# APPLICATION OF SANDY BED SOLAR COLLECTOR SYSTEM FOR EXTRACTION OF WATER FROM AIR

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## ABSTRACT

In the present study the effect of using sandy bed solar collector system for extraction of water from air has been demonstrated. The sandy bed used to simulation of the Arab country desert condition. The system is studied experientially at three different tilt angle 15, 20 and 25 degree. The theoretical model was constructed to study the effect of various parameters such as solution concentration and solar radiation intensity. The results show that the system can provide an amount of 1.2 liter of fresh water per square meter of glass cover per day. The agreement between theoretical results and experimental measurements is found to be reasonable. Results show also that the tilt angle of 25 degree give a higher productivity during the experimental period.

**Keywords:** Desiccant, water from air, absorption, regeneration

## 1- INTRODUCTION

Water is the basic necessary for life. The amount of fresh water on the earth is only 2.53 percent (35 million km) of the total amount (1.384 billion km). A large fraction of fresh water (24 million km$^3$) is ice and permanent snow in the Antarctic and Arctic regions. The main source of water for human consumption (fresh water lakes and rivers) contains about 0.26 percent of the total global fresh water reserves (90,000 km$^3$) [1].

Atmospheric air contains about 14,000 km$^3$ of water in in vapor form [2], and hence it can be used as a new and renewable water resource. Extraction of water form atmospheric air can be accomplished by two different methods. The first method is by cooling moist air to a temperature lower than the air dew point [3, 4, 5, 6, 7, 8]. The second one is by absorbing water vapor from moist air using a solid or liquid desiccant, with subsequent recovery of the extracted water by heating the desiccant and condensing the evaporated water [3, 5, 8].

Moreover, solar energy can be used as a renewable source of heat in extraction processes of water from atmospheric air. Hamed, A.M. [9] presented a flow diagram of the most technological processes that can be used in separation of water from atmospheric air using solar energy. Water vapor can be absorbed from moist air using a solid or liquid desiccant, then solar energy is used to regenerate the absorbed moisture, which can be condensed after that. On the other hand, solar cooling systems can be used to cool moist air to a temperature lower than its dew point, where condensation can be occurred. Also, moist air can be compressed using solar electric power plants then it expands to separate water vapor.

## Extraction of atmospheric moisture by absorption

Hall, R.C [10] proposed a cycle for production of water from atmospheric air by absorption using ethylene glycol as a liquid desiccant with subsequent recovery in a solar still. The proposed equipment consists of absorption tower, which is a vertical sheet of plywood, solar still and a suitable pump connects with tubing system. The water lean absorbent is fed and distributed by appropriate means along the top of the tower and flows downward by gravity as a thin liquid film in contact with ambient air. Mass transfer takes place due to the difference in vapor pressure in atmospheric air and on desiccant surface. The water rich absorbent is fed to the solar still to generate the absorbed vapor, then it is pumped to the top of the tower again.

An experimental study for water extraction from atmospheric air using solar energy by two different methods is presented in [8]. The first method was based on cooling the moist air to a temperature lower than the air dew point, using a solar LiBr-H2O absorption cooling system. The second one was based on absorption of moisture from atmospheric air during night using calcium chloride solution as a liquid desiccant, which is carried by a porous material, with subsequent recovery of absorbed moisture at daytime. The amount of produced water ranged from 1 to 1.5 liter /day per square meter of the plant surface in Kransondar conditions (Russia). As a result of this study, the second method was recommended as a most suitable application of solar energy for water recovery from air.

Gandhidasan, P. and Abualhamyel, H.I. [10] reported an analytical procedure for calculation of mass of absorbed moisture from atmospheric air using liquid desiccant as a function of meteorological data and initial desiccant conditions. Calcium chloride solution, which is cheap and available in the market, was used as a liquid desiccant while the absorber is a single flat tilted surface exposed to the atmosphere. Water-lean desiccant flows over the absorber as a thin film over the surface and contact with the ambient air. Mass transfer takes place from atmospheric air to the desiccant due to the vapor pressure difference between them. The water-rich desiccant is heated to generate the absorbed moisture, which can be condensed after that.

In the present work, a solar powered system using calcium chloride solution as an absorbent is constructed and tested. The system is designed with sandy bed carrying the absorbent solution. The study, which is carried out both experimentally and theoretically, aims to evaluate the effect of different parameters on the system performance, especially during the regeneration period. These parameters include the outside driving parameters, which are radiation intensity and ambient temperature.

## 2- MATHEMATICAL MODEL OF THE REGENERATION PROCESS

The absorption area can positively enhance the absorption process and regeneration process. .When a flat plate collector containing the desiccant bed is applied for regeneration process, bed area in the collector can be increased by liquid desiccant which is carried by porous material (sand), which is suitable to the dry desert regions.

The mathematical model depends on the energy balance analysis of the system used as shown in the following figure 1.

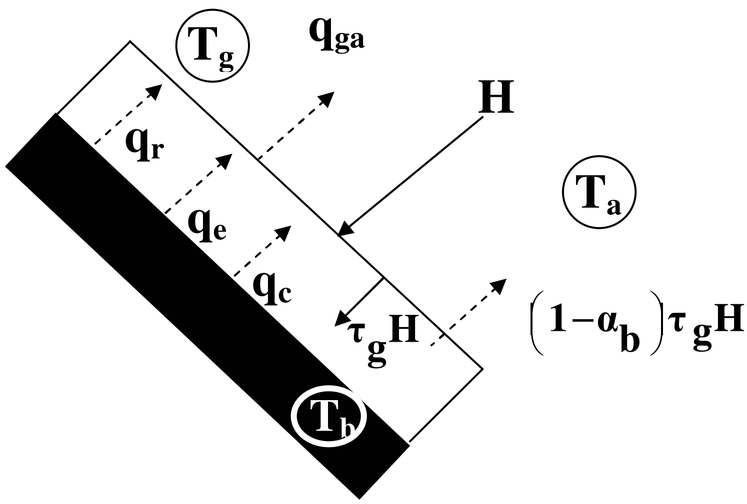



Fig. (1): Energy flow diagram for the proposed system.

The heat balance equations of the glass cover and the system as a whole can be expressed in the following equations:

$$q_{ga} = q_r + q_c + q_e + \alpha_g H \tag{1}$$

$$\alpha_g H + \alpha_b \tau_g H = q_{ga} + q_B + C_s\left(\frac{dT_b}{d\tau}\right) \tag{2}$$

Values of $q_{ga}$ , $q_r$ , $q_c$ , $q_e$ and $q_B$ are expressed as given by [20] as:

$$q_{ga} = h_{ga}(T_g - T_a) + F_{g\text{-}sky}\ \sigma\left[\left(T_g + 273\right)^4 - \left(T_a + 273\right)^4\right] \tag{3}$$

Heat transfer coefficient between glass cover and ambient can be calculated from the following relation [19].

$$h_{ga} = a + b\,(v)^n \tag{4}$$

a, b and n are coefficients which depend on the roughness of the cover and wind speed [19].

$$q_C = k_a \left( \frac{T_s - T_g}{\Delta y} \right) \tag{5}$$

where:

$K_a$ Thermal conductivity of the air gap

$$\mathbf{q_e = F_{bg}\, \sigma \left[ (T_s + 273)^4 - (T_g + 273)^4 \right]} \tag{6}$$

where $F_{bg}$ is the shape factor between the bed and glass cover which equals 1 in this analysis.

