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Novel Concept on the Enhancement of Conventional Solar Still Performance via Constant Heat Rate Supply to the Saline Water

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ABSTRACT

One of most reduction reasons of simple conventional solar still productivity is the coupling between high solar intensity and the high ambient temperature in the same time. The high intensity increases the saline water temperature while the outside temperature increases the glass temperature and consequently reduction in saline water and glass temperature difference leads to reduction in condensation and productivity. The present theoretical study focuses on the completion of the absorbed solar energy in the basin to be constant during the day. The basin water will be in high temperature level all day especially at the time of low outside temperature far away the noon. The absorbed heat in the basin is held constant at $\alpha_w I_{max}$ by extra heat from wind turbine power with battery storage system all day hours. The results show that, the solar still productivity with constant heat supply is more than that with same amount of variable energy during sun rise time only (6 AM to 6 PM) by 69.133 %. So, constant absorbed heat in the water basin ($\alpha_w I_{max}$) through the 24 hr of the day enhances the performance with productivity up to 248 % with the hybrid solar and electric power consumption of the wind turbine power. The water in the basin is held constant at 2 cm via makeup water to compensate the evaporation rate.

Keywords: Conventional solar still; constant heat rate; theoretical study

Nomenclature

A	Area, m^2
a	Wire cross sectional area, mm^2
Cp	Specific heat, J kg^{-1} $^oC^{-1}$
C.O.P	Coefficient of performance

F	Radiation shape factor
h_{bw}	Heat transfer coefficient in the saline water, W m^{-2} ^{o}C^{-1}
h_{ca}	Outside air heat transfer coefficient, W m^{-2} ^{o}C^{-1}
h_{cw}	Trapped air heat transfer coefficient in the still, W m^{-2} ^{o}C^{-1}
h_{fg}	Evaporation heat load (latent heat) at atmospheric pressure, J kg^{-1}
I	Solar radiation, W m^{-2}
i	Electric current, Ampere
L	Wire length, m
m	Mass, kg
m_p	Daily productivity, kg s^{-1}
m_{re}	Instantaneous productivity, kg s^{-1}
p	Water vapour pressure, N m^{-2}
R	Resistance, Ω
t	Temperature, ^{o}C
V	Volt
U	Heat transfer coefficient from basin and sides to ambient, W m^{-2} ^{o}C^{-1}
W_a	Wind speed, m s^{-1}

Greek letters

α	Absorptive factor
ε	Emissivity
τ	Time, s
σ	Stefan-Boltzmann constant, W m^{-2} K^{-4}

Subscripts

a	Ambient
b	Basin
g	Glass
sky	Sky
w	Water in basin

1. Introduction

The need for freshwater has been dramatically increasing with the rapid increase in the human population all over the earth. The presence of an extreme amount of dissolved salts in the available water on the earth's surface makes the water brackish. In the literature, various methods are available to convert the brackish water into a clean form; however, most of these methods have a negative impact on the environment, need difficult technological inputs and are considered highly energy intensive (Jamil and Akhtar 2014; Safe 2011). In recent years, efficient technologies based on renewable energy sources are being developed mainly to deal with the increasing demands of distilled water. One of the oldest techniques for water purification is the distillation of seawater using solar energy to separate salts and water (El-Maghlany et al. 2020 ; El-Sebaii 2004 ; Li at al. 2013 ; Nayi and Modi 2018; Omara et al. 2017; Rajaseenivasan and Murugavel 2013; Sampathkumar and Senthilkumar 2012; Sathyamurthy et al. 2017) . The main advantages of using the solar stills as solar desalination units are their low cost, simple operation, and self-reliant water supply systems (El-Maghlany et al. 2020). The solar still desalination technique uses two main processes: evaporation and condensation phenomenon similar to those occurring in the atmosphere to form rain. The processes involved in the solar stills techniques are the solar radiation for the natural evaporation of water, followed by condensation process. Through the still cavity, the vapors travel to reach the still cover and once the heat is released, a condensation process occurs, where the vapors are condensed back into liquid form. Via the evaporation stage in the still, only water evaporates and all impurities are left to be blushed later via drainage. Thus, the condensed distillate obtained in the solar still is potable. Even though, solar stills could be considered as an appropriate option for the distillation of water with free cost solar energy to fresh water production, but they have low distillate yield and efficiency (Jamil and Akhtar 2014). In the literature, a large number of research studies focus on the enhancement of solar still performance aiming to improve its low distillate yield and efficiency. Factors affecting the performance of solar still include the climate condition as the performance of the solar still is very sensitive to climate conditions. The main effective climate conditions parameters are ambient temperature, solar intensity, and the surrounding air velocity around the still (Ahsan et al. 2014; Alfaylakawi and Ahmed 2012; El et al. (2015); Hamdan et al. 1999; Muftah et al. 2014; Omara et al. 2013; Prakash and Velmurugan 2015; Selvaraj and Natarajan 2018; Sharshir et al. 2016; Thirugnanasambantham et al. 2013; Tiwari et al. 2009; Kabeel et al. 2019). Other main factors that affect the solar still performance comprises some essential design parameters. These main design parameters include the inclination, type and thickness of glass cover type, orientation of still, absorber plate material and thickness, and the depth of water in basin (Nafey et al. 2000; Omara et al. 2013; Omara et al. 2014; Samee et al. 2007; Velmurugan and Srithar 2011; Khalifa 2011). Research studies show that simple solar still possess low efficiencies and output. Thus, research mainly focuses on new methods to enhance the solar still performance by either internally modifying its existing designs with the incorporation of new technologies or by coupling with external devices to enhance the productivity of solar stills. Regarding the enhancement of the solar still performance by modifying its existing designs, various studies are carried out on different solar still designs, including spherical solar still, pyramid solar still, hemispherical solar still, double basin glass solar still, concentrator coupled single slope solar still, tubular solar still and tubular solar still coupled with pyramid solar still, wicked, stepped, pyramid and "V" type solar stills, (Omara et al. 2013; Abdullah et al. 2019; Saadi et al. 2018; Murugavel and Srithar 201; Kumar et al. 2008; Velmurugan et al. 2008; Kabeel et al. 2020; Thirugnanasambantham et al. 2012). Focusing on conventional solar stills, some research focus on improving the production of water by enhancing the yield through the application of energy storage, either latent or sensible heat energy storage (Ansari et al. 2013; Sathish et al. 2020; Shashikanth et al. 2015; Yousef et al. 2019 ; Gugulothu et al. 2015 ; Sarada et al. 2014). Enhancement to the solar still productivity, yield and performance can also be done by improving the absorbing materials (Abdallah et al. 2009; Gugulothu et al. 2015) . Other studies deal with improvement in the absorber aiming to enhance the solar still performance. Studies using floatable absorbers, baffled absorber, and corrugated absorber are conducted to check their effect on the productivity of solar still (Omara et al. 2011; Srivastava and Agrawal 2013; El-Sebaii et al. 2000). It is concluded that water production is increased by changing the absorber type. In addition, another method to enhance the performance of conventions solar still is to add fins in the basin to decrease the preheating time essential for evaporating the still basin water. The fins increase the area of the absorber plate; hence, the absorber plate temperature and saline water temperature increase. The conclusion is that productivity increases as the temperature difference between water and glass increases (Srivastava and Agrawal 2013; Velmurugan et al. 2008). Furthermore, another method to enhance the heat transfer inside the solar basin is by adding Nanofluid that accelerates the water evaporation rate compared with the simple conventional solar still (Gupta et al. 2017; Gupta et al. 2016; Mahian et al. 2013; Kabeel et al. 2017). Additionally, other studies show that adding aluminum balls to the solar distillates increase the distillation of distilled water by about around 27.16 % (Attia et al. 2020). Moreover, some studies show that preheating the saline water by passing it over the solar panel front surface before entering the still rises the freshwater yield of the solar desalination system (Abd Elbar and Hassan 2020). (Kabeel et al. 2016) use two main methods to enhance freshwater productivity by using hot air injection and PCM. The results show that the developed air bubbles increase the evaporation rate through the modified still with PCM.

3. Aim of the present study

From the previous literature and up to the authors' knowledge, the enhancement of the solar still performance via constant heat rate supply during the day has not been under investigation before. The novelty of the present study was to prove that the regular constant heat supply to saline water takes the solar still to the finest. The results will prove that a specified amount of heat to the saline water with constant rate is more effective than the same amount of heat in random mode. Previously, the PCM was used to store energy during the day and release heat in night hours. However, the use of PCM as energy storage in the night period is a random heat supply technique depending on the type of PCM and its amount without any time history to heat absorbed or supply. Therefore, the present study aims to prove that the steady constant heat supply to the solar still is an effective technique to enhance the conventional solar still performance.

