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Design, Construction and Performance Test of a Box Type Solar Cooker

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ABSTRACT

Solar energy is that produced by the sun's light. It is one of the largest renewable resources which is used for various domestic and industrial purposes like cooking, dehydration, drying, heating power generation etc. and available almost everywhere. The paper provides information about the collection of solar energy by a box type solar cooker. Solar cooker retains heat from the sun and focus it in a container that holds the food and traps the gathered heat. Capturing and thermal conversion are accomplished by the greenhouse effect, thermal conversion is accomplished with a material that absorbs solar energy and thereby increases its own internal energy. A cover system consisting of one or several layers of materials such as glass, which transmit the solar radiation but do not transmit thermal radiation the reflected light is either absorbed by other materials within the space or because it doesn't change wavelength, passes back out through the glass. The maximum temperature inside the cooking pot was found to be 114^{o} C with no load condition at a radiation level of 223-313 W/m^2.

Keywords: Solar Cooker, Solar Energy, Thermal Conversion, Greenhouse Effect.

1. Introduction

In modern civilization, energy is a fundamental requirement for an industrial society. Considerable effort is therefore being devoted to find new sources of energy to power different machines efficiently. Demand on energy is growing because of vigorous development of industry day by day. Solar radiation is an energy resource many times larger than man's energy needs. Human beings have been able to make use of these resources only on a limited scale mainly for drying crops and producing salt from brines. The direct utilization of solar energy involves its conversion directly to thermal energy. Solar radiation of all wavelengths is converted to thermal energy by using a black surface to absorb the radiant energy using a flat plate collector. A solar oven is one of the direct thermal technologies and basically it consists of collector systems. The collector systems consist of a concentrator and a receiver. The concentrator reflects and focuses sun light on the receiver using aluminum foil, glasses or mirrors as reflector. The receiver is a black body which absorbs the solar radiation and converts it to heat. Using renewable energy is the most promising solution for meeting the growing energy demand of the 21st century. Renewable energy is energy which comes from natural resources such as sunlight, wind, rain, tides and geothermal heat. In 2008, about 19% of global final energy consumption came from renewable energy [1]. Energy resources are diminishing chronologically, but solar energy is an ideal source in many ways. Its use does not diminish a given reservoir as in the case of fossil fuels. For this reasons many organizations and governments have given emphasis on the use of solar energy in efficient ways.

.In developing countries like Bangladesh energy consumption for heating and cooking is a great part of the total energy consumption. In rural areas of Bangladesh cooking is mainly made by wood. In the urban areas of Bangladesh this purpose is served by using gaseous or liquid fuels. But, in most of the areas mainly woods are used for heating food which is a major cause of deforestation [2]. The most of the energy requirement for cooking are met by noncommercial fuels such as firewood, agricultural waste and animal dung cake in rural areas. For cooking purpose 85% of population of developing countries like Bangladesh use domestic fuel such as wood, cow dung etc. [3]. Among various type of solar oven the box type solar oven is a good solution for use of solar energy for heating purpose as its low cost, easy construction and better output.

2. Literature Review

Earth receives 174 petawatts (PW) of incoming solar radiation (insolation) at the upper atmosphere. Approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses. The spectrum of solar light at the Earth's surface is mostly spread across the visible and near-infrared ranges with a small part in the near-ultraviolet [5] .The sun's energy is created in the interior region of the sun as a result of continuous fusion reaction. The relative coolness of the outer surface of the sun is an indication that the energy created in the interior is dissipated by radiation from the outer surface of the sun. The intensity of solar radiation reaching earth's atmosphere has been determined more by a series of high-altitude measurements made by using balloons, aircraft and spacecraft from 1967 to 1970.The resulting energy is known as the solar constant and its value is 1353 W/m^2, when the earth is at its mean distance from the sun. As the earth moves around the sun in a slightly elliptical orbit, the distance between them varies from 98.3% of the mean distance when the earth is closest to the sun to 101.7% of the mean distance when the earth sun distance is maximum [6]. Earth's land surface, oceans and atmosphere absorb solar radiation, and this rises their temperature. Warm air containing evaporated water from the oceans rises,

