Journal of Energy Research and Environmental Technology (JERET)
Print ISSN: 2394-1561; Online ISSN: 2394-157X; Volume 2, Number 3; April-June, 2015; pp. 200-204

http://www.krishisanskriti.org/jeret.html

Design and Experimental Testing of Solar Cooker with Sensible Heat Storage

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Abstract—*In this article, the thermal performance of sensible heat storage units (sand, stone pebbles, iron grits and iron balls) in a solar cooker based on parabolic dish type solar collector for late evening cooking is experimentally investigated. In the experimental setup, solar cooker with sensible heat storage unit was placed at focus of parabolic dish type collector. During sunshine hours, the sensible heat storage unit store solar heat and in the evening time, the solar cooker is transferred to an insulator box and then loaded with cooking food. Sensible heat storage unit transfers its stored heat to the cooking pot. It has been found that, food was cooked when sand, stone pebbles and iron grits are to be used as sensible heat storage unit and partially cooked when iron balls is to be used as sensible heat storage unit.*

Keywords*: Parabolic dish type collector, sensible heat storage units, solar cooker, thermal performance*

1. 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 this 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 this 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 acteamide as PCM based on parabolic trough 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 sensible heat storage unit. The objective of this paper is to investigate the thermal performance of the solar cooker is studied under different sensible heat storage units. The experimental setup is installed at NIT Kurukshetra, India [29° 58´ (latitude) North and 76° 53´ (longitude) East].

2. EXPERIMENTAL SETUP

This experiment is performed to investigate the thermal performance of solar cooker with sensible heat storage unit. The test section of solar cooker is based on parabolic dish type collector. The experimental setup is shown in Fig. 1 consists of following components:

2.1 Parabolic dish collector

2.2 Cooker with sensible heat storage unit (Solar cooker)

2.3 Insulator box

Fig. 1: Photograph of the experimental setup

2.1 Parabolic dish collector

The solar dish is a point focusing collector. At the focus of parabolic dish collector, a holding tray is provided upon which cooker is to be placed. The tracking of parabolic dish collector is done manually after 30 minutes. 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	120.5º
Aperture area of dish	1.539 m2
Concentration ratio of dish	33

2.2 Cooker with Sensible heat storage unit (Solar cooker)

Solar cooker is made up of hollow concentric cylindrical pot of aluminum and a pressure cooker placed at their centre. The diameter and height of pot is 0.285 m and 0.14 m respectively while the pressure cooker has diameter 0.13 m and height as 0.11 m as shown in Fig. 2. In experiment 1, 2, 3 and 4 the space of cooker is filled with sand, stone pebbles, iron grits and iron balls respectively. Thermo physical properties of these units which are used to store heat are given in Table 2.

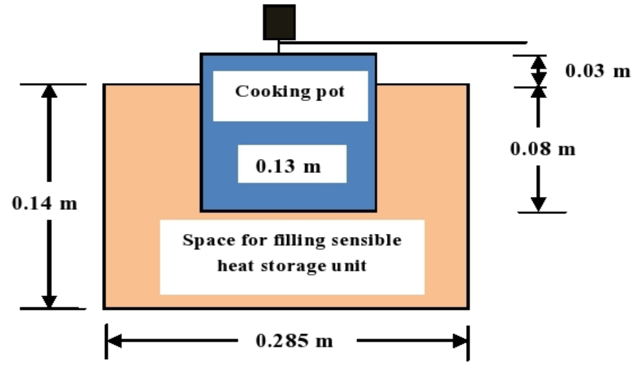

Fig. 2: Section view of solar cooker

Table 2: Thermophysical Properties of Sensible Heat Storage Unit

Materials / Properties	Sand	Stone pebbles	Iron grits	Iron balls
Mass (kg)	12.78	14.39	12.46	26
Specific heat (kJ/kg °C)	0.8	0.88	0.46	0.45

2.3 Insulator box

A cardboard box having dimension as 0.534 m × 0.534 m × 0.406 m respectively is filled with wooden chips and used as an insulator, as shown in Fig. 3. A cylindrical cavity having diameter 0.30 m and depth 0.15 m is created at its centre for placing the solar cooker. Top insulation is provided by using a sack which is also filled with wooden chips.

