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Solar Cooker Based on Parabolic Dish Collector for Evening Cooking using Dual Heat Storage Materials

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Abstract—*This paper presents an investigation of thermal performance of PCM in combination with different sensible heat storage materials (SHSMs) in a solar cooker based on parabolic dish collector for evening cooking. In the experimental setup, a pressure cooker is placed at the centre of two concentric pots containing PCM in the inner pot and different SHSMs in the outer pot. Twocases were studied by filling different SHSM (stone pebblesand iron grit) in the outer pot. During sunshine hours, this unit (solar cooker) is placed on plate of parabolic dish collector for storing the thermal energy in the SHSMs. Initially the material in the outer pot stores energy and meanwhile transfers it to the PCM in the inner pot, which further stores and transfers heat to the pressure cooker. In the evening, the solar cooker is kept in an insulator box and loaded with cooking food, where the PCM deliver heat to the food. It has been found that PCM-Stone pebblecase stores 3.6 times more heat as compared to PCM-Iron grit case.The PCM assists in cooking while the outer material assists PCM to maintain its performance.*

Keywords: *Thermal performance, parabolic dish collector, solar cooker, phase change material, sensible heat storage materisl (SHSM), latent heat, sensible heat.*

1. INTRODUCTION

Cooking is a prime necessity for all people across the world. About 75% of people living in rural India fulfill their cooking energy needs from noncommercial fuels like wood from the forest which contributes to deforestation and green house effect. On the other hand price of LPG, which is another major source of energy for cooking, is rising day by day. Due to this cooking by using renewable energy sources is a burning issue. Fortunately, India is blessed with ample amount of solar radiation. This offers solar cooking as one of the most attractive options. Successful application of solar energy depends to a large extent on the method of energy storage. Energy storage not only provides bridge between supply and demand, but also improves the performance and reliability of the system. Different types of thermal energy storage system may involve only sensible heat storage (storing of energy by heating or cooling), latent heat storage (by melting or vaporizing or solidifying or liquefying) or a combination of both. If solar cookers are provided with the thermal storage unit, then there is possibility of cooking food during the off-sunshine hours.

Several efforts were made for day and evening cooking using concentrating type of collectors with thermal storage. The concentrating type of collectors can be categorized into two groups based upon their applications, first achieving the high temperature range up to 300°C - 400°C in solar power plants and second, in industrial process heat applications where the temperature range required is 150°C - 250°C. The parabolic dish type concentrator has high collector efficiency so it is widely used in the area of solar cooking [1- 4]. Foong et al. [1] studied a small scale double reflector solar concentrating system with high temperature heat storage medium ($NaNO_3$ and KNO_3) and a finite element model was used to numerically analyze the latent heat storage unit. The experimental results demonstrated that the melting of phase change material occurred in 2 to 2.5 hr and reached a temperature range of 230-260℃, suitable for cooking and baking purposes. Chaudhary et al. [2] 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. [3] simulated a portable solar cooker of parabolic type using 1-D finite difference method. A numerical model was used to study its transient behavior with two different types of PCMs: Paraffin and Erythritol. High melting heat and conductivity of a PCM like erythritol is an advantage for fast cooking.

FarooquiSuhail [4] presented a solar cooker based on Fresnel lens type collector. The proposed cooker consists of rectangular glass mirror strips mounted on wooden frame and requires one dimensional solar tracking. 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. With the development in the field of solar energy, the parabolic trough collector was also used for solar cooking [5-6]. Umanand L. and Prasanna J.R. [5] modeled and designed the solar thermal system with parabolic collector for hybrid cooking. The system is modeled using the band graph approach. They compared the results of the simulated modeled system with experimentally results at different flow rates. At optimal flow rate, there is about 6% increase in efficiency as compare to thermosyphon flow rate. Velraj et al. [6] studied the performance of a solar parabolic trough collector with a thermal energy storage system and took therminol-55 as heat transfer fluid. Various performance parameters like useful heat gain and thermal efficiency of individual components were evaluated. Mussard and Nydal [7] used two different types of heat storage units with solar parabolic trough. The latent heat storage unit contained nitrate mixtures (salt) and oil was used as the heat transfer fluid which self circulates in the loop connecting the collector and storage unit. A storage based on thermal oil is much more efficient than aluminium based storage unit as it reduces thermal losses in the pipe and absorber. Saini et al. [8] experimentally investigated the thermal performance of a solar cooker with acteamide as PCM based on parabolic trough collector with vacuum tube receiver. They used two different heat transfer fluids separately, for heat circulation through natural phenomenon called thermosiphon. It was observed that using thermal oil as heat transfer fluid, quantity of heat stored by PCM was increased by an amount of 26.66% to 67.49% as compared to water as heat transfer fluid.

