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Mathematical simulation of the Vertical solar still (VSS) production with the external reflector

Ahmed J. Mohammed

Polymer Research Center, University of Basra, Basra - Iraq
E-mail: ahamd.jasim@yahoo.com

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Abstract

In this work, a vertical solar still was constructed in Basra city in Iraq. An experimental achievement was carried out on two solar stills under the same conditions. Also, each still has one evaporative side. The still contains a basin with the total area of (0.125 m^2). The still basin covers with a piece of black cotton cloth wet with brackish water. In addition, one of the still was provided with an external reflector, in order to reflect the direct sunlight to the absorber surface. The solar still was prepared from available local materials. We found in this experimental study that the efficiency without any improvement vertical solar still is (17.6 %) and increases to (38.2 %) by using vertical solar still with external reflector of the day 17 July 2012.

Introduction

Water is the source of life; it is the basic element for the development and growth. Since ancient times, mankind's were looking for the water source and living beside it. All lived and flourished ancient civilizations were found where the water is found. The world is facing an increasingly current shortage in the quantities of fresh water needed to meet essential needs in the various aspects of civilized life, this is due to the limited sources of fresh water and the successive demands for it. Now day, all the world are looking for new sources of fresh water such as that extracted from sea water and brackish water, fulfilling the mankind demand of fresh water ***[1].*** The presence of fresh water gives the life on the earth the opportunity to continue since about 10,000 to 20,000 people die every day due to diseases that transmitted contaminated water ***[2].*** Earth's water divided to, fresh water is 3% and brackish water is 97% for us to use, only lakes and rivers are accessible***[3-8].*** Suffering a lot of areas in the world a sharp shortage of the fresh water, and plentiful brackish water, and desalination of salt water by using solar energy is the best solution [9]. The rate of solar energy per unit area which falling on a subject surface perpendicular to the path of the solar radiation outside the earth atmosphere casing is called the solar constant and equals to(1370 W/m^2) ***[10-11].*** Vertical solar stills may be conveniently used in places where land area is expensive or sufficient horizontal space is not available for installation of basin type solar stills. Very few papers have appeared concerning the vertical solar stills. In 1965 ***[12],*** the state of Florida has decided to build four vertical solar stills. In 1975, Coffee suggested ***[13],*** studied experimentally deferent concepts of vertical solar stills, such as ground suction and floating still. In 1980, he studied Wibulswas and his group ***[14],*** cylindrical solar still having a vertical absorbing, evaporating surface of 0.1 m diameter and 1 m height inside a cylindrical cover of 0.3 m diameter. The annual average daily rate of distillation was about 1.7 $1/m^2$ of the vertical surface. In 1983, researchers studied the Ramli and Wibulswas ***[15],*** constructed a two sided vertical solar still. The annual average daily rate of distillation was about two $1/m^2$ of the vertical surface. In 2004, researchers studied the M. Bowker, A. Harmim[16], Parametric study of a vertical solar still under desert climatic conditions. The daily still productivity varied from 0.5 to 2.3 kg/m^2 on the sponged cloth area. In 2005, researchers studied the M. Bowker, A. Harmim ***[17],*** Performance evaluation of a one-sided vertical solar still, tested still yield varies from 0.275 to 1.31 $l/m^2.d$ for a corresponding energy varying from 8.42 to 14.71 MJ and daily overall efficiency ranging from 7.85 to 21.19%. In 2012, Aqeel Y. ***[18]*** designed and studied performance of the vertical solar still. Also, he manufactured two stills, the first one has evaporative one side while the other one has two sides. The results show the still with the two sides gives better daily production compared to the still with one side, about 20%. Aim of the research, a mathematical simulation was conducted to calculate the rate of production per hour for solar still, and the results of these calculations were compared to the productivity that found experimentally.