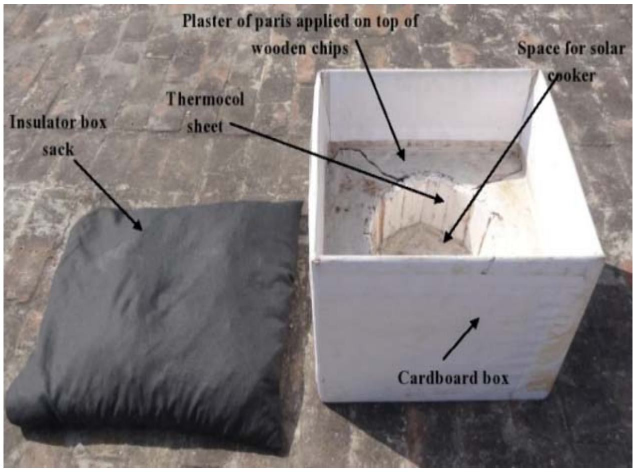

Fig. 3: Photograph of insulator box with sack

3. MEASURING DEVICES AND INSTRUMENTS

Sensible heat storage units 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.

4. SYSTEM OPERATION

The main objective of this experimental setup is to investigate the thermal performance of sensible heat storage unit in solar cooker for late evening cooking. In the experiment 1, solar cooker is filled with sand, in the experiment 2, solar cooker is filled with stone pebbles, in the experiment 3, solar cooker is filled with iron grits and in the experiment 4, solar cooker is filled with iron balls. Solar cooker is placed on the holding tray of parabolic dish type collector and the system is exposed to solar radiation from 13:00 hr to 16:00 hr. A part of available heat is absorbed by sensible heat storage unit. The temperature of sensible heat storage unit, cooking food temperature, ambient temperature and solar intensity is measured after every 30 minutes. The parabolic dish type collector is tracked manually after every 30 minutes. At 16:00 hr, the solar cooker is transferred from the parabolic dish type collector to insulator box and loaded with cooking load. During evening cooking, sensible heat storage unit transfer its stored heat to the cooking pot to cook the food.

5. ANALYSIS OF EXPERIMENTAL DATA

Heat stored by the sensible heat storage unit is given as

$$Q_m = m_m [C_m (T_m - Ta)]$$

It is assumed that the specific heat of materials does not change with temperature and materials are initially at ambient temperature.

6. EXPERIMENTAL RESULTS AND DISCUSSION

Every day, solar collector was exposed to solar radiation at 12:50 hr and readings were taken from 13:00 hr upto 20:00 hr at an interval of 30 minutes. Sensible heat storage unit was studied under same cooking load of 200 g rice and 400 ml water.

Experiment 1: Solar cooker with sand as a sensible heat storage unit; September 27, 2014

On September 27, the experiment was conducted with sand as a sensible heat storage unit. From Fig. 4, it can be observed that the maximum temperature of sand was 104.1°C at 14:30 hr. The maximum temperature of food was 64.8°C. The food was found to be cooked and the food temperature at 20:00 hr was 59.7°C.

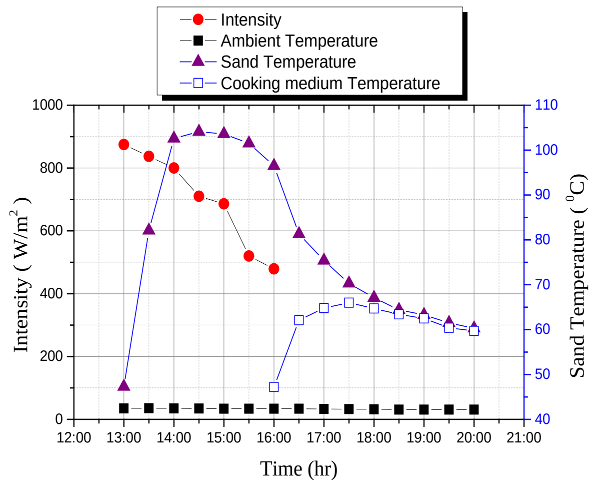

Fig. 4: Variation of temperature and solar radiation intensity for experiment 1; September 27, 2014

Experiment 2: Solar cooker with stone pebbles as a sensible heat storage unit; September 28, 2014

On September 28, the experiment was conducted with stone pebbles as sensible heat storage unit. From Fig. 5, it can be observed that maximum solar intensity was 921 W/m^2 at 13:00 hr and the ambient temperature lies in the range of 31℃ to 36 ℃. The maximum temperature of food was found to be 62.2°C at 17:30 hr. At 20:00 hr the temperature of food was found to be 58.9^{0}C and the food was cooked.