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causing atmospheric circulation or convection. When the air reaches a high altitude, where the temperature is low, water vapor condenses into clouds, which rain into the earth's surface, completing the water cycle. The latent heat of water condensation amplifies convection, producing atmospheric phenomena such as wind, cyclones and anti-cyclones. Sunlight absorbed by the ocean and land masses keep the surface at an average temperature of 14°C. By photosynthesis green plants convert solar energy into chemical energy, which produces food, wood and the biomass from which fossil fuels are derived [7]. Solar energy is the most abundant energy resource and it is available for use in its direct (solar radiation) and indirect (wind, biomass, hydro, ocean etc.) forms. Even if only 0.1% of this energy reaching the earth could be converted at an efficiency of 10%, it would be four times larger than total world world's electricity generating capacity of about 5000 GW [8]. Not all energy expressed by the solar constant reaches the surface of the earth because of strong absorption by carbon-di-oxide, ozone and water vapor in the atmosphere. The solar radiation incident on the earth's surface is also depends on the atmospheric content of dust and other pollutants. The box type solar cooker has the Achilles heel of slow heating rate, low temperature delivery and low cooking efficiency. One of the drawbacks of the cooker is attributed to partial shading of water vapors on the inner surface of the glazing, which dampens the intensity of radiation. This kind of cooker depends on the greenhouse effect in which the transparent glazing permits the passing of shorter wavelength solar radiation but is opaque to radiation coming from relatively low temperature heated objects [22].

The solar constant (G_{sc}) is the energy from the sun, per unit time, received on a unit area of surface perpendicular to the direction of propagation, at mean earth-sun distance, outside of the atmosphere. The availability of very high altitude aircraft, balloons and spacecraft has permitted direct measurement of solar radiation most or the earth's entire atmosphere. The measurements were made with a variety of instruments in nine separate experimental programs. The resulted in a value of solar constant G_{sc} of 1353 W/m^2 with an estimated error of $\pm$ 1.5% [10]. The solar energy is produced in the interior of sun's sphere by fusion reaction at temperature of many millions of degree. The temperature at the outer surface of the sun is approximately 5762 K. The amount of solar energy intercepted by the planet earth is 5000 times greater than the sum of all other inputs (terrestrial located 150, nuclear geothermal and gravitational energies and lunar gravitational energy) of this amount 30% is reflected to space and 47% is converted to low temperature heat and radiated back into space and 23% power the evaporation cycle of biosphere. Less than 0.5% is represented in the kinetic energy of the wind and waves and in photosynthesis storage in plants. 99% of sun's energy is contained within the wavelengths 0.28 to 4.96μm. Since solar energy is concentrated at short wavelengths as opposed to much longer wavelengths for most "earth bound" thermal radiations a particular material may exhibit entirely different absorbance and transmittance properties for the two types of radiation. The classic of this behavior is "greenhouse effect". Ordinary glasses transmit radiation very rapidly of wavelength below 2μm. Practically all the low temperature radiation emitted by the objects in the green house is of such a long wavelength character that remains trapped in the green house. Countries like USA, France, Canada and other developed countries are using solar energy in many fields such as industrial sector, building heating and cooling, agricultural drying, power production etc. [11].The total solar energy absorbed by Earth's atmosphere, oceans and land masses is approximately 3,850,000 exajoules (EJ) per year. In 2002, this was more energy in one hour than the world used in one year. The amount of solar energy reaching the surface of the planet is so vast that in one year it is about twice as much as will ever be obtained from all of the earth's non-renewable resources of coal, oil, natural gas, and mined uranium combined [7].

3. Methodology

3.1 Design of the Proposed Solar Oven

In the proposed box type solar oven more solar radiation can be trapped. The oven can work for a longer period of the day. The construction of this oven is however, slightly harder than usual box type but it can be considered reasonable in respect to its improved performance. The isometric and top view of proposed solar oven is shown in Fig.1 and 2.

