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Performance and Efficiency of an Autoclave Made from Local Materials in Winter and Summer in Iraq

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Abstract

A solar-powered autoclave, made of a parabolic dish reflector that collects solar radiation at the focal point to heat a vessel, was established and tested. Thermal performance was tested and compared between months June and December 2022 through thermal energy efficiency equations and the total required thermal energy to evaporate water and the required thermal energy, where the highest values in June 2022 were 9%, 46 W, and 18 W, respectively at 9:00 am. Because solar radiation values are low, the energy required for heating is high and the lowest values were 0.2%, 1.9 W, and 0.5 W, respectively at 12:30 pm Because solar radiation values are high, the energy required for heating is less. While the highest values on December 2022 were 22%, 23 W, and 14 W, respectively, at 9:00 am, the lowest values were 0.6%, 1.16 W, and 6.6 W, respectively. At 12:00 pm, the values of December are considered higher for several reasons, including the values of solar radiation and the ambient temperature are lower than those of June, as well as the difference in the angle of incidence of solar radiation, so the thermal energy required for heating is higher. The effectiveness was tested against *pseudomonas aeruginosa* bacteria and samples of surgical kits made of stainless steel, where the highest values of steam temperatures for sterilization were recorded between 122 °C to 132 °C. Under a steam pressure of 1.3 to 1.9 bar between 11:00 am to 3:00 pm, one sterilization cycle took 30 minutes in June 2022, and for the month December 2022 the highest values of steam temperatures for sterilization were between 101 °C to 117 °C. Under steam pressure 0.7 to 1.03 bar between the hours 10:30 am to 12:30 pm, where the sterilization cycle was between 40 to 60 minutes, as a result of the decrease in solar radiation.

Keywords: solar autoclave, sterilizing, parabolic dish, solar energy.

الخلاصة

تم إنشاء واختبار الأوتوكلاف الذي يعمل بالطاقة الشمسية، وهو مصنوع من عاكس طبق مكافئ يجمع الإشعاع الشمسي في نقطة التركيز لتسخين الوعاء. تم اختبار الأداء الحراري ومقارنته بين الأشهر يونيو ديسمبر ٢٠٢٢ من خلال معادلات كفاءة الطاقة الحرارية وإجمالي الطاقة الحرارية المطلوبة لتبخير المياه والطاقة الحرارية المطلوبة، حيث كانت أعلى القيم في يونيو ٢٠٢٢ هي ٩٪ ، ٤٦ واط و ١٨ واط ,على التوالي عند الساعة ٩:٠٠ صباحًا. لأن قيم الإشعاع الشمسي منخفضة، فإن الطاقة اللازمة للتسخين مرتفعة وأدنى القيم كانت ٠,٢٪ و ١,٩ واط و ٠,٥ واط ,على التوالي الساعة ١٢:٣٠ ظهرًا ولأن قيم الإشعاع الشمسي مرتفعة، فإن الطاقة اللازمة للتسخين تكون أقل. بينما كانت أعلى القيم في ديسمبر ٢٢٪ و ٢٣ واط و ١٤ واط ,على التوالي عند ٩:٠٠ صباحًا وأدناها ٠,٦٪ و ١,١٦ واط و ٦,٦ واط ,على التوالي. الساعة ١٢:٠٠ مساءً،تعتبر قيم شهر ديسمبر أعلى لعدة أسباب منها قيم الإشعاع الشمسي ودرجة الحرارة المحيطة أقل من قيم شهر يونيو وكذلك الاختلاف في زاوية سقوط الإشعاع الشمسي لذا فإن الطاقة الحرارية اللازمة للتدفئة هي أعلى.. تم اختبار فعالية التعقيم ضد بكتيريا *Pseudomonas aeruginosa* وعينات من أطقم جراحية من الفولاذ المقاوم للصدأ، حيث سجلت أعلى قيم درجات حرارة البخار للتعقيم بين ١٢٢ درجة مئوية إلى ١٣٢ درجة مئوية. تحت ضغط بخار ١,٣ إلى ١,٩ بار بين ١١:٠٠ ص حتى ٣:٠٠ م ، كانت دورة التعقيم الواحدة ٣٠ دقيقة في يونيو ٢٠٢٢، وبالنسبة لشهر ديسمبر ٢٠٢٢ أعلى قيم لدرجات حرارة البخار للتعقيم ما بين ١٠١ درجة مئوية إلى ١١٧ درجة مئوية. تحت ضغط البخار ٠,٧ - ١,٠٣ بار بين الساعة ١٠:٣٠ ص الى ١٢:٣٠ م حيث كانت دورة التعقيم ما بين ٤٠-٦٠ دقيقة نتيجة انخفاض الاشعاع الشمسي.