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 withdual thermal storage unit i.e. combined sensible and latent heat thermal storage system. The objective of this paper is to investigate the thermal performance of PCM in combination with different sensible heat storage materials (SHSMs) in a solar cooker based on parabolic dish collector for evening cooking in Indian climatic conditions. The experimental setup is installed at NIT Kurukshetra, India (29° 58´ (latitude) North and 76° 53´ (longitude) East).

2. EXPERIMENTAL SETUP

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

- Parabolic solar dish collector
- Solar cooker
- Latent heat storage unit (Acetamide)
- Sensible heat storage materials (sand, iron balls)
- Insulator box

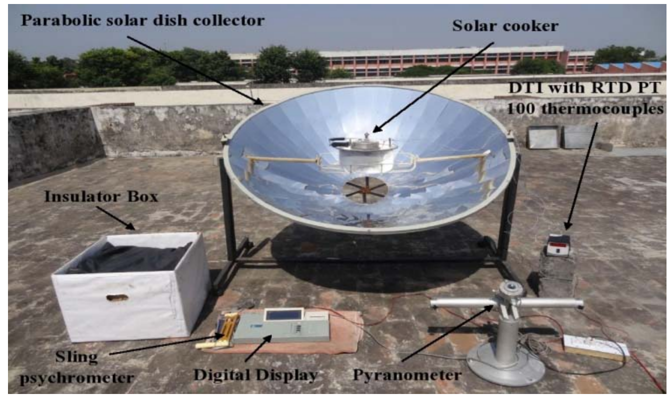


Fig. 1: Photograph of the experimental setup

2.1. Parabolic solar dish collector

The solar parabolic dish collector isa point focusing device which includes concentrator, plate for placing the cooker and frame. In this system, 40 segments of the anodized aluminium are joined to form the concentrator. At the focal length of parabolic dish collector,a plate is provided upon which cooker is to be placed. Specifications of the parabolic dish collector are shown in Table 1.

Table 1: Specifications of the parabolic 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

2.2. Solar cooker

Solar cooker is made up of two hollow concentric cylindrical pots of aluminum and a pressure cooker placed at their centre. The diameters of inner and outer pots are 0.23 m and 0.28 m respectively while the volume of pressure cooker is 1.5 litre. The inner space of cooker is filled with PCM and the outer space is filled with different sensible heat storage materials (one at a time). Four ports (two in inner space and two in outer space) are provided on the top surface of solar cooker, two for filling the storage material and two for inserting thermocouple. The side view, top view and photo of solar cooker are shown in Fig. 2(a), 2(b) and 2(c) respectively.

2.3. Latent heat storage unit

The selection of phase change material depends upon its properties such as melting temperature, latent heat of fusion, toxicity etc. In this paper, commercial grade acetamide is used as a phase change material with its thermo physical properties given in Table 2.

Table 2: Thermophysical properties of commercial grade acetamide

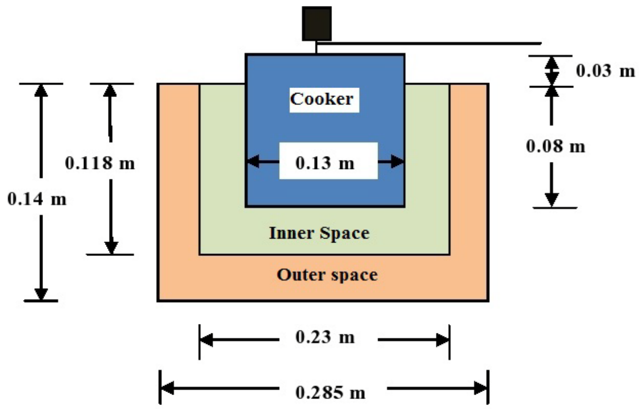
Melting temperature of acetamide (commercial grade)	82℃
Latent heat of fusion of acetamide (commercial grade)	263 kJ/kg
Specific heat of acetamide	1.94 kJ/kg℃