Experimental set-up

Two vertical solar stills have been built in Basra city (Iraq), of transparent glass with a thickness of (4 mm) and have the same dimensions of the measurement of the walls and cover inclination angles. Each stills consisting of vertical basin is made of aluminum area ($0.25m^2$), the basin surfaces were painted with black paint, pieces of cloth have been fixed on the vertical basin to take advantage of them in the process of water absorption, the brackish water is fed through the vertical absorbing for cloth from the top of the absorber, It flows under gravity. Start of evaporation as a result of solar radiation penetrative of the glass, As a result of the temperature high of the vertical basin. The evaporated water is condensed on the inner surface of both transparent covers and trickles down into a drainage available at the bottom of the glass cover. Distance between the vertical basin and glass cover (1cm) used to collect the distilled water, it has been developed by putting hollow screw (double ended screw pipe) of (8mm) in diameter on the channel to get distilled water linking transparent rubber tube in this screw, goes to the distilled water collecting flask, diameter of the plastic tube (1cm). putting a hollow screw (double ended screw pipe) of (8mm) in diameter in the channel disposing of surplus water ,channel designed for depth of (3cm) located in the bottom of the cloth to also help wetting the cloth from the bottom and climbing capillary tubes, linking transparent rubber tube in this screw, goes to salt-water (brain) container. The base of the still are insulated with pieces of wood (wood block) with thickness (1cm) to avoid thermal losses to the external ambient, proven the basin on the base by silicon rubber, and the solar still directed to the south, the direction geographical advantage from solar radiation and to be the first side towards the sunrise and the other side heading towards the sunset, and the Fig. (1) shows the schematic diagram of the still. An external reflector (dish covered with aluminum paper), is used to reflect and concentrate sunlight onto the vertical basin. The dish was mounted on the vertical basin manually to reflect the highest percentage of sunlight possible onto the vertical basin.

Results and discussion

The principle of operation for solar stills. The basin of the still is filled with brackish or seawater, the incident solar radiation is transmitted through the glass cover and is absorbed as heat by a black surface (basin) which contains the salt (brackish) water. Thus, the water is heated and gives off water vapor. The vapor condenses on the glass cover, which is at a lower temperature because it is in contact with the ambient air, if the glass cover is tilted, the formed condensation drops will start running down the cover by gravitational forces, and may then be collected in a channel to go out the side of the still to a storage tank.The product water was measured every hour by calibrated beaker of 1 liter volume. The productivity of the still with respect to the solar radiation has been studied. experimental hourly productivity of the vertical solar still with external reflector of the day 4 July 2012 and 17 July 2012 are shown in Fig.(2) and Fig.(3), and the experimental hourly productivity of the vertical solar still of the day 4 July 2012 and 17 July 2012 shows in Fig.(4) and Fig.(5). It is clear from the figures that the productivity of the still has the same behavior with the solar radiation.

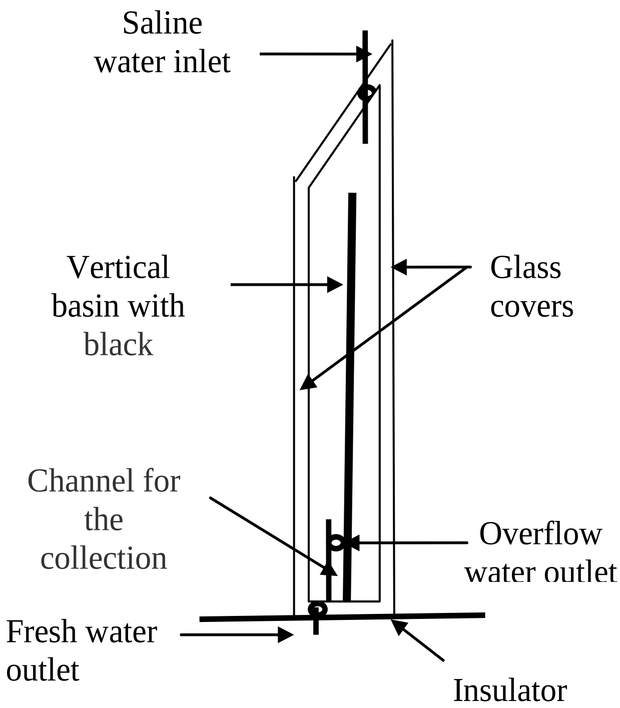

Figure-1: A schematic diagram of the vertical solar still (VSS)

