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Design and Construction Solar Oven Sterilizer

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ABSTRACT

Researchers are seeking to help doctors, especially surgeons, in remote areas overcome the problem of diseases transmission by using non-sterile surgical equipment. This study presented a design and model of a low-cost solar sterilizer to sterilize surgical equipment with hot dry air. Sterilization with dry hot air requires a temperature160℃ for 60 minutes. The design includes a stainless steel box with dimensions of 60 cm×30 cm×12 cm in which the surgical equipment is placed. This box is placed inside a chamber with insulated walls, except for the front and top. The front and top are a layer of tempered thermal glass. This chamber rests on an iron base that rotates around an axis in its center to follow the sun from east to west. Placed reflective sheets arranged in a cone shape around the surgical equipment box to increase the thermal enablement of the box. The system was tested in several variants. With and without surgical equipment and with and without reflective plates. The system achieved 160℃ hot air in 121 minutes. This period increased by 23.9% when surgical equipment weighing 1.2 kg was placed. The presence of reflective plates reduced the time required to achieve the required heat by 9%.

1. INTRODUCTION

Sterilization of medical surgical equipment is one of the basics in preserving human life. Sterilization is the process of eliminating all microorganisms present on the surface of a substance or liquid to prevent the transmission of harmful organisms through repeated use of these materials and liquids, and thus the transmission of infection from one person to another. The sterilization process is carried out in several ways [1], physical and chemical. Sterilization is done by physical methods using steam or hot dry air. The steam sterilization process requires steam at a temperature of 121.1℃ and a pressure of 2.1 bar for 15 minutes. The dry hot air sterilization process requires air at 160℃ for 60 minutes. As for sterilization by chemical methods, it uses ethylene oxide (EtO) sterilization, formaldehyde sterilization, plasma gas (H_2O_2), and acetic acid sterilization. There are some effective chemicals that perform the sterilization process for all surgical equipment, but these materials are very expensive. The type of sterilization method is selected based on the type of surgical equipment [2], to be sterilized. Some surgical equipment is affected by humidity and cannot be sterilized by steam. Sharp and microscopic metal equipment, powders, and glass are affected by moisture, so steam sterilization is not recommended. Also, some organisms are active in moisture. Some equipment, such as rubber and textile equipment, cannot withstand high temperatures, so it cannot be sterilized with hot dry air. The autoclave was manufactured for the purpose of steam sterilization and the oven for the purpose of sterilization with dry hot air. These devices have contributed to some extent in reducing the problem of cross-infection with surgical equipment. The problem of transmission of infection was not completely resolved, as it was impossible to use sterilization devices in remote areas where there is no electricity. Researchers and scientists had to use alternative energy sources, such solar energy, to produce the heat needed for sterilization. But all the researchers focused on the method of steam sterilization without the sterilization by hot dry air because steam sterilization does not need high temperatures as in needed with the method of sterilization with dry hot air. The methods of generating steam from solar energy differed among researchers, some of them used parabolic reflectors to generate steam, as Lawrence et al. [3]. They used a box with a length of 2 m, coated on the inside with a reflector and in the form of a parabola, and closed with a glass panel on the side opposite the sun, while the box was thermal insulated on the other sides. In the center of the parabola, a tube made of galvanized steel passes, through which water passes to take the heat that the inverter concentrates on the tube to gradually turn into steam, which in turn is rushed into the pressure chamber (autoclave). The system achieves temperatures of 118℃ and pressures of 18 psi, respectively. These results were close to what was required due to the heat loss from the walls of the autoclave and tubes.

Sunny et al. [4] Four convex lenses, 65 mm in diameter and 250 mm in focal length, were arranged in a circular frame to focus heat onto a 1.5 mm thick mild steel rectangular parallelepiped tank. The water is passed through 6 mm in diameter and 762 mm long copper tubes from the water tank to be converted into steam by the action of concentrated heat. The steam is then forced into a pressure chamber where surgical instruments are sterilized. Steam generation was achieved at a temperature of 132℃.

