WATER PRODUCTION FROM AIR USING MULTI- SHELVES SOLAR GLASS PYRAMID SYSTEM

إنتاج المياه من الهواء باستخدام هرم زجاجي شمسي متعدد الأرفف

A. E. Kabeel
Faculty of Engineering, Mechanical Power Department,
Tanta University, Egypt
E-mail kabeel6@hotmail.com

ملخص البحث :

فى هذا البحث تمت دراسة إمكانية استخدام الشكل الزجاجي الهرمى لأنتاج المياه من الهواء الرطب بواسطة محلول ملــح مــاص لرطوبة الجو ، حيث تم استخدام هرمين يحتوى كل منهما على أرفف داخلية موضوع عليهــا فرشــة مشــبعة بمحلــول كلوريــد الكالسيوم (30% تركيز). تفتح جوانب الهرم الزجاجي الأربعة ليلاً لامتصاص الرطوبة من الهواء الجوى، ويــتم إغلاقهــا نهــاراً لاستخلاصها بواسطة الإشعاع الشمسى الذى يطلق بخار الماء ليتكثف على الأسطح الداخلية لجدران الهرم. الفرشة فى الهرم الأول عبارة من مخدات من نشارة الخشب المشبعة بالمحلول وفى الهرم الثاني تم استخدام مخدات من القماش المشبع بالمحلول بــنفس ابعــاد المخدات السابقة وقد لوحظ فى البداية أن تشبع مخدات القماش بالمحلول أكبر من نشارة الخشب حيث تشبعت بـــ 9 كيلــو جــرام محلول كلوريد الكالسيوم بينما تشبعت مخدات النشارة بـ 8 كيلو جرام من نفس المحلول. تمت دراسة النظام عمليا تحت الظــروف المختلفة لدراسة تأثير استخدام الشكل الهرمى وأيضاً دراسة تأثير المخدات المستخدمة فى عمليــات الامتصــاص والتوليــد. وقــد أظهرت النتائج العملية إمكانية الحصول على كميات مياه مجمعة تصل الى 2.8 لتر فى اليوم لكل متر مربع. هــذه القيمــة تزيــد بمقدار 90-95 % عن القيم المستنتجة فى الأجهزة السابقة المسطحة الشكل وقد أوضحت النتائج أيضا أن أداء الهرم المحتوى على مخدات القماش المشبع بالمحلول أعلى من الهرم الزجاجي الأخر بنسبة تصل الى حوالى 5 %. وقد تم اســتنتاج أن هــذه الزيــادة ترجع الى زيادة كمية محلول الملح المستخدم فى تشبيع المخدات فى بداية التجربة.

Abstract

The capability of the glass pyramid shape with multi-shelf solar system to extract water from humid air is explored. Two pyramids were used with different types of beds on the shelves. The beds are saturated with 30% concentrated Calcium Chloride solution. The pyramid sides were opened at night to allow the bed saturated with moist air and closed during the day to extract the moisture from the bed by solar radiation. The bed in the first pyramid was made of saw wood while it is made of only clothes in the second pyramid with the same dimensions. The system was experimentally investigated at different climatic conditions to study the effect of pyramid shape on the absorption and regeneration processes. Preliminary results have shown that the cloths bed absorbs more solution (9 kg) as compared to the saw wood bed (8 kg). Adopting this approach produce 2.8 Liter/day.m^2. The use of the pyramid shape with four glass surfaces and multi-shelves enhances the produced water by about 90-95 % compared with solar desiccant/collector system with horizontal and corrugated beds. Results shows also that the clothes bed has higher productivity than that of saw wood bed by about 5% This is due mainly to the greater carrying solution at the onset of the experimental work. The obtained results may help in designing more efficient system.

Introduction

The supply of water, clean water in particular, is a serious problem in many parts of the world. In countries where the salt water is available, traditional desalination systems may be considered as a new reliable source of potable water. These systems are available in many countries that have salt-water resources per the water demand area. But in countries that suffer from a lack of salt water, or that in the places far from that seashore, it is required to seek for an alternative

source such as the moist in atmosphere to produce fresh water. Extraction of water from atmosphere is one of the important methods of producing fresh water because air is considered a huge source of pure water.

The fact that the atmospheric air absolute humidity is constant regardless of the change in air temperature has been proved experimentally. A comparison of absolute humidity between two places in Egypt with different climatic condition is shown in table 1 [1].

