DESIGN MODIFICATION AND CONSTRUCTION OF A SOLAR OVEN

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CERTIFICATION

cknowledge that I have read and study this work 'Solar Oven Design' being carried out by uyi Oluwashina Daniel in my view, this project is adequate in terms of scope and quality for award of Bachelor Degree in Mechanical Engineering

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I hereby declare that this project report has been written and design by me, also is my own effort and that no part has been plagiarized without citation"

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DEDICATION

This work 'design and modification of box solar oven' is dedicated to God almighty who is my source of living and strength in completing this work, to all men of good heart who take pleasure in investing on humanitarian works and to entire Faluyi's family.

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May the Almighty God reward you all beyond your expectations.

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ABSTRACT

The need for alternative source of energy for food preparation has given rise to the use of solar energy for cooking. This technology which is not widely utilized in Nigeria has been a major research study to harness solar energy for cooking in order to reduce the depleting forest zone and environmental degradation resulting from fuel-wood utilization. A concentrating solar oven was designed and constructed at Federal University Oye- Ekiti, Department of Mechanical Engineering. The solar oven which comprises of three parts namely; concentrator, support and oven box has its concentrator produced from an Aluminum foil paper and glass. The performance of the solar oven was evaluated using solar ovens at Federal University Oye-Ekiti, Department of Mechanical Engineering. The results of the test experiment showed that the solar oven worked well in satisfy efficiency. The major factor that affected the performance of the solar oven was the harmattan haze which was predominant during the testing period. It took 60mins for the solar oven to attain a maximum temperature of 69.0^0C during the unloaded test and 150mins to bake flour dough. The cooked food sample proved to be palatable and delicious.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Energy is the focal point of all human activities; it is the basis of industrial civilization. Without energy, modern life would cease to exist. In the past, the demand for energy sources was minimal because it was primarily used for cooking and local production. But as time went on, population increase and technological advancement led to more demand for energy. The major sources of energy are the conventional sources, which include: fossil fuels, and nuclear fuels. Fossil fuels, which include petroleum, coal, and natural gas, provide most of the energy need of modern industrial society. Other uses are found in the transportation, residential heating, and electric-power generation. Nuclear fuels are used to generate electricity, but it is utilized mainly in the developed countries due to high level of supervision and maintenance required. The non- conventional (renewable) sources of energy include: hydroelectric power, solar energy, wind energy, biomass, ocean thermal energy, tidal energy, and geothermal energy, but the potential of these sources is still underutilized because they are much more expensive to harness than energy derived from fossil fuels. Hydroelectric power requires a large capital investment, so it is often uneconomical for a region where coal or oil is cheap. As such, they contribute a little percentage to the massive energy requirement of the world population. However, the fear of depletion of fossil fuels due to the fast rate of consumption has provoked further development of these alternative energy sources, such as solar energy.

Household energy need is one of the biggest issues in the daily lives of people around the world. The most important energy-consuming activities in most households are cooking, lighting and use of electrical appliances. Cooking accounts for a staggering 91 percent of household energy consumption, lighting uses up to 6 percent and the remaining 3 percent can be attributed to the use of basic electrical appliances such as televisions and pressing irons (Sesan, 2008). Cooking is an activity that must be carried out almost on a daily basis for the sustenance of life. An enormous amount of energy is thus expended regularly on cooking. Cooking may be classified in four major categories based on the required range of temperature, viz. baking (85-90°C), boiling (100 to 130°C), frying (200 to 250°C) and roasting (more than 300°C).

The major baking fuels in the rural areas in Nigeria are agricultural wastes, wood fuel and animal dung's while in the urban areas and sub-urban cities, the main baking fuels are Kerosene, Liquefied Natural Gas (LNG), Electricity, fossil fuels such as coal and natural gas. The use of Fuel wood is the most widely used, supplying over 80 percent of household energy, while less than 20 percent is supplied by the other sources and complemented by small quantities of coal and charcoal (Sesan, 2008). The increasing cost of Liquefied Natural Gas due to the bad economic situation in the country also contributed to restriction of the use of liquefied natural gas by only the rich in the society (Vieira de Silva, 2005). In this modern day civilization in environmental control, it has been realized that the use of wood fuel and other biomass, kerosene and liquefied natural gas for baking introduces Carbon II Oxide and other greenhouse gases in household environments and this in great measure contributes to global warming, health hazard and climate change. The persistent use of firewood for baking had also leads to soil erosion, deforestation, desert encroachment, health hazard and the shortage of firewood. In advance search for other alternative ways of baking technology, solar energy becomes a good alternative source of energy for baking in Nigeria. Renewable energy alternatives include biogas, which is used for household heating, cooking and lighting, as well as agricultural and industrial activities. Solar radiation presents an alternative energy source for a variety of applications. Solar radiation has been identified as 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 kWh/m^2- 8 kWh/m^2 per day (Abdulrahimet al., 2011). Its intensity varies according to season, geographical location, and orientation of the collector. This is because Nigeria is endowed with abundant sunshine of not less than 9 hours per day throughout the year due to its position near the equator (Bald et.al, 2000). However, solar baking cannot be able to replace the other baking technology in Nigeria, but the use of solar energy for baking would save the forest reserves of Nigeria. It would also improve baked food nutrition and health condition as has been found out and as well serve as a good alternative source for baking during the periods of shortage of other baking fuels. The use of solar energy for baking in Nigeria could be beneficial because solar energy is inexhaustible, universal, abundant and free but solar energy is not available continuously because of the day/night cycle and cloud cover. Solar ovens can be used for baking at any areas and that includes the most remote rural areas in Nigeria.

1.2 Objectives of the Solar Oven Project

The objectives of this work are as follows;

1. Design a concentrating solar box oven with four reflecting surface

2. To identify systems that are simple, easy to use in environments of rural communities in developing countries and preferably systems that could be used in individual households.

3. To provide a comprehensive overview of available technologies in the solar oven landscape including types of radiation collectors, types of cooking, types of materials suitable for heat conduction and heating methodology.

1.3 Purpose and Scope

The aim of this project is to design, construct and itemize the project contributions into Nigeria. Also to determine the performance evaluation of a solar oven that can reduce the stress in baking and reduce the cost of baking. The materials for its construction have to be locally sourced. The oven has to be easy to operate with low maintenance cost and should be capable to bake food. The choice of the latitude orientation make the project easy to carried out at Federal University Oye-Ekiti (FUOYE), though areas with similar characteristics as Federal University Oye-Ekiti (FUOYE) can adopt the technology with very little variations that might be experienced in the performance of the oven.

1.4 Limitation

The limitations of the project are as follows;

1. The solar oven is only solar powered.

2. Baking is restricted to sunny periods.

3. There must be continuous movement of the solar oven every 10 minutes to track maximum solar radiation.

CHAPTER TWO

2.0 LITERATURE REVIEW

The sources of energy used in cooking in most Nigeria homes are fossil fuel and biomass. The fuel is becoming expensive beyond the reach of common person. There is need to source for suitable alternative. Therefore, the work focused on use of solar cooker for cooking some staple foods in Nigeria. Preliminary study was carried out to quantify appropriate water requirements for cooking some staple foods (rice, flour, bean, maize and yam) in Nigeria. Used quantity of water was determined by material balance analysis. Solar device was used to cook rice, beans, yam and fish. In addition was baking of cake. Temperatures of device were recorded when un-loaded and loaded. Water required to cook a given quantity of rice was 1.25 times the quantity of rice. To cook a given weight of beans about 1.4 times of water by weight was used while1.63 times the quantity of the maize was required. Yam was properly cooked by water of 0.2 times weight. Mean stagnation temperatures of the solar device were 134 ± 8.9^0C, 120 ± 6.2^0C and 121 ± 7.1^0C for first, second and third year respectively Jollof rice (520 g), beans (420 g) and yam (1400 g) were properly cooked in 80, 120 and 70 minutes respectively. In addition, flour (650 g) was successfully baked into cake after 150 minutes. The study reinforced the views that solar devices can play a major role in solving Nigerian's domestic energy problem especially in the rural areas rather than being a novelty demonstration of solar energy use (Muhammed 2015).

Solar energy is clean, renewable, abundant and available in the tropical region of the world. Its increased utilization would result in an all-round benefit, both in terms of cleaner environment and monetary gain, for the individual users as well as the nation (Ghobeity and Mitos. 2012). The earth receives annually, energy from the sun amounting to 1 x 1018 kWh (Ahmed. 2012). This is equivalent to more than 500000 billion barrels of oil or about 1000 times the energy of known reserves of oil or more than 20000 times the present annual consumption of energy of the whole world. Therefore, the work focused on use of solar cooker for cooking some staple food in Nigeria.

2.1 Baking Technology

There have been numerous baking technologies since the inception of baking. These technologies tend to ease the difficulties encountered during baking and also reduce the cost of buying fuel by reducing the combustion of fuel such that very little smoke is emitted during the baking process. The technology ranged from the use of firewood, kerosene and gas oven to the use of solar ovens. The improvement on these baking systems has been to create efficient and clean burning stove that will be most convenient to the user. Some common methods of baking technology include the use of three stone, charcoal fire baking, kerosene stove, gas baking, electric baking and solar baking technologies.

2.1.1 Clay Mold Baking Technology

This is the traditional way of baking food by initially burn high quantity of firewood inside the baking region in order to meet up the initial oven temperature. During the baking process firewood will be set and burning at the oven combustion chamber under the oven bed to maintain oven normal baking temperature. It is the cheapest baking system that can easily be adopted by anybody. This baking method usually required at the commercial areas. This type of baking has so many problems associated with it. It often exposes the user to fire hazard, takes longer processing period and much fire wood fuel consumption to bake food. It is commonly used in the rural areas because it is at no cost since there is availability of fire wood in nearby bushes that can be used for this technology.

2.1.2 Tripod Stand

The tripod stand is a replica of the clay mold baking system. It consists of three steel rods at equidistance from each other that bent over another circular rod to join the three steel rods. The baking pot is placed at the upper part while firewood and other biofuels are fed through the underneath of the tripod stand. This type of baking system can easily be moved from one place to the other but it still has the disadvantages of its limitation to roasting, the user's is prone to health, fire hazard and at large causes environmental hazards to the society.

