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Research Article

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Calculation of mathematical models for the production of solar distillers (Single slope solar still)

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Abstract A single slope conventional solar still with reflector (mirrors) has been constructed and it's performance has been evaluated under different atmospheric circumstances of Basra city (Iraq)**.** Some additions have been made and examined in order to increase the performance of the solar still and the outcomes as thermal efficiency account to solar still. A mathematical model was developed accordingly to compare with the experimental results. The effect of various operating conditions were studied experimentally and compared with theoretical results. The hourly variation behavior of yield is similar to that of solar intensity. The maximum efficiency of the experimental still varies from (42 % - 52 %).

Keywords solar energy, reflector (mirrors), solar still, single slope conventional solar still, Mathematical model

Introduction

Sea water (brackish water) represents very high percentage of the total water on the surface of the earth, (97% - 97.5%), and the rest is fresh water (3% - 2.5%), which in turn people still cannot benefit it totally because of the difficulty of access [1-6]. 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 transferred by polluted water [7]. The remote arid warm places in the Middle East and North Africa and other regions in the world are suffering a sharp shortage of fresh water. These regions are characterized by high salinity of ground water, lack of rains and a good solar energy. It is an international problem and the best solution, is the use of solar energy for desalination of salt water [8]. Now a day's all the world are looking after a new sources of fresh waters such as that extracted from sea water and brackish water, to fulfill the mankind demand of fresh water All lived and flourished ancient civilizations were found where the water is found .It is well known that 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 of the limited sources of fresh water and the successive demands for it [9]. Sun produces a radiation form of energy falls on earth called electromagnetic radiation a wave propagating at speed of light having associated with it an oscillating electric field and magnetic field both mutually perpendicular to each other and to the direction of propagation. The rate of solar energy per unit area falling on a subject surface perpendicular to the path of the solar radiation out side the earths atmosphere casing is called the solar constant and equals to (1370 W/m ^{2}) [10]. In this work, a mathematical simulation has been conducted to calculate the rat of production per hour.

Experimentation

A single slope solar still has been constructed and it's performance has been evaluated under different atmospheric circumstances of Basra city (Iraq) (Latitude 30° 33' 56.55"N, Longitude 47° 45' 5.86"E).

The single slope solar still has been built of transparent glass and glass one face reflector with a thickness (4 mm) and has the same dimensions of absorber plate which contains the Saline water, an absorber plate and glass cover that creates a cavity. The cavity length, width and height for the single slope solar still are (0.25 m), (0.25 m) and (0.14 m). This plate in still is made of aluminum with surface area (0.0625 m^2), the surface was coated with black paint to absorb the maximum amount of solar radiation incident on them. The brackish water is fed to the still through the hole screw (double ended screw pipe) of (8mm) diameter on the cover glass and join with rubber tube to the tank of saline water with capacity (20 liter). The condensed channel in still lies between the absorber plate and the glass cover with width (1cm) and height (2cm). The absorber receives solar radiation from both sides. Flowing water gets heated and evaporation starts from absorber plate. The evaporated water was condensed on condensed channel, it has been developed by putting hole screw (ended screw pipe) of (8mm) 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 (0.5cm).

The base of the still is insulated with pieces of wood (wood block) of (1cm) thickness to avoid the thermal losses to the external ambient, proven the basin on the base by silicon rubber. Figure (1) shows the schematic diagram of the still. Figure (2) shows a photograph picture of the still. An external reflector (mirror) was used to reflect and concentrate sunlight onto the basin. Figure (3) shows a photograph picture of the still with external reflector (mirror). The single slope solar still directed to the south geographic, the direction geographical advantage from solar radiation and to be the first side towards the sunrise and the other side heading towards the sunset. The experiments on the still was carried out during some days of (August 2018 and September 2018) to study their performance under different field conditions. In each experiment, the hourly amount of distilled water and the insulation are monitored for the still. The total daily amount of distillate water was recorded.