Table 1

Middle Delta

Month	T	R.H	w
1	22	38	6.4
2	24	35	6.5
3	28	29	6.9
4	33	27	9.4
5	37	24	11.5
6	38	34	14.5
7	38	33	13.5
8	39	32	14
9	36	42	10.5
10	33	31	10.5
11	28	50	12
12	23	57	10

EL-Salom

Month	T	R.H	w
1	19	52	6.6
2	20	50	7.3
3	21	50	7.5
4	24	51	9.5
5	26	58	12.5
6	30	56	14.7
7	31	59	16.5
8	30	62	16
9	29	62	15.5
10	27	56	12
11	25	60	11.5
12	20	75	10.5

The experimental data recorded from two areas; El-Salom as a deserted area and the Middle Delta as a sea shore area show that the absolute humidity, W is almost the same in each month of the year, in spite the temperatures in the two sites are much different. Countries with large deserts (like Egypt) are the most places which are favored by .higher weather temperature. These conditions are the most suitable for the production of fresh water from atmospheric air, since the solar radiation is abundant in such areas.

Cooling the atmospheric air to a temperature below its dew point, the moisture in air condenses and can be collected to form the process of extraction of water from air.

Description and operation of systems using this process can be found in several investigations [2-4]. Another approach for water extraction from air by absorption of moisture into a liquid or solid desiccant such as Silica gel, $CaCl_2$ and LiCL, then separation of water from the desiccant by heating it

and then condensation of the vapour on a cold surface [5-8]. In the literatures the most of water production from air systems use solar system with only one glass cover and one horizontal or corrugated bed. To increase the productivity there are two methods. The first is by increase the horizontal layer. The second is by increase the number of layers. The direction of this work is to increase the number of layers by using a pyramid system with multi shelves. This system has a main advantage of higher absorption and regeneration area. Also it has a higher

ability to carry more desiccant solution. This system is simple and has economical construction and minimal operational and maintenance requirements. Also, it can be situated in any location, independent of external power sources.

The aim of this work is study the performance of two pyramid solar systems with multi shelves on which the beds saturated with $CaCl_2$ solution experimentally. In this experimental work, study the variation of the suggested system productivity under different conditions and compare it with that yielded with some other traditional shapes from the previous works.

Experimental setup

The system used in this experimental work is a pyramid quadratic shape solar system, which has four glass faces and square base. Figures (2-a) and (2-b) show a photograph and a schematic diagram of the two pyramid system used (illustrating the system different components). The pyramid structure is built of aluminum and glass faces. The sides of the two pyramids are covered with glass covers 5 mm thickness. The edges of any glass cover are surrounded with a frame of sheet shaped as if it is an alphabetical letter V. Inside the pyramid, there is a perpendicular pipe of water in the middle. Four shelves of steel wire that is about 5 mm diameter are soldered

with this pipe. Also the shelves are folded on the steel corners inside and they are empty to allow condensed vapour to go through them. A preparation of steel sheet and bolts is made to fix glass precisely to the frame. Also a piece of rubber is inserted between the glass faces and steel frame of the pyramid to prevent vapour leak. The height of the pyramid is 160 cm. The insulation layer thickness of the pyramid base is 15 cm. The base of the pyramid is 100 cm x 100 cm. There are four shelves inside the pyramid. The vertical distance between every shelf is about 30 cm. There are wheels to move the pyramid assembly easily to any place. In the present work two identical units were constructed. The two units have the same shape and dimensions.

