

Experimental investigation of solar cooker with dual sensible heat storage unit for evening cooking

Avadhesh Yadav

Abstract-In this article, the thermal performance of dual sensible heat storage unit in a solar cooker based on parabolic dish collector for evening cooking is experimentally investigated. In the experimental setup, solar cooker with dual sensible heat storage unit was placed on absorbing plate of parabolic dish collector. During sunshine hours, the dual sensible heat storage unit stores solar heat and in the evening time, firstly the solar cooker with sensible heat storage unit is transferred to an insulator box and then loaded with cooking food. Inner sensible heat storage material transfers its stored heat to the cooking pot while the outer sensible heat storage material helps in compensating the heat loss during the transfer of solar cooker from absorber plate to insulator. It has been found that, food was cooked when transfer time is 05 minutes, partially cooked when transfer time is 10 minutes and not cooked when transfer time is 15 minutes.

Keywords- Thermal performance, parabolic dish collector, solar cooker, sensible heat storage unit.

I. Introduction

Solar cooking is better substitute for cooking by fuel or wood in India. Solar energy has become one of the most promising alternative energy resources because it is free, environmental friendly and available in abundance. From the last few decades, solar energy is utilized in the field of cooking using different types of collector such as box type solar cooker, parabolic dish collector, parabolic trough collector and evacuated tube collector. Several efforts were made for day and evening cooking using solar cooker with thermal storage.

Sharma et al. [1] designed and developed a cylindrical PCM storage unit for a solar cooker with two reflectors and compared the performance of that solar cooker with a standard solar cooker. Acetamide was used as PCM and experimental results showed that the melting temperature of PCM should be in the range of 105°C to 110°C for evening cooking. Schwarzer and Silva [2] tested a solar cooking system with or without heat storage in different countries of the world. The system presented many interesting features such as possibility of indoor and night cooking, heat flow control in the pots, modularity and the possibility of further adjustments to incorporate a baking oven. Sharma et al. [3] investigated the thermal performance of a prototype solar cooker based on an evacuated tube collector with PCM storage unit. The system achieved high temperatures up to 130°C without tracking when erythritol was used as a PCM, which was sufficient to cook food during late evening. Chaudhary et al. [4] investigated a solar cooker based on parabolic dish collector with phase change material. It was observed that solar cooker with phase change material having outer surface painted black along with glazing stores 32.3% more heat as compared to PCM in ordinary solar cooker. Lecuona et al. [5] simulated a parabolic type solar cooker by using finite difference method. A numerical model was used to study its transient behavior with two different types of PCMs: Paraffin and Erythritol. Erythritol is an advantage for fast cooking due to high melting temperature and conductivity. Farooqui Suhail [6] presented a solar cooker based on fresnel lens type collector. The maximum temperature attained in the experiment was 250°C. Heat absorption capacity of that collector was five times more than conventional box type solar cooker. Saini et al. [7] experimentally investigated the thermal performance of a solar cooker with acetamide as PCM based on parabolic trough

Department of Mechanical Engineering, National Institute of Technology, Kurukshetra Haryana-136119, India

Tel. +91-9896103634

collector with vacuum tube receiver. It was observed the rate of evening cooking was found to be approximately 1.63 to 4.44 times faster as compared to noon cooking.

Many researchers have worked on solar cooker based on box type collector, evacuated tube solar collector, parabolic dish collector and parabolic trough collector with phase change thermal storage unit but none of them worked on solar cooker based on parabolic dish collector with dual thermal storage unit. The objective of this paper is to investigate the thermal performance of the solar cooker is studied under different transfer time of cooker from the dish to insulator box. The experimental setup is installed at NIT Kurukshetra, India [29° 58′ (latitude) North and 76° 53′ (longitude) East].