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INTRODUCTION

Energy forms the basis of human life and renewable energy utilization is becoming more crucial in light of the expanding environmental problems and limited reserves of fossil fuels [1]. Solar energy is one of the most promising renewable energy sources since it is free, available at all locations, and non-polluting, in addition to reducing global warming [2]. sun is the main source of this energy that reaches the earth's surface in the form of electromagnetic radiation called solar radiation [3]. There are many applications for thermal solar energy among these applications is the solar autoclave [4]. It is used to sterilize medical instruments and treat biomedical waste steam based on neutralizing potentially infectious microorganisms by exposing them to high-temperature pressurized steam. Sterilization and disinfection are of fundamental importance in any health care provided that there is sufficient contact time with the material to be sterilized [5]. In steam sterilization, every fiber and surface of medical equipment will be penetrated and reached, respectively, at a specified saturated steam temperature, pressure, and time [6]. There is an inverse relationship between time and temperature in this method, which must be maintained to achieve effective sterilization. Usually, the time of a cycle is dependent on the degree of temperature [7]. Standardized autoclave sterilization is performed either at 121 °C and 1.1 bar for 20–30 min or at 134 °C and 2 bar for 5–7 min [8]. There are three indicators that can be used to detect the efficiency of the autoclave, and they include (1) physical indicators, which are the recording of temperature and pressure by devices. (2) Chemical indicators are used, and color change must be detected in the chemical indicator holder that has been sterilized after exposure to high temperatures 121 °C [9]. (3) Biological indicators are considered the most reliable monitor of sterilization effectiveness and are based on microorganisms, (e.g., *Bacillus stearothermophilus*, *Bacillus subtilis*, or *Geobacillus stearothermophilus)* spores that are killed at the standard autoclave temperature (121 °C) because these microorganisms are more resistant to high humidity and high temperatures than other pathogenic microorganisms [10][11]. There are many researchers studied solar autoclave designs, Sharma et al. (2017) [12] designed a device consisting of a parabolic reflecting basin with a surface area of 1.6 m^2 supported by wooden frames. The focal length of the basin is 18.3 cm. basin: reflects solar radiation towards a metal tube and passes inside a transparent vacuum tube. Water flows into the metal tube, where it is heated by the clear vacuum tube and converted into steam, which is used as a sterilant. The results showed that the temperature and pressure of the steam inside the pressure vessel (autoclave) were 132 °C and 1 bar. With the ability to maintain the generated steam for more than 15 minutes. The performance of a 1.8 m diameter parabolic dish-shaped solar collector covered with reflective aluminum foil was studied by Asfafaw *et al.* (2018) [5]. It reflects solar radiation towards the focus under a 3 mm thick, black-painted container to absorb the sun. It contains a thermometer, pressure gauge, and relief valve to maintain the steam pressure at the value required for sterilization standards. The results showed that this technology can produce steam at a temperature of 147 °C and can maintain it for 15 minutes. A solar system (steam generator) consisting of a coiled copper tube acting as a solar collector based on a layer of floating foam was used by Xinyu Wang et al. (2019) [13]. The copper tube has surfaces coated with a highly hydrophobic layer of black copper oxide to prevent corrosion of the tube, absorb heat, and prevent clogging. steam is generated at the inlet of the copper tube by the evaporation of water carried by a wick to the inlet of the tube and then heated inside the hot tube as it absorbs solar radiation as the steam moves from inlet to inlet of the tube. A biological indicator was used to verify the success of the sterilization process. It was placed at the outlet of the tube for 2.6 minutes, during which time the steam temperature was 132 °C. The indicator showed the success of the sterilization process. Khan et al. (2020) [14] created an experimental model (a black pressure vessel) equipped with a parabolic dish covered with aluminum metal to increase solar reflection. has been put inside the vessel 1.5 kg of medical supplies and 0.3 liters of water. According to the data, the parabolic dish generates steam at 121 °C and 1 bar of pressure. These properties can be maintained for 15 minutes, which is sufficient to carry out the sterilization process. The research aims to invent a sterilization device that works with alternative energy to serve the community and provide sterilization in rural areas and areas where electrical power is not available or areas where electrical power outages occur.

