Experimental Study of a Solar Oven based on Evacuated Tube Collector in Indian Climatic Conditions

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Abstract. A solar oven system of evacuated tube collector using copper food tray was fabricated and experimental analysis was done to evaluate its performance. The experiments conducted on clear sunny days in the month of December in NIT Kurukshetra, Haryana. The maximum temperature obtained from the food tray was 84°C. Food items can be cooked, fry or bake with this solar oven. Potatoes were baked with this solar oven and kept warm for a time period of about 5 hours and water is heated up to 81°C within 1 hour. The testing of solar oven was carried with and without cooking load. Without any cooking load, the maximum temperature of food tray observed was 84°C. With cooking load, the maximum temperature observed was 81°C. In this solar oven, reflecting sheet is being used beneath the evacuated tube to increase the absorption rate of the evacuated tube. This paper gives experimental results from portable solar oven for water heating and baking potatoes.

Keywords: Solar oven, Solar cooking, Evacuated Tube collector

1. Introduction

Energy consumption is one of the key criteria for determination of the development of a country. Now a day, in most of the countries, whether it is developed or developing, non-renewable sources are being used primarily for energy generation. The situation is scarier for the countries like India, which depends on other countries for the fulfilment of its energy need. To transit from developing to developed nation, it is important to become an energy independent nation. Waste from household and forest is the main source of energy for the people of rural area especially in India. Rural areas mainly require energy for cooking purposes as food is one of the basic need for human. Use of solar energy for cooking is very efficient because Solar Energy is the most abundant source of renewable energy. India is blessed with solar energy as it gets more than 300 sunny days in a calendar year with average solar irradiance of 200MW/km². For cooking purpose, different types of collectors can be used. Evacuated tube collector are more efficient because there is no heat loss due to convection, which is the major heat loss factor in other types of collectors. Time required for heat generation in evacuated tube collector is less as compared to other type of collectors. Many researchers have worked on the concept of solar cooking and found results for various solar cooker. Sharma et al. (2005) calculated the thermal performance of evacuated tube based solar cooker using phase change material as storage unit. Erythirol of commercial
grade was used as PCM to store the latent heat to make the cooker use in off sunshine hours. These experiments was conducted in summer in Japan and the conclusion was made that there is no effect of noon cooking on evening cooking and maximum temperature reached is 110°C in the evening cooking and the phase change material did not melt in winters.

Mehla et al. (2016) did thermal analysis of behaviour of phase change material based on evacuated tube solar collector. Acetamide was used as a phase change material. It was observed that the efficiency is more when system was operated with high rate of airflow and the maximum efficiency obtained was about 18% during charging and discharging of PCM simultaneously. Atul Bhave et al. (2018) developed a solar thermal based cooking and storage device by using salt hydrate. During sunshine hours, a family size solar cooker was used. Magnesium Hexahydrate was used as thermal storage, which has melting point of 118°C. The device was able to cook 140gm of rice in 30 minutes using stored heat. Time require to store the heat was about 50 minutes. Sanjeev Kumar et al. (2018) experimentally investigated a solar cooker based on evacuated tube with PCM thermal storage unit in Indian climatic conditions. Water was used as a working fluid and acetanilide was used as a phase change material. Reflectors were used beneath the evacuated tube to enhance the performance of evacuated tube. The cooking time was reduced by 30 minutes when reflectors are used and PCM achieved maximum temperature of about 89°C when reflectors are used.

The present experimental study has an objective that is to demonstrate the feasibility of a solar oven based on evacuated tube to boil, cook, or fry the food or to heat water or just to keep food warm. Novelty of the works lies in the experimental analysis of Evacuated tube based solar oven to checks its viability in Indian climatic conditions using parabolic sheet reflector.

2. Experimental Setup
The solar oven mainly consists of five major parts: Evacuated Tube, Food tray, Reflecting Sheet, Supporting Structure, and measuring devices. As we can see from Figure 1, all the parts are fitted on a supporting structure that is parabolic in shape.

![Figure 1. Evacuated Tube based Solar Oven](image)
Table 1: Specification of the Experimental Setup

| Sr. No | Part                   | Specification            | Material                           |
|--------|------------------------|--------------------------|------------------------------------|
| 1      | Evacuated Tube         | Length = 500mm           | Inner Tube = Copper coated Glass    |
|        |                        | Inner Diameter = 47mm    | Outer Tube = Glass                 |
|        |                        | Outer Diameter = 55mm    |                                    |
| 2      | Food Tray              | Length = 450 mm          | Copper                             |
| 3      | Reflecting Sheet       | Length = 550mm           | Aluminium                          |
|        |                        | Breadth = 550mm          |                                    |

2.1. Evacuated Tube

The evacuated tube is a solar collector. This is made up of 2 concentric tubes with vacuum in between them. Due to the fact that in vacuum the rate of heat loss is very less. Both ends of the glass tubes are sealed and the internal tube is coated to absorb sunlight to provide heat for food, water or anything to cook which required heat. The efficiency of the evacuated tube is more compared to other solar collectors. The solar oven is filled with food and left facing towards sun to let the food cook unlike other methods in which require a proper supervision. Keep in mind that there should not be any kind of blockage of sunlight or shadow on evacuated tube. As from Figure 2, it can be said that the geometry and performance of evacuated tube is optimized as an evacuated tube consists of two glass tubes, which are concentric sealed in the shape of a semi-circle on one side and joined together on the other side. The space is between two tubes is evacuated and sealed. For the proper absorption of solar energy, the internal layer is coated with a highly heat conductive layer which is environmental friendly as well. Variety of materials have been used to improve the glazing property of the solar oven. The efficiency of evacuated tube collector is about 20% more than that of other collectors. Evacuated tube used in the experiment has inner diameter of 47 mm and outer diameter of 58 mm. Internal tube is coated with copper for maximum heat conduction.