4. Mathematical model

The energy balance for water basin, absorber and the glass cover will be applied. Via the solving of the energy equations simultaneously in unsteady mode; the temperatures of basin plate, saline water, and glass cover could be estimated. So, the performance of the solar still will be found. The glass cover is assumed to be un-stored element (thin) without any vapour leakage.

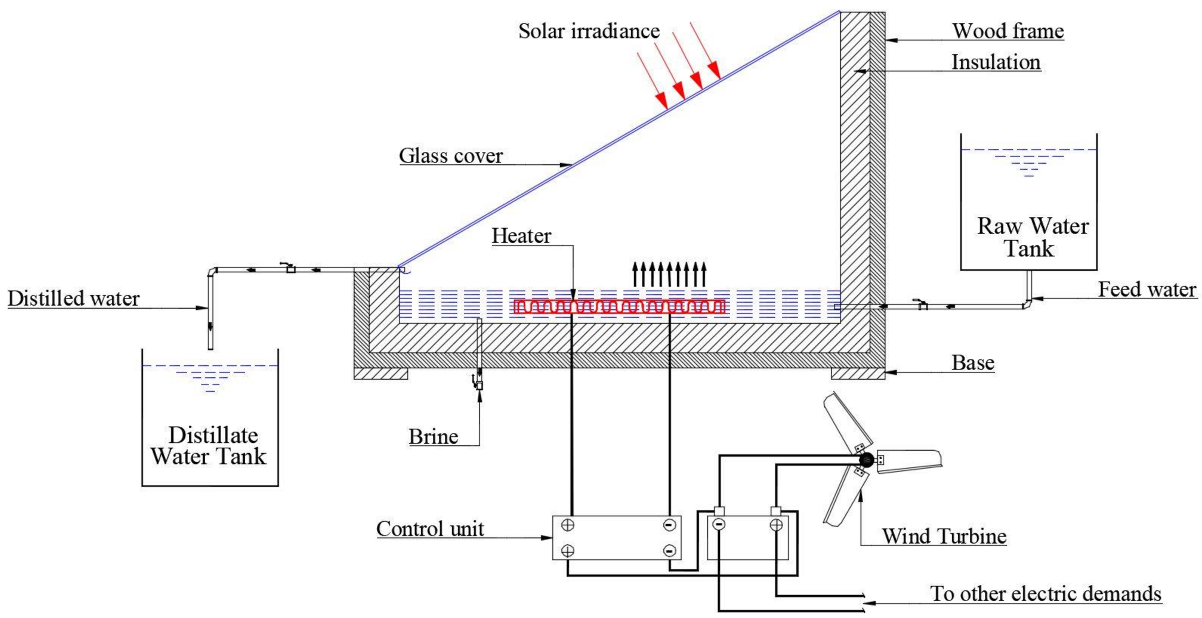

Fig. 1. Conventional solar still with supplementary heat added

The temperature variation of the basin plate could be found from the energy balance as follow with some brief

$$m_b Cp_b \frac{dt_b}{d\tau} = (\alpha_b) A_b I - h_{bw}\, A_b (t_b - t_w) - U_b\, A_b (t_b - t_a) \qquad (1)$$

Where:

$$h_{bw} = 135 \text{ W/ m}^2\,{}^{o}\text{C and } U_b = 14 \text{ W/ m}^2\,{}^{o}\text{C} \qquad (2)$$

In case of constant water thickness, the energy balance for the saline water will be

$$Cp_w m_w \frac{d}{d\tau}(t_w) = (\alpha_w) A_w I + h_{bw}\, A_b (t_b - t_w) - \frac{\sigma\left[(t_w+273)^4 - (t_g+273)^4\right]}{\left(\frac{1-\varepsilon_w}{A_w \varepsilon_w}\right) + \left(\frac{1}{A_g F_{gw}}\right) + \left(\frac{1-\varepsilon_g}{A_g \varepsilon_g}\right)}$$

$$- 0.884\left[t_w - t_g + \frac{(p_w - p_g)(t_w + 273)}{268900 - p_w}\right]^{\frac{1}{3}} A_w (t_w - t_g)$$

$$- (16.237 \times 10^{-3}) h_{cw}\, A_w (p_w - p_g) - m_{re}(Cp_w t_w - Cp_a t_a) \qquad (3)$$

Where

$$p_w = e^{\left(25.317 - \frac{5144}{t_w + 273}\right)} \qquad (4)$$

$$p_g = e^{\left(25.317 - \frac{5144}{t_g + 273}\right)} \qquad (5)$$

Energy balance for the glass cover

$$m_g Cp_g \frac{dt_g}{d\tau} = (\alpha_g) A_g I + \frac{\sigma\left[(t_w + 273)^4 - (t_g + 273)^4\right]}{\left(\frac{1-\varepsilon_w}{A_w \varepsilon_w}\right) + \left(\frac{1}{A_g F_{gw}}\right) + \left(\frac{1-\varepsilon_g}{A_g \varepsilon_g}\right)}$$

$$+ 0.884\left[t_w - t_g + \frac{(p_w - p_g)(t_w + 273)}{268900 - p_w}\right]^{\frac{1}{3}} A_w (t_w - t_g)$$

$$+ (16.237 \times 10^{-3}) h_{cw}\, A_w (p_w - p_g) - h_{ca}\, A_g (t_g - t_{sky})$$

$$- \varepsilon_g A_g \sigma\left[(t_g + 273)^4 - (t_{sky} + 273)^4\right] \qquad (6)$$

Where

$$t_{sky} = t_a - 6.0 \qquad (7)$$

$$h_{ca} = 5.7 + 3.8\, W_a \qquad (8)$$

The time dependant still productivity is

$$m_{re} = \frac{(16.237 \times 10^{-3}) h_{cw}\, A_w (p_w - p_g)}{h_{fg}} \qquad (9)$$

The accumulated daily still productivity is

$$m_p = \sum_{\tau=0}^{\tau=24hr} m_{re} \qquad (10)$$

5. Solution proceeding

Via FORTRAN in house code, the linear differential equations 1, 3 and 6 for the energy balance are solved numerically with one second time step. Table 1 contains the all thermal properties and dimensions of the solar still with its contents. The weather data of Alexandria city in Egypt with average values of August is introduced to the governing equations (solar intensity, wind speed and ambient temperature). Fig.1 represents the solar still schematic diagram and the weather data is given in Fig.2 representing solar intensity, wind velocity and ambient temperature.

Table 1

The thermo-physical and operating parameters of the solar still (El-Maghlany et al. 2020).

Item	*m (kg)*	*A (m^2)*	*C_p (J/kg K)*	*α*	*ε*
Saline water	*20*	*1.00*	*4190*	*0.05*	*0.95*
Glass cover	*9.0*	*1.15*	*840*	*0.05*	*0.85*
Basin plate	*14.5*	*1.00*	*460*	*0.95*	----

Latent heat for water at atmospheric condition (h_{fg}) =2335000 J/kg.

