Building and Performance Evaluation of Novel Solar Cooking System in Gujarat, India

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Abstract. Wood is generally used as a source of energy for cooking in rural and semi-urban areas of India. Approximately 216 million tons per year of wood is consumed in the cooking of which 9.731 million tons per year is used in Gujarat. The use of wood causes deforestation and increases indoor pollution. To reduce this, solar energy can be used as an alternate source of energy for cooking. The current research aims to present the findings of two weeks of experiments in the Indian (Gujarat) climate with the novel solar cooker. The cooker was build using a parabolic dish collector (85% reflectivity) with a supporting structure and adjustable mechanism, a receiver (heat exchanger) and a cooking burner with a pot. The experimental result shows that the maximum temperature available at the receiver is 110°C with 560.7 W/m² of average solar irradiation, justifying solar cooking as a viable alternative source of energy for cooking in Gujarat and India.

1. Introduction
Currently, about 67.3% of the population in rural areas and 14% in urban and semi-urban areas consume wood as a fuel for various purposes (NSSO 2012). A woman uses wood to a large degree for cooking purposes in rural areas. They spend roughly 374 hours on cutting wood in a year [1]. 216.4 million tons of wood is used as fuel every year by 854 million people (FSI, 2011), of which 9.731 million ton is used annually in Gujarat. Coal, cow dung-cakes, firewood, etc. are still used as the primary source of energy for cooking in about 100 million households [1, 12]. The smoke produced by the burning of such fuel causes indoor pollution and lead to respiratory diseases, particularly in women and children [2, 10, 11]. More than 1, 00,000 people die prematurely as a result of inhaling the smoke. Burning wood also increases the emission of greenhouse gases by 93%.

Solar energy is one of the most promising paths for lowering air pollution and optimizing the usage of natural energy sources in India. The solar energy capacity at various locations varies from 4 to 7 kWh/m² [3]. Solar cookers can be used in cooking for more than 300 days a year in arid areas of India [7]. The energy required in cooking per house of a small family comes out to be much smaller than the solar energy available on the roof of such houses [4]. The use of biomass, cow dung and kerosene as fuel can also be reduced by cooking with solar energy which can lead to reduced indoor pollution and deforestation.
The Ministry of Non-Conventional Energy Sources (MNES) was established in 1982 by the Government of India to promote the use of non-conventional sources of energy. In the early 80s, MNES promoted the use of box type solar cookers for household cooking [8, 9]. The box type solar cooker was made up of four pots, a single flat plate reflector and a box type enclosure [14]. Looking at the potential market of solar cooker, industries were motivated to enhance and optimize the design of cooker for improved efficiency. On account of which various types of solar cookers are now available in the market with different designs and cooking features. Solar cooker with parabolic concentrator has been recently introduced in India by Sheffler Group and EG Solar. EG solar focused on the solar cooker for household use, while Sheffler group focused on large solar cookers suitable for community cooking [5, 13].

Considering the recent trends in solar cooker design, a parabolic dish type solar collector was selected for the current study to develop a novel solar cooker. High temperatures values can be obtained by a parabolic collector, which is ideal for Indian cooking [2, 15]. A parabolic dish collector is made from a mirror-polished aluminum sheet with 85 percent reflectivity. An experimental study has been carried out to predict the solar cooker's output at a different time interval and different weather conditions. Results from the study were used to analyze the performance of the proposed solar cooker.

2. The building of the proposed cooker

2.1. Construction Details of the cooker

The prototype of the proposed solar cooker consists of a parabolic dish type collector, receiver and cooking pot. It was constructed from mild steel pipes, aluminum reflector sheets, copper tubes, insulating material, aluminum cooking pot and glass. Aluminum reflector sheets are mounted in a series of segments to construct a parabolic dish collector. In the cooking system, a glass wool coated aluminum cooking pot was used as the burner. The supporting structure of the parabolic dish collector was made from mild steel pipes. A spiral-shaped copper tube filled with thermic fluid was used as a receiver to absorb solar energy from the sun. The receiver was composed of a 0.5 mm thick and 1076 mm long copper tube. The thermic fluid is then used to transfer heat from the receiver to the cooking pot. The various parts of the cooker are shown in Figure 1. The complete experimental setup was assembled at Gujarat Power Engineering and Research Institute, Mehsana, Gujarat, India as per the standard procedure.
Figure 1. Schematic diagram of the proposed solar cooker

Table 1. Test Details

| Parameters                  | Designation | Test data     |
|-----------------------------|-------------|---------------|
| Ambient temperature         | $T_a$       | 21.5 °C       |
| Average solar beam radiation| $I$         | 560.7 W/m$^2$ |
| Average cooking power       | $P$         | 23.5 W        |

2.2. Testing and Evaluation
An experimental study was carried out at Gujarat Power Engineering and Research Institute, Mehsana, Gujarat, India [Latitude: 23.5275311 and Longitude: 72.3881041]. The experimental set-up was placed on the terrace of the Institute workshop in such a way that it can receive solar radiation on the parabolic collector without any obstruction, as shown in Figure 1. The solar radiation reflected through the reflector is concentrated on the receiver. The receiver is kept in a glass enclosure to minimize the convective heat loss to the surrounding. Absorbed solar energy is transported by thermic fluid to the burner, which is gradually transferred to a cooking load in the cooking pot. The novelty of the present
prototype lies in the use of the heat absorbed by thermic fluid for cooking as thermic fluid can absorb and store heat throughout the day. Manual tracking of the device was done during the testing of a cooker to get maximum efficiency. Since dal rice is the most popular food in Gujarat, the mixture of rice and water was selected for a cooking load. Initially, water was used as a cooking load to measure the thermal performance of the cooker. The results obtained from the experiments were validated with existing literature.

