PERFORMANCE EVALUATION OF HEAT STORAGE SYSTEM FOR PARABOLIC DISH TYPE SOLAR COOKER

[1]Harshal Patil, [2]Dr. Nishikant Kale
Phd Scholar, Mechanical Engineering, Prof. Ram Meghe Institute of Technology and Reseach, Badnera[1],
Professor, Mechanical Engineering, Prof. Ram Meghe Institute of Technology and Reseach, Badnera[2]
hdpatil1986@gmail.com[1], nwkale@gmail.com[2]

ABSTRACT

Cooking with the sun has become a potentially best solution for fuel-wood in food preparation in much of the developing world. Energy requirements for cooking account for 36% of total primary energy consumption in India. The rural and urban population, depend mainly, on non-commercial fuels to meet their energy needs. But, Solar cooking acceptance has been limited partially due to some barriers. Solar cooker cannot cook the food in late evening. This drawback can be overcome by providing a heat storage unit for a solar cooker. So that food can be cooked in the absence of the sunlight.

In this paper, an attempt has been made to analyze the performance of heat storage system designed for parabolic dish type solar cooker. A comparison of performance of two heat storage fluids; Thermic fluid Hytherm 600 and phase change material, high density polyethylene (HDPE) is made.

1. INTRODUCTION

India is blessed with good sunshine. Most parts of the country receive mean daily solar radiation in the range of 5–7 kWh/m^2, and have more than 275 sunny days in a year [1]. Solar cooking has been part of India's National Program since 1982. Parabolic and box-type solar cooker are low cost options for meeting the cooking energy needs as well as environmental protection. Even though over 600,000 box-type solar cookers have been sold so far in India and the large potential of solar cookers is yet untapped [2]. Hence, solar cooking has a high potential of diffusion in the country, and offers a viable option in the domestic sector. It is identified as an appropriate technology for Indian masses, and has numerous advantages such as no recurring costs, potential to reduce drudgery, high nutritional value of food, high durability, etc. In spite of these advantages, the main hurdles in its dissemination are reluctance to acceptance as it is a novel technology, intermittent nature of sunshine, limited space availability in urban areas, higher initial costs and convenience issues. The growing urban lifestyle also warrants faster cooking which is not possible in box solar cookers [3,4]. Solar energy is free, environmentally clean, and therefore is recognized as one of the most promising alternative energy recourses options. In near future, the large-scale introduction of solar energy systems, directly converting solar radiation into heat, can be looked forward to. However, solar energy is intermittent by its nature; there is no sun at night. Its total available value is seasonal and is dependent on the meteorological conditions of the location. Unreliability is the biggest retarding factor for extensive solar energy utilization. Of course, reliability of solar energy can be increased by storing its portion when it is in excess of the load and using the stored energy whenever needed. Energy storage is, therefore, essential to any system that depends largely on solar energy. It adjusts temporal mismatches between the load and the intermittent or variable energy source, thereby improving the system operability and utility. Solar radiation cannot be stored as such, so first of all an energy conversion has to be brought about and, depending on this conversion, a storage device is needed. Solar energy can be stored by thermal, electrical, chemical, and mechanical methods.[5]

The use of phase change materials (PCMs) for storing the heat in the form of latent heat has been recognized as one of the areas to provide a compact and efficient storage system due to their high storage density and constant operating temperature [6,7]. Theoretical and experimental efforts have been made to use these materials in solar collectors, solar air heaters, buildings and space craft thermal control [7-14]. Many researchers have been performed the work in the field of solar cookers with latent heat storage, to our knowledge.[18] The objective of the present experimental study is to demonstrate the feasibility of using a PCM and heat storage fluid in a solar cooker as the storage medium to cook and/or to keep food warm in the late evening. In this paper, a heat storage system has been experimentally tested, and the results have been discussed.

HEAT STORAGE SYSTEM

The existing heat storage system is designed for parabolic dish type solar cooker as shown in figure 1. In this solar cooker, surface focused is found and the available space for pot holder is about 250 mm diameter as shown in fig. 2. Therefore, the maximum dimensions of heat storage unit are 250 mm in diameter and 300 mm in height. The storage fluid capacity of this heat storage unit is 10 litres.[15]

Fig. 1 Parabolic dish type solar cooker [15]

Figure 2 - Platform for cooking pot on solar cooker.[15]

2. DESIGN OF EXPERIMENT

Experimentation is performed with two variables i.e. Heat storage material and time at which steam has generated. Both above variables are varied at different levels for better output.