MATERIALS AND METHODS

Device Description

A solar-powered autoclave was designed using 500 ml of water in a vessel. The type of *(Pseudomonas aeruginosa)* bacteria was tested during the study period June and December 2022 from 9:00 am - 3:00 pm, in the local time of the city of Baghdad 33.31. latitude 44.361. longitude. The device consists of several parts:

Parabolic Dish

An elliptical dish is an old satellite dish that was recycled and painted with reflective chrome to increase the amount of reflected solar radiation. It was covered with square pieces of aluminum-coated mirrors whose dimensions are 0.05 × 0.05 m² at a reflectivity rate of 95 % [15]. It has a diameter of 95 cm, a depth of 11 cm, a focal length of 51.3 cm, and an area of 0.7452 m^2. Shown in Figure 1a.

Control and steering base

It is designed from recycled pieces of iron to become an iron structure that allows the dish to turn 360° horizontally and vertically with the flexibility to follow the sun and ensure that the solar radiation reflected from the surface of the dish is collected to the focal point at the base of the vessel. The structure is equipped with moving wheels at the bottom base. shown in Figures 1b, 1c.

Vessel

Pressure cooker made of steel with a capacity of 7 liters, coated in a matte black color to increase the absorption of sunlight. A pressure device was installed to measure the steam pressure inside the vessel, a thermometer to measure the steam temperature inside the vessel, and a steam control valve inside the vessel that could be closed tightly or opened to discharge the steam. shown in Figure 2.

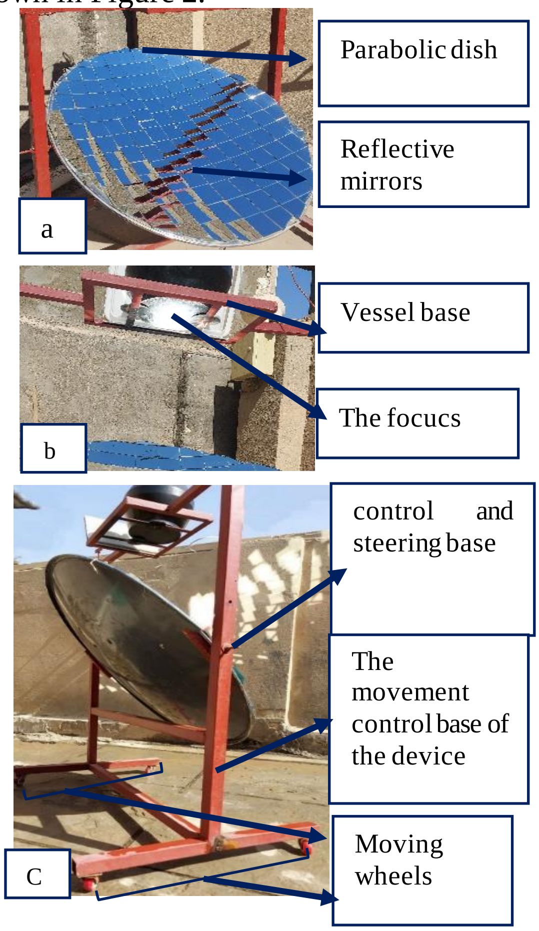

Figure 1. The solar autoclave

Extra tools to improve the performance of the device

An old light cover made of white acrylic plastic was added, in addition to two pieces of secondary ceiling made of the same plastic material that surround the bowl on three sides. This type of plastic is able to selectively reflect near-infrared radiation [16], that its reflection of solar radiation is about 80% [17]. These plastic pieces act as windbreaks to maintain vessel temperature without wasting energy.

