ENHANCEMENT OF SOLAR DESALINATION STILL PRODUCTIVITY USING FLASH EVAPORATION

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ABSTRACT

A Solar desalination system with flashing chamber is experimentally investigated. It was found that the productivity and performance of the system were significantly positive dependent on both the mass flow rate of the impure water and the linear speed of the nozzle's holder, and slightly increase with the using of a porous medium in basin of the still as a heat storage sink. There is an optimum mass flow corresponds to the holder linear speed with respect to both thermal efficiency and water production. The unit daily productivity reaches 6.7 L/m^2.day. The average daily thermal efficiency reached 77.35%.

1. INTRODUCTION

The increasing population and industrial agricultural development of rural areas are creating an unbalance between drinking water demand and fresh water supply. It is well known that solar desalination exhibits considerable economic advantages over other salt water desalination processes because of cost-free energy, reduced operating costs and its simple structure.

Rahim [1] introduced new techniques developed to improve the efficiency of both evaporating and condensing zones, and concluded that:

1. Separating the evaporator and condenser in two different units allows the temperature difference between the evaporator and condenser zone to be controlled independently to a relatively large amounts during the day.
2. As the potable water is collected in the condenser unit, the re evaporation of the condensed potable water is eliminated.

Ziqian et al. [2] developed and tested a special desalination unit which utilizes solar or waste energy. He concluded that by the simulation of his unit operating with a solar system under practical weather conditions, the yield rate of the unit is more than two times comparing with that of a conventional single basin type of solar still.

Tripathi and Tiwari [3] made the following conclusions:

1- Solar fraction plays very significant role in thermal modeling of a solar still.
2- The change in the height of the north wall for a given basin area and the width of the solar still affects the daily output.
3- The change in the length of a solar still for a given height and width of a solar still does not affect the daily output.

Al-Hayek and Badran [4] found that the distilled water out put of the asymmetric green house type was 20% higher than that of symmetric greenhouse type.

Yuan and Zhang [5] concluded that:

1- For a fixed solar area (absorber), the feed water flow rate increasing will decrease fresh water production because of the spray temperature decrease.
2- The matching of the cooling water flow rate with the collector area is very important to obtain maximum fresh water production.
3- The year-round study shows that in (Xi'an China), 5.2 kg/m^2.d can be obtained in June. In December, 2.7 kg/m^2.day can be reached.

A numerical study was carried out by Fath et al. [6] to investigate the thermal performance of a new still. The results show that: The still productivity is about 5.2 kg/m^2.day, and decreasing air flow rate has insignificant influence on the productivity.

For an innovative water desalination system using low grade solar heat, Al-Kharabsheh and Goswami [7] concluded that: the performance of this system is superior to a flat basin solar still, and the output may be twice that of a flat basin type for the same input.

A single basin solar still was fabricated and tested by Samee et al. [8]. The efficiency was calculated as 30.56%.

Janarthanan et al. [9] proposed a floating cum tilted wick type solar still with flowing water over the glass cover. They have concluded the followings:

1- Glass cover temperature decreases significantly due to the water flowing over the glass cover which causes fast evaporation during peak sunny hours.
2- The effect of water flowing over the glass cover has a fascinating role on the performance of the still.

Tanaka et al. [10] investigated theoretically a vertical multiple-effect diffusion-type solar still. It was found that:

1- The overall daily productivity is larger for the optimum solar collector angle stills than the fixed one on the summer or winter solstices.
2- The productivity increases with a decrease in the feed rate of saline water to the wicks
3- To increase the productivity, a simple device such as a black tube can be used to increase the feeding temperature of saline water to the wicks.

Abdel-Rahim and Lasheen [11] designed a modified solar desalination system. It has two modifications; the first one is a backed layer. The second modification is the using rotating shaft installed close to the basin water surface. Based upon the results obtained from the comparisons between the two modified stills and a conventional type, the following conclusions were reached:

1- The overall efficiency of two modified systems were higher than the conventional type
2- Modified solar desalination system used packed layer had higher productivity than that one used rotating shaft and both are better than the conventional type.

Dia and Zhang [12] tested a solar desalination unit with a humidification and dehumidification (HDD) cycle. The unit improved the effect of evaporation and over came the difficulty of increasing the evaporation temperature and decreasing the condensation temperature at the same time by using a falling film humidifier with large evaporation surface and forced convection to enhance the heat and mass transfer. The thermal efficiency of the system is about .85 under optimal operating conditions.

Orfi et al. [13] studied theoretically a solar desalination system with HDD. He said that the daily production of fresh water depends on the ratio between the salt water and the air mass flow rates. It was found that this desalination unit can produce fresh water at high rates (more than 15 L/m^2.day).

Hongfei and Xinshi [14] constructed and tested an active regenerative solar still with an area of 1.03 m^2, indoors. He concluded that the performance ratio is about two to three times greater than that of a conventional basin-type solar still.

Badran et al. [15] studied a single-stage, basin-type solar still connected with a conventional flat-plate collector. He reports that the productivity of the system was substantially increased in comparison with that of the still alone. Meanwhile, efficiency was reduced by a few percentage points.

El-Fiqi et al. [16] studied an extensive experimental work on the flashing process using fresh liquid. The work concerned the spray flash evaporation occurring in a super heated water jet injected through circular nozzles into a low-pressure vapor zone. The results showed that:

1- Increasing the degree of super heat leads to an increase in the flashing vapor to a certain amount.
2- With the increase of the degree of super heat, both the flashing efficiency and the flashed vapor increase.
3- Decreasing the water level inside the flash chamber, increases slightly both the flashing efficiency and the amount of the flashed vapor.

Voropoulos et al. [17] and Mathioulakis and Belessiotis [18] designed and investigated a solar still-storage tank system. It has been shown that this design leads to higher distilled water output. The proposed solar distillation system concerns finally a hybrid design from the usage point of view and from the heat source point of view. It can exploit not only solar energy incident on saline water but also any other heat source available nearby, such as waste heat , conventional sources, electricity, solar collectors, solar pools, etc.

Bekheit et al. [19] concluded that the use of corrugated wick surface increases the output of the roof type solar still. The productivity of the system is enhanced with about 30%.

