HIGH-EFFICIENCY SOLAR OVEN FOR TROPICAL COUNTRIES

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ABSTRACT

In today's society, pollution is becoming an increasing problem. Since the solar energy is a limitless clean free energy that can be harnessed, suggestions have arisen such that solar energy can be incorporated in our daily lives to produce energy to conserve other non-renewable energy. Solar oven refers to a type of oven which uses the sun's energy to cook food inside of it. It has been planned to design a high efficiency solar oven which is convenient and comfortable for all kind cooking, baking and heating with high efficiency without spoiling the foods nutrients. This solar oven is capable of making a temperature change up to 150 ^{0}C in 60 minutes. Once the prototype was completed, several experiments were conducted to determine the efficiency between two designs which are; without the parabolic dish and with the parabolic dish. With the presence of parabolic dish on top of the box proves that the efficiency increases when compared without using it. It is estimated that the efficiency attained by the solar oven with parabolic collector at 150 minutes is 53.62% whereas, for the same time duration, the solar oven efficiency without parabolic collector is estimated to be 35.86%. This solar oven would be very useful to conserve the electricity and healthy food cooking.

Keywords: Solar oven, tropical countries, parabolic collector.

INTRODUCTION

The sun is a constant source of energy. Each day, the sun bathes the Earth in unimaginable amounts of solar energy, most of which comes in the form of visible light. All over planet Earth, sunlight is the most important source of energy for all living things. Without it, Earth would be lifeless. Sunlight can be a practical source of energy for such everyday jobs as cooking, heating water, or warming up homes. The challenge is to find ways to transform sunlight into useable heat. In order to make a better use of sunlight, an attempt has been made to develop a High Efficiency Solar Oven (HESO) for tropical countries. There are many advantages in using a solar oven. One of them is that it is eco-friendly; it doesn't depend on gas or electricity. The other one is that it is economic, for the purpose of the operation, all that is needed is sunlight. A significant amount of money can be saved over the long term. As a result, solar cookers are being used increasingly in different parts of the world, especially in poorer communities with limited access to fuel and power.

A vast literature review was carried out in the area of the solar oven and is discussed as below. Geddam *et al*. (2015) have determined the thermal performance of a box type solar cooker [1]. Mustapha *et al*. (2014) have conducted the proximate analysis study of fish dried with solar driers [2]. They found that the nutrient compositions of the species dried with the solar driers were high and compared well with other methods of open drying. Beltramo and Levine (2013) investigated the effect of solar ovens on fuel use, emissions and health related issues [3]. The electrical and physical properties of structures with p-n transition produced from silicon obtained by the fivefold meltdown of metallurgical silicon in a solar oven have been studied by Saidov *et al.* (2013) [4]. A comprehensive review on solar cookers has been done by Cuce, E. and Cuce, P.M. (2013) [5]. The use of a hybrid solar oven for houses in dry climates has been studied by an experimental study of thermal performance by Nollens *et al.* (2012) [6]. The study of chemical and microbiological properties of saffron dehydrated by using solar drying system has been done by Feili *et al.* (2012) [7]. Ebieto (2012) have constructed and analysed a hybrid solar oven [8]. Hernández-Luna and Huelsz (2008) have designed and constructed a solar oven for intertropical zones and evaluated the cooking process [9]. The design and development of efficient multipurpose domestic solar cookers and dryers have been analysed by Kumar *et al.* (2008) [10]. This work incorporates the design of two types of solar oven, namely the Box-type and the Parabolic-concentrating solar oven to attain better efficiency.

Construction of solar oven

A normal solar oven that usually being develops all over the world consists of two types, box type and parabolic type. The box oven is the most common types of solar oven. Its design is based on the concept of a traditional modern oven. These cookers can typically reach temperatures of 300° F (150° C) which is plenty hot to cook any food. Food containing larger quantities of moisture cannot get much hotter than 100° C so it is not necessary to cook at higher temperatures. The parabolic oven can reach high temperatures more quickly. Some parabolic cookers are limited in the quantity of food that is possible to be cooked at one time since they usually have only one pot that is suspended in the centre of the path of highest solar energy concentration.