2.1.3 Charcoal Fired Baking Technology

This type of baking system uses charcoal as its thermal energy source. Charcoal is one of the byproducts of wood after complete combustion of wood. It can be used efficiently to bake food. There are different designs of this baking system. The commonest model consists of two basic units namely; the combustion unit and baking unit (Ndirika, 1991). The combustion unit is where the charcoal is fed in and when heated, it transfers heat to the baking unit which is thermal isolated region. Another type of charcoal fired baking stove is the rocket stove mostly used in Kenya. The charcoal fired baking system is an improvement in use of fire wood for baking because of its minimal smoke production.

2.1.4 Kerosene Stove oven

Kerosene stove oven uses kerosene which is one of the end products of petroleum fractional distillation. It is mostly used in the urban and semi urban areas. Appropriate designed kerosene stove is very efficient and bakes food very fast. There are various types of kerosene stove oven but the main two types are the wick and the pressurized stove oven. This type of baking system is easy to control and operate. They do not produce smoke as much as fire wood ovens but they can be very dangerous when improperly handled and are expensive to maintain especially during the time of shortage of supply of kerosene.

2.1.5 Gas Baking Oven Technology

The baking gas comprises of butane or propane which are hydrocarbon gases produced during petroleum refinery process. Liquefied petroleum gas is used for baking when they are compressed inside a gas cylinder in gaseous form. They are very easy to use, very efficient and smokeless and are not commonly found in the rural areas. The gas cylinders are made in different sizes and shapes. They are made with thermal isolated box with tray holders. The problems associated with this type of baking system its initial cost, irregularity supply and high cost of gas. There is also high risk of explosion when misused.

2.1.6 Electric Ovens

The use of electricity as a source of thermal energy for baking has been growing over time. This is because it is pollution free, easy to operate and enables fast baking. The system mechanism involves conversion of electrical energy to heat energy through metallic barrier that is in contact with a resistive heating coil. The resistive heating coil heats up an isolated vacuum. The major disadvantage of electric ovens is the unreliable power supply in Nigeria especially in rural areas and risk electric shock.

earth are essentially parallel. The characteristics of the sun and its spatial relationship to the earth result in a nearly fixed intensity of solar radiation outside the earth's atmosphere known as solar constant. Earth's solar constant is about 1353W/m^2. This solar constant fluctuates slightly as the earth moves towards and away from the sun at different point on the orbit. Sun provides light, heat and other sources of energy to all living things on earth. It is also responsible for weather changes and oceanic current. It is the most inexhaustible renewable source of energy known to man and also primary source of almost all type of energy even the non-renewable energy source like coal, petroleum and natural gas (Narayanaswamy. 2001).

Basics two mode of solar energy heating are following;

1. Active: convert sun's energy from heat to other useful form, such as electricity and hot water
2. Passive: direct use of sun's heat energy for home heating, etc.

2.3 Solar Radiation

Solar radiation is the amount of energy from the sun reaching a specific location on the surface of the earth at a specified time. Due to the interference of the atmosphere, solar energy hits a horizontal plane on earth in direct and diffuse forms. The direct form is the parallel rays from the direction of the sun while the diffuse forms is radiation scattered in many directions by matter and gases in the atmosphere. The total solar radiation that gets through the earth even with a clear sky is about 70 percent (Hug, 2007) of the solar constant. The radiation upon a surface can typically be described as interacting with surface in one or more of following three ways namely;

- It can be absorbed into the material,
- Transmitted through the material
- Reflected off the material.

The proportion of each of the three ways depends on the wavelengths of the radiation, chemical composition and physical structure of the material and the angle incidence at which the radiation strikes the material.

2.3.1 Solar Angles

2.3.1.1 Solar Declination

Declination (δ): is the angular distance of the sun, north of the earth's equator. The earth's equator is tilted 23.45 degrees with respect to the plane of the orbit around the sun, so that at various time of the year, as the earth orbits the sun, declination varies from 23.45 degrees north to 23.45 degrees south. Fig 2.2 shows the variation of declination angle with the day of the year. It is estimated as follows;

$$\delta = 23.45 \, \mathrm{Sin}\left(\frac{360 \;\; 284+N}{365}\right) \qquad (2.1)$$

Where;

δ = declination angle

N = number of days of the year

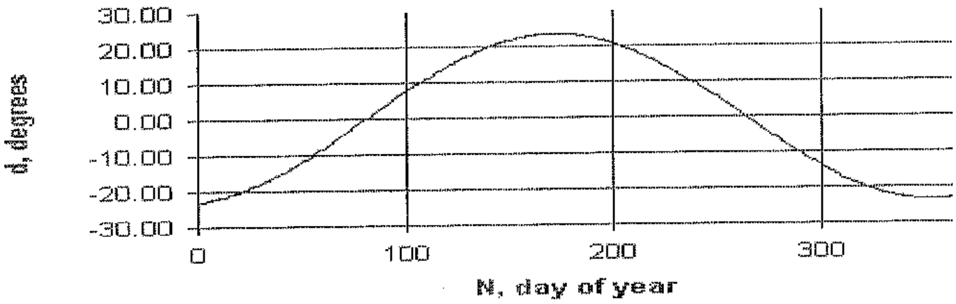

Fig 2.2: Declination angle versus days of the year

2.3.1.2 Hour Angle

Hour angle (H) is the angular displacement of the sun, east or west of the local solar noon per hour due to rotation of the earth on its axis at 15 ^{0}. The hour angle is positive in the morning, zero at noon and negative in the afternoon. It is estimated as

$$H=\frac{360}{24}\ 12-T \qquad (2.2)$$

Where;

H = hour angle

T = solar time

2.3.1.3 Zenith Angle

Zenith angle (θ) is the angle between the beam from the sun and the vertical line to the zenith (i.e. point directly overhead). The zenith angle of the sun is estimated as follows

$$\text{Cos}\ \theta = \text{Sin}\beta = \text{SinL x Sin}\ \delta + \text{CosL x Cos}\ \delta\ \text{x CosH} \qquad (2.3)$$

Where;

θ= zenith angle

β= altitude angle

L=latitude

δ = declination angle

H= hour angle

2.3.1.4 Solar Altitude

Solar altitude (β) is the angle on the vertical plane between the beam from the sun and the horizontal plane on the earth's surface. It is estimated as;

$$\beta=90^0-\theta \tag{2.4}$$

Where;

β= altitude angle

θ = zenith angle

2.3.1.5 Azimuth angle

The azimuth angle (φ) is the deviation of the normal to the surface from the local meridian. An object due north has an azimuth of 0^0, due east is 90^0, south and west is 180^0 and 270^0 respectively. For instance, at sunrise, the sun is positioned in the east at an azimuth of approximately 90^0, while at midday, it is located high in the sky at nearly 0^0 azimuth. The angle is estimated as;

$$\text{Sin } \varphi = \text{Cos}\delta \frac{\text{SinH}}{\text{Cos}\beta} \quad (2.5)$$

Where;

φ = azimuth angle

δ = declination angle

β = altitude angle

H = hour angle

2.3.2 Solar Intensity

Due to the earth's natural tilt on its axis, the amount of direct sunlight that geographical locations receive varies with latitude locations near the equator and it is positioned at nearly 90^0 angle reference to the sun. Locations at higher latitude are positioned at much greater angles and receive far less direct sunlight unlike location at lower latitude (Duffie and Beckman, 1974). This is the cause of variations in the amount of solar radiation received in different locations. To determine the total solar intensity of solar radiation falling on a surface in a given locality, it is the sum of the beam radiation (I_b), diffuse radiation (I_d) and the reflected radiation (I_{ref}). This is expressed as follows;

$$I_t = I_d + I_b + I_{ref} \quad (2.6)$$

Where;

I_t = total solar intensity, W/m^2

I_b = beam radiation, W/m^2

I_d = diffuse radiation, W/m^2

I_{ref} = reflected radiation, W/m^2

2.3.3 Solar Collector Orientation

The angle by which the sun's rays strike the earth varies by geographical location, and time of the year. This is as a result of the earth tilt on its axis and its revolution around the sun. Solar collectors are equipment that transforms solar radiation to some other useful energy forms. There are two types of collectors namely; flat plate collector and concentrating collector. The orientation of the solar collectors (i.e. the way the collectors face and how they are tilted) optimizes their collection ability (Garg, 2000).

2.3.4 Measurement of Solar Radiation

Solar radiation measurement are most often made of total (beam and diffuse) radiation in energy per unit time per unit area on a horizontal surface. Pyranometer or pyrhelimeter is the instrument used to measure solar radiation received from a given area. There are other expressions that are necessary in the measurement of solar radiation. They are described as follows for a tilted surface;

The beam radiation at normal incidence (I_{bn}) is calculated using equation below

$$I_{bn} = \frac{A_{ap}}{e^{\frac{B}{\sin\beta}}} \qquad (2.7)$$

Where;

I_{bn} =intensity of beam solar radiation at normal incidence, W/m^2

A_{ap}= apparent solar irradiation just outside the atmosphere

B = atmosphere extinction coefficient

β = altitude angle

A_{ap} and B are constants whose values are tabulated for an average day of every of the month in the year as shown in (Hsieh, 1986).

The intensity of beam radiation (I_b) incidence upon a surface at sea level is given as

$$I_b = F_c\, I_{bn} \cos\Theta \qquad (2.8)$$

Where;

I_b= intensity of beam radiation, W/m^2

F_c= air clearness factor

Θ= zenith angle

I_{bn}=intensity of beam radiation at normal incidence, W/m^2

The solar intensity of diffuse radiation from a clear sky falling on a tilted surface is given as

$$I_d = C I_{bn} \frac{1+\text{Cos}\Sigma}{2} \qquad (2.9)$$

Where;

I_d = intensity of diffuse radiation, W/m^2

C= diffuse radiation factor

Σ= tilted angle of the surface

The reflected radiation falling on adjusted surface I_{ref} is expressed as follow

$$I_{ref} = R_{ref} F_{r-s} I_b + I_d \quad (2.10)$$

Where;

I_{ref} = intensity of the reflected radiation, W/m^2

R_{ref} = reflectance of reflected surface

F_{r-s} = shape factor between reflected and the receiving surface

I_b = intensity of beam radiation, W/m^2

I_d = intensity of diffuse radiation, W/m^2

2.4 Applications of Solar Energy

There are numerous applications of solar energy. Some of them include;

2.4.1 Solar Water Heating

Solar energy can be easily converted to heat and this is used to provide a significant proportion of the domestic hot water demand (Mcveigh, 1977). It consists of a flat plate collector and a storage tank.