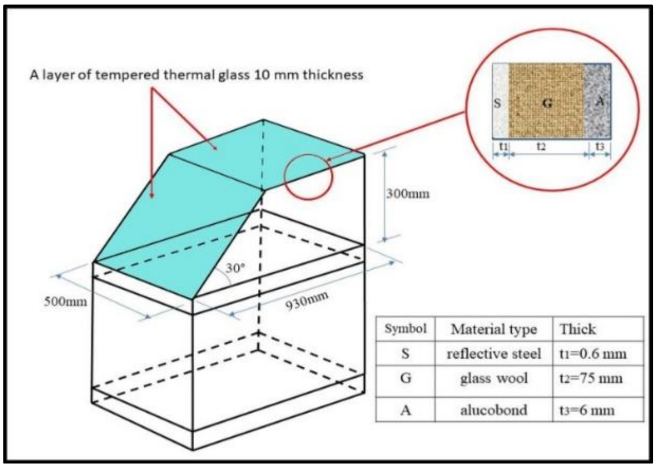
Harikrishnan et al. [5] came up with a design and construction of a solar collector to feed the steam sterilizer drum along with a water purification system. It consists of a magnesium-coated aluminum plate reflector, and a copper tube absorber of 2.5 feet in length and 30 mm in diameter, and a cylinder with a capacity of 3 liters. The steam coming after sterilization is condensed to generate pure water by a heat exchanger. The steam temperature was reached above 121℃ with a pressure of 0.1.8 bar in the pressure cylinder.

Hassan Abbood et al. [6] presented a design and model for a solar steam sterilizer. The system they presented did not use solar concentrators. Through it, they achieved steam with a temperature of 121.1℃ and a pressure of 2.1 bar within 151 minutes, when the average solar radiation during the test period was (988 W/m2 and an average ambient temperature of 37℃.

The lack of interest of researchers in the production of solar steam sterilizers is due to the fact that steam sterilization requires a lower temperature compared to sterilization with dry hot air, in addition, the sterilization process does not take long. Practical, while sterilization with dry hot air takes longer. They also used special bags in which they wrapped surgical equipment that was affected by moisture and that is supposed to be sterilized with hot, dry air. The question here is what if those bags are not available at the time that requires sterilization of materials that cannot be sterilized with steam, but rather need to be sterilized with hot dry air. And what about drying equipment that is sterilized by steam. Therefore, this study came to produce a design and model capable of generating dry hot air from available and inexpensive materials to be used for sterilization and drying. In this study, researchers invested in the properties of glass to collect solar energy and convert it into thermal energy to generate steam and dry hot air needed to sterilize and dry all types of surgical equipment.

2. EXPERIMENTAL SETTINGS

The design included the creation of a dry hot air sterilization chamber with a total volume of 0.1395 m^3. Its internal dimensions are 50 cm in width, 30 cm in high and 93 cm in length. Except for the top and front face of the chamber, the chamber walls consist of three layers: an inner layer of 0.6mm thick reflective steel, a layer of 75 mm thick glass wool, and an outer layer of 6mm alucobond. The back wall of the room was a gate built from the same layers as the other walls. The upper and front sides of the chamber were made of a layer of 10 mm thick thermo-strengthened glass.



Symbol	Material type	Thick
S	reflective steel	t1=0.6 mm
G	glass wool	t2=75 mm
A	alucobond	t3=6 mm

Figure 1. Schematic of sterilization chamber details

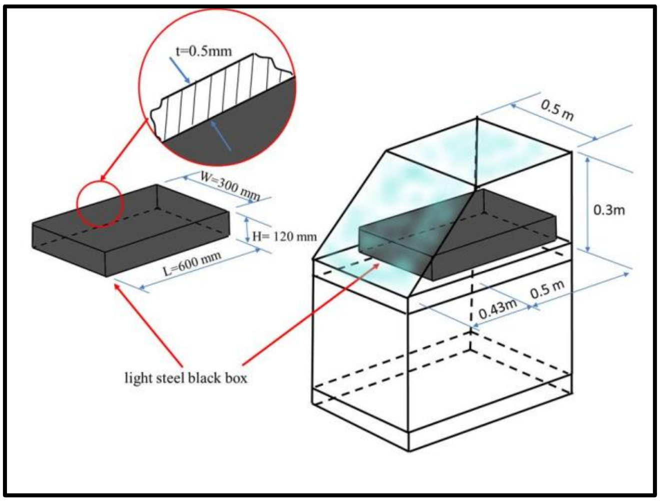


Figure 2. A simplified diagram of the sterilizer chamber

The top face was horizontal and the front face was tilted at an angle of 30°, as shown in Figure 1. Inside this room there is a thin stainless steel box with dimensions (30 cm×60 cm×12 cm). Surgical equipment to be sterilized is placed inside the box. As shown in Figure 2, the outer surface of the box has been coated with a matte black paint to absorb maximum heat from the solar radiation. The system is equipped with a solar tracking system that allows the system to track the sun from east to west.