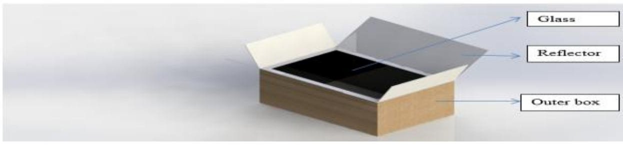

Fig.1 Isometric View of Box Type Solar Oven

Fig.2 Top View of Box Type Solar Oven

In solar oven was made up of glass, glass frame, M.S. sheet as collector and outer wood box. The outer box was made of 1 inch thick wood. The dimension of outer box made of wood and collector box of mild steel are shown in Fig.3 and 4.

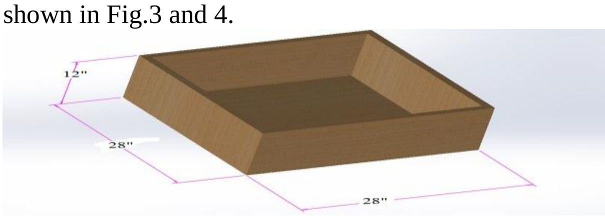

Fig.3 Outer Box made of wood

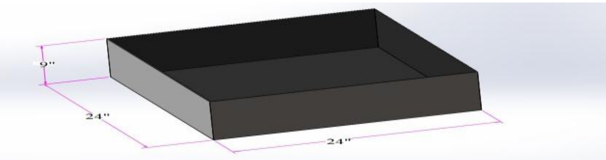

Fig.4 Collector box of M.S. Sheet

The oven consists of collector of M.S. sheet of 2 mm thickness. The M.S. sheet was encased in a box made of wood. The clearance between the M.S. sheet and the encasing were filled with cotton to provide thermal insulation. The clearance between the outer box and the M.S. sheet collector which filled with cotton is 2 inch. The Glass frame gives support to the glass is made by wood of 1 inch thickness and 3 inch breadth. The dimensions of the frame contains the glass is shown in Fig.5

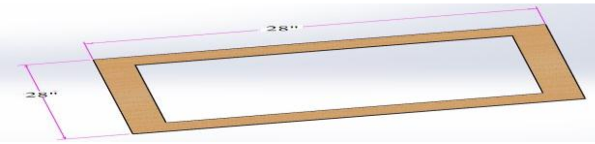

Fig.5 Glass Frame

The solar oven consist a glass of 5 mm thickness. The dimension of glass in inch is shown in Fig.6.

Fig.6 Single Glass

The dimension of reflector (mirror) frame made of wood is shown in Fig.7

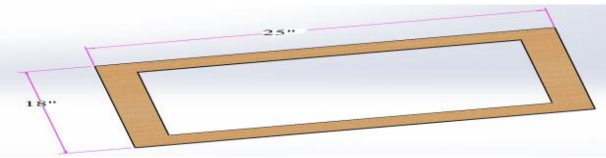

Fig.7 Wood frame for reflector (mirror)

The dimension of reflector (mirror) is shown in Fig.8

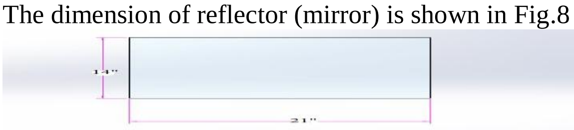

Fig.8 Reflector (mirror)

The pot has diameter of 18.5 cm and height of 8 cm.

Fig.9 Dimension of Pot

3.2 Construction of the solar oven

At first outer box of the oven was made by wood according to the proposed design and specification. After that an inner box was made by M.S sheet kept inside the outer box made by wood and the space between the two boxes is filled with cotton insulation. The inner surface of the mild steel was painted black. Then the upside of this box was covered by a transparent glass with frame. Four mirrors as reflector were attached with the box by eight hinged joints.

