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Study and Design for the Development of a Solar Powered Autoclave

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ABSTRACT: *In this study, a battery powered autoclave was designed and produced using locally sourced materials. The autoclave consists of a double walled cylinder with an outer wall of 300mm diameter and inner cylinder of 260mm diameter. Test carried out on the autoclave's suitability and for sterilization of medical equipment showed that there was a phenomenal decrease in the microbe population growth after 5 minutes of operation with total destruction of the microbe after 30 minutes of operation of the device at sterilization temperature of 1300C. Comparisons made between the fabricated battery powered autoclave and a conventional electrical autoclave showed that there were similarities in attaining temperatures and sterilization of test specimens with a time difference of 10 minutes arising from the difference in maximum times of 20 minutes and 30 minutes to reach sterilization temperature by the conventional autoclave and the fabricated autoclave respectively. The results revealed that the fabricated inverter/battery powered autoclave was effective in carrying out sterilization as compared with standard existing autoclave powered by electricity from mains.*

Keywords: *Solar power, Design, Autoclave, Battery, Sterilization, Temperature, Health care*

I. INTRODUCTION

Autoclave is a device that sterilizes laboratory instruments, glassware and medical equipment by using highly pressurized saturated steam to effectively kill microorganisms. An Autoclave is a sealed vessel that operate at high temperature and pressure in order to kill microorganisms and spores. Biological hazards are also rendered inactive by an autoclave machine. Autoclaves provide a physical method for disinfection and sterilization. They work with a combination of steam, pressure and time. Autoclaves are used to sterilize tools and equipment in medical, dental and laboratory environments by treatment with high temperature steam. Prior to the use of autoclaves, sterilization was frequently performed using boiling water at 1000C, an insufficient treatment as many bacteria and microorganisms survive temperatures up to 1200C. The steam temperature of the autoclave must therefore exceed 1200C to reach adequate sterilization (Vårdhandboken, 2011). According to present regulations, a temperature of 1340C must be upheld for at least 3 minutes inside the sterilization chamber.

The pressure inside the sterilization chamber is increased in order to obtain dry saturated steam with the temperature suitable for sterilization. Fossil fuel remains a major source of power for such equipment in the absence of hydro generated electricity. Fossil fuels is non-renewable and environmentally hazardous hence, the need to explore safe, clean renewable energy such as solar energy becomes imperative, particularly in the medical environment for the sterilization of medical equipment such as the autoclave. An autoclave, converter or a steam sterilizer is a widely used method of heat sterilization. The sun is one of the gifts of nature. Its ability to solve most of developing nations of Africa's challenges, some of which have been stated earlier cannot be over emphasized. One of the major ways in which the energy from the sun (often called solar energy) has been utilized is through solar heating technologies (Ahmad, 2001), which is available in different types (Otte, 2013). A solar powered autoclave will utilize the solar energy from the sun and through a setup of solar collectors, inverter and batteries which converts the energy to electricity and used for the sterilization process. Per Hamlin (2012) from Chalmers University of Technology

