EXPERIMENTAL STUDY FOR PRODUCTIVITY ENHANCEMENT OF A PARABOLIC SOLAR CONCENTRATOR SYSTEM

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ABSTRACT

In this research a parabolic solar concentrator system has been experimentally studied. The experimental devise consists of a communication satellite dish with 1.5 m diameter and 0.17 m depth. Its interior surface is covered with aluminum reflecting layer and equipped with a disc receiver, (with diameter of 0.22 m and depth of 0.07 m) in its focal position. The orientation of the dish is assured by the tracking system for the satellite, as a tracking system for the sun, with some limitations. Performance of the solar evaporating system is tested under the local conditions of Najaf city during the interval from 10/3 to 25/4/2010. The data are collected on ambient temperature, temperature of inflow water, water and vapor temperatures inside the receiver. The obtained results showed that the amount of distillate was much dependent on the incident solar radiation intensity and the accurate focusing of the system. The system productivity can range from 6.9 to 15.3 L/day of fresh water, when the air was used to condensate the vapor receiver output (air – cooling), and this productivity increased by 28 – 33.5% when the inflow water used to condensate the vapor receiver output (water – cooling).

KEYWORDS: Solar concentrator, Fresh water, Productivity enhancement, solar evaporating system

دراسه عمليه لتعزيز إنتاجيه منظومه مركز شمسي دو قطع مكافئ

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الخلاصه

في هذا البحث تم إجراء دراسة عملية لمنظومة مركز شمسي ذو قطع مكافئ. المنظومة العملية تتالف من صحن يستخدم في الاتصالات التلفازية الفضائية بقطر ١,٥ متر وعمق ٠,١٧ متر. تم اكساء السطح الداخلي للصحن بطبقة عاكسة للإشعاع من الالمنيوم وزود بمستقبل للإشعاع على شكل قرص (قطره ٠,٢٢ متر وعمقه ٠,٠٧ متر) وضع عند البؤره. يتم توجيه الصحن عن طريق نظام تتبع الاقمار (كنظام تتبع للشمس) مع بعض التحديدات. تم اختبار اداء منظومة المبخر الشمسي تحت الظروف المحلية لمدينة النجف خلال الفترة من ٣/١٠ ولغاية ٢٠١٠/٤/٢٥. تم جمع المعلومات لكل من درجة حرارة الجو، درجة حرارة الماء الداخل للمستقبل، درجات حرارة الماء والبخار داخل المستقبل للإشعاع الشمسي. النتائج المستحصلة اوضحت بان

كمية الماء المقطر تعتمد كثيرا على شدة الإشعاع الشمسي الساقط ودقة مكان بؤرة المنظومة. إنتاجية المنظومة تتراوح من ٦,٩ إلى ١٥,٣ لتر/يوم من الماء النقي عندما يستخدم الهواء لتكثيف البخار الخارج من المستقبل (تبريد بالهواء)، وتزداد هذه الإنتاجية بقيمة ٢٨-٣٣,٥% عندما يستخدم الماء الداخل إلى المستقبل لتكثيف البخار الخارج منه (تبريد بالماء).

NOMENCLATURE

Symbol	Definition	Units
A,B	Constant parameters depend on the month	
d	Opening diameter of a paraboloid	m
f	Focal length	m
h	Depth of the parabolic solar concentrator	m
I_D	Incident solar radiation on inclined surface	w/m^2
I_{DN}	Direct normal solar radiation	
S	Surface area of a paraboloid	m^2
S_o	Opening surface area of a paraboloid	m^2
SR	solar radiation	MJ/m^2.day
Tair	Ambient (air) temperature	^{o}C
Tvd	Vapor temperature inside the receiver	^{o}C
Twd	Water temperature inside the receiver	^{o}C
Twin	Inflow (receiver input) water temperature	^{o}C

Greek symbol	Definition	Units
β	Altitude angle of the sun	deg.
θ	Incident angle of the solar radiation	deg.
$\sum$	Tilt surface angle	deg.

1. INTRODUCTION

One of the possible solutions for availability of potable water, which become a burning problem in rural areas, could be desalination of saline water. Desalination of saline water has been practiced regularly for over 55 years and is well established means of water supply in many countries. However, the purpose of using desalination process is to produce fresh water at reasonable cost. Most of the desalination processes are based on expensive fuels like electricity, coal, gas, etc. Thus, to provide fresh water at reasonable cost, it is urgent to convert fuel operated technology to solar operated technology (**Ahmad et al., 2005 and Qiblawey and Banat, 2008.**).

The sun is an outstanding energy source for mankind. It is clean and comes to the earth for free. There is no need to drill and refine it or mine it out of the ground. The devices needed to gather its energy are simple, quiet and non-polluting (**Li et al., 2002**).

Two forms of solar energy are distinguished, direct radiation and diffused radiation. Solar high temperature designs require concentration systems, such as parabolic reflectors. In general solar concentrating systems comprise a reflective surface in the shape of paraboloid of revolution intended to concentrate solar energy on an absorbing surface, which makes it possible to reach a high temperature (**Kalogirou, 2004 and El Ouederni1 et al., 2008**).

This process gives the possibility to use solar energy in many high temperature applications. But the manufacture of the most of these systems is very expensive due to materials quality, dimensions and precision. So that, many authors worked to reduce the cost of this kind of systems (**Palavras and Bakos, 2006 and Kalogirou et al., 1994**).

Some experimental studies have been carried out to investigate the performance, the productivity of the solar concentrator and the suitable sun tracking system, which will further improve the efficiency of the evaporator. **Singh et al., 1996**, have investigated the performance of a concentrator assisted still and a flat-plate collector assisted still. They conclude that the efficiency of the system utilizing the concentrator was higher than the collector assisted system. **Ahmad et al., 2005**, have done an experiment on a parabolic solar reflector alongwith a suitable heat-mechanism for desalination of saline groundwater. To enhance the output of the system, two flat collectors were put in series. The developed evaporating system was capable of producing 12-15 liter/day of potable water. **Zulqurnan, 2002**, have investigated the performance of a parabolic concentrator coupled with solar still. The parabolic concentrator was coupled with still in such a way that the solar radiations were made to focus at the base of the tray of the still. The maximum amount of distillate was 2.2 l on August 4, 2002 and minimum amount of distillate 0.37 l on August 16, 2002.

