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Design and construction of a solar powered and charcoal oven

Taofeek Olanrewaju Adebobola [1*], Olaoluwa Omoniyi [2], Damilola Gbadebo Bobola [3]
[1- 3] Department of Civil Engineering, Federal Polytechnic Ile-Oluji, Nigeria

* Corresponding Author: **Taofeek Olanrewaju Adebobola**

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Abstract
The solar oven was designed to convert solar energy into useful heat energy within a confined space (oven chamber) which can be used for cooking and baking purposes. The oven was designed to a length of 707.5mm with a thickness of 33mm, having components like mild steel, tungsten, fibre, solar panel and a reflector to concentrate the solar radiation on the collector. The heat supply to the chamber is based on the continuous adjustment of the reflector and the solar radiation. The oven was tested for about 5hours to bake, and within the first 30minutes of putting the oven on, the heat within the oven space was at designed temperature (300^0C), which is very suitable for baking. The oven was used to bake meat pie, cake and chin chin, all these were baked at different time interval and was very effective using solar energy. Charcoal was also used to bake for 2hours and immediately the charcoal started burning, the heat was distributed equally in the oven's chamber and the heat was used to bake meat pie, chin chin. At the end of the day, its shows that solar and charcoal oven is very suitable for baking.

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Keywords: Design, Construction, Solar Energy, Temperature, Area, Volume, work done, Power

1. Introduction

An oven is a tool which is used to expose materials to a hot environment. Ovens contain a hollow chamber and provide a means of heating the chamber in a controlled way. We have different types of ovens depending on their purpose and way of generating heat. Some ovens generate their heat using combustion of a fuel, such as wood, coal or natural gas, while many use electricity. The study on electric baking oven has received a considerable attention over the decades, due to its durability, efficiency and availability, (Temitope and Oluwole, 2018) [6]. But due to epileptic power supply in the country, there is need for alternative power such as solar power.

Solar power is the conversion of energy from sunlight into electricity, either directly using photovoltaic (PV) or indirectly using concentrated power. Solar panels use the photovoltaic effect to convert light into an electric current. Solar radiation presents an alternative energy source for a variety of applications. Solar radiation has been identified as solar the largest renewable resource on earth. The maximum intensity of solar radiation at the earth's surface is about 1.2kW/m^2, but it is encountered only near the equator on clear days at noon. Under these ideal conditions, the total energy received is from 6 - 8kWh/m^2 per day, Abdulrahim., (2011) [1].

Charcoal is a lightweight black carbon residue produced by strongly heating wood (or other animal and plant materials) in minimal oxygen to remove all water and volatile constituents.

The reasoning for embarking upon this research work is to explore the possibility of constructing an effective, durable and efficient combined solar powered and charcoal oven, constructed using locally available materials, which could be used in remote areas where power supply is not available.

1.1. Problem Statement / Justification

Uses of oven includes, heating, drying, baking, and smoking of consumable items for both domestic use and industrial uses. The most commonly used oven are; electric current oven and gas oven.

But with the inflation on cooking gas price and instability of electricity in our environment or absence of electricity in the rural areas, this has made it difficult for these types of oven to function effectively. Hence there is need to design and construct a combined solar powered and charcoal oven for the rural and urban areas with poor connection to the electricity supply or unavailable, because less than 45% of people in Nigeria have access to electric power (Suleiman, 2011) [5].

1.2. Aim and Objectives

The research aim is to design and construct a solar powered and charcoal oven with a high efficiency at lowest cost.

Specific objectives are to

1. Design and construct a high efficient and cost effective solar powered and charcoal oven;
2. Select appropriate materials (bearing in mind availability and durability) for the various parts of the solar oven, and
3. Exploit the local facilities available in the construction of the oven instead of imported ovens.