![Figure 2. Schematic diagram of evacuated tube](image)

2.2. Food tray

Figure 3 shows a food tray made of copper. It is the container, which is inserted in the evacuated tube and the food or water is put in it for cooking or heating. It is made up of copper which is lightweight and have good thermal conductivity and cheap as well. It holds the food that is cooked in solar oven. There is a PVC handle included as shown in Figure 3, with the help of that the user can hold to insert or to extract the tray in the tube.
2.3. Reflecting Sheet
Figure 4 shows an aluminium reflecting sheet which is bent into parabolic shape. Reflecting sheet used is made up of aluminium due to its reflective properties and lightweight. The shape of the sheet is parabolic which reflects and concentrate sunlight on the evacuated tube. The parabolic sheet acts as a line-focusing device. The dimensions of the parabolic sheet is 550mm×550mm.

2.4. Supporting Structure
Figure 5 shows a parabolic shape frame, which is used to hold all the parts together. Reflecting sheet is fitted on it so that it can focus the sunrays on the evacuated tube properly. It has the same dimensions as the reflecting sheets. It also has an evacuated tube holder, which is semi-circular in shape to hold evacuated tube and a locking mechanism to hold reflector on desired position according to the sun position.
2.5. Measuring Devices
Different devices are used to measure different parameters like food/water temperature, ambient temperature, and solar intensity. Mainly, two measuring devices were used one is to measure the temperature and other is to measure solar intensity. For temperature measurement, RTD PT100 thermocouple is used and for solar intensity, pyranometer is used.

2.5.1 RTD PT100 thermocouple
Figure 6 shows RTD PT100 thermocouple which is used to measure temperature of surface of food tray and food surface or water temperature. It can measure temperature with a resolution of 0.1°C. RTD is a temperature sensitive resistor with a positive temperature coefficient, which means as the temperature increases its resistance also increases. It is used with digital temperature indicator.

2.5.2. Pyranometer
Figure 7 Shows a Pyranometer which is a device that is used to measure global solar radiation. Global solar radiation is sum of beam and diffuse radiation. Due to difference between temperature of hot and cold junction of pyranometer an emf is generated which is proportional to solar radiation. EMF ranges between 0 to 10mV with a calibration of 2%. Solar intensity is measured in W/m² by using Pyranometer.
3. Results and Conclusions
This experimental work has objective to check the performance of evacuated tube based solar oven in Indian climatic conditions during sunshine hours. The experiments are done on clear sunny days in the month of December in 2018 with ambient temperature ranges from 15°C to 35°C. The readings were taken from 9:00hr to 17:00hr.

3.1: Solar Oven without cooking load

The experiment is conducted on 04/12/2018 on solar oven without cooking load. Figure 8 shows, the variation of solar intensity and food containing tray temperature with time. It has been observed that the maximum temperature achieved by food tray is about 84°C and maximum solar intensity is 788W/m² at 12:30hr.

![Figure 8. Variation in cooking tray temperature, ambient temperature, and solar intensity without cooking load on 04/12/2018](image-url)
3.2: Solar Oven with 500ml water as cooking load

The experiment is conducted on 11/12/2018 on solar oven with 500ml of water as cooking load to see if the setup is feasible enough to use as a water heater. Figure 9 shows the variation of ambient temperature, solar intensity, water temperature and cooking tray temperature with time. It has been observed that the maximum temperature by food tray and solar intensity achieved is about 82°C and 735W/m² and water reached a maximum temperature of 79°C at 13:00hr.

Figure 9. Variation in cooking tray temperature, ambient temperature, water temperature, and solar intensity with 500ml water as cooking load on 11/12/2018
3.3 Solar Oven with 1 kg potato as cooking load

The experiment is conducted on 17/12/2018 on solar oven with 1 kg potato as cooking load. Figure 10 shows the variation of solar intensity, food tray temperature, food temperature, and ambient temperature with time. It has been observed that the potatoes are completely baked after putting them in oven for about 1.5 hours. After that, the oven is used to keep the food warm for about 5 hours. The maximum temperature achieved by food tray, food, and maximum solar intensity is observed to be about 78°C, 72°C and 695 W/m² respectively at 12:30hrs.

Figure 10. Variation in cooking tray temperature, ambient temperature, water temperature, and solar intensity with 1 kg Potato as cooking load on 17/12/2018

It has been observed that when the solar intensity increases the temperature of the food tray and the food also increases up to noon-time after the temperature and solar intensity start decreasing. The setup is feasible to cook food and heat water in the area where the sunlight is good and of high intensity. This is a cheaper replacement to expensive ovens as the cost of whole setup is about ₹1500 and no energy is required other than solar energy for the working of evacuated tube based solar oven. This experiments results shows data of 3 days but the setup work efficiently during sunny days.
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