Following are the levels of Process parameters

1. Time at which heat steam has generated - after 4 Hrs, after 6 Hrs and after 12 Hrs.

2. Heat storage material- Thermic fluid Hytherm 600 Oil and High density polyethylene HDPE (PCM) [16,17]

During Experimentation, following parameters are kept constant for analysing the performance of heat exchanger.

1. Initial temperature of heat storage fluid : 200^0 C
2. Initial temperature of water : 30^0 C
3. Surrounding Air Temperature : 30^0 C
4. Mass flow rate of water: 250 ml per minute.

In this work, following parameters are monitored for optimum output:

1. Drop in temperature of heat storage fluid with time
2. Time duration for which steam is generated
3. Temperature of steam during generation
4. Drop in temperature of heat storage fluid during steam generation
5. Drop in temperature of heat storage fluid with time after the steam generation
6. Temperature of hot water with respect to time after the steam generation.

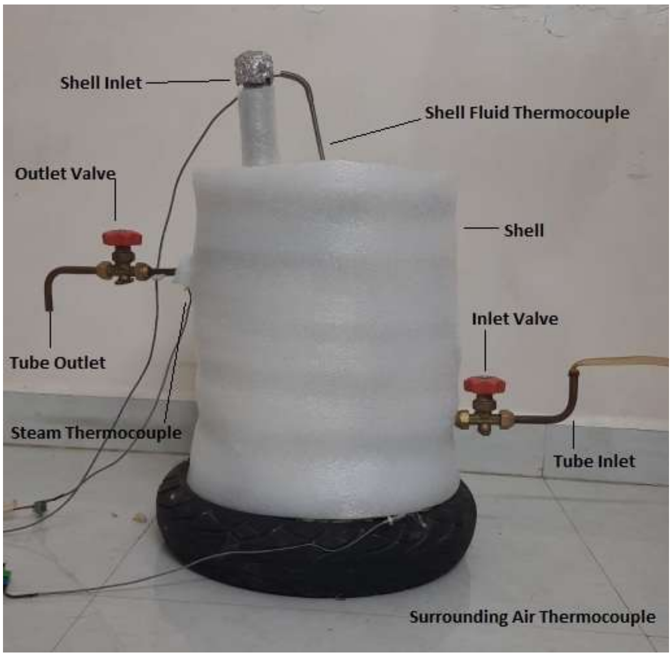
Table 1- Experimentation Table

Experiment No.	Heat Storage Material	Steam generation test
1	Hytherm 600, Quantity 8.8 kg	After 4 hrs
2	Hytherm 600,Quantity 8.8 kg	After 6 hrs
3	Hytherm 600,Quantity 8.8 kg	After 12 hrs
4	HDPE, Quantity 9.7 kg	After 4 hrs
5	HDPE, Quantity 9.7 kg	After 6 hrs
6	HDPE, Quantity 9.7kg	After 12 hrs

3. Experimentation Setup

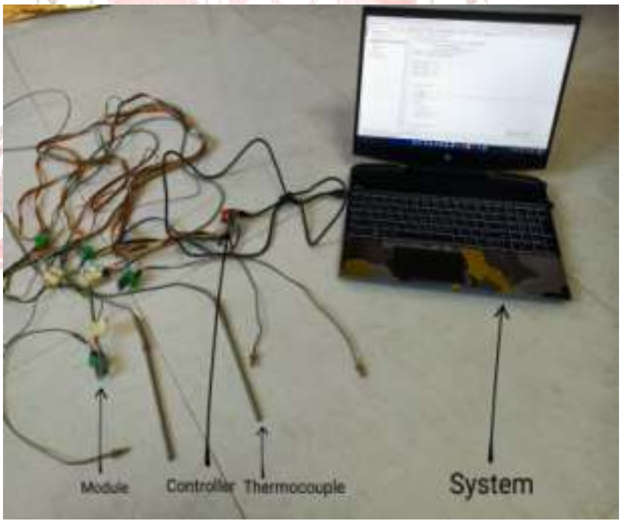
As per above discussion, experiment is conducted as per decide parameters and their levels as mentioned above. The experimental layout is shown in Table 1 for selected parameters.