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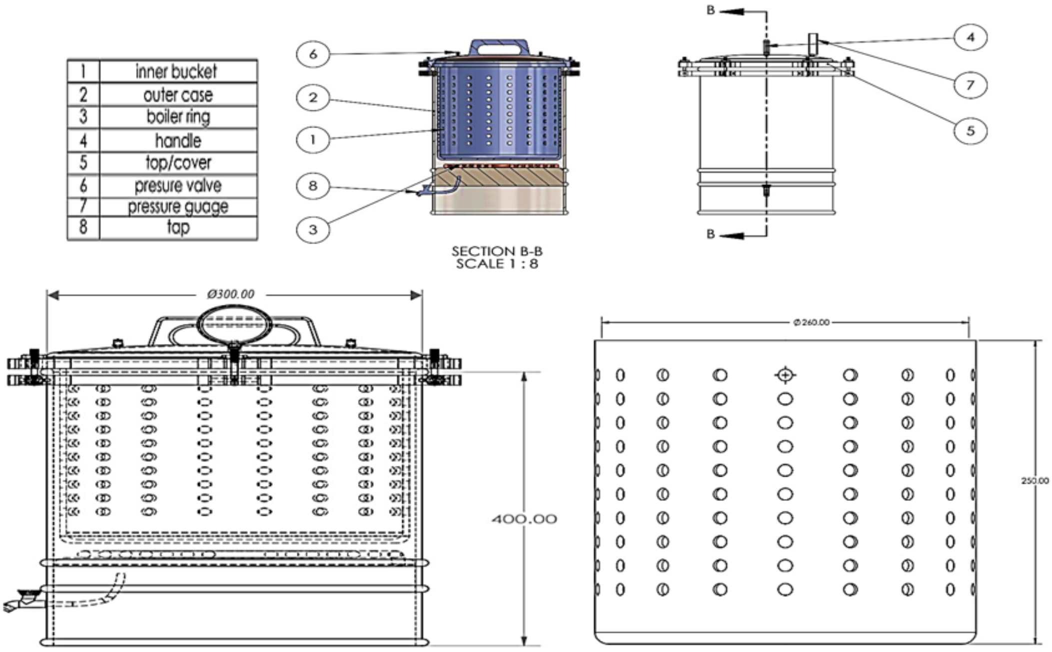
Sweden, worked on the on the generation and distribution of Steam in an Autoclave. However, due to epileptic power supply from the public utility, this has been a major challenge and has resulted in some dire consequences. This study is aimed at designing an autoclave that runs on solar photovoltaic electricity which can be available at all times. Autoclaves used in sterilization of medical equipment in Nigerian hospitals are mostly electrically powered. Their use has led to complications during times of electrical failures or epileptic supply as prevalent in some developing countries like Nigeria. In response to the problem, scientists and engineers are turning their attention to renewable energy such as solar energy to power equipment like the autoclave. Though the sun may not be available in 24 hours of the day, the development of a solar powered autoclave with energy storage capabilities that sterilizes medical equipment can be a viable solution to this problem.

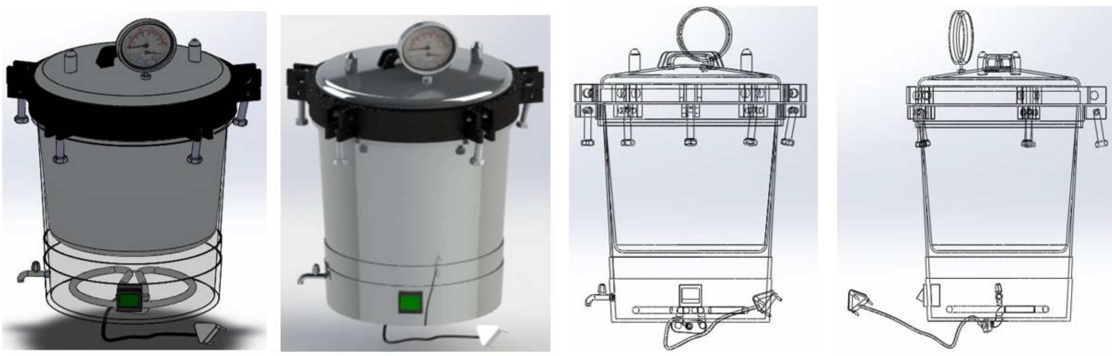
II. Autoclave Design and Analysis

The autoclave consists of a double walled cylinder with an outer wall of 300mm diameter and inner cylinder of 260mm diameter. The inner cylinder is perforated to admit steam when the water boils. The sterilization cylinder and the inner container are shown in Figure 1. The cylinder and the accessories of the cylinder were bought off the shelf. Computer aided designs of the autoclave are presented in Figure 2.



a. Sterilization Cylinder b. Inner Container

Figure 1: Sterilization cylinder and inner container



a. Rendered view of Bucket Autoclave b. Rendered view of Autoclave c. Orthographic front view of Autoclave d. Orthographic side view of Autoclave