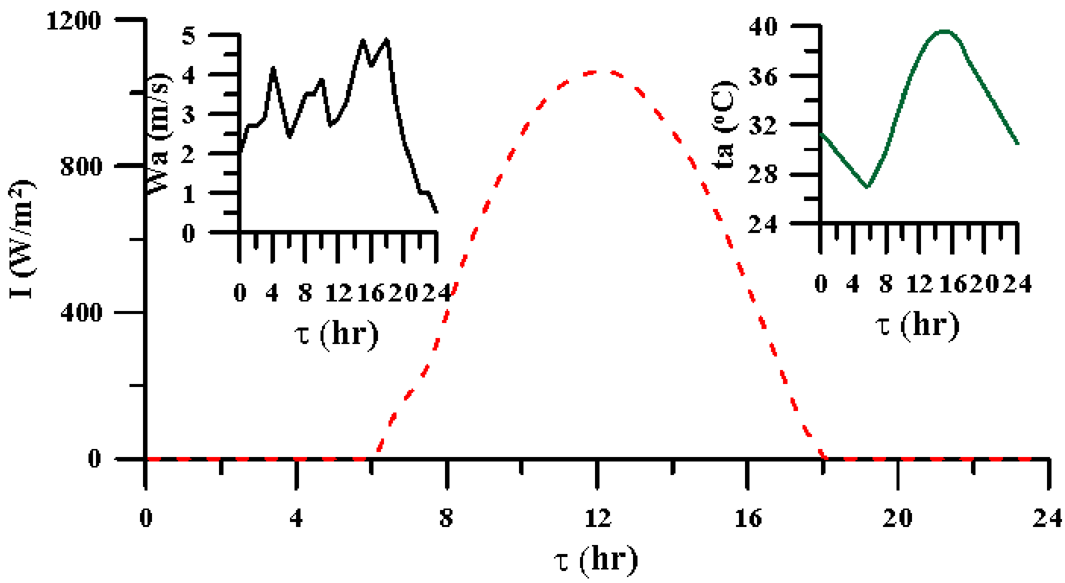

Fig. 2. Average daily weather meteorological data of Alexandria in August

6. Results and discussion

As shown in Fig.2 which represents the average daily weather meteorological data of Alexandria in August, the peak solar intensity takes place around the noon which reflects high input energy to the saline water. Unfortunately, the outside air temperature is also peak around the noon. The productivity will be very high in case of the low outside air temperature which is not found in the actual case. With low outside air temperature, the convection heat transfer inside the trapped air in the still is high due to the less glass temperature. So, the night hours after the sunset are very important for high productivity. Wind turbine generates electric power coupled to the storage battery. Electric heater (C.O.P=1) is immersed in the saline water heated the water in the basin all day by electric energy from the storage battery less than or equal to the wind turbine power. The power generated from the renewable wind energy is the peak consumed power in the electric heater. Simple new clarification will be discussed in Fig.3 which represents the new concept towards the productivity enhancement of the solar still. The effective solar energy in the still as shown in Fig.2 (red line) is found from 6 AM to 6 PM with value of $0 \leq I \leq 1000$ W/m^2 with total energy of 7545.265 W hr/m^2. This total energy is theoretically replaced by constant solar intensity (I_c=628.82 W/m^2) for the same period (6 AM to 6 PM) which gives the same energy of 7545.265 W hr/m^2 in the still. The equations from 1 to 10 are solved in two cases. The first one with $I = function\ (\tau)$, $0 \leq I \leq 1000$ W/m^2 as the actual case, the second one with I_c=628.82 W/m^2 with value independent on time.

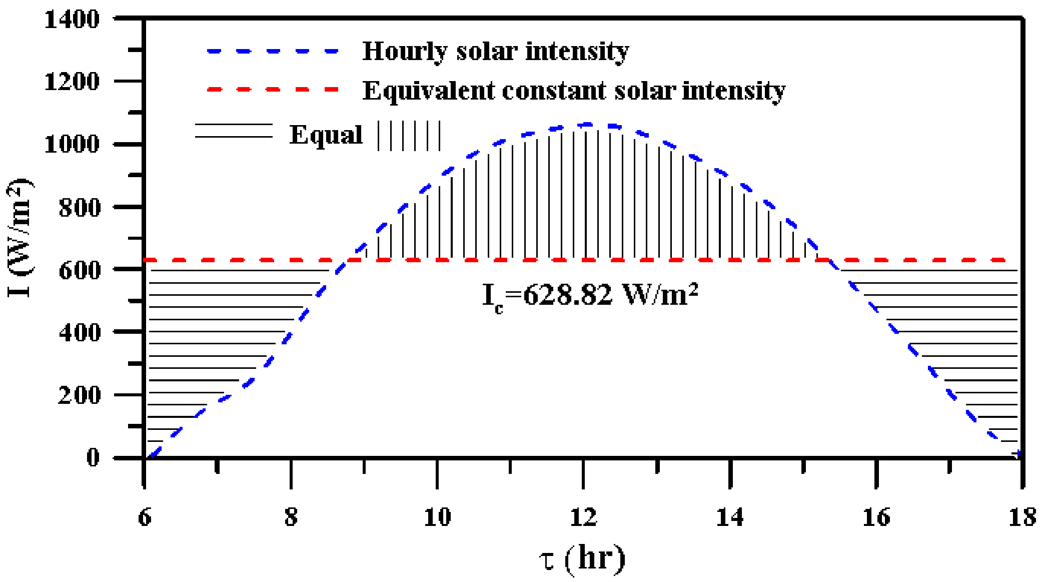

Fig. 3. Average solar intensity and equivalent constant intensity

The accumulated productivity at the end of period of 6 AM to 6 PM for the two cases is given in Fig.4. With constant solar intensity the productivity is 4.16 L/day while with variable solar intensity the productivity 2.5 L/day. In other words, the constant heat supply is recommended during the day. This behaviour is due to the large utilized temperature difference between the saline water and the glass cover due to heating at the time of low outside air temperature. The previous clarification was to prove that the constant heat rate supply to the basin enhanced the productivity rather than variable one. However, it is not possible to achieve it actually.

There is no control on the solar intensity and the constant heat rate (new concept) will be as the maximum daily solar intensity with completion from the storage electric power in the storage battery that has been supplied by the wind turbine.

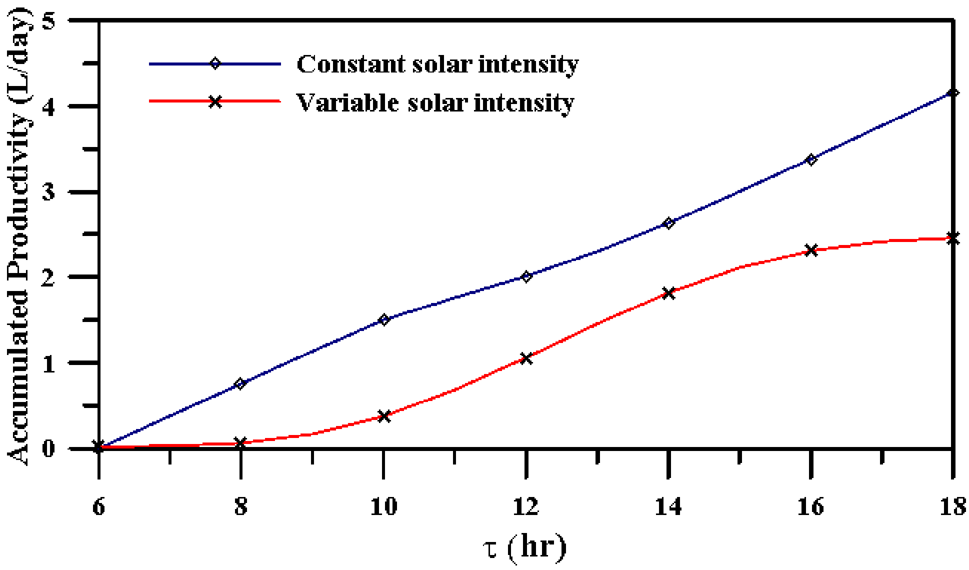

Fig. 4. Accumulated productivity for both variable and constant solar intensity

The linear differential equations 1, 3 and 6 for the energy balance are solved numerically with one second time step. The solar intensity in Eq.1 for basin plate is the actual solar intensity as shown in Fig.2 while the basin water will absorb heat from sun as $\alpha_w I$ with addition to the heat supply from the electric heater to be constant. The absorbed heat in Eq.3 for the water in the basin ($\alpha_w I$) will be constant at I_c with basin surface area equal unity (Table 1) as

$$Cp_w m_w \frac{d}{d\tau}(t_w) = I_c + h_{bw} A_b (t_b - t_w) - \frac{\sigma\left[(t_w + 273)^4 - \left(t_g + 273\right)^4\right]}{\left(\frac{1-\varepsilon_w}{A_w \varepsilon_w}\right) + \left(\frac{1}{A_g F_{gw}}\right) + \left(\frac{1-\varepsilon_g}{A_g \varepsilon_g}\right)}$$

$$-h_{cw} A_w \left(t_w - t_g\right) - 0.884\left[t_w - t_g + \frac{(p_w - p_g)(t_w + 273)}{268900 - p_w}\right]^{\frac{1}{3}} A_w \left(t_w - t_g\right) - (16.237 \times$$

$$10^{-3}) h_{cw} A_w (p_w - p_g) - m_{re}(Cp_w t_w - Cp_a t_a) \quad (11)$$

Where

$$I_c = \alpha_w I + Q_{electric\ heater} \quad (12)$$

As shown in Fig.5, for August month, the required constant heat rate supply to the water basin should be around 53 W/m^2 all the day time which is corresponding to the maximum solar energy peak value. This value corresponding to total energy to the water as 1272 W hr/m^2, 377.29 W hr/m^2 from the solar energy and 894.71 W hr/m^2 from the electric heater. The results in Fig.5 could be simply obtained for the eleven months to get the approximate required constant heat for the electric heater year around. With very simple control unit fed by these results, the required time dependent electric current to the solar still electric heater could be controlled to get maximum productivity of the conventional solar still. Fig.6 represents the hourly and accumulated productivity for 24 hr set time for the conventional solar heated solar still and the constant hybrid heat rate supply from both solar energy and electric heater energy. The new proposed system has a jump enhancement in the productivity up to 8.7 L/day in compared to 2.5 L/day for the conventional solar still. The new concept introduced in this study will be more excellent and professional in winter months. The wind turbine efficiently operates with high water productivity due to the low outside air temperature. The required heat supply to the electric heater to keep the heat supply to the saline water constant during the day is given in Fig.7 (extracted from Fig.5); the peak required energy to the still from storage energy in the battery is 894.71 W hr (as the basin area is equal to unity). As mentioned above in Fig.5, the peak electric heater power is 53 W. So, small wind turbine 1 kW will be used for both electric power generation and the electric heater capacity, Fig.8.