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In the present work, an attempt has been made to combine both of the boxes and the parabolic type oven in order to prove that by combining both the types will increase the efficiency. The designs of the solar ovens also allow them to be taken to anywhere as long as there is sunlight, making them with high mobility. The main purpose of the solar cooker is to transfer the energy from the sunlight into heat energy to cook or pasteurize the food. A solar box works when the interior of the box is heated by the energy of the sun. This light energy of the sun is collected by the parabolic-shaped collector with a series of mirrors attached on it to direct or reflect the sunlight. The sunlight enters the solar box through the glass of certain transmittance. It turns to heat energy when it is absorbed by the dark absorber plate. This heat input causes the temperature inside of the solar box cooker to rise until the heat loss of the cooker is equal to the solar heat gain. A layer of insulation consists of polystyrene (melting temperature is 240 ^{o}C) is added inside the box to minimize the effect of heat loss. The melting temperature of polystyrene is 240 ^{o}C.

The heat gain is the heat received by the box to heat up the temperature. Heat from the sunlight is used to heat up the box through the greenhouse effect. This will result in the heating of the space in which the light rays are kept inside the box. The interior of the box is painted black so as to convert the absorbed sunlight rays into longer wavelength. This is important as longer wavelengths of the rays are not able to pass through out of the glass and therefore is trapped inside. Also, the positions of the mirrors are important. This is because the more directly the mirrors face the sun, the greater the amount of solar radiation received. They require frequent adjustment to receive the maximum amount of sunlight. As the design of HESO combines the box-typed and parabolic-concentrating typed solar cooker, the influence of the parabolic collector is also important. The collector here is in a parabolic shape to bounce additional sunlight through the glass. The parabolic shape can reflect the sunlight more and thus produce more concentrated sunlight into the box. Not all systems are perfect and have 100% efficiency. There will be energy loss from the solar cooker. In general, the heat loss occurs in three modes namely, conduction, convection and radiation.

For the idea of generating heat inside our box, we use a square box and put a Grade A glass on top of it in order the heat and photon from the sun enter the box and trap inside the oven. To further increase the efficiency and reduce heat loss from the box, Styrofoam is used and it acts as an insulator for all the sides. The Styrofoam, we wrap it using aluminium foils in order to reflect our heat and absorb by the food. For the bottom part, an aluminium plate is combined with MDF (medium density fibre) and screws it together. The MDF board acts as an insulator so that heat will not lose from the bottom.

Experimental procedures

The equipment was set up as shown in Figure-1, but without parabolic dish initially. The glass was lifted for a while to take the initial temperature inside the box using a thermometer. Then the glass was put back on top of it and the reading for light intensity for the glass was recorded. Measure the temperature and light intensity for interval 30 minutes. The equipment was left for about 2-3 hours. The light intensity and temperature was measured again before ending the experiment. The readings were recorded and tabulated to determine the efficiency of the oven without the parabolic dish. Then the various steps were repeated by incorporating the parabolic dish on top of the box.

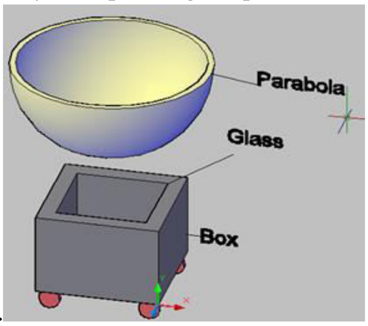

Figure-1. Schematic of the solar oven with parabolic dish.

Thermal analyses

The collector performance efficiency needs to be determined. In this context, the series of equations used to calculate the efficiency is:

$$(Hs - Hd)\left(\frac{\cos\theta t}{\cos\theta z}\right)\tau\alpha = (Hs - Hd)R\tau\alpha \quad (1)$$

Where, Hs is the solar energy flux density on the surface (cal/cm^{2}hr), Hd is the diffuse-radiation flux density (cal/cm^{2}hr), cosθ_t and cosθ_z are the incidence angles of direct sunlight on a tilted surface and on a horizontal surface respectively, τ is the overall transmittance of glass plates for direct solar radiation (0.658 for glass grade A of thickness 0.2cm) and α is the absorptivity of the blackened collector surface for incident solar radiation (0.55 for glass) [10].