2. SYSTEM DESCRIPTION AND WORKING PRINCIPLE

The solar desalination system under study sprays impure water with a defined different flow rates is schematically shown in figure (1). This system includes stepped basin still with 10 steps; which represents the absorber with area of 1.0 m^2 (1.54*0.65 m^2), higher side and the two similar sides constructed from 2 mm blackboard coated iron, 30 mm rock wool insulation, while the casing constructed from 0.8 mm galvanized steel. The lower side of the still is made of plastic sheet 3 mm thickness in aluminum frame. The main condenser is the still body cover, which made of 3 mm plastic sheet thickness (1.54*1.06 m^2) in aluminum frame, there is a secondary condenser which constructed from 0.8 mm galvanized steel (1.3*0.1*0.4 m^3) and 9 copper tubes 0.25 inch in diameter. The system includes two loops, the main loop is used for injecting impure water in the flash chamber (evaporation area) and it consists of many parts, which are water supply tank, water flow meter (orifice meter), controlling valves, 3 sprayers-these sprayers could be modified to provide a variety of profiles but only one set is used during all experiments. The exit diameter of the spray nozzles is about 1.25 mm. Special mechanism for moving the sprayer's holder in a reciprocating linear motion is designed and constructed. The mechanism converts the rotary motion of 0.37 kW electric motor to the reciprocating linear motion with the required speed. The second loop is used to condense, collect and measure the flashed vapor. The entire test facility was constructed of iron tubes (0.5 inch), stainless steel tube (0.5 inch), copper tubes (0.25 inch) and rubber tubes. The test loop is designed to work in a flow range of 0-16 L/h, and an electric motor speed range 0-350 rpm (0-.0237 m/s for the rectilinear motion).

Impure water is continually sprayed at a defined constant flow rate through the nozzles to form falling scattered (small) drops on the heated stepped basin (absorber), because of the flash evaporation and mass exchange between impure water and air, the vapor born and condenses mainly on the inner cover surface and secondarily (partially) in the condenser unit, turning into fresh water. The remaining impure water is drawn continually by gravity.

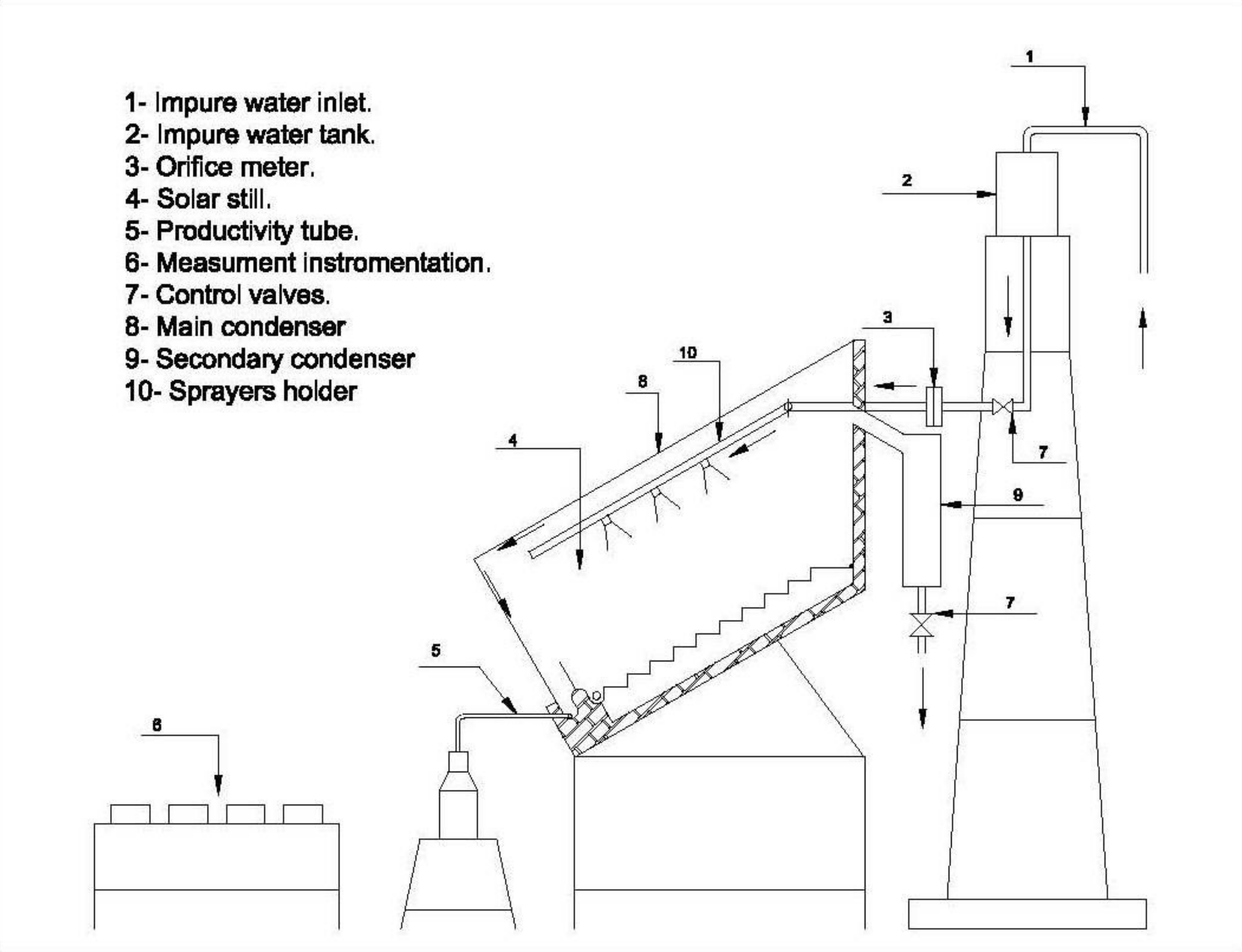

Figure (1) schematic diagram of the set-up

3. EXPERIMENTAL PROCEDURE

The experimental tests of this work were conducted at Tanta University, Egypt during the period from April 2008, to July 2008. Each experiment is conducted in one day, during which the following measurements have been recorded:

- Base (absorber) mean temperature.
- Outer and inner plastic cover temperature.
- Productivity
- Total solar radiation intensity on a horizontal plane.
- Ambient air temperature and wind speed.

The experimental data are collected at regular intervals of one hour, starting from about 9 a.m. to the sun set.

4- INSTRUMENTATION

The temperatures at different points in the system are measured by T-type thermocouples (0.5 mm diameter). There are twelve thermocouples located at the base of the still, two thermocouples at the inner cover surface (condenser) and other two thermocouples at the inner cover surface.

The temperatures are recorded by a digital thermometer model 922 of 0.1 °C resolution instrument three selecting switches, twelve points. The instrument has a reference junction compensation for ambient air temperature.

The solar radiation is measured by using of both TD 208 b- solarimeter 6 digits and a silicon cell pyranometer model 3120.

The productivity is measured by graduated vessel 1000 mL plus or minus 10 mL.

5. RESULTS AND DISCUSSION

Results for different experiments are given in graphical form in order to simplify the discussion. The experimental results of the present work are divided into three groups.

The first group concerns with the effect of speed variation at constant flow rate of the impure water (3.635 L/hr) on the system performance. It is carried out during the period from 3/4/2008 to 13/4/2008. Figure 2 shows the variation of base temperature and inner cover temperature with time during the day time. From this figure it can be seen that: the base and so, cover temperature increases with time starting from sunshine hour, reaches its maximum value around 12 a.m. and then decreases gradually. The differences in the base temperature and so, the cover temperature for the different speeds reaches its maximum value (about 10°C) around 12 a.m.