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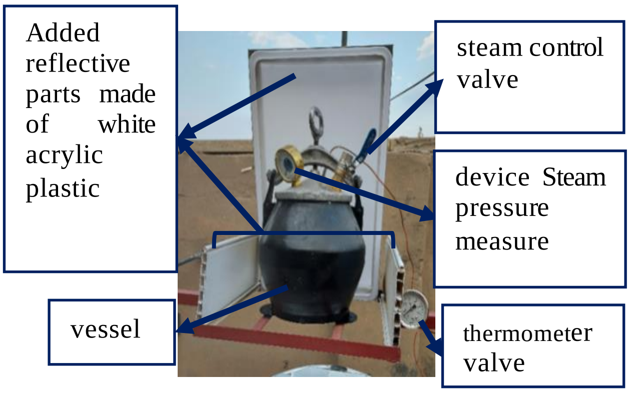

Figure 2. Parts of the solar autoclave with parts added to improve performance.

Thermal Analysis

This analysis is used to determine the total heat required for sterilization of the solar autoclave and associated losses. The minimum amount of power required to sterilize stainless steel surgical kits used for minor surgery is calculated based on the total mass of the sterilizing vessel and the assumed mass of a standard complete kit of steel surgical instruments contained within it. weight of each kit is 0.32 kg [18].

Two medical kits were considered as a load of sterilization that would be sterilized at a time in a 7-liter size vessel. A medical equipment sterilization test was conducted using heat collected from the sun to generate steam in a pressure vessel. 500 ml of water was used and converted to steam. A minimum steam temperature of 121 °C with a microorganism sterilization time of 30 minutes. The Thermal energy required to heat the vessel and the medicinal kits package inside it was calculated using Eq. (1) and the amount of steam needed was determined by Eq. (2). The total heat energy required to vaporize the water was calculated using Eq. (3).

$$Q_{required} = \frac{Q}{\Delta t} = \frac{m_i c_i \Delta T_i + m_v c_v \Delta T_v}{\Delta t} \quad (1)$$

where, Q: thermal energy, mi: the total mass of stainless steel tool kits =0.64 kg

C_i, C_v: specific heat capacity of stainless steel = 420 kJ/kg [19].

ΔT_i: the change in temperature of stainless steel tool kits

ΔT_v: the change in temperature of vessel

m_v: total mass of stainless steel of vessel= 2 kg

Δt: the time for sterilization=30 minutes=1800s

$$m_s = \frac{Q_{req}}{h_{fg}} \quad (2)$$

m_s: mass of steam in kg/s

h_{fg}: Enthalpy of evaporation= 2201 kJ/kg [20].

$$Q_w = \frac{m_w \, c_{pw} \Delta T_w}{\Delta t} \quad (3)$$

m_w: mass of water = 0.5 kg

C_{pw}: specific heat of water=4183 J/kg K [21].

Thermal Energy Efficiency

Energy analysis is building upon the first law of thermodynamics, solar autoclave energy efficiency can be defined as the ratio of the output energy of the system, which refers to the enthalpy change of water in the vessel due to temperature rise to the input energy, which refers to incoming solar radiation. Solar radiation falling on the reflective surface of a parabolic dish as follows [22]:

$$\eta = \frac{E_o}{E_i} \times 100 \quad (4)$$

where: η = Energy efficiency.