$$q_e = 0.0061 \left[ (T_b - T_g) + \left( \frac{p_b - p_g}{0.265 - p_b} \right) (T_b + 273) \right]^{1/3} (p_b - p_g)\, L_b \tag{7}$$

$$q_B = h_B (T_b - T_a) \tag{8}$$

Saturation pressure and Latent heat of water can be calculated as a function of Tb using the following equation [19]

$$Log_{10}\ (P_b) = -\ 3.21254 + 3.13619 \times 10^2 T_b - 1.22512 \times 10^{-4} T^2_b + 3.63841 \times 10^{-7}\ T^3_b - 5.67607 \times 10^{-10}\ T^4_b \tag{9}$$

$$L_b = 10^3\ (2501.67 - 2.389\ T_b) \tag{10}$$

Instantaneous system productivity, P, can be evaluated using the following relation

$$p = \frac{q_e}{L_b} \tag{11}$$

The operation efficiency of the system can be defined as the ratio of heat consumed to evaporate water to the total incident radiation as follows:

$$\eta = \frac{\sum q_e}{\sum H} \tag{12}$$

**Mass transfer coefficient**, β

The mass transfer coefficient, β obtained from the following relations:

$$m_w = \beta\ A\ \ \Delta p\ \ \Delta\tau \tag{13}$$

Where $\Delta p$ is the vapor pressure difference between ambient air and desiccant surface, which can be expressed as:

$$\Delta p = P\infty - P_v \qquad (14)$$

Vapor pressure of calcium chloride solution on the bed Surface, $p_v$, can be calculated as a function of solution temperature, T, within a temperature range from 10 to 65° C and concentration range from 20% to 50% according to the following equations, [4].

$$Ln(P_V) = A(x) - \frac{B(x)}{T + 111.96} \qquad (15)$$

Where $p_v$ in mm Hg, T in °C, A(x) and B(x) are regression dependent parameters, which can be expressed as a linear function of concentration according to the following relations:

$$A(x) = a_o + a_1 x \qquad (16)$$

$$B(x) = b_o + b_1 x \qquad (17)$$

Where:

$a_o = 10.0624$ $a_1 = 4.4674$ $b_o = 739.828$ $b_1 = 450.96$

For temperature higher than 60 °C, the following relation used to calculate the vapour pressure for the concentration range from 20 to 50 % [2]

$$Ln(P_V) = A - \frac{B}{T + 273} \qquad (18)$$

where A, B are regression constants and obtained from the following table.

**Table (1): Regeneration constants [22]**

| Concentration % | A | B |
|---|---|---|

## Calculation the amount of water in solution

The inlet and exit the concentration calculated from the following expressions:

$$\mathbf{X_1 = \frac{M_S}{M_1}} \tag{19}$$

$$\mathbf{X_2 = \frac{M_S}{M_2}} \tag{20}$$

From equations (19), (20)

$$\therefore \mathbf{M_2 - M_1 = M_S \left[ \frac{1}{X_2} - \frac{1}{X_1} \right]}$$

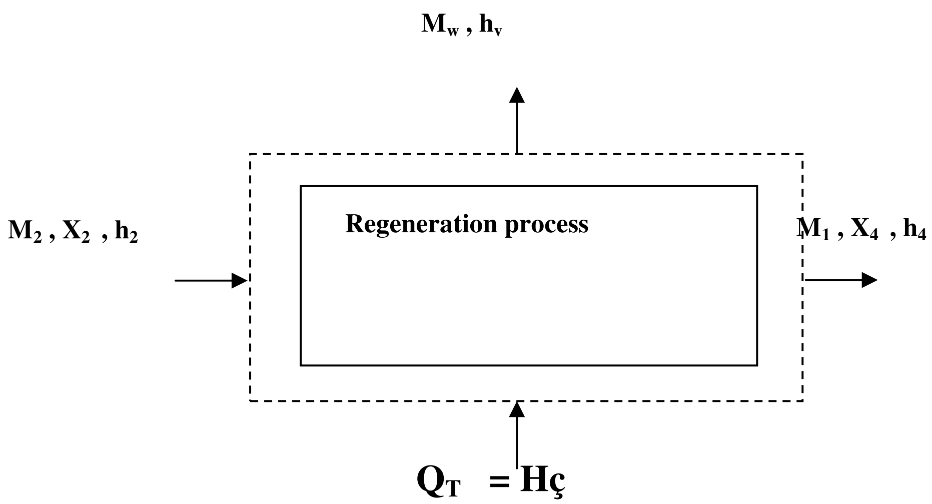
$$\mathbf{M_w = X_1\ M_1 \left[ \frac{1}{X_2} - \frac{1}{X_1} \right] = X_2\, M_2 \left[ \frac{1}{X_2} - \frac{1}{X_1} \right]}$$

$$\mathbf{M_w = M_1 \left[ \frac{X_1}{X_2} - 1 \right]} \tag{21}$$

From this equation we notice that, the more $M_1$ increased . the more $M_w$ increased , and so we calculate the ideal $M_1$ at which the optimum $M_w$ is calculated .

## The analysis is carried out per $M_w$ of generated vapor from the absorbent:

The regeneration process can be represents in the following figure:



From the heat balance and mass balance, the following equations (22) and (23) can be obtained:

$$Q_{sol.} + M_2 h_2 = M_w h_v + M_1 h_4 \tag{22}$$

$$M_2 X_2 = M_1 X_1 \tag{23}$$

$$\therefore \mathbf{M_1} = \frac{\mathbf{X_2}}{\mathbf{X_1}} \mathbf{M_2} \tag{24}$$

$$\therefore \mathbf{M_w} = \mathbf{M_2} \left[ \mathbf{1} - \frac{\mathbf{X_2}}{\mathbf{X_1}} \right] \tag{25}$$

$$\mathbf{Q_{SOl.}} = \mathbf{M_2} \left[ \left( \mathbf{1} - \frac{\mathbf{X_2}}{\mathbf{X_1}} \right) \mathbf{h_v} + \left( \frac{\mathbf{X_2}}{\mathbf{X_1}} \right) \mathbf{h_4} - \mathbf{h_2} \right] \tag{26}$$

$$\mathbf{Q_{Sand}} = \mathbf{M_{Sand}} \cdot \mathbf{C_P} \cdot \mathbf{\Delta T} \tag{27}$$

$$\mathbf{Q_T} = \mathbf{H}\,\boldsymbol{\eta} = \mathbf{Q_{SOl.}} + \mathbf{Q_{Sand}} \tag{28}$$

$$H.\,\boldsymbol{\eta} = M_2 \left[ \left( 1 - \frac{x_2}{x_1} \right) h_v + \frac{x_2}{x_1} h_4 - h_2 \right] + M_{sand} \cdot Cp_{sand} \cdot \Delta T \tag{29}$$

Assume values for $T_4$ to get $X_1$, $M_2$. By substitution in eq (25) by $X_1$, $M_2$ to get the values for $M_w$

## 3- EXPERIMENTAL SET-UP

Fig. 2 shows a schematic diagram of the experimental apparatus. It consists mainly of two parts, flat plate collector with a movable glass cover and sand bed. The inner surface of the collector is made of 1mm thickness steel sheets to form, by welding, a box having a square base of 1m x 1 m and 0.25 m height.

