Performance Analysis Of Solar Energy Storage Unit For Cooking

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Abstract. Energy requirement for cooking is about 1/3rd of primary energy consumption. The paper deals about design and testing of a solar cooker for both day and night cooking. The amount of energy required to cook a particular quantity of food has been determined using LPG as fuel. Then the experiment was conducted using solar energy to determine the peak temperature attained. A cooker with an energy storage unit has been designed according to energy requirement calculations. In the present scenario of energy crisis, this cooker can efficiently meet the energy requirements of both day and night cooking. Night cooking can be successfully achieved by using a phase change material based solar cooker with proper insulation.

Keywords: Solar cooker, Phase change material, Green energy

NOMENCLATURE

h_f - Latent heat of fusion, kJ/Kg
MP - Melting point, ^{0}C
T - Temperature, ^{0}C
t - Time, min
ρ - Density, Kg/m^3

1. Introduction

Energy requirements for cooking account for 36% [1] of total primary energy in India. The most widely used commercial fuel LPG is a non-renewable source of energy. India is consuming 9.9 million tons of LPG per year [2]. A large amount of this has to be imported from other countries. If the current trend of exploitation of LPG continues, it will exhaust in the near future.

Wood and other biomass are major fuels for cooking and burning carried out in rural areas and to some extent in urban areas. Cooking in over 90% of rural, half of semi-urban and a fifth of urban homes is generally done in smoky [3], soot-filled and often dark kitchens in simple stoves that burn fuel-wood incompletely and inefficiently, causing a lot of smoke to be produced that spreads into the kitchen. Constant inhalation of smoke brings about various diseases like chronic eye disorder, lung cancer etc.

Such a high dependence on fuel-wood as the main energy source for cooking (200 Mt/yr in India) has often been considered as a threat to the green cover [3]. This demand is expected to always be on the increase, threatening to create a rapid loss of tree cover.

Solar cookers give solution for all these problems. There are various reasons for selecting solar energy as fuel. It is clean, renewable, eco-friendly, available in abundance and is free of cost. But at present, there are limited users of solar cookers as there exists a phase difference between supply and demand of energy. In addition to this, the other major disadvantages associated with conventional solar cookers are heat loss during the cooking process, in sufficient temperature level and fluctuation in solar radiation intensity.

These problems would be addressed by designing a solar cooker with energy storage facility. One way of storing solar energy is by using Phase Change Material with appropriate melting point and latent heat. A PCM is a substance which is capable of storing and releasing large quantity of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa.

Thus an attempt has been made to design a PCM based solar cooker which can be used for both day and evening cooking with proper insulation by which continuous cooking can be achieved.

2. Literature Review

It is observed that, concentrating collectors are widely used for attaining high temperature in short duration. Significant number of papers on different types of solar cookers with collectors has been published. A study on parabolic commercially available solar cookers reveals that a reflectors designed as a segment of paraboloid shape (Figure 1) attains temperature up to 120 ^{0}C within 1 hr. The shape of the reflectors appears like wings of a butterfly, hence it is popularly known as “butterfly” type solar cooker. The focal point of the reflector lies above the reflector.

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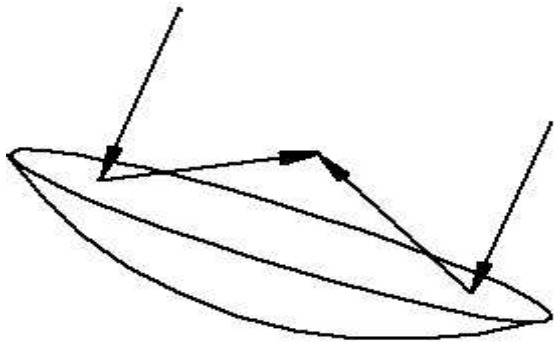

Figure 1. Profile of Paraboloid Collector [4]

As mentioned earlier the major problems associated with solar cooking are variation in solar radiation intensity and non availability during evening. A cooker coupled with PCM can address these problems.

