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The Effect of Coupling Flat Plate Collectors With Basin-Solar Stills

S. A. Srbet[1], T. M. Jaballa[2], and E. I. Dekam[2]

[1] *Libyan Center for Remote Sensing and Space Sciences, National Authority for Scientific Research, Libya*
e-mail: ssrabet@yahoo.com
[2] *Faculty of Engineering, University of Tripoli, Tripoli-Libya*
e-mails: jaballatuhami@yahoo.com, eidakkam@hotmail.com

الملخص: تم في هذه الدراسة تصميم وتصنيع وتقييم مقطرتين متماثلتين شمسيتين أحاديتي التأثير ذات الحوض الواحد. تم تشغيل إحداهما منفردة بينما ربطت الأخرى بلوح مجمع شمسي مستو. تم تركيب الاثنتين في نفس الموقع بمدينة طرابلس- ليبيا عند الزاوية '51 48 °32 طولاً و '17 26 °13 عرضاً. وجهت المقطرتان باتجاه الجنوب بزاوية ميل °23. أخذت القياسات للعوامل المتعددة في شهر أغسطس لسنة 2009 عند كل ساعة لعدة أيام تحت ظروف مختلفة ونمطين تشغيليين بثلاثة أنماط تشغيلية. أجريت الاختبارات بماء البحر بملوحة 35,000 جزء لكل مليون وبعمق ثابت مقداره 60 مم. كان إنتاج الماء العذب للمقطرة المزدوجة 6.6 لتر/يوم وهو أعلى من إنتاج المقطرة المنفردة بـــ 55.84%. حسبت الكفاءة القصوى اليومية فكانت 14.48% للمقطرة المنفردة بينما هي 24.18% للمقطرة المزدوجة. وجد أن السلوك الحراري للمقطرة دالة معقدة في الشكل الهندسي وفي بنائها وفي الظروف التشغيلية وفي خصائص الموقع وفي تفاصيل وضعها.

Abstract: Two identical single - effect of single basin solar stills were designed, fabricated, tested, and evaluated. One was operated alone while the other was coupled to a flat plate solar collector. Both were installed at the same site in Tripoli, Libya, at 32° 48' 51' N and 13° 26' 17' E. They were south oriented with a tilt angle of 23°. Measurements of various parameters were taken in August 2009 at each hour for several days under different operating conditions. Two operational modes were considered. The tests were conducted using seawater of 35,000 ppm. The depth of water in the basin was kept fixed at 60 mm. Fresh water production of the coupled still was measured to be 6.6 L/day which is higher than that of the single still by 55.84%. The maximum daily efficiency was calculated to be 14.48% for the single still while it was only 24.18% for the coupled still. The still thermal performance was found to have a complex function of geometry, construction, operational conditions, site characteristics and layout details.

Keywords: Single effect solar stills, Solar desalination, Performance of single basin solar stills.

1. INTRODUCTION

Fresh water resources are almost completely exhausted in many Middle-East countries [1]. Renewable energies are expected to have a flourishing future and an important role in the domain of brackish and seawater desalination in developing countries. Small production systems as solar stills can be used if fresh water demand is low and the land is available at low cost. High fresh water demands make industrial capacity systems necessary. These systems consist of a conventional seawater distillation plant coupled to a thermal solar system. This technology is known as indirect solar desalination. Many small size systems of direct solar desalination and several pilot plants of indirect solar desalination have been designed and implemented. Nevertheless, in 2002 solar desalination was only 0.02 % of the global desalination capacity as represented by renewable energy systems [2].

In Libya, where the water demand is thought to increase, many research papers were completed in the RSCSE, and devoted to the solar energy, such as passive heating and cooling strategies for Libya[3], and maintenance strategy for salt gradient solar pond coupled with an evaporation pond[4].

The solar still which is fabricated and experimented for this work is relatively simple in construction with low maintenance cost, and it can be operated by any laborer amongst the inhabitants. The utilization of solar still systems is becoming very active in the Arab world where the solar radiation intensity is very high. In this work, the effect of combing a flat plate collector with a single-effect of single basin solar still was investigated. The results of this augmentation on the behavior of the still under the local Libyan climatic conditions are presented.

