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THERMAL PERFORMANCE OF SOLID AND LIQUID ENERGY STORAGE MATERIALS IN A PARABOLIC DISH SOLAR COOKER

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ABSTRACT

The thermal energy storage is essential for late evening cooking due to intermittent nature of solar energy. A solar cooker was fabricated with sensible heat storage (SHS) materials in the periphery of the cooker and the materials selected are liquid and solid materials. The SHS materials were pebbles, sand and iron grits, steel balls, sunflower oil, olive oil and coconut oil. The SHS materials are useful for cooking at off-sunshine periods. The enhanced thermal performance of cooking pot was observed with around 300 kJ and 900 kJ for the selected solid and liquid SHS materials respectively.

Key words: Solar cooker, Parabolic dish collector, Sensible heat storage.

INTRODUCTION

Solar energy is one of the preferable resources for its eco-friendliness. Different types of solar cookers such as box type solar cooker (BSC), and PDC based cookers were investigated with or without thermal energy storage (TES). Parabolic dish solar cooker (PDSC) cooks food faster than the BSC. TES may consist of latent heat storage (LHS) or SHS or a combination of both. If the thermal storage unit is provided with solar cookers, then there is a possibility of cooking food during the off-sunshine hours. The diluted source of energy also necessitates the TES for faster rate of cooking. Several researchers investigated a solar cooker with sensible and or latent heat thermal energy storage for late evening cooking[1-3]. A solar cooker based on PDC with PCM was investigated and observed with 32.3% more heat storing[4]. The thermal performance of solar cooker with a dual thermal storage unit with sand and acetamide was investigated[5]. An optical efficiency of PDSC was determined as 35% and the optical efficiency factor was inversely proportional to the cooking mass[6]. The thermal performance of three thermal oils for solar cookers during

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charging period with an insulated 20 liters storage tank was conducted. The oils were Sunflower oil, Shell Thermia C and Shell Thermia B. It was found that Sunflower oil performs better than the other thermal oils under high power charging[7]. A parabolic trough collector based solar cooker with thermal energy storage (acetanilide) was observed with the temperature of thermal oil was 10-24% higher than water as the working fluid[8]. System advisor model was used to optimize the thermal output of parabolic trough collector in Malaysian climate for an output of steam at 200-230°C, which was suitable for industrial applications[9]. Exergy analysis of solar thermal systems was discussed[10]. Thermal energy storage modules were integrated in solar water heater and its thermal performance was evaluated[11]. Several researchers have worked on solar cooker based on box type collector, evacuated tube solar collector, PDC and parabolic trough collector with PCM unit. However, few of them worked on solar cooker based on PDC with sensible heat thermal storage. The thermal performance of a solar cooker with SHS materials was investigated experimentally and results are reported.

EXPERIMENTAL

The parabolic dish solar cooker (PDSC) consists of PDC and solar cooker. At the focus of PDC, a holding tray is provided upon which cooker is placed (Fig. 1). The manual tracking of PDC is adopted. PDSC is made up of polished aluminum sheet and stainless steel support members. The diameter of the dish is 1 m and focal distance is 0.45 m. The cooker dimensions are 0.20 m diameter and 0.22 m height. The concentration ratio is 25. The rim angle is 58°. In SHS medium, thermal energy is stored by raising the temperature of solid or liquid. SHS system utilizes the heat capacity and the temperature of the material during the process of charging and discharging. The faster thermal response of sensible heat materials are considered as one of the suitable property.

Fig. 1: PDSC

The annular region in the cooker outer and inner surface is filled with sensible heat materials to retain the heat as well as to provide uniform heat flux to the cooker inner vessel. The cooker is filled with sand, stone pebbles, iron grits, steel balls and vegetable oils separately or combined during the outdoor experiments. Thermo-physical properties of SHS materials are given in Table 1.

