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# Performance of Developed Parabolic Solar Cooker for Cooking Purpose in Hilly Areas of Northeast India

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## ABSTRACT

A parabolic solar cooker was developed and tested for usage by small farmers and households in the North East Region (NER) of India. The parabolic solar cooker was developed with an aperture area of 0.8624 $m^2$ to prepare food items such as rice, tea, potatoes, eggs and others. To check the performance, hourly statistics were recorded throughout the testing period, which ran from 9:00 A. M. to 17:00 P. M. A no load test and full load test was conducted to determine the temporal variations in ambient temperature, focus point temperature, sun insolation and relative humidity. The maximum ambient and focal point temperature was found to be 32, 37.60, 33.90 and 46.80, 54.0, 48.2°C at 14:00, 12:00 and 12:00 P. M., respectively, for tests, $T_1$, $T_2$ and $T_3$ under no load condition. Also, the maximum solar irradiance recorded was 565 W/$m^2$ at 14:00 PM, 589 W/$m^2$ at 12:00 PM and 503 W/$m^2$ at 12:00 PM, respectively for $T_1$, $T_2$ and $T_3$ of no load tests. In the water boiling test, the average maximum ambient temperature recorded was 35.4°C at 12:00 P. M. and the maximum temperature of water recorded was 80.87°C at 13:00 h. For cooking of rice, boiling of potato and making tea, the average time consumed was 90, 128 and 85 min, respectively. For boiling of eggs, the average time consumed was 95 min. The overall thermal efficiency of the developed parabolic solar cooker was found to be 13.64%. As compared to Liquefied Petroleum Gas (LPG), the estimated payback period of the parabolic solar cooker was found to be 1.4.

**Key words:** Focal point temperature, parabolic solar cooker, renewable energy, pay-back period, solar intensity, thermal efficiency

## INTRODUCTION

Sustainability refers to meeting current needs without compromising those of future generations. According to a recent study, the world is expected to run out of energy from fossil fuels by the year 2088 (Ahmed *et al.*, 2020). In certain developing nations, like India, where cooking energy consumption ranges from 1.7 to 2.7 MJ per person per day, cooking accounts for about 40% of total energy consumption (Indora and Kandpal, 2018; Zhao *et al.*, 2018). India uses coal as its primary and most abundant fossil fuel, providing 55% of the country's energy requirements (Khatri *et al.*, 2021). People typically utilise electricity for cooking as well as petroleum products like kerosene, coal and LPG. However, as a result of this, people are having issues with high and continually rising costs that have an impact on profitability levels, the lack of supply of these fuels, environmental degradation, etc. The globe is paying more attention to renewable energy sources as a result of the dramatic rise in oil prices, supply disruptions, production and transportation challenges, rising consumption of fossil fuels and environmental damage caused by conventional fuels (Sharma *et al.*, 2022).

Although there are many different types of renewable energy, including biomass, wind and solar energy, solar energy is the most affordable, abundant and sustainable option (Coccia *et al.*, 2021; Khatri *et al.*, 2021), which is widely accessible in most developing nations like India. Since commercial fuels like LPG and electricity are not readily available and firewood used for cooking contributes to deforestation, solar cookers hold the greatest promise because cooking accounts for a significant portion of energy consumption in developing nations (Ahmed *et al.*, 2020).