The beds in each pyramid unit have thickness of 10 cm and saturated with $CaCl_2$ solution at a concentration of 30%. In the first unit the bed is saw wood and in the second unit the bed consists of heavy black clothes. At night the glass sides of the pyramids are opened and the beds absorb the moisture from atmospheric air. After sunrise, as the day becomes warm, the sides are closed again. The solar radiation passes through the pyramid glass sides raising the internal temperature and causing the moisture that was absorbed in the bed to evaporate. The vapour rises to the top of the pyramids, where it condensates into droplets. Also some of this vapour will condensate at the inside surface of the pyramid sides.
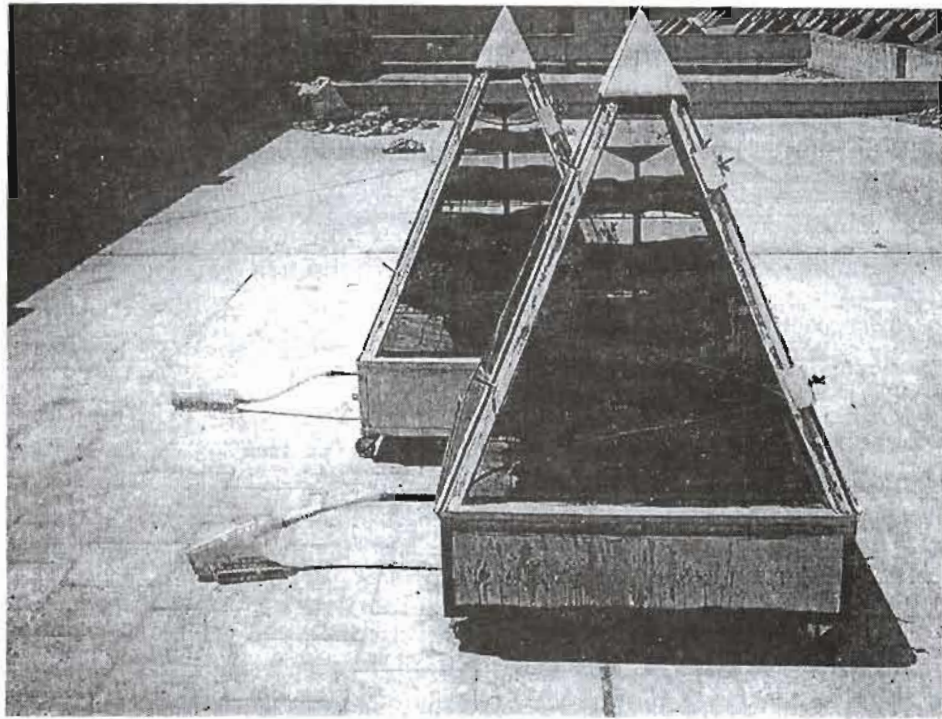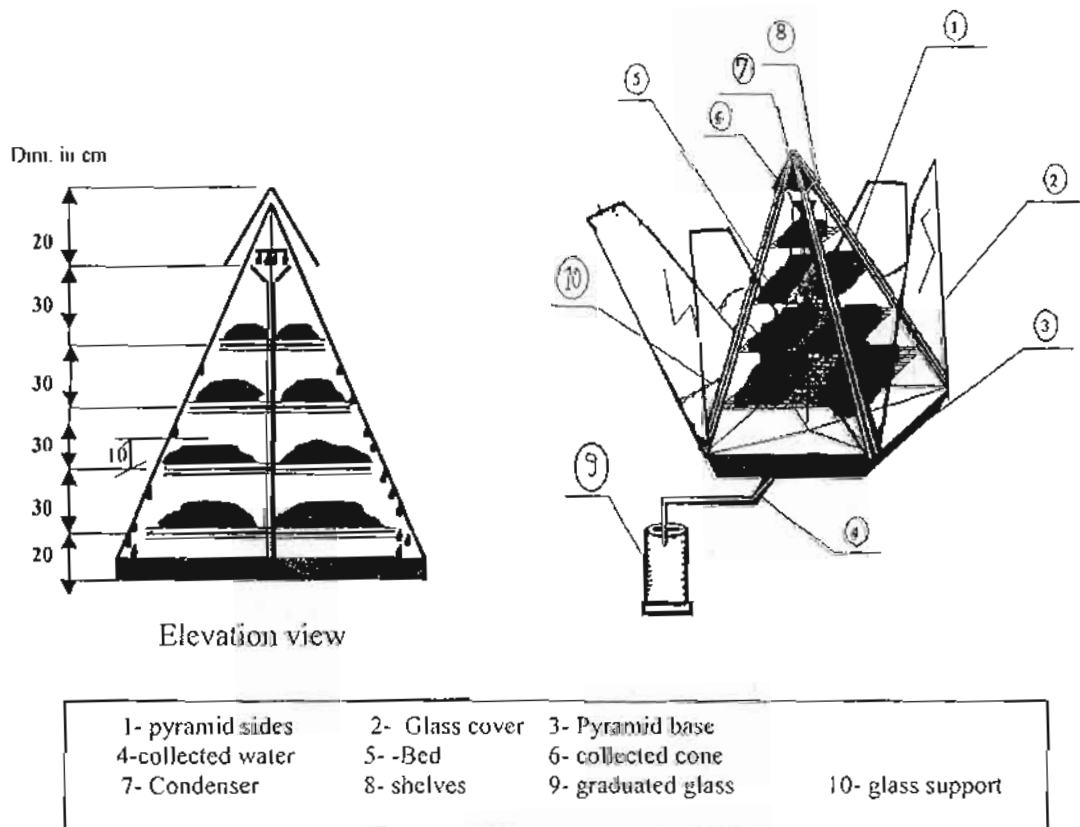
Fig. (1-a) : Photograph of the system used

Dim. in cm

Elevation view

1- pyramid sides	2- Glass cover	3- Pyramid base	
4-collected water	5- -Bed	6- collected cone	
7- Condenser	8- shelves	9- graduated glass	10- glass support

Fig. 1-b: Pyramid with glass covers open at nigh

The base is slightly inclined towards its center to allow the condensate to be collected at this point. The two units are suitably instrumented to measure the temperatures at different points of the glass cover of the four sides of the pyramids. Also, the bed temperatures are measured at different points. The total solar radiation intensity is also measured each hour during the day time. The collected distilled water is measured at one hour intervals.