2. Materials and Method

2.1. Materials

Table 1: Components and Materials Table

Components	Materials Selected	Criteria For Selection
Frames and Body	Mild steel	It is malleable, ductile, available and affordable. It gives good rigidity to the frame structure.
Heating element	Tungsten	Capable of generating the required heating for the oven, available and high conductivity of heat.
Insulator	Fibre	Fibre are covers used to prevent heat loss by convection from the collector.
Panels	Solar Panels	Capable of generating large amounts of heat which is required for processing heat from solar energy.

2.1.1. Reflectors

Concentrating solar collectors require the use of reflective surfaces to direct the beam component of solar radiation onto a receiver. This requires surfaces of high specular reflectance for radiation in the solar spectrum (Duffie and Beckman, 2001) [4]. Specular surfaces are usually metals or metallic coatings on smooth substrates. Specular surfaces can also be applied to transparent substrates including glass or plastic.

2.1.2. Mild Steel

This is an alloy of carbon with carbon content ranging from 0.1- 0.3%. The square metal bar for the oven body frame work and angular bar used for supporting the wire mesh are all made of mild steel material.

Mild steel is a good conductor of heat. It has a melting point of 1650ºC. The maximum temperature the oven produces is 300ºC - 350ºC, which is far below the melting point of the mild steel. It has a density of 7900kg/m^3, and due to its light weight, it can be carried from one place to another when needed. It has a low specific capacity. Its expansion with respect to increase in temperature is very small.

Mechanical Properties

These are properties determined by the application of force. They include; ultimate strength, yield strength, hardness and ductility. Mild steel is hard and cannot be easily damaged. Mild steel possesses good weld-ability. This plays a great role in the joint formation and strength of the compartment in withstanding load or applied force (Akinfaloye, 2021) [2].

2.1.3. Heating Element

This material possess features such as;

a) Ability to resist oxidation at high temperature;

b) Very high melting point and high electrical resistivity; and

c) Has high resistance to corrosion. The heating elements for this project is made of tungsten material (Akinfaloye, 2021) [2].

2.1.4. Solar Panel

Two solar panels each containing a power of 175WP were used, each of the panel has the following properties;

Peak Power (PMP) …….. 175WP

Production Tolerance ……. ± 3%

Open-circuit Voltage …… 21.6V

Maximum Power Current ……. 9.72A

Maximum Power Voltage …….. 18V

Short-Circuit Current…….. 10.2A

Maximum System Voltage ……. 1000VDC

Cell Technology …….. Monocrystalline Silicon

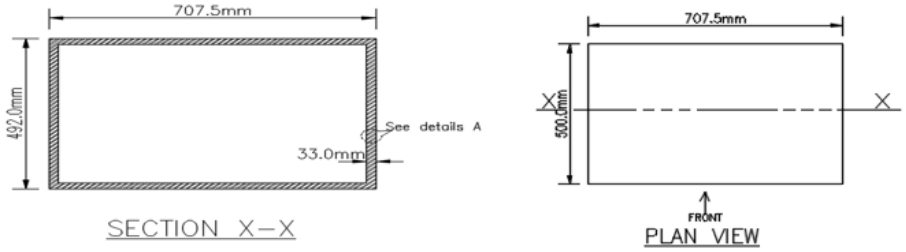
Module Dimension …….. 1480 x 680 x 30mm

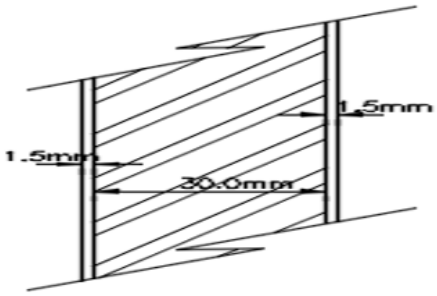
All technical data at standard test condition. Am = 1.5E = 1000WM^2 T^C = 25^{0}C

ISO 9001 – 2008 ROHS

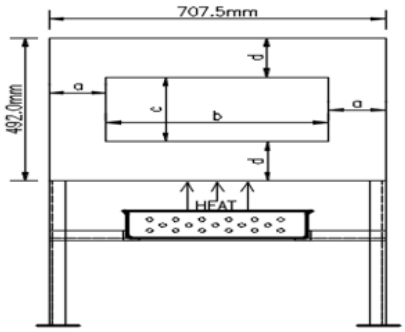
2.2. Method

An auto-cad software was used for the isometric and 2D drawing of the Solar Powered and Charcoal Oven. And it was fabricated using locally made materials of high efficiency at economical cost.