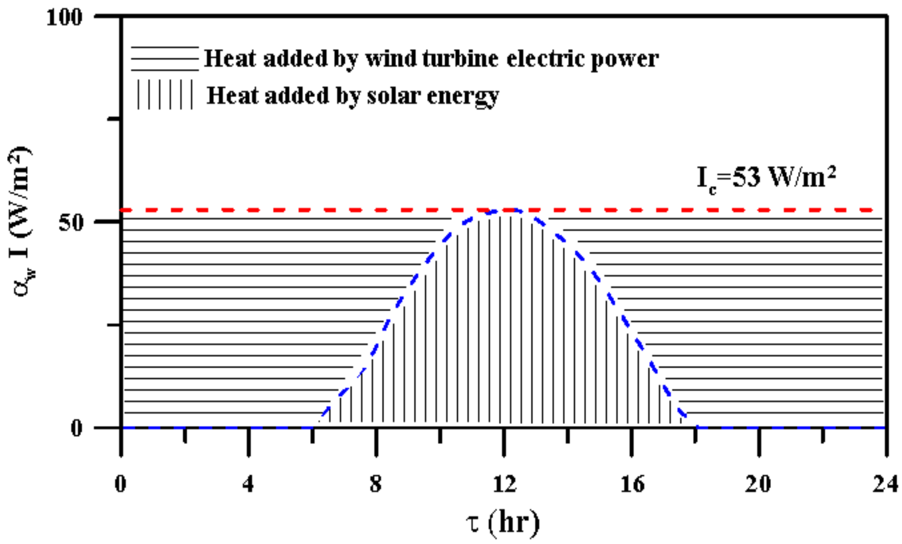

Fig. 5. Total heat supply to the water in the still during the day hours

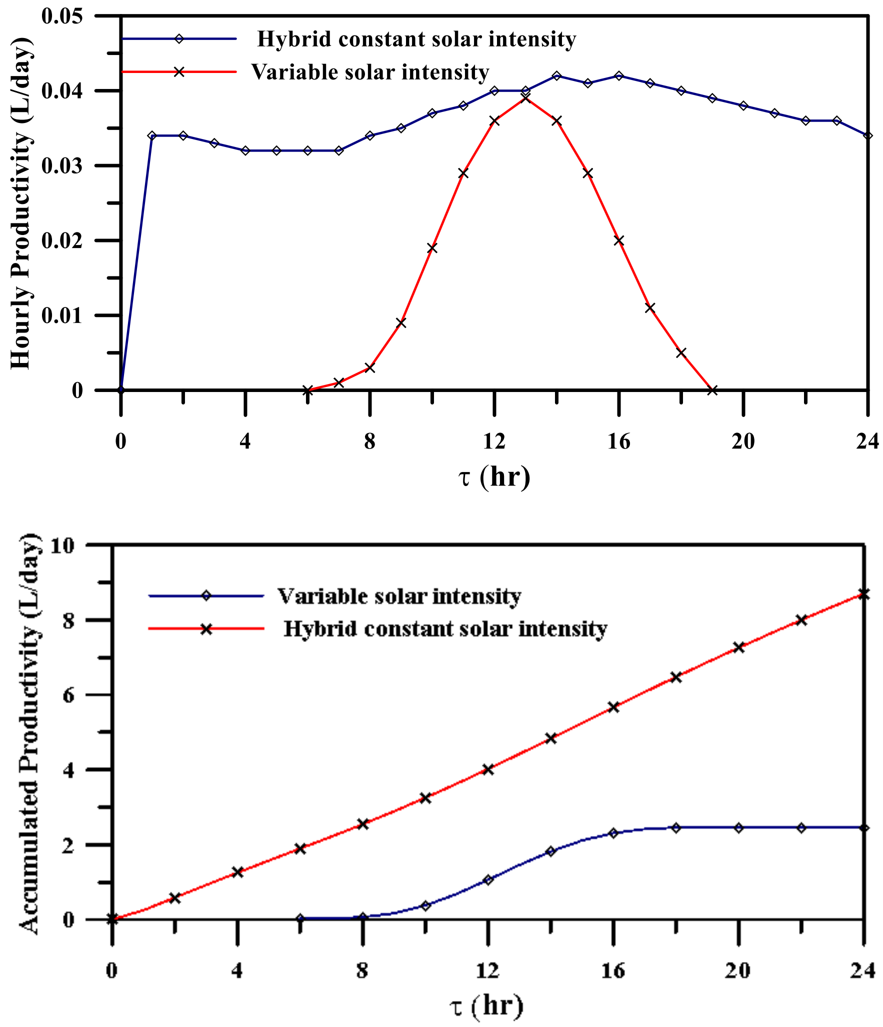

Fig. 6. Hourly and accumulated productivity for both conventional and hybrid heating solar still

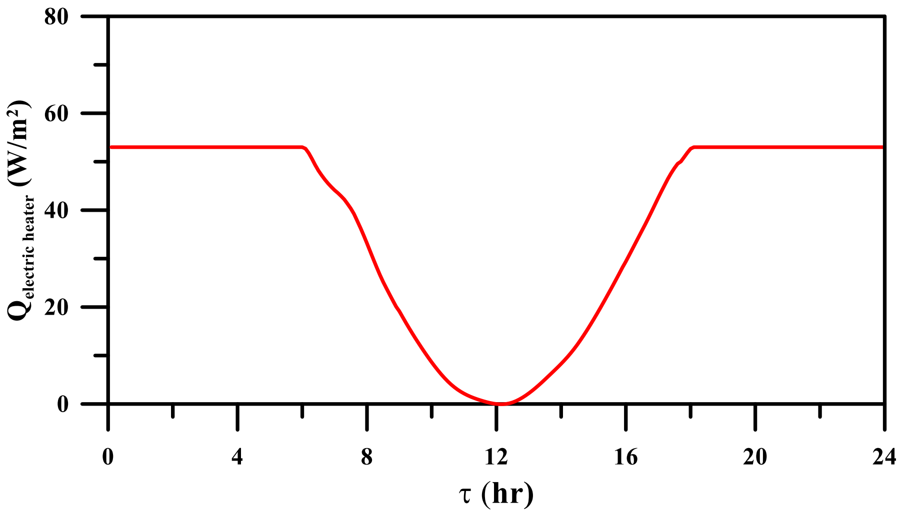

Fig. 7. required supplementary heat supply to the electric heater

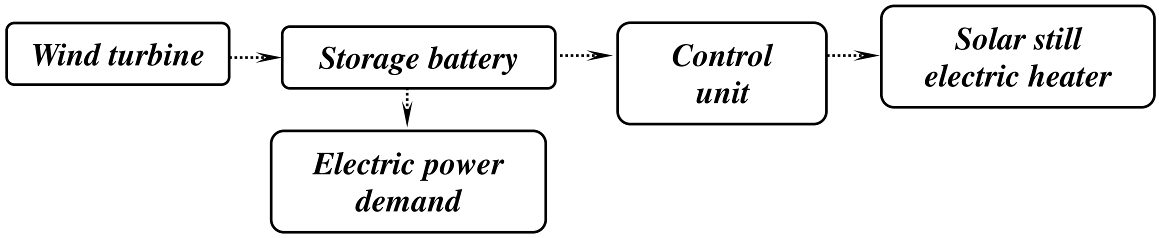

Fig. 8. Wind turbine power storage and electric heater control unit

In order to generate the required amount of energy used for the application, it is mandatory to store the electric energy generated from the wind turbine in an electric battery first and then re-use it throughout the whole day and night. This is performed through a standard charge controller from the generator of the wind turbine. The amount of electric energy generated by the wind turbine (around 1000 W). Once the energy is stored in the 12V-battery, the normalized loading shown in Fig. 7 can be adopted in order to produce the required heat for the overall process operation. The minimum and maximum values are 0 and 53 W/m^2 respectively. The loading pattern, shown in Fig. 7, spans the whole 24 hours of the day with peaks during the night and lower values down to zero at noon. The maximum power dissipation is designed to be 60 W/m^2 (above 53 W/m^2). The resistance of the heating element is calculated from the following equation.

$$R = \frac{V^2}{maximum\ Power} = 12.4\ \Omega \quad (13)$$

The battery voltage is applied to the heating element, which is taken to be a nickel-chrome wire (of resistivity $\rho = 1.35\ \mu\,\Omega.m$) and cross-sectional area (a = 1 mm^2). The length (L in meters) of the wire is calculated as in the following equation.

$$L = \frac{R\ .\ a}{\rho} = 9.185\ m \quad (14)$$

More details about the control unit is given in appendix B

7. Endorsement of the present work

Table 2 presents the current daily productivity of the new proposed system with previous modified conventional solar still. The selected previous studies are chosen with different modification technique and both the same current study metrological data of Egypt and other different weather conditions. The new proposed system philosophy enhances the performance with high grade. The bulky enhancement in the productivity due to the water productivity in all day hours with constant peak saline water heat supply.