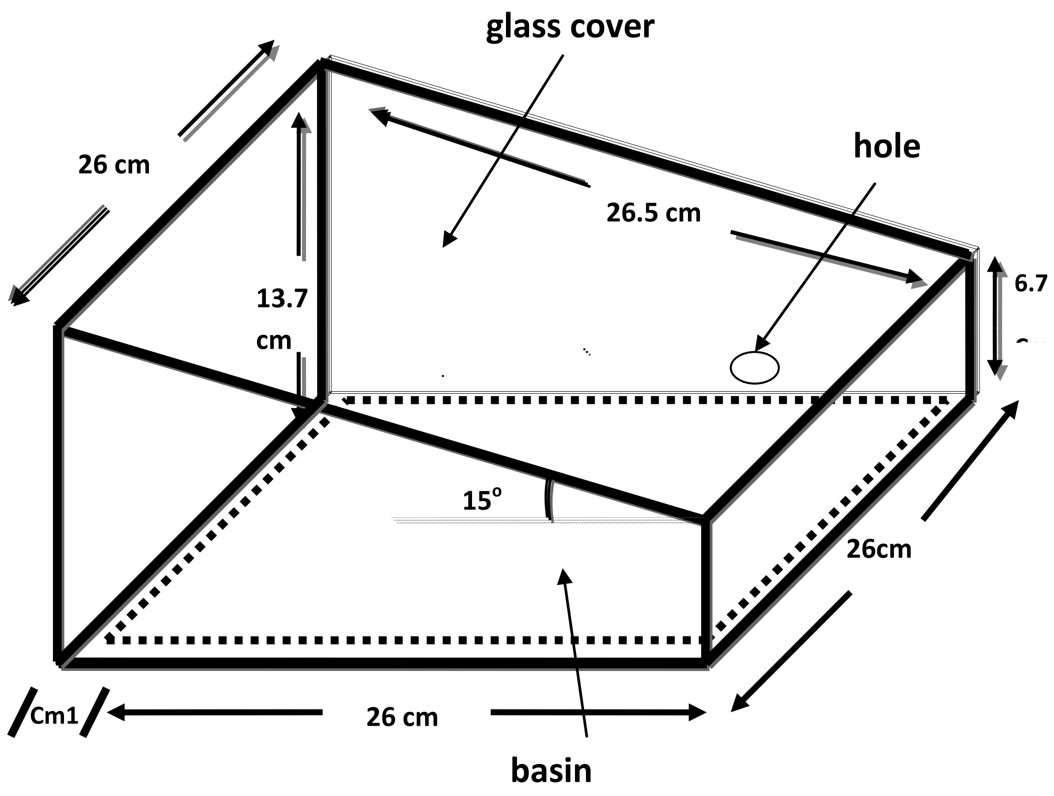

Figure 2: Schematic diagram of the single slope solar still

Figure 2: A photographic picture of the Single Slope Solar Still (glass one face reflector)