The box is isolated by a high density foam of 0.05 m thickness. The glass cover which has a square area of $1m^2$ and 3 mm thickness is supported by a metallic frame to form the apparatus upper side. The frame is hinged with the box from one side. A steel frame with a variable tilt angles are 15°, 20° and 25° to the horizontal supports the apparatus. The apparatus is fixed such that the glass cover is facing south. General view of the experimental apparatus is illustrated in Fig. 2.

The averge thermal capacity of the system, $C_s$ , is evaluated as the summation of thermal capacities of different materials used (metals , sand glass and salt) as given in the following expression,

$$C_S = (\mathbf{m} \times \mathbf{C})_{\mathbf{Steel}} + (\mathbf{m} \times \mathbf{C})_{\mathbf{Sand}} + (\mathbf{m} \times \mathbf{C})_{\mathbf{solution}} + (\mathbf{m} \times \mathbf{C})_{\mathbf{glass}}$$

Values of mass and thermal capacity of different items are given in the Table (2).

**Table (2): Masses and thermal capacities of the system elements**

| | Inner surface of the collector | Sand | Calcium chloride solution | Glass cover |
|---|---|---|---|---|
| m | 15.644 | 56.3 | 14.68 | 7.5 |
| C | 444 | 800 | 3000 | 750 |
| Ref. | 20 | 20 | 21 | 20 |

As the air gap between glass cover surface and sandy layer surface is equal to 0.20 m was considered in thermal calculations. Average values of glass cover transimissivity and absorptivity are taken as 0.87 and 0.12 respectively. For black coated surface of the bed, the absorptivity is assumed to be 0.87.

The system is suitably instrumented by a number of copper-constantan thermocouples, which are connected to a temperature recorder, to measure the bed and glass mean temperatures. Also, the ambient temperature and radiation intensity are recorded during the experimental test. Graduated glass flask is located at the condensate collection point as shown in Fig. 3. The total mass of absorbed or evaporated water is evaluated from the collected vapour during the regeneration process. Variation of solution concentration during regeneration time is evaluated by knowledge of the hourly mass of collected vapor.

The glass cover of the collector is opened at night and absorption process is carried out to absorb the moist water from the air. At the daytime system glass cover is closed, the sand bed absorbs the incident solar radiation and consequently, the bed temperature increases. As a result, the vapor pressure of the solution on the bed surface increases and vapor pressure difference between the bed surface and glass cover is created. At this situation, evaporation of vapor from the bed with subsequent condensation on the glass surface is carried out. Evaporation and condensation continues until the vapor pressure on the bed surface is equal to that on the glass surface to complete the cycle. The cycle absorption and regeneration is repeated.

## 4- RESULTS AND DISCUSSIONS

### 4.1 Theoretical Results

Figure 4 shows the theoretical results for one day as the example of the variation of total solar radiation intensity on the collector surface, surface temperature, bed temperature ambient air temperature and glass cover temperature

Figure 5 shows the variation of the system productivity during the daytime. It can seen that the evaporation begin at 10 o clock and reached to 250 ml/m$^2$ hr after noon and then decrease to zero at 4 p.m.

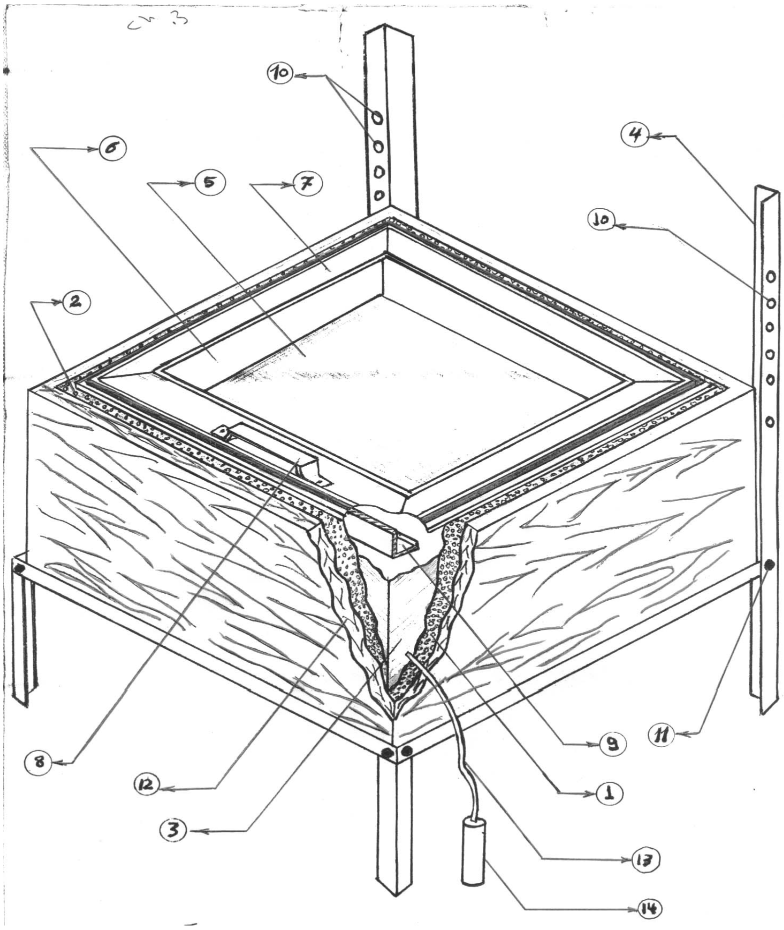



**Fig (2): Schematic diagram of the experimental apparatus**

1- Foam (Isolation).
2- Steel sheets.
3- Collector Support.
4- Sandy Layer.
5- Glass Cover.
6- Metallic Frame.
7- Handle.
8- Collection basin.
9- Holes of Fixation.
10- Linking Bolt.
11- Wood sheets.
12- Collected Water Tube of Collector.
13- Graduated Flask.