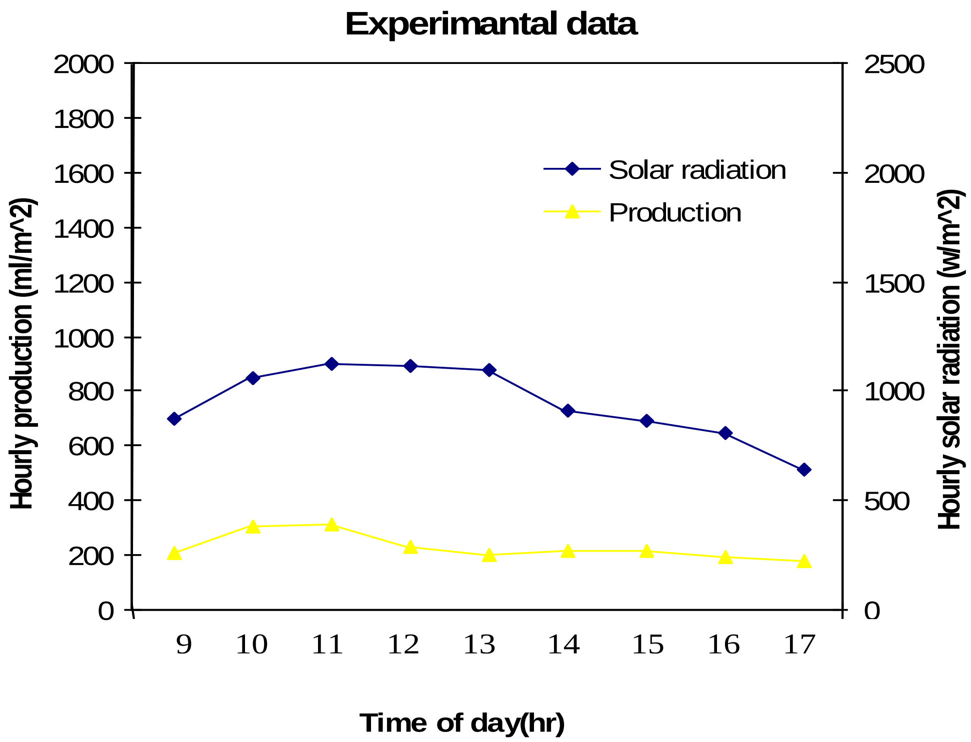

Figure- 2: Experimental hourly productivity of the vertical solar still with external reflector & solar radiation during the day of 4 July 2012.