Table 2

Comparison between the present still performance and previous studies

Authors	Location (Test year)	Conventional productivity (L/m²/day)	Modified productivity (L/m²/day)	Enhancement (%)
(Abdullah et al. 2019)	Alkharj, KSA (May-June 2018)	2	7	250
(Yousef et al.2019)	Borg El-Arab city, Egypt (September 2017)	3.26	3.81	16.87
(Abd Elbar and Hassan 2020)	Borg El-Arab city, Egypt (September 2019)	2.334	3.534	51.41
(Sathish et al. 2020)	Coimbatore, India (Feb- March 2019)	2.72	3.4	25
(Kabeel,et al. 2016(	Tanta city, Egypt (June-July 2015)	4.5	9.36	108
(Gupta et al.2016)	Jabalpur, India (April 2015)	2.12	2.57	21.22
(Kabeel et al. 2017)	Kafrelshikh, Egypt (September 2014)	3.72	4.2	12.9
Present study	Alexandria city, Egypt (August 2019)	2.5	8.7	248

8. Conclusions

This theoretical study showed that the steady constant heat supply to the solar still is an effective technique to enhance the conventional solar still performance. The absorbed heat in the basin is held constant besides adding the rest from renewable energy for instance wind turbine connected to the storage battery all day. The enhancement of the solar still performance is given in terms of the enhancement of the water productivity all day hours with constant peak saline water heat supply. The results show that, the solar still productivity with constant heat supply is more than that with same amount of variable energy during sun rise time only (6 AM to 6 PM) by 69.133 %. Accordingly, constant absorbed heat in the water basin through the 24 hr of the day enhances the performance with productivity up to

248% with the hybrid solar and electric power consumption of the wind turbine power. Finally, the proposed system is applicable not only for one solar still but for more than one with the same storage system (batteries) and the control unit. The proposed system gives high productivity of the common cheep solar distiller units with free supplementary heating from wind turbine in addition to the extra generated electric power for domestic use.

-Ethical Approval

Approved

-Consent to Participate

Approved

-Consent to Publish

Approved

-Authors Contributions

Wael M. El-Maghlany: Conceptualization, Methodology and results discussion.

Enass Massoud and *Mohamed ElHelw*: Results discussion and paper writing.

-Funding

No funding

-Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

- Availability of data and materials

Not applicable

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Appendix B

The control of the power in order to mimic the exact power requirement curve against time given in Fig. 7 above is performed using Pulse Width Modulation (PWM) driving a step-down Buck converter (chopper) MOSFET transistor. The curve above is stored in the memory of the microcontroller responsible for the PWM in the form of an array of 128 elements (from 0 to 127). In this case, the curve is subdivided into 128 points corresponding to the time and the corresponding ordinate values are stored in the 128 elements of the array. The time interval between each two consecutive samples is 11 minutes and 15 seconds. This array is presented in Table B; the values stored in memory (third column of the array) will constitute the reference signal for the PWM operation.

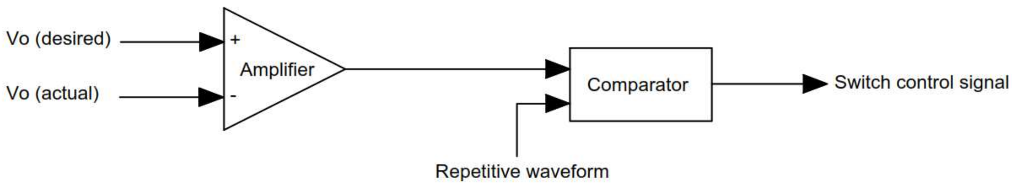
Table B

Sampled data array of the required power

Time of day (HH:MM:SS)	*Memory Address/Sample Number*	*PWM Reference*

00:00:00	0	53
00:11:15	1	53
00:22:30	2	53
00:33:45	3	53
…	…	…
12:00:00	63	0
12:11:15	64	0
…	…	…
23:37:30	126	53
23:48:45	127	53

The pulse width will increase in order to accommodate for the large value of required power (53 W/m^2) and it will decrease to zero at noon in order to generate zero output pulse and consequently zero output power. The operation of the PWM controller is depicted in Fig.B1. The microcontroller system employed (An Arduino Mega) is shown in Fig. B2. It is equipped with a Real-Time-Clock (RTC) connected as a shield to the Arduino. The RTC is responsible for generating the time-of-day that will in turn produce the PWM reference signal from the array. The carrier signal of the PWM is assumed to be a saw tooth signal. It is compared to the reference signal generated from the above array. The comparison of the carrier signal (saw tooth) and the modulating signal (reference) yields a binary (High/Low) decision, which is used after proper electronic buffering and isolation to drive the PWM MOSFET transistor responsible for the Buck converter operation. The PWM implemented in this case is performed as a software program inside the microcontroller. This part is denoted by the dotted of Fig. B2.



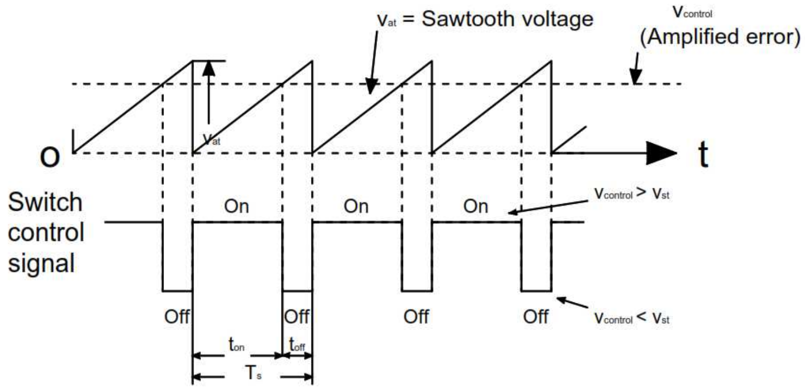


Fig.B1 PWM block diagram and comparator signals

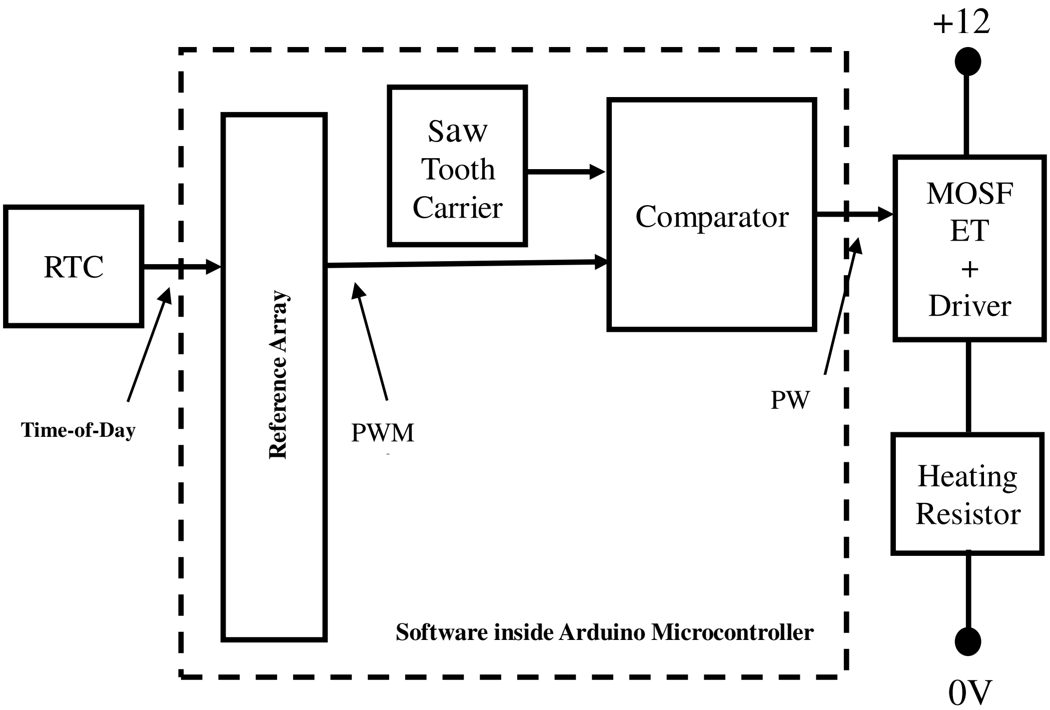


Fig. B2 Microcontroller system block diagram

The DC chopper power circuit of the MOSFET (including the MOSFET, driver circuit and heating resistor) is shown in Fig. B3, where the MOSFET is represented by a switch CH. The freewheeling diode (FD) is used in order to remove the effect of any stray and/or wiring inductances, which would damage the switching circuit. The heating element is represented here by a resistance (R). The output voltage and currents are pulse width modulated signals. The average of the product of these two signals represents the required power from Fig.7. This power will follow the curve desired according to the time of the day as mandated by the heating requirements of the overall system.