**Fig. 3: The experimental set up**

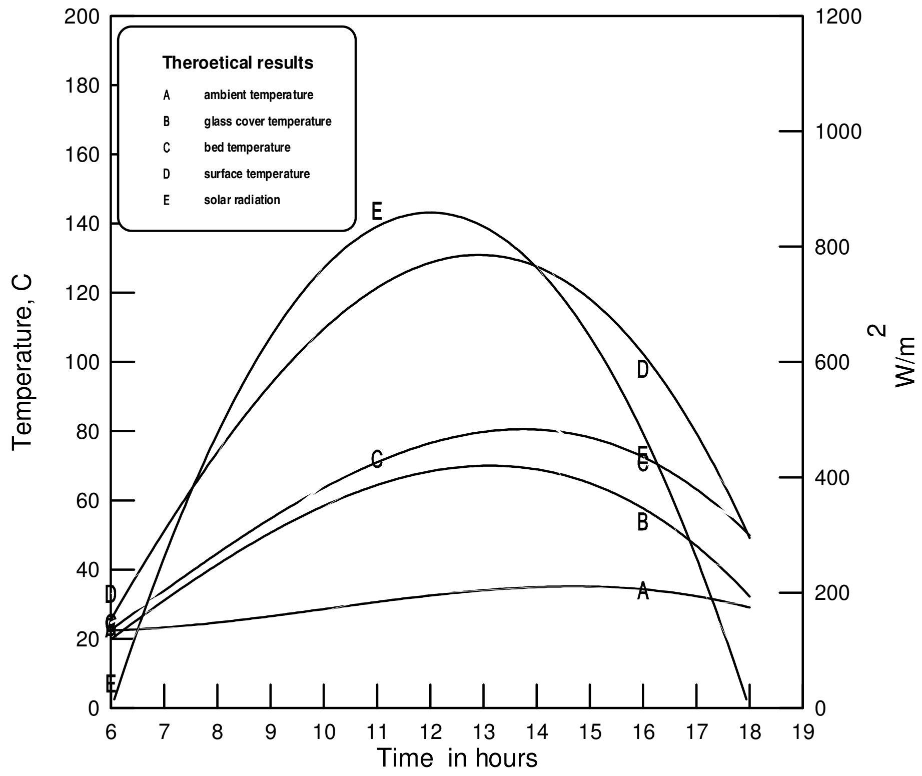



**Fig. 4: Variation of the bed, glass cover, surface, ambient temperatures and solar radiation during the day**

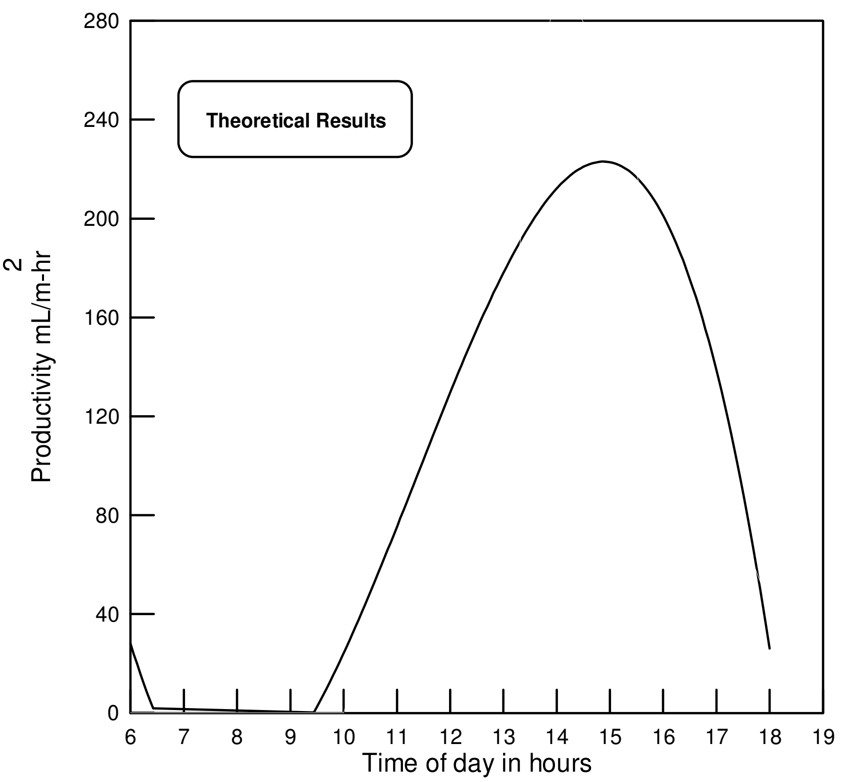



**Fig. 5: Variation of the system productivity during the day**

## 4.2 Experimental Results

### 1- Variation of temperatures during the day

The variation of the bed surface, glass cover, ambient temperatures and solar radiation for different days at three different tilt angles 15, 20 and 25 degree are illustrated in figures 6 to 11. The figures show that the all temperatures increase with time till after noon and then decrease the surface temperature reached to about 100 C and the bed temperature reached to 80 C and glass cover reached to 60 °C.

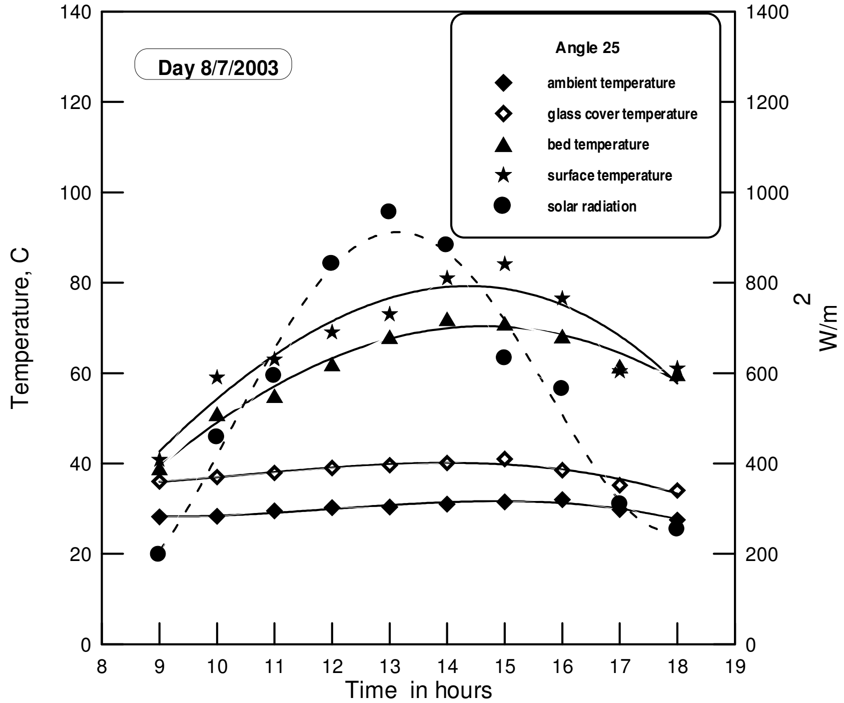



**Fig. 6: Variation of the bed, glass cover, surface, ambient temperatures and solar radiation during the day at tilt angle 25**

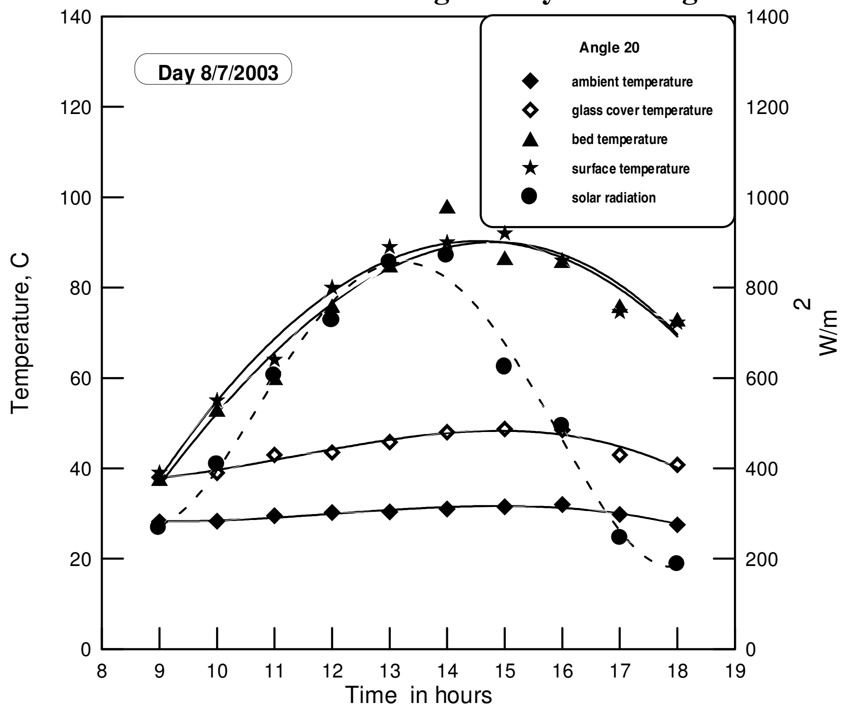



**Fig. 7: Variation of the bed, glass cover, surface, ambient temperatures and solar radiation during the day at tilt angle 20**