2.4.2 Solar Pond

Solar ponds are mainly used in areas where there is considerably small seasonal variation in solar radiation. The technology is based in natural pond technology but an additional technique. In a natural pond or lake, when the sun's rays heat up the water in the pond, the water rises from within the pond, reaches the top and loses heat into the atmosphere by the action of convection current. The solar pond comprises of three zones namely; top zone which is at atmospheric temperature and has little salt content, mid-zone which is hotter than top zone and the bottom zone which is very hot and salty. The water at the bottom zone can be collected and stored as heat.

2.4.3 Solar Distillation

This is another popular application of solar energy which is used to purify water. It consists of shallow tray filled with salt or brackish water covered by a sloping glass cover plate. As solar radiation heats the water in the tray, the fresh water evaporates and when the vapour comes in contact with the colder surface of the glass, it condenses and runs down the inner surface in form of droplets and collected in a trough at a lower edge. It is widely used in area where there is scarcity of purified drinking water.

2.4.4 Photovoltaic

This is the direct conversion of solar energy into electricity using photovoltaic converter (solar cells). The solar cells absorb most of the solar spectrum and convert a fraction of the radiation to electrical energy while the remaining energy is given off as thermal energy. This technology has been one of the major solar energy applications.

2.4.5 Solar Cooker

Solar cooking is the simplest, safest and most convenient way to cook food without consuming any fuel or heating up the cooking appliances which use solar energy to cook food. It can also be refers to as solar oven in term of functionality and usefulness.

2.4.6 Solar Oven

Solar oven is one of the emerging solar energy technologies in which solar energy is used to generate heat for baking. It is a device which uses the energy of sunlight to heat or to cook or sterilize food. High-tech versions, for example electric ovens powered by solar cells, are possible, and have some advantages such as being able to work in diffuse light. However at present, they are very unusual because they are expensive. The vast majority of solar cookers presently in use are relatively cheap, low-tech devices, because they use no fuel and cost nothing to operate.

There are three types of solar ovens namely;

1. Concentrating solar box type
2. panel type ovens
3. Parabolic or concentrating ovens.

1. Solar Box Oven

Solar box oven (SBO) type is the simplest of the solar ovens. It is an insulated container with a glass cover. This kind of oven depends on the greenhouse effect in which the transparent glazing unit permits passage of shorter wavelength radiation coming from relatively low temperature heated object (Narayanaswam, 2001). Removable lid on the cover of the box oven acts as the solar box door and this door is heat resistant transparent cover which can allow solar radiation inside the box and allows the removal or placing of mixed food inside the oven. The commonly used reflecting surface is mirror and aluminum fossil. Insulating material inside the box ovens is mainly crumpled newspapers, wool, rags, dry grass, and sheets of cardboard, rice husk etc. Inside of box oven are painted black for maximum absorption of heat. Box ovens can attain temperature as high as 150^0C over a long period of time but for food containing mixture, it cannot get hotter than 200^0C (en.wikipedia.org, 2003). It can be used to warm food, pasteurize water or milk, dry agricultural products, etc. An example of solar box oven is shown in Fig 2.3.

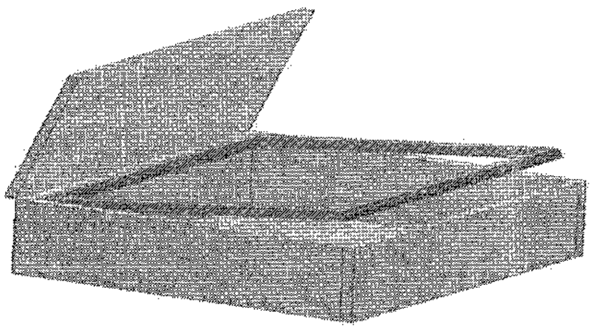

Fig 2.3: Solar box oven

2. **Solar Panel Oven**

A solar panel oven consists of a number of flat reflecting surfaces that focus solar radiation to an oven based bed in a clear heat resistant oven base box. One of the reflecting surfaces serves as the floor of the oven while the others serve as walls. This type of oven is foldable kit made from cardboard. Solar panel oven attains higher temperature than the box type because of its multiple reflecting surfaces though it requires periodical movement in other to trap sun energy. A solar panel oven is shown in Fig 2.4.

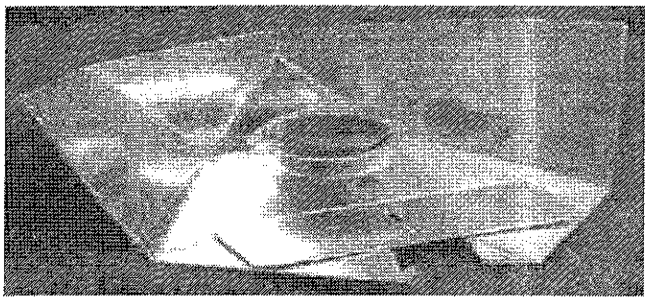

Fig 2.4 Solar panel oven

2.5 Solar Energy Resources in Nigeria

Nigeria is located in the tropical region of the equator ranging between 4 and 11 degrees north latitude (Narayanaswamy. 2001). It has been said that Nigeria is blessed with abundance of solar energy to help alleviate its numerous energy insufficient problems when harnessed and utilized effectively. According to (Bald et.al 2000), Nigeria is endowed with an annual average daily sunshine of 5.2KW/m^2/day for 6.25 hours ranging between 3.5KW/m2/day for 3.5 hours at the coastal areas to 7.0KW/m^2/day for 9 hours at the far northern areas. (Ikuponisi. 2004) stated that this amount of energy from the sun in Nigeria is equivalent to 1.082 million tons of its oil production per day, four thousand times Nigeria's current daily crude oil production, thirteen thousand times which of natural gas daily production and one hundred and seventeen thousand times the amount of electric power generated in Nigeria in 1998. He analyzed his statistics and found out that the annual solar energy isolation value is about twenty seven times the Nigeria's total convectional energy resources. This therefore shows that Nigeria with a total land mass of 9.24×10^3 Km2 and average of 1.804×10^{15} KWh of incidence solar energy annually requires only 3.7 % of her national land area to be utilized effectively in order to collect amount of sun energy equivalent to the nation's conventional energy reserve.

Only recently with the invasion of the world energy crisis in 1970s which has brought about global realization of the need for diversity of energy from exhaustible fossil fuel resources to other energy sources has Nigeria started showing interest in other energy resources (Dohn. 2000). This resulted to Federal Government of Nigeria in 1980 to established four energy research centers with the mandate to source for other rich available energy resources in various areas of renewable energy (Adetola. 2006). With so many researches on renewable energy, it was found that fossil fuels are not inexhaustible and they have environmental consequences due to their reckless consumption.

2.6 History of Solar Baking Technology

Baking using solar energy started in the 18th and 19th centuries (Mcveigh. 1977). This was when a successful oven was made and was used for baking. The first oven was the hot-box type which was developed by a French-Swiss naturalist, Horance de Saussure in 1767 (Jennifer. 2005). The outer box had lower temperature but higher than ambient temperature while the inner most box had the highest temperature. After Horance de Saussure successful oven, other scientists continued in the quest to improve on the knowledge of solar ovens and W. Adams of Bombay in India designed an oven in 1876 (Narayanaswawy, 2001 and Adam, 1876) that consisted of octagonal, glass-enclosed oven surrounded by glass mirror that collected the sunlight and directed it into the enclosure. It was reported that the span of the reflector rim is 31cm and it was able to bake the ratio of seven people in two hour in the month of August. Other models of solar ovens were developed in the United States by C.G Abbot (Abbot, 1939) in 1916 in which he used cylindrical parabolic reflector to focus sunlight on black pipe filled with motor oil and the tube enclosed by a transparent glass tube to prevent heat loss. The black pipe carries the hot oil to a reservoir in an insulated box where the baking pot is located. As time went by, it was found that properly constructed solar oven not only can bake food thoroughly and nutritionally but also are very easy to build and use, therefore, the United Nations and other agencies began supporting solar oven production and because of the new designs, programs were adopted to introduce these designs to locations to aid those in special need. Today, solar ovens function well than the ones designed by the earlier predecessors because of advancement in technology and contemporary materials.

2.7 Solar Baking In Nigeria

The history of solar baking in Nigeria started when Dr Robert Metcalf, the founder of solar oven international toured most of African nations on solar baking promotion and worked with Nigerian society for the improvement of rural people (www.wikipedia posted 2008). The organization introduced the use of solar ovens and it was reported that around 50 families were using solar oven to pasteurize water and also bake food. Through research and development centers and higher institutions, solar baking technology has gained much acceptance in terms of designs. A box type oven was constructed by (Amiyodu. 1993), he introduced steam relief line to help let off steam from baking chambers. The experimental analysis of the oven recorded plate temperature of 103^0 C and it took 145mins to bake flour, 80mins to bake yam and 190mins to bake 0.22kg of mixed bread. In Akure Ondo state, a solar box oven was reported to attain temperature of 50^0 C above ambient on 1200ml of water for 4 hours. Other researchers have basically been on concentrating solar ovens. (Onyishi. 1992) designed and constructed a concentrating solar oven and the experimental result showed concentration ratio 37.78 and 13.69% efficiency. A parabolic solar oven by (Musa et.al. 1991) has Fresnel design with mirrors as its reflecting surface. It was recorded that the oven was able to bake 1kg of mixed food in 60mins and bake bread in 120mins at maximum temperature of 98^0C. There are other projects and researches on solar ovens going on at various institution, research centers and non-governmental organizations in order to promote the use of solar energy in Nigeria and to reduce the dependence on the of use of biomass and liquefied natural gas as the major energy source for baking.