Figure 2: Computer aided designs of autoclave

The cylinder has a swiveling cover that is clamped down to make the autoclave air tight. Finally, a provision is made on the top for attachment of pressure relief valves and temperature/ pressure gauge. The sterilization cylinder is the heart of the autoclave, where the sterilization of materials is carried out. The source of steam generation in the chamber is through electrical heating. At the bottom, there is a space between the inner and outer cylinder to accommodate the heating element and water for the operation. The inner cylinder is perforated to admit steam when the water boils. The cylinder has a swiveling cover that is clamped down to make the autoclave air tight. The water is heated by the boiler, thereby producing steam. Maximum operating (sterilization) temperature of 121^0C and corresponding vapor pressure of 2bars at 121^0C were specified for the autoclave design while the power source was obtained from solar energy comprising photovoltaic cells, inverter and dc batteries. In order to determine the capacity of the autoclave, it is necessary to calculate the energy required for a cycle of operation. This was determined in the following steps.

i. Step 1: Energy to heat the autoclave mass to 121^0C
ii. Step 2: Energy to heat water to steam at 121^0C and pressure of 2bar
iii. Step 3: Energy to vaporize water
iv. Step 4: Energy to heat entrapped air from ambient to 121^0C at 2bar pressure
v. Step 5: Energy losses.

2.1. Energy to heat the autoclave mass to 121^0C

To determine the energy to raise the temperature of the autoclave from ambient temperature of 25^0C to 121^0C. The mass of the autoclave was first determined. This, in turn follows from the determination of the volume of the autoclave. Dimension of the sterilizing cylinder was 0.3m diameter and 0.4m height while the dimension of the inner cylinder was 0.26m diameter and 0.25m height. Volume of the outer chamber material (V_1) was calculated as 0.001526983675 m^3 using Equation 1. Volume of the inner chamber of cylindrical material (V_2) was calculated as 0.0007648207315 m^3 using Equation 2.

$$V_1 = \pi (r_{o1}^2 - r_{o2}^2) h_1 \quad (1)$$

$$V_2 = \pi (r_{i1}^2 - r_{i2}^2) h_2 \quad (2)$$

where r_{o1} is the radius of outer cylinder, r_{o2} is the inner radius of outer cylinder and h_1 is the height of outer cylinder, r_{i1} is the outer radius of inner cylinder, r_{i2} is the inner radius of inner cylinder and h_2 is the height of inner cylinder. Volume of Stainless the Steel (V_{ss}) was 0.002291804406 m^3 while the mass (m_{ss}) was 18.18kg ≈ 20kg (Julie Quah. 2008). The energy (Q) required to heat a certain mass (m) of a substance is a function of the material's specific heat capacity (Cp) and the change in temperature (ΔT)

$$Q_{ss} = m_{ss} * Cp_{ss} * \Delta T \quad \text{(Deborah M. Katz. 2016)} \quad (3.5)$$

where Q_{ss} is the heat of autoclave mass, m_{ss} is the mass of stainless steel = 20kg = 20,000g, $Cp_{ss}$is the specific heat capacity of stainless steel = 0.502J/gK and ΔT is the Temperature difference = $(121^0 – 25^0)$ K. Therefore,

$$Q_{ss} = 20{,}000g * 0.502J/g/K * (121^0 – 25^0) K$$

$$Q_{ss} = 963{,}840J = 963.84kJ$$

2.2. Energy to heat water from 25^0C to 121^0C

The autoclave is design to use 2kg mass of water. The autoclave is a modified pressure cooker and should be analyzed as a pressure cooker. In a sealed pressure cooker, the boiling point of water increases as the pressure rises, resulting in superheated water. At a pressure of 1bar or approximately 100kPa above the existing atmospheric pressure, water in a pressure cooker will reach a temperature of 121^0C. Inside the pressure cooker, once the water is boiling and the steam is trapped, the pressure from the steam increases and pushes on the liquid surface, which increases its boiling temperature.

$Q_w = m_w C_{pw} \Delta T$ (Deborah M. Katz) (3.6)

where Q_w is the heat of water, m_w is the mass of water = 2kg = 2,000g, C_{pw} is the Specific heat capacity of water = 4.186J/g/K, ΔT is the temperature difference = (121^o– 25^o) K. Therefore,

Q_w=2,000g * 4.186J/g/K *(121^o– 25^o) K

Q_w = 803,712J = 803.712kJ

2.3. Energy to Heat Entrapped Air

This was determined at Ambient Temperature of 25^0C to 121^0C at 2bar using Equation 3.

$$Q_{air} = m_{air} * c_{vair} * \Delta T \quad (3)$$

where Q_{air} is the energy to heat entrapped air, m_{air} is the mass of air = 318.153g, C_{vair} is the specific heat capacity of air at constant volume = 0.718J/gK and ΔT = Temperature difference = (121 – 25) K.