Budhhi et.al. [5] have developed a PCM storage unit for a solar cooker to store energy during sunshine hours. The stored energy was utilized to cook food in the late evening. Commercial grade acetanilide (melting point 118.9^0C, latent heat of fusion 222 kJ/kg) was used as a latent heat storage material. Evening cooking experiments were conducted with different loads and loading times during the winter season. The experimental results showed that late evening cooking is possible in a solar cooker having three reflectors to enhance the incident solar radiation with the PCM storage unit.

Studies done by Atul Sharma et.al. [1] give an idea about the available thermal energy storage technology for solar cookers. With the storage unit, food can be cooked at late evening, while late evening cooking was not possible with a normal solar cooker. So that, solar cooker with energy storage unit is very beneficial for consumers and as well as for the energy conservation. This study presents the past and current research in this particular field of energy storage for solar cookers

Studies have been carried out using many materials as potential PCMs, but only a few of them are commercialized. Table 1 presents different chemicals (inorganic, organic and fatty acids), that have been studied by different researchers for their potential use as PCMs.

Table 1- Properties of different PCMs (6)

PCM	MP (0C)	hf (kJ/Kg)	ρ (kg/m3)
Paraffin wax	64	173.6	790
Polyglycol	66	190	1085
Biphenyl	71	119.2	931
Naphthalene	80	147.7	991
Oxalic acid	95	370	976

Table 1 show that, oxalic acid has the melting point in the range of the peak temperature attained by the concentrating collectors under consideration. Further, the heat of fusion is also higher when compared to other PCM's.

Based on the literature studies and considering the commercial availability of chemical and its properties oxalic acid was used as PCM in the current study.

3. Design of PCM based energy storage unit

Several experiments have been conducted in order to know the energy requirement to cook particular quantity of food for a typical house hold of 5 persons. Based on the results obtained, one parabolic and one butter fly type solar reflector were selected for testing.

Initially, a performance study on parabolic solar reflector with black painted conventional cooker was carried out for both insulated and non insulated conditions during rice cooking. Similar experiment was repeated by using butterfly type collector. Since butterfly type collectors found to be more effective than parabolic collectors, it is used for the further experiments.

After conducting these experiments PCM based storage unit was designed. Butterfly type collector is used to concentrate the solar radiation. At the focal point, a cooking vessel which is made of two concentric cylinders is placed. The annular space is filled with oxalic acid which is a phase change material. The stuff to be cooked is filled in a vessel and is placed inside the inner cylinder. The dimensions of the cooking vessel were selected based on the energy storage requirements and the latent heat value of Oxalic acid. Figure 2 shows sectional view of PCM storage unit with cooking vessel. The unit consist of a stain less steel vessel with an annular space to fill the PCM. The cooking vessel would be kept inside the inner space filled with water. Temperatures of PCM and inner vessel water or food item are measured using thermometers.

After the fabrication of PCM storage unit, initially experiments were conducted before filling oxalic acid into the unit. Water heating and rice cooking experiments were conducted in the unit using butterfly cookers. It was found that the air inside the annular space between the two cylinders acts as a thermal barrier and helps in retaining the heat inside the vessel.

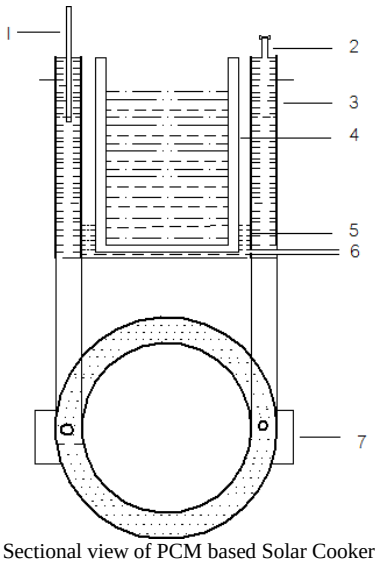

Figure 1 Sectional view of PCM based Solar Cooker

1 - Thermometer,
2 - Valve to fill PCM,
3 - Annular space to fill PCM,
4 - Vessel to fill stuff to be cooked,
5 - PCM,
6 - Pipe to drain out water,
7 - Handle.

Plate 1 shows experimental set up for rice cooking using butterfly type solar collector with PCM based storage unit.