2. SOLAR STILLS: An Overview

An excellent review on the use of renewable energy in various types of desalination systems and a survey of the various types of solar thermal systems and applications were presented by Hazim Qiblawey, Fawzi Banat [5]. Many experimental and theoretical works have been conducted on single basin solar stills for testing the performance of different enhancement parameters. Different absorbing materials were used by K.Kalidasa Murugavea, Kn.K.S.K. [6] to study their effect in a solar still, and thus enhance the productivity of water, using a single-basin solar still with double slopes.

Bilal A. Akash [7] examined the effect of using a solar still with various cover tilt angles of 15, 25, 35, 45 and 55, and the optimum tilt angle for water production was found to be 35. Also the authors studied the effect of the salinity of water on solar distillation, and concluded that the distilled water production decreased with salinity. A. Safwat Nafey [8], investigated the main parameters affecting solar still performance using four different still design parameters operated under the same weather conditions.

A general equation is developed to predict the daily productivity of a single sloped solar still. Whereas, Bilal A. Akash, Mousa S. Mohsen [9], studied experimentally the use of black rubber or black gravel materials within a single sloped solar still as a storage medium to improve the still productivity. O.O. Badran, Mazen M. Abu- Khader [10], studied experimentally the effect of coupling a flat plate solar collector on the productivity of single sloped basin solar still.

It was found that coupling of a solar collector with a still has increased the productivity by 36%. A flat plate collector was integrated with a single basin solar still by Ali A. Badran, Al-Hallaq [11]. They found that the maximum increase in productivity of potable water was 52%. Boukar and Harmim [12], studied the effect of desert climatic conditions on the performance of a double simple basin solar still and a similar one coupled to a flat plate solar collector. The performance of the simple still is compared with the coupled one. They found that the coupled still is more productive than the simple one.

Sanjeev Kumar and G.N. Tiwari [13], studied the annual performance of active solar still analytical expressions for water and glass cover temperatures and yield have been derived in terms of design and climatic parameters. Numerical computations have been carried out for Delhi climatic conditions where it has been observed that for given parameters, the annual yield is optimum when the collector inclination is 20° and the still glass cover inclination is 15°.

3. EXPERIMENTAL SETUP

Two similar units of a single sloped solar still were designed and constructed in especial workshop to maintain the comparison under the same design conditions. Each unit consists of two metallic boxes inner and outer having four sides. The four sides and the bottom are made of a 2 mm thick steel sheet. The overall size of the inner box is 170cm×60cm×10cm and that of the outer box is 180cm×75cm×20cm. The gap between the inner and outer basin was injected with foam as insulation material of k = 0.03 W/m.K in order to reduce the heat losses to the surrounding, The insulation thicknesses of the long sides and of the north side are 5cm, while the thicknesses of the bottom insulation and that of the frontal side are 10cm.

Three openings were made in the box; one is for the entrance of seawater, the second is for the condensed fresh water, and the third is for the discharge of brine water. The sides of each inner box were painted white from the inside in order to reflect the solar radiation to the water surface, while the absorbing surface, area = 1.02 m^2, of each basin was painted black to increase the surface absorptivity. A collection V-shaped channel is fixed to the forward side of the still box to collect the condensed water. The condensing surface in each still unit is the inside surface of the glass cover which is made of 4mm thick ordinary glass.

The glass cover of each still box was fixed to an aluminum frame on the edge of the east and west sides with an angle of 23°. Rubber gasket sealant was used to prevent leakage from any gap between the glass covers and the still box. A constant pressure head tank, 50cm×50cm×30cm was used to control the level of water inside the two stills by a float-type regulating valve. A feeding tank cylindrical-shape (100×50Ø) cm was used for compensation.

The solar still was oriented in order to face the south. In the design of the present solar stills the following facts were highly considered. A flat plate collector, shallow box, 184 cm long, and 90 cm width and 10 cm thicknesses, was employed. The collector is made of eight parallel copper tubes, 12mm inside diameter with 100-mm spacing and 170 cm length. The tubes were fixed to a 0.7 mm thickness copper plate, coated by ordinary black matte paint. Selective layer fixed on rock wool insulator of 50mm thick. The technical specifications of the solar stills and of the flat plate collector are summarized in Table 1.

Table 1: Technical specifications of solar stills and the flat plate collector.