Q_{air} = 318.153g * 0.718J/gK * (121-25) K
Q_{air} = 21,930J = 21.930kJ
Total Amount of Energy to heat up the Autoclave = $Q_{ss} + Q_w + Q_{vap} + Q_{air}$
= (963.84 + 803.712 + 160.396 + 21.930) kJ = 1,949.878kJ
1,949.878kJ is the Amount of Energy Required to Heat up the Autoclave.

2.4. Autoclave Power

A heat up duration of 30minutes is assumed. Therefore, 1,949.878kJ was calculated as the amount of energy required to heat up the Autoclave. The power, P required to achieve energy input of 1,949.878kJ in 30 minutes is given as:

P = Energy/ Time

P = 1,949.878/ 30*60 = 1.0833kW

2.5. Energy Losses

The type of heater used in the autoclave is the heater in the chamber. This type of heater is always immersed at the bottom part that is occupied by water in the autoclave. There are two types of energy losses when considering energy losses in autoclave. They are determined thus;

i. Convection Heat Loss

This type of heat loss can be determined using Newton's Law of Cooling. Using Equation 4, the heat transfer per unit time was calculated as 995.26W.

$Q_{conv.} = h_c A \Delta T$ (Rajput, 2006) (4)

Where Q_{conv} is the heat transfer per unit time (W) and h_c is the convective heat transfer coefficient of the process = 20 W/m^2K, A is the heat transfer area of autoclave given by Equation 5.

$2\pi r^2 + 2\pi rh$ (5)

= $2\pi (0.15^2) + 2\pi (0.15 \times 0.4) = 0.5183627878m^2$
ΔT = Temperature difference = (121 – 25) ^{o}C
Therefore,
$Q_{conv.}$ = $20W/m^{2O}C$ [2π (0.152) + 2π (0.15 × 0.4)] m^2 x (121- 25) ^{o}C
= $20W/m^{2O}C \times 0.5183627878m^2 \times 96^0C$
$Q_{conv.}$ = 995.26W

ii. Radiation heat loss

The heat transfer from radiation is described by using the Stefan-Boltzmann's Law. Using Equation 6, the heat transfer from radiation was calculated as 6.289W.

$Q_{rad.} = \epsilon\sigma A(T^4 s - T^4 amb)$ (6)

where T_s is the surface temperature = 121^{O}C, T_{amb} is the ambient temperature = 25^{O}C, ϵ is Emissivity = 1, A is the radiated area = 0.5183627878m^2 and σ is Stefan's constant = 5.67 x 10^{-8}W/m^{2}K^4. Therefore,

Q_{rad}= 5.67 x 10-8W/m^{2}K^4 x 1 x 0.5183627878m^2 x (121^4 – 25^4) K^4
= 5.67 X 10^{-8}W/m^2/K^4 x 0.5183627878m^2 x (214358881 – 390625) K = 6.289W
Total heat loss = 995.26W + 6.289W = 1001.549W = 1.0015kW

Final Total Amount of Power Required to heat the Autoclave for 20mins

= 1.0833kW + 1.0015kW = 2.085kW ≈ 2kW

2.6. Battery Sizing

Storage Batteries are the fuel tank of solar powered autoclave system. Without batteries to store energy we only have power in a day time or the generator was running. Using Equation 7, the size of the battery was calculated according to (Ahmad, 2002).

$$C_B = \frac{El \times Nc}{DOD \times Vdc} \quad (7)$$

where Nc is the number of continuous cloudy days in the selected region (2-5 days), E_L is the Load energy in Wh (It is designed to run for 3 cycle of operation), DOD is the Depth of Discharge, V_{DC} is the system voltage equal to 24V and C_B is the battery capacity. Before we calculate the capacity of the battery, we should understand the system is designed to run for 3 cycles of operation.