4. Results and discussion

To begin with, experiments were carried out to know the effect of insulation provided on the outer surface of the cooker vessel. Then, the experiments were

Plate 1. Rice cooking using Butterfly type Solar Collector

conducted to study the use of PCM with water as the fluid medium. Further, rice cooking experiments were conducted to find out the time required for cooking using PCM. Since there is no significant change in intensity of solar radiation during a period of experiments, the data obtained on different days were used for comparison

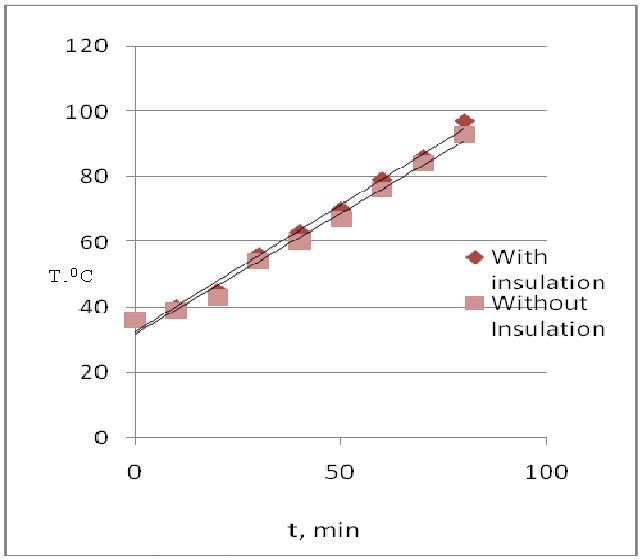

Figure 3 Plot of T v/s t for water heating with and without insulation, without PCM

Figure.3 shows the plot of T v/s t for water heating with and without insulation, with PCM condition. Peak temperatures attained during "with insulation" condition is 97^0C and during "without insulation" condition is 93^0C.

When water was heated using butterfly type solar collector inside the PCM based solar cooker, the peak temperatures attained during heating were found to be 99^0C and 100^0C under without and with insulation condition respectively. The unit was brought under shade and was allowed to cool. Figure 4 shows the plot of water cooling under with and without insulation, with PCM condition. After 90 minutes the temperatures attained were 79^0C and 76^0C under with and without insulation condition respectively.

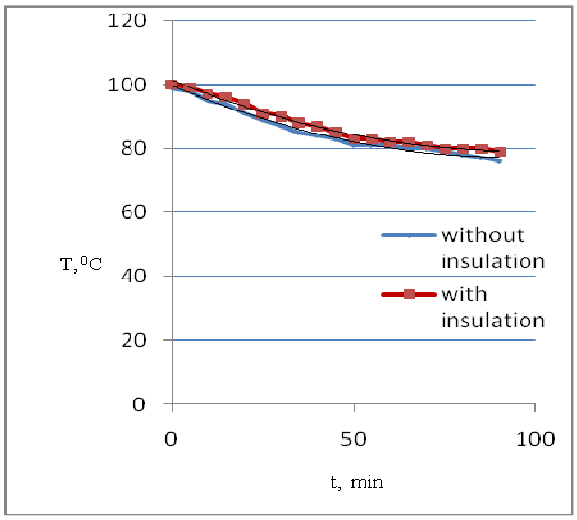

Figure 4 Plot of T v/s t for Water cooling, Without and With Insulation, With PCM

Further, rice cooking experiment was done by using the heat stored in the liquid PCM i.e, by using the latent heat of solidification of PCM. Cooking of rice was done during daytime only. The rice was found to be cooked in 3hr. It was found that the PCM could hold the energy around a temperature of 65^0C for 90 minutes.With proper insulation, PCM can retain the heat for longer duration and night cooking can be successfully achieved.

5. Conclusion

The air column inside the annular space of PCM unit acts as a thermal barrier between food inside the cooker and outside environment. This is one of the major advantages of PCM based solar cooker.

Night cooking experiments were conducted using the fabricated PCM based storage unit. With the heat rejected by the PCM, cooking was successfully achieved. But the PCM was able to hold heat only for 3 hr at a temperature of 65^0C. If proper insulation is provided, the PCM can hold the heat till night.

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