2.4. Sensible heat storage materials

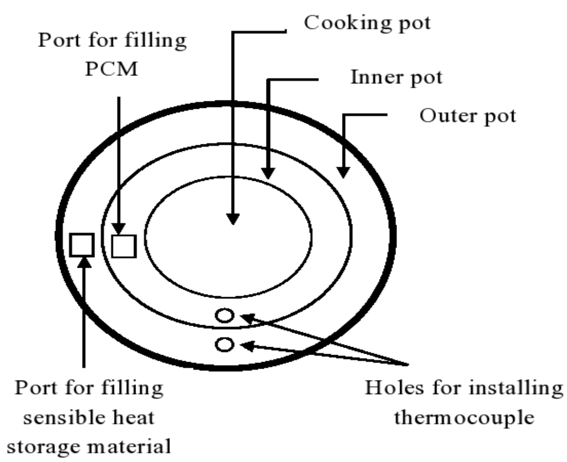
Sand and iron balls are used as a sensible heat storage materials which are filled in the outer space of the solar cooker. High melting pointand availability in abundance made these materials a goodoption for SHSM. Thermo physical properties of thesematerials which are used in this paper are given in table 3.

Table 3: Thermophysical properties of SHSMs

Properties	Iron grits	Stone pebbles
Density (kg/m^3)	1550	1790
Specific heat of sand (kJ/kg°C)	0.46	0.88



(a)



(b)
Fig. 2: (a) Section view of solar cooker
(b) Top view of solar cooker

2.5. Insulator box

A cardboard box filled with wooden chips is used for insulation is shown in Fig. 3. A cavity of diameter 0.30 m is provided at its centre for placing the solar cooker. This box provide insulation from bottom and side while for insulation at top a sack filled with wooden chips is used.

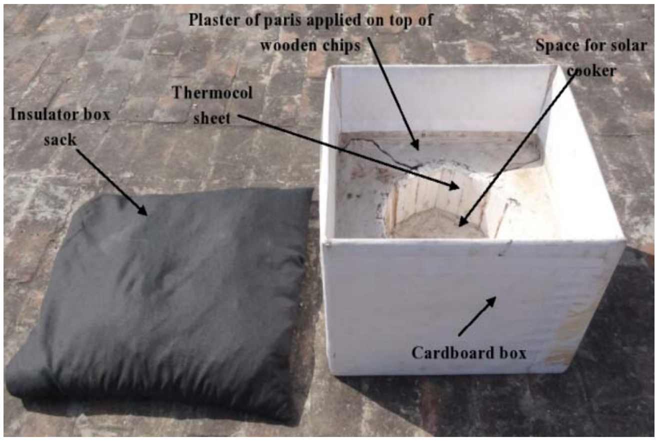


Fig. 3: Photograph of insulator box with sack

3. MEASURING DEVICES AND INSTRUMENTS

Different parameters are measured, these are:

- PCM temperature, Sensible heat storage materials temperature and cooking medium temperature
- Ambient temperature
- Solar radiation intensity

PCM temperature, sensible heat storage materials temperature 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.

4. SYSTEM OPERATION

The main objective of this experimental setup is to investigate the thermal performance of PCM in combination with different sensible heat storage materialsfor evening cooking. In the experimental setup, twopairs are formed by filling PCM in the inner space of cooker and different sensible heat storage material (taking one at a time) in the outer space of the solar cooker. Solar cooker is placed on the plate of dish collectorand 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 SHSMs and is transferred to the PCM. 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 for evening cooking. During evening cooking, PCM transfer its stored heat to the cooking pot while the sensible heat storage material in outer pot helps in compensating the loss in heat of PCM thus maintaining its performance even at off sunshine hours.

5. ANALYSIS OF EXPERIMENTAL DATA

Heat stored by the PCM

$$Q_{PCM} = m_{PCM}\left[C_{PCM}(T_m - T_a) + L + C_{PCM}(T_{PCM} - T_m)\right]$$

It is assumed that the specific heatof solid and liquid phase of PCM is same.