Khalifa and Al-Mutawalli, 1998, presented an experimental study for the effect of using two-axis sun tracking system on the thermal performance of compound parabolic concentrators (CPC). It was reported that tracking CPC collector showed a better performance with an increase in the collected energy of up to 75% compared with an identical fixed collector. A parallel experimental study presented by El Ouederni1 et al., 2008, for a parabolic solar concentrator devise, which consists of a dish of 2.2 m opening diameter. Its interior surface is covered with a reflecting layer and equipped with a disc receiver in its focal position. The orientation of the parabola is assured by two semi-automatic jacks. The obtained results describe correctly the awaited physical phenomena.

The review of the above research efforts emphasizes the need to increase the output of solar based distillation approaches. The low efficiency is still a major concern for solar operated evaporators (**Ahmad et al., 2005**). Therefore, study was carried to develop and test solar concentrator for desalination of water and to investigate the productivity of the solar concentrator with and without water – cooling, which also called the preheating method, for different focal lengths.

2. EXPERIMENTAL EQUIPMENT

The components of the proposed solar concentrator system **Fig. (1**) include: parabolic solar reflector, sun tracking mechanism, receiver (heat absorber), water supply system and preheating system. The details of these components are given as below:

2.1 Parabolic Solar Reflector

The reflector was used in this work consists of a parabolic concentrator of 1.5 m opening diameter and 0.17 m depth. Its interior surface is covered with a reflecting layer (aluminum foil with 0.5 mm thickness), which reflects solar rays on the face of a receiver placed at the focal position of the concentrator. A variable length holder was fixed at the centre of the reflector to hold the receiver (heat absorber) within the focal length of solar reflector.

The surface of a paraboloid of opening diameter (d) whose focal distance (f) is giving by (**El Ouederni1 et al., 2008**):

$$S = \frac{8\pi}{3} f^2 \left[\left\{ 1 + \left(\frac{d}{4f} \right)^2 \right\}^{\frac{2}{3}} \right] \tag{1}$$

The surface of opening of a paraboloid is:

$$S_o = \frac{\pi d^4}{4} \tag{2}$$

The focal distance is given by the following expression:

$$f = \frac{d^2}{16\,h} \tag{3}$$

Where,
h: is the depth of the parabolic solar concentrator.

Thus, the characteristics of the parabolic solar concentrator of this experimental device are given in **table (1)**.

2.2 Sun Tracking Mechanism

Electric motor with remote control commonly used for satellite tracking was purchased from the market and used to rotate the reflector for east-west rotation with one degree for each five minutes to ensure the reflected rays continuously in the focal zone. One end of the motor was attached to the base which joined to the backside of the reflector, while the other end was fixed to the main holder of the system. The motor was attached to an electronic tracking unit that constructed locally.

For north-south rotation the reflector moving manually every six days toward the sun declination, after specified it for that day, to insure the correct focal point.

The reflector focusing was a very laborious job. In order to avoid the laborious job of focusing the system repeatedly as well as to improve the efficiency of the evaporator, there was a need to develop a fully automatic tracking system, which is underway by using solar sensors (**Ahmad et al., 2005**).

2.3 Receiver (Heat Absorber)

The receiver is a stainless steel disc with a diameter of 0.22 m and depth of 0.07 m. It is located in the focal zone of the parabola. All sides of the receiver are insulated, to reduce the heat dissipated to the surrounding, except the side which placed to face the reflected rays is covered with a thin coat of black paint to decrease the reflexion of the solar rays.

For water inlet and steam outlet, two valves are welded on the top of the receiver to controlling the water amount from the water supply system with the evaporation rate inside the receiver. A stainless steel pipe (0.05 m length and 0.003 m diameter) welded at the base of the receiver and curved towards the top. This pipe extended by Pyrex pipe (0.20 m length and 0.003 m diameter) as a sight glass for the water level inside the receiver and addition to this, it is used to remove the concentrated salts, which accumulated at the bottom of receiver during the evaporation process of raw water. The accumulated salts are usually removed at the end of day.

2.4 Water Supply System

During the operation of the solar system the receiver (heat absorber) reaches the maximum level at 1.98 m from the ground. In order to supply water to heat absorber, an overhead water tank was placed on a 2.5 m high stand. The water flow rate to the heat absorber was controlled by gate valve welded to the top of it. Thus, pressure head and water flowing from the overhead water tank to heat absorber was controlled. The water flow rate to the heat absorber was also maintained according to the rate of evaporation inside it.

2.5 Preheating System

An aluminum pipe of 0.01 m diameter and 0.78 m length was covered with a water jacket, a galvanized iron pipe of 0.025 m diameter and 0.7 m length. The jacket was designed to receive water inflow from the water tank and deliver to the heat absorber. In this way, water jacket served two purposes: condensing the vapor from the absorber as well as to harvest vapor heat to further warm the water flowing to the heat absorber.

Thermocouples were distributed along the solar system, calibrated with standard thermometer between 0 ^{o}C and 110 ^{o}C, to measure the ambient air temperatures, the temperatures of water and vapor inside the receiver, the inflow water temperatures.

All experiments are achieved during the months of March and April of 2010 in Najaf, Iraq (latitude angle 32.2^{o}N), and the solar radiation estimated during this interval of time depending on the equations which giving by (**Garg and Prakash, 2007**):

$$I_D = I_{DN} \cos(\theta) \tag{4}$$

Where:

$$I_{DN} = A \exp\left(\frac{-B}{\sin(\beta)}\right) \tag{5}$$

$$\theta = \cos^{-1}\left(\sin(\beta)\cos(\Sigma) + \cos(\beta)\sin(\Sigma)\right) \tag{6}$$

(β) and (Σ) are shown in **Fig. (2)**

Two manners are used to achieved experiments; one with using the ambient air to condensate the vapor deliver the heat absorber (air – cooling) to produce the fresh water and the other with using the preheating unit (water – cooling) to condensate this vapor for increasing the fresh water productivity. For each test the position of the receiver was varied, depending on the dish diameter (d), to reaches the best focal point. Thus, four values for the focal length were selected (0.5d, 0.55d, 0.6d and 0.65d).