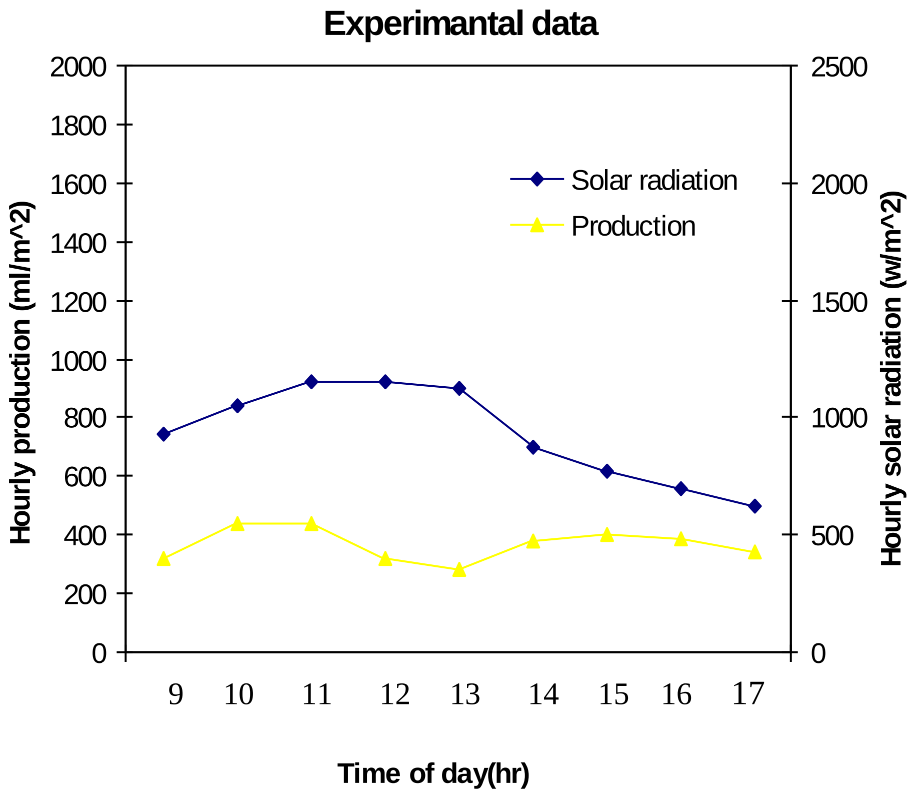

Figure- 3: Experimental hourly productivity of the vertical solar still with external reflector & solar radiation during the day of 17 July 2012.

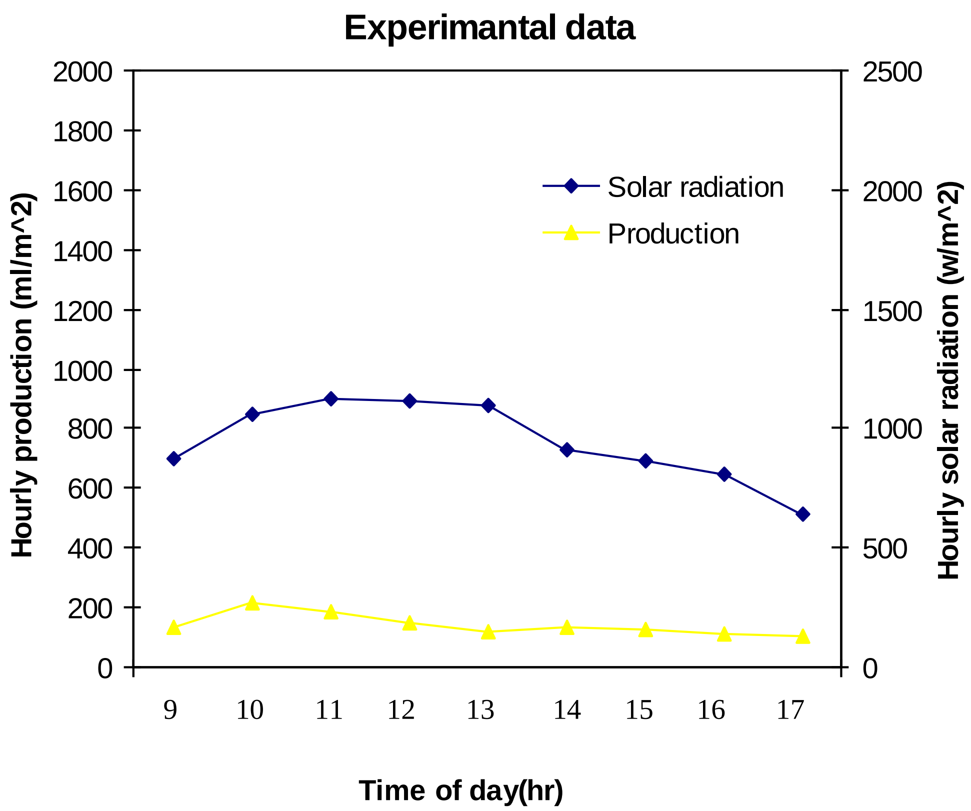

Figure- 4: Experimental hourly productivity of the vertical solar still & solar radiation duringthe dayof 4 July 2012.