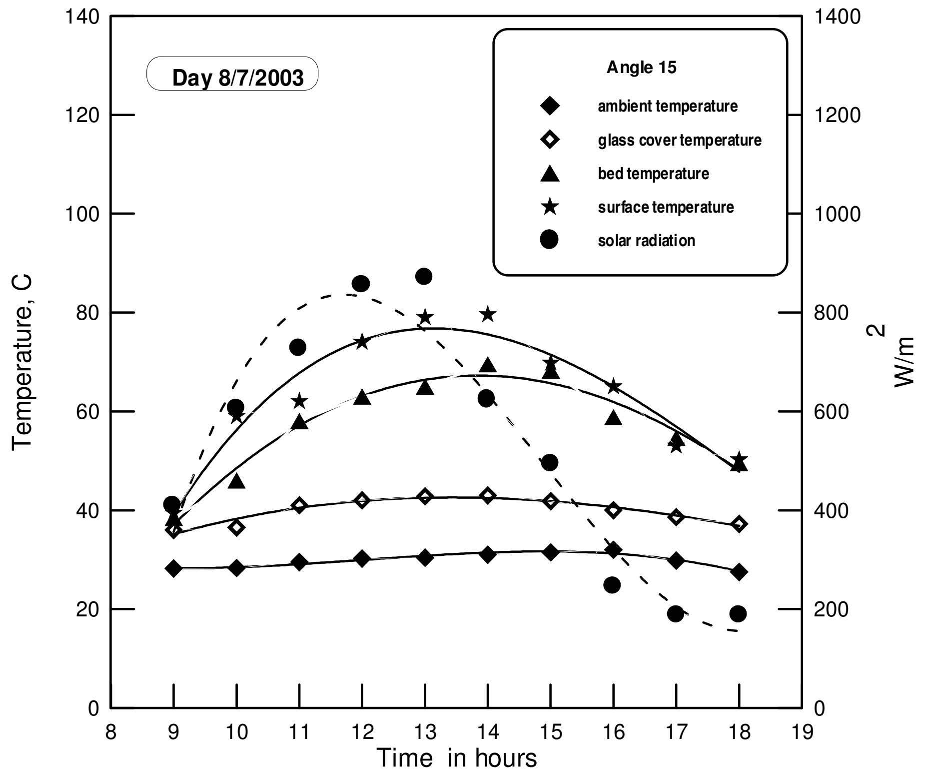



**Fig. 8: Variation of the bed, glass cover, surface, ambient temperatures and solar radiation during the day at tilt angle 15**

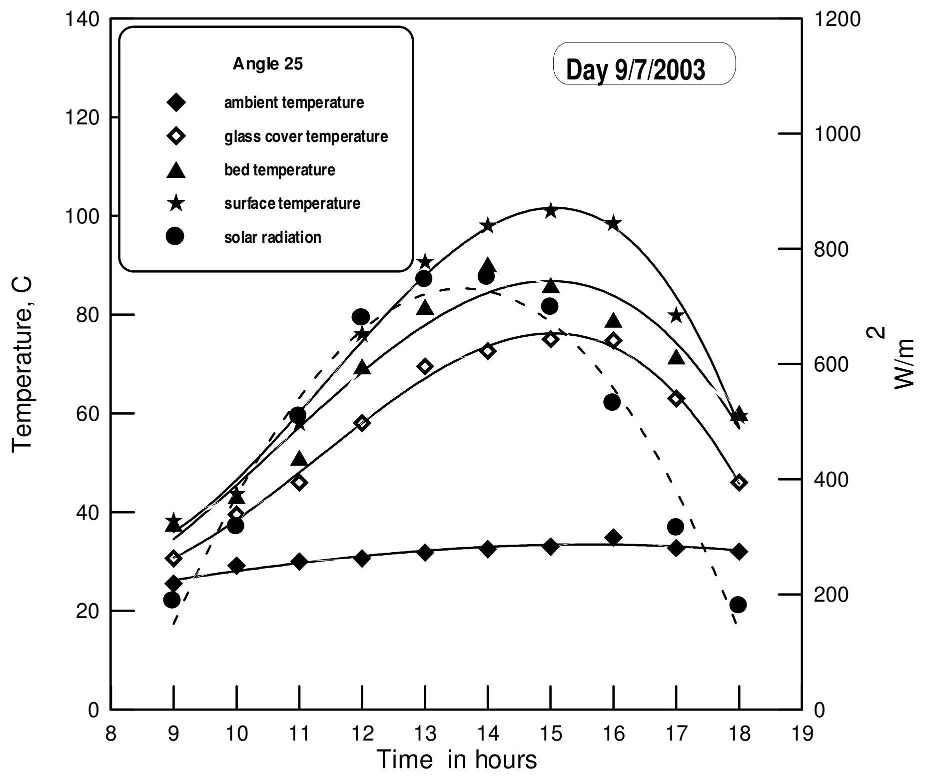



**Fig. 9: Variation of the bed, glass cover, surface, ambient temperatures and solar radiation during the day at tilt angle 25**

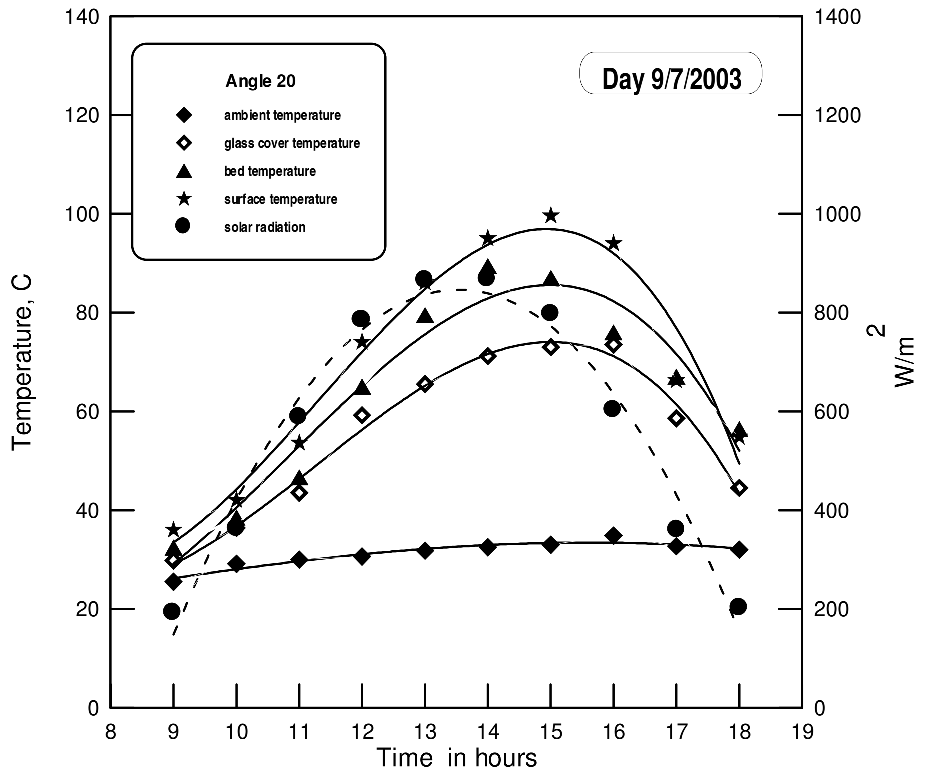



**Fig. 10: Variation of the bed, glass cover, surface, ambient temperatures and solar radiation during the day at tilt angle 20**