Solar cooking system allows for cooking without the need of wood or gasoline and represents one of the most notable uses of solar energy. They is a fascinating and practical option, particularly in underdeveloped nations where abundant solar radiation is received for most of the year (Arunachala and Kundapur, 2020). In addition to saving fossil fuels, solar cooking maintains a pollution-free environment without sacrificing the food's nutritional content (Aramesh *et al.*, 2019; Aragaw and Adem, 2022). It is an easy, secure and practical means to prepare food for fuel-less cooking or degrading the environment (Coccia *et al.*, 2021). Categorisation of solar cookers is done in a variety of ways, however, they are primarily split into three groups: solar box type cookers, solar panel cookers and solar parabolic cookers (Zhao *et al.*, 2018; Abd-Elhady *et al.*, 2020). A conventional solar cooker consists of a parabolic reflector, the reflector's focus point on which a cooking pot is positioned on, and sturdy frame work for supporting the system (El-Moussaoui *et al.*, 2020).The concentrated solar cooker is moved into position so that it faces the sun using a tracking device. The cooker vessel is positioned at the focus point of the parabolic reflector during the cooking process. Direct focusing solar cookers is simple to build and run (Lentswe *et al.*, 2021). Compared to other forms of concentrated solar cookers, a parabolic solar cooker can reach high temperatures of between 350-400°C. In an experiment, the performance of a solar parabolic cooker in open environmental climate condition was examined using a polished stainless steel parabolic solar trough having a concentration ratio of 9.867 (Noman *et al.*, 2019). The optical efficiency, experimental efficiency and the theoretical efficiency were found to be in the ranges 53 to 33%, 38 to 5% and 50 to 30%, respectively. Additionally, the maximum water temperature of 37.2°C of the parabolic trough's output was achieved.

The parabolic solar cooker has been designed, developed and tested in many parts of the world, but the research on usage of parabolic solar cooker for the Northeast region (NER) of India climatic condition is still yet to gain popularity. Because of numerous advantages of using solar cooker over conventional ways of cooking and to assess its performance in hilly terrains of NER, an attempt was made to develop and test a parabolic solar cooker for theprevailing climatic conditions of the region.

## MATERIALS AND METHODS

The developed system was fabricated at workshop of Fouzia Steel Enterprices, Meherpur, Silchar and tested at Department of Agricultural Engineering, Assam University, Silchar located in Assam (Fig. 1). The study area fell under Latitude 24.833°, Longitude 92.779° and average annual solar radiation was about 4.56 (kwh/m$^2$/day). Table 1 gives the assumptions and conditions considered to carry out development of parabolic solar cooker.

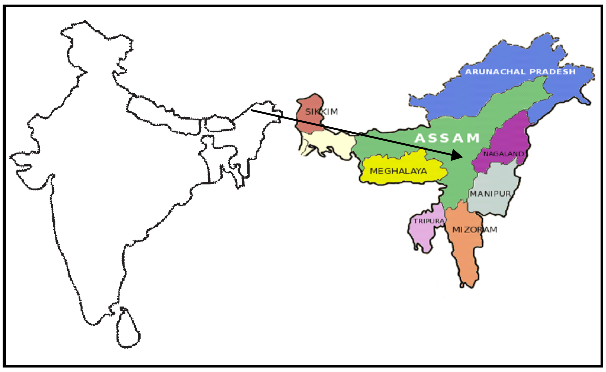


Fig. 1. Geographical location of study area (*www.google.com*).

For direct concentration of solar energy in the parabolic cooker, the cooking utensil was positioned at the parabolic reflector's focus point during the cooking process. The concentrator (parabolic dish) was used to focus the incoming solar radiation onto the focal point, which is situated on the receiver. The

**Table 1.** Design conditions and assumptions for development of parabolic solar cooker

| S. No. | Particulars | Conditions and assumptions |
|---|---|---|
| 1. | Location | Silchar (24.83°N, 92.77°E) |
| 2. | Orientation | South |
| 3. | Food material | Water, tea, rice, potato and egg |
| 4. | Loading capacity | 1 kg |
| 5. | Sunshine hour | 8 h |
| 6. | Global solar radiation (I) for Silchar region | 4.69 kwh/m$^2$/day |
| 7. | Reflecting materials | Aluminium foil |
| 8. | Insulating materials | Cotton |
| 9. | Average ambient temperature | 31.8 °C |
| 10. | Average wind speed | 1.2 kmph |
| 11. | Average relative humidity | 40% |

pot's bottom and side walls were painted black to help the solar radiation absorb more energy as it fell on the parabolic surface. Some of the incidence solar radiation was reflected back to the atmosphere, but the majority concentrated over the pot (Lentswe *et al.*, 2021). The water inside the pot got heated up as a result of the rising temperature, and the food inside the pot cooked as a result of the rising temperature.