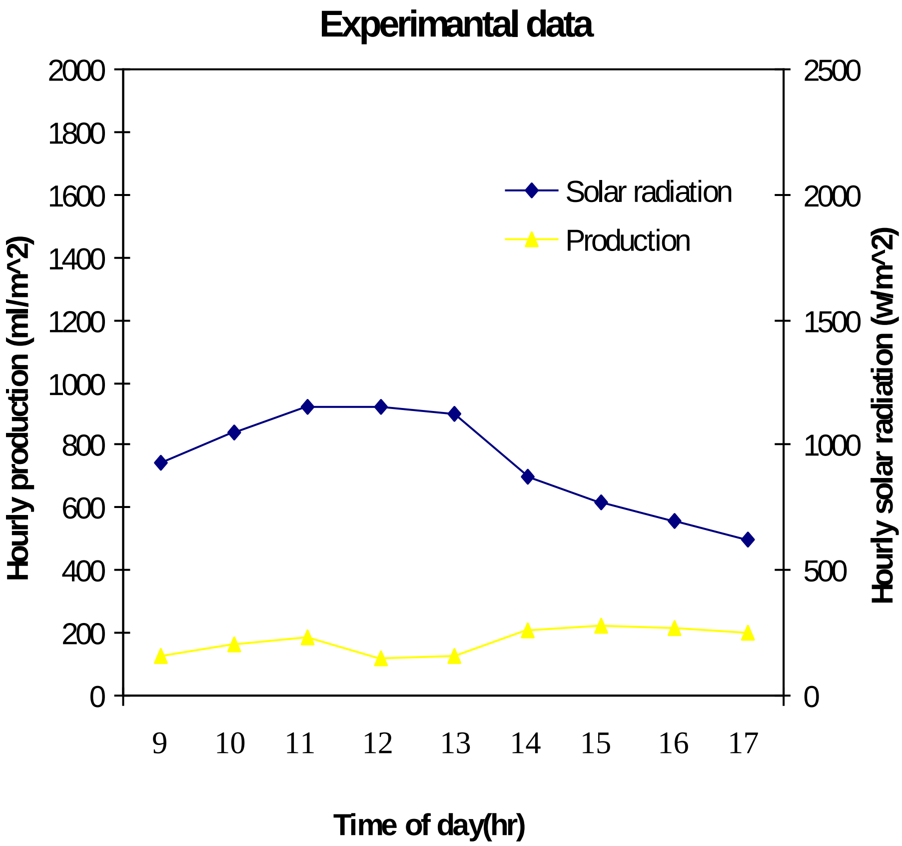

Figure-5: Experimental hourly productivity of the vertical solar still & solar radiation during the day of 17 July 2012.

It is clear from Figures (2,3,4,5) that the hourly production of the two stills have the same behavior but differ in the solar radiation behavior because the solar radiation measured to the inclined surface, and there is a significant increase in the productivity of vertical solar still with external reflector due to the effect of the external reflector on the vertical basin. The hourly production was measured experimentally and calculated mathematically using the following equation ***[19].***

(1)

$$P_h = (q_{ew}/L)\times 3600 = [h_{ew}(T_w - T_g)/L]\times 3600$$

$$q_{ew} = h_{ew}(T_w - T_g)$$

Where:

P_h: The hourly productivity.

L: The latent heat of evaporation of water (kJ/ kg).

h_{ew}: Evaporative heat transfer coefficient.(Wm^{-2} K^{-1})can be found throughout the following equation:

$$h_{ew} = 16.273\times 10^{-3} h_{cw}(P_w - P_g)/(T_w - T_g) \quad \textbf{(2)}$$

h_{cw}: Convective heat transfer coefficient (Wm^{-2} K^{-1})can be found through the following equation:

$$h_{cw} = 0.884[(T_w - T_g) + (P_w - P_g)(T_w + 273)/(2689\times 10^3 - P_w)]^{1/3} \quad \textbf{(3)}$$

Where:
T_w: Water temperature (K).
T_g: Glass temperature (K).
p_w: Partial pressures of the moist air is functions of water temperatures (N^2 / m).
p_g: Partial pressures of the moist air is functions of cover temperatures (N^2 / m).
p_w and p_g are calculated using the following relation:

$$P = 7235 - 431.43T + 10.76T^2 \tag{4}$$

The hourly distillate output of the stills and the hourly solar radiation on the glass covers are recorded in the tables (1,2,3,4).