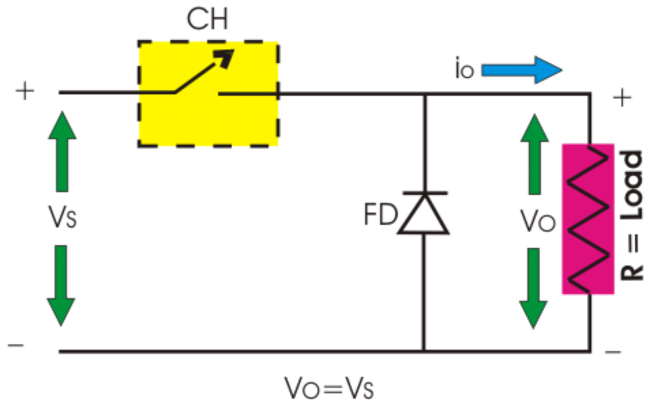


Fig.B3 Power circuit of the MSOFET and heating resistor

Figures

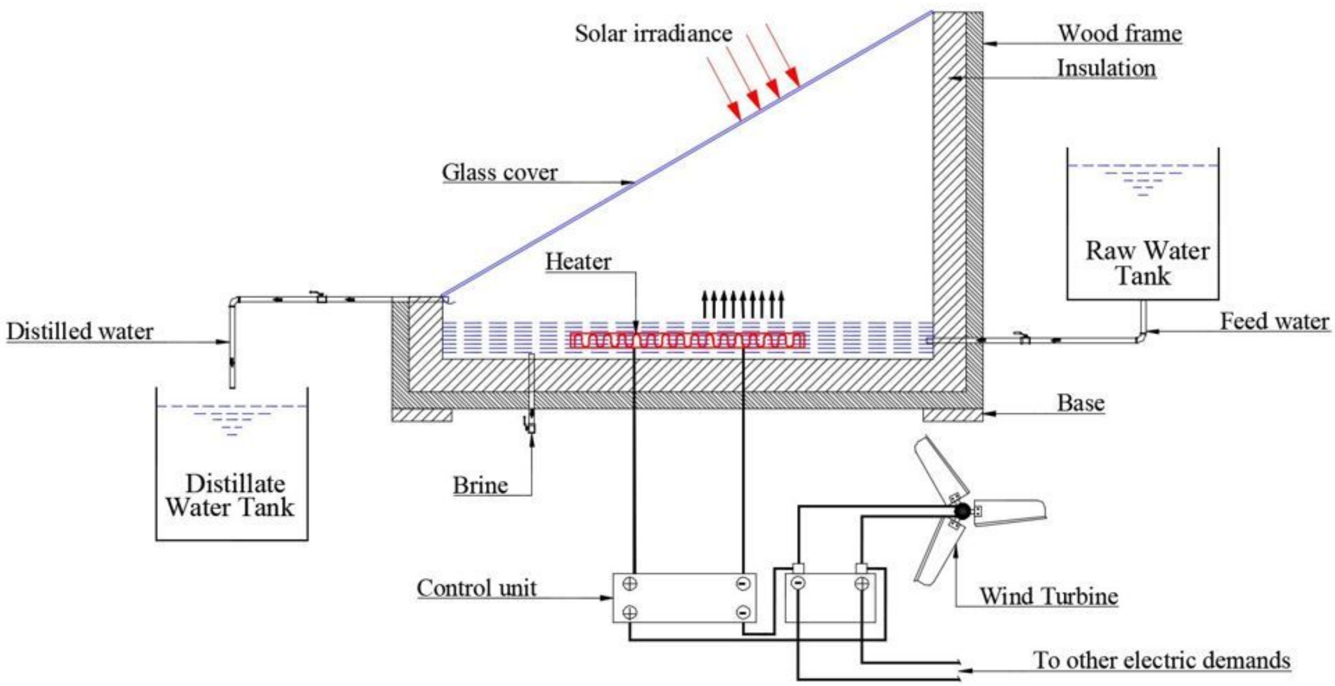


Figure 1

Conventional solar still with supplementary heat added

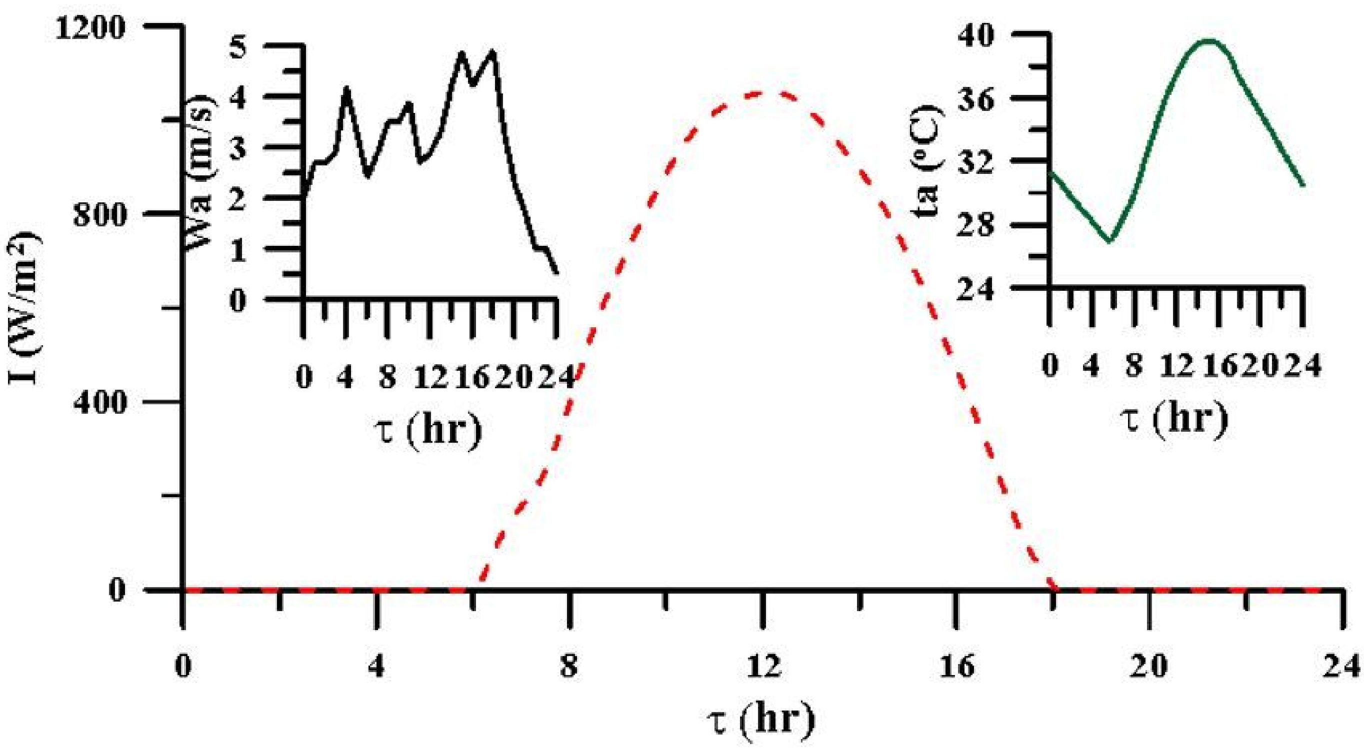


Figure 2

Average daily weather meteorological data of Alexandria in August

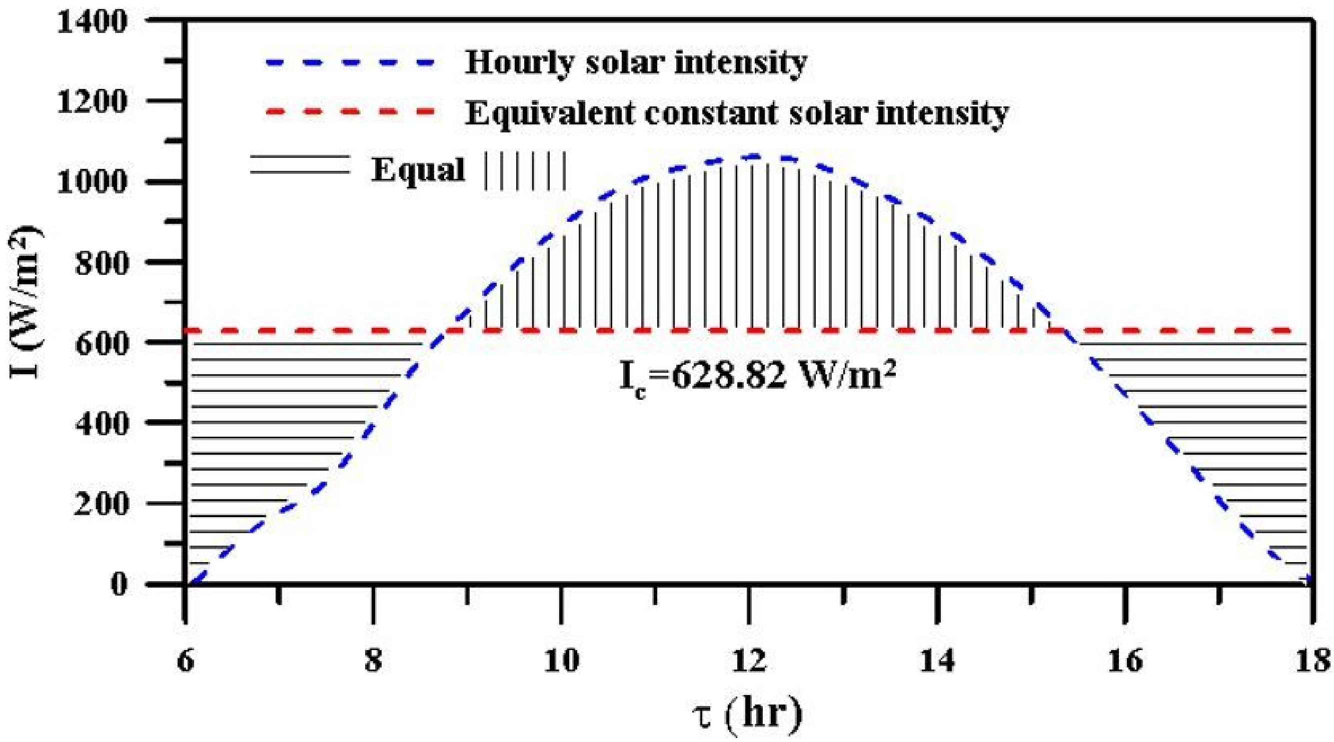