Analysis of the experimental measurements

In the present analysis, only the mass transfer aspect in different layers of the bed over the different shelves is considered. The aim of the experimental work is to study the transient variation of desiccant properties during the absorption and regeneration processes for different beds on the shelves and then evaluate the suggested system efficiency.

The solution concentration in the bed is evaluated at the experimental work during the day using bed-weight as follows:

Solution concentration X is defined as the ratio of mass of salt M_s to the mass of solution M_{SOL}, which equals the summation of the mass of water M_w and mass of salt M_s, i.e

$$X = \frac{M_s}{M_{sol}} \qquad (1)$$

$$M_{sol} = M_s + M_w \qquad (2)$$

To evaluate the instantaneous value of X during the absorption or regeneration of desiccant in the bed, the following expression can be used,

$$X_o\,M_{SOL,o} = X_I\,M_{SOL,i} \qquad (3)$$

Where the subscripts o and i refer to the initial and instantaneous values of X and M_{SOL}. By knowing the initial concentration for each layer and the initial mass of solution, the instantaneous value of concentration can be obtained from the measurement of the mass of absorbed water using Equations (1) and (2) in the following combined form,

$$\frac{1}{X_i} - \frac{1}{X_o} = \frac{M_{sol,i} - M_{sol,o}}{M_s} \qquad (4)$$

Where:
$$M_{sol,i} - M_{sol,o} = M_{L,i} - M_{L,o} \qquad (5)$$

Where $M_{L,i}$ and $M_{L,o}$ are the instantaneous and initial mass of the layer, respectively.
The efficiency η can be calculated from the following formula :

$$\eta = \frac{m_w\,L}{\langle \tau\alpha \rangle\,H\,A} \qquad (6)$$

where,
    H is the solar radiation intensity, (W/m^2)
    L latent heat of water at average bed temperature, (J/kg)
    A is the surface area (m^2),
    $\langle \tau\alpha \rangle$ is the transmissivity absorbtivity product.

Results and Discussions

The objective of this experimental work is study the performance of the pyramid solar system, i.e. the effect of the pyramid shape with multi bed on the amount of water extracted from atmospheric air. It can be expected that the proposed system has a higher productivity than that of previous systems used because of the following reasons :

1-This shape has a higher effective area, which receives solar radiation.

2- This system has a higher regeneration and absorption area due the multi-shelves used

3- Opening the four sides at night helps in extracting the moisture from air.

Figures 2 and 3 show the variation of glass cover temperature for the four faces of the pyramid, ambient temperature, and the solar radiation intensity for the two units used in this present work. These results are recorded in a typical experimental day. It can be observed from Fig. 2. that the temperature difference between the four faces of the pyramid is small. The difference reached 3 C, a figure that depends on the direction of the face towered sunrays. Glass temperature increases to a maximum value near the noon hour, then decreases with time as that of total solar radiation.
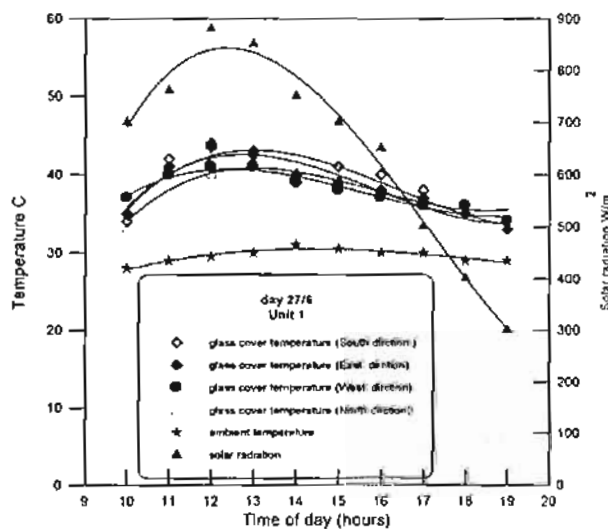
Fig. 3: The variation of glass cover temperature for the four face of pyramid (unit 2)
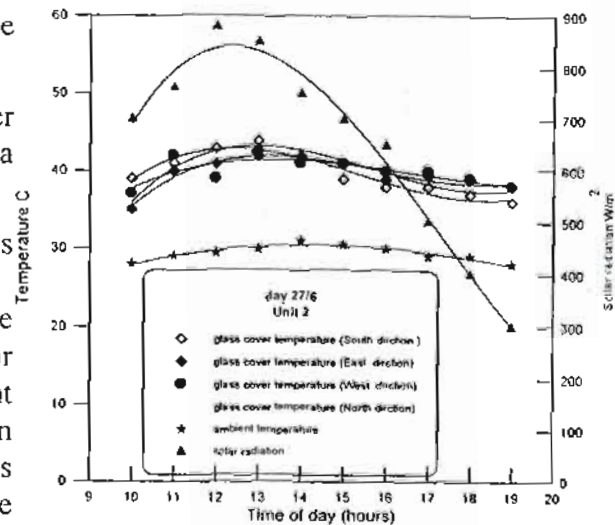
Fig. 2 The variation of glass cover temperature for the four face of pyramid (unit 1)