Aluminium foil was used to cover the body of the dish (umbrella) of the parabolic solar cooker due to which the parabolic solar cooker's overall weight was reduced. The dish and the super-jack were supported by a rigid rectangular, hollow steel bar which was resilient against deflection by often occurring winds and had the capacity to support the transverse and cross-sectional loads of the entire heating region of the parabolic solar collector. The rectangular, vertical axis steel bar that supported the parabolic dish was given sturdy and rigorous support by flat and angle bars. Water was chosen as the heat transfer fluid due to its stability at high temperatures, low maintenance requirement, low shipping costs, easy to use, and prominent in household heating applications and cotton was chosen as the solar irradiance material since it was popular and minimized the thermal loss.

An Auto-Cad model sketch was created for the parabolic solar cooker using a variety of prior research. In accordance with the sketch, MS steel bar was used to create the primary frame for the parabolic solar cooker, including the base and pot holder. After that, cotton layer insulation was completed as per the proportions of the umbrella. The insulated umbrella was then covered with aluminium foil that had been taped. The umbrella was adjusted on the main frame for additional tests after aluminium foil had been adhered to the inside of the umbrella. Table 2 lists the technical specifications of the parabolic solar cooker.

With dimensions of 1200 mm by 600 mm, the rectangular base was built from steel angle and flat bars. For the tracking of the umbrella and the pot holder, vertical hollow steel bars were built at the opposite two ends. On the first bar across from the bar holding the pot, an umbrella with a 0.8624 $m^2$ aperture area was fixed. Reflective surface made of aluminum foil was coated on the inside of the umbrella. The base was made portable by using four wheels, one on each corner. The following equation was used to identify the focal point of the parabolic solar cooker (Tibebu and Hailu, 2021):

**Table 2.** Technical specification of parabolic solar cooker

| S. No. | Items | Dimensions |
|---|---|---|
| 1. | Aperture area | 0.8624 $m^2$ |
| 2. | Aperture diameter | 1.1 m |
| 3. | Length of circumference | 2.78 m |
| 4. | Focal length | 0.34 m |
| 5. | Receiver diameter | 0.17 m |
| 6. | Receiver area | 0.02269 $m^2$ |

$$x^2 = 4 \times a \times y \quad \ldots(1)$$

Where, x = was the x axis (m); y = was the y axis (m); a = was the focal point to be calculated (m). The aperture area (AP) of the parabolic surface was calculated by the following equation:

$$AP=\pi/4 \times \text{major axis} \times \text{minor axis}=\text{Aperture} \quad \ldots (2)$$

To assess the effectiveness of the parabolic solar cooker without load inside the container, no load test was performed. Thermocouples that were installed at various spots on the cooker were used to measure the temperature. A single thermocouple was fastened to the cooking pot's bottom, side walls, and interior. A lid made of galvanised iron sheet that was lined with glass wool on the inside helped to reduce heat loss from the top of the cooking pot. The bright spot was placed at the base of the cylinder, close to one side, using the parabolic umbrella's adjustments. Until the bright spot was moved to the exact opposite side of the cylinder, the parabolic umbrella's position remained unchanged. By using a mercury thermometer and a k-type thermometer, temperature readings were taken every hour. At predetermined intervals throughout the test, information on the temperature of the food item, the ambient temperature, the relative humidity, the solar irradiance and the focus point temperature was also recorded.

To assess how well the parabolic solar cooker would operate under actual load, a complete load test was conducted. In this experiment, water was heated and then tested to see if it would boil. Also, cooking of rice, boiling of potato, making tea and boiling of egg was performed to assess the performance of the developed solar cooker.