At 1 cycle of operation = 2000W * 2* 12V = 1000Wh

Therefore for 3 cycles of operation (Load) = 3 * 1000Wh = 3000Wh

$$C_B = \frac{3{,}000 \times 4}{0.5 \times 24} = 1{,}000Ah$$

Now, the number of batteries must be determined based on the type of connection used (parallel or series battery connection)

i. **Parallel Connection**

$$Battery\ size\ in\ Ah = \frac{total\ watt}{system\ voltage}$$ (Ahmad, 2002)

$$= \frac{3{,}000}{24} = 125Ah$$

$$Number\ of\ batteries\ in\ parallel = \frac{Battery\ Ah}{Ah\ rating} = \frac{125}{200} = 0.625 \approx 1battery$$

ii. **Series connection**

$$\text{Number of batteries in series} = \frac{System\ voltage}{Battery\ voltage}$$ (Ahmad, 2002)

$$= \frac{24}{12} = 2\ batteries$$

Total number of batteries in battery bank = Number of batteries in series × Number of batteries in parallel

Number of batteries in parallel = 2x1 = 2×200Ah, 12V batteries.

2.7. Inverter Sizing

Unless when planning to use battery power for everything, Power Inverter will be required. The Power Inverter will be the heart of Solar Powered Autoclave System. It does not only convert the low voltage DC to the 220 volts AC that runs the autoclave, but also can charge the batteries if connected to the utility grid or an AC generator as in the case of a totally independent stand-alone solar power system. The Autoclave load was calculated using Equation 8 while the size of inverter was calculated using Equation 9.

$$Autoclave\ load\ (VA) = \frac{Autoclave\ load\ (watts)}{Power\ factor\ (P.F)} \quad (8)$$

where P.F is = 0.8 and Autoclave load = 2,000W.

Autoclave load (VA) = 2000 ÷ 0.8= 2,500VA

Sizing of inverter = Load of autoclave (VA) x [(1+AF) ÷ Ie] (9)

Transformers in the market are either 3000VA OR 4000VA

Therefore, we can round it off to 4000VA= 4kVA.

2.8. The Total Watt-Peak Rating Needed for PV Modules

Different size of PV modules will produce different amount of power. To find out the sizing of PV module, the total peak watt produced is needed. The peak power (W_P) produced depends on size of the PV module and climate of site location. Required power is given by Equation 10.

$$Ppv = \frac{E_L}{\eta_{cable} * \eta_{reg} * \eta_{bat} * \eta_{inv}} \quad (10)$$

Where E_L is the average daily load energy consumption kWh/day and typical value of efficiency of cable, regulator, battery and inverter are: η_{cable} = 95%, η_{reg} = 95%, η_{bat} = 80% and η_{inv} = 95%.

$$Ppv = \frac{3}{0.69} = 4.35kWh/day$$

$$Ppeak = \frac{Ppv}{PSH} \quad (11)$$

where PSH is peak solar hours (hours at1kW/m^2 = kW/m^2/day)

PSH = 4.76h/day

$$Ppeak = \frac{4.35}{4.76} = 0.913kWp \approx 913Wp$$

2.9. Number of PV Modules for the System

The number of modules in series (Ns) as given in Equation 9 is determined by dividing the designed system voltage VS $_{system}$ (usually determined by the battery bank or the inverter) and the nominal module voltage V_{module} at Standard Test Conditions (STC).

$$N_S = \frac{Vdc}{Vm} = \frac{24}{24} = 1 \quad (12)$$

The number of strings in parallel (N_P) as given in Equation 10 is determined by dividing the designed array output P_{PV} array by the selected module output P $_{module}$ max. And the number of series modules N_S.