Figure 3

Average solar intensity and equivalent constant intensity

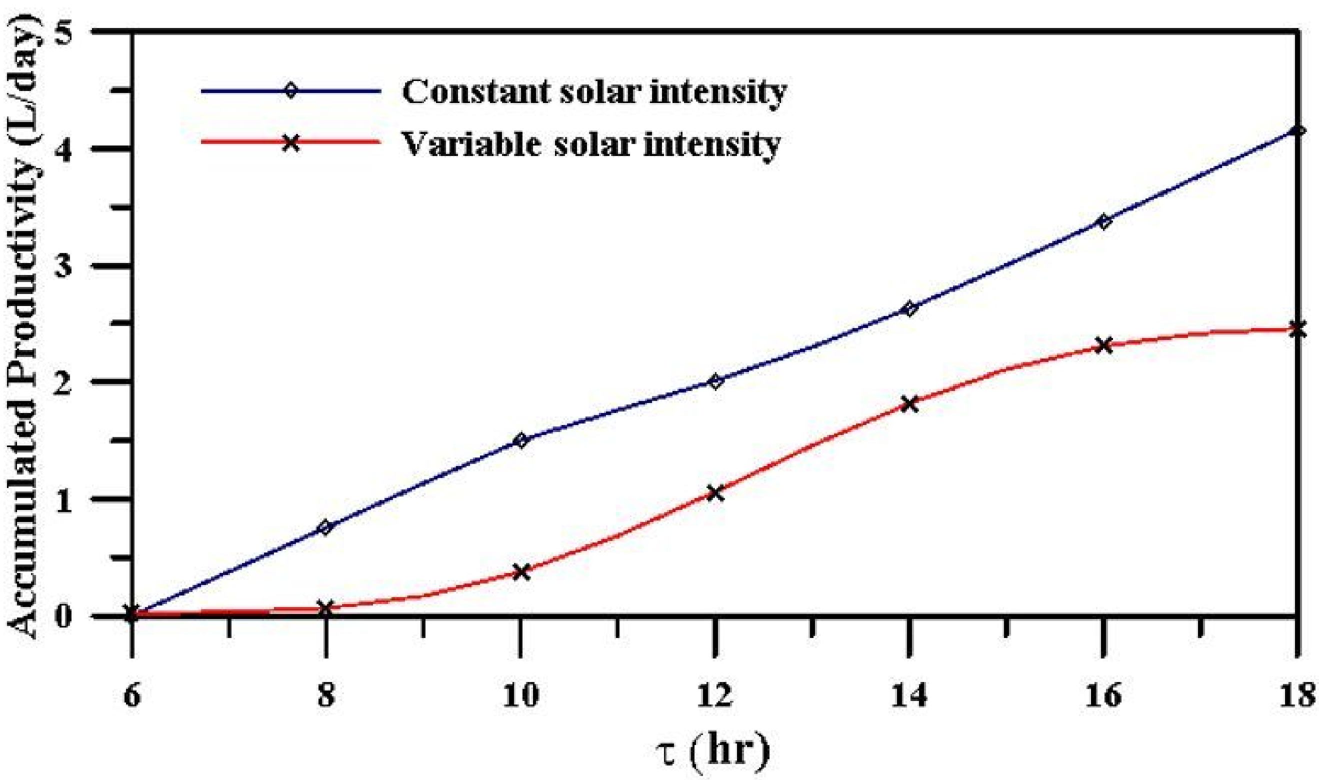


Figure 4

Accumulated productivity for both variable and constant solar intensity

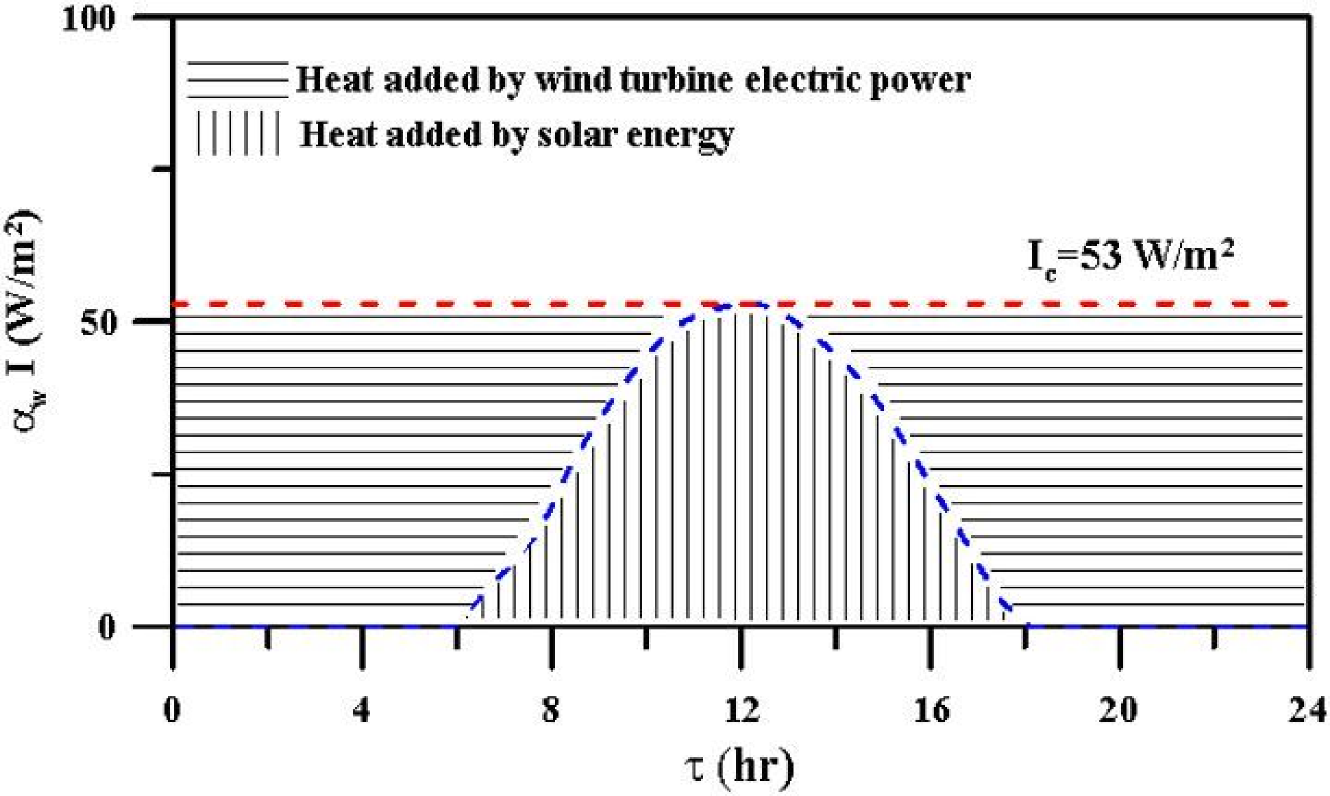


Figure 5

Total heat supply to the water in the still during the day hours

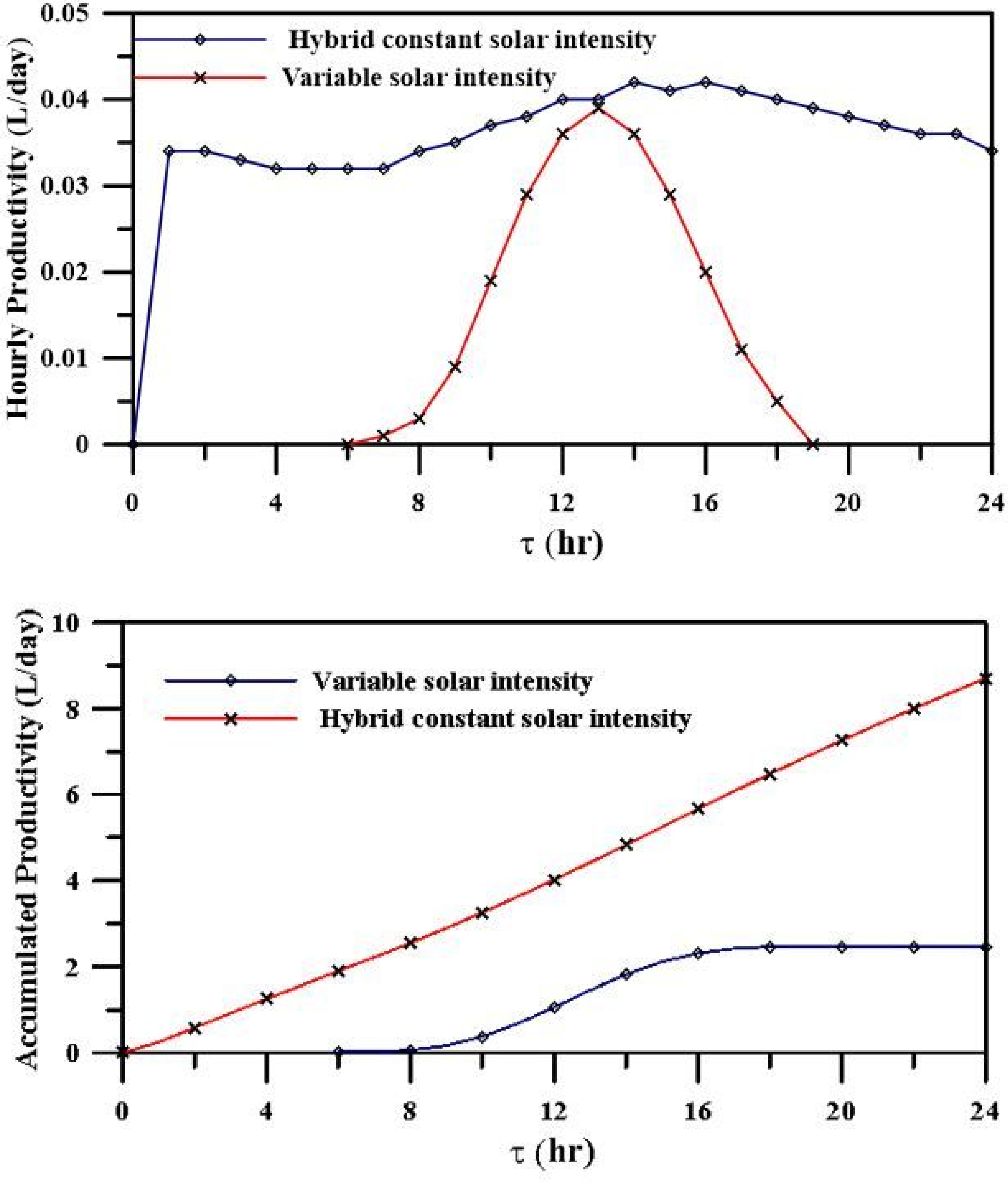


Figure 6