### 2.3. Heating Test
The experiments were carried out between 17th January 2020 and 29th January 2020 to determine the cooker’s efficiency. The solar radiation, wind velocity, ambient temperature, receiver temperature and cooking pot temperature were taken at different time intervals during the load test. The data collected was evaluated at the end of the test and the performance of the cooker was estimated. The thermal performance indicator such as cooking power, standardized cooking power and thermal efficiency can be determined through equation (2.3.1) – (2.3.3).

#### 2.3.1. Cooking Power [6]:
Useful amount of solar energy acquired for the duration of heating. It is calculated as a change in the sensible heat of the water. Now, cooking power can be obtained theoretically using equation (2.3.1).

\[
P = \frac{T_2 - T_1}{t} m_w C_{pw} \tag{2.3.1}
\]

Where \( P \) is the power required for cooking in watts (W), \( m_w \) is mass of water in kilogram (kg), \( C_{pw} \) is specific heat in J/kgK, \( t \) is time in second, \( T_1 \) and \( T_2 \) are the initial and final temperature of water respectively in °C.

#### 2.3.2. Standardized Cooking Power [6]:
Using the predefined value of standard solar isolation as 700 W/m², standardized cooking power is calculated using the equation (2.3.2).

\[
P_s = P \left(\frac{700}{I}\right) \tag{2.3.2}
\]

Where \( I \) is interval average isolation in W/m², and \( P_s \) is standardized cooking power (P_s) in watts (W)

#### 2.3.3. Efficiency [6]:
Thermal efficiency is obtained using equations (2.3.3) by ref. [6]

\[
\eta = \frac{m_w \cdot C_{pw} \cdot (T_2 - T_1)}{A_{sc} \cdot \int I dt} \tag{2.3.3}
\]

Where \( m_w \) is mass of water in kilogram (kg), \( C_{pw} \) is the specific heat of the water in J/kgK, \( A_{sc} \) is the surface area of the solar cooker (m²), \( I \) is interval average isolation in W/m², \( T_1 \) and \( T_2 \) are an initial and final temperature of water respectively in °C.

After the various load tests, it is to be noted that the surface temperature of the receiver can be achieved as 100°C to 110°C provided 500 W/m² solar irradiation. Cooking power and then cooking efficiency can be calculated by equation 2.3.1 and 2.3.3 respectively.

### 3. Result and discussion
Load test on the cooker was carried with 500 ml of water in a cooking pot. The wind velocity, ambient temperature, receiver temperature, cooking pot temperature and solar radiation received by the concentrator were measured at different time intervals. Based on the results, graphs have been plotted for further analysis, as shown in Figure 2, 3 and 4. Solar radiation intercepted by the concentrator varied from 373 to 515 W/m² for an average ambient temperature of 21.5 °C. At the beginning of the
load test, the water temperature was 18 °C, which steadily rose to its boiling point as the day advanced. The decrease in temperature (Figure 3) was caused by an increase in heat loss on the side of the receiver tube, which was then reduced by the glass cover which improved the surface temperature. The intensity of solar radiation declines after 14 hours which also evident from Figure 2, 3 and 4. Due to this, the temperature of the cooking pot decreases steadily. The maximum temperature measured on the surface of the receiver was 110°C. The temperature and cooking power obtained by the suggested method can be varied for domestic cooking in Gujarat.

**Figure 2.** Graph of solar radiation against ambient temperature
Figure 3. Graph of solar radiation against receiver tube surface temperature

Figure 4. Graph of solar radiation against cooking pot water temperature
The thermal efficiency of the proposed device is in the range of 5 to 15 percent, which is in line with literature data [4]. The efficiency of the cooker can be further improved by using a material with higher reflectivity and reducing the convective heat loss.

4. Conclusion
The proposed prototype of the solar cooker was build and installed at Gujarat Power Engineering and Research Institute, Mehsana, Gujarat, India. Load test on the proposed cooker was carried with 500 ml of water in a cooking pot. The results obtained were used to analyze the performance of the cooker. The measured solar radiation incident on the concentrator varied from 373 to 515 W/m² with an average ambient temperature of 21.5 °C. The intensity of the solar radiation decreases after 14 hours which causes the temperature of the cooking pot to decrease. The maximum temperature measured on the surface of the receiver was 110°C. The thermal efficiency of the proposed cooker is in the range of 5 to 15 percent which can be further improved by using a material with higher reflectivity and reducing the convective heat loss. Unlike other types of solar cooker, the proposed solar cooker can work effectively throughout the day time. The test results obtained show the practical viability of the proposed solar cooker for different cooking processes, including water boiling and rice cooking. The use of the proposed solar cooker can mitigate the harm to the atmosphere and human health caused by the burning up of wood as a fuel.

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Nomenclatures and abbreviations

- $A_{sc}$: Surface area of solar cooker [m$^2$]
- $C_{pw}$: Specific heat of water [J/kgK]
- $dt$: Time difference
- $I$: Average isolation [W/m$^2$]
- $m_w$: Mass of water [kg]
- $\eta$: Thermal efficiency
- $P$: Cooking power [W]
- $P_s$: Standardized cooking power [W]
- $t$: Time
- $T_1$: Initial temperature of water [$^\circ$C]
- $T_2$: Final temperature of water [$^\circ$C]