$$R = \left(\frac{\cos\theta t}{\cos\theta z}\right) \quad (2)$$

The useful heat collection is q_U is determined by,

$$q_U = q_A - q_L - q_B \quad (3)$$

where q_A is the total absorbed energy.

$$\frac{q_A}{A} = 3.69(Hs - Hd)R\tau\alpha \quad (4)$$

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q_L is the total heat loss from the plate through the glass layer to the air above.

$$\frac{q_L}{A} = h(T_1 - T_2) + \sigma\epsilon_G\left({T_1}^4 - {T_2}^4\right) \quad (5)$$

Where, h is the convective heat coefficient (1for glass), σ is the Stefan-Boltzmann constant (5.670373*10^{-8} W m^{-2} K^{-4}), ϵ_G is the emissivity of the glass surface (0.90 for glass), T_1 is the temperature reached, T_2 is the ambient temperature and q_B is the total heat loss from the plate though the insulation and bottom of the container (usually zero). Thus, the efficiency is calculated by,

$$\eta = \frac{q_U}{AG_t} = \frac{mC_P(T_o - T_i)}{AG_t} \quad (6)$$

where G_t is the global solar radiation. Besides, the transmittance of the glass that is used at the top part of the container also plays an essential part. To determine the performance of the oven, the term optical efficiency is introduced. Optical efficiency is defined as the ratio of the energy absorbed by the receiver to the energy incident on the collector's aperture. It depends on the optical properties of the materials involved, the geometry of the collector and various imperfections arising from the construction of the collector.

$$\eta_o = \rho\tau\alpha\gamma(1 - A_f \tan\theta \cos\theta) \quad (7)$$

Where, ρ is the reflectance of the glass, τ is the transmittance of the glass, γ is the intercept factor, α is the absorptance of the receiver, A_f is the geometric factor and θ is the angle of incidence.

RESULTS AND DISCUSSIONS

The experiment was conducted in two stages namely solar oven without parabolic collector and solar oven with the parabolic collector. The readings were tabulated for every 30 minutes. Then the performance of the solar oven is determined for both the cases and is listed in Table-1 and Table-2. Manual sun tracking is used in the experiment.

Table-1. Performance of solar oven with parabolic collector.

Time (min)	**Amount of solar radiation collected** (W/m^2 K)	**Absorbed heat energy,** $\frac{q_A}{A}$ (J/m^2)	**Heat energy loss,** $\frac{q_L}{A}$ (J/m^2)	**Efficiency, η** (%)
0	230.4	1107643.30	23175.16	37.66
30	351.4	1689336.00	215790.64	51.16
60	380.4	1828765.24	475362.98	46.99
90	519.4	2497004.90	809050.10	58.61
120	510.3	2453256.84	876341.44	54.75
150	503.5	2420565.98	876341.44	53.62

From the Table-1 and Table-2, it is clear that the efficiency of the solar oven increases as the time increases due to more heat energy is trapped. Also, it is observed that the heat energy absorbed by the solar oven with the parabolic collector is higher when compared with the heat energy absorbed by the solar oven without parabolic collector. Since the heat energy absorbed is higher with solar oven with the parabolic collector, the efficiency is also higher in this case.

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Table-2. Performance of solar oven without parabolic collector.

Time (min)	**Amount of solar radiation collected** (W/m^2K)	**Absorbed heat energy,** $\frac{q_A}{A}$, (J/m^2)	**Heat energy loss,** $\frac{q_L}{A}$ (J/m^2)	**Efficiency, η** (%)
0	117.5	564878.8	23175.1	18.81
30	198.6	954765.4	190999.8	26.52
60	294.2	1414360.5	368950.6	36.30
90	254.9	1225426.5	502516.9	25.10
120	336.8	1619159.1	698922	31.95
150	325.2	1563392.3	529894	35.86