The instantaneous productivity of the two units during that day are shown in Figures 4,5 and 6. It can be seen that the system productivity follows the same trend as the change in solar radiation intensity. The rate of collected water increases with time up to a maximum value at a certain time lag after the solar noon, then decrease. The productivity has reached 0.4 L/h/m^2 for day 27/6/2004, 0.45 L/h/m^2 for day 28/6/2004 and 0.432 L/h/m^2 for day 29/6/2004. This figure shows also that the productivity of unit 2 is higher than that of unit 1. The average value of productivity difference between the two units is about 5% during the daytime. This difference is due to the difference in the amount of solution in the beds for each unit.

The amount of solution in the bed of unit 2 is greater than that of unit 1 with about 12% at the beginning of the experimental test for the first day. The figures show also that the productivity of the first unit higher than second unit after 16 hour due to energy storage in the bed.
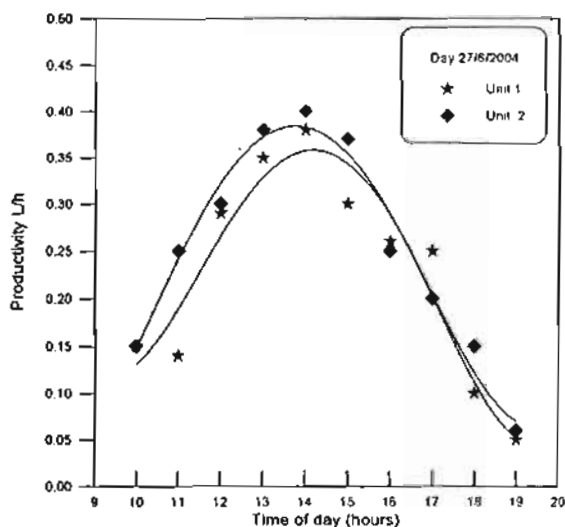

Fig. 4: The variation of productivity during the day 27/6/2004 for two units
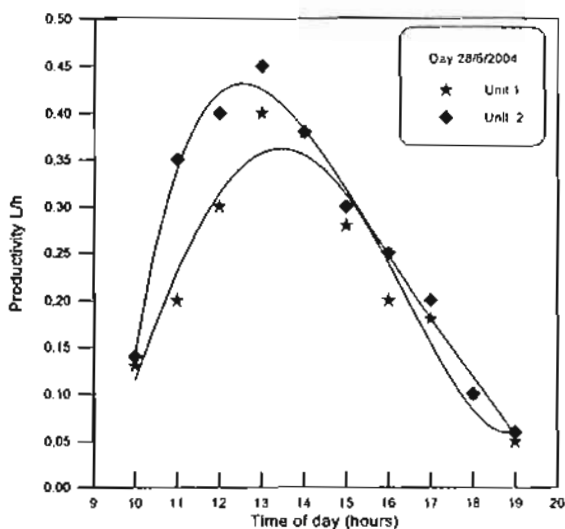

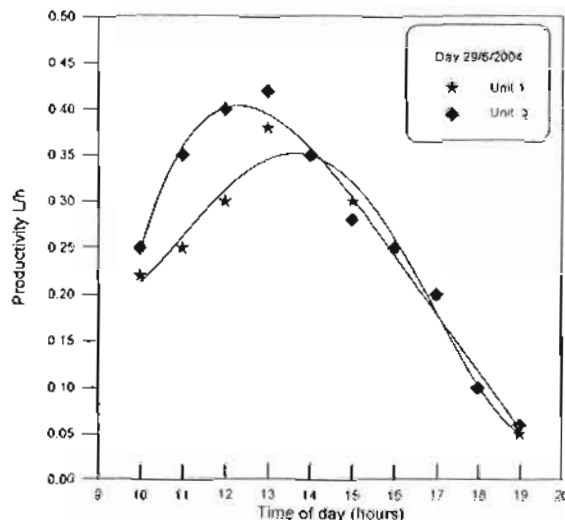Fig. 5: The variation of productivity during the day 28/6/2004 for two units