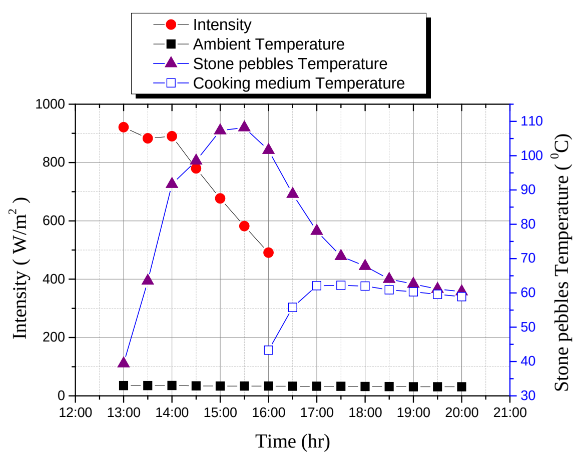

Fig. 5: Variation of temperature and solar radiation intensity for experiment 2; September 28, 2014

Experiment 3: Solar cooker with iron grits as a sensible heat storage unit; September 29, 2014

On September 29, the experiment was conducted with iron grits as a sensible heat storage unit. From Fig. 6, it can be observed that the maximum temperature of iron grits was 120.5°C at 15:00 hr. The maximum temperature of food was

68°C. The food was found to be cooked and the food temperature at 20:00 hr was 63.1°C.

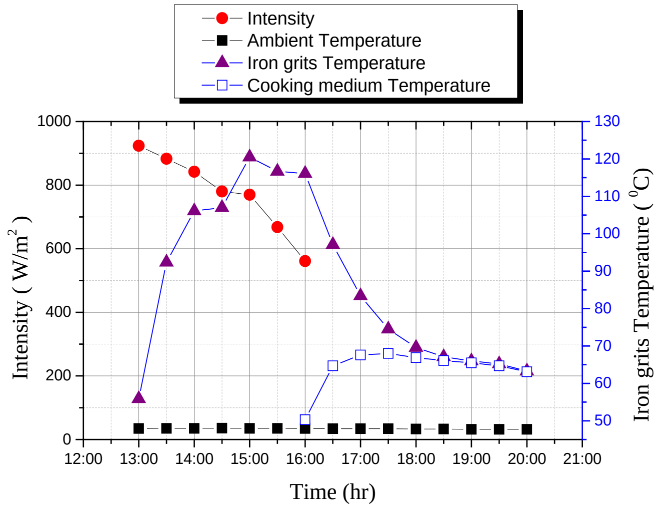

Fig. 6: Variation of temperature and solar radiation intensity for experiment 3; September 29, 2014

Experiment 4: Solar cooker with iron balls as a sensible heat storage unit; September 30, 2014

On September 30, the experiment was conducted with iron balls as sensible heat storage unit. From Fig. 7, it can be observed that maximum solar intensity was 917 W/m^2 at 13:00 hr and the ambient temperature lies in the range of 32℃ to 36 ℃. The maximum temperature of food was found to be 64.4°C at 18:00 hr. At 20:00 hr the temperature of food was found to be 58.4^{0}C and the food was partially cooked.