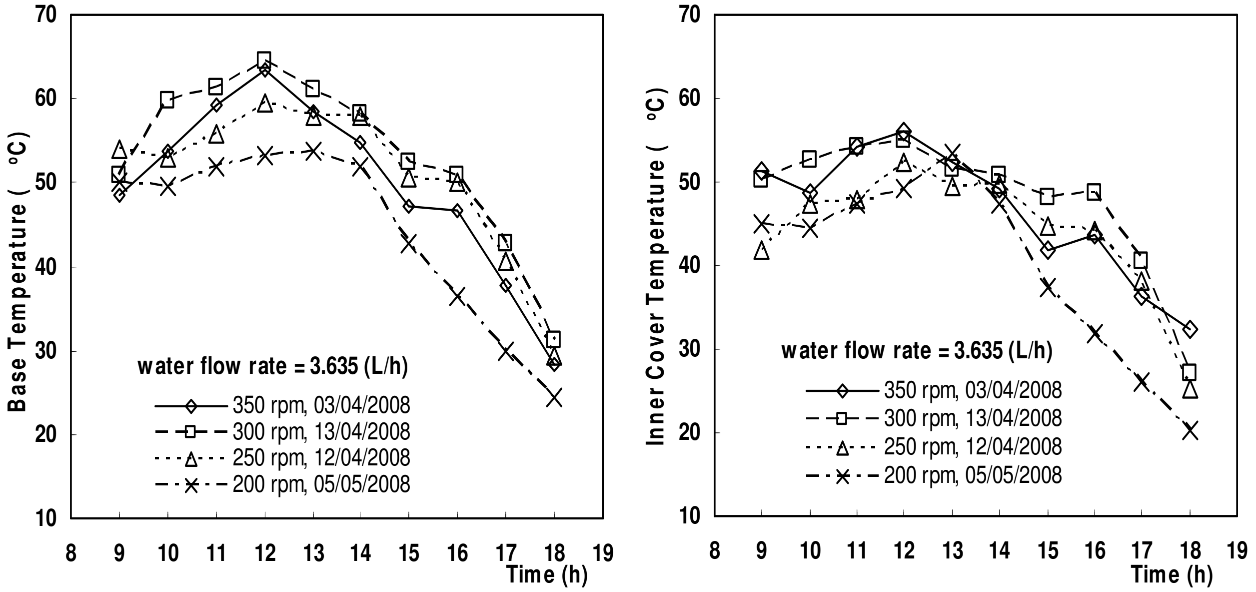

Figure (2) Variations of base and inner cover temperatures along the day with different motor speed at constant water flow rate

Figure 3 shows the variation of both solar radiation and ambient air temperatures along the day. It can be seen that both solar and so ambient air temperature increases up to 12 a.m., and then decreases gradually.

Figure 4 illustrates the hourly and accumulated productivities for various speeds. As shown in the figure, both the hourly and accumulated productivities increase with the increase of speed. Accumulated productivity reaches about 2 to 3 times of the traditional type at the same time of the year (water depth 3 cm.)

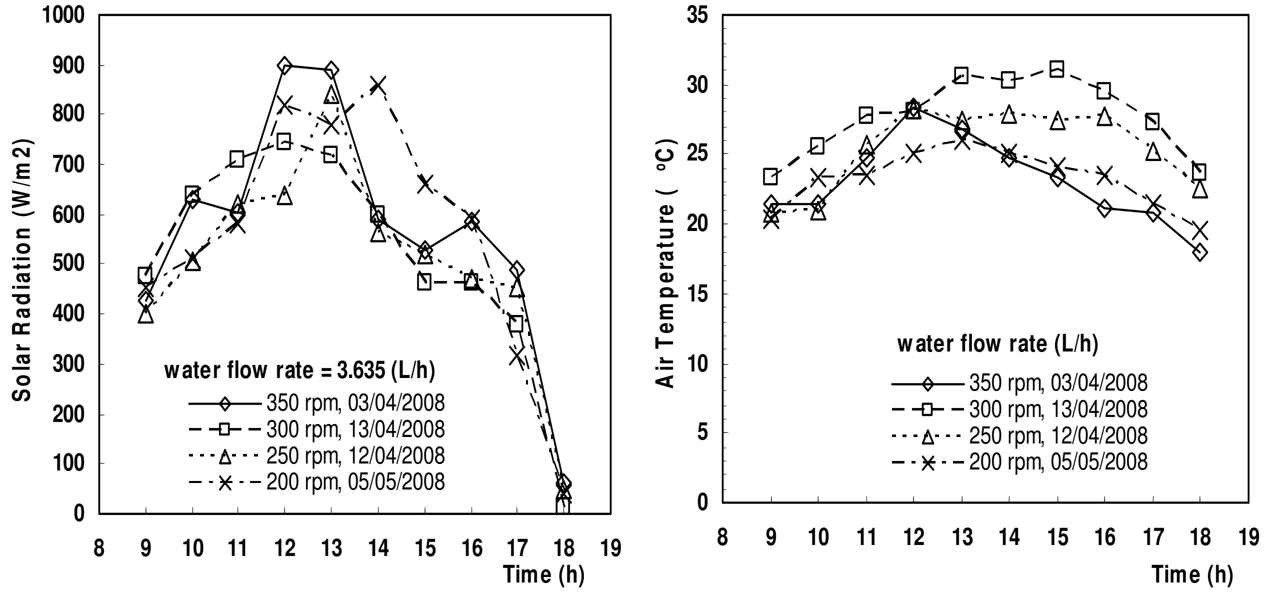

Figure (3) Variations of solar radiation and measured air temperature along the day with different motor speed at constant water flow rate