3. FINAL DESIGN OF THE MODEL

Model looked manufactured as a solar collector, it has external dimensions of 68 cm in length, 1 meter in depth, 136 cm in back height, and 68 cm in front height. It has a heavy iron base is based on four wheels that rise from the ground at a distance of 20 cm and rotate easily on its vertical and horizontal axes. The researchers added thin, reflective sheets that were arranged in a conical shape around the surgical equipment box inside the chamber. This plate placed to increase the reflection of solar radiation towards the box and thus increase the thermal enablement of it. The model rotates around its axis of rotation and is installed in the middle of the base during the process of solar tracking from east to west, as shown in Figure 3.

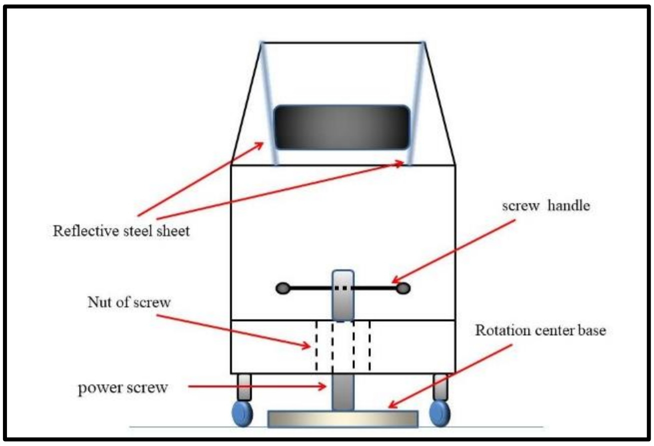


Figure 3. A simplified diagram of the front view of the final shape of the model

4. GOVERNING EQUATIONS

It was worked a thermal balancing of the system, and thus knowing the governing equations of the system, from which it was possible to know the amount of heat needed to heat the air inside the surgical instrument box and the time required for heating to reach the air temperature needed for sterilization, which should not be less than 160°C, as follows [6]:

$$\dot{E}_{in} - \dot{E}_o = \dot{E}_{system} \tag{1}$$

The solar radiation passes through the glass layer of the upper and front sides of the sterilization chamber and turns into heat energy. Its quantity depends on a number of factors, the first of which is the intensity of the incident solar radiation (I_{total}), the area of the glass layer through which the solar radiation penetrates (a), and the permeability of the glass layer (τ_g). Because the front face tilts the glass at an angle, which means that the geometric factor (R_b) must be taken into account in order to convert the radiation intensity perpendicular to the horizontal surface to perpendicular to the inclined glass surface. Therefore, when all these elements are multiplied, they give the amount of heat entering the chamber ($\dot{E}_{in}$). This heat is distributed such that part of it goes to heating the metal of the surgical equipment box ($Q_{abs,st.box}$) over time and also to heating the air (Q_{air}) over time, and when using surgical equipment it is placed inside the box with a mass of (m kg), and these devices will absorb part of the amount of heat that It enters the steam sterilization chamber, so the heat ($Q_{sur.abs}$) will be among the heat absorbed by the system. The sum of the three temperatures gives the heat absorbed by the system ($\dot{E}_{system}$), as well as the heat lost to the outside through the chamber walls ($\dot{E}_o$), which depends on the thickness and type of materials used in the layers of the walls as shown in Figure 4.