Figure 1- Experiment Setup [15]



Temperature data logger has used to measure thermocouple reading. Mass flow rate of water was adjusted using a flow control valve.

Figure 2- Temperature data Logger System



4. Observations and Result

First set of experimentations was carried out with Hytherm 600 oil and Second set of experimentations was carried out with HDPE as heat storage fluid and various parameters were observed at different levels.

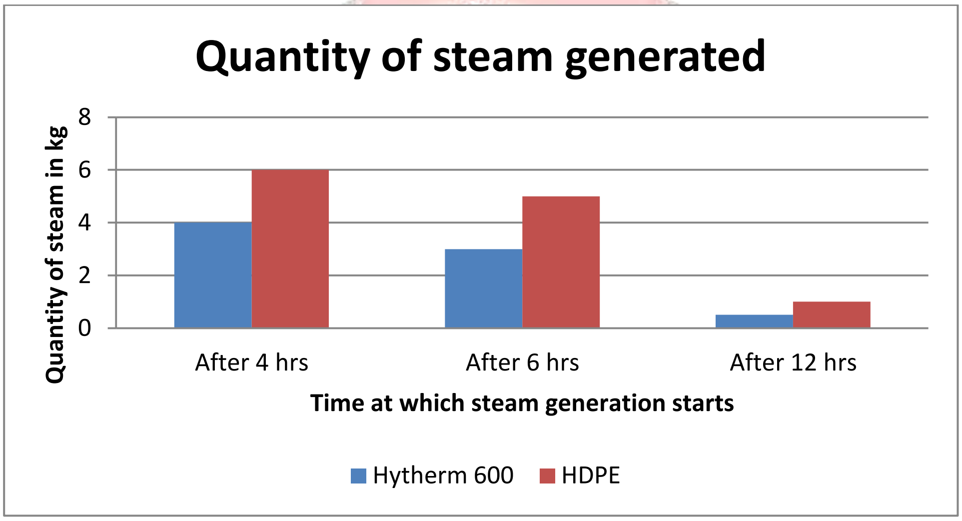
Steam Generation

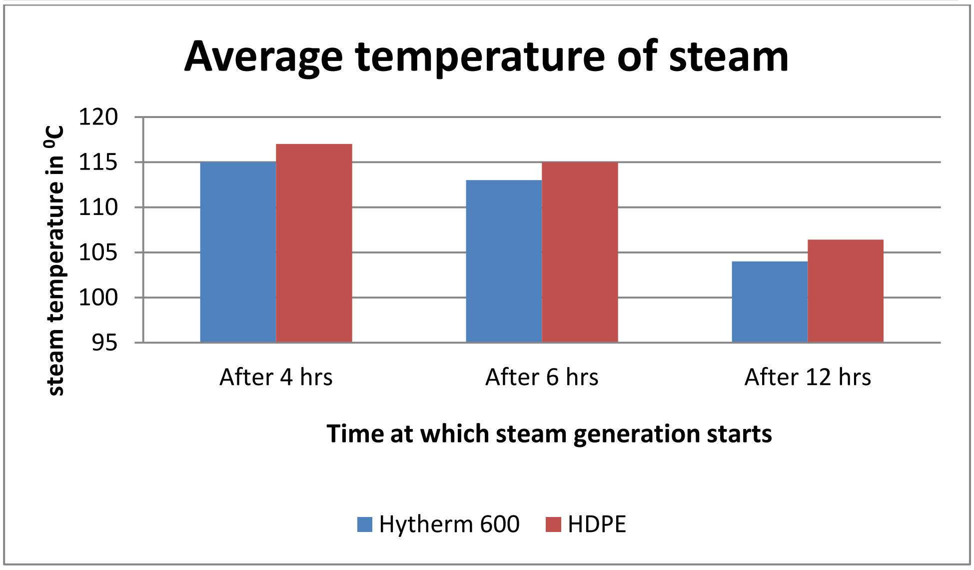
In this research work, heat storage system is analyzed for three different times, so as to know the quantity of steam generated after the sunshine hours. And for the same experimentations are conducted.