The energy input represents the total solar energy that is incident upon the plane of the solar autoclave per unit time per unit area, which can be estimated from the expression [23]:

$$E_i = I_b \times A_{sc} \quad (5)$$

where; E_i is energy input to the solar autoclave in Watt.

I_b: intensity of solar irradiance (W/m^2) during time interval Δt.

A_{sc}: The parabolic dish surface area (m^2) can be given using Eq. (6):

$$A_{sc} = \frac{8 \times \pi}{3} \times f^2 \left[\left(\left[\frac{d}{4f} \right]^2 + 1 \right)^{3/2} - 1 \right] \quad (6)$$

$$A_{sc} \simeq 7452 \, cm^2 = 0.7452 \, m^2$$

where: d= diameter, f: focal length. The distance between the center and the focus point that termed the focal length [24].

$$f = \frac{d^2}{16 \times h} = (95)2/16 \times 11 = 51.3cm = 0.513m \quad (7)$$

h: the depth of the dish.

The output energy of the solar autoclave can be defined from the efficiency of the solar collector that converts the solar radiation energy into heat energy. This heat energy is transmitted to the heating vessel. The solar output energy can be defined as:

$$E_o = \frac{M_w\, C_{pw}\, (T_{wb} - T_{wa})}{\Delta t} \quad (8)$$

where: E_o = energy output in Watt

T_{wa}: primary temperature of the water in (K),

T_{wb}: final temperature of the water in (K).

The overall exergy balance of the solar autoclave can be written as follows: [25].

$$Energy\ input = Energy\ output + Energy\ loss \quad (9)$$

RESULTS AND DISCUSSION

Figure 3 shows that the average steam temperatures for the month of June 2022 that have low values at the beginning of the day when the average solar radiation intensity values are low. The lowest value of the average steam temperature is 33 °C that recorded inside the vessel and the lowest value of the average steam pressure 0 bar at 9 am when the average intensity of solar radiation is 667 W/m^2. However, the values are gradually increased until they reach the maximum at 12:30 pm, when the average steam temperature inside the vessel becomes 132.6 °C and the higher values to the average steam pressure inside the vessel is 1.95 bar. When recording the highest average intensity of solar radiation 939 W/m^2 the values begin to decrease gradually until the average steam temperature inside the vessel reaches 122 °C and the average steam pressure becomes 1.31 bar at 3 pm, while the average intensity of solar radiation is 699 W/m^2.

June is one of the summer months when the solar radiation values are the highest. Through the values shown, we notice that the best sterilization period for the device was between 11:00 am to 3:00 pm, where the average steam temperature was recorded between 122 °C to 132 °C. Under a steam pressure between 1.31 to 1.95 bar. The sterilization cycle took 30 minutes.

Several samples of bacteria *(Pseudomonas aeruginosa)* were used to examine the sterilization efficiency of the solar autoclave device. The sterilization efficiency reached 100%, knowing that the period between 10:00 am - 11:00 am was tested during which the sterilization was Successful at the steam temperature average values ranged between 100 °C to 117 °C, at steam pressure average ranging from 0.7 to 1.12 bar, but it took a longer time for one Cycle, ranging from 40 to 60 minutes.

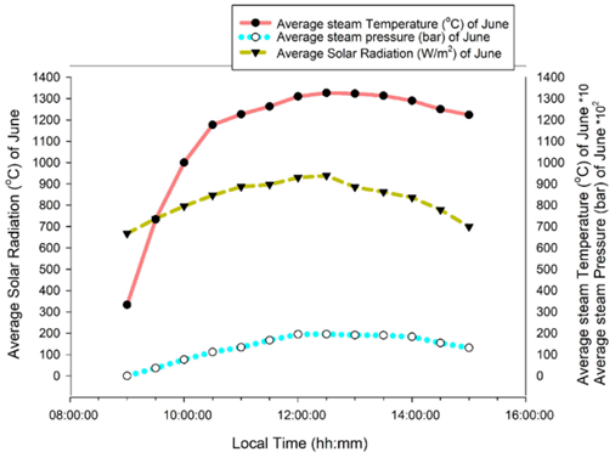

Figure 3. Relation between Solar Radiation and Average Steam Temperature and Average Steam Pressure with time in June.