Accordingly, the heat entering the chamber will be equal to the sum of the heat absorbed by the system (the box and the air) and the heat lost to the ambient. Thus, the mathematical relationship can be written as:

$$\begin{aligned} I_{tatal}.A.R_b.\tau_g + I_{tatal}.A.\tau_g - Q_{losses} \\ = (E_{abs,steel\ box} + E_{sur.abs} \\ + E)/\Delta t \end{aligned} \tag{2}$$

$$\mathrm{E_{abs,steel\ box}} = \rho_{st}.\forall_{st,box}.C_{p,st}(T_2 - T_1) \tag{3}$$

$$\mathrm{E_{u,air}} = \rho_{air}\forall_{space}C_{v,air}(T_2 - T_1) \tag{4}$$

$$\mathrm{E_{sur.abs}} = m.C_{p,s.i}(T_2 - T_1) \tag{5}$$

where, that the volume of the walls of the box ∀, according to Figure 2.

$$\forall_{st,box} = 2t[(w+L)\mathrm{H} + (wL)] = 2.88 * 10^{-4}\ m^3$$

where, the volume of the hot air sterilization chamber space according to Figure 2:

$$\forall_{space} = 0.1395\ m^3$$

When taking into account the amount of energy reflected by the reflecting plates inside the sterilization chambers, the term $Q_{reflected}$ can be added to Eq. (2), where:

$$Q_{reflected} = (\mathrm{I_{tatal}}\ \mathrm{A}\ \mathrm{R_b}.\tau_g + \mathrm{I_{tatal}}\ \mathrm{A}\ \tau_g)r_{steel} \tag{6}$$

sub in Eq. (2).

where [7]: r_{steel}: Reflective steel sheet surface reflectivity=0.9, ρ_{st}=7865 Kg/m³, $C_{p,st}$=420 J/kg °C. From Figure 5, A=0.25m².

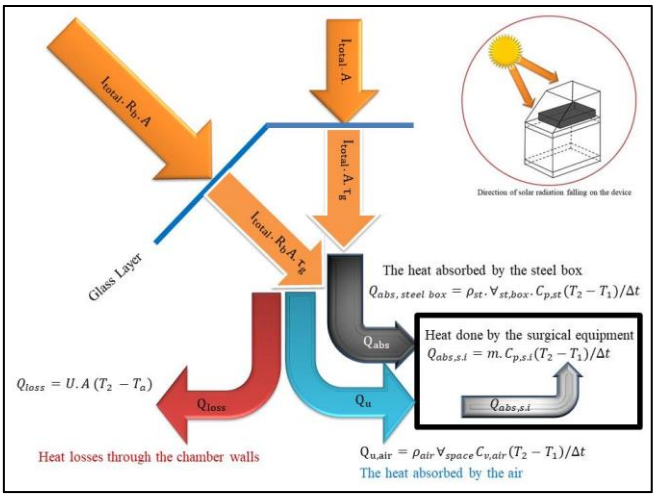


Figure 4. Thermal balancing diagram for the dry hot air sterilizer chamber

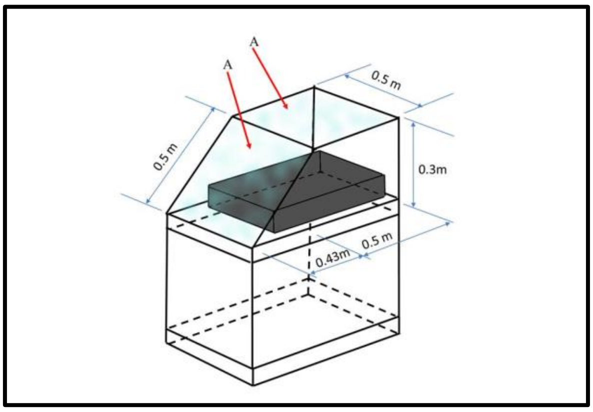


Figure 5. The total glass area through which solar radiation passes

To calculate the amount of heat losses to the external environment through the walls of the sterilization chamber Q_{losses} [8]:

$$\mathrm{Q_{losses}} = U_L.A_{surface}\,(T_2 - T_{amb}) \tag{7}$$

$$U_L = \frac{1}{\sum R} \tag{8}$$

$$\sum R = R_{conduction} + R_{convection,out} \tag{9}$$

$$R_{convection,out} = \frac{1}{h_{out}} \tag{10}$$

Calculation of the convective heat transfer coefficient at the outer surface of the heat sterilization chamber wall [9]:

$$h_{out} = h_w = 5.7 + 3.8\,V_w \tag{11}$$

where, V_w: Wind speed.