$$Ns = \frac{Ppeak}{Pm \times Ns} \quad (13)$$

$$= \frac{913}{200 \times 1} = 4.565 \approx 5$$

The total number of panels

$N = N_S \times N_P = 1\times5 = 5$panels

2.10. Solar Charge Controller Sizing

Since the brighter the sunlight, the more voltage solar cells produce, the excessive voltage could damage the batteries. A charge controller is used to maintain the proper charging voltage on the batteries. As the input voltage from the solar array rises, the charge controller regulates the charge to the batteries preventing any overcharging. Most quality charge controller units have a three-stage charge cycle as followings: During the bulk stage of the charge cycle, the voltage gradually rises to the Bulk level (usually 25.6 to 26 volts) while the batteries draw maximum current. During this stage the voltage is maintained at Bulk voltage level for a specified time (usually an hour) whiles the current gradually tapers off as the batteries charge up. After the absorption time passes, the voltage is lowered to float level (usually 25.2 to 25.5 volts) and the batteries draw a small maintenance current until the next cycle (Emad, 2013). Most multi-stage charge controllers are Pulse Width Modulation (PWM) types. The newer Maximum Power Point Tracking (MPPT) controllers are even better. They match the output of the solar panels to the battery voltage to insure maximum charge Ampere. The Charge Controller is installed between the Solar Panel array and the Batteries where it automatically maintains the charge on the batteries using the three-stage charge cycle described above. The Power Inverter can also charge the batteries if it is connected to the AC utility grid or in the case of a standalone system (John, 2002). The solar charge controller is typically rated against Amperage and Voltage capacities. Selection of solar charge controller depends on the voltage of PV array and batteries. The charge controller is rated by the output Amperage that they can handle, not the input current from the solar panel array. To determine the current and power required by the charge controller, the following calculations were employed.

$$V_{in} = V_{DC} = 24V \qquad (14)$$

$$I_{in} = \frac{Ppeak}{Vdc} = \frac{913}{24} = 38.04A$$

$$V_{out} = V_{DC} = 24V$$

$$P_{out} = 2000W$$

$$I_{out} = \frac{Pout}{Vout} = \frac{2{,}000}{24} = 83.3A$$

Sincethe value 83.3A charge controller is not readily available in the market, then 100A charging controller will be use for the design.

2.11. Autoclave System

Solar powered autoclave system includes different components that must be selected accordingly. The major components are PV modules, solar charge controller, inverter, battery bank, and autoclave. The design is such that the solar panel will be installed on a platform considering some specifications like angle of tilt and direction of sunlight. The 24V dc battery that will power the autoclave will be connected to the solar panel via the charge controller for charging purpose and inverter. The autoclave will then be connected to the inverter. Figure 3 shows the block diagram of the system components as proposed by Ezugwu (2012).

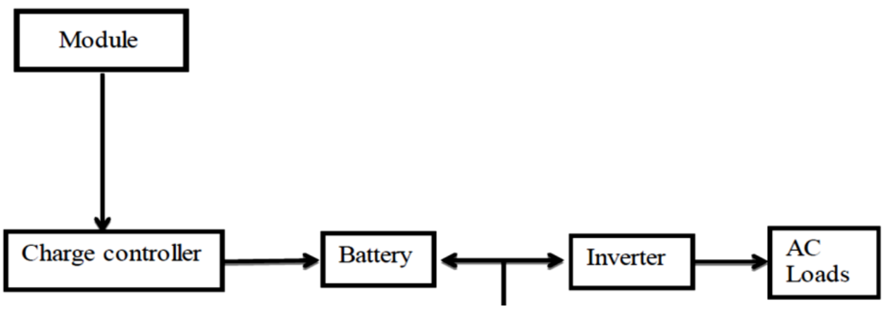


Figure 3: Block diagram of system components

Two different methods were used in charging the battery bank and they include; charging with solar panels and charging with power utility. Figure 4a depicts the battery that is charged with solar panels. Charging the battery with Power Utility is shown in Figure 4b.

Figure 4a: Battery charged with Solar panel

Figure 4b: Battery charged with power utility

III. Results and Discussion

3.1. Charging the Battery

The autoclave set-up was powered by 2 x200Ah deep cycle batteries that were charged to full capacity by either using solar panels or power utility. Table 1 shows the results when the charging was done with solar panels while Table 2 shows the results when the batteries were charged with power utility. Charging with public utility was carried when steady power is expected in the night. Full charge of the battery was attained at approximately 3hours, 30minutes as shown in Table 1 while full charge of the battery was attained at approximately 1hour 5minutes as shown in Table 2.