Table-1: The production of the solar still evaluated through the experimental and mathematical simulation for vertical solar still with an external reflector during the day of 4 July 2012.

Time of day(hr)	T_w (C°)	T_g (C°)	T_a (C°)	Water production (ml/m²/hr)		I(W/m²)
				Exp.	Math.Sim.	
9.00	55	38	40.5	260	123.4	700
10.00	61	41	42	380	199.9	850
11.00	63	45	43.5	390	177.6	900
12.00	64	51	46	285	102.2	890
13.00	64	53	46.5	250	75.2	875
14.00	63	49	47.5	265	113.8	730
15.00	61	49	47	270	81.3	690
16.00	60	48	47	240	78.9	650
17.00	56.5	47	46	220	46.2	510

Table- 2: The production of the solar still evaluated through the experimental and mathematical simulation for vertical solar still with the external reflector during the day of 17 July 2012.

Time of day(hr)	*T_w (C°)*	*T_g (C°)*	*T_a (C°)*	*Water production (ml/m²/hr)*		*I(W/m²)*
				Exp.	*Math.Sim.*	
9.00	60	41	44	400	177.5	740
10.00	64	43.5	45	550	228.7	840
11.00	66	45.	46	550	252.5	920
12.00	67	52	47	400	143.3	920
13.00	66	53	46	350	107.6	900
14.00	66	50	46	470	156.9	700
15.00	64	50	45	500	116.8	620
16.00	63	49	44	480	113.8	560
17.00	60	49	42	430	67.3	500

Table- 3: The production of the solar still evaluated through the experimental and mathematical simulation for vertical solar still during t he day of 4 July 2012.

Time of day(hr)	T_w (C^o)	T_g (C^o)	T_a (C^o)	Water production (ml/m²/hr)		I(W/m²)
				Exp.	Math.Sim.	
9.00	46	34	40.5	165	46.5	700
10.00	46.5	35.5	42	265	41	580
11.00	49	36	43.5	230	61.5	900
12.00	50	38	46	185	55.7	890
13.00	48	38	46.5	150	37.09	875
14.00	47	37	47.5	170	35.4	730
15.00	47	37	47	160	35	690
16.00	46	36	46	140	33.8	650
17.00	44	34	45	130	30.6	510

Table- 4: The production of the solar still evaluated through the experimental and mathematical simulation for vertical solar still during t he day of 17 July 2012.

Time of day(hr)	T_w (C^o)	T_g (C^o)	T_a (C^o)	Water production (ml/m²/hr)		I(W/m²)
				Exp.	Math.Sim.	
9.00	47	36	44	160	41.7	740
10.00	48	37	45	200	43.8	840
11.00	50	37	46	230	64.7	920
12.00	53	42	47	150	53	920
13.00	52	42	46	160	43.3	900
14.00	51	39	46	260	58	700
15.00	49	37	45	280	53	620
16.00	47	35	44	270	48	560
17.00	45	34	42	250	38.2	500

Shows the mathematically calculated of the hourly productivity of the vertical solar still with external reflector of the day 4 July 2012 and 17 July 2012 in Fig. (6) and Fig. (7).