$$R_{conduction}[8] = \frac{X_{st}}{K_{st}} + \frac{X_{g.w}}{K_{g.w}} + \frac{X_{alu}}{K_{alu}} \qquad (12)$$

where, $X_{st}=t_1$, $Xg.w=t_2$, and $X_{alu}=t_3$: Thickness of steel layer, glass wool, and alucobond respectively. K_{st}, $K_{g,w}$, and K_{alu}: Thermal conductivity of steel, glass wool, and alucobond (W/m. K) [7, 10].

K_{st}=16.3 W/m. K
$K_{g,w}$=0.038 W/m. K
K_{alu} for 6mm thickness=0.35 W/m. K

By applying the values of thermal conductivity and the thickness of each layer of the chamber walls, assuming a wind speed of 6 m/s, the value of the heat lost to the outside environment is shown at a rate of 2.334(T_2-T_{amb}) Watts. The amount of energy absorbed by the surgical equipment box is 951.35(T_2-T_1) Joules.

5. RESULTS AND DISCUSSION

The final model was tested for several days and under various conditions. The tests began in April and continued until the end of May, when the first type of tests were conducted to test the model when exposed to the sun without placing any surgical equipment. The change in air temperature over time inside the surgical equipment box in the sterilization chamber was recorded. The test began at 10:00 AM, as the air temperature inside the surgical equipment box in the sterilization chamber was 76.8°C, because the system absorbed heat during the early hours of the day, from sunrise until the start of the test, and the increase in temperature was recorded over time every 20 minutes until the air temperature inside the surgical equipment box reached 160°C which is the temperature required for sterilization with dry hot air at 12 hours and 1 minute as shown in Figure 6. The climatic conditions in this test were with an average solar radiation intensity of About 903 W/m^2 and an average ambient temperature of 35°C.

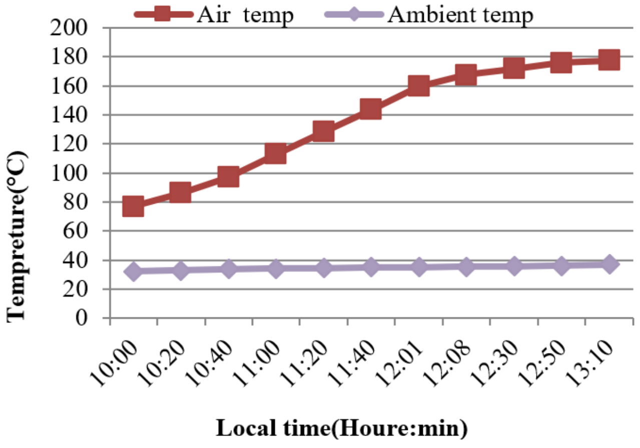


Figure 6. The air temperature changes inside box over time

Another test was conducted in which surgical instruments weighing 1.2 kg were placed in the sterilization box with the dry hot air in climatic conditions with the average solar radiation intensity was 967 W/m^2 and the average ambient temperature was around 36°C, as shown in Figure 7. Although the climatic conditions for this test were higher than it in the first test, the time required to reach the temperature required for sterilization was longer than in the first test, where the air temperature inside the surgical equipment box reached 160°C at 12:30 PM, after it was 74.4°C at the beginning of recording the readings. The reason was that metal surgical equipment absorbed part of the heat energy entering the sterilization chamber, where according to Equation 5, the value of heat absorbed by surgical instruments was about 49 kJ inside the sterilization chamber with dry hot air during the period from the beginning of test until the achieving 160°C. This means that the presence of 1.2 kg of surgical instruments caused an increasing in the time to achieve the temperature required for sterilization by 23.9%.