Table 1: Charging of battery with solar panels

S/No	Time	Chargervoltage	Charger Current	Charger Power	Batteryvoltage
1	9:00am	19.8	1.9	37.62	19.8
2	9:30am	20.1	2.2	44.22	20.1
3	10:00am	20.2	2.5	50.5	20.2
4	10:30am	20.3	2.8	56.84	20.3
5	11:00am	20.1	3.4	68.34	21.0
6	11:30am	20.3	2.8	56.84	21.3
7	12:00pm	22.4	6.5	146.60	23.8
8	12:30pm	25.2	7.5	189	25.9

Table 2: Charging of battery with power utility

S/No	Time	AC Voltage	DC Voltage
1	3:15am	220	21.2
2	3:25am	218	21.8
3	3:35am	220	22.5
4	3:45am	215	22.9
5	3:55am	200	23.2
6	4:00am	200	23.5
7	4:05am	220	24.1
8	4:10am	215	24.6
9	4:15am	218	25.1
10	4:20am	220	25.8

3.2. Autoclave Performance Test

The assembled bucket type autoclave was put into operation in order to determine the operational capacity and efficiency of its respective components and the overall integrated system. Relative comparison was also made between working efficiency of the respective components of the assembled autoclave and that of a foreign existing autoclave. In this project, two different methods were used in testing the solar powered autoclave and they include the physical and biological test.

3.2.1 Physical Test

This type of test involves the operation of the solar powered autoclave to determine if it will attain a temperature of 121^{O}C and above and pressure of 1. 25bar.The procedure of test carried out is outlined and the data obtained for analysis is tabulated in the Tables 3 and Figure 5. The procedure of test carried out is outlined as follows:

1. The autoclave (bucket type), 2x200Ah Batteries, 4kva Inverter (locally made), solar charge controller and 2x2solar panels were made available and all necessary connections were made.
2. The assembled autoclave heating chamber was filled with 2litres of water to its designed capacity.
3. The autoclave was powered by the deep cycle batteries which were fully charged to full capacity as shown in Tables 1 and 2 respectively. It was switched ON.
4. The system was carefully observed for a period of one hour and data were recorded as seen in Table 3 and Figure 5.

This same type of test was carried out for an existing/foreign type of autoclave but instead of using deep circle battery to power the autoclave, power utility was used. The results of the test are shown in Table 3 and Figure 5.

Table 3: Operational data of assembled and existing autoclave

Design variables	Temperature (^{0}C)						
	100°C	105°C	110°C	115°C	120°C	125°C	130°C
	Time (min)						
Assembled Autoclave	8	13	15	18	30	33	35
Existing Autoclave	6	11	14	16	19	21	26

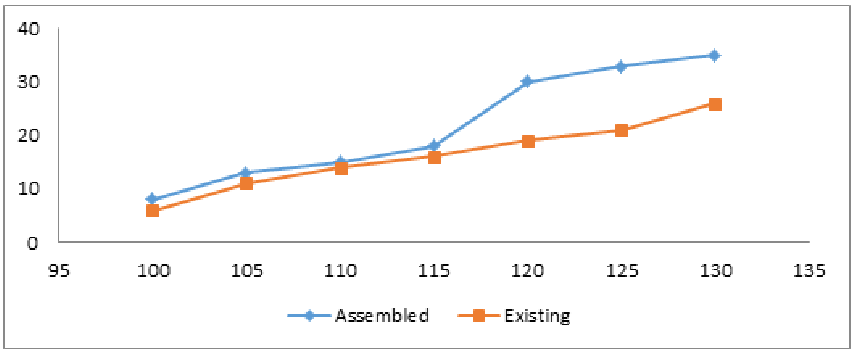


Figure 5: Operational capacities of solar powered autoclave and existing autoclave

A surgical scissor was inserted in the sterilizing chamber. The sterilizer was operated for 5, 10, 15, 20, 25, and 30 minutes at 1.25 bar (sterilization time domain) before it was stopped. At every interval of 5^{0}C of autoclaving, a swab was taken and cultured in a medium. A blood agar culture was used. Commencing the experiment, at constant time of 5 minutes for the first test, swab was taken with cotton wool at interval of 5^{0}C temperature, starting with 30^{0}C to 130^{0}C, and this was cultured for 3-days and the result was observed and recorded as shown in Table 4 and Figure 6.