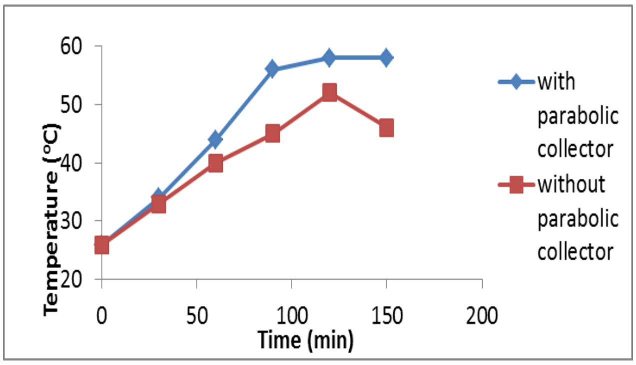

Figure-2. Relationship between the time and temperature attained by the solar oven.

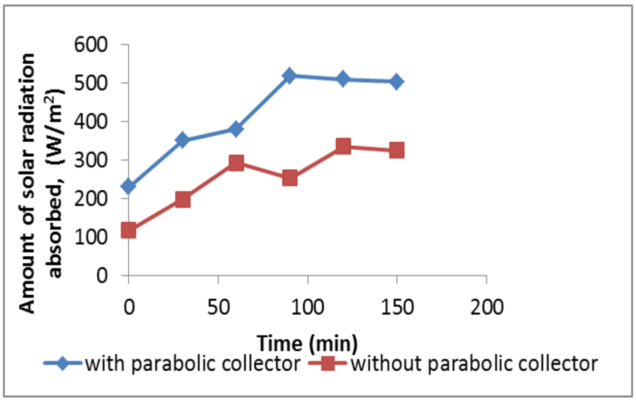

Figure-3. Relationship between the time and the amount of solar radiation absorbed by the solar oven.

The relationship between the time and the temperature attained by the two types of the solar oven is shown in Figure-2. In both the cases, the temperatures increase as time progress. However, the overall temperature reached by the oven with the parabolic collector is higher than the temperature attained by the solar oven without parabolic collector. The amount of solar radiation absorbed also increases with time for both ovens with and without the parabolic collector. Also, the overall energy absorbed by the oven with the parabolic collector is higher than the energy absorbed by the oven without parabolic collector which is illustrated in Figure-3. Also, it is found that the fluctuations in the increase in temperature and the amount of heat energy absorbed are due to the change in weather.

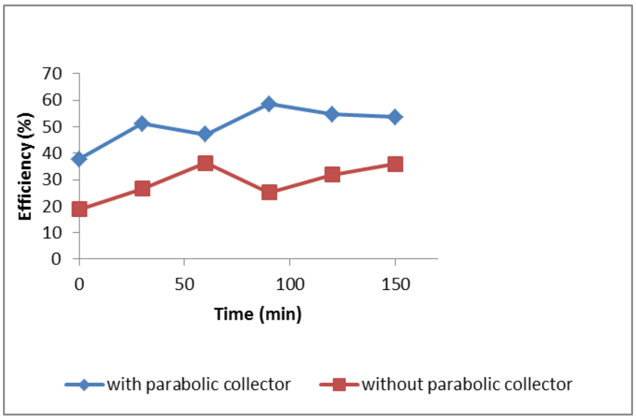

Figure-4. Efficiency of solar oven.

Figure-4 shows the efficiencies of the solar oven with and without parabolic collectors. It is found that the overall efficiency is higher for the cooker with the parabolic collector. It is estimated that the efficiency attained by the solar oven with parabolic collector at 150 minutes is 53.62% whereas, for the same time duration, the solar oven efficiency without parabolic collector is estimated to be 35.86%.

CONCLUSIONS

In this research, an attempt has been made to design and construct the two types of solar oven namely solar oven with the parabolic collector and solar oven without parabolic collector. Then the thermal analysis has been carried out in both the oven. The experiment was conducted at regular intervals of every 30 minutes. The heat energy absorbed by the solar oven with the parabolic collector and without parabolic collector are determined as 2420.5 kJ/m^2 and 1563.4 kJ/m^2 respectively for the time duration of 150 minutes. It is concluded that the solar oven proposed in this research would be very much helpful to conserve the electricity and eco-friendly food production.

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