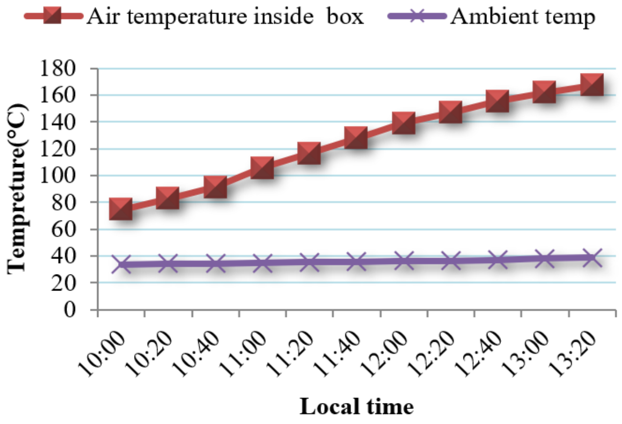


Figure 7. Air temperature changes inside the box over time with surgical equipment

After that, a test was conducted to increase the thermal enablement of the hot dry air sterilization box, after placing a thin reflective steel sheets that were arranged in a conical shape around the box to increase the concentration of solar radiation towards it. The results are as shown in Figure 8, which resulted in a 9% reduction in the time to achieve the required temperature inside the box from it at the last test.

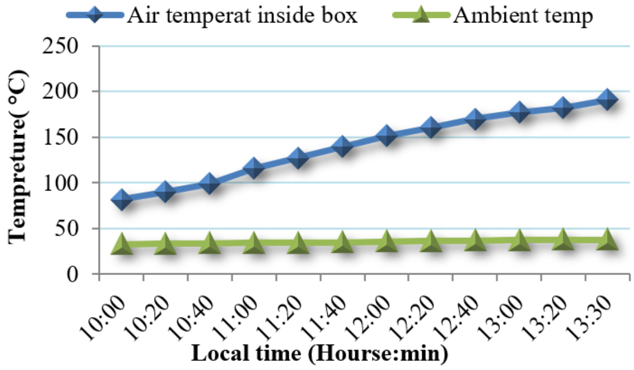


Figure 8. The temperature changes over time when using reflective plates with surgical equipment

The system was tested to find out the behavior of the temperature change inside the surgical toolbox along the hours of brightness, where the system was exposed to the sun from 7 AM, until 5 PM, and the temperature change was recorded during this period. It was found that the temperature began to gradually rise to achieve 160°C, at an hour 11:59 AM, as the intensity of the solar radiation was 1019 W/m^2 and the ambient temperature was 37.6℃. The temperature inside the surgical equipment box continued in rising until it reached a maximum value of 191.3℃ at 2:21 P.M with a solar radiation intensity of 920 W/m^2 and an ambient temperature of 38.8℃. It fixed at this value until 3:12 P.M and then began to decline until it reached 152℃ at 5 PM, when the intensity of solar radiation at that time was 677 W/m^2. It should be noted that the highest value of the ambient temperature was recorded at 39℃ between 3 PM and 4 PM, as shown in Figure 9.

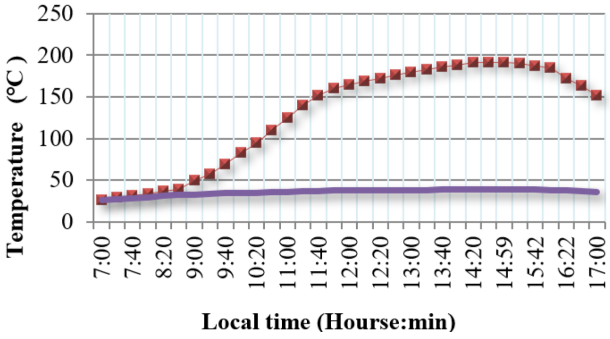


Figure 9. Air temperature inside box changes over time from 7 AM to 5 PM with surgical equipment and reflective plates

6. CONCLUSIONS

(1) The results of test of this test showed that the device can achieve two single sterilization cycles during the day on the days when the highest ambient temperature is around 35-37℃.

(2) The results showed that the presence of surgical instruments in the sterilization rooms causes an increase in the time required to achieve steam sterilization by 23.9% for every 1.2 kg of surgical devices.

(3) The presence of the cone-shaped reflective panels placed around the steam sterilization drum reduced the time required to reach sterilization standards by 9%, with 1.2 kg of surgical equipment.

(4) The temperature inside the surgical equipment box reached its highest value, reaching 191.3℃ at 2:21 PM. On a day when the peak of solar radiation was at 12:06 noon, the ambient temperature was 39℃.

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