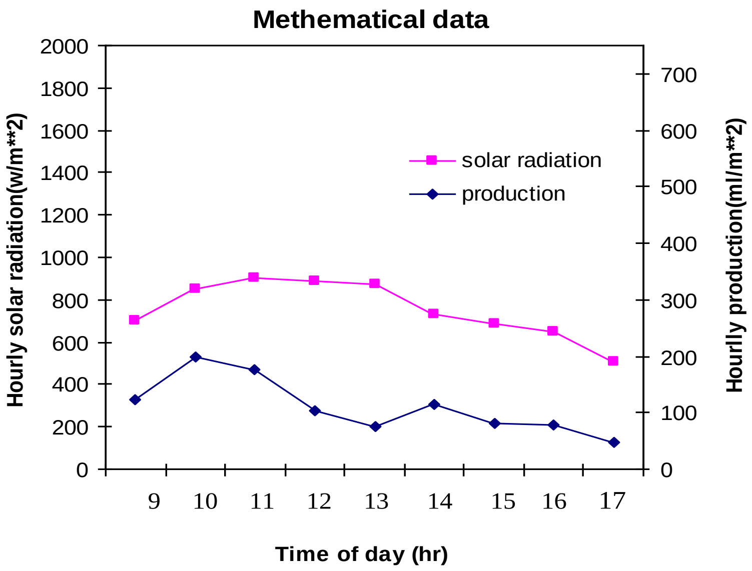

Figure- 6: Mathematical hourly productivity of the vertical solar still with an external reflector of the day 4 July 2012.

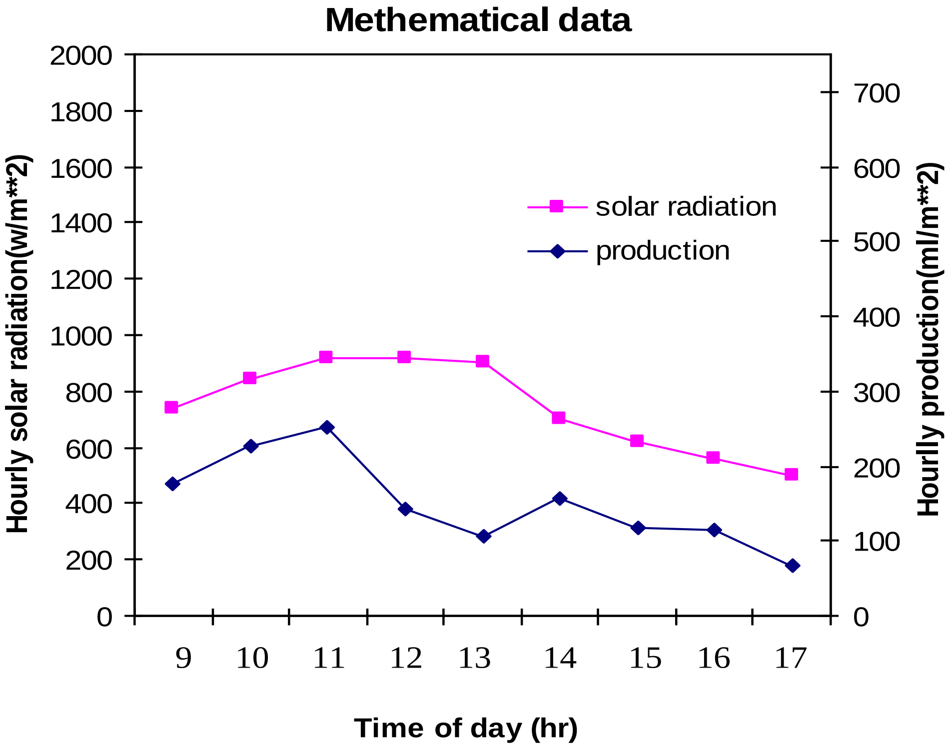

Figure- 7: Mathematical hourly productivity of the vertical solar still with an external reflector of the day 17 July 2012.

Shows the mathematically calculated of the hourly productivity of the vertical solar still of the day 4 July 2012 and 17 July 2012 in Fig. (8) and Fig. (9).