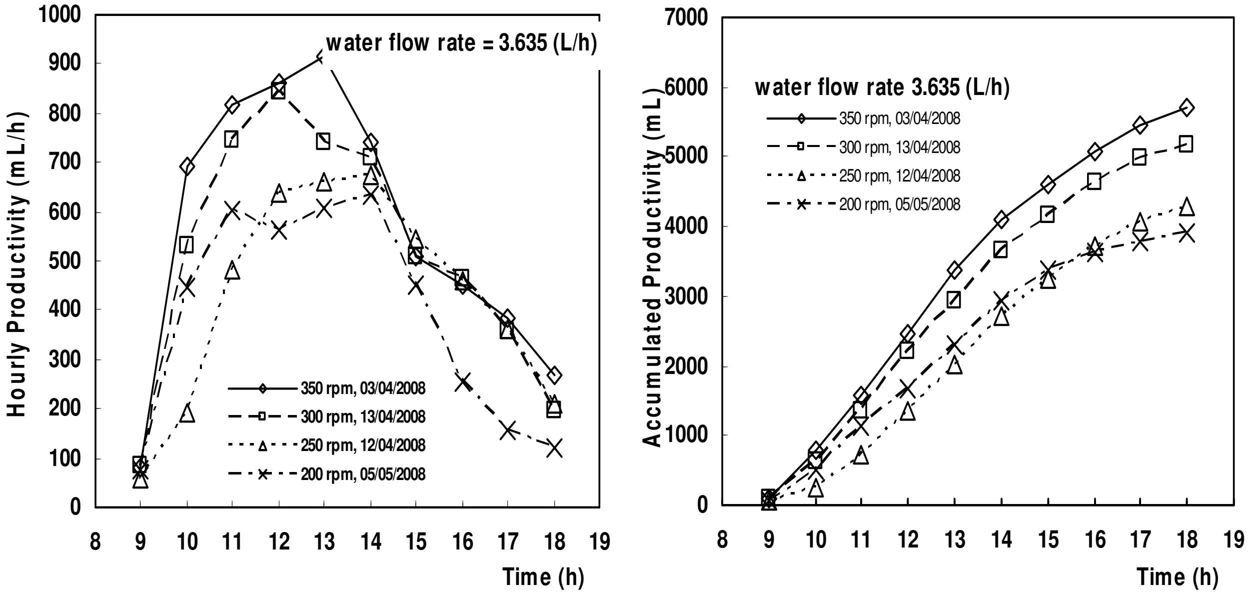

Figure (4) Hourly and accumulated productivity along the day with different motor speed at constant water flow rate

The variation of both daily productivity (L/m^2.day) and the average daily efficiency with speed are shown in Figure 5, it is clear that the productivity and so, average daily efficiency increases with speed to a certain amount. The hourly efficiency can be calculated from the following equation,

$$\eta = \frac{(HP * 10^{-3})\rho_w \, Lw}{3600 \, A \, H} \qquad (1)$$

where;

HP is the hourly productivity, (mL/h).

ρ_w is the density of water = 1000 kg/m^3.

Lw is the latent heat of vaporization of water at the average base temperature (kJ/kg).

A is the basin area (1.0 m^2).

H is the incident solar radiation on the horizontal surface, (W/m^2).

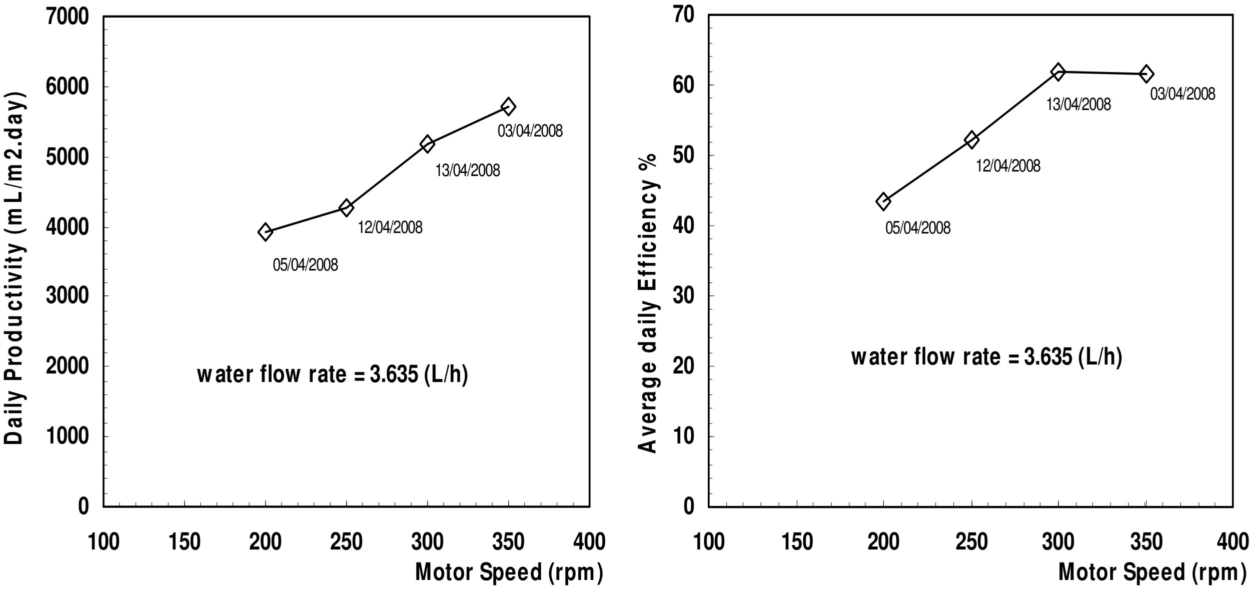

Figure (5) Variations of the daily productivity and still average efficiency with motor speed at constant water flow rate

The second group deals with the influence of the impure water flow rate on the performance of the system for different constant motor speeds. It is carried out during the period from 29/05/2008 to 25/07/2008. Figure 6 and Figure 7 show the variation of base temperature and inner cover temperature with time respectively. From these figures it is clear that both base and inner cover temperatures have the same trend; they reached the maximum value about 1 p.m. A converge of the two values for both base and cover temperatures at the same time is observed.