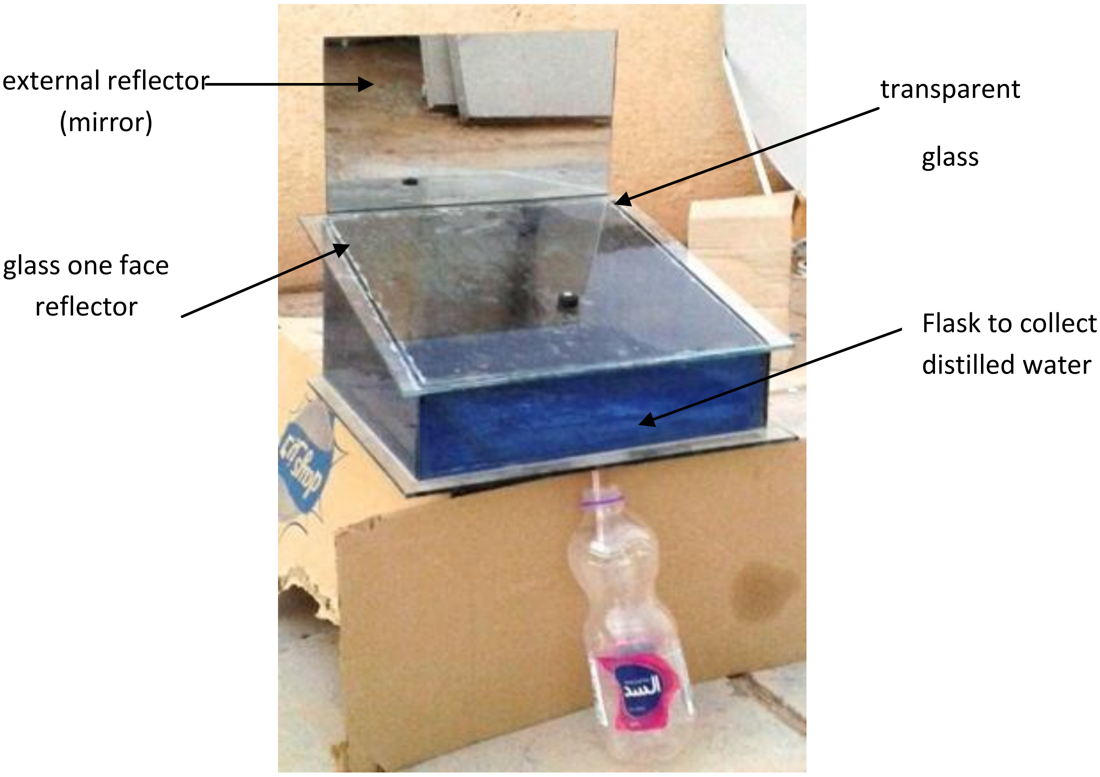

Figure 3: A photographic picture of the Single Slope Solar Still with external reflector (mirror)

Mathematical Modeling

The objective of still design is to maximize Q_{evap}, the transport of absorbed solar radiation to the cover condenser by water vapor, as this is directly proportional to the still productivity. All other energy transfer from basin to surroundings should be suppressed, as far as is possible. Most energy flows can be evaluated from basic principles, but terms such as leakage and edge losses are difficult to quantify and may be lumped together and determined experimentally for a particular still. Between basin and cover energy transfer occurs by evaporation and condensation, in addition to convection and radiation. The losses from the back of the still are to the ground and because of insulation can be neglected. The depth of the water in the still is usually such that its capacitance must be taken into account. The hourly production was measured experimentally and calculated mathematically using the following in equation [11].

$$P_h = (q_{ew} / L) \times 3600 = [h_{ew}(T_w - T_g) / L] \times 3600 \quad (1)$$

$$q_{ew} = h_{ew}(T_w - T_g) \quad (2)$$

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 through out the following equation:

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

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

$$h_{cw} = 0.884[(T_w - T_g) + (P_w - P_g)(T_w + 273)/(268.9 \times 10^3 - P_w)]^{1/3} \quad (4)$$

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 [11] :

$$P = 7235 - 431.43T + 10.76T^2 \quad (5)$$

Results and Discussion

The product water is measured hourly by calibrated beaker of 1 liter volume. The productivity of the still with respect to the solar radiation has been studied. The results of the during some days of (August 2018 and September 2018). The hourly distillate output of the still and the hourly solar radiation on the glass covers are recorded in the tables (1,2). Figures (4,5) shows the experimental results and mathematically simulation of the hourly productivity of each stills with solar radiation for days (29 August 2018), (8 September 2018) respectively.