2.8 Benefits of Solar Ovens

Since baking accounts for 90% of the total energy consumed in the developing world especially in the rural domestic sector (GTZ. 2002 and Burgos. 2008), baking with solar energy is the most desirable option to the developing nations such as Nigeria. The environmental benefits of solar baking to wood burning energy source includes that it reduces CO_2 release from the burning firewood, preserve forest reserve by reducing cutting down of trees thereby reducing soil erosion, water pollution, loss of soil fertility and untimely desertification. There are social benefits of using solar ovens in areas where collecting fire wood can mean long hours of work and dangerous. The use of solar ovens can also help improve people's health since it can be used to sterilize water by heating to 65^0C. This can highly be beneficial to areas where people do not have access to safe drinking water and often suffer sickness or death as a result of impure water consumption (Metcalf. 1999). In addition, many people suffer respiratory and eye ailment as a result of extreme smoky baking condition in homes by using fuel wood. Solar baking is obviously smokeless and so eliminates this problem as well as reduces burns and other fire related injuries.

CHAPTER THREE

DESIGN AND MATERIALS USED FOR SOLAR OVEN

3.0 Design Consideration

The major considerations in the design of the solar oven is portability and resistance to environmental condition such that the oven could easily be transported from one point to another and as well withstand thermal and mechanical stress for a long time. Ultimately, the oven should be able to bake and roast stable local food stuffs such as flour pastries, samosa and roasted chicken. Another important consideration in the design is in the reflector orientation since the major factor influencing the collection efficiency of concentrating oven is solar collector orientation. The design took into account the axial and azimuth movement of the oven for maximum solar energy tracking.

3.1 Materials and Methods

The thickness of the plywood used in constructing the sides and the base of the box was 1.91 cm and a thickness of 0.57 cm for the mirror grooves. These thicknesses are used so that the box will not be too heavy. Each side of the box is lagged using cardboard that has already glued with aluminum to prevent heat loss due to convection, heat escaping from its sides is negligible and the flow per second is now constant along the length of the cardboard. The dimension of the box used was 50 cm x 35 cm x 40 cm, while the dimension of the absorber plate was 50 cm by 40cm. There are grooves made around the top of the box to serve as a slot for the mirrors. The inner part of the box is painted black to absorb the heat and trap the heat needed for baking. A black surface is a good emitter and absorber of radiation.

For this project, a shallow pot that is slightly larger than the food to be baked is used. The mirrors serve as reflectors. Inside the box is a mechanism which makes the mirror slant at an angle as soon as it is slotted into the groove made for it. When radiation from the sun is incident on the mirror, it is reflected in the opposite direction in such a way that it is absorbed by the glass on top of the box which serves as the lid. Glass provides about 10% better performance than plastic. And there is reason to believe that under windy conditions, glass is preferred since it doesn't flap in the wind and pump heat out of the oven. For this project, the thickness of the glass used is 4mm. The glass dimension was 33cm x 26cm. The box oven was placed on the high altitude for the box oven to be heated faster since there are no obstructions at that height. A thermometer was used to measure the temperatures of the absorber plate in the box oven and the ambient at different time intervals.

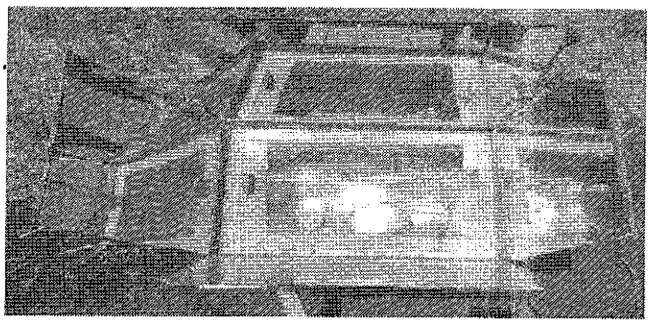

Fig 3.1 plywood design solar oven

Furniture Design Tools

- ✓ Wood Saw
- ✓ Cooping Saw
- ✓ Metal Saw

- ✓ C-Clamps
- ✓ Measuring Tape
- ✓ Pencil
- ✓ Wood File
- ✓ Utility Knife
- ✓ Silicone Gum
- ✓ Hammer
- ✓ Measuring Stick Or Square
- ✓ Drill Bits
- ✓ Hand Drill
- ✓ Regular And Star Screwdrivers
- ✓ Oven Thermometer
- ✓ Plywood

Solar Oven Materials

- ✓ ¼Inch Tacks
- ✓ 1inch Nails
- ✓ 2 by 3 Square Hinges
- ✓ 4 by 8 Sheet of ¼ Thick Plywood
- ✓ 1 by 1 Wooden Rods
- ✓ 1 Liter of Wood Glue
- ✓ Assorted Wood Screws 0.5 To 1.5 In Length
- ✓ 1 Wide Roll Of Heavy Aluminum Foil
- ✓ Sunglasses

- ✓ 2 Sheets Of 4mm Thick Clear Glass:
- ✓ Insulating Materials Such Shredded Paper And Rice Husks

3.2 Solar Ovens Design

Solar ovens design and construction involves a careful study and application of principles of energy and heat transmission by conduction, convection and radiation.

3.2.1 Radiation

Solar energy reaches a solar oven by radiation. Visible, ultraviolet and near infrared radiation get into the oven and get absorbed by a black baking pot and lid that works as a black body. White or reflecting pots don´t work the same way and reject sun radiation. Glass or plastic window in the upper part of the oven must allow this type of radiation get into the oven.

Technical overview of four types of heating techniques includes:

1. Reflected concentration method
2. Trapped heating method
3. Indirect heating method
    a. Using heat transfer medium
    b. Using steam/vapor
4. Direct solar absorption method

3.2.2 Conduction and Convection

Heat stored in the oven escapes by conduction through solid walls of the oven and convection of air trapped inside. The hot oven base bed generates infrared radiation, so it must be surrounded by surfaces that reflect the radiation (mirror, glass, some types of plastic like polypropylene, polyester, and methacrylate). Any hot area must be separated from the outside elements and surrounded by insulation or air. Hot air surrounding the bake food can transfer heat to the upper cover and walls. For the cover, it can be avoided with a double layer of transparent glass or plastic. It must be noted that in solar cookers the upper part is warmer than lower (as opposed to the traditional cuisine)

3.3 Component Description

The mirrors concentrating solar oven comprises of three essential parts namely the concentrator, supports and oven box. Each of these components has a specific function it plays in order to ensure that the solar oven functions appropriately. The concentrator, otherwise known as the reflector tracks the sun. The support holds and controls the position of the concentrator very firm while the oven box is the portion where the baking food is placed while baking.

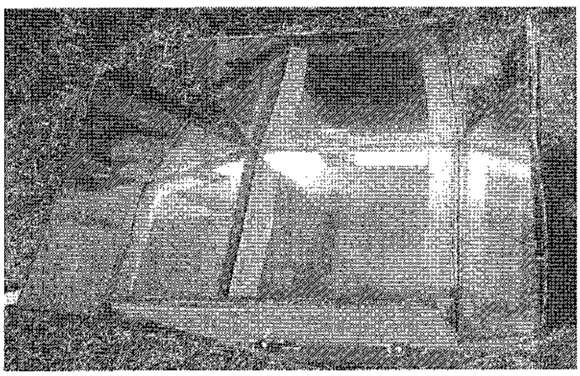

Fig 3.2 Solar Oven showing Components

3.3.1 Concentrator

The main component of the concentrating solar oven is the concentrator which receives, reflects and concentrates solar radiation to a focal point. The concentrator can either be square or parabolic in shape. The material used for the construction of the concentrator is mirrors. This was considered suitable because its properties and can be cut into required size and shape. The material is considered to be light enough to be carried from one place to the other. Mirrors were used because of its surface texture which will boost the optical efficiency of oven. The major properties of mirrors considered were its thermal, mechanical and chemical.

3.3.2 Support

The support of the solar oven holds the concentrator and also allows for manual rotation of the concentrator to follow the diurnal movement of the sun. The Y component of the solar oven carries the mirrors concentrator which is screwed at four sides of the Y component to allow for azimuth tracking of the sun. It also has a locking mechanism that holds the mirrors concentrator at a desired position. It is considered that the support has to be made of Y components in other to allow for altitude tracking of the sun movement across the sky while the base support carries the whole component of the solar oven firmly.

3.3.3 Base Oven Box

The main function of the base oven box is to carry baking food at a fixed position where the baking food receives optimum concentrated solar radiation. The major consideration in the design of the base oven box was the focal point, the size and initial temperature of the baking food with horizontal adjustment of the base oven box. Owing to the fact that the oven can be operated by different individuals, the base consists of the thermal absorber and horizontal adjustable mechanism to ensure that focal point is maintained at any given point of usage. The oven box is shown in fig 3.3 below.

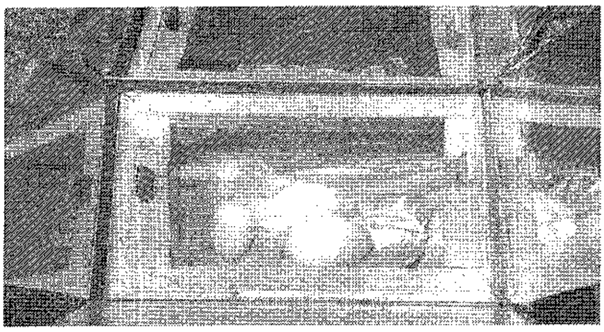

Fig 3.3 Loaded Solar Oven

3.4 Design Analysis and Calculation

3.4.1 Concentrator Area

The concentrator area is calculated using the area of the concentrator and it is calculated using equation 3.1.

$$A_T = 4\ (L\ X\ B) \qquad (3.1)$$

Where;

A_T= concentrator area, m^2

L = Length, m

B = Breath, m

$A_T = 4\ (50cm\ X\ 45cm)$

$A_T = 0.9m^2$

3.4.2 Aperture Area

The aperture area is the cuboid region of the base solar oven where the baking food is placed to trap the concentrated solar energy.