II. Experimental setup

This experiment is performed to investigate the thermal performance of solar cooker with the stone pebbles and sand in inner and outer space respectively. The test section of solar cooker is based on parabolic dish collector. This system consists of parabolic dish collector and solar cooker as shown in figure 1. The experimental setup consists of following components:

- A. Parabolic solar dish collector
- B. Solar cooker with sensible heat storage unit
- C. Insulator box

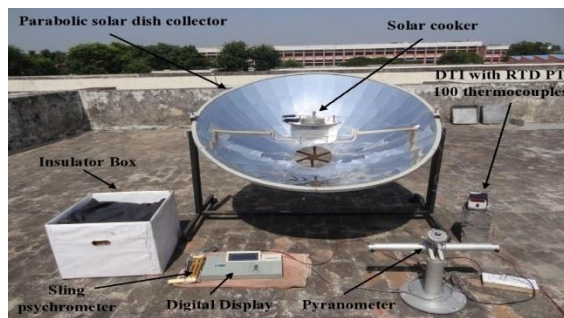


Figure 1: Photograph of the experimental setup

A. Parabolic solar dish collector

The solar dish is a point focusing collector which includes concentrator, absorbing plate for placing the cooker and frame as shown in figure.2. At the focal length of parabolic dish collector, an absorbing plate is provided upon which cooker is to be placed. The tracking of parabolic dish collector is manually.

Specifications of the parabolic dish collector are shown in Table 1.

TABLE 1: SPECIFICATIONS OF DISH COLLECTOR

Diameter of outer ring	1.4 m
Focal length of dish	0.2 m
Dish rim angle	120.5°
Aperture area of dish	1.539 m ²
Concentration ratio of dish	33

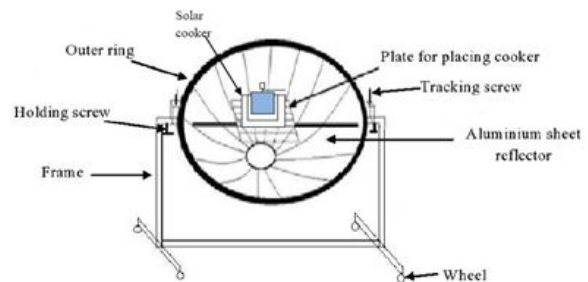


Figure 2: Schematic diagram of parabolic solar dish collector

B. Solar cooker with Sensible heat storage materials

Solar cooker is made up of two hollow concentric cylindrical pots of aluminum and a pressure cooker placed at their centre. The diameter of inner and outer pots is 0.23 m and 0.285 m respectively while the pressure cooker has diameter 0.13 m and height as 0.11 m. The inner space of cooker is filled with stone pebbles and the outer space with sand. The section view and photo of solar cooker are shown in figure 3(a) and 3(b) respectively.

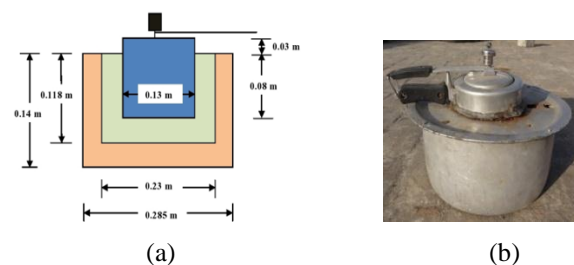


Figure 3: (a) Section view of solar cooker (b) photograph of solar cooker

C. Insulator box

A cardboard box filled with wooden chips having dimension as 0.534 m × 0.534 m × 0.406 m respectively is used as an insulator, as shown in figure 4. A cylindrical space having diameter 0.30 m and length 0.15 m is created at its centre for placing

the solar cooker. Top insulation is provided by using a sack which filled with wooden chips.