Fig.10 Construction of the box type solar oven

A hole was made in one side of the box to enter thermocouple wire. One end of the thermocouple wire is connected to the digital temperature indicator box which displays the temperature and other end is immersed at the pot.

Fig.11 Top view of the constructed oven

3.3 Material Selection for the Proposed Solar cooker

However common factors, on which selection of materials for box type solar cooker generally depends on are thermal, optical and radiation properties, availability of material, cost of material, durability, portability, ease of maintenance and adaptability to local skill

3.3.1 Material for Collector

The factors on which the choice of collector materials depends are high thermal conductivity, good corrosion resistance, adequate tensile and compressive strength, cost of material, ease of fabrication, and resistance to stagnation temperature conditions. A list of materials generally employed as collector is given in Table 1.

Table 1 Properties of metals used for collector

Material	Density (kg/m^3)	Thermal Conductivity (W/m°C)	Specific heat (kj/kg°C)
Copper	8954	386	0.383
Aluminum	2707	204	0.996
Mild steel sheet	7833	54	0.465

So copper and aluminum are the best suited as collector material. But high cost associated with them led to choose the third option mild steel sheet also known as M.S. sheet as collector material.

3.3.2 Material for Outer Box

Partex board, woods etc. are suitable as the material of outer box. Among this two, partex board is rigid and lightweight. It can cut easily and glued easily for the entire construction. On the other hand, wood is comparatively durable but heavy weighted. Wood is easily available to us and its cost is lower than partex board. Therefore, wood is selected in this purpose.

3.3.3 Material for Reflecting Surface

For reflecting systems, materials of high quality and good specular reflectance properties are required. Due consideration must be given to the effect of accumulation of dust and contamination, stability, reflective coating, environmental effect, cleaning problem and cost. Good candidates reflecting materials are mirror and Aluminum foil. Most fresh Aluminum surfaces have reflectivity of 80-85% while reflectivity of mirror surface (ρ) can achieved more than 95%.

3.3.4 Material for Insulation

As the main function of thermal insulating materials is to reduce heat losses from the collector walls and floor, the desired characteristics of an insulating material are low thermal conductivity, stability at high temperature, self-supporting feature without tendency to settle, no contribution in corrosion, ease of application. Thermal conductivity of glass wool is lower than cotton wool. But cotton wool has lower cost, available at local market and use of cotton wool is also easier then glass wool.

3.3.5 Cover Material

The most critical factors for the cover materials are strength, durability, non-degradability and solar energy transmittance. Window glass is mostly performed for solar ovens of a box type as cover materials have high transmittance (τ) for solar radiation, glass does not degrade in sunlight, it protected from thermal strains and impacts is more, durable than most plastic glazing, glass has less percentage of expansion in length. So, less allowance is required. The glass is more available in both rural and urban areas than other cover material.

3.3.6 Material for Pot

As the pots should have high absorption capability of heat, aluminum pots can be used which are also light in weight, commonly found in this country and most importantly can be made darken to its external surface. Paint required for the interior of the collector and exterior of pots should nontoxic and fumeless in both hot and cold condition. It also should have moisture resistance property. Black paint, which has the property to increase the absorption capability of the material on which it is coated. Therefore, above description of wide range of material helps to find out the appropriate material for several components of the proposed box type solar oven and can be summarized as shown in Table 2.

Table 2 Selection of material for solar cooker

Component	Selected material
Outer box	Wood
Insulation	Cotton
Collector	M.S. sheet
Reflector	Mirror
Cover material	Plain glass
Cooking pots	Aluminum pots
Coating material	Black paint

4. Experimental Results Analysis

4.1. Experimental Setup

The entire constructed oven set in such a way that no turning is required towards the sun. The cooker was placed under open sky directing to the sun. By manual arrangement it was ensured that reflector of the cooker is perfectly directed to the sun.

Fig.12 Experimental Setup

To evaluate the performance of the solar cooker the following equipment's are used:

4.1.1 Solarimeter

It is used to measure the solar intensity in W/m^2.It has a sensor that is placed in the atmosphere and the display shows the instant solar intensity.