This area is calculated as follows;

$$A_r = 2(WL + LH + HW) \quad (3.2)$$

Where;

A_r =Aperture area, m^2

W = Width, m

L = Length, m

H = Height, m

$A_r = 2[(45cm \times 35cm) + (45cm \times 30cm) + (30cm \times 35cm)]$

$A_r = 0.8m^2$

3.4.3 Concentration Ratio

The concentration ratio of the solar oven is estimated from the expression given by Duffie and Beckman (1980).

$$C = \frac{A_T}{A_r} \quad (3.3)$$

Where;

C = concentration ratio

A_T = concentrator area, m^2

A_r = aperture area, m^2

Substituting the values of A_T and A_r as calculated from the above equation as $0.9m^2$ and $0.8m^2$ respectively.

$$C = \frac{0.9m^2}{0.8m^2}$$

$$C = 1.125$$

The concentration ratio of the solar oven is estimated to be 1.125. This implies that the ratio of the aperture area to the area of the receiver is 1.125.

3.4.4 Focal Length

Focal length of a rectangular surface is calculated using equation 3.4

$$F = \frac{r}{2} \qquad (3.4)$$

r = concentrator radius distance, m

3.5 Solar Collector Orientation

It is important to note that the orientation of the concentrator and receiver relative to the direction of propagation of solar radiation (beam radiation) is important. The tracking of sun is through its altitude and azimuth angle, the design of the concentrating solar oven was based on the selection of the altitude and azimuth angle. The concentrator was designed in such a way to rotate the concentrator about different axis; this axis of rotation may be north-south, east-west or inclined and parallel to the earth's axis such that in whichever case, the rate of rotation is 15^0/hr.

3.5.1 Selection of Altitude and Azimuth Angles

To select the altitude and azimuth angles, the baking time during which the oven is expected to be used is very important. For this design, the estimated baking time is between 8.00am and 5.00pm. Therefore for allowance of one hour each, the minimum and maximum altitude angle is taken between 8.00am and 5.00pm solar time. This is estimated using the equation of altitude angle and azimuth angle given below.

3.5.1.1 Altitude Angle

The altitude angle is expressed by

$$\text{Sin}\beta = \text{SinL Sin}\delta + \text{CosL Cos}\delta \text{ CosH} \quad (3.5)$$

Where;

β= altitude angle

L= latitude of the locality, the latitude angle of FUOYE Ikole Ekiti, Ekiti-State is 7.67^0N.

H= hour angles

δ= declination angle

3.5.1.2 Declination Angle

The declination angle is calculated using the expression as

$$\delta = 23.45 \text{ X Sin } [\frac{360}{365} \text{ X } 284 + \text{N}] \quad (3.6)$$

Where;

δ= declination angle

N= nth day of the year

Using 25th January, the declination angle is calculated as

$\delta = 23.45 \text{ X Sin } [\frac{360}{365} \text{ X } 284 + 25] = -19.26^0$

3.5.1.3 Hour Angle

$$\text{Hour angle (H)} = \frac{360}{24}(12 - T) \quad (3.7)$$

Where;

T= solar time

For 8.00am, the hour angle is calculated as

$H= \frac{360}{24}\ 12 - 8 = 60^0$

For 5.00pm, the hour angle is calculated as

$H= \frac{360}{24}\ 12 - 17 = -75^0$

The minimum altitude angle is then calculated as

$\text{Sin}\beta = \text{Sin}7.67^0 \text{ Sin } (-19.26) + \text{Cos}7.67^0 \text{ Cos } (-19.26) \text{ Cos } 60$

$\beta = \text{Sin}^{-1} [\text{Sin}7.67^0 \text{ Sin } (-19.26) + \text{Cos}7.67^0 \text{ Cos } (-19.26) \text{ Cos } 60]$

$\beta = 25.07^0$

The maximum altitude angle is also calculated as

$\sin\beta = \sin 7.67^0 \sin(-19.26) + \cos 7.67^0 \cos(19.26) \cos -75$

$\beta = \sin^{-1}[\sin 7.67^0 \sin(-19.26) + \cos 7.67^0 \cos(19.26) \cos -75]$

$\beta = 11.43^0$

3.5.1.4 Azimuth Angle

The calculation for the selection of minimum and maximum azimuth angle is estimated using equation 3.8 below

$$\text{Sin } \emptyset = \text{Cos } \delta \left[\frac{\text{SiinH}}{\text{Cos}\beta}\right] \quad (3.8)$$

Where;

Ø= azimuth angle

H= hour angle

β= altitude angle

At 8.00am, declination angle is -19.26^0, hour angle is 60^0 and the altitude angle is 11.43^0. Substituting these values into equation 3.8,

The minimum azimuth angle is calculated as:

$$\text{Sin } \emptyset = \text{Cos } \delta \left[\frac{\text{SinH}}{\text{Cos}\beta}\right]$$

$\varnothing = \mathrm{Sin}^{-1}\,(\mathrm{Cos}\ \delta\ [\frac{\mathrm{SinH}}{\mathrm{Cos}\beta}])$

$\varnothing = \mathrm{Sin}^{-1}\,(\mathrm{Cos}\ {-19.26}\ [\frac{\mathrm{Sin}60}{\mathrm{Cos}25.07}]) = 64.50^0$

$\varnothing = 64.50^0$

The maximum azimuth angle is calculated at 5.00pm. The hour angle is -75^0, declination angle is -19.26^0 and the altitude angle is 11.43^0.

Therefore the maximum angle to be set for the azimuth angle is calculated as

$\mathrm{Sin}\ \varnothing = \mathrm{Cos}\ \delta\ [\frac{\mathrm{SinH}}{\mathrm{Cos}\beta}]$

$\varnothing = \mathrm{Sin}^{-1}\,(\mathrm{Cos}\ \delta\ [\frac{\mathrm{SinH}}{\mathrm{Cos}\beta}])$

$\varnothing = \mathrm{Sin}^{-1}\,(\mathrm{Cos}\ {-19.26}\ [\frac{\mathrm{Sin}{-75}}{\mathrm{Cos}11.43}]) = -68.48^0$

$\varnothing = -68.48^0$

The negative sign indicated that the concentrator is oriented along the east –west axis of the solar altitude.

3.6 Thermal Load and Efficiency

3.6.1 Heat Input

The amount of heat that is supplied to the oven is calculated by using the expression below

$$Q_i = IA \qquad (3.9)$$

Where;

Q_i= heat input, W

I= beam radiation, W/m^2

A= Surface area of the solar oven, m^2

As mentioned earlier, concentrating collector uses only beam radiation and so to calculate the beam radiation at normal incident on a solar oven, ASHRAE (1981) expressed it as follows

$$I_{BN} = \frac{A_{ap}}{e^{\frac{B}{\sin\beta}}} \quad (3.10)$$

Where;

I_{BN}= beam radiation at normal incident, W/m^2

A_{ap} = apparent solar irradiation just outside the atmosphere

B= atmospheric extinction coefficient

β= altitude angle

The average beam radiation at 11am solar time on 25th January for

FUOYE at latitude 7.67^0 is determined by estimating the hour angle, declination angle and the altitude angle. The values of A_{ap} and Bare obtained from Hsieh (1986) as 1229.5W/m^2 and 0.448 respectively.

At 11am, the hour angle (H)

$$H = \frac{360}{24}(12 - 11) = 15^0$$

$$H = 15^0$$

For January 25th, the n^{th} day (N) is 25, therefore the declination angle is calculated from equation 3.6 as follows

$$\delta = 23.45 \text{ X Sin } [\frac{360}{365} \text{ X } (284 + 25)] = -19.26^0$$

$$\delta = -19.26^0$$

The hour angle, declination angle and the latitude angle are substituted into equation 3.5 to estimate the altitude angle.

$$\beta = Sin^{-1} [Sin7.67^0 \, Sin(-19.26) + Cos7.67^0 \, Cos(-19.26) \, Cos\, 15]$$

$$\beta = 59.28^0$$

The beam radiation at normal incident on the concentrator (I_{BN}) is estimated as

$$I_{BN} = \frac{A_{ap}}{e^{\frac{B}{Sin\beta}}}$$

$$I_{BN} = \frac{1229.5}{e^{\frac{0.448}{Sin59.28}}} = \frac{1229.5}{1.684} = 730.14 W/m^2$$

$$I_{BN} = 730.14 W/m^2$$

The beam radiation on the horizontal surface of the concentrator is estimated from the expression

$I = I_{BN} \, Sin\beta$ (3.11)

Where;

I= beam radiation on the surface, W/m^2

I_{BN}= beam radiation at normal incident, W/m^2

β= altitude angle

$I = 730.14 \, X \sin 59.28 = 627.68 W/m^2$

$I = 627.68 W/m^2$

This is the average amount of solar radiation that is estimated to fall on the surface of the concentrator at 11am solar time on 25th of January at FUOYE. Hence, this value varies depending on the weather condition of the day. Magneswaran (2000) suggested 20% deduction from the estimated average beam radiation on the surface of the collector to account for the weather variation and other possible losses due to radiation and convection.

Thus the estimated solar radiation (I) on the surface of the concentrator after accounting for radiation and convection losses is estimated as follows;

Solar radiation considering conventional Losses $= \frac{20}{100} \times 627.68 = 125.54 W/m^2$

Total beam radiation at the surface (I_b) = $I - I_{losses} = 627.68 - 125.54$

$I_b = 502.144 W/m^2$

From this, the energy input Q_i to the solar oven is beam radiation $I_b$at the reflector multiplied by surface area of the reflector (A_r) which is

$$Q_i = I_b x\ A_r \quad (3.12)$$

$$Q_i = 502.144 \times 0.8$$

$$Q_i = 401.72W$$

3.6.2 Estimated Heat Output

The box solar oven is designed for flour food baking.