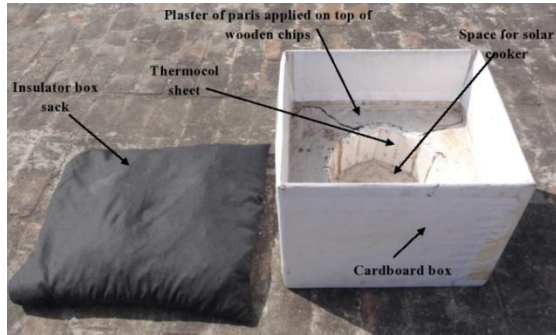


Figure 4: Photograph of insulator box with sack

III. Measuring Devices and Instruments

Sensible heat storage materials and cooking medium temperature are measured with RTD PT100 thermocouples which are connected with a digital temperature indicator that shows the temperature with a resolution of 0.1°C.

Dry bulb temperature of ambient air is measured with sling psychrometer.

The solar radiation intensity is measured during the day time with a Pyranometer.

IV. System Operation

The main objective of this experimental setup is to investigate the thermal performance of dual sensible heat storage unit in solar cooker for successful evening cooking. In the experimental setup, stone pebbles are filled in the inner space while sand in the outer space of the solar cooker. Solar cooker is placed on the absorbing plate of dish collector and the system is exposed to solar radiation from 13:00 hr to 16:00 hr. Solar radiations are made to concentrate on the solar cooker by the parabolic dish collector. The available heat is absorbed by dual sensible heat storage unit. The dish collector is tracked manually in every 15 minutes with the movement of sun. At 16:00 hr, the solar cooker is lifted from the dish collector and placed in the insulator box and loaded with 200g rice and 400ml water for evening cooking. During evening cooking, inner material transfer its stored heat to the cooking pot while the outer material helps in compensating the loss to maintain

its performance even during the transfer of cooker from the dish to insulator box.

V. Analysis of Experimental Data

Heat stored by the sensible heat storage material is given as

$$Q_m = m_m C_m (T_m - T_a)$$

VI. Experimental Results and Discussion

In the experimental setup, cooking was conducted at evening time using a solar cooker with dual sensible heat storage unit based on parabolic dish type collector. The performance of the solar cooker is studied under different transfer time of cooker from the dish to insulator box. The experiments were conducted during the month of September 2014. Every day, solar collector was exposed to solar radiation at 12:50 hr and readings were taken from 13:00 hr up to 20:00 hr at an every interval of 30 minutes.

(a) Solar cooker for transfer time of 05 minutes; September 16, 014

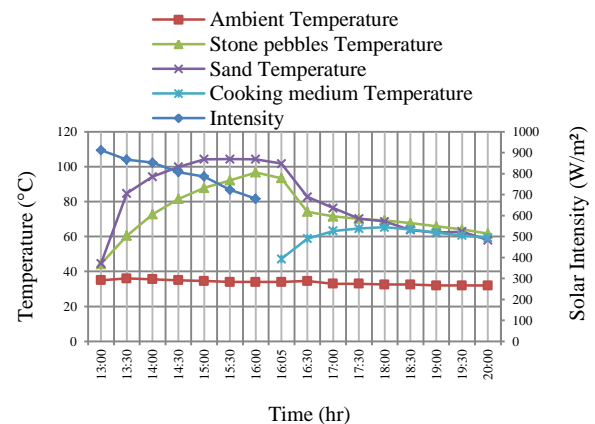


Figure 5: Variation of temperature and solar radiation intensity for transfer time of 05 minutes; September 16, 2014

On September 16, During the day, the maximum intensity was 912 W/m² at 13:00 hr and the ambient temperature was in the range of 32°C to 36°C. The maximum temperatures of sand and stone pebbles were 104.3°C and 96.7°C respectively. The figure 5 shows that the sand and stone pebbles were charged

continuously till 16:00 hr and afterwards it started discharging the stored energy. The maximum temperature of food in cooking pot reached 65.3°C at 18:00 hr and it was observed that at 20:00 hr the food temperature was 59.3°C. The food was found to be cooked.