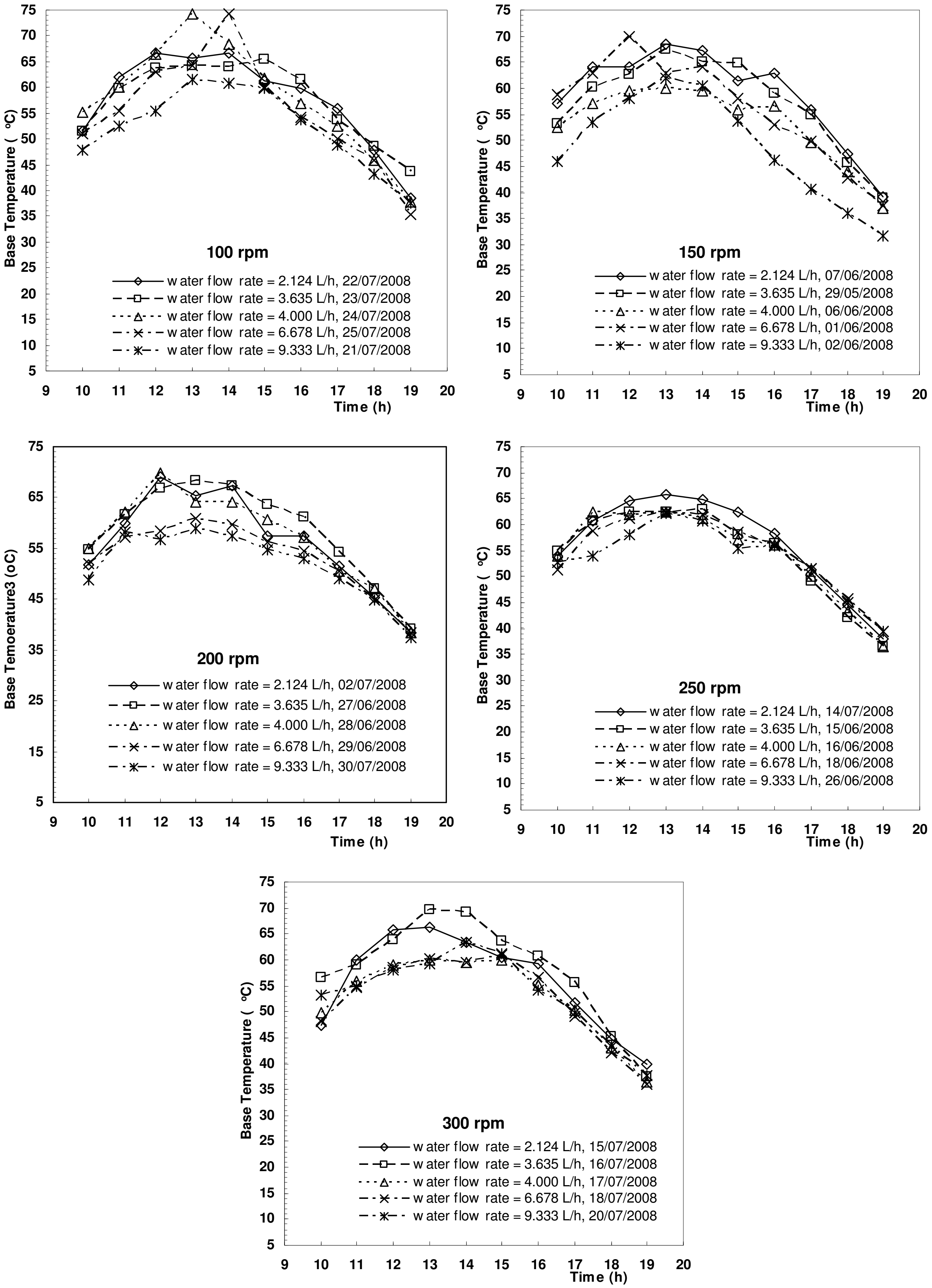

Figure (6) Measured base temperature along the day for different impure water flow each for constant speed rates, at constant speed

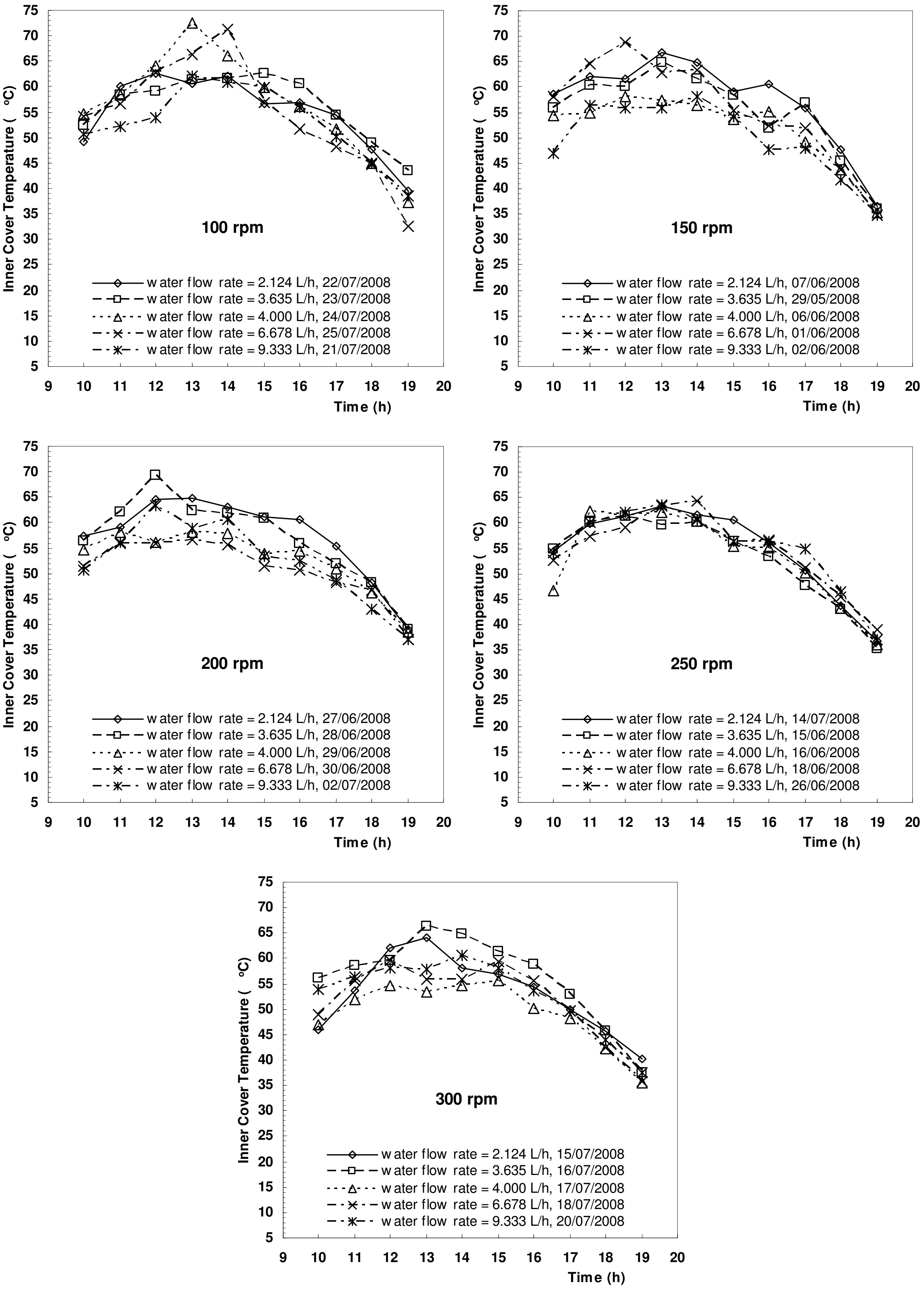

Figure (7) Variation of inner cover temperature along the day for different flow rates, each at constant speed

Figure 8 illustrates the accumulated productivity for five groups, each one for five different flow rates at the same motor speed. As shown in the figure(s), at 100, 150, 200, 300 rpm of motor speed the optimum flow rate is 3.635 L/hr and the corresponding accumulated productivity are 5881, 6051, 6162, 5812 L/m^2.day respectively. While at 250 rpm the optimum flow rate is 4 L/hr and corresponding accumulated productivity is 6.655 L/m^2.day. It is noticed that the accumulated productivity reaches about 2.5 times of the traditional type at the same time of the year. The accumulated productivity increases upto flow rate 3.635 L/h at 100, 150, 200 and 300 rpm and it increases upto 4 L/h at 250 rpm and then decreases gradually. In general, the accumulated productivity is the higher at 250 rpm.

The third group tests the influence of porous medium on the productivity of the system. The porous medium is reached through using one layer black gravel of nominal diameter 5-10 mm which put at absorber base. Figure 9 (a, b) shows a comparison between the base temperature with and with out porous medium. Figures 10 (a, b), 11 (a, b) and 12 (a, b) show the same comparison for the inner cover temperature, the accumulated productivity and the hourly productivity, It is clear the very small effect of the porous medium. Figure 13 (a, b) illustrates the solar intensity.

