EXPERIMENTAL INVESTIGATION OF SOLAR COOKER WITH TWO SENSIBLE HEAT STORAGE MATERIALS FOR EVENING COOKING

Himanshu Agrawal[1], Avadhesh Yadav[2]

[1,2]*Department of Mechanical Engineering, National Institute of Technology, Kurukshetra Haryana, (India)*

ABSTRACT

In this article, the thermal performance of two sensible heat storage materials (iron grits and iron balls) in a solar cooker based on parabolic dish type solar collector for evening cooking is experimentally investigated. In the experimental setup, solar cooker with two sensible heat storage materials was placed at focus of parabolic dish type collector. During sunshine hours, the sensible heat storage materials store solar heat and in the evening time, the solar cooker 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 holding tray of parabolic dish to insulator. It has been found that solar cooker is more efficient when iron grits is filled in inner space and iron balls in outer space than iron balls in inner space and iron grits in outer space. It has also been found that, food was cooked when transfer time (time gap between transferring the solar cooker from dish to insulator) is 05 minutes, partially cooked when transfer time is 10 minutes and not cooked when transfer time is 15 minutes.

***Keywords*: Parabolic Dish Type Collector, Sensible Heat Storage Materials, Solar Cooker, Thermal Performance**

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 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 two sensible heat storage materials. 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 combination of two sensible heat storage materials in inner and outer space. The test section of solar cooker is based on parabolic dish type collector. The experimental setup as shown in figure 1 consists of following components:

1. Parabolic dish collector
2. Cooker with sensible heat storage materials (Solar cooker)
3. Insulator box

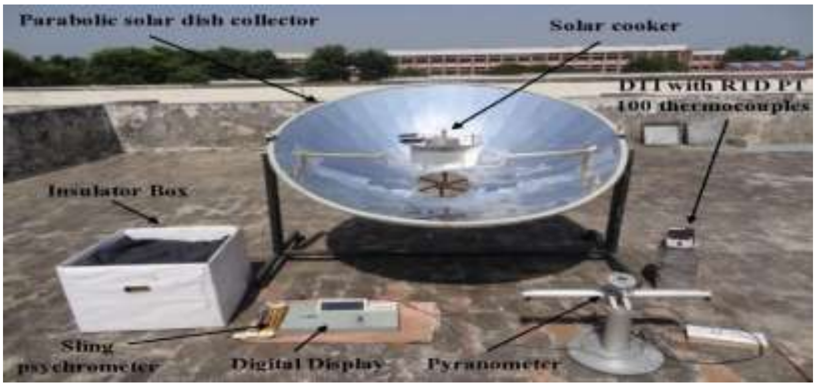

Fig 1: Photograph of the Experimental Setup

2.1 Parabolic Dish Collector

The solar dish is a point focusing collector as shown in figure 2. 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. 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 m^2
Concentration ratio of dish	33

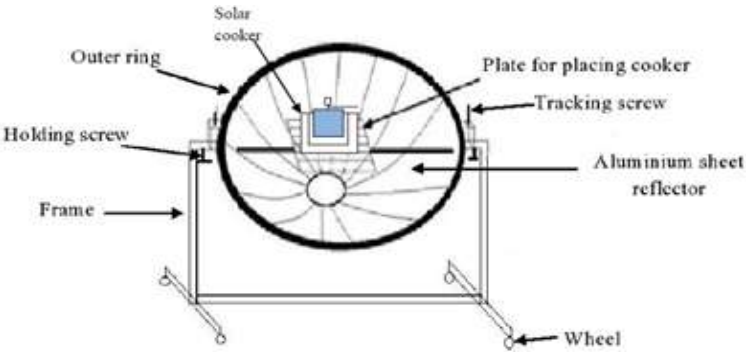

Fig 2: Schematic Diagram of Parabolic Dish Collector

2.2 Cooker with Sensible Heat Storage Materials (Solar Cooker)

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. In experiment 1 the inner space of cooker is filled with iron grits and the outer space with iron balls as shown in figure 3 (a) and in experiment 2 they are filled alternatively. The photograph of solar cooker is shown in figure 3(b). Thermo physical properties of these materials which are used to store heat are given in Table 2.