(b) Solar cooker for transfer time of 10 minutes; September 22, 2014

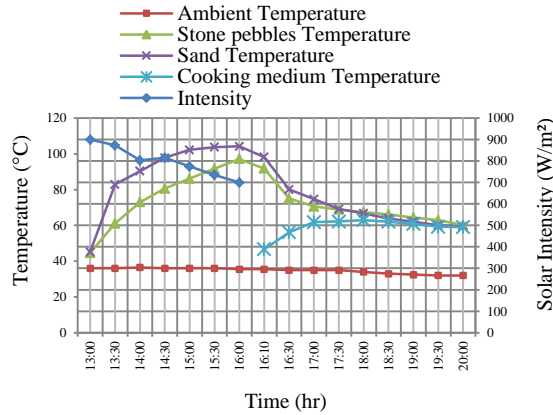


Figure 6: Variation of temperature and solar radiation intensity for transfer time of 10 minutes; September 22, 2014

On September 22, Sand temperature and stone pebbles temperature rises reaching to their maximum values of 104.2°C and 97.2°C as shown in figure 6. Maximum solar intensity was 900 W/m² at 13:00 hr and the ambient temperature lies in the range of 32°C to 36°C. The maximum temperature of food was found to be 63°C at 18:00 hr. At 20:00 hr the temperature of food was found to be 59°C and the food was partially cooked.

(c) Solar cooker for transfer time of 15 minutes; September 23, 2014

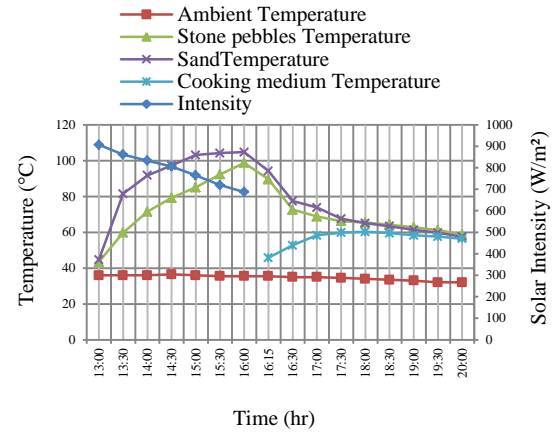


Figure 7: Variation of temperature and solar radiation intensity for transfer time of 15 minutes; September 23, 2014

On September 23, the maximum solar intensity was 907 W/m² at 13:00 hr. The maximum temperature attained by sand and stone pebbles was 104.7°C and 98.7°C respectively, as shown in figure 7. The maximum temperature of 60.2°C was attained by food at 18:00 hr. At 20:00 hr the temperature of food was found to be 56.4°C and the food was not cooked.

(d) Heat stored by sensible heat storage materials for different cases

In different cases of the experiment performed, the energy stored by sensible heat storage materials during charging process is shown in the figure 8.

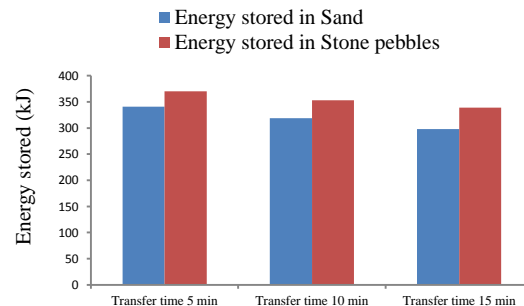


Figure 8: Heat stored by sensible heat storage materials

VII. Conclusions

1. During the transfer process, when the transfer time is 5 minutes, 10 minutes and 15 minutes then the temperature of outer sensible heat storage unit drops to 3°C, 6°C and 10°C respectively.

2. The maximum energy stored by stone pebbles during the transfer of 05 minutes, 10 minutes and 15 minutes is found as 370 kJ, 353 kJ and 339 kJ respectively, where as for sand it is 341 kJ, 319 kJ and 259 kJ respectively.
3. Food was cooked when transfer time is 05 minutes, partially cooked when transfer time is 10 minutes and not cooked when transfer time is 15 minutes.

Nomenclature

Q_m	heat stored by material, kJ
m_m	mass of material, kg
C_m	specific heat of material, kJ/kg°C
T_m	temperature of material, °C
T_a	ambient temperature, °C

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