The distilled water is accumulated in plastic container and measured by scaled flask every hour. Daily accumulated of fresh water ranging from 6.9 to 15.3 l/day.

The raw water in the overhead tank, with salinity of 1790 ppm, is poured into the heat absorber through the gate valve to fill it with knowing level. The reflected rays from the reflector surface on the face of the heat absorber will heats the water inside it to evaporate and escape from the other gate valves to passes either through aluminum pipe with 0.158 m length and 0.006 m diameter to condensate depending on the ambient air temperature or through the preheating unit to condensate depending on the inflow water temperature. Eventually, the condensate was accumulated in the plastic container to measured hourly by the scaled flask.

3. RESULTS AND DISCUSSION

The temperature of the ambient (Tair), inflow water (Twin), water and vapor inside the receiver (Twd and Tvd respectively) and the solar radiation (SR) versus time for different focal lengths (0.5d, 0.55d, 0.6d and 0.65d), for the two manners of condensation, are shown in **Figs. (3-10)**. It can be seen from these figures that the same trends of the temperature behavior for all focal lengths, where the temperature rises during the measuring time up the maximum value at 14:00 hr and then trend to decrease. It is noticed that the solar system operates at high temperature when the heat absorber fixed at a focal length equal to 0.55d, because the most reflected rays from the reflector surface was focused on the heat absorber (receiver) face.

Figs. (11-14) show the dependence of the production rate (distillated) on the focal length and the manner of product vapor condensation, addition to the main two factors: the ambient temperature and the solar radiation. Generally, it is found that the production rate increase with increasing the solar intensity to reaches the maximum value at 14:00 hr, after that the decrease in temperature gradually reduce the production rate. The greater amount of the distilled water is obtained when the focal length was 0.55d and the preheating unit was used as vapor condensation manner (water – cooling).

4. CONCLUSIONS

The findings in the present study indicated that:

1. The parabolic solar concentrator can be used successfully for desalination of water to provide potable water for domestic usage.
2. The parabolic solar concentrator operates with temperatures higher than that of the different types of the solar stills.
3. The best focal length of the parabolic solar concentrator is equal to 0.55 of the dish diameter (d).
4. The amount of the potable water was much dependent on the accurate focusing of the system and increased by 28 – 33.5% when the preheating method was used.

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Table 1: Characteristics of the solar concentrator

Diameter of opening of the parabola	1.5 m
Total surface of the parabola	1.86 m^2
Surface collecting of the parabola	1.76 m^2
Depth of the parabola	0.17 m
Focal length	0.827 m