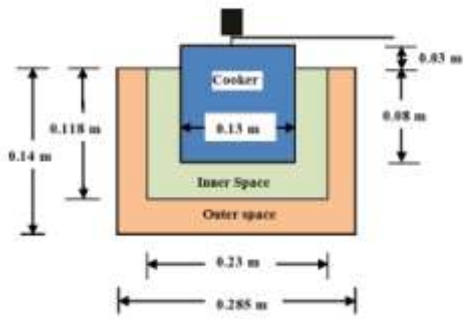

Fig 3: (A) Section View of Solar Cooker

Fig 3: (B) Photograph of Solar Cooker

Table 2: Thermophysical Properties of Sensible Heat Storage Materials

Materials / Properties	Iron grits	Iron balls
Mass (kg)	6.2	13
Specific heat (kJ/kg^{o}C)	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 figure 4. 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.

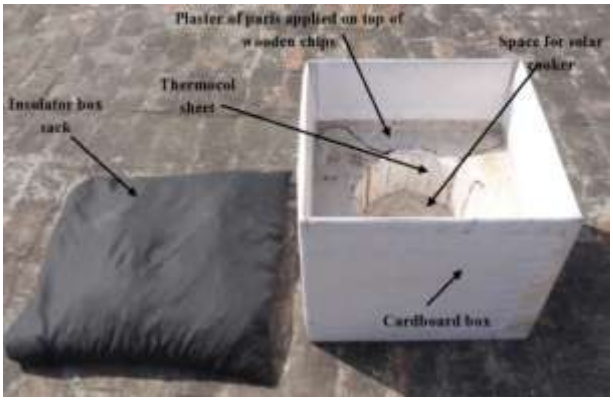

Fig 4: Photograph of Insulator Box With Sack

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 two sensible heat storage materials in solar cooker for successful evening cooking. In the solar cooker for experiment 1, iron grits are filled in the inner space while iron balls in the outer space and in experiment 2, iron balls are filled in the inner space while iron grits in the outer space. 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 materials. 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, 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.

From the two experiments, the best combination of sensible heat storage materials is considered for the transfer time gap of 05, 10 and 15 minutes.

V. ANALYSIS OF EXPERIMENTAL DATA

Heat stored by the sensible heat storage material is given as

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

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

VI. 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. Two different pairs of sensible heat storage materials were studied under same cooking load of 200 g rice and 400 ml water.

Experiment 1: Solar cooker with iron grits in inner space and iron balls in outer space; August 08, 2014

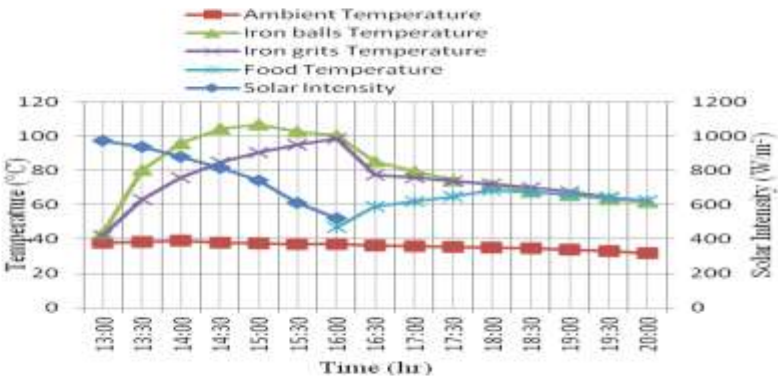

Fig 5: Variation of Temperature and Solar Radiation Intensity for Experiment 1; August 08, 2014

On August 08, the experiment was conducted with iron grits in inner space and iron balls in outer space. From figure 5, it can be observed that the maximum temperature of iron grits and iron balls were 98.7°C and 106.7°C respectively. The maximum temperature of food was 68.5°C. The food was found to be cooked and the food temperature at 20:00 hr was 62.2°C.

Experiment 2: Solar cooker with iron balls in inner space and iron grits in outer space; August 09, 2014

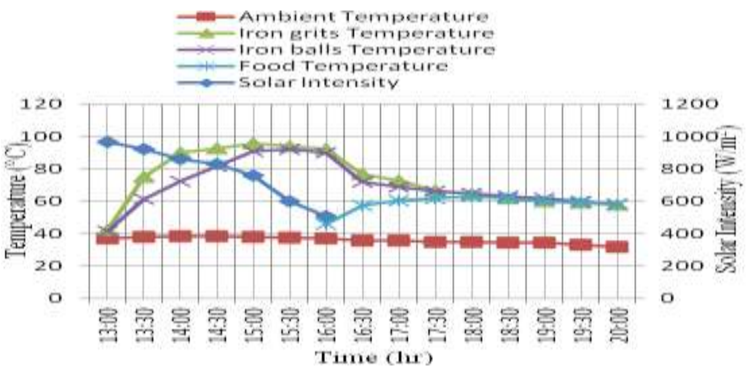

Fig 6: Variation of Temperature and Solar Radiation Intensity for Experiment 2; August 09, 2014

On August 09, the experiment was conducted with iron balls in inner space and iron grits in outer space. . From figure 6, it can be observed that maximum solar intensity was 965 W/m^2 at 13:00 hr and the ambient temperature lies in the range of 32°C to 38°C. The maximum temperature of food was found to be 63.2°C at 18:00 hr. At 20:00 hr the temperature of food was found to be 58°C and the food was partially cooked.