Table 1: The production of the solar still evaluated through the Experimental and mathematical simulation for solar still during the day of 29 August 2018

Time of day(hr)	T_w (C°)	T_g (C°)	T_a (C°)	Water production (ml/m²/hr)		I(W/m²)
				Exp.	Math. Sim.	
8.00	60	43	39	240	146.8	450.6
9.00	63	44	42	320	195.05	560.3
10.00	70	48	45	400	304.5	795.5
11.00	74	52	48	512	335.7	890.5
12.00	75	52	49	768	371.2	950.6
13.00	77	53	50	1040	418.2	935.7
14.00	74	51	48	752	362.7	826.3
15.00	69	49	46	672	251.6	635.6
16.00	63	47	45	512	144.5	468.7
Sum				5216	2530.5	6513.4

Table 2: The production of the solar still evaluated through the Experimental and mathematical simulation for solar still during the day of 8 September 2018

Time of day(hr)	T_w (C^o)	T_g (C^o)	T_a (C^o)	Water production ($ml/m^2/hr$)		$I(W/m^2)$
				Exp.	Math.Sim.	
8.00	59	42	40	160	142.1	580.6
9.00	64	44	43	240	219.3	620.5
10.00	68	47	43.5	368	266.7	800.7
11.00	71	49	44	608	312.3	784.8
12.00	72	50	45	640	320.13	945.9
13.00	74	52	46	800	335.7	925.3
14.00	71	50	47.5	640	288.1	825.1
15.00	68	49	47	560	224.2	644.4
16.00	64	48	45	320	148.6	443.2
Sum				***4336***	***2257.48***	***6566.8***

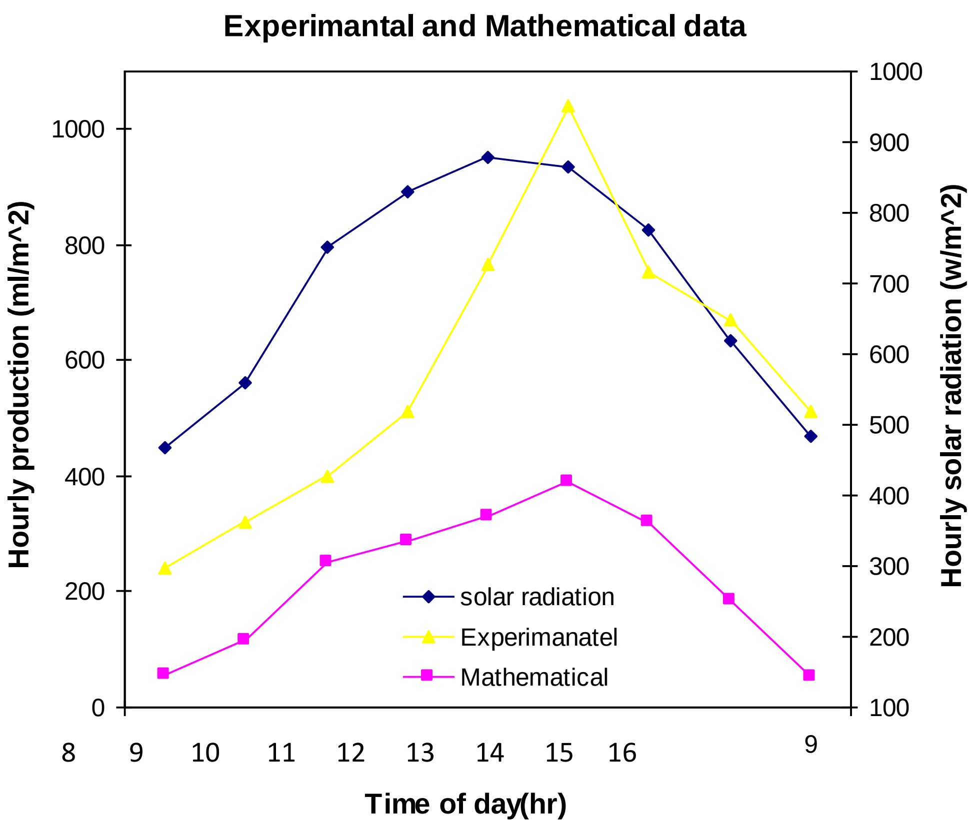

Figure 4: The experimental and mathematically simulation of the hourly productivity of solar still with solar radiation at 29/08/2018.