Fig. 6: The variation of productivity during the day 29/6/2004 for two units

Figures 7, 8 and 9 show accumulated water produced from the moist as a function of daytime for three selected days. Each figure shows the variation for the two units used in this work. It can be seen that the water produced reached 2.4 L/m2/day for day 3/7/2004 and 2.6 L/m2/day for day 4/7/2004, 5/7/2004. The change of water produced from one day to another is due to different climatic variables such as ambient condition during the day and during the nighttime, solar radiation intensity, wind speed, and the solution concentration in the bed. It shows also that the accumulated productivity of unit 2 is greater than that of unit 1 with about 5 %. This is due to the bed carrying solution of unit 2 as mentioned before in the experimental setup. This means that the bed type and the amount of carrying solution in the bed must be properly selected. The amount of water produced from the proposed system is approximately twice the amount of water produced from other systems given in references [2,6].

To show how effective is this proposed system. A comparison for its productivity, which is nearly about 2.4 L/m2/day by other shapes, was necessary. A similar work is done by Gad etal [7], in which one corrugated clothes bed layer using forced power (fan) at night to enhance the absorption process. The actual water productivity in this case was about 1.2 L/m2/day. These value gives that the productivity of the proposed pyramid system with multi shelves is enhanced by about 100%. Also another comparison is done with Kabeel [6]. In his work, sandy bed solar still system is used. The water productivity has reached to about 1.2 2.4 L/m2/day which gives also, an advantage for the proposed system by doubling its productivity.. It is seen to be promising, especially it has the same components of conventional system reported in literature.

The transient variation of the bed temperature on the four shelves is illustrated in figures 10 and 11. It can be seen that the bed temperature for all layers increase with time to maximum value then decreases. It takes the same trend with time as the solar radiation intensity. Also it can be observed that the temperature of the upper layer is slightly higher than that of other lower layers. This is due to the effect of solar radiation on the effective area and also the effect of natural circulation occurring inside the pyramid.
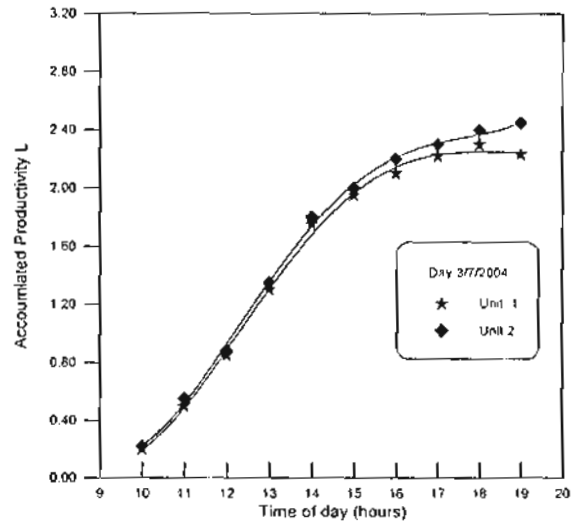
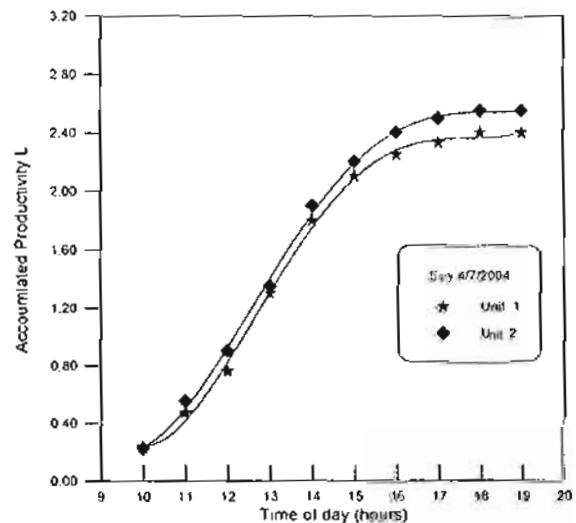Fig. 7: The variation of productivity during the day 3/72004 for two unit