Fig. (1): Experimental device

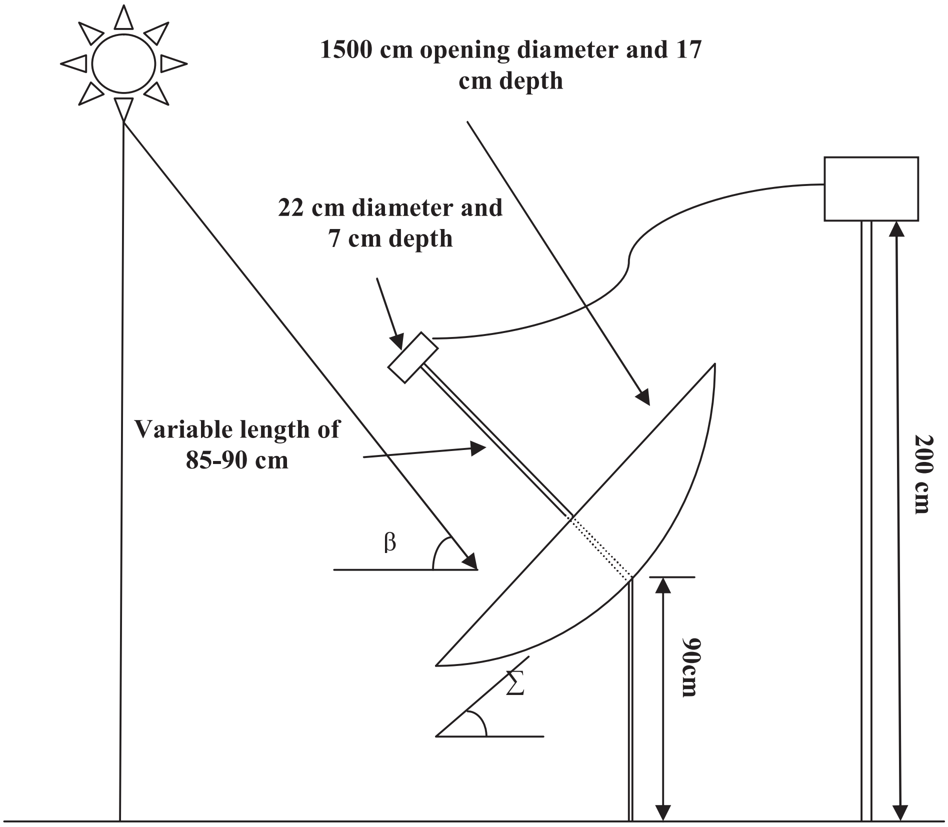

Fig. (2): Planning of experimental main parts device

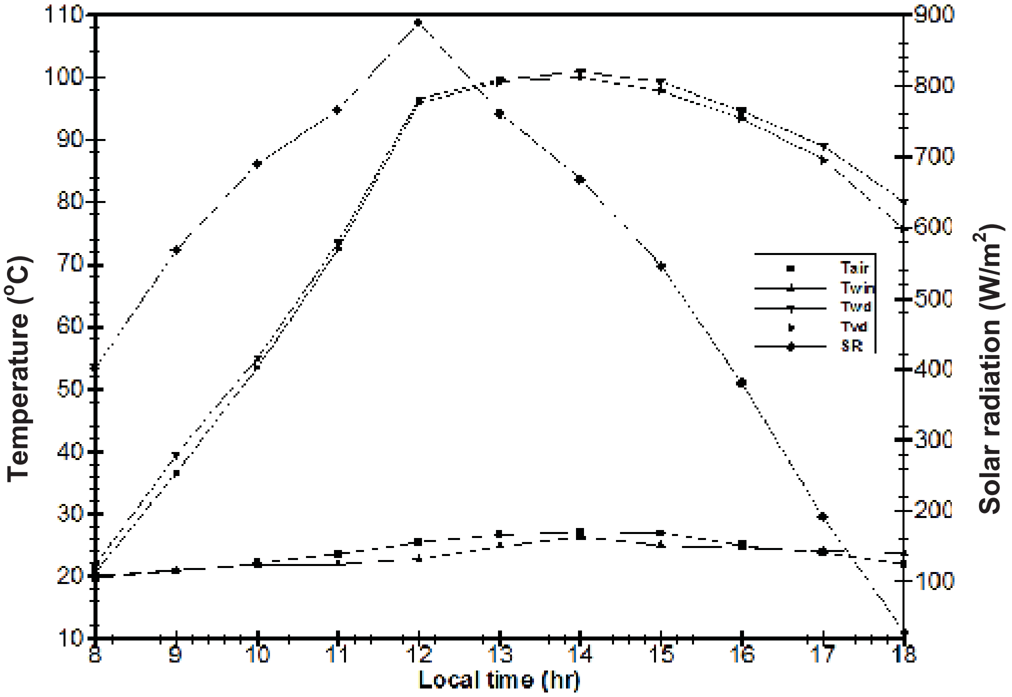

Fig. (3): Hourly variation of temperatures for the solar system with air cooling and focal length of 0.5d.

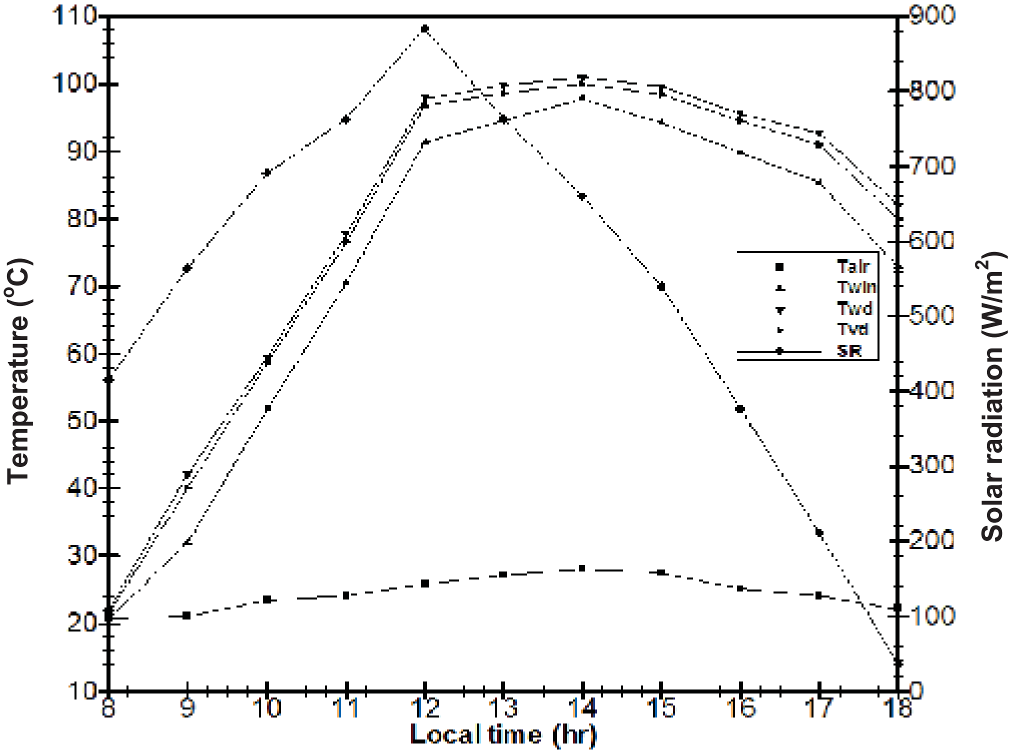

Fig. (4): Hourly variation of temperatures for the solar system with water cooling and focal length of 0.5d.

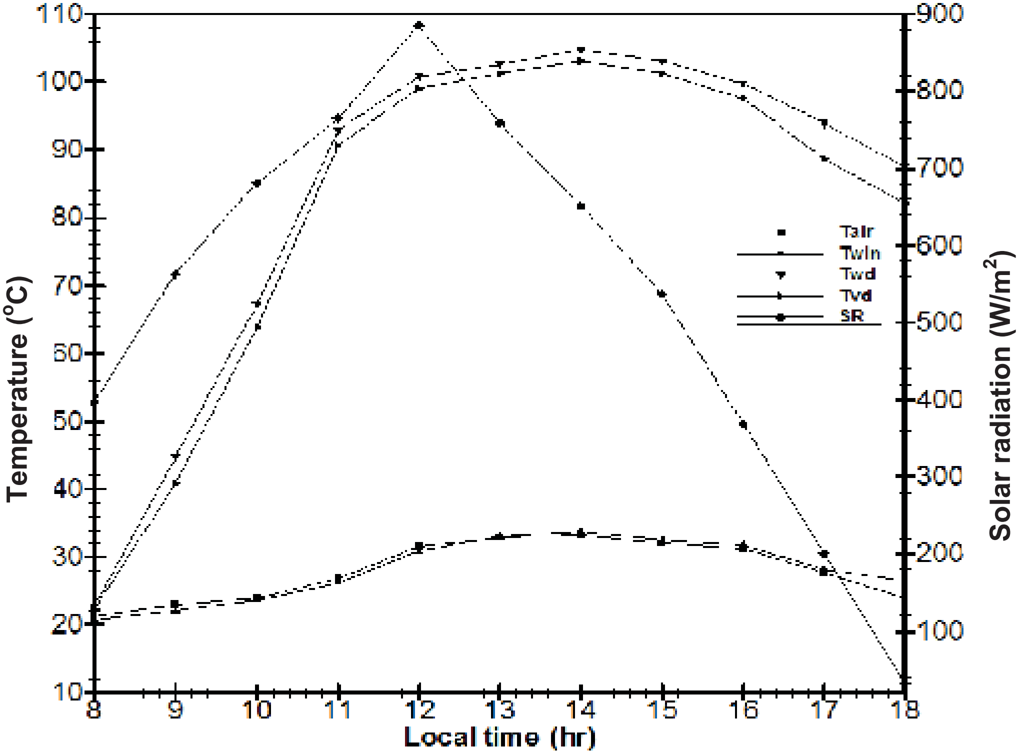

Fig. (5): Hourly variation of temperatures for the solar system with air cooling and focal length of 0.55d.