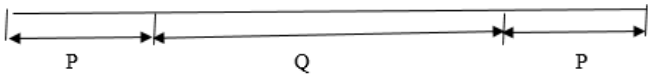


DETAIL A



ELEVATION

The interior size of the oven is the difference between the total size of the oven and external thickness of the walls.



Where;
P = 1.50mm (thickness of mild steel in millimeters)
Q = 30.0mm (thickness of lagging material in millimeters
Then;
Total thickness (T) = P + Q + P (millimeters)… …….. (1)
Length = L – 2(T) ……..……(2)
Width = W – 2(T) ……..……..…….. (3)
Height = H – 2(T) ……..……..……(4)
Internal Area = L x W …….. (5)
Internal Volume = L x W x H ……..…….. (6)

2.2.1. Heat Supplied through the Solar Power

From Ohm's law, power is given by; P = IV…… (7)
Since Power P = IV, and V = IR, then
Power P = I^2R …….. (8)
Where;
P = Power of the heating element in Watts
I = Current in Ampere
V = Voltage in Volts (220V)
R = Resistance in ohms Therefore;
I = (current flowing through heating element)
I = P/V or V/R or √(P/R) …… (9)
Therefore;
R = (resistance of heating element)
R = V/I or P/I^2 …… (10)

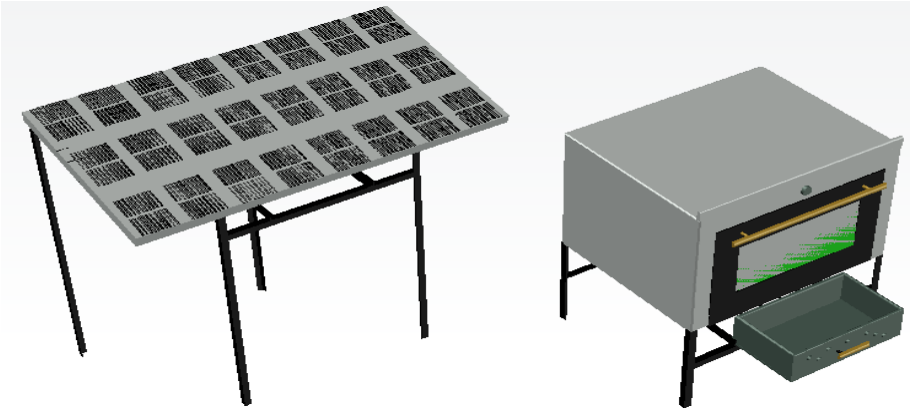
2.2.2. Total Work done of the heating element

W = IVt ……..…… (11)
Where t = time taken (in minutes)

The oven design is made up of both internal and external body, made of mild steel material, both separated with lagging material, and the whole assembly made rigid by a rectangular framework.

3. Results and Discussion

3.1. Results



Solar Panel **Oven**

3.1.1. Design Calculation

The size of the solar and charcoal oven is as follow;
Area = Length (L) x Breadth (B)
Volume = Length (L) x Breadth (B) x Height (H)
Total thickness (T) = P + Q + P (millimeters)
P = 1.50mm (thickness of mild steel in millimeters)
Q = 30.0mm (thickness of lagging material (millimeters)
Total thickness (T) = (1.50 + 30.0 + 1.50) = 33.0mm
Length L = 707.5mm, Width W = 492.0mm and Height H = 500.0mm
Length = L – 2(T) = 707.5 – 2(33) = 641.5mm
Width = W – 2(T) = 492.0 – 2(33) = 426mm
Height = H – 2(T) = 500.0 -2(33) = 434mm
Internal Area = L x B = 707.5 x 492.0 = 348,090mm^2 = 0.3481m^2
Internal Volume = L x W x H = 707.5 x 492.0 x 500.0 = 174,045,000mm^3 = 0.1740m^3