Table 1: Thermo-physical properties of SHS materials

Solid and liquid sensible heat storage materials							
Material properties	**Sand**	**Stone pebbles**	**Iron grits**	**Steel balls**	**Coconut oil**	**Sunflower oil**	**Olive oil**
Density (kg/m^3)	1515	1790	1550	3233	9080	9160	14675
Specific heat (kJ/kg K)	0.8	0.88	0.46	0.45	2112	2500	2300
Thermal conductivity (W/m K)	0.27	1.7	72.7	19	0.18	0.161	0.15

The concentrating collector utilizes only beam radiation. The solar cooker is placed on the plate of dish collector and exposed to solar radiation. The solar cooker is displaced from the PDC and then placed in the insulator box for later cooking. The average solar radiation received at the aperture area I_D of the PDC is calculated as:

$$I_D = I \times A \quad \text{...(1)}$$

The useful energy for cooking during evening time is calculated by Eq. (2):

$$Q_u = m\, C\, (T_{max} - T_{amb}) \quad \text{...(2)}$$

The system is exposed to the atmosphere and the heat losses can be calculated by:

$$C_l = h \times A_{sc} \times \Delta T + \sigma \times A_{sc} \times T^4 \quad \text{...(3)}$$

RESULTS AND DISCUSSION

The cooker consists of two concentric cylinders. The inner cylinder is used to cook the food and the annular space is filled with SHS materials. The usual cooking process is carried out from morning 9.00 hr and the effect of storage is studied afternoon sessions only. In the experimental setup, water heating experiments were conducted in the evening using a solar cooker. Experiments were conducted on the solar cooker with PDC at SRM University, Chennai [12° 80′ N, 80° 02′ E] with sand, pebbles and steel rods and vegetable oils. K-type thermocouples are used in temperature measurements (accuracy, ± 1%). The solar collector was exposed to solar radiation. The maximum temperature of SHS materials are theoretically calculated using the equations and also the temperatures were measured experimentally and compared to the theoretical data as shown in Table 2.

Table 2: Theoretical and experimental temperature of materials

Material	Theoretical maximum temperature (^oC)	Experimental maximum temperature (^oC)
Sand	102.3	97.5
Stone pebbles	96.2	94.7
Iron grits	106.1	103.8
Steel balls	107.6	104.6
Sun flower oil	120.4	116
Coconut oil	100.1	98
Olive oil	107.3	104

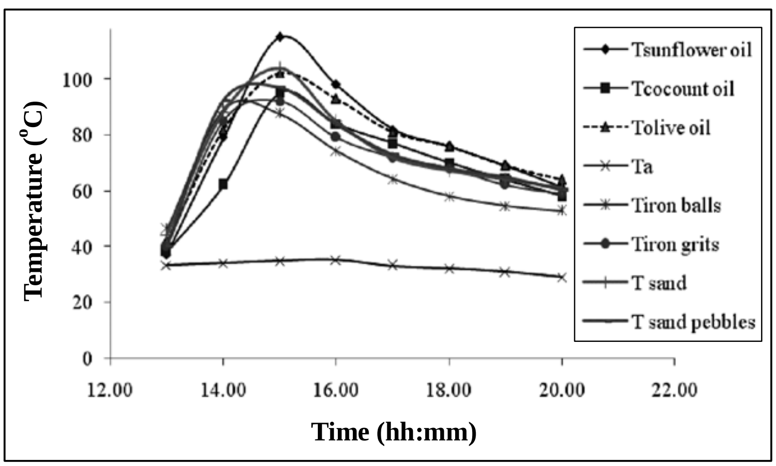

Fig. 2: Temperature variation of SHS materials

The experiment was conducted with inner space filled with SHS materials in February 2016. During the day, the maximum intensity was 850 W/m^2 at 13 hr and the ambient temperature was in the range of 32°C to 35°C. The maximum temperatures of sand were 83.5°C and 104°C, respectively. Fig. 2 shows that the different sensible storage materials were charged continuously till 16:00 hr and afterwards they started discharging the stored energy. Fig. 3 illustrates the energy stored during the stipulated time periods. The energy stored in the form of sensible heat in the selective vegetable oils was experimentally investigated and the sunflower oil was found with 1015 kJ when compared to coconut and olive oils. During the first week of February 2016, the experiments were conducted with inner space filled with stone pebbles, iron balls, iron grits, sand and bubbles. Stone pebbles temperature rises reaching to their maximum value of 97°C. Maximum solar intensity was 877 W/m^2 at 13 hr and the ambient temperature lies in the range of 27 to 32°C. The maximum temperature attained by iron grits was 89.1°C.

