Development of Solar Oven employed with Parabolic Concentrator

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Abstract. The main purpose of our project is to replace old stoves with an eco-friendly solar oven. This parabolic solar oven is a form of outdoor cooking and uses the energy of sunlight to heat food or drink or to sterilize it. They use no fuels and cost, nothing to operate; they reduce air pollution and deforestation. This device works on the principle of converting sun’s light energy into heat energy, which is retained for cooking and sterilizing the medical equipment. It reflects the sun light through a parabolic trough which surface is covered with a reflective film and concentrates it on the evacuated tube, which is fitted on the focus point of the parabolic trough. Parabola with a diameter of 600mm and depth 150mm is used to manufacture a parabolic trough. The evacuated tube’s inner surface is coated with aluminium, which generates heat inside the hollow region. Aluminium foil is used as a reflecting film to reflect sun light, which has a reflectivity of 90%. So that the heat generation increases inside the evacuated tube. Whatever the subject (e.g. Food, water, medical equipment, etc.) we need to heated are placed inside the evacuated tube through a tray for heating. The maximum temperature achieved inside evacuated tube is 302°C.

Keywords: Solar Energy, Parabolic Trough, Evacuated Tube, Solar Oven

1. Introduction

LPG and other fuels that we use are not infinitely available and also due to the consumption of wood and other sources we exploiting our natural resources. So the alternative way is to use the solar energy efficiently in every possible manner [15]. As the solar energy is easily available until the sun stays on the sky. So we use the solar reflecting films to reflect the sun rays in a parabolic trough to concentrate on its focus point to attain a maximum amount of heat that can possible. This solar oven works on a basic principle of converting sun’s light energy into heat energy which is retained for cooking [12].

This solar oven helps in cooking foods, sterilizing the medical equipment in rural areas, etc., Day to day usage of LPG and other sources cost our future of mankind [13]. So utilizing the renewable resources such as sun light, wind, etc., will preserve the future of mankind and reduces deforestation, desertification, air pollution, etc., and lead mankind in a healthy way [11].

The solar collectors commonly refer to solar hot water panels, but may refer to installations such as parabolic troughs [1] and solar towers. Solar thermal collectors use heat-absorbing panels to absorb sunlight directly. Here the solar energy is directly used for heating purpose [2] and in large it can be...
used to produce steam that can run the generator to produce electricity [3]. The two types of solar collectors are imaging and non-imaging types. The parabolic trough is a non-imaging type concentrator that is able to concentrate rays to smaller absorber surface [4]. The sunray falling on the absorber is not focused, therefore concentration is achieved with a parabolic trough design [5].

The parabolic trough reflector is a collector which concentrate solar thermal energy in its focus point [10]. No matter what part of the collector the sunlight hits first but all incoming sunlight should be reflected from the surface and concentrate on its focus point [14]. The technical feasibility of using PTSC results in the thermal energy at temperatures up to 150°C for solar irradiance about 400-500 W/m².[6].

The light rays coming from the edges of the sources are redirected to the edges of the receiver. This confirms that all light rays coming from the inner points in the source will make contact with the receiver as shown in figure 1.

![Figure 1. Edge ray principle in parabola](image)

The rays falling on the CPC should be reflected to the receiver, so a reflective material is used which reflects the rays to the evacuated tubes. The reflective material should have high reflectivity.

Evacuated tube collectors are devices, which consists of cylindrical absorbing surface in which the vacuum is created between concentric glass tubes made up of borosilicate glass [7]. The outer layer is transparent allowing the light rays to pass through with minimal reflection. The inner layer is coated with a special selective coating (Al-N/Al), which provides excellent solar radiation absorbing properties. The evacuated tube absorbs the solar energy reflected from the CPC and converts into the heat energy. Thus, vacuum acts as an insulator, which does not lose the heat. To maintain vacuum between two glass layers a barium getter is used. This barium layer absorbs any CO, CO₂, N₂, O₂, H₂O and H₂ out-gassed from the evacuated tube during storage and operation, thus maintaining the vacuum [9].