Technical specifications of both solar stills		Technical specifications of the FPC	
Specification	Dimension	Specification	Dimension
Length, m	1.70	Number of riser tubes	8
Width, m	0.60	Length of riser tube, m	1.7
Base area, m^2	1.02	Number of head tubes	2
Cover tilt, °	23	FPC tilt, °	23
Glass cover area, m^2	1.176	Glass cover area, m^2	1.566
Glass depth, mm	4	Tube head diameter, mm	25
Transmissivity of glass	0.85	Thickness of insulation, mm	50

4. TEST APPARATUS

Five temperatures at various locations were measured by means of copper-constantan, Type-T, thermocouples.

Temperature read-outs were taken by a multichannel microprocessor.The locations are on the inside and outside surfaces of the glass cover, surface of the basin, inside air space temperature and seawater in the basin.

The data were then handled on a PC. Wind speed was measured by a digital anemometer installed in a horizontal position near the still cover. Solar radiation was measured by a silicon pyranometer, model 096, which was fixed in position that takes the same angle cover of 23° on the top of the frame of the solar still.

The outlet and inlet temperatures of sea water to and from the flat plate collector and the ambient temperature were measured by PT100 thermocouples.

For the collection of the data, a measurement system, data logger, was used. The sampling rate for measurements were set to 1 second, while average values were stored every 30 minutes, the data logger coupled with personal computer to storage and analyze all data. Table 2 shows the accuracies and ranges of the measuring apparatuses. The thermocouples were calibrated by two ways, the first calibration uses ice water mixture, and the second uses boiling water.

5. EXPERIMENTAL WORK

The experimental work is divided into two parts. The first part for the passive solar still, the experimental set up consists of a passive solar distillation unit with condensing cover inclination 23°, and fabricated to accommodate a maximum water depth of 10cm to conduct tests at various water depths. The second part of the experimental work which deals with active solar still is conducted with water heating solar flat plate collector.

The production of fresh water can be enhanced by increasing the temperature of the water in the basin by coupling the solar still to a flat plate collector employing the thermo-siphon phenomena.

In the active distillation process, hot water from the collector panel is fed into the basin of the solar still in order to achieve a faster rate of water evaporation. A schematic view of an active solar still is shown in Figure 1.

Table 2: Accuracies and ranges of measuring apparatus.

No.	Instrument	accuracy	range
1	Thermocouple (type-T)	±1℃	-200 to 350 ℃
2	Pyranometer Model 096	± 5%	0.3 to 3 wavelength(μm)
3	Anemometer	±0.1%	0 -15 m/s
4	Collecting vessel	5 ml	0-1500 ml
5	Thermocouple (PT100)	±1℃	-200 to 800℃

6. TESTING PROCEDURE

The experimental investigations were performed in the summer season of 2009, and were conducted in the experimental area of the Center for Solar Energy Research and Studies, in Tripoli, Libya at 32° 48' 51' N and 13° 26' 17' E. The behavior of the systems was investigated through two modes of operation:

(1) Still operating alone for a 24-h period (all during sunrise to sunset, day), and (2) still is connected to the flat plate collector under the Thermosiphon mode of operation, for a 24-h period (all day), and during sun rise to sunset. The testes were performed with sea water (35000 ppm) at the same temperature and under the same weather and operational conditions for both modes.

7. RESULTS AND DISCUSSION

The experimental results for the passive still were compared with the experimental results obtained from the active still. These results were determined under the variations of solar radiation intensity that received on the tilted surfaces of the solar stills and flat