The amount of heat required for baking is estimated as

$$Q = \frac{M_W\ C\ \Delta t}{\Delta t} \quad (3.13)$$

Where;

M_W= mass of material, kg

C = specific heat capacity of material, J/kg^0 C

Δt = temperature difference, ^{0}C

ΔT = time duration, sec

It was designed to bake flour pastries and roasting from an average temperature of 50^{0}C to 180^{0}C in 50 minutes. The amount of heat required to heat 0.5kg of pastry is

$$Q = \frac{1.45X\ 4186\ X\ 180-50}{3000} = 272.09$$

$Q = 272.09W$

3.6.3 Estimated Heat Loss in Mirrors Concentrating Oven

Heat loss is estimated by the expression

$$Q_l = Q_i - Q \quad (3.14)$$

Where;

Q_l = heat loss, W

Q_i = heat input, W

Q = heat output, W

The estimated heat loss by the oven is then

$Q_l = 401.72 - 272.09 = 129.63W$

$Q_l = 129.63W$

3.6.4 Efficiency

The thermal efficiency of concentrating solar ovens is given by the expression,

$$\eta = \frac{Q}{I.A} = \frac{Q}{Q_i} \quad (3.15)$$

Where;

η = efficiency of the solar oven

Q = heat output

I = solar radiation on the surface of the collector

A = surface area of the collector

Q_i = heat input, W

The thermal efficiency of the concentrating oven is then estimated from equation 3.15 as

Efficiency (η) $= \frac{272.09}{401.72} = 0.602$

η =67.7 %

3.7 Thermal Properties of Food Materials

Design and operation of processes that involve heat transfer requires special attention due to the heat sensitivity of food. This heat can be transferred in three different ways namely; conduction, convection and radiation but the ones that are predominant in heat transfer processes is the heat conducted through the food product and the heat transferred by forced convection between the product and moving fluid that are in contact with the food material. The heat demand for baking different food material therefore varies from one material to another because of their different thermal characteristics. It is therefore important to specify the food materials that can be baked with the solar oven considering the thermal properties of food material. These properties include specific heat, thermal conductivity and thermal diffusivity. The thermal properties will help to determine how much water is used in baking, how long the food is baked and at what temperature the food material is to be baked and since solar ovens performance is dependent on so many factors such as the time of the day, the knowledge of the thermal properties of the food material is very essential.

3.7.1 Specific Heat (cp)

Specific heat of food material is the amount of heat required to raise one unit of the material by one degree. Equation relating specific heat, mass of the sample (M), the amount of heat that must be added (Q), and the initial and final temperatures of the sample (T_1 and T_2) is given below.

$$Q = M\ c_p\ T_2 - T_1 \qquad (3.16)$$

3.7.2 Thermal conductivity (k)

It is a property that tells how well a material conducts heat. Heat conduction is the transfer of energy between neighboring molecules within a material. The following equation as predicted by Fourier's law of heat conduction relates the thermal conductivity to the amount of heat that flows through the material per unit of time (Q), the cross sectional area of the material through which the heat flows (A) with thickness of the food material (x), and the temperature difference per unit of length of the conducting material ($T_2 - T_1$).

$$Q = KA\ \frac{T_2 - T_1}{x} \qquad (3.17)$$

Thermal conductivity is influenced by a number of factors such as temperature, porosity moisture content and fiber orientation of the material (Dutta et.al, 1988).

3.7.3 Thermal diffusivity

Thermal diffusivity defines ability of material to conduct heat relative to its ability to store heat. It is related to thermal conductivity and specific heat through density as follows;

$$\alpha = \frac{K}{\varrho C_p} \qquad (3.18)$$

3.8 Baking Time of the Oven

To estimate the baking time for the solar oven is difficult because of the unpredictability of solar radiation. However, on an average clear weather, it can be estimated through the sunset hour. The sunset or sunrise hour is calculated by solving for hour angle in equation 3.8 as given by (Duffie and Beckman. 1974).

$$CosH = -TanLTan\delta \tag{3.19}$$

Where;

H=hour angle

L = latitude

δ = declination angle

Considering the hour angle at local solar noon is zero with each 20^0 of longitude equivalent to one hour, the hour angle is then expressed as follows;

$$H=\frac{1}{20}Cos^{-1}\cdot(-TanLTan\delta)$$

Therefore, the day length use, of the concentrating solar oven which is the time interval between the sunrise and sunset is expressed by (Magneswaran. 2000) as;

$$\text{Day length} = \frac{2}{20}Cos^{-1}(-TanLTan\delta)$$

δ= declination angle for FUOYE at latitude 7.67^0N on 25^{th} January, the declination angle from equation 3.6 is -19.29 so the day length is estimated as

Day length = $\frac{2}{20}$ Cos^{-1} [-Tan7.67 X Tan (-19.26)]

Day length = 9.13hours

Sunrise hours = 12noon - $\frac{9.13}{2}$ hours

Sunrise hours= 7.44hours

This implies that sun rises by 7.44am on 25th January at FUOYE campus.

Sunset = 12noon + $\frac{9.13}{2}$ hours

Sunset = 16.57hours

This implies that the sun will set at 16.57pm or 4.57pm on 25th January at FUOYE campus. Normally, household baking takes place between 6am and 8am for breakfast, 11am to 2pm for lunch and 5pm to 8pm for dinner. Therefore, the use of the oven for preparing dinner will not be possible because there is no solar radiation at this time of the day. For breakfast, the solar radiation available at 7am is estimated from equation 3.7.

The declination angle is estimated from equation as

$$\delta = 23.45 \text{ X Sin } [\frac{360}{365} \text{ X } (284 + 25)] = -19.26^0$$

The hour angle (H) from equation 3.7 of 7am is estimated as

$$H = \frac{360}{24} (12 - 7) = 75^0$$

The altitude angle for FUOYE at latitude 7.67^0N is estimated from equation 3.5 as:

$\text{Sin}\beta = \text{Sin}7.67^0 \ \text{Sin}\ (-19.26) + \text{Cos}7.67^0 \ \text{Cos}\ (-19.26)\ \text{Cos}\ 75$

$\beta = \text{Sin}^{-1}\ [\text{Sin}7.67^0 \ \text{Sin}\ (-19.26) + \text{Cos}7.67^0 \ \text{Cos}\ (-19.26)\ \text{Cos}\ 75]$

$\beta = 12.07^0$

The beam radiation at normal incident on the concentrator is then estimated using equation 3.10. Substituting the values of A and B as obtained from Hsieh (1986) as 1229.5W/m^2 and 0.448. The beam radiation at normal incident (I_{BN})

$$I_{BN} = \frac{A_{ap}}{e^{\frac{B}{\text{Sin}\beta}}}$$

$$I_{BN} = \frac{1229.5}{e^{\frac{0.448}{\text{Sin}12.07}}} = \frac{1229.5}{8.52} = 144.30\text{W/m}^2$$

$$I_{BN} = 144.30\text{W/m}^2$$

The average beam on the horizontal surface of concentrator at 7am on 15thJanuary is estimated as

$$I = I_{BN}\ \text{Sin}\beta$$

$$I = 144.30 \text{ X } \text{Sin}12.07 = 30.18\text{W/m}^2$$

$$I = 30.18\text{W/m}^2$$

This amount of solar radiation 30.18W/m^2 is low compared to the required solar radiation for the oven's operation. Hence, the oven may not be efficient to bake food in early morning.

For the lunch time, using the same parameters as calculated earlier for solar time at 10.00am, the beam radiation of $46.24W/m^2$ can be used to heat flour pastry requiring $43.24W/m^2$ quantity of heat at efficiency of 54%.

3.9 Material Selection

The performance of solar oven depends greatly on the choice of materials for its construction. Materials selected for the construction of the mirror concentrating solar oven has to be capable of satisfying a major desired function such as

- To be capable of resisting structural damage by strong wind and other storm conditions in a fixed position.
- Ability sustains easy operation, maintenance and reproduction.
- To ensured that the materials can be sourced locally.
- To reduce the bulkiness of the solar oven
- To ensured that the oven can withstand environmental, thermal and chemical damages.

To fulfill these requirements, the material for the concentrator which is the main component of the solar oven has to be carefully selected. The most desirable characteristics of the concentrator are low heat absorbability and high resistance to corrosion. Many materials were considered such as the use of concrete for the reflector shell but due to the heaviness of these materials and their cost, the idea was discarded. Consequently, mirrors a moldable composite material which can be manipulated at any time was selected since it can give the desired result. It is a good insulator with thermal conductivity of $0.05W/m\ ^0K$. Its conductivity is low because it uses trapped pockets of still air within it as a physical barrier in' other to reduce the flow of heat. Mirrors reduce heat due to convention and emissivity value of 0.6.

3.10 Construction of mirrors concentrating solar oven

The solar oven is a direct concentrating oven with a rectangular type reflector directing intercepted solar radiation to a point of focus as shown in Fig 3.5. The concentrated solar energy then heats up the baking food set at the focal point and heat is transferred from reflective mirror to the foods content. The construction of the components of the solar oven is described below.

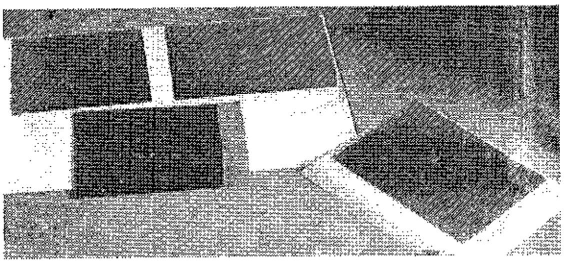

Fig 3.4The Reflector Mirrors

3.11 Operation of the Solar Oven

The operation principle of the solar oven is easy and friendly one. It does not require much technical knowledge though trained personnel who understand its safety measures and operation principle would operate the oven better. The oven can only be used when there is adequate sun energy. The operation of the solar oven includes the following;

1. Coupling the parts of the oven

2. Adjusting the azimuth and altitude angles of the oven to ensure that the oven is facing the sun

3. Placing the baking black baking pot and its content on the oven

4. Adjusting the oven every 15 minutes in order to track the sun

3.12 Safety Measures and Maintenance of the Oven

3.12.1 Safety measures

The safety measures when operating the solar ovens are as follows;

1. The operator of the oven must protect the eyes from sun glares.

2. When operating the oven, the operator has to stand beside the oven in other not to intercept the incoming sun rays.

3. The baking pan should not be too large in other to minimize heat loss.

4. Children should not be allowed near the oven when in use.

3.12.2 Maintenance for efficiency performance

For efficient performance of the oven, the following maintenance culture is necessary. They are;

1. Ensure regular cleaning of the concentrator surface before used in other to keep its sun ray absorbing surface shinny for excellent sun reflection.