Fig.13 Solarimeter

4.1.2 Thermocouple wire and Digital Temperature indicator

One end of the thermocouple wire is connected to the digital temperature indicator box which displays the temperature and other end is immersed at the pot. This thermocouple was T type (copper/constantan) thermocouple which overall range is -200^{o}C to 400^{o}C and typical accuracy is 1^{o}C. For the best accuracy, this thermocouple often used for food monitoring and environmental applications.

Fig.14 Digital Temperature Indicator

4.2 Experimental Procedure

To evaluate the performance and characteristics of the constructed box type solar cooker the following type of procedure were performed:

According to the measurement different amount of foods were taken into the pot and positioned at the right direction toward the sun. Temperature inside the pot was recorded by digital temperature indicator after every five minute interval. At the same time solar intensity and solar energy were also recorded from the solarimeter. Pizzas, sandwich, Burger, vegetable roll, chicken cutlet etc. were used as a food for this purpose. Different amount of food were used at different day. A fixed amount of food was heated up for a fixed time interval and the quality after heating up was compared. The time required for heating up to a fixed temperature of a fixed amount of food was thus determined.

4.3 Overall Thermal Efficiency

Overall thermal efficiency was calculated by following equation (EI-Sebaii and Ibrahim):

$$\eta_u = \frac{m_f C_f \Delta T_f}{I_{av} A_c \Delta t} \qquad (1)$$

Where η_u = overall thermal efficiency (%), m_f = mass of cooking food (kg), C_f = specific heat of cooking food (j/kgK), ΔT_f = difference between the maximum and ambient air

temperature, I_{av} = average solar intensity (W/m2)

during the time interval, A_c = the aperture area (m2) of the cooker, Δt = time required to achieve the maximum temperature of

the cooking fluid (s).

4.4 Cooking Power

The cooking power of the different solar cookers was calculated using equation given by Kundapur and Sudhir

(2009) as follows:

$$P = \frac{T_{w_2} - T_{w_1}}{t} m_w C_{p_w} \qquad (2)$$

Where, P = cooking power (w), T_{w_2} = final food temperature (℃), T_{w_1} = initial water temperature (℃), m_w =mass of food (kg) C_{p_w} = food heat capacity, t = time(s).

4.4 Result

The performance of the box type solar oven was found to be depend on climate parameters like ambient temperature, solar radiation etc. design parameters like properties of black paint used inside the collector and outside the pot, properties of absorber plate material, insulation properties and on the operational parameter like amount and type of food kept for heating, number of pot used etc. The variation of the temperature inside the pot for a sunny day it is shown in Fig.15.It was seen that the temperature inside the pot increased with the time of the day and maximum temperature reached at about 12:30 PM when the solar intensity was 313 W/m^2.

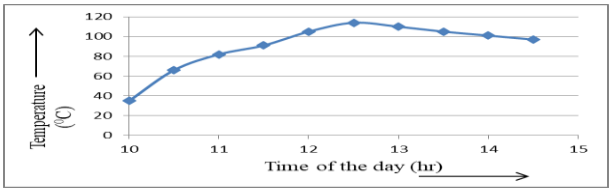

Fig.15 Variation of temperature inside the pot with time of the day (Without load)

The variation of temperature with time of heating element inside the pot are shown in following figures:

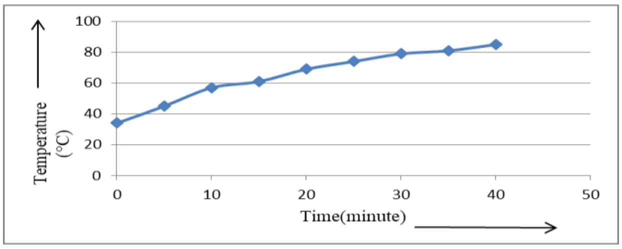

Fig.16 Temperature Vs. time curve for 85 gm. chicken cutlet (12/04/16;12:10PM-1.00PM)

