined. Based on the obtained simulation results, the following conclusions can be drawn:

-The final concentration for the operating desiccant is strongly dependent on the initial concentration, absorption temperature and regeneration temperature.

-The system efficiency has peak values depending on the cycle time, regeneration temperature, final concentration and absorption air stream velocity.

-The system efficiency increases with the initial concentration and decreases with the increase of regeneration air velocity and the absorption temperature.

REFERENCES

[1] Danelen A.E, An equipment for collecting potable water in arid areas using solar energy, Patent No. 582800, in Russian, 1947.

[2] Hamid A.M., Non-conventional method for collecting water from air using solar energy, Ph. D. Thesis, Russian Academy of Science, 1993.

[3] Awad M.M., Sultan, A.A. and Abdel-Raouf M.M., Using refrigeration systems to extract water from moist air. In: Proceeding of the 1st U A E Conference on Air-Conditioning in the Gulf, ACG, 1996, p.96.

[4] Sultan A.A., Hamid A.M.and Sultan G.I., Comparative study for extracting water from atmospheric air using alternative cooling systems, In: Proceeding of the 10th international conference of mechanical power engineering, Assuit, Egypt, 1997.

[5] Khalil A., Dehumidification of atmospheric air as a potential source of fresh water in the UAE, Desalination 1999, 93:587-96.

[6] Stepankova, B. A., "Renewable energy sources in agricultural economy", Book, M. Agropromizdat, USSR, 1988

[7] Protsenko, V. P,, Savanov, V. K. and Rashepkin M. I., " Autonomous plant for water extraction from moist air", A. C. No. 1484886, F.G.R. in 07-06-1989.

[8] Hall R.C., "Production of water from the atmosphere by absorption with subsequent recovery in a solar still", Solar Energy, No. 10, pp. 42-45, 1966.

[9] Sofrata, H., "Non-conventional system for water collection", Proc. Of Solar Desalination Workshop, No. 2, pp. 71-78, 1981.

[10] Hall R.C., Rao G.V. and Livingston R., Prediction of liquid hold up on an absorption tower for the production of water from the atmosphere with subsequent recovery in a solar still, Solar Energy, 1968; 12: 147-61.

[11] Ahmad A. Sultan, Experimental study on the transient regeneration of multi-coaxial cyliderical layers of cloth material impregnated with calcium chloride solution., Mansoura Engineering Journal, Vol. 26, No. 1, Mach 2001, p. M29-M41

[12] Gad H.E., Hamid A.M. and El-Sharkawy I.I., Application of solar desiccant/collector system for water recovery from atmospheric air, Renewable Energy Journal, 2001; 22: 541-556.

[13] Ahmad A. Hamid, Absorption-regeneration cycle for production of water from air-Theoretical Approach, Renewable Energy Journal, 2000; 19: 625-635.

[14] Ahmad A. Sultan, Theoretical and experimental study on the performance of cotton knitted fabric as desiccant holder., Mansoura Engineering Journal, Vol. 25, No. 4, December 2000, p. M29-M41