Hourly and accumulated productivity for both conventional and hybrid heating solar still

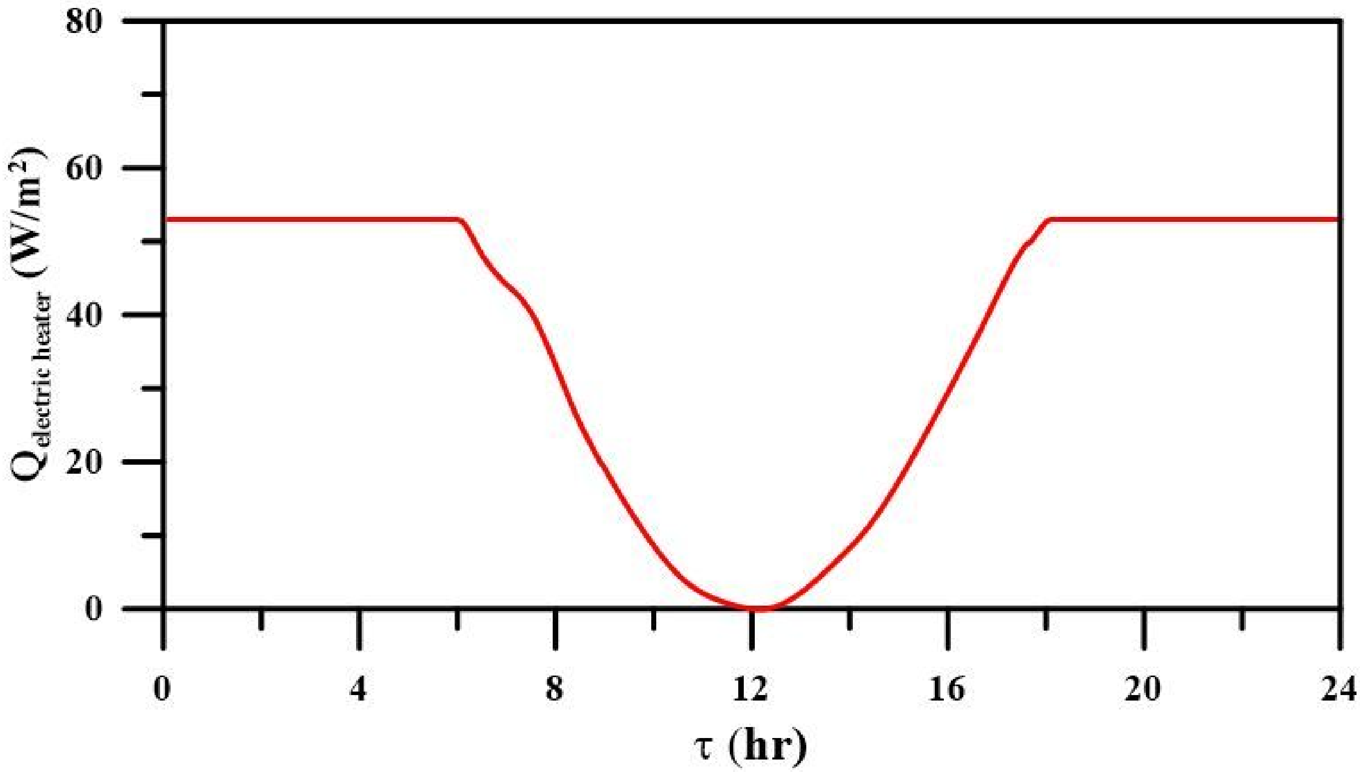


Figure 7

required supplementary heat supply to the electric heater

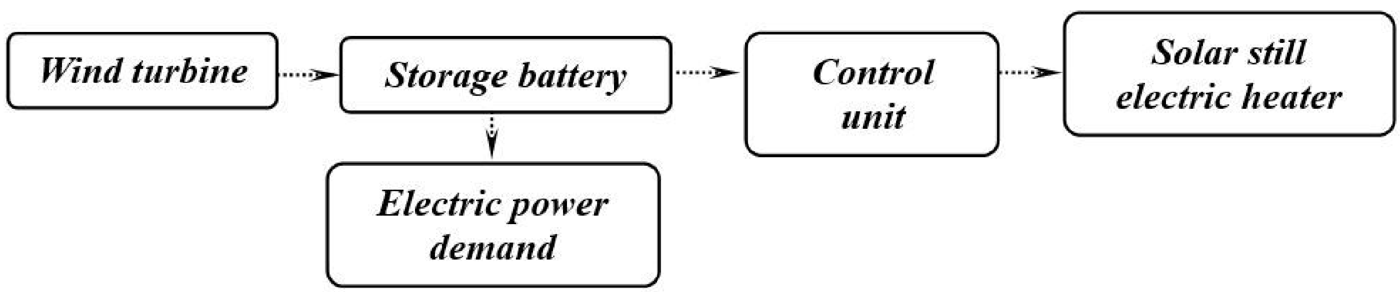


Figure 8

Wind turbine power storage and electric heater control unit

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- AppendixB.docx