Heat stored by the SHSM

$$Q_{SHSM} = m_{SHSM}\left[C_{SHSM}(T_{SHSM} - T_a)\right]$$

6. EXPERIMENTAL RESULTS AND DISCUSSION

In the experimental setup, cooking was conducted at evening time using a novel design of solar cooker with dual heat storage unit based on parabolic dish type collector. The performance of the solar cooker is studied using PCM in combination with different SHSMs at NIT Kurukshetra, India. The experiments were conducted during the month of October 2014. Every day, solar collector was exposed to solar radiation at 12:50 hr and readings were taken from 13:00 hrupto 20:00 hr at an every interval of 30 minutes. Two pairs of PCM and different SHSMs were studied under same cooking load of 200 g rice and 400 ml water.

Case 1.Solar cooker with inner space filled with PCM and outer space filled with stone pebbles

On October 09, the experiment was conducted with inner space filled with PCM and outer space filled with stone pebbles.PCM temperature and stone pebbles temperature rises reaching to their maximum values of 82.9℃ and 99.6℃ as shown in Fig. 4. Maximum solar intensity was 867 W/m^2 at 13:30 hr and the ambient temperature lies in the range of 27℃ to 32℃. The maximum temperature of food was found to be 68.4°C at 17:30 hr. At 20:00 hr the temperature of food was found to be 61.2℃ and the food was cooked.

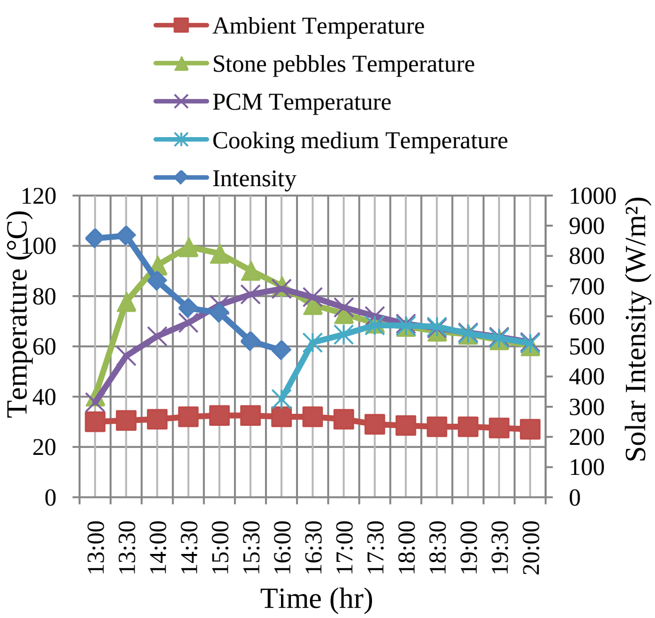


Fig. 4: Variation of temperature and solar radiation intensity with time in case of solar cooker with inner space filled with PCM and outer space filled with stone pebbles.

Case 2. Solar cooker with inner space filled with PCM and outer space filled with iron grit

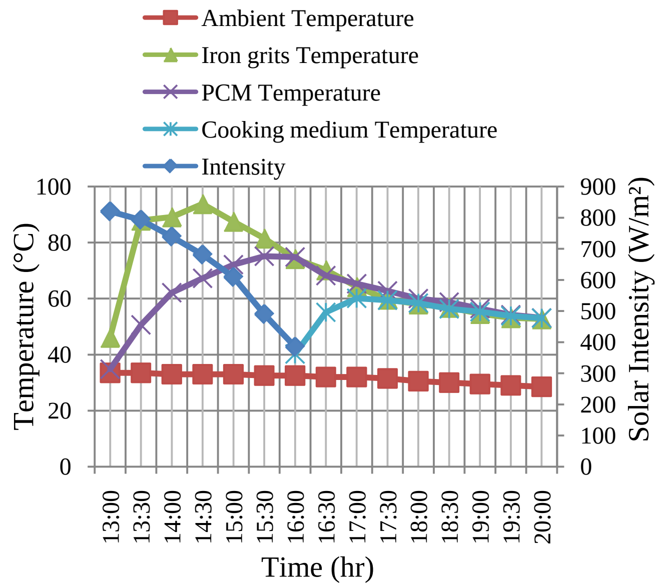


Fig. 5: Variation of temperature and solar radiation intensity with time in case of solar cooker with inner space filled with PCM and outer space filled with iron grits

On October 10, the experiment was conducted with inner space filled with PCM and outer space filled with iron grits. On that day, the maximum solar intensity was 820 W/m^2 at 13:00 hr. The maximum temperature attained by PCM and iron grits were 75.1°C and 93.8°C respectively, as shown in Fig. 5. The maximum temperature of 60.1°C was attained by food at 17:00 hr. At 20:00 hr the temperature of food was found to be 53.0℃ and the food was not cooked.