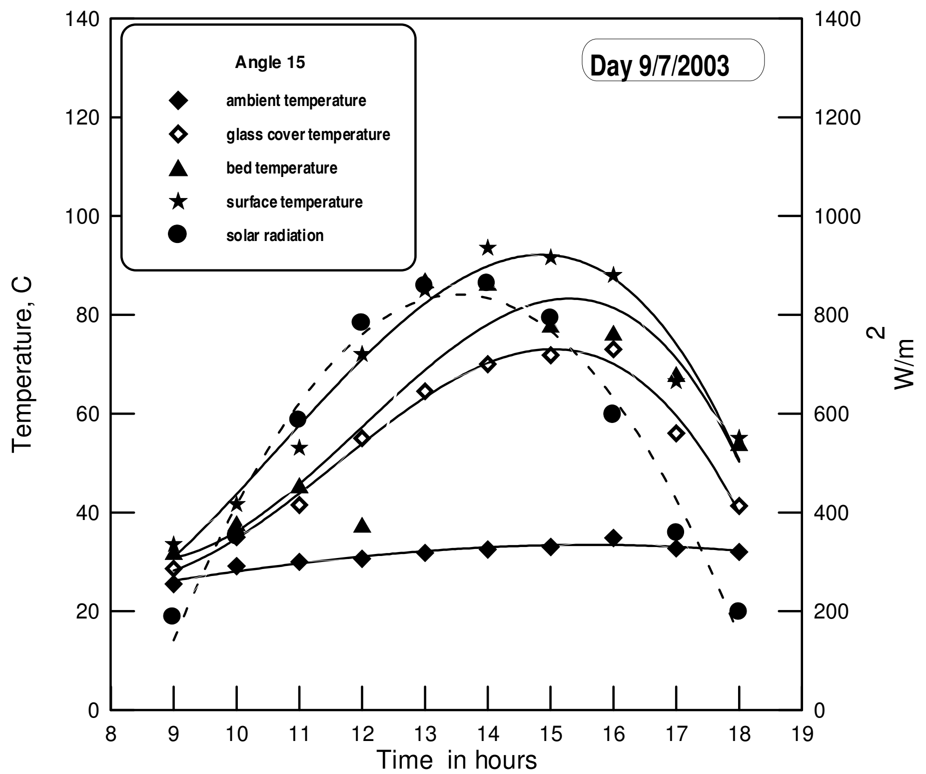



**Fig. 11: Variation of the bed, glass cover, surface, ambient temperatures and solar radiation during the day at tilt angle 15**

The hourly values of the system productivity are shown in figures 12, 13, 14 and 15. Each figure represents the productivity for three-inclination angles 15, 20 and 25 degree. Each figure shows that the amount of extracted water for angle 25 degree is higher value than angle 15 and 20 degree. Also the figure shows that the productivity increases with time due to increase the solar radiation to maximum value and then decrease. It reached to about 235 ml/m$^2$ h after solar noon.