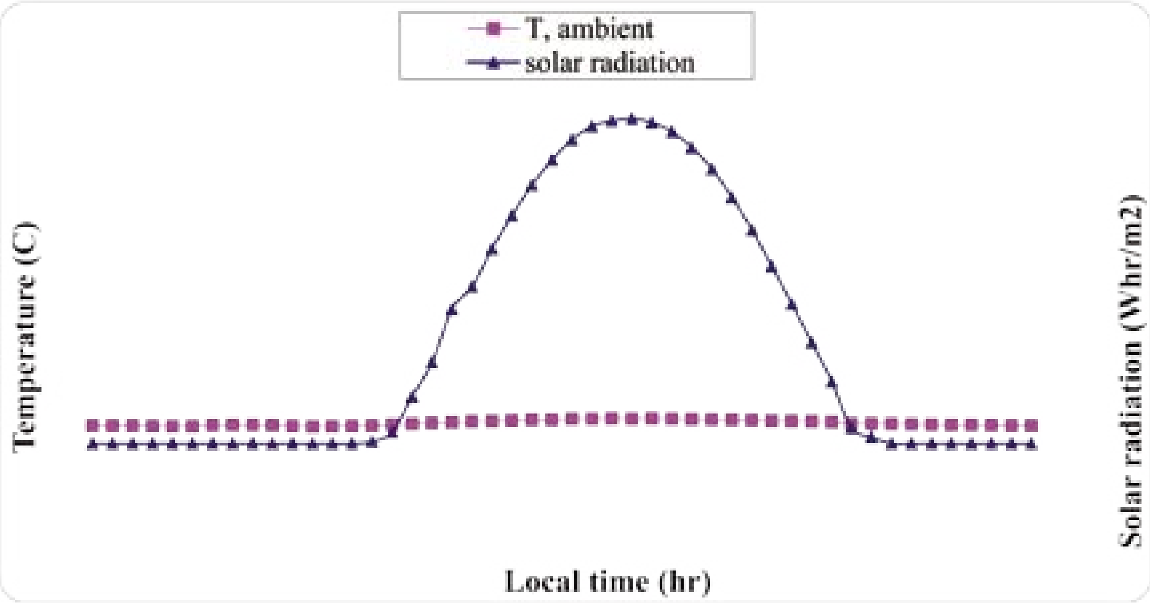

Figure 2: Solar radiation intensity and the ambient temperature.

Table 3: Total daily production of water distillate from both stills

Type of still	7 am to 19pm	19pm to 7am	all day (24 hr)
The Passive still	3115 ml	1120 ml	4235 ml
The Active still	5480 ml	1120 ml	6600 ml

plate collector. These are done based on the hourly behavior of both solar radiation and both stills.

The solar radiation values on tilted surfaces with an angle of 23° were calculated using the mid-hour solar radiation values. The solar radiation values were measured by pyranometer. On the 26th of August, the passive and active stills were tested under the same operating water depth of 6 cm and the same weather conditions.

Figure 2 shows the hourly variation of solar radiation intensity incidents on the tilted solar cover surface, and the variation of the ambient temperature. Here, the solar intensity increases along the morning hours and it continues to increase until it reaches the maximum at around the solar noon, and then it decreases in the late afternoon. The total daily solar energy was calculated to be 26.738 MJ/m^2 per day.

Figure 3 presents the hourly variation of the production of distillate water from the two units and the hourly variation of solar radiation. It can be seen that as the solar intensity increases, the productivity increases due to the increase in heat gain for water vaporization inside the stills. The productivity rate varies as time passes from morning until late afternoon. The production rate of the passive still starts very slowly at the hours 10:00-1:00 due to the low solar solar energy received during the morning period. The production rate of the active still starts with higher rate at this period compared to the passive still. A peak production rate is achieved at the hours 14:00-15:00 for the two units. The total daily production of the two units is reported in table 3. It can be seen from figure 3 that the productivity rate continues to increase until the first hours of the nigh. Both models seem to have the same production in the hours of the night. Comparing the daily production of the two tested units, it is clear that there is a considerable advantage of the active still, with a percentage enhancement of about 55.84% more than the passive still production.