7. HEAT STORED BY PCM AND SHSMsIN DIFFERENT CASES

In different cases of the experiment performed, the energy stored by PCM and sensible heat storage materials during charging process is shown in the Fig. 6.

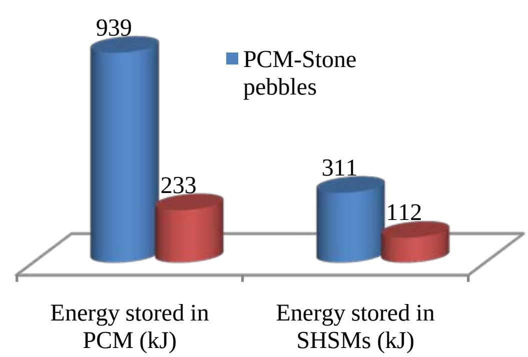


Fig. 6: Heat stored by PCM and sensible heat storage materials for different cases

It was found that in the case of PCM-Sand the energy stored by PCM during charging process were 935 kJ. Whereas, the energy stored by PCM in the case of PCM-Iron ballswas 226 kJ. The energy stored by PCM for later case was low because the PCM could not reach its meting point and thus could not store latent heat. For different cases senbile energy stored by SHSMs was found in the range of 226 kJ to 293 kJ.Sensible energy stored bySHSMshelps in maintaining the stored heat of PCM, thus keeping the food warm up to late evening hours.

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. 7.

$$\text{Utilization factor (UF)} = \frac{heat\ stored - heat\ left}{heat\ stored}$$

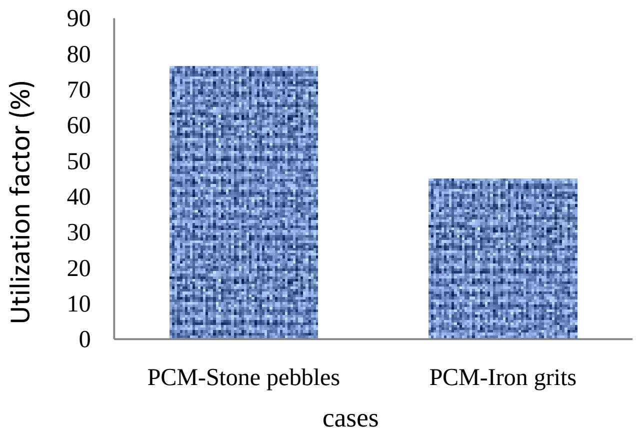


Fig. 6: Utilization factor for different cases

9. CONCLUSIONS

It was found that for case 1 and case 2 the maximum temperature of PCMreached 82.9℃and 75.1℃ respectively while the energy stored by PCM were 939 kJ and 233 kJ respectively. Food was found to be cooked in the cases of PCM-Sand (case 1) and not cooked in the cases of PCM-Iron balls(case 2). Cooking was unsuccessful in case 2 because there is point contact between iron balls due which there is low rate of heat transfer.Thus PCM does not reach its melting point and could not store latent heat.The above results show the feasibility of a solar cooker with dual thermal storage unit based on parabolic dish collector for late evening cooking in Indian climatic conditions.

10. NOMENCLATURE

Q_{PCM} heat stored by PCM, kJ

m_{PCM} mass of PCM, kg

C_{PCM} specific heat of PCM, kJ/kg℃

T_m melting temperature of PCM, ℃

T_{PCM} temperature of PCM at 16:00 hr, ℃

Llatent heat of fusion of PCM, kJ/kg

Q_{SHSM} heat stored by SHSM, kJ

m_{SHSM} mass of SHSM, kg

C_{SHSM} specific heat of SHSM, kJ/kg℃

T_{SHSM} temperature of SHSM at 16:00 hr

T_a ambient temperature, ℃

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