6. CONCLUSION

An extensive experimental investigation on a stepped solar still augmented with porous medium using flash evaporation was carried out. The work concerned the variation of the speed of the nozzle's holder ranging between 0.013 and 0.0237 m/s, feed flow rate ranging between 2.124 and 9.333 L/hr and augmented porous medium (black gravel 5-10 mm). The results show that:

- Increasing the speed, leads to an increase in the flashing vapor (productivity) to a certain amount.
- In the investigated limits there is an optimum value to the flow rate, it is about 4 L/hr.
- The adding of porous medium gives very slight increase of the still productivity.
- The reached productivity is 6.7 L/m^2.day with a thermal efficiency of 77.35%. Such productivity represents 2 to 3 times of the traditional type at the same time of the year.

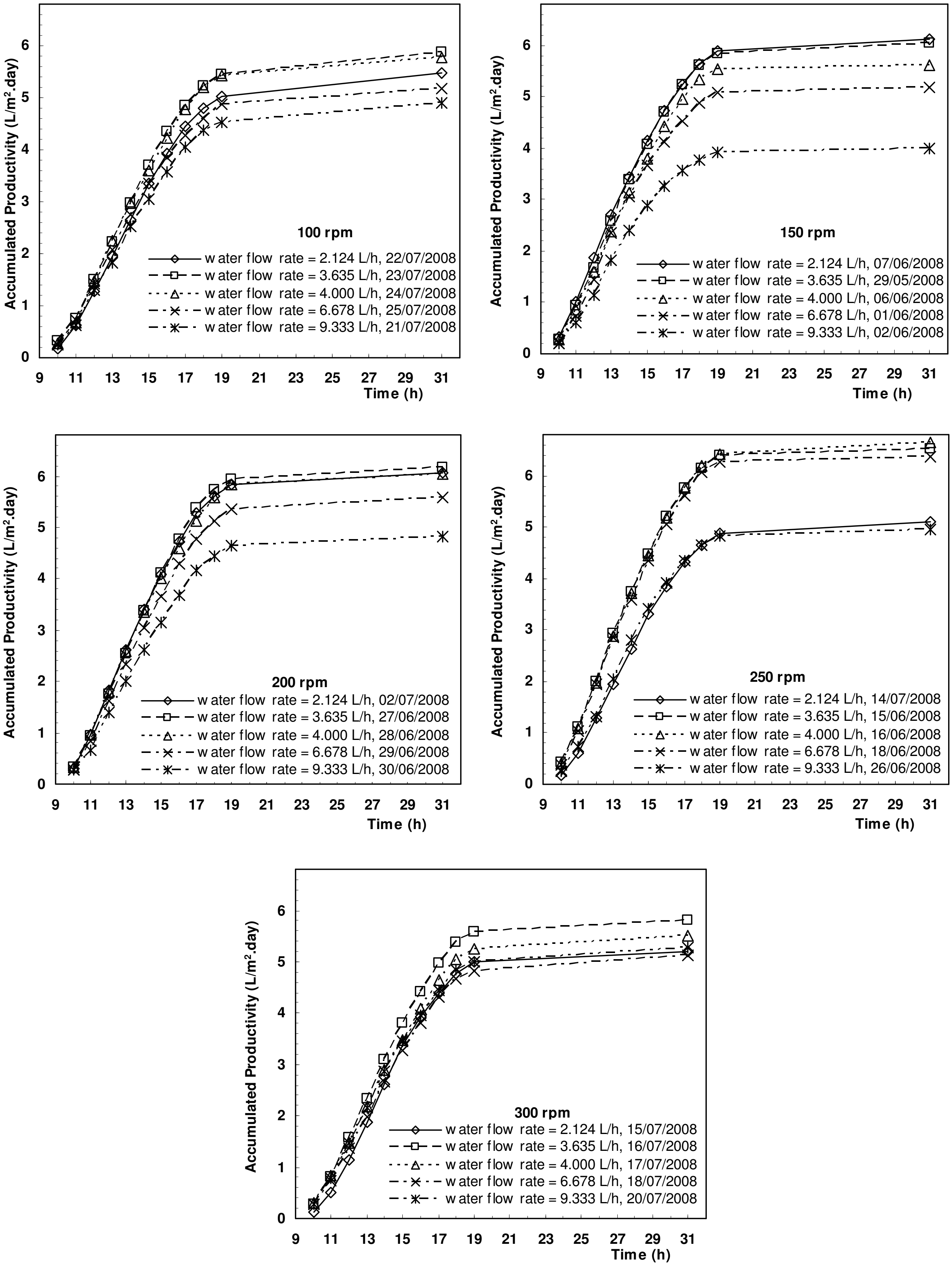

Figure (8) Experimental results for accumulated productivity for the five different water flow rates each at different constant motor speed

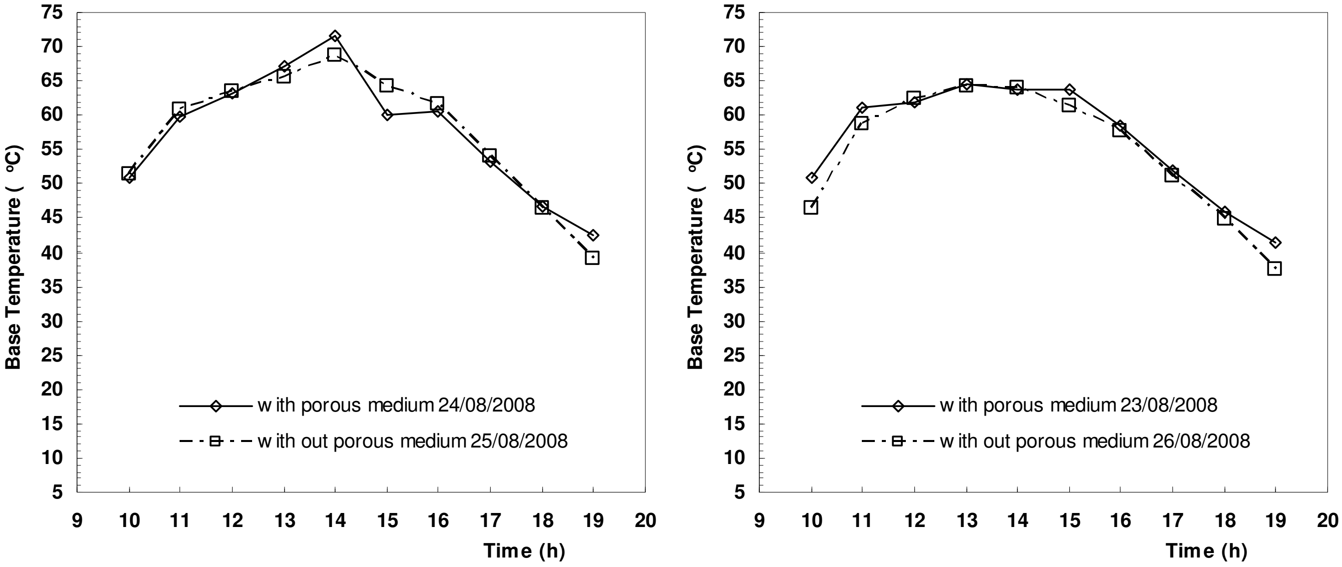

Figure 9-a. **Figure 9-b**

Fig. 9: Variation of the base temperature with time at 250 rpm and water flow rate=3.635 L/h and 4L/h respectively