All samples were examined in the Department of Biology Sciences, College of Sciences, Mustansiriyah University. The results of the examination proved that the samples were 100 % sterile as shown in Figures 4a – 4c.

a. Bacterial Samples before sterilization	b. Bacterial Samples before sterilization inside the vessel	c. Bacterial Samples after sterilization and examination

Figure 4. Photographs of bacteria samples prior to sterilization inside the solar autoclave and sterilization test results.

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Figure 5 shows that the average steam temperatures for the month of December 2022 have low values at the beginning of the day when the average solar radiation intensity values are low. The lowest value of the average steam temperature 25 °C recorded inside the vessel and the lowest value of the average steam pressure 0 bar at 9 am when the average intensity of solar radiation is 137 W/m^2. The values gradually increase until they reach the highest values at 12 pm, of the average steam temperature inside the vessel becomes 117.6 °C and the higher values to the average steam pressure inside the vessel is 1.03 bar when recording the highest average intensity of solar radiation 385 W/m^2 the values begin to decrease gradually until the average steam temperature inside the vessel reaches 48 °C and the average steam pressure becomes 0.2 bar at 3 pm, while the average intensity of solar radiation is 118 W/m^2. December is one of the winter months when the solar radiation values are the lowest. Several samples of bacteria (*Pseudomonas aeruginosa)* were used to examine the sterilization efficiency of the solar autoclave device. knowing that the period between 10:30 am to 12:30 am was tested during which the sterilization was Successful at the steam temperature average values ranged between 101 °C to 117 °C, at steam pressure average ranging from 0.7 bar to 1.03 bar, but it took a longer time for one cycle, ranging from 40 to 60 minutes.

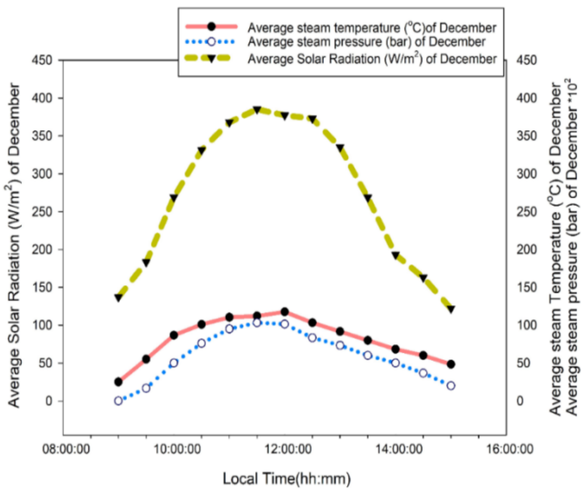

Figure 5. Relation between Solar Radiation and Average Steam Temperature and Average Steam Pressure with time in December.

All samples were examined in the Department of Biology Sciences in the College of Science at Mustansiriyah University, and the results show that they were completely sterile.