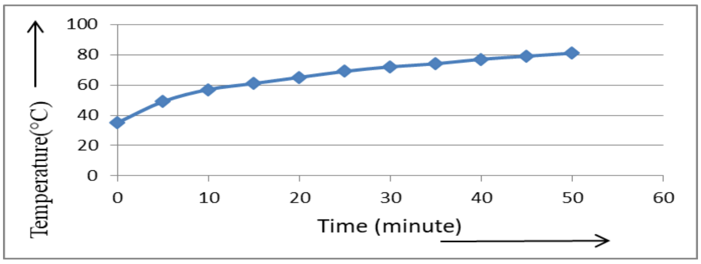

Fig.17 Temperature Vs. time curve for 475 gm. pizza (11/04/16; 11:00AM-11:45AM)

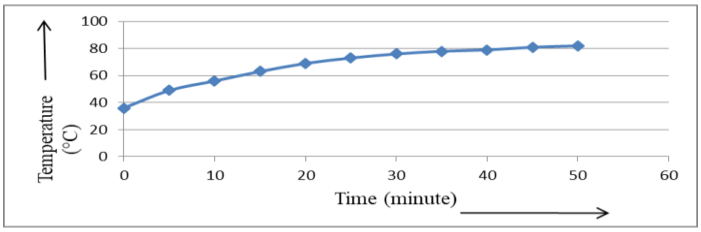

Fig.18 Temperature Vs. time curve for 75 gm. vegetable roll (13/04/16; 1:30PM-2:20PM)

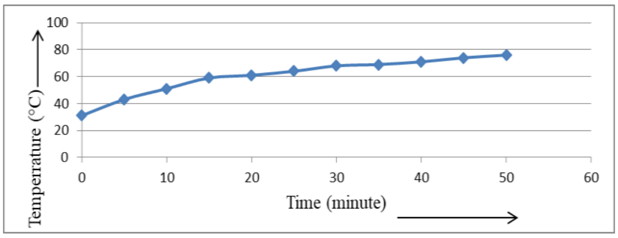

Fig.19 Temperature Vs. time curve for 81 gm. sandwich (14/04/16; 10:30AM-11:20AM)

Temperature was maximum when radiation intensity of the sun was maximum. In fig.15 to 19 Temperatures Vs. time curve for different load at different days are shown.

From these Figures it is clear that the temperature inside the pot increases as the time increases. In fig.15 maximum temperature inside the pot was found 114°C without any load at an available radiation level of 223-313 W/m^2 .In fig.16 maximum temperature inside the pot was found 87°C within 45 minutes at a radiation level of 223-304 W/m^2. In fig.17 maximum temperature inside the pot was found 81°C within 50 minutes at a radiation level of 267-313 W/m^2. It is also clear from this that as radiation level decreases, the time required for heating increases.

5. CONCLUSION

The box type solar cooker represents a potential alternative way of heating upon the conventional ways. After the construction of the proposed cooker, the experimental results have shown many effective utilities. After construction of the experimental setup, the data were analyzed. As efficiency of heating of the constructed cooker is found to be remarkable, this type of solar cooker system can be used in remote and rural areas where national grid line is unreachable or highly expensive, In terms of life time limit, it is more worth than most other energy sources. The main problem for box type solar cooker is its capital cost, which make it economically uncompetitive with a majority of other energy sources. Its cost will be further reduced if its commercial fabrication is possible in our country.

RECOMMENDATIONS

Besides a lot of promises the constructed oven has some drawbacks. In Bangladesh it is very difficult to use solar cookers during the days when the sky is cloudy. So recommendations for further study for both performance and construction improvements are more reflectors can be used to increase the boosting of solar radiation and thus the temperature of the enclosure will be increased.

An attempt can be taken to modify the solar cooker to accept a small amount of electrical energy in addition to solar energy so that heating becomes possible in cloudy days. For this purpose, auxiliary energy can be supplied by either built-in electrical heating element under the absorber plate.

ACKNOWLEDGEMENT

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