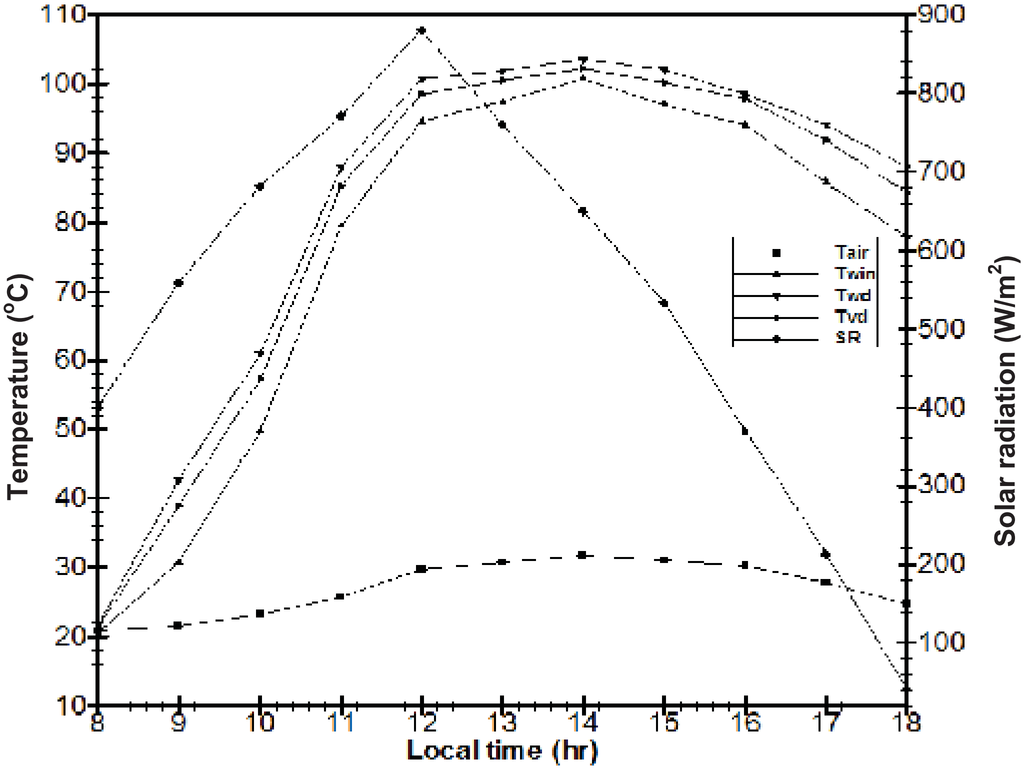

Fig. (6): Hourly variation of temperatures for the solar system with water cooling and focal length of 0.55d.

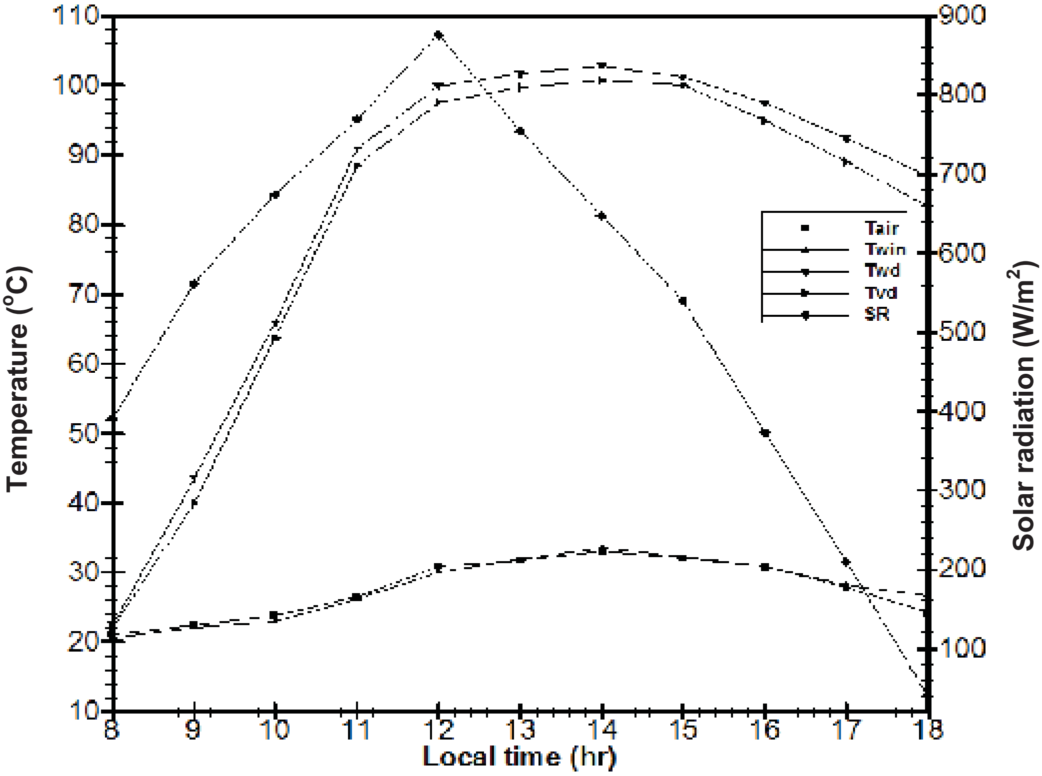

Fig. (7): Hourly variation of temperatures for the solar system with air cooling and focal length of 0.6d.