The overall thermal efficiency was calculated by following equation (Tibebu and Hailu, 2021):

$$\eta_u = \frac{M_f \times C_f \times \Delta T_f}{I_{av} \times A_c \times \Delta t} \quad ...(3)$$

Where, $\eta_u$= overall thermal efficiency (%); $M_f$ = mass of cooking fluid (kg); Cf = specific heat of cooking fluid (J/kg K); $\Delta T_f$= difference between the maximum and ambient air temperature; $I_{av}$= average solar intensity (W/m$^2$) during time interval; $A_c$ = the aperture area (m$^2$) of the cooker; $\Delta t$ = time required to achieve the maximum temperature of the cooking fluid (s). The payback period is the duration of time from the start of the project to the point at which the capital investment's total net value equals the net value of the incremental production stream. It displays the interval between cumulative net cash outflows that have been recovered as yearly net cash inflows. The usage of a solar cooker can take the place of cooking using firewood, kerosene, LPG and electricity.

$$\text{Payback period} = \frac{\text{Cost of solar cooker}}{\text{Cost of energy saved/year}} \quad ...(4)$$

## RESULTS AND DISCUSSION

In the months of March and April, 2022, the developed parabolic solar cooker was put to the test. The performance of the developed solar cooker was evaluated for different load conditions such as boiling water, making tea, cooking rice, boiling eggs and boiling potatoes. The experiments were conducted in three replicates, and the average value was calculated.

The no load test was conducted on days with clear sky condition and the measurement of various parameters during the days of experiment are presented in Table 3. The performance average of the parabolic solar cooker under no load test is presented in Fig. 2 and it shows the fluctuation in average ambient temperature, focal point temperature and solar insolation over time.

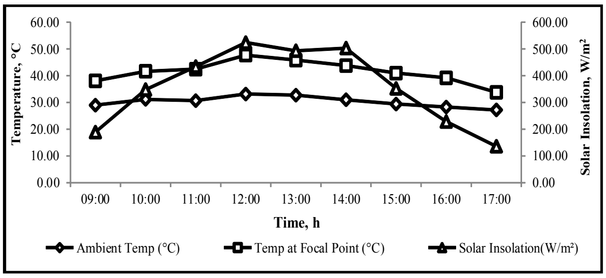


Fig. 2. Average ambient temperature, temperature at focal point and solar insolation during no load test.

The maximum average ambient temperature was recorded at 12:00 h during the average of no load test, and it was 33.2°C. The highest average focus point temperature measured at 12:00 h was 47.7°C. It was noticed that maximum solar insolation occurred within 12:00 to 14:00 h of the day, and around 12:00 h, the average solar insolation was at its highest point of 552 W/m$^2$ and the lowest average solar insolation of 189.33 W/m$^2$ was recorded at 17:00 h.

A container containing one litre of room-temperature water was placed on the cooker to test the water heating process. A 60-min interval was used to measure both the water temperature and the outside temperature (Table 4). The average water temperature and ambient temperature during the water boiling test are presented in Fig. 3. The concentrator is heated by exposing it to sun light until boiling occurs in the pot with a full load of water. The water temperature was found to be highest at 13:00 P. M. with average $T_w$ and $T_a$ of 81.1 and 33.1°C, respectively.