From the above two experiments, performed at almost same atmospheric conditions, it is found that combination of materials in experiment 1 is more efficient than experiment 2. Therefore we will use this combinations of materials from experiment 1 for transfer time i.e. time gap between transferring the solar cooker from dish to insulator, of 05, 10 and 15 minutes.

6.1 Solar Cooker for Transfer Time of 05 minutes; August 11, 2014

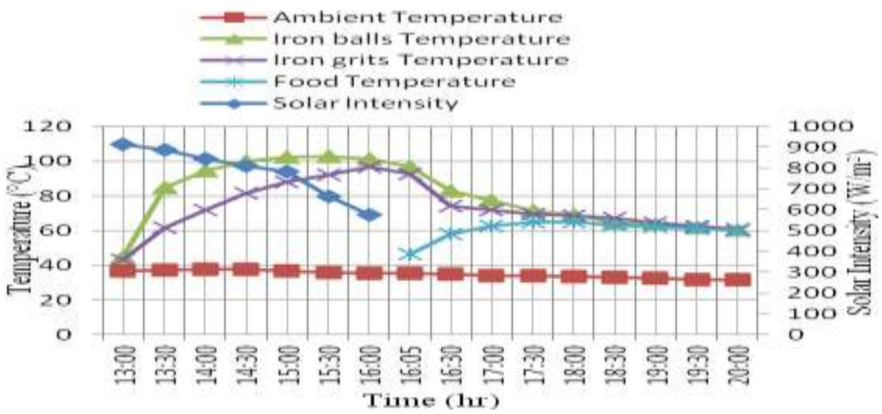

Fig 7: Variation of Temperature and Solar Radiation Intensity For Transfer Time Of 05 Minutes; August 11, 2014

On August 11, the maximum temperatures of iron grits and iron balls were 96.8°C and 103.1°C respectively. The figure 7 shows that the iron grits and iron balls were charged continuously till 16:00 hr and afterwards it started discharging the stored energy. The maximum temperature of food in cooking pot reached 65.1°C at 17:30 hr and it was observed that at 20:00 hr the food temperature was 60.1°C. The food was found to be cooked.

6.2 Solar Cooker for Transfer Time of 10 Minutes; August 12, 2014

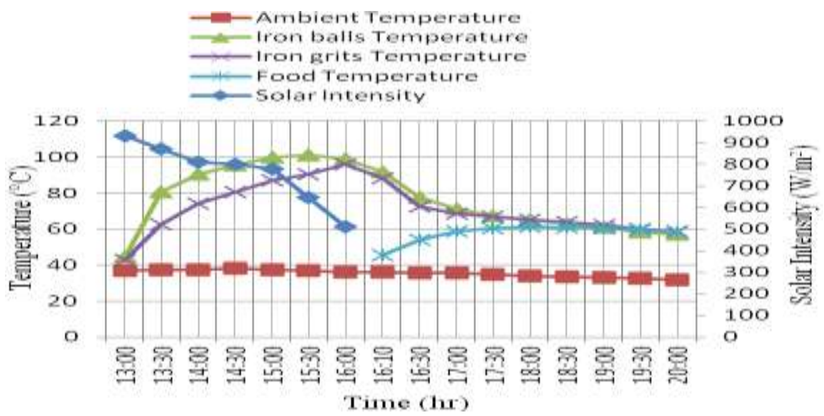

Fig 8: Variation of Temperature and Solar Radiation Intensity for Transfer Time of 10 Minutes; August 12, 2014

On August 12, iron grits temperature and iron balls temperature rises reaching to their maximum values of 96.1°C and 101.1°C as shown in figure 8. Maximum solar intensity was 933 W/m^2 at 13:00 hr and the ambient temperature lies in the range of 32°C to 38°C. The maximum temperature of food was found to be 61.3°C at 18:00 hr. At 20:00 hr the temperature of food was found to be 58.4°C and the food was partially cooked.