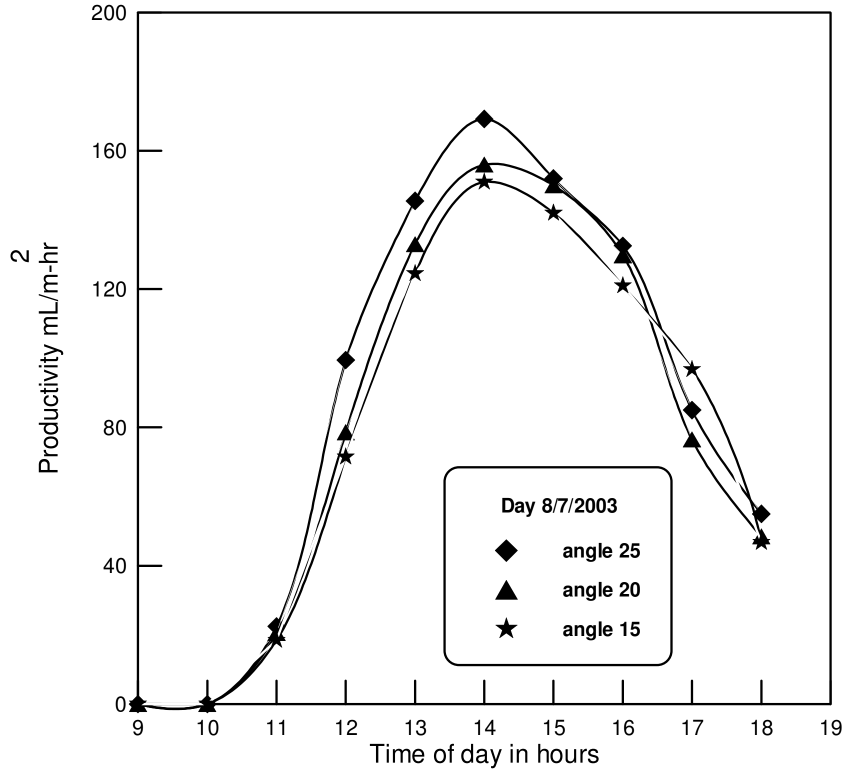



**Fig. 12: Variation of instantaneous productivity during the day 8/7/2003**

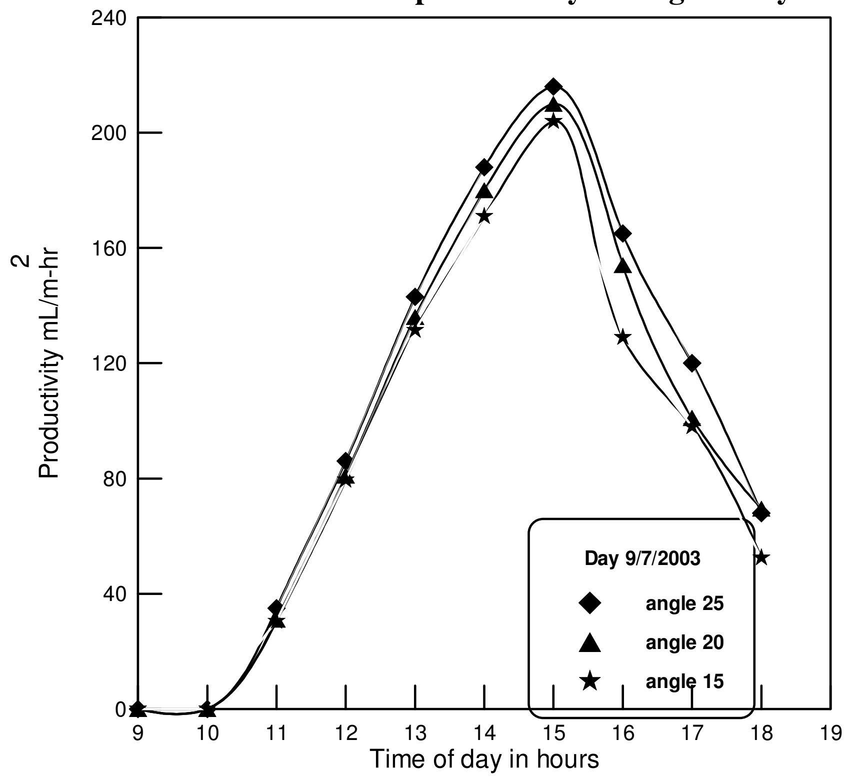



**Fig. 13: Variation of instantaneous productivity during the day 9/7/2003**

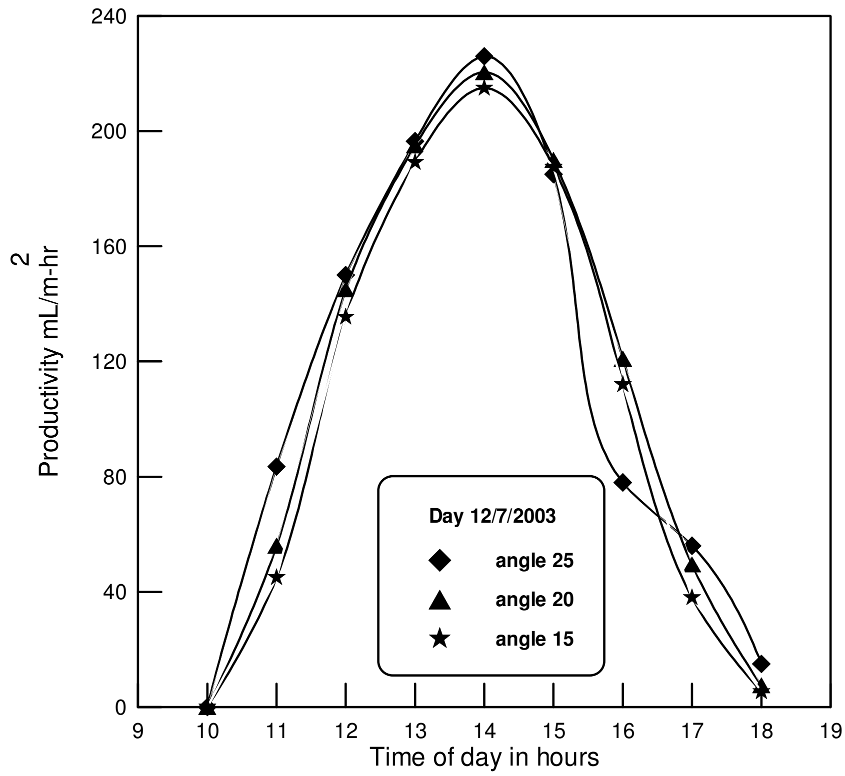



**Fig. 14: Variation of instantaneous productivity during the day 12/7/2003**

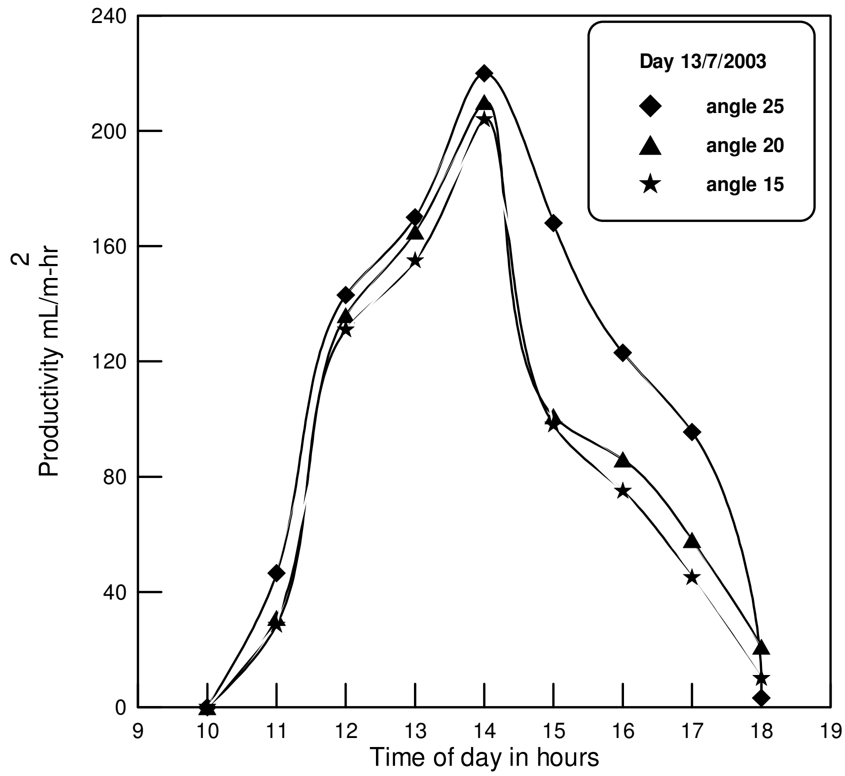



**Fig. 15: Variation of instantaneous productivity during the day 13/7/2003**

### 4.3 Comparison between theoretical results and experimental results

A Comparison between experimental results for the accumulated productivity during three days and theoretical results showed in figure 16. The figure shows that the accumulated productivity is about 1100 ml/m$^2$ per day from the experimental results. The accumulated reached to about 1200 ml/m$^2$ per day for the theoretical analysis. The deviation between the theoretical analysis and experimental results equals 10 % which shows the good agreement between the theoretical and experimental results.

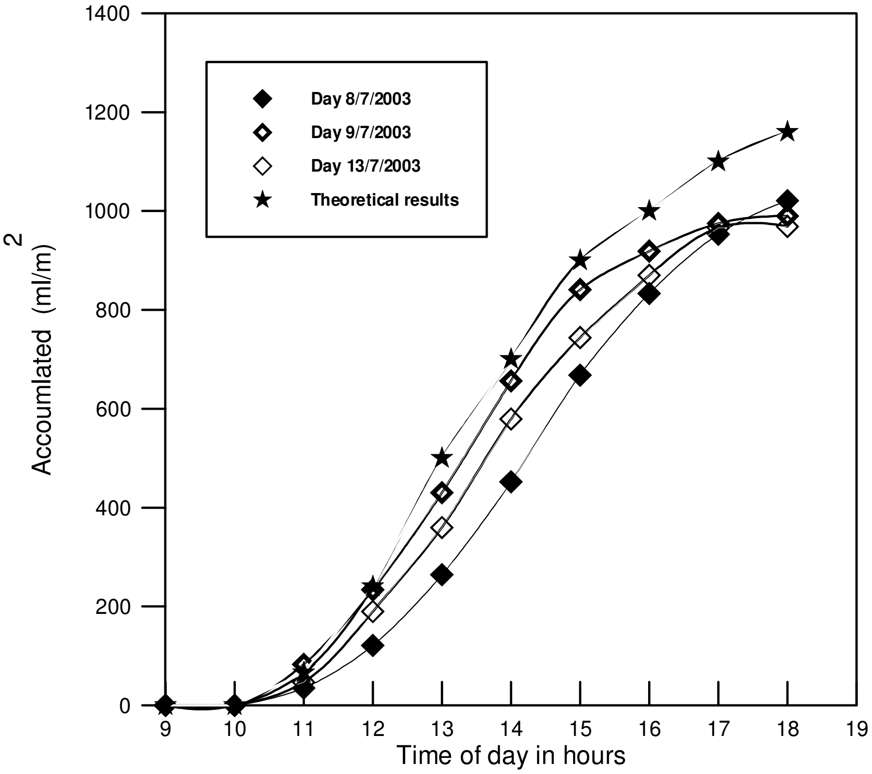



**Fig. 16: Comparison between experimental results for the accumulated productivity during three days and theoretical results**

## 5- CONCLUSIONS

Application of sandy bed in a solar collector system for recovery of water from air shows that the system is experimentally feasible. About 1.2 liter of fresh water can be collected per m$^2$ per day. The inclination angle 25 degree is the most efficient; however the difference in productivity is small. The comparison between the theoretical results and experimental results show good agreement.