**Table 3.** Observed readings for no load test of the parabolic solar cooker

| Time (AM/PM) | No load test | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $T_1$ | | | $T_2$ | | | $T_3$ | | |
| | $T_a$ | $T_f$ | R | $T_a$ | $T_f$ | R | $T_a$ | $T_f$ | R |
| 09:00 | 27.6 | 33.5 | 95 | 29.5 | 37.3 | 225 | 31.2 | 43.5 | 248 |
| 10:00 | 27.2 | 35.2 | 285 | 33.8 | 43.2 | 490 | 32.5 | 46.6 | 270 |
| 11:00 | 27.5 | 38.9 | 401 | 32.6 | 42.6 | 510 | 32.5 | 45.9 | 391 |
| 12:00 | 28.8 | 40.9 | 480 | 37.6 | 54.3 | 589 | 33.4 | 48.2 | 503 |
| 13:00 | 31.7 | 42.7 | 510 | 35.5 | 50.6 | 520 | 31.7 | 44.2 | 450 |
| 14:00 | 32.4 | 46.8 | 565 | 30.9 | 42.3 | 518 | 30.1 | 42.3 | 427 |
| 15:00 | 31.4 | 43.5 | 340 | 28.2 | 42.1 | 485 | 29.3 | 37.3 | 233 |
| 16:00 | 28.5 | 42.4 | 202 | 28.1 | 40.5 | 360 | 28.9 | 35.2 | 124 |
| 17:00 | 27.3 | 33.2 | 108 | 27.6 | 33.7 | 180 | 27.6 | 34.5 | 120 |

$T_a$–Ambient temperature (°C), $T_f$–Temperature at focal point (°C) and R–Solar insolation (W/m$^2$).

**Table 4.** Observed readings for boiling 1000 ml of water in the parabolic solar cooker

| Time (AM/PM) | Water heating test | | | | | |
|---|---|---|---|---|---|---|
| | $T_1$ | | $T_2$ | | $T_3$ | |
| | $T_a$ | $T_w$ | $T_a$ | $T_w$ | $T_a$ | $T_w$ |
| 09:00 | 33.1 | 25.1 | 29.3 | 25.1 | 30.6 | 25.3 |
| 10:00 | 32.5 | 42.3 | 33.8 | 43.8 | 32.8 | 44.5 |
| 11:00 | 31.3 | 52.4 | 32.6 | 76.2 | 33.7 | 65.5 |
| 12:00 | 33.9 | 68.1 | 33.5 | 80.6 | 35.4 | 74.8 |
| 13:00 | 33.5 | 77.7 | 31.7 | 84.7 | 34.1 | 81.0 |
| 14:00 | 30.2 | 82.6 | 30.9 | 80.3 | 32.3 | 81.2 |
| 15:00 | 29.3 | 78.2 | 29.5 | 74.5 | 30.4 | 75.9 |
| 16:00 | 28.5 | 72.5 | 27.5 | 71.3 | 28.8 | 71.5 |
| 17:00 | 27.3 | 70.3 | 26.5 | 63.5 | 27.6 | 66.7 |

$T_w$–Temperature at focal point (°C).

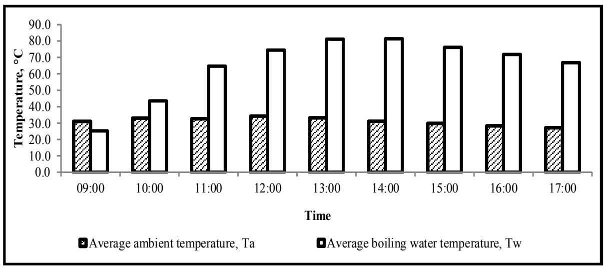


Fig. 3. Average ambient and water temperature during boiling of 1000 ml of water.

Cooking test was done to determine how long it takes to prepare a specific amount of food, such as rice, potatoes, tea and eggs. The ambient temperature, cooking temperature and amount of time needed to cook the food were all recorded during the test (Table 5). The longest cooking time of 128 min was spent boiling potatoes until they were fully cooked, while making tea took 85 min and cooking rice and boiling an egg took about the same amount of time (95 and 90 min). The temperature within the parabolic solar cooker and the solar insolation both have an impact on how long food will cook. As the cooking temperature rises, the cooking time also decreases since water begins to boil more quickly and vice versa. The effectiveness of the cooker could be decreased by numerous variables like temperature, wind, clouds, day of the year, hour of the day, or type of reflecting material to name a few. The effectiveness of a parabolic solar cooker can also be impacted by profile deformation, mechanical torsion and local imperfections (Tibebu and Hailu, 2021). Aluminium foil served as the cooker's reflecting material. Although aluminium foil is an effective reflector, it will eventually shatter. Additionally, it won't be applied to the dish smoothly. As a result, the rays do not focus on the receiving end, which lowers the cooker's efficiency.