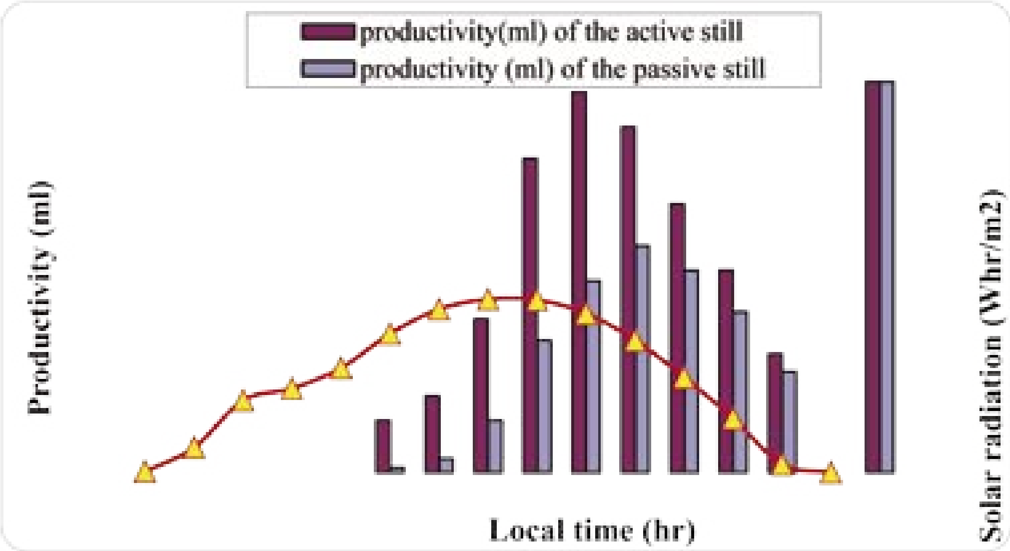

Figure 3: The productivity of distillate water of the two units with

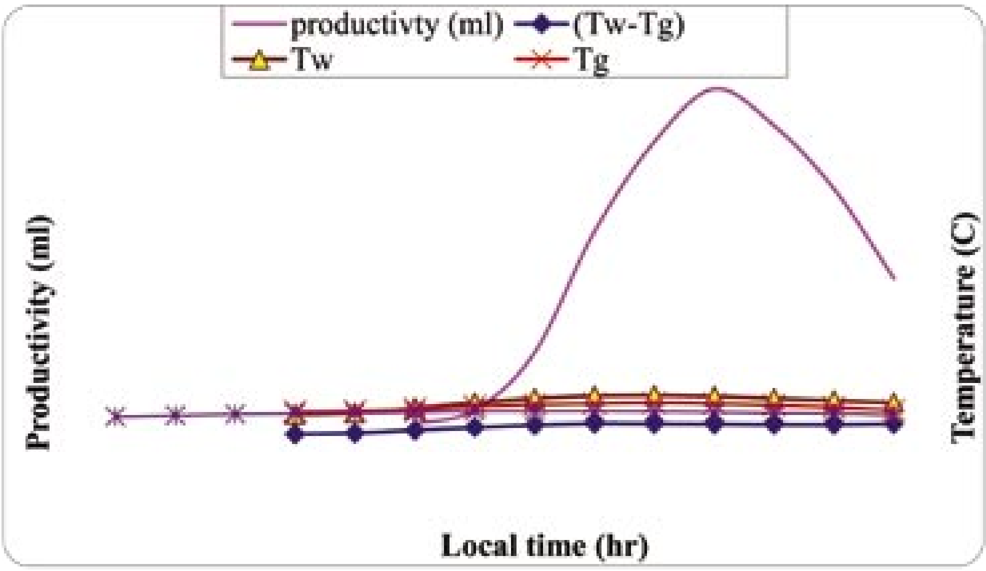

Figure 4: Basin water and glass temperatures and the temperature difference between the basin water and glass and production rate for the passive still.

This increase in productivity is related to the higher average temperature of the active still than that of the passive still. The higher average temperature of the active still is expected since it is coupled to a collector. The solar flat plate collector preheats the feed seawater and increases its temperature in basin still to nearly the saturated temperature of the brine fluid.

Figures 4 and 5 show the variation of the basin water temperature, mean glass temperature, the difference between the basin water and glass temperature, and production rate for the passive and active stills, respectively.

The passive and active stills reach the maximum production rate just after the basin water temperature attained the maximum point. The water production starts when the temperature difference between the basin water and glass is around 7°C for both stills as shown in Figures 4 and 8. The temperature difference reaches a maximum when the basin water temperatures are 67°C