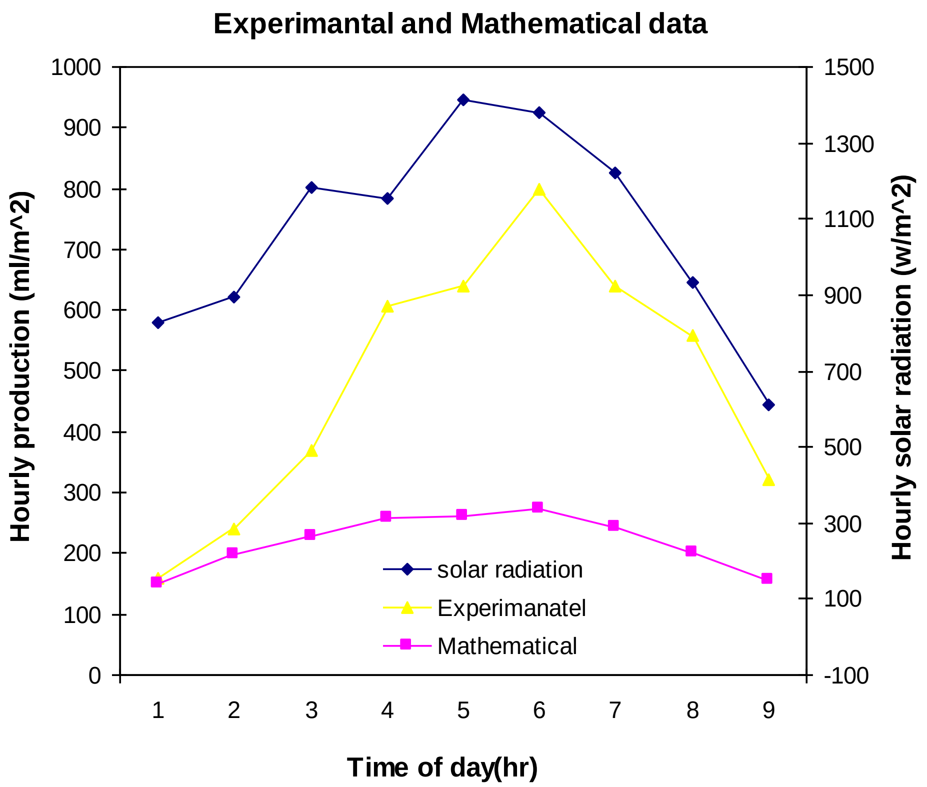

Figure 5: The experimental and mathematically simulation of the hourly productivity of solar still with solar radiation at 8/09/2018

It is clear from figures 4-5 that there is a difference between the experimental and the simulation results, These differences come from the improvements that were added to the stills reflector (mirrors) who are working to increase the temperature of the water basin solar still, which lead to increase the difference between the temperature of the basin solar still and temperature of the cover condensation (glass cover) which is an important factor in increasing the productivity of solar still.

The thermal efficiency (E) of the stills was calculated for the same day 29 August 2018 using the following equation [12] :

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

Where:

E: thermal efficiency.

P: Daily output of distilled water.

L: latent heat of water evaporation (KJ / Kg).

I: daily solar radiation (W / m^2. Day).

A_b: area of the solar still (m^2).

The maximum efficiency of the experimental still varies from (42 % - 50 %). Table (1) shows the results of the thermal efficiency of the single slope solar still with external reflector.

Table 3: Thermal efficiency of the single slope solar still

Date	Production (ml/m^2/day)	Solar radiation(w/m^2)	Efficiency %
29 August 2018	5216	6513.3	50.2
08 September 2018	4336	6566.8	42.1

Conclusions

The largest part of distillate production was seen to take place between noon and sunset, where the productivity was increased with the increase of solar radiation. The distillate production can be increased when the temperature of the brackish water increases. The hourly variation behavior of yield is similar to that of solar intensity. The maximum efficiency of the experimental still varies from (42 % - 52 %).

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