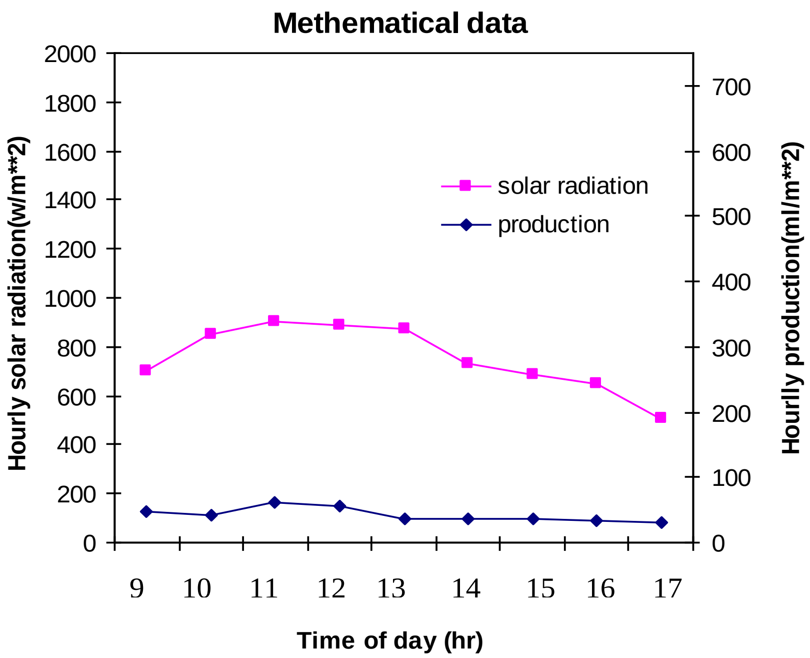

Figure- 8: Mathematical hourly productivity of the vertical solar still of the day 4 July 2012.

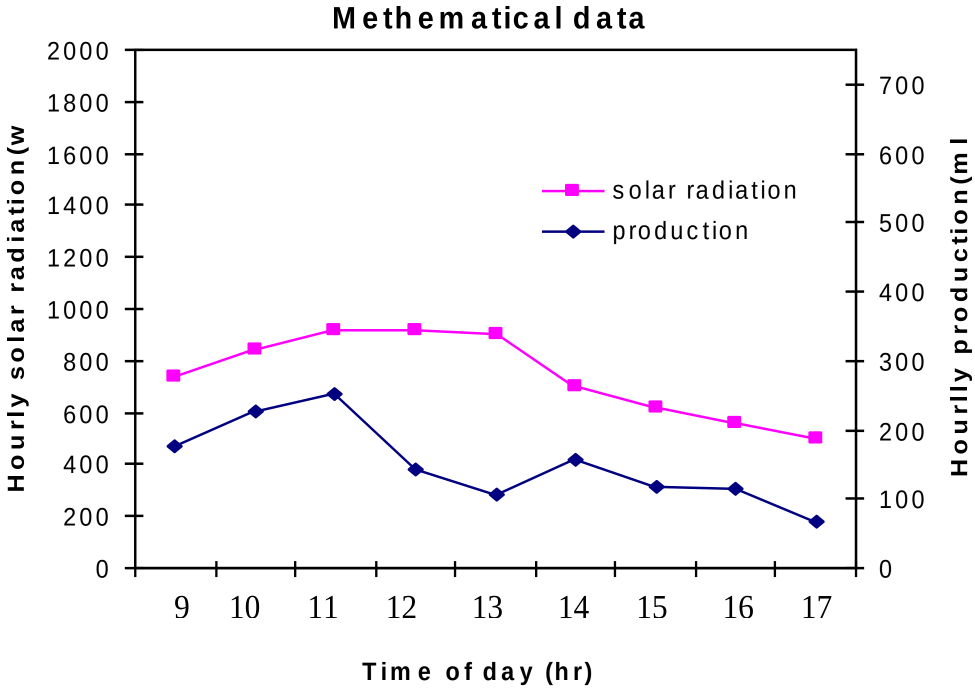

Figure- 9: Mathematical hourly productivity of the vertical solar still of the day 17 July 2012.

The thermal efficiency (E) of the stills was calculated for the same day 17 July 2012 using the following equation : ***[20]***

$$E = \frac{P \times L}{I \times A_b}$$

Where:
E: thermal efficiency.
P: Daily output of distilled water.
L: latent heat of water evaporation (KJ / Kg).
I: daily solar radiation (W / m². Day).
A_b: area of the solar still (m^2).
Table (5) shows the results of the thermal efficiency of the solar stills of the day 17 July 2012.

Table- 5: Thermal efficiency of the solar stills.

The stills	Production ($ml/m^2/day$)	Solar radiation (w/m^2)	Thermal efficiency %
Vertical solar still	1710	6200	17.6
Vertical solar still With external reflector	3700	6200	38.2

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