At time T = 5 minutes, the temperature (^{O}C) was tested at 30^{o}, 100^{o}, 105^{o}, 110^{o}, 115,120, 125 130^{o}C. The procedure was repeated for the specified time interval mentioned above and the corresponding microorganism growth was noted. The temperature and pressure build up was taken up to when the operational temperature and pressure required to sterilize the equipment was reached. The sterilizing temperature is maintained for a given time of 35minutes for complete sterilization as signaled by the inserted indicators and the test sample taken for culture for 3 days and the result observed. Data collected were compared to that obtained from standard practice. Relative comparison between the assembled autoclave and an existing foreign autoclave was also carried out.

Table 4: Microbe growth and temperature build up with time

Time (minutes)	Time interval(min.)	Microbe growth	Temperature (^{0}c)
10:34 AM	0	100	30
10:38 AM	5	80	100
10:42 AM	10	70	105
10:44 AM	15	60	110
10:47 AM	20	50	115
10:49 AM	25	40	120
10:51 AM	30	30	125
10:54 AM	35	20	130

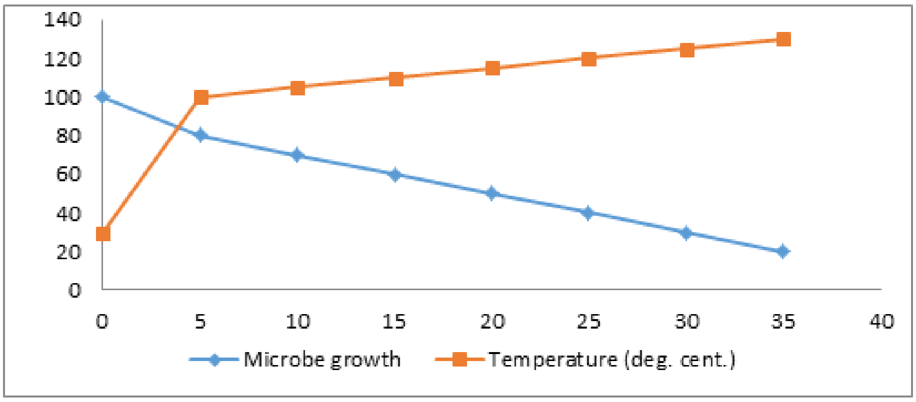


Figure 6: Graph of microbe growth against time and temperature increase

From the data and graphs presented in Table 3 and 4 as well as Figure 5 and 6, it was observed that there was a phenomenon decrease in the microbe population growth as temperature increased with respect to time. A crucial observation was the relation of the microbe growth and time of exposure to the sterilizing temperature. This is in agreement with Oyawale, (2007), Tao, (2012) and data obtained from a standard autoclave operation. The microbes were heat resistant organisms which could only be destroyed at higher temperatures and at elongated exposure. From Figure 5, it was observed that sterilization was not achieved due to less time exposure of the test materials to temperatures. Significant and better sterilization were observed as time of exposure of the microbe was increased at the sterilization temperature until complete sterilization was achieved after 30 minutes at the sterilization temperature as indicated in the graph in Figure 6. The sterilization process results were made evident from culture results of unsterilized, partially sterilized and complete sterilized test material. Also, from the graph in Figure 6, it is observed that the assembled solar powered autoclave and the main electricity powered autoclave showed similar pattern in attaining sterilization temperatures. The time lag was only about 10 minutes difference resulting from the difference in maximum time (20 minutes) to reach sterilization temperature by the existing autoclave and that used by the assembled autoclave which was about (30 minutes). This may not be unconnected with the gradual depletion of the battery power as time progresses. The above results show that the assembled solar powered autoclave was effective in carrying out sterilization as obtained from standard existing autoclave powered by electricity from mains.

IV. CONCLUSIONS

In accordance to the objectives of this research work which include design and fabrication of a solar powered autoclave, the device has been produced and tested to examine its operational capability. From the operational data collected and analysis of the machine which are also part of the objectives of this research, it can be concluded that the fabricated bucket type autoclave performed up to required or desirable capacity. The use of alternative source here in this research has again proved the potential and viability for use of solar and inverter energy systems in our daily energy requirement for the powering of facilities. The use of locally sourced materials in the production of some components of the autoclave clearly indicates that with the proper selection of the right materials, virtually most devices and machines can be produced to perform to some desired capacity. If this is perfected, our local production and products will be of high market value and demand and of relative competition with the foreign manufactured equipment imported from abroad into our territorial sphere.

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