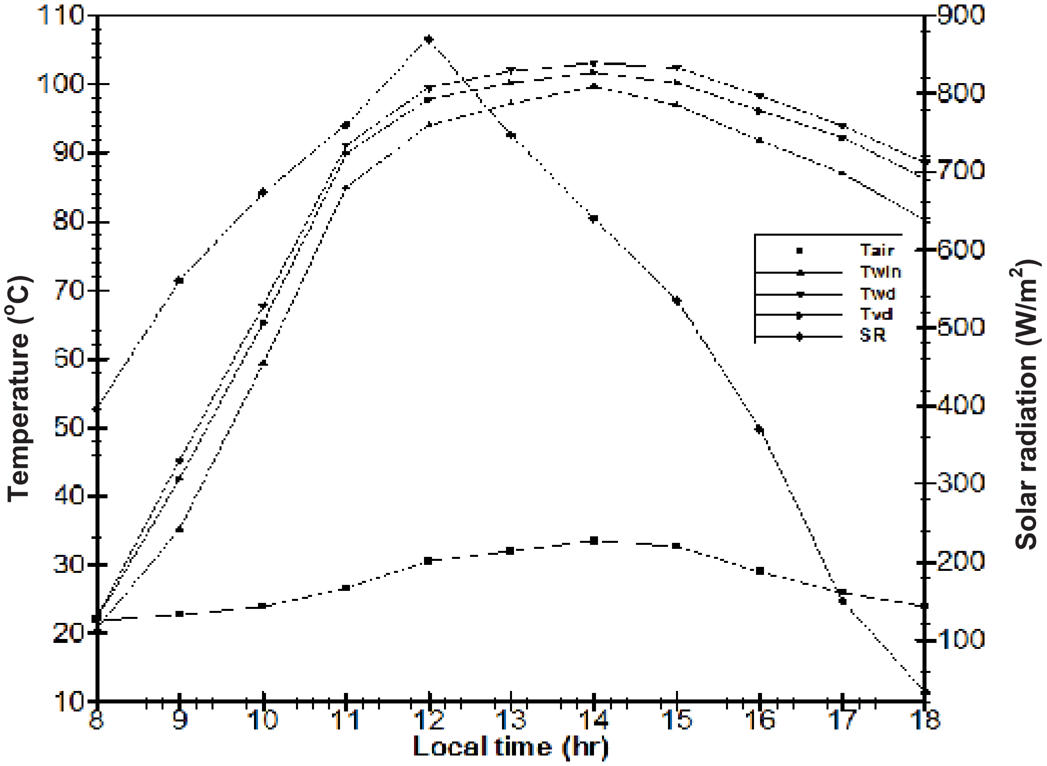

Fig. (8): Hourly variation of temperatures for the solar system with water cooling and focal length of 0.6d.

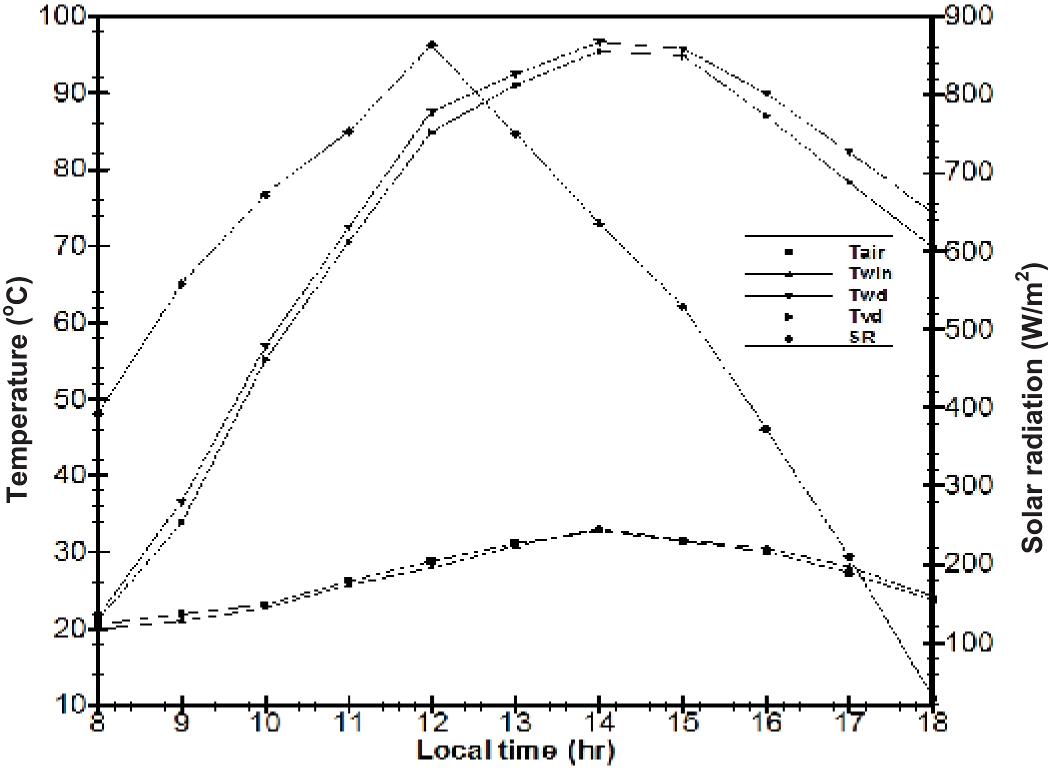

Fig. (9): Hourly variation of temperatures for the solar system with air cooling and focal length of 0.65d.