3.1.2. Total Work done of the heating element

W = IVt t = time taken in a minute 1minute = 60seconds

W = 74.343 x 220 x 60
W = 981,327.6 Joules (The total work done in one minute)

3.1.3. Linear Expansitivity and Stress on the materials

A = Mild steel
B = Lagging material (fibre glass)
Since the internal temperature increases, the materials undergo thermal stress and stress depends upon the amount of force acting on the materials over the area covered. The coefficient of linear expansion for mild steel is greater than that of the lagging material (fibre glass), thus the mild steel expands more. The coefficient of linear expansitivity for mild steel (A) = 13.0 x 10^{-6}/k and for fibre (B) = 39.4 x 10^{-6}/k. Young modulus (E) of mild steel is 210x10^9 N/m^2 and for fibre is 13x10^9 N/m^2

Workdone $W = \frac{1}{2}$ (Force F x Extension e) ..... (12)

$2W = Fe$ $e = 2W/F$ ..... (13)

$E = FL/Ae$ $e = FL/AE$ ..... (14), then to compare the two equations together;

$2W/F = FL/AE$ $F^2L = 2WAE$ $F = \sqrt{2WAE/L}$ ..... (15)

Force on mild steel (F_m) = $\sqrt{2 \times 981327.6 \times 0.3481 \times 210x10^9} / \sqrt{0.6415}$ $F_m = 4.73x10^8$ N

Force on fibre (F_f) = $\sqrt{2 \times 981327.6 \times 0.3481 \times 13x10^9} / \sqrt{0.6415}$ $F_f = 1.18x10^8$ N

Stress = Force /Area
Stress on mild steel S_m = 4.73x10^8 / 0.3481 = 1.36x10^9 N/m^2
Stress on fibre S_f = 1.18x10^8 / 0.3481 = 3.12x10^4 N/m^2

3.1.4. Power of Heating Element

From Stefan's law for power radiated emitted in a body
$P = \varepsilon\sigma AT^4$ ..... (16) (Derby and Yeckel, 2015)

Where; P = Total power emitted by the heating body
ε = 0.9 (emissivity of the body)
σ = 5.67x10^{-8} W/m^2k^4 (Stefan-Boltzmann Constant)
Length of coil (L) = 0.531m
Diameter of coil (D) = 0.017m
A = Area = 0.3481m^2
T = Temperature of heating element is between = $300^0 - 350^0$ C 325^0 C + 273.15 = 598.15K
P = 0.9 x 5.67x10^{-8} x 0.3481 x 598.15^4
P = 2,273.89 Watts
From Ohm's law, P = IV, with voltage of 220V and 2,273.89W power of the heating element, therefore;
I = (current flowing through heating element)
I = P/V
$I = \frac{2273}{220} = 10.33$
I = 10.33A
R = (resistance of heating element)
R = V/I
$R = \frac{220}{10.33} = 21.297$
R = 21.3Ω

3.2. Discussion

The solar powered and charcoal oven was fabricated using locally made materials of high standard. A switch was used to control the flow of electric current within the system, current flows in once the switch is on, so that the energy absorbed through the solar panel can be converted to electrical energy and then the electrical energy can be converted to heat energy through the heating element. The oven was properly done and all the four sides were lagged properly in order to prevent loss of heat to the surrounding.

4. Conclusion

The design and construction of the solar powered and charcoal oven was done in such a way that it will easily be maintained and replaced the faulty parts anytime there is problem with the oven. The oven was tested with both solar and charcoal to examine the power delivering and effectiveness of the oven. It was discovered that within the first few minutes (30 minutes) of testing the oven, the temperature of the oven was over 300^0C which happens to be the designed temperature.

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