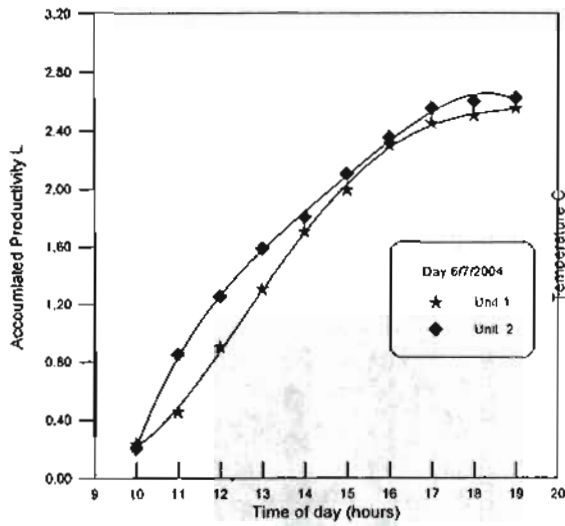Fig. 8: The accumulated productivity during the day 4/7/2004 for two units

Fig. 9: The accumulated productivity
during the day 6/7/2004
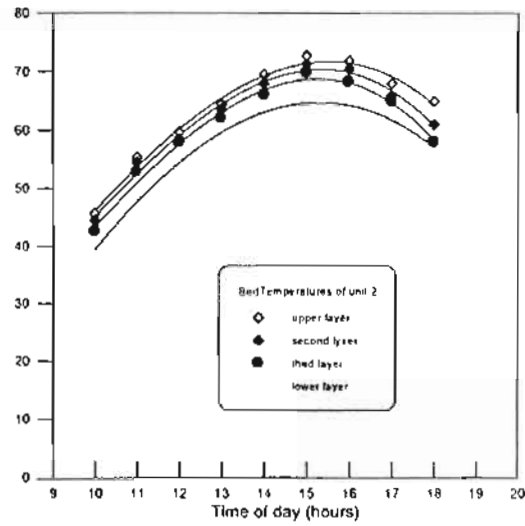for two units

Fig. 11: The variation of bed
temperatures for the different shelves
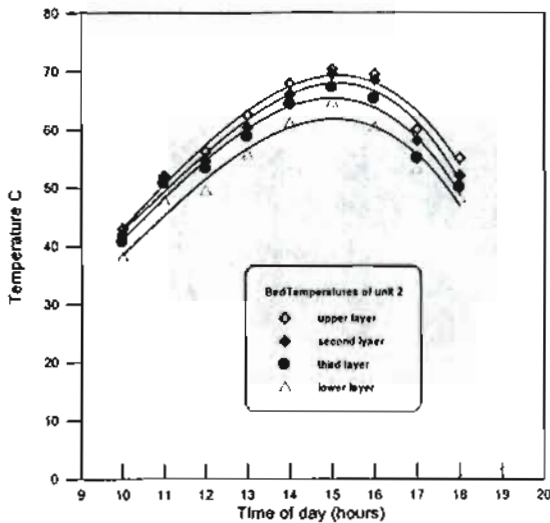for unit 2 (Day 4/7/2004)

Fig. 10: The variation of bed
temperatures for the different shelves
for unit 1 (Day 4 /7/2004)

Figures 12 and 13 show the instantaneous variation of the system efficiency during the day for the two units for the two days as the example. It can be seen that the efficiency reached 32% for unit 2. Also it can be observed that the efficiency of unit 2 is higher than that of unit 1. This is because the solution content in unit 2 is greater than that of unit 1 at the beginning of the experiment
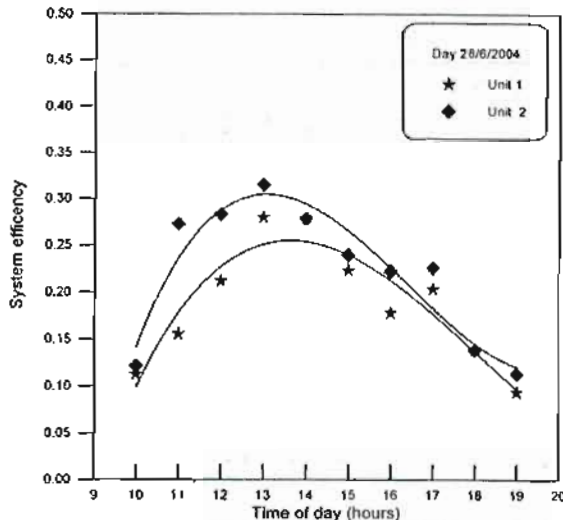
Fig. 12: The variation of the efficiency
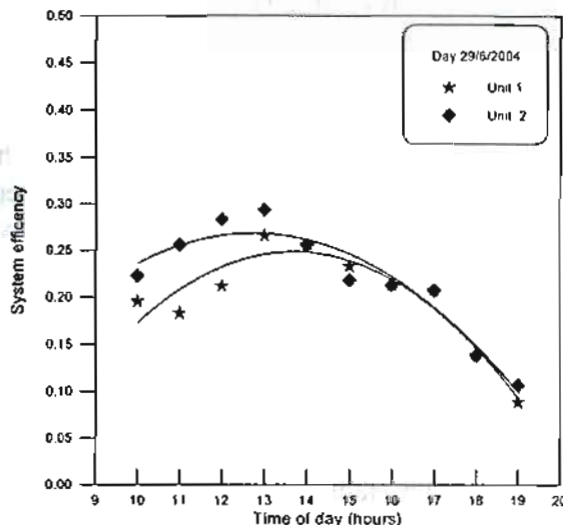for the two units
(Day 28/6/2004)