2. As the reflecting material wears out, it should be replaced with a new one.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Presentation of Results

The box solar oven was used to conduct series of baking operations in other to evaluate its performance level. Certain quantities of baking food items were baked using the solar oven. The experiment took place at FUOYE in the month of June, 2017. There are series of test analyses carried out on the solar oven which were subjected to different climate condition over time.

The objectives of the test analyses carried out were to achieve the following;

1. Promote uniformity and consistency in the terms and units used to describe, test, rate and evaluate the solar oven, solar oven component and oven operation.
2. Provide a common format for presentation and interpretation of test results to facilitate communication.
3. Provide unified measure of performance that consumers may use in evaluating different designs when selecting a solar oven.

4.2 Test Procedure

The procedures taken during the experiment are as follows;

- The solar ovens were assembled in an open place for five consecutive days at Federal University Oye-Ekiti, Ekiti State. (FUOYE)
- The solar ovens were set to face the east in the morning
- The azimuth and altitude angle was set
- The food samples/water and pots were weighed on a weighing balance

- The pot trestle is set at the focal point.
- Ambient temperature and food content temperature measurement is recorded every ten minutes. Solar radiation and wind speed were obtained from data logger corresponding the time of the experiment. This is because as of the time of the experiment, Eppley Pyranometer and Anemometer were not available

4.3 Flour Dough Baking Test

The Flour Dough Baking test was conducted on 6th of November 2017 with the solar ovens set in an open place at FUOYE ensuring that there is no obstacle intercepting the incoming sun rays. The Flour Dough Baking consist of food contents such as 30g of flour, 1 teaspoon of milk, 2 teaspoon of mixed egg, 2 teaspoon of sugar, 10g of butter and 12g of water were placed at the focal point of the solar box oven. The temperature was determined by measuring the Flour Dough temperature every ten minutes.

Table 4.1 Unloading Test

Time of the day	Box Oven Temperature (^{0}c)	Ambient temperature (^{0}c)
12:15	44.0	30.1
12:20	45.0	31.6
12:25	46.2	33.8
12:30	48.6	34.1
12:35	49.1	35.4

12:40	49.0	32.1
12:45	50.1	32.8
12:50	51.8	33.6
12:55	52.1	34.1
1:00	53.4	34.8
1:05	56.4	35.1
1:10	68.3	35.8
1:15	69.0	36.4
1:20	65.2	35.5
1:25	65.0	34.5
1:30	59.4	35.2

Table 4.2 Loading Test

Time of the day	Box Oven Temperature (^{0}c)	Ambient temperature (^{0}c)
10:50	46.1	30.3
11:00	43.5	30.6
11:10	49.8	31.3

11:20	49.6	31.9
11:30	48.7	32.2
11:40	51.6	31.5
11:50	50.8	32.1
12:00	51.3	32.5
12:10	53.8	33.7
12:20	53.4	32.8
12:30	54.4	33.9
12:40	57.0	34.2
12:50	60.0	35.2
1:00	64.1	34.4
1:10	64.0	34.1
1:20	59.4	33.6

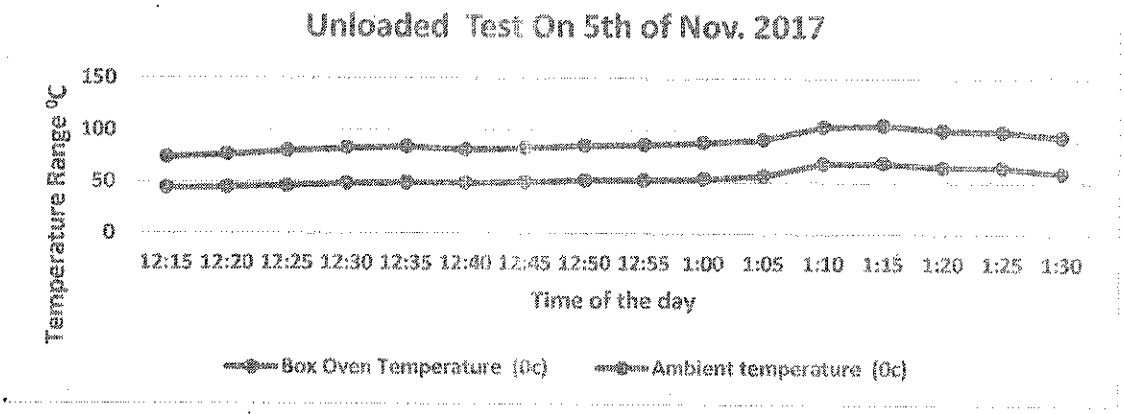

Fig 4.1: Graph of Box Oven Temperature and Ambient temperature over range of Time.

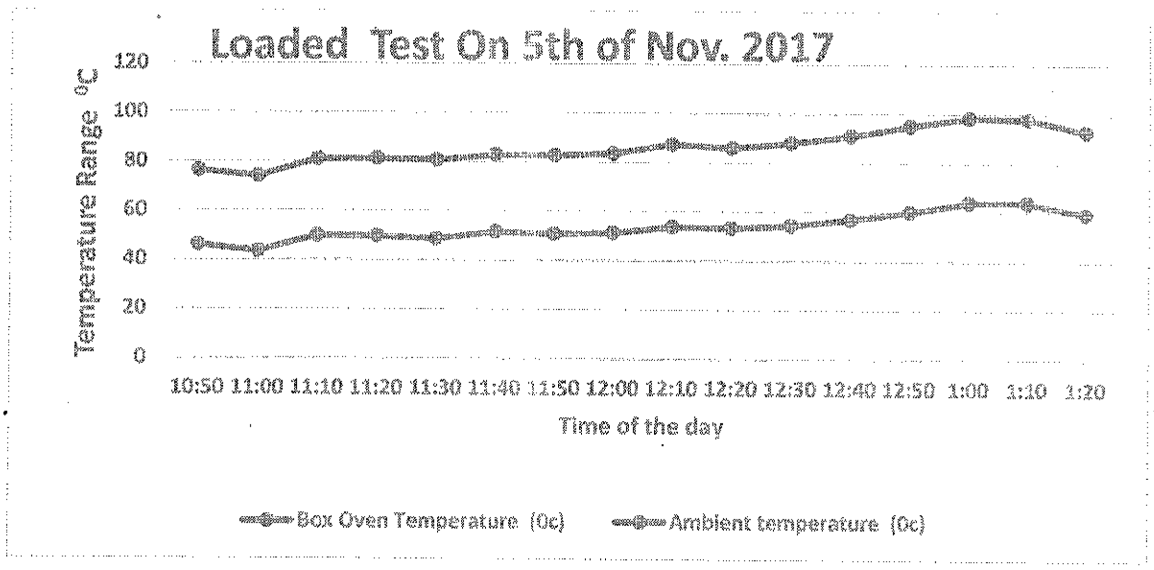

Fig 4.2: Graph of Box Oven Temperature and Ambient temperature over range of Time.

The experimental performance for unloading the solar box oven with food and loading of the solar oven box with Flour Dough food content are shown in Table 4.1 and 4.2 respectively. The Unloaded test started from 12:15am to 13:30pm and the loaded test from 10:50am to 1:20pm was evaluated under clear sky, windy weather and on an average weather condition. From the results, it is revealed that the factors that determined the performance of the ovens include, wind speed, amount of solar radiation and the time of the day.

1. Time of the day – time of the day determines the amount of solar radiation the reflector tracks. Solar radiation is highest when the hour angle is 0o i.e at solar noon. At this time, the azimuth angle is directly north.

2. Wind speed – high wind speed generally decreases the performance of concentrating solar oven because it generates dust particles that covers the surface of the solar oven and as well offsets the reflector from the focal point.

3. Amount of solar radiation – the greater the amount of solar radiation received at a given period of time, the greater the performance of concentrating solar ovens.

4.4 Cooking Power

The baking power is determined using 0.1kg of water. This is calculated using equation 4.1. Considering the weight of the mixed flour.

The amount of power required for baking is estimated as

$$Q = \frac{(M_W C_W + M_f C_f)\Delta t}{\Delta t} \quad (4.1)$$

Where;

M_w= mass of water, kg

M_f= mass of mixed flour, kg

C_w = specific heat capacity of water, J/kg^0 C

C_f = specific heat capacity of mixed flour, J/kg^0 C

Δt = temperature difference, ^{0}C

ΔT = time duration, sec

It was designed to bake flour pastries and roasting from an average temperature of 43.5^{0}C to 64.1^{0}C in

150 minutes. The amount of heat required to heat 0.6kg of pastry is

$$Q = \frac{[(0.1 X4186 + 0.6 X980) X 64.1 - 43.5]}{9000} = 1.39238W$$

Q = 1392.38ΩW

4.4.1 Efficiency of the solar box oven

The thermal efficiency of concentrating solar ovens is given by the expression,

$$\eta = \frac{Q}{I.A} = \frac{Q}{Q_i} \quad (4.2)$$

Where;

η = efficiency of the solar oven

Q = heat output

I_b = beam radiation

A_r = surface area of the collector

Q_i = heat input, W

4.4.2 Declination Angle

The declination angle is calculated using the expression as

$$\delta = 23.45 \text{ X Sin } [\frac{322.5}{365} \text{ X } 284 + N] \quad (4.3)$$

Where;

δ= declination angle

N= nth day of the year

Using 6th January, the declination angle is calculated as

$$\delta = 23.45 \text{ X Sin } [\frac{322.5}{365} \text{ X } 284 + 6] = -22.54^0$$

4.4.3 Hour Angle

$$\text{Hour angle (H)} = \frac{322.5}{24} (12 - T) \quad (4.4)$$

Where;