Figure 6 shows the relationship between the average intensity of solar radiation and the average energy efficiency in the solar autoclave at the time from 9 am to 3 pm for the months of June 2022 and December 2022, which is a comparison between the summer and winter seasons r/b. It was noted that the minimum value of the average intensity of solar radiation was at the beginning of the day at 9 am in June 2022 which was about 667 W/m^2. The average energy efficiency reached the maximum value 9%. This means that the energy required to raise the water temperature from the ambient temperature to the boiling point is very high because of the low intensity of solar radiation. However, the average intensity of solar radiation was in the minimum value 137 W/m^2 at the beginning of the day at 9 am for December 2022 while the average energy efficiency reached the maximum value 23%. This means that the energy required to raise the water temperature from the ambient temperature to the boiling point is much higher, as a result of the significant decrease in the intensity of solar radiation, after which the average intensity of solar radiation gradually increases. It reached the highest value 939 W/m^2 at 12:30 pm for the month of June 2022, then the average energy efficiency rate gradually decreased to reach 0.2% at the same time. This means that the energy required to raise the water temperature from the ambient temperature to the boiling point is very small due to the increase in the average intensity of solar radiation, and the average intensity of solar radiation increases gradually to reach the highest value 385 W/m^2 at 12 pm for the month December 2022. Then, the average energy efficiency rate will gradually decrease to reach 0.6% at the same time. This means that the energy needed to raise the water temperature from the ambient temperature to the boiling point is very small due to the increase in the average intensity of solar radiation, then the average intensity of solar radiation begins to decrease gradually to reach 699 W/m^2 at 3 pm for a month June 2022, and the average energy efficiency begins to increase gradually until it reaches 0.9%. This means that the energy required to raise the water temperature from the ambient temperature to boiling has become higher as a result of the decrease in the average intensity of solar radiation, and the average intensity of solar radiation also begins to decrease gradually to reach 118 W/m^2 at 3 pm for the month December 2022, and the average energy efficiency begins to increase gradually until it reaches 18%, and this means that the energy required to raise the water temperature from the ambient temperature to a degree. The boiling point becomes higher as a result of the decrease in temperature in the average intensity of solar radiation.

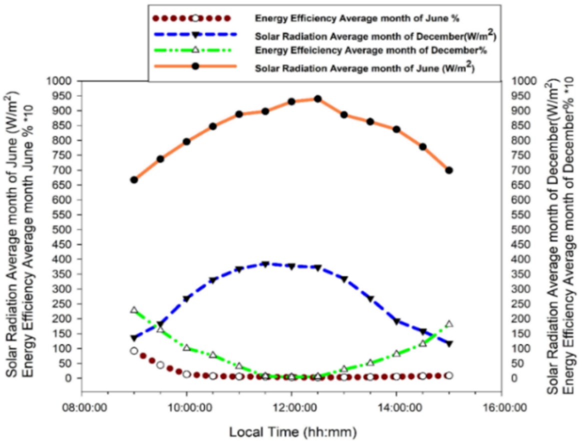

Figure 6. Relation between average solar radiation and average energy efficiencies with time in June and December.

Figure 7 shows the relationship between the average intensity of solar radiation, the total thermal energy required for water evaporation, and the thermal energy required in the solar autoclave for the month June 2022, where the average intensity of solar radiation reached its minimum value 667 W/m^2 at 9 am and was the thermal energy required to evaporate the water is the maximum value of 46 W, meaning that the energy required to raise the water temperature to the boiling point is very high, and the required thermal energy reached maximum value of 18 W. As a result of the decrease in the intensity of solar radiation and after that the average intensity of solar radiation gradually increases to reach the maximum 939 W/m^2 at 12:30 noon, and the average total thermal energy required for the evaporation of water reached the minimum value 1.9 W and this means that the energy required to raise the water temperature to the boiling point is much less, and the required thermal energy has reached the minimum value 0.5 W, as a result of the high intensity of solar radiation, after which the average intensity of solar radiation begins to gradually decrease to reach 699 W/m^2 At 3 pm, the average total thermal energy required to evaporate water was the high value 4.6 W. This means that the energy required to raise the water temperature to its boiling point becomes higher as a result of the decrease in the intensity of solar radiation, and the required thermal energy has reached a high value 2.7 W, as a result of the lower intensity of solar radiation.

Figure 8 shows the relationship between the average intensity of solar radiation, the total thermal energy required to evaporate water, and the required thermal energy, in the solar autoclave for the month December 2022.