Fig. 13: The variation of the efficiency
for the two units
(Day 29/6/2004)

Variation of the solution concentration in bed

During the experimental work the variation of concentration with time takes the minimum value at the beginning of the experimental work (at morning). Figures 14 and 15 show the variation of the solution concentration for the beds on the shelves for the first day of the experimental work and for other day. At the first day of the experimental work (day 27/6/2004), the solution concentration for the upper bed has changed from 30% to 52%. At the other day 28/6/2004 the variation

of concentration has changed from for the same upper layer bed from 32 % to 53%. It is worth noting that the initial concentration has changed from day to another due to changed meteorological conditions such as solar radiation. Ambient temperature and wind velocity
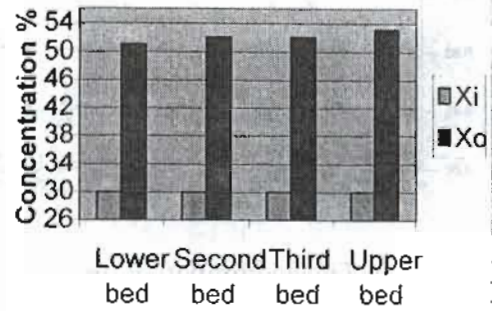

Fig. 14: The variation of the solution concentration for beds (At the first day of experimental work)
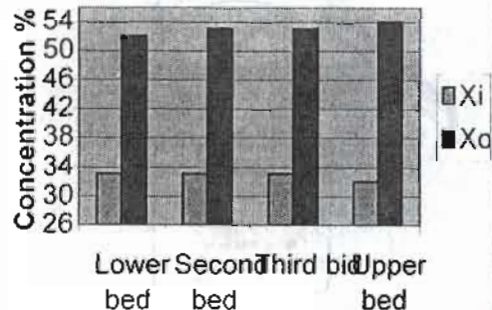

Fig. 15: The variation of the solution concentration for beds
(At day 28/6/2004)

Conclusions

An integrated desiccant solar pyramid collector system for production of water from ambient air has been designed, constructed and experimentally tested. Calcium chloride is applied as the working desiccant in this investigation work. The system operation involves night absorption of water from ambient air by opening the four sides of the pyramid. During the daytime, the four sides are closed and then the desiccant

regeneration as well as water vapor condensation.

The outdoors experimental results during sunny clear days have shown the following important conclusions:

1- The amount of water produce from the moist air reached about 2.8 liter /day/m^2 .

2- The system productivity is greater with about 90-95% than that of the previous systems

3- The clothes bed system higher efficiency compared to that of saw wood bed. This is because the amount of carrying solution at the beginning of the experimental work is greater than in the case of saw wood bed..

Recommendations

1- More types of the bed materials have to be tested to choose the best that carries maximum amount of solution

2- Future study on the effect of change in the pyramid dimensions should be conducted.

3- Studying the effect of the variation of the number of shelves in the pyramids and the distance between them.

4- Studying the system performance using solar concentrators in the regeneration process.

Nomenclature

A the surface area (m^2)
L latent heat of water at average bed temperature, (J/kg)
M_w the mass of water, kg
M_s mass of salt, kg
M_{sol} mass of solution, kg
M_L instantaneous mass of the layer,kg
$M_{L,o}$ initial mass of the layer, kg
H solar radiation intensity, (W/m^2)
T temperature, C
W humidity ratio, g/kg$_{air}$
X solution concentration
$\langle \tau\alpha \rangle$ is the transmissivity absorbtivity product.

o , i the initial and instantaneous values

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