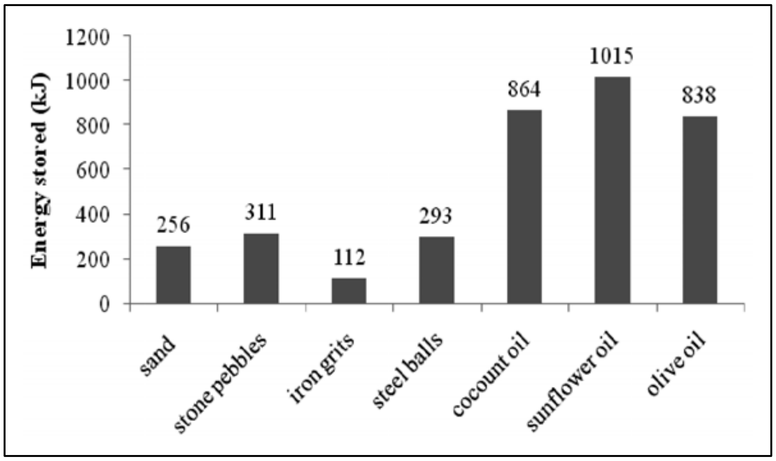

Fig. 3: Energy stored in sensible storage materials

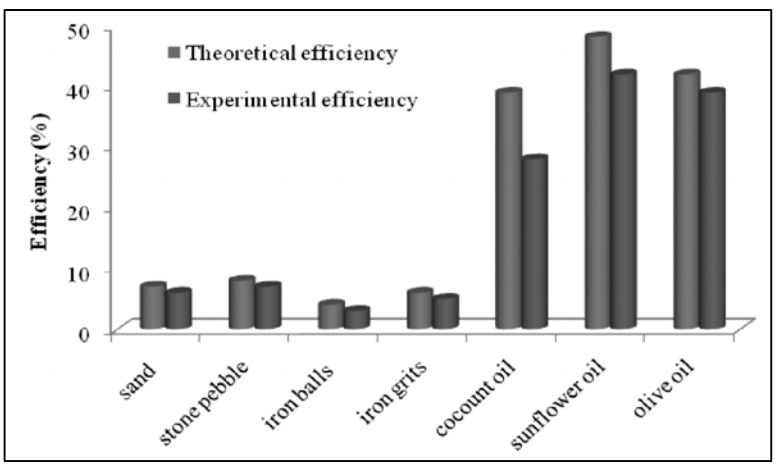

Fig. 4: Efficiencies of SHS materials

The experiments were conducted with inner space filled with sunflower oil, coconut oil and olive oil during the second week of February 2016. The maximum solar intensity was 845 W/m^2 at 13:00 hr. The maximum temperature attained by sunflower oil, coconut oil and olive oil were 115°C, 96°C, and 104°C, respectively. Fig. 4 shows the efficiencies of different SHS materials. It shows stone pebbles having higher efficiency because of its higher specific heat among the other solid SHS materials and is around 8%, where as sunflower oil having the better performance due to its high density and high specific heat compared to other oils. The SHS is heavier than the PCM based storage; however the quicker responses with better heat transfer is during the day time while cooking at a faster rate during the forenoon session. During the afternoon session, the SHS materials in the cooking vessel were found useful in providing heat for a shorter duration after the lean solar time and evening.

CONCLUSION

The SHS materials were found effective in the storage of heat as well as aiding conduction heat transfer during the cooking process. The SHS provides uniform heat supply to the inner cooking vessel and around 300 kJ and 900 kJ with solid and liquid SHS materials respectively to the cooked foods to keep warm for the later periods also. The near spherical shaped solid materials provide better conduction heat transfer. The effective design and combination of thermal conductivity enhancing materials like fins, cubes and metal meshes will enhance the thermal performance to do late evening cooking in the SHS based PDSC.

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