T= solar time

For 10.50am, the hour angle is calculated as

$$H= \frac{322.5}{24} 12 - 10.5 = 22.5^0$$

For 13.20pm, the hour angle is calculated as

$$H= \frac{322.5}{24} 12 - 13.2 = -18^0$$

The minimum altitude angle is then calculated as

$$\sin\beta = \sin 7.67^0 \sin(-22.54) + \cos 7.67^0 \cos(-22.54) \cos 22.5$$

$$\beta = \sin^{-1}[\sin 7.67^0 \sin(-22.54) + \cos 7.67^0 \cos(-22.54) \cos 22.5]$$

$$\beta = 52.61^0$$

The maximum altitude angle is also calculated as

$$\sin\beta = \sin 7.67^0 \sin(-22.54) + \cos 7.67^0 \cos(22.54) \cos -18$$

$$\beta = \sin^{-1}[\sin 7.67^0 \sin(-22.54) + \cos 7.67^0 \cos(22.54) \cos -18]$$

$$\beta = 55.02^0$$

4.4.4 Azimuth Angle

The calculation for the selection of minimum and maximum azimuth angle is estimated using equation 3.8 below

$$\sin \emptyset = \cos \delta \left[\frac{\mathrm{SiinH}}{\cos\beta}\right] \quad (4.5)$$

Where;

Ø= azimuth angle

H= hour angle

β= altitude angle

At 11.50am, declination angle is -22.54^0, hour angle is 22.5^0 and the altitude angle is 55.02^0. Substituting these values into equation 3.8,

The minimum azimuth angle is calculated as:

$$\text{Sin } \emptyset = \text{Cos } \delta \left[\frac{\text{SinH}}{\text{Cos}\beta}\right]$$

$$\emptyset = \text{Sin}^{-1} \left(\text{Cos } \delta \left[\frac{\text{SinH}}{\text{Cos}\beta}\right]\right)$$

$$\emptyset = \text{Sin}^{-1} \left(\text{Cos } -22.54 \left[\frac{\text{Sin}22.5}{\text{Cos}52.61}\right]\right) = 22.97^0$$

$$\emptyset = 22.97^0$$

The maximum azimuth angle is calculated at 13.20pm. The hour angle is -18^0, declination angle is -22.54^0 and the altitude angle is 55.02^0.

Therefore the maximum angle to be set for the azimuth angle is calculated as

$$\text{Sin } \emptyset = \text{Cos } \delta \left[\frac{\text{SinH}}{\text{Cos}\beta}\right]$$

$$\emptyset = \text{Sin}^{-1} \left(\text{Cos } \delta \left[\frac{\text{SinH}}{\text{Cos}\beta}\right]\right)$$

$$\emptyset = \text{Sin}^{-1} \left(\text{Cos } -22.54 \left[\frac{\text{Sin}-18}{\text{Cos}55.02}\right]\right) = -29.86^0$$

$$\emptyset = -29.86^0$$

The negative sign indicated that the concentrator is oriented along the east –west axis of the solar altitude.

The beam radiation at normal incident on the concentrator (I_{BN}) is estimated as

$$I_{BN} = \frac{A_{ap}}{e^{\frac{B}{\sin\beta}}}$$

$$I_{BN} = \frac{1229.5}{e^{\frac{0.448}{\sin 52.61}}} = \frac{1229.5}{0.2024} = 6074.44 W/m^2$$

$$I_{BN} = 6074.44 W/m^2$$

The beam radiation on the horizontal surface of the concentrator is estimated from the expression

$$I = I_{BN} \sin\beta \quad (4.6)$$

Where;

I= beam radiation on the surface, W/m^2

I_{BN}= beam radiation at normal incident, W/m^2

β= altitude angle

$$I = 6074.44 W/m^2 X \sin 52.61 = 4826.27 W/m^2$$

$$I = 4826.27 W/m^2$$

This is the average amount of solar radiation that is estimated to fall on the surface of the concentrator at 11am solar time on 6th of August at FUOYE. Hence, this value varies depending on the weather condition of the day. (Magneswaran. 2000) suggested 40% deduction from the estimated average beam radiation on the surface of the collector to account for the weather variation and other possible losses due to radiation, wind, cloud, sun intensity and convection. Thus the estimated solar radiation (I) on the surface of the concentrator after accounting for radiation and convection losses is estimated as follows:

Solar radiation considering conventional Losses $= \frac{40}{100} \times 4826.27 = 1930.50 W/m^2$

Total beam radiation at the surface (I_b) $= I - I_{losses} = 4826.27 - 1930.50$

$I_b = 2895.76 W/m^2$

The thermal efficiency of concentrating solar ovens is given by the expression,

$$\eta = \frac{Q}{I.A} = \frac{Q}{Q_i} \quad (4.7)$$

The thermal efficiency of the concentrating oven is then estimated from equation 4.2 as

Efficiency (η) $= \frac{1392.38}{2895.76 \times 0.8} = 0.6010$

$\eta = 60.1\ \%$

4.5 Instrumentation and Measurement

There are variables that must be considered during the experimental period. These are controllable and uncontrollable variable such as wind, ambient temperature, food content, temperature, solar altitude and azimuth.

4.5.1 Solar Radiation

The solar radiation data can be obtained from any data logger of FUOYE. The data logger records solar radiation every one hour. Throughout the period of the experiment, the solar radiation recorded ranged between the minimum of 200W/m^2 to maximum of 500W/m^2.

4.5.2 Wind

Wind is one of the uncontrollable variables that its effect can greatly affect the test result if not appropriately carried out. The wind speed at the test of solar ovens should be less than 1.0m/s during experiment. This was considered during the baking/heating experiment only that the test was carried out in the month of August when the weather condition in FUOYE is not steady. At this time, the weather was hazy and windy so the recorded wind speed during the time of the experiment ranged from 0.47m/s to 4.05m/s.

4.5.3 Solar Altitude and Azimuth Angle

The solar altitude and azimuth angle were set at 11.00am at the beginning of the test experiment at the angle of 15^0 and 45^0 respectively. The oven is set at a height of 16mm and the concentrator is adjusted every 10 minutes to follow the diurnal movement of the sun.

4.5.4 Food Content Temperature

The food temperature was recorded every ten minutes interval. The time was recorded using wrist watch. The base bed oven box used is exterior black Aluminum foil paper. As the oven box absorb the heat at the focal point, the temperature of its content increases with time. The food content temperature was measured using digital thermometer.

4.5.5 Ambient Temperature

At the beginning of each day experiment, the ambient temperature was recorded between 25^0C to 35.5^0C. The temperature reading of the food content and the ambient were measured simultaneously at interval of ten minutes using digital thermometer.

4.6 Discussion of Results

The results of the experiment can be analyzed by the varying temperature gradient in the cookers. The initial temperature rise varied slightly between the cookers which can be seen in the differences in steepness of the slopes of the graph (Fig 4.1 and 4.2). The plot of ambient temperature, box oven temperature against time indicates that temperature attainment of the concentrating cookers depends largely on sun intensity, concentrator, heat absorber and weather condition. It shows that the day that had relatively low wind speed and average sun shiny recorded highest temperature attainment for the cooker. The result from the cooking test the box type cooker is affected by wind blow and its content retains variable. For efficient cooking it is required that the cooking food is heated from the bottom. The altitude angle is low and some of the reflected ray strike side of the cooking food. Wind blows offset the concentrators from their focal point most of the time and the cooker will not be able to cook the food because of high forced convection loses. According to (Dandakota et al. 2007), attenuation of solar radiation by the harmattan dust particles in respect to collector surface occur in two stages namely;

- On the incident radiation before reaching the collector surface due to particle suspended in the lower part of the atmosphere.

- On the collector surface due to accumulated particles on the aperture of the collector

The reflection of sun rays on the reflector has greater effect on the efficiency of the cooker and it could be attributed to the mirror concentrator which has be known to reflect a larger portion of incoming beam and diffuse radiation in all directions thus increase efficiency of the cooker (Burgos et al. 2008). The major problem in the theoretical and experimental performance of the cookers suggested that the weather condition has a major impact on box type cookers which gives greater buffer between changes in solar radiation and inside cooker temperature. The water requirement of some food staples determined shows that the long cooking rate associated with solar cooking could be reduced by avoiding excess water usage.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In Nigeria, the potential of using solar for cooking is high. The cooker was able to cook most foods that require cooking by boiling and was able to bake in reasonable times. The study reinforced the views that solar devices can play a major role in solving Nigerian's domestic energy problem especially in the rural areas rather than being a novelty demonstration of solar energy use.

As the need for alternative energy sources for cooking increases, new technologies continue to evolve on how to solve the problems. Generally, solar cookers have a tremendous social, economic and environmental value to every community. This is because using solar cookers rather than firewood for cooking in areas where firewood is the major cooking energy source will help reduce desert encroachment, drudgery in cooking and preserve the environment and most of these areas where firewood is used for cooking are sun rich areas which are around the equator. Solar cooker could be used in such areas 160-280 days in a year and will be available 5-7 hours in a day (Metcalf, 1996). In the course of this work, a box solar cooker was designed and constructed. The solar cooker is portable and can easily be assembled and disband. It can withstand environmental factors such as rust. The cooker was tested at Federal University Oye Ekiti on 6th of August, It was used to bake mixture of dough flour. The maximum temperature attained during the unload test was 69.0^{0}C for a period of 2 ½ hrs. It took the cooker 2hrs 30mins to bake the dough flour. The cooker performance was fair though it was greatly affected by prevailing weather condition.

5.2 Recommendations

The following recommendations would help to improve and ease further research in solar oven design and construction:

1. Tracking devices could be used to enhance solar radiation collection. Solar panels may be used to power such devices.

2. There is need for the use of experimental design analysis for better performance evaluation and results analysis.

3. There is need for further studies on this research work to include comprehensive seasonal studies in other to obtain enough data for fair performance evaluation.

4. The use of various oven cavity geometries should be investigated in collector design, in order to study the effect of various geometries on the performance.

5. Alternative methods of heat retention in the collector should be explored. Most of the heat is lost by convection from the glass cover. Top loss from the collector could be reduced by using multiple glazing.

6. Automatic light sensitivity controller could be introduced to rotate the receiver surface according to the direction of the sun.

7. An experimental analysis has to be undertaken to obtain the maximum angle through which the focal point and aperture diameter of the reflector can be tilted so that no reflected ray may miss the bottom of the cooking vessel.

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