6.3 Solar Cooker for Transfer Time of 15 Minutes; August 13, 2014

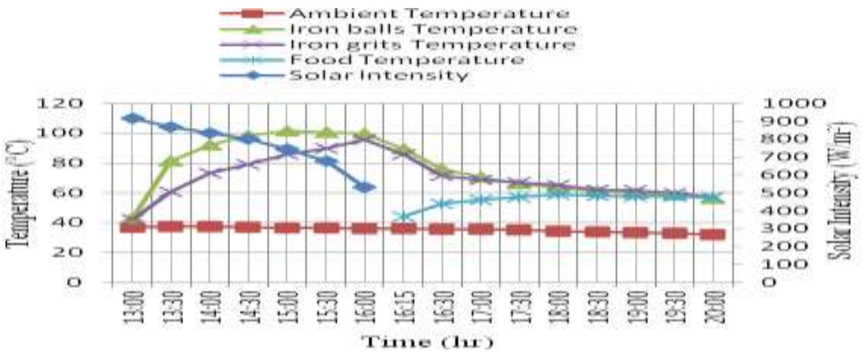

Fig 9: Variation of Temperature and Solar Radiation Intensity for Transfer Time of 15 Minutes; August 13, 2014

On August 13, the maximum solar intensity was 915 W/m^2 at 13:00 hr. The maximum temperature attained by iron grits and iron balls was 95.8°C and 101.3°C respectively, as shown in figure 9. The maximum temperature of 58.8°C was attained by food at 18:00 hr. At 20:00 hr the temperature of food was found to be 57°C and it was found to be not cooked.

6.4 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 10.

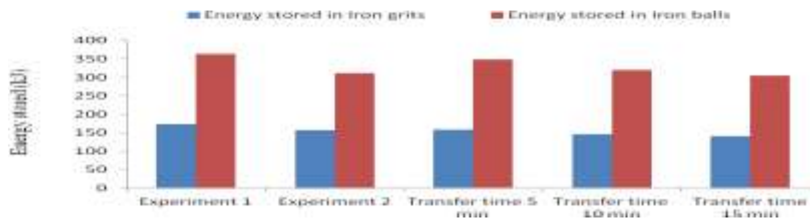

Fig 10: Heat Stored By Sensible Heat Storage Materials

VII. CONCLUSIONS

Food was cooked in experiment 1 and partially cooked in experiment 2 while the environmental conditions were almost same. So, the combination of materials in experiment 1 is more efficient than experiment 2. During the transfer process, when the transfer time is 5 minutes, 10 minutes and 15 minutes then the temperature of outer and inner sensible heat storage materials drops to 4.6°C, 7.5°C, 10.5°C and 4°C, 7.8°C, 9.8°C respectively. The maximum energy stored by iron balls during the transfer of 05 minutes, 10 minutes and 15 minutes is found as 349 kJ, 320 kJ and 305 kJ respectively, where as for iron grits it is 159 kJ, 146 kJ and 140 kJ respectively. 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.

7.1 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

REFERENCES

[1]. Sharma S.D., Buddhi D., Sawhney R.L., Sharma A., 2000, "Design, development and performance evaluation of a latent heat storage unit for evening cooking in a Solar cooker", Energy Conversion and Management, vol. 41, pp 1497-1508.

[2]. Schwarzer K. and Silva M.E.V., 2003, "Solar cooking system with or without heat storage for families and institutions", Solar Energy, vol. 75, pp 35-41.

[3]. Sharma S.D., Iwata T., Kitano H., Sagara K., 2005, "Thermal performance of a Solar cooker based on an Evacuated tube collector with a PCM storage unit", Solar Energy, vol. 78, pp 416-426.

[4]. Choudhary A., Kumar A., Yadav A., 2013, "Experimental investigation of solar cooker based on parabolic dish collector with phase change thermal storage unit in Indian climatic conditions", Renewable & Sustainable Energy, vol.5 023107.

[5]. Lecuona A., Nogueira J.I., Ventas R., Hidalgo M.D.C.R., Legrand M., 2013, "Solar cooker of the portable Parabolic type incorporating heat storage based on PCM", Applied Energy, Article in press.

[6]. Farooqui S.Z., 2013, "A vacuum tube based improved solar cooker", Sustainable Energy technologies and Assessments, vol.3, pp 33-39.

[7]. Saini K., Gagandeep, Singh H. and Yadav A., 2013, "Solar cooker with PCM unit based on parabolic trough collector with vacuum tube receiver: Experimental investigation", Encyclopedia of Energy Engineering and Technology, Article in Press.