The overall efficiency of the developed parabolic solar cooker was found to be 13.64%. Taking the value of $M_f$ = 1000 L; Cf = 4.18×10³ J/kgK; $\Delta T_f$ = 52 °C; $I_{av}$ = 328W/m²; $A_c$ = 0.8624 m²; Δt = 95×60 s and using equation (3), the energy efficiency was calculated.

$$\text{Energy efficiency, } \eta_u = \frac{1 \times 4.18 \times 1000 \times (80 - 28)}{328 \times 0.8624 \times 95 \times 60} = 13.64\%$$

The parabolic cooker is intended to cook for a five-person household keeping in mind that a single person needs 900 kJ of heat energy to cook, although it can only prepare, say, 80% of the meal (the remaining items are often fried). When two meals are cooked each day, the solar cooker generates 7200 kJ of heat energy daily (5 x 2 x 80% x 900). LPG (a propane and butane mixture) has a calorific value per kg of 12.6 kWh. A typical LPG cylinder weighs 13.5 kg, hence, a full cylinder has a total energy of 12.6 x 13.5 = 170 kWh/cylinder = 612,360 kJ/cylinder. The number of days needed by the parabolic solar cooker to provide energy comparable to an LPG cylinder, assuming that LPG is replaced is calculated as:

$$\text{Energy equivalent of LPG cylinder} = \frac{\text{Cylinder's total useful energy}}{\text{Energy produced by cooker/day}}$$

$$= \frac{367416 \text{ kJ}}{7200 \text{ kJ/day}} = 52 \text{ days}$$

**Table 5.** Readings in average for cooking various food materials

| Food item | Quantity | Cooking time($T_c$) | Ambient temp. ($T_a$) (°C) | Cooking temp. ($T_c$) (°C) |
|---|---|---|---|---|
| Rice+water | 100 g rice+200 ml water | 95 min | 30.7 | 77.6 |
| Boiled potato | 100 g potato+200 ml water | 128 min | 31.7 | 74.5 |
| Tea | Tea+sugar+200 ml water+milk | 85 min | 30.1 | 76.3 |
| Boiled egg | 200 ml water+raw eggs | 90 min | 31.3 | 79.1 |

The total cost of the developed parabolic solar cooker was Indian Rupees 7000. Considering the price of an LPG cylinder as Rs. 700, a family of five members will need (365/52) = 7 LPGs in a year. Thus, the payback period is (7000)/(700×7) = 1.4 years.

## CONCLUSION

A parabolic solar cooker was developed utilizing components that were readily available in the area. Aperture area, receiver area, focal length, rim angle, paraboloid surface area, circumferential length and concentration ratio were the design factors. Hourly statistics were compiled during the testing period, which lasted from 9:00 A. M. to 17:00 P. M., to evaluate the performance. The average maximum ambient and focus point temperatures were 33.17 and 47.70°C at 12:00 h, respectively, for the no load condition. In the water boiling test, the maximum recorded water temperature was 80.87°C at 13:00 h, and the average maximum ambient temperature was 35.40°C at 12:00 h. The built-in parabolic solar cooker demonstrated the best performance when it came to boiling tea in 85 min. However, cooking rice, eggs and potatoes using the parabolic solar cooker required a long time. The built-in parabolic solar cooker had a 13.64% efficiency. One of the main causes of the prolonged cooking time may be reflective material (aluminium foil) splitting, which also contributes to the cooker's decreased efficiency. In order to increase the effectiveness of the cooker, further research should be done to find a reflective material that is sturdy and long-lasting to replace aluminium foil. Parabolic solar cooker can be a dependable technology, especially for hilly parts of Northeast India, due to its cost and time effectiveness.

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