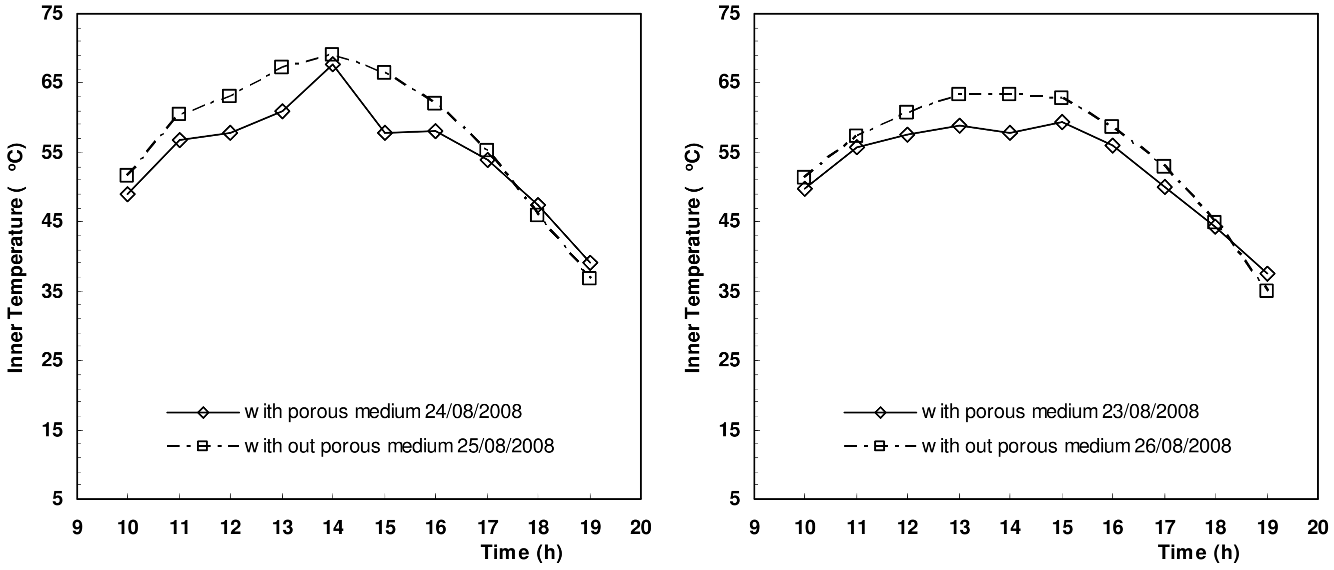

Figure 10-a **Figure 10-b**

Fig. 10: Variation of the inner cover temperature with time at 250 rpm and water flow rate=3.635 L/h and 4L/h respectively

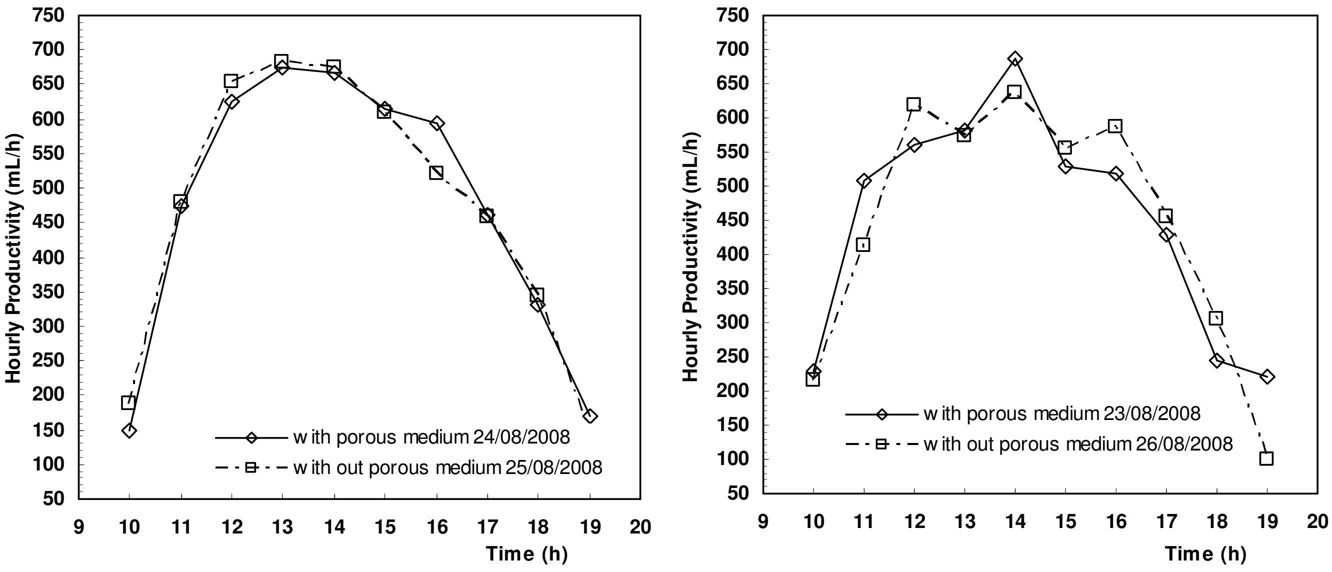

Figure 11-a **Figure 11-b**

Fig. 11: Variation of the hourly productivity with time at 250 rpm and water flow rate=3.635 L/h and 4L/h respectively