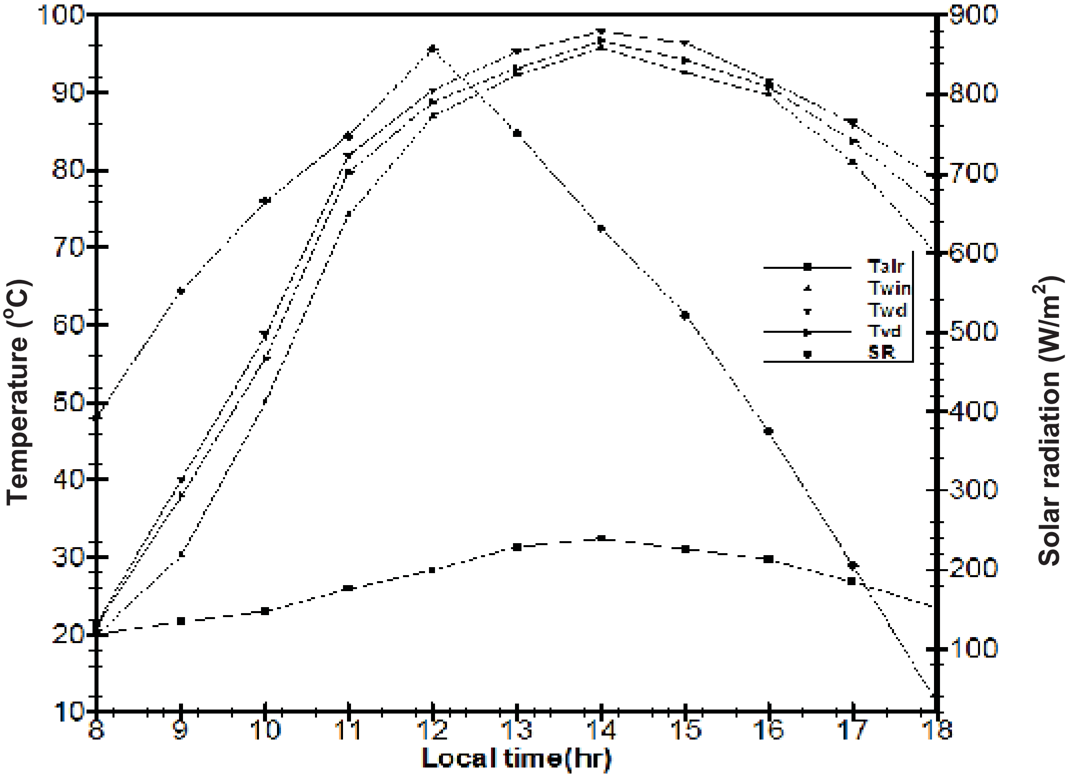

Fig. (10): Hourly variation of temperatures for the solar system with water cooling and focal length of 0.65d.

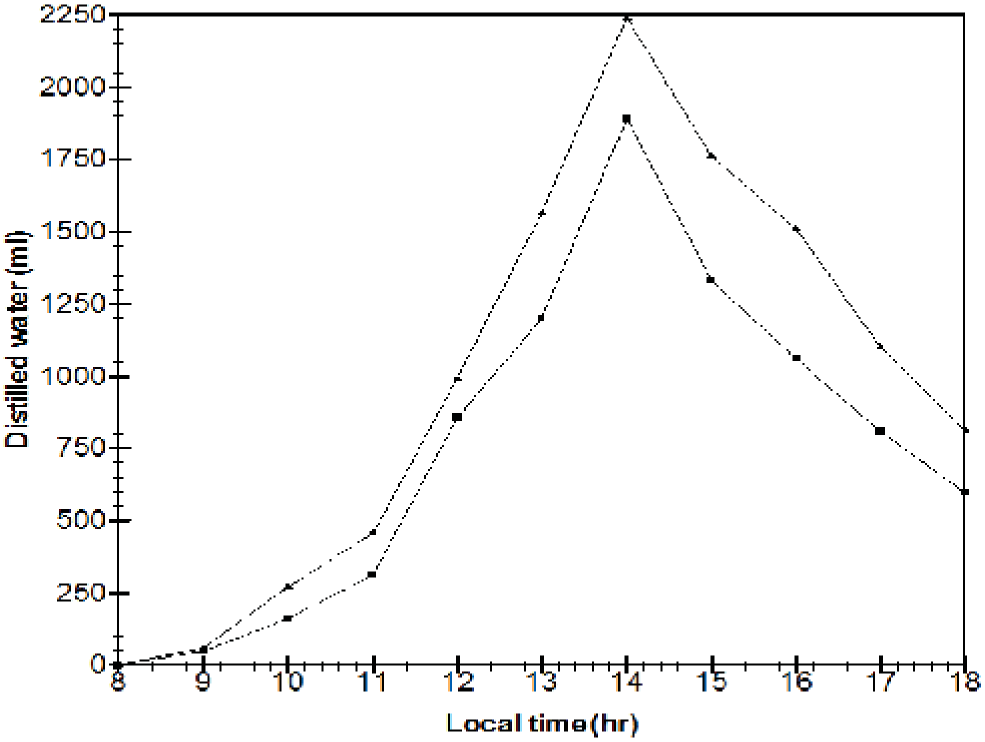

Fig. (11): Hourly variation of the solar system productivity for focal length of 0.5d.

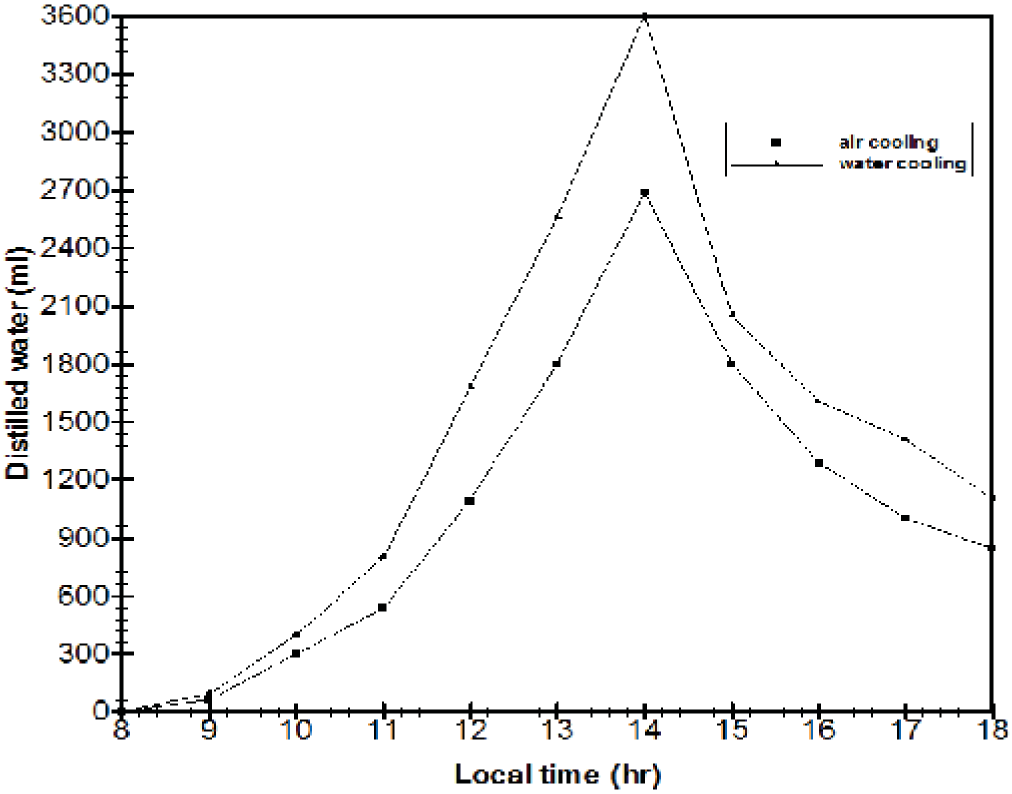

Fig. (12): Hourly variation of the solar system productivity for focal length of 0.55d.