## NOMENCLATURE

| | |
|---|---|
| A, B, a, b | empirical constants of equations |
| C | thermal capacity, J/kg C° |
| $C_s$ | thermal capacity of the proposed system, J/m $^2$ °C |
| $\Delta p$ | vapor pressure difference, mmHg |
| $F_{be}$ | shape factor between bed and glass cover |
| $F_{g\text{-}sky}$ | shape factor between glass and surroundings |
| H | incident solar radiation, W/m$^2$ |
| $h_B$ | Heat transfer coefficient through the system base and sides, W/ m$^2$°C |
| $h_{ga}$ | Convective transfer coefficient between glass cover and ambient W/m$^2$°C |
| $k_a$ | Thermal conductivity of the air gap, W/m°C |
| $k_b$ | thermal conductivity of the bed, W/m°C |
| $L_b$ | latent heat of water at average bed temperature, J/kg |
| M | mass of solution, kg |
| $M_f$ | final mass of solution, kg |
| $M_I$ | initial mass of solution, kg |
| $m_c$ | mass of collected water, kg/m$^2$ |
| $\dot{m}_c$ | rate of collected water, kg/m$^2$ hr |
| Ms | mass of salt, kg |
| $M_w$ | mass of water in solution, kg |
| $M_w$ | mass of absorbed moisture, kg |
| P | instantaneous system productivity, kg/$h_s$ |
| $P_b$ | Vapor pressure above the bed surface at average bed temperature and average solution concentration, MN/m$^2$ |
| $P_v$ | Vapor pressure above the desiccant surface, mmHg |
| $P_g$ | saturation pressure of water at glass cover temperature, MN/m |
| $P_\infty$ | atmospheric vapor pressure, mmHg |
| $q_B$ | rate of heat loss from system base and sides to the surroundings, W/m$^2$ |
| $q_c$ | rate of heat transfer by conduction through the air gap between the bed surface and glass cover, W/m$^2$ |
| $q_e$ | rate of heat transferred by evaporation from the bed to the glass cover, W/m$^2$ |
| $q_r$ | rate of heat transferred by radiation between the bed surface and glass cover, W/m$^2$ |
| $q_{ga}$ | rate of heat transferred from glass cover to ambient, W/m$^2$ |
| $T_a$ | ambient temperature, °C |
| $T_b$ | average bed temperature, °C |
| $T_g$ | average glass cover temperature, °C |
| $T_s$ | bed surface temperature, °C |
| V | wind speed, km/hr |
| X | solution concentration |

| | |
|---|---|
| $X_f$ | final solution concentration |
| $X_i$ | initial solution concentration |
| Greek | |
| $\alpha_b$ | average bed absorptivity |
| $\alpha_g$ | average absorptivity of glass cover |
| $\beta$ | mass transfer coefficient, kg/m$^2$- mmHg-hr |
| $\sigma$ | stefan-boltzmann constant =5.67 x 10$^{-8}$ W/m$^2$-k$^4$ |
| $\delta$ | bed thickness, m |
| $\eta$ | operation efficiency of the system |
| $\Delta y$ | air gap thickness, m |
| $\tau$ | time, s |
| $\tau_g$ | average transmissivity of the glass cover |
| $\Delta\tau$ | time interval, s |

## REFERENCES


1. Shiklomanova, I., "World fresh water resources." P. Geick (ed.), Water in Crisis, Oxford University Press, Oxford, New York, (1993).
2. Hamed, A.M., "Absorption-regeneration cycle for production of water from air-Theoretical approach", Accepted for publication, Renewable Energy Journal, (1999).
3. Kolodin M., "Water and arids", M., Misi, USSR, (1981)
4. Obrezkova, V.E., "Hydro-energy" Energoatomezdat, Moscow, (1988).
5. Hamed, A.M., "Non-conventional method for collecting water from air using solar energy", Ph.D. Thesis, Russian Academy of Science,(1993).
6. Tygarinov, V.V., "An equipment for collecting water from air", patent. No. 69751, In Russia, (1947).
7. Nebia,. G., "The Problem of obtaining water from the air". Proc. Of the conf. On Solar and Aeolian Energy. Part V., pp. 33-46, (1961).
8. Sofrata, H., '"Non-conventional system for water collection" Proc. of solar desalination workshop. 2, pp. 71-87, (1981).
9. Stepankova, B.A., "Renewable energy sources in agricultural economy", M., Agropromizdat, USSR, (1988)
10. Protsenko V. P., Safanov V. K. and Rashepkin M. I., "Autonomous plant for water extraction from moist air", A. C.No.(1484886) JF.G.R. in 07- 06- (1989)
11. Khalil, A., "Dehuroidification of atmospheric air as a potential source of fresh water in the UAE" Desalination, No. 93, pp. 587-596, (1993).
12. Awad, M.M., Sultan. A.A and Abd El Raouf, M.M., "Using refrigeration systems to extract water from moist air" Proc. of the first UAE conference on air conditioning in the Gulf, ACG. 96, (1996).
13. Hall, R.C., "Production of water from the atmosphere by absorption with subsequent recovery in a solar still", Solar Energy, 10, pp. 42-45, (1966).
14. Alayli, Y., Hadji. N.E. and Leblond, J., "A new process for the extraction of water form air". Desalination, No. 67, pp. 227-229, (1987).

15. Gandhidasan, P. and Abualhamayel, H. I, "Water recovery from atmosphere" WREC. pp. 745-748, (1996).
16. Dunkel, R.V "The roof type still and a multiple effect diffusion still" International Heat Transfer Conference, University of Colorado, USA, part 5, 895-902, (1961).
17. Me Adams, W.H., "Heat Transmission", McGraw-Hill Bock Company, (1954).
18. Duffie, J.A. and Beckman W.A. "Solar engineering of thermal process" Second Edition, Wiley, USA (1991).
19. Elsayed, M.M, "Comparison of transient performance predictions of a solar-operated diffusion-type still with a roof-type still" Journal of solar engineering. Vol. 105, pp. 23-28, (1983).
20. Olaf, A.H. and Watson, K.M., "Chemical processes principals, part one, material and energy balances" John Wiley, Son, Inc. New York, (1944).
21. Lorch, W., "Hand book of water purification" McGraw-Hill Book Company, (1981).
22. Gad, H.E., Hamed, A., El-Sharkawy, I., Production of water by extraction of atmospheric moisture using solar energy, M.Sc. Thesis, Faculty of Engineering, Mansoura University, (2000).