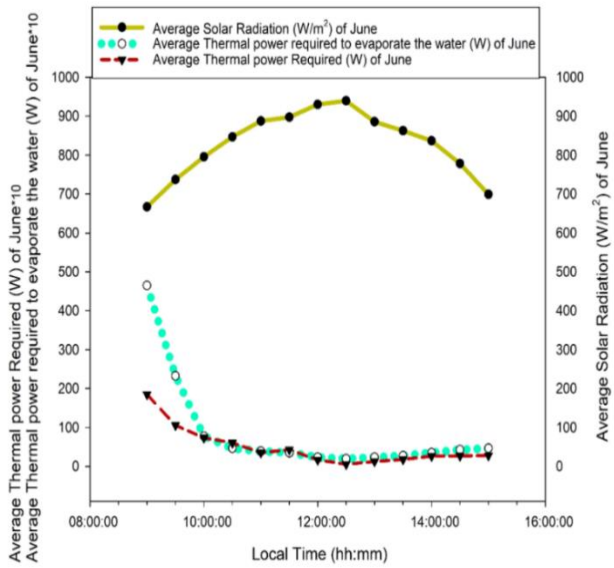

Figure 7. Relation between average solar radiation and average overall thermal power required to evaporate the water average thermal power required with time in June.

We note that when the value of the average intensity of solar radiation was the lowest value at the beginning of the day at 9 am, which amounted to 137 W/m^2, the average total thermal energy required to evaporate water was the highest value 23 W, and this means that the energy required to raise the temperature The temperature of the water reached a very high boiling point, and the required thermal energy reached the highest value 14 W. As a result of the decrease in the intensity of solar radiation, after which the average intensity of solar radiation gradually increases to reach the highest value 385 W/m^2 at 12 noon. Then the average total thermal energy required to evaporate the water reached the lowest value 1.1 W, meaning that the energy required to raise the water temperature to the boiling point is much less, and the average required thermal energy reached the lowest value 6.6 W, as a result of the high solar energy density. After that, the average intensity of solar radiation begins to decrease gradually to reach 118 W/m^2 at 3 pm, and the average total thermal energy required to evaporate water reaches the highest value 15.8 W, which means that the energy required to raise the water temperature to the boiling point has become higher, and the average heat energy required has reached a higher value 8.4 W due to the lower intensity of solar radiation as shown in Figure 8.

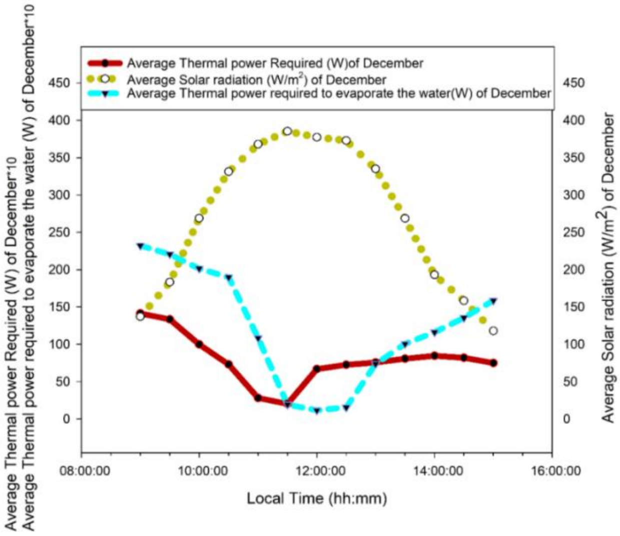

Figure 8. average overall thermal power required to evaporate the water average thermal power required with time in December.

CONCLUSIONS

The solar autoclave was designed in an economical way to solve sterilization problems and reduce pollution resulting from the consumption of fossil fuel energy, which contributes to the exploitation of renewable energies in a way that serves society and preserves the environment from pollution. The device uses the solar energy available in Iraq, and through the results and data. It was noted that the sterilization efficiency of the solar autoclave device in the summer was 40% higher than it was in the winter. In addition, it is found that the sterilization efficiency of the device was 100% when the value of the solar radiation intensity exceeds 590 W/m^2 as the energy efficiency of the device increases with the increase in the intensity of solar radiation. As for the efficiency of the thermal energy required to heat the device, the total thermal energy required to evaporate the water, increases whenever the intensity of solar radiation is low.

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Disclosure and Conflict of Interest: The authors declare that they have no conflicts of interest.

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