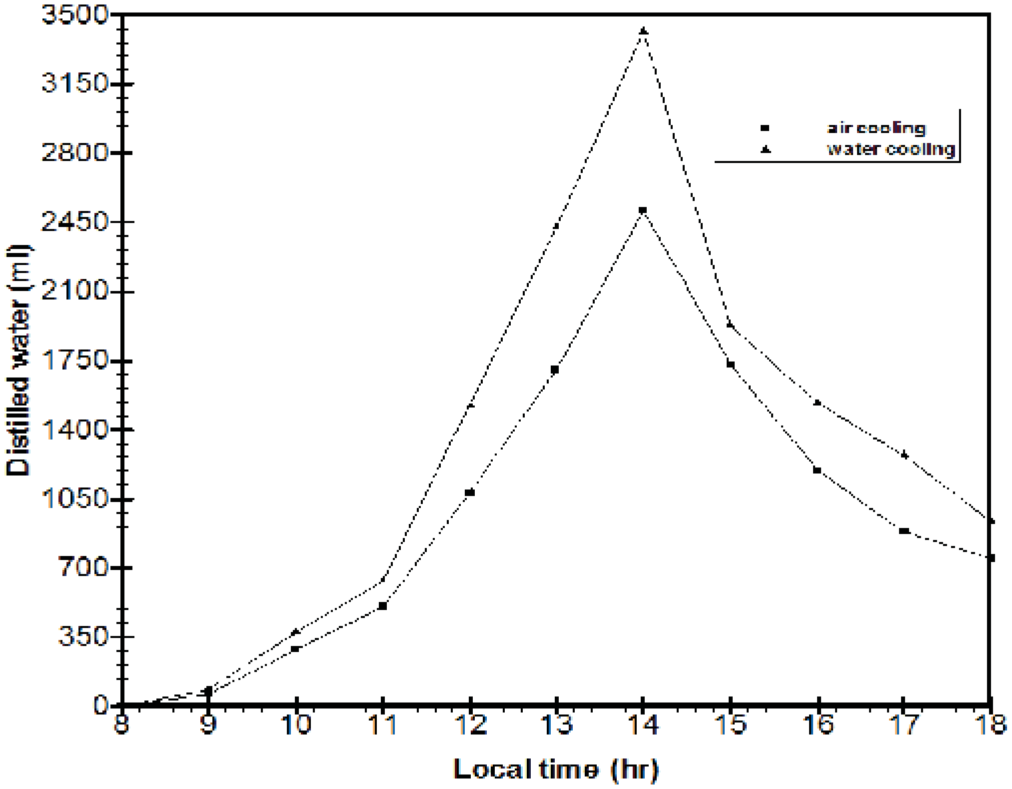

Fig. (13): Hourly variation of the solar system productivity for focal length of 0.6d.

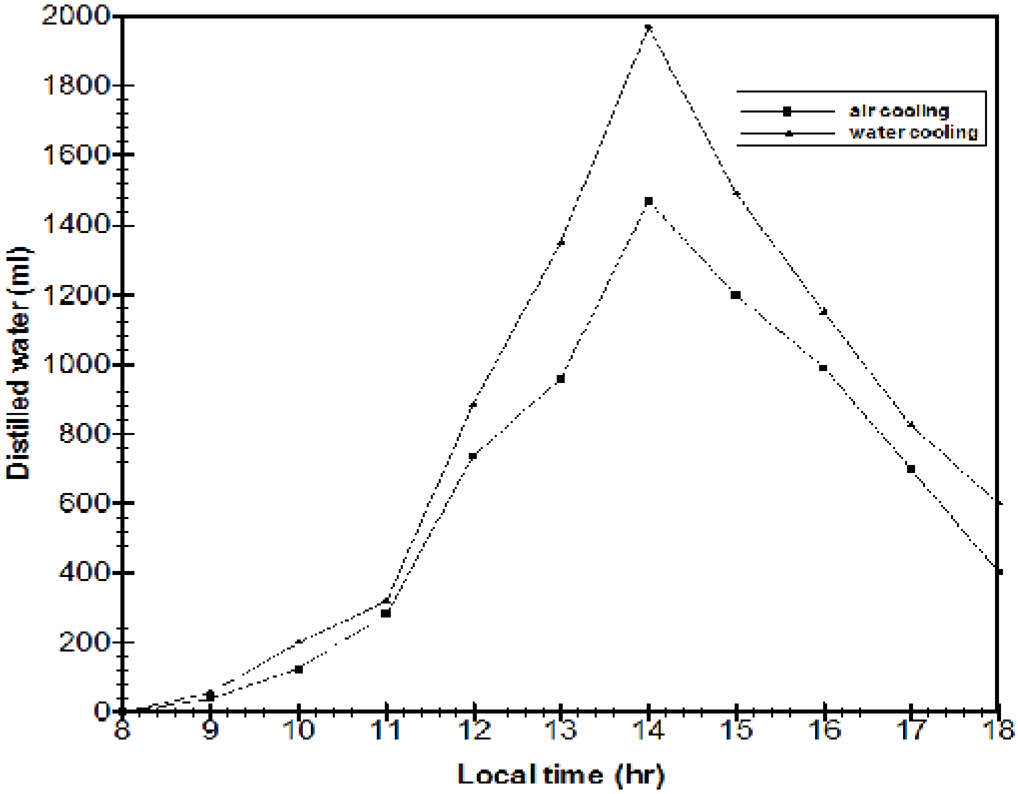

Fig. (14): Hourly variation of the solar system productivity for focal length of 0.65d.