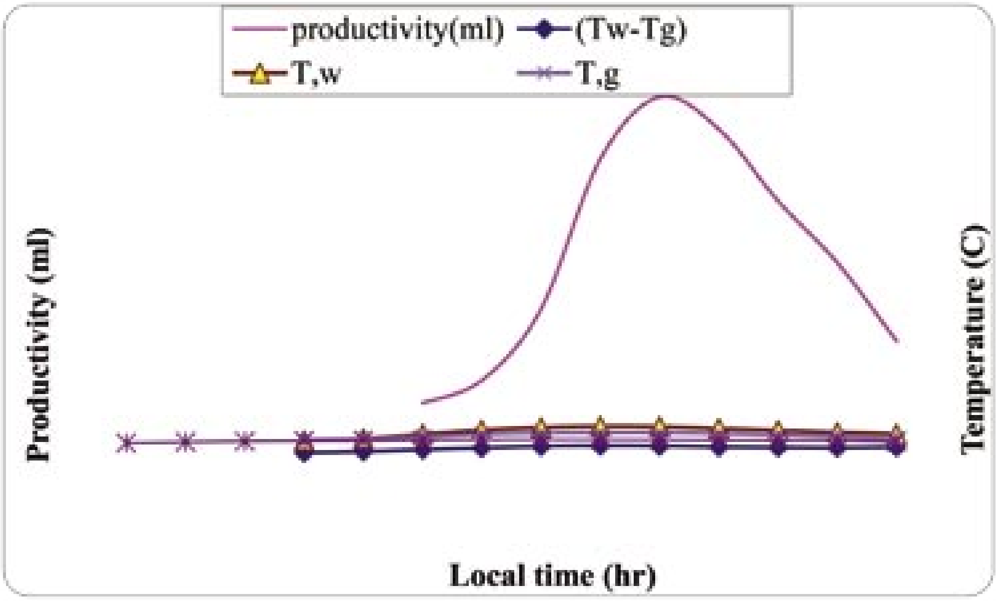

Figure 5: Basin water and glass temperatures and the temperature difference between the basin water and glass and production rate for the active still

and 78°C for the passive and active stills respectively and then it starts to decrease gradually for both stills. The fresh water production rate increases with the decrease of the temperature difference between the basin water and glass for certain period. It is clear from the two figures that maximum fresh water production lags maximum basin water temperature.

The basin water temperature increase leads to higher evaporation rate. High temperature difference between the basin water and the glass enhances the bulk motion of the air-vapor mixture inside the still, which in turn increases evaporation, and condensation rates.

As well known, the water production rate is also influenced by several other parameters depending on which period of time is considered. Hence the production rate is a complex function of the type of the basin water, the cover glass, the temperatures differences between basin water and glass, and between the glass and the ambient, in addition to the design parameters and the geometry and layout of the unit.

8. CONCLUSIONS

1. The maximum amount of distillate obtained from the passive and the active still was 4640 ml/m^2.day, 7110 ml/m^2.day, respectively. The total daily yield from solar energy falling on the cover of the solar stills and FPC when measured on 25/8/2009 was 27.181 MJ/m^2 per day.
2. When the active still system was operated for 24-h on 26/8/2009, its production was increased by 55.84% compared to the passive system.
3. The passive and active stills production rate is a function of the temperature differences between the basin water and glass for certain period of time. It also depends on the level of solar radiation, wind speed, the overall heat loss, and the properties of the inlet brackish water, beside the design parameters. Hence, the production rate is a complex function of many parameters that may require further studies and analysis.

9. RECOMMENDATIONS

1. The effect of the static pressure inside the still and glass cover inclination on the productivity for the passive and active still are expected to be pronounced, studying such effects could have valuable results.
2. The cost of the solar distillation unit is important. Durable but cheap materials

and simple designs of solar stills are preferred.

3. The performance of the solar still depends on the source of raw water. Closer source of raw water, or locating the system near sea shores reduce the overall cost of the system.
4. The performance of the solar still depends also on the solar radiation intensity, which is function of the location and orientation of the solar still. Choice of the location and movable orientation to face the sun at all times of the day one important.
5. Solar still coupled with an insulated storage tank in which water is heated by a solar flat plate collector is expected to increase productivity for a 24-h period, mainly at night, and eliminates the dependency on climatic conditions.

10. NOMENCLATURE

T_b	*Temperature of basin liner, °C*
T_w	*Temperature of water in still, °C*
T_v	*Temperature of inside moist air, °C*
T_a	*Temperature of ambient, °C*
T_g	*Temperature of glass cover, °C*
$T_{in,g}$	*Temperature of inner surface glass cover,*
$T_{ou,g}$	*Temperature of outer surface glass cover,*
$T_{inlet\ to\ FPC}$	*Inlet temperature of water to flat plate collector, °C*
$T_{outlet\ from\ FPC}$	*Outlet temperature of water from flat plate collector, °C*
A_g	*Glass cover area of solar still, m²*
A_c	*Glass cover area of flat plate collector, m²*
Vi	*Hourly productivity distillate water, ml*
Pd	*Daily productivity distillate water, kg*
Ii	*Hourly global solar radiation intensity fall on the plane of glass cover of solar still and flat plate collector, W.hr.m-2or MJ.m-2*
Id	*Daily global solar radiation intensity fall on the plane of glass cover of solar still and flat plate collector, (W/day.m-2)*
PC	*Personal computer*
ppm	*parts per million*
FPC	*Flat Plate Collector*
RSCSE	*Research and Studies Centre of solar energy*

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