2. Methodology
The components involved, their respective design, analysis and materials involved for the Parabolic Solar oven are briefed.

Methodology has three steps they are,
- Design
- Fabrication
- Experimentation
2.1. Conceptual design

![Parabolic Solar Oven Diagram]

Figure 2. Conceptual design

2.2. Components

The components of the parabolic solar oven are listed below.

2.2.1. Parabolic trough. Parabolic trough and other solar concentrators are increasing the attention by industry as well as engineering students which will provide a heat energy without help of any other external resources. Considering the application of parabolic trough for concentrating and illumination, the side wall of parabolic trough is made by reflective material. The base of the parabolic trough is made of wood. The outline of the parabolic trough is drawn on the plywood and is cut with the help of cutting wheel. The plywood acts as the supporter of the parabolic trough and holds the aluminium sheet metal and evacuated tube.

| Table 1. Parabolic trough specifications |
|----------------------------------------|
| Parabolic trough | Specifications |
| Length | 1200mm |
| Diameter | 600mm |
| Height | 150mm |
| Material | Plywood and Aluminium metal sheet |
2.2.2. **Evacuated tube.** The solar absorber tube has two concentric glass tubes closed at one end with an annular vacuum space and a selective surface absorber on the outer surface (vacuum side) of the inner tube [8]. In heat pipe evacuated tube collectors, a sealed heat pipe, usually made of copper to increase the collector’s efficiency in cold temperatures, and is attached to a heat absorbing reflector plate within the vacuum sealed tube.

| Evacuated tube | Characteristics |
|----------------|-----------------|
| Length         | 1500mm          |
| Outer Diameter | 47mm            |
| Inner Diameter | 37mm            |
| Glass thickness| 1.6-2.0mm       |
| Material       | Borosilicate Glass |
| Absorbance     | Above 93%       |
| Emittance      | Above 8%        |
| Heat loss      | <0.8W/(m² °C)   |
| Startup temperature | <=25°C (77F) |
| No of coatings | 3               |
| Coatings       | Al/N/Al         |

2.2.3. **Aluminium foil.** The Aluminium foil is the reflective material used to reflect the falling radiation to the receiver tube. The reflectivity of the material is important and it shouldn’t absorb the falling radiation. The Foil is made of Al8011 type Aluminium material.

| Aluminium foil | Characteristics |
|----------------|-----------------|
| Reflectivity   | Above 85%       |
| Thickness      | 30 microns      |
| Surface area   | 0.96m²          |

2.2.4. **Frame.** The frame is the base component which carries all other components of the experimental setup. It is made up of mild steel square pipe of side 25mm and thickness 1mm. The frame was welded using normal electrode arc welding.

2.2.5. **Tray.** It is a simple structure made of aluminium metal sheet inside the evacuated tube to hold the food and other materials which is to be subjected to high temperature.

2.3. **Collection of materials**
The following table shows the materials required to do the fabrication work and the other components readily available in the market.

| Part No. | Description             | Quantity No. | Material                          |
|----------|-------------------------|--------------|-----------------------------------|
| 1        | Frame                   | 1            | Mild Steel                        |
| 2        | Parabolic trough        | 1            | Plywood and Aluminium metal sheet |
| 3        | Reflective material     | 1            | Al8011                            |
| 4        | Evacuated tube          | 1            | Borosilicate glass                |
| 5        | Tray                    | 1            | Aluminium metal sheet             |
2.4. Design calculations

2.4.1. Design of a parabolic trough

General equation for parabola

\[ x^2 = 4 * f * y \]
\[ r^2 = 4 * f * h \]

Where,

\( r = x \) = radius of the parabola
\( h = y \) = depth of the parabola
\( f \) = focal length of the parabola

Calculation of focal length for \( r = 300\text{mm} \) and \( h = 150\text{mm} \)

\( f = 150 \text{ mm} \)