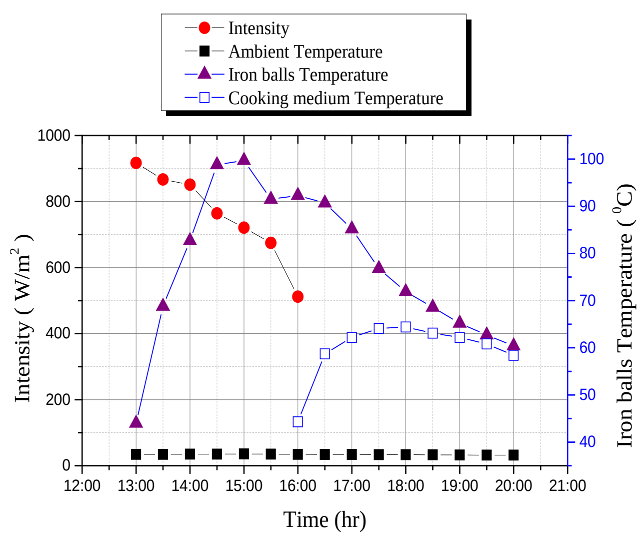

Fig. 7: Variation of temperature and solar radiation intensity for experiment 4; September 30, 2014

7. HEAT STORED BY SENSIBLE HEAT STORAGE MATERIALS FOR DIFFERENT CASES

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

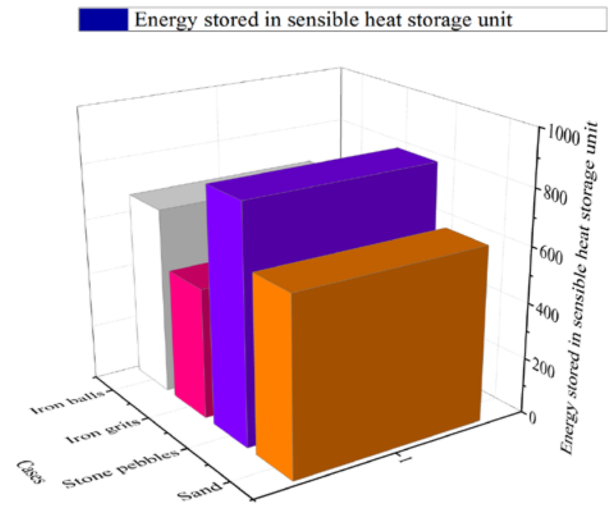

Fig. 8: Heat stored by sensible heat storage unit

8. UTILIZATION FACTOR

The utilization factor or use factor is the ratio of the amount of energy used divided by the maximum possible to be used. The utilization factor for different sensible heat storage unit is shown in Fig. 9.

Utilization factor (UF) = $(Q_m - Q_l) / Q_m$

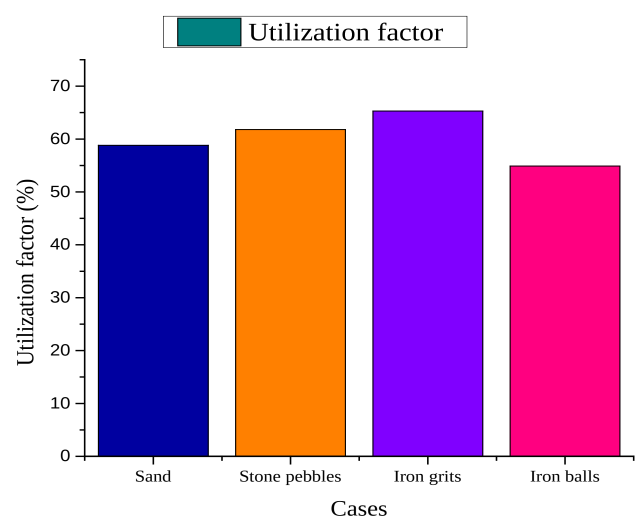

Fig. 9: Utilization factor of sensible heat storage units

9. CONCLUSIONS

Food was cooked in experiment 1, 2 and 3 and partially cooked in experiment 4 while the environmental conditions were almost same. The maximum temperature of sand, stone pebbles, iron grits and iron balls is 104.1^{o}C, 108.2^{o}C, 116.7^{o}C and 99.7^{o}C respectively. The maximum energy stored by sand, stone pebbles, iron grits and iron balls is 628.77 kJ, 843.33 kJ, 467.69 kJ and 670.4 kJ respectively. So we can use sand, stone pebbles and iron grits as sensible heat storage unit for successful late evening cooking. These units are also cheap, easily available, non toxic and non hazardous.

10. NOMENCLATURE

Q_m heat stored in the material at 16:00 hr, kJ

Q_l heat left in the material at 20:00 hr, 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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