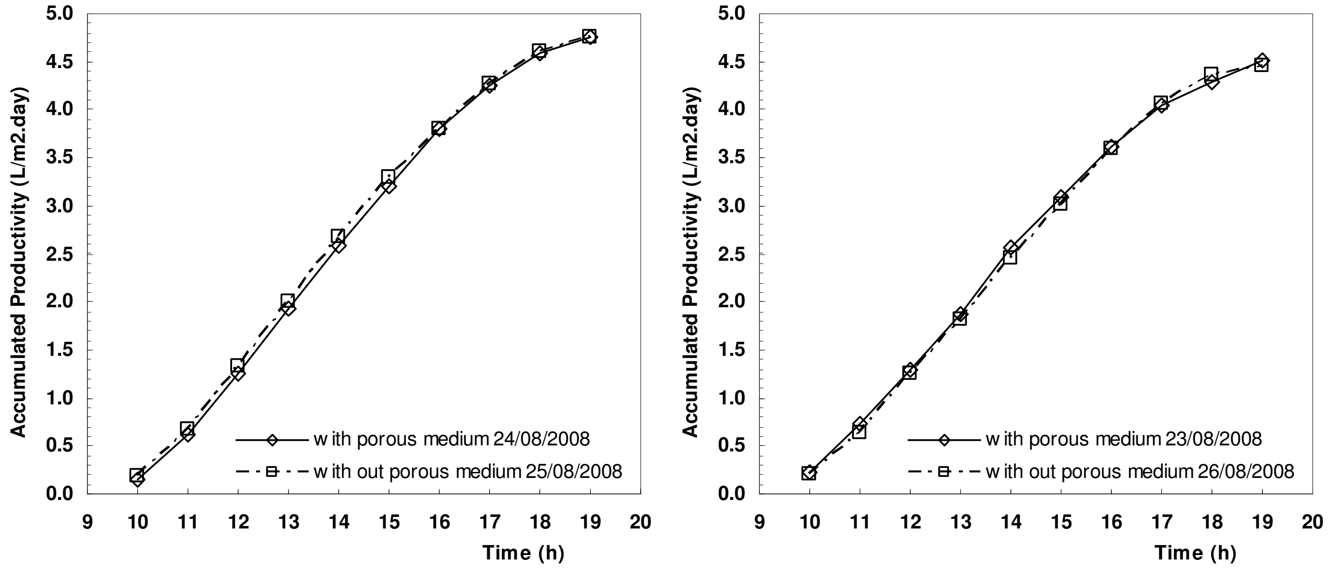

Figure 12-a **Figure 12-b**

Fig. 12: Variation of the accumulated productivity with time at 250 rpm and water flow rate=3.635 L/h and 4L/h respectively

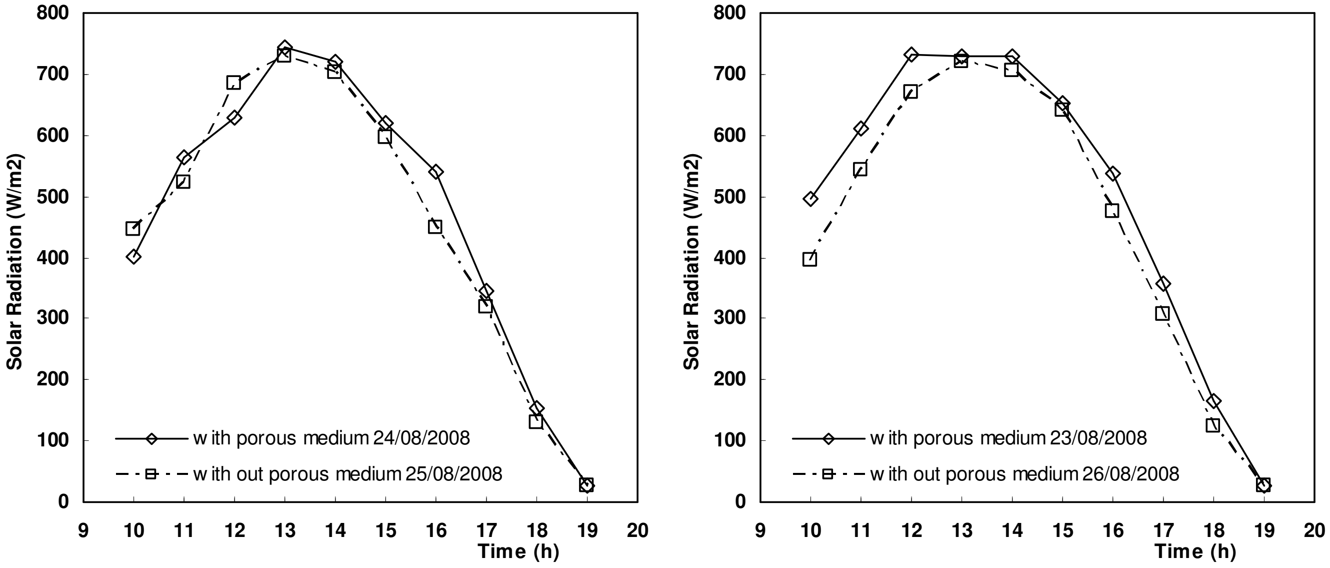

Figure 13-a **Figure 13-b**

Fig. 13: Variation of the solar radiation with time at 250 rpm and water flow rate=3.635 L/h and 4L/h respectively

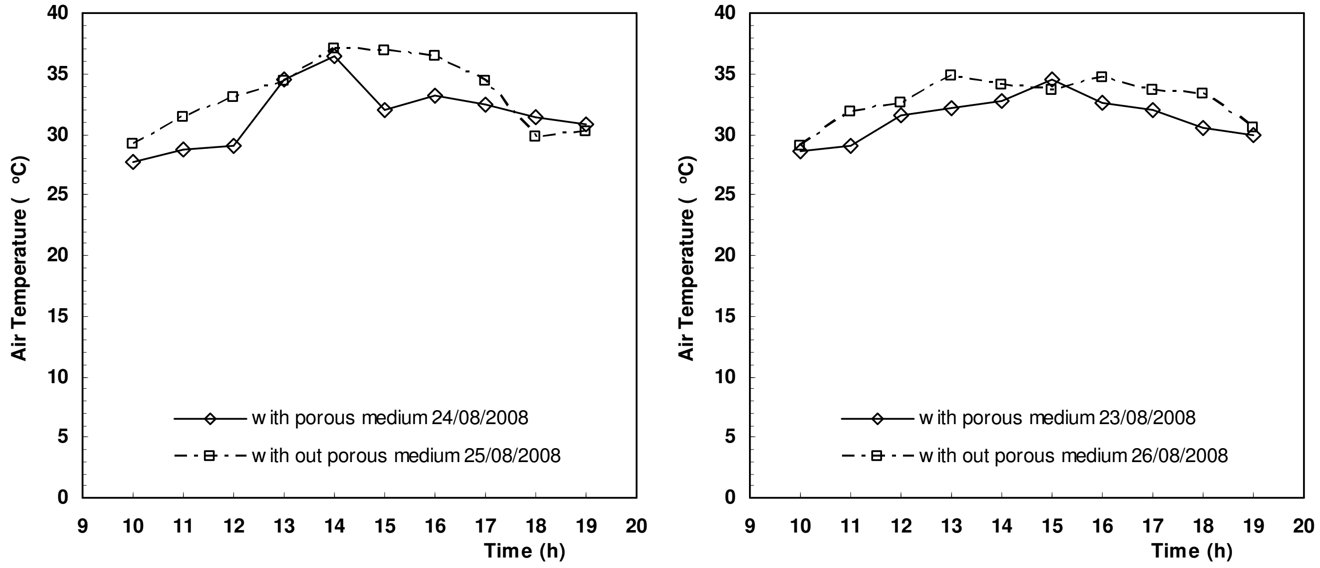

Figure 14-a **Figure 14-b**

Fig. 14: Variation of the air temperature with time at 250 rpm and water flow rate=3.635 L/h and 4L/h respectively

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