2.4.2. Heat flow

Heat transferred from outer surface to the inner region of the evacuated tube is

\[ Q = \frac{\Delta T}{R} = \frac{T_2 - T_1}{R} \]

Where,

\( T_2 \) = Temperature inside evacuated tube in °C
\( T_1 \) = Temperature outside evacuated tube in °C
\[ R = \frac{1}{2\pi L} \left[ \frac{1}{R} \ln \left( \frac{r_2}{r_1} \right) \right] \]

Where,

\( K \) = Thermal conductivity of glass = 1 W/(m.K)
\( r_2 \) = inner radius of the evacuated tube
\( r_1 \) = outer radius of the evacuated tube

Calculation of heat flow at different ambient temperature and time for \( r_2 = 23.5\text{ mm} \), \( r_1 = 17.5\text{ mm} \) and \( L = 1.5\text{m} \)

\[ R = \frac{1}{2\pi(1.5)} \left[ \frac{1}{(1)} \ln \left( \frac{23.5}{17.5} \right) \right] = 0.0312 \text{ K/W} \]
2.5. Fabrication process
The fabrication process listed is done with the help of conventional machines available. The components and methods used to fabricate the components were discussed

- Drawn a parabola in a sheet by using eccentricity method.

![Diagram of parabola](image)

*Figure 3. Eccentricity method*

Where,
\[ 1f = f2 = \text{radius of the parabola} \]
\[ hv = \text{depth of the parabola} \]
\[ f = \text{focus of the parabola} \]
\[ v = \text{vertex of the parabola} \]

- Pasting the sheet in the plywood.
- Cutting the plywood in a parabolic shape.
- Nailing the aluminium sheet in a parabolic shaped plywood.
- Through above process parabolic trough is manufactured.
- Frame is welded and bolted with a parabolic trough.
- Evacuated tube is fitted on the focus point of a parabolic trough.
- By rolling the aluminium sheet the tray is being manufactured.
- Handle is fitted to the tray.
- Reflecting film is pasted on inner surface of the parabolic trough to increase the reflectivity.
2.6. Testing methodology

2.6.1. Boiling of water. Time taken to reach 100°C of water at an atmospheric temperature of 36°C with the help of stop watch.

2.6.2. Temperature inside Evacuated tube. Finding the temperature inside the evacuated tube and temperature on the outer surface of the evacuated tube at various time and atmospheric temperature with the help of IR thermometer.

2.6.3. Heat flow. Calculating the heat transferred from the outer surface of the evacuated tube to the inner surface of the evacuated tube at various time and atmospheric temperature.

3. Results and discussions

The parabolic solar oven was designed and fabricated as explained. The testing is done based on the testing methodology. Overall specifications with economic analysis, and test results found were mentioned below.

3.1. Working

The working of the parabolic solar oven is described in this portion.

- The heat reflected from the parabolic trough is received by the Evacuated tube.
- Aluminium coating inside the evacuated tube gets heated.
- The heat is generated inside the evacuated tube and reaches high temperature.
- Tray is used to load the food and other materials, which are to be heated.
- IR thermometer is used to measure the temperatures at certain points.
- The readings at various time intervals were taken and compared.
3.2. Result
The fabricated prototype is made to work and we observed for its results.
Test is conducted on 36°C of atmospheric temperature.
Time taken to attain 100°C for 50ml water = 220 seconds
Maximum temperature achieved inside evacuated tube = 302°C

Heat flow at various ambient temperatures and certain time in day hours (in railways time)

![Figure 5. Result chart]

4. Conclusion
The testing of solar oven results in improved performance by using parabolic trough. The additional setup of evacuated tube further increases the temperature. The edge ray principle helps to achieve a parabolic trough, so that the maximum rays can be utilized which results in higher concentration of rays. Thus, the efficiency is further increased. This solar oven employed with parabolic concentrator has better efficiency, which can meet the energy demand increasing day to day. This provides higher temperature than box type solar ovens.
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