Table 2 – Steam generation for Hytherm 600 and HDPE

	Hytherm 600 oil at 200 ^{0}C			High density polyethylene HDPE at 200 ^{0}C		
	Expt. 1	Expt. 2	Expt. 3	Expt. 4	Expt. 5	Expt. 6
	After 4 hrs	After 6 hrs	After 12 hrs	After 4 hrs	After 6 hrs	After 12 hrs
temperature of HTF before steam generation (^{0}C)	180	170	123	180	168	132
temperature of HTF after steam generation (^{0}C)	130	133	110	132	130	110
Quantity of steam generated, kg	4	3	0.5	6	5	1
Avg. temperature of steam produced (^{0}C)	115	113	104	117	115	106.4

It is found that, 8.8 kg of Hytherm 600 oil produced 4 kg of steam after 4hrs of heat storage, 3 kg of steam after 6 hrs of heat storage and 0.5 kg of steam after 12 hrs of heat storage. On the other hand 9.7 kg of HDPE produced 6 kg of steam after 4hrs of heat storage, 5 kg of steam after 6 hrs of heat storage and 1 kg of steam after 12 hrs of heat storage.



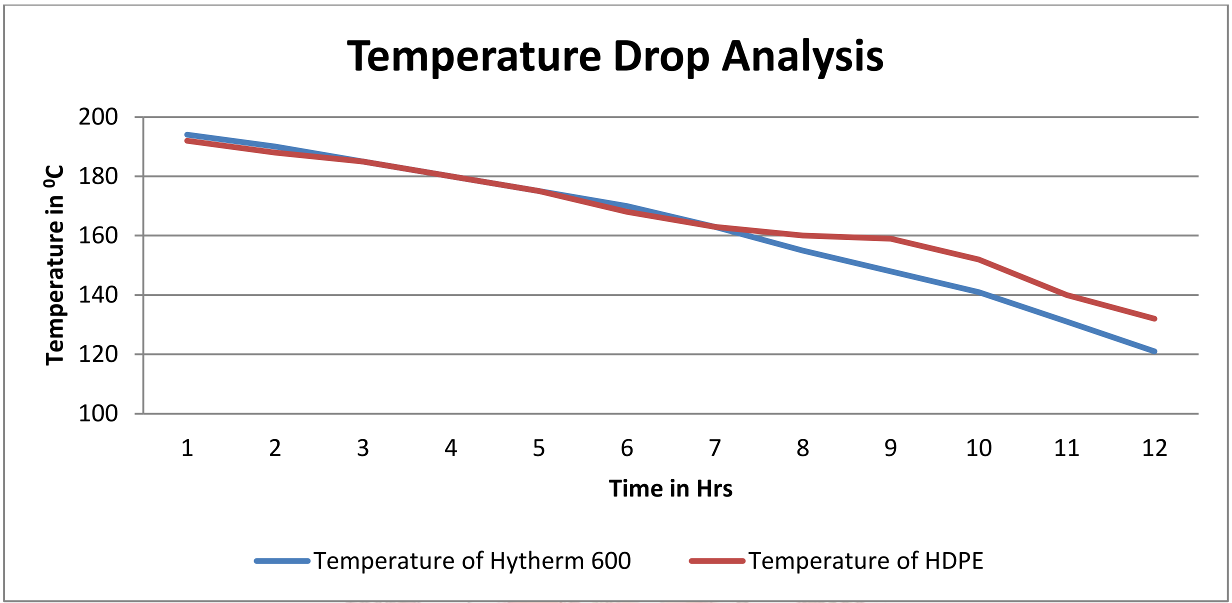


It is analyzed that, Hytherm 600 oil produced steam having 115 ^{0}C temperatures after 4hrs of heat storage, 113 ^{0}C steams after 6 hrs of heat storage and 104 ^{0}C temperature of steam after 12 hrs of heat storage. On the other hand HDPE produced steam of 117 ^{0}C after 4hrs of heat storage, 116 ^{0}C temperature steams after 6 hrs of heat storage and 106.4 ^{0}C temperature of steam after 12 hrs of heat storage.

It is found that average temperature of steam is 2 ^{0}C more in every experiment of HDPE as compared to Hytherm 600 oil at same time.

Temperature drop analysis for Heat Storage System

Temperature drop analysis for heat storage material is carried out. Initially, Heat transfer fluid stored the heat at 200^{0}C and observed the temperature drop with regular interval.



For Hytherm 600 oil, it wase found that, in initial 6 hrs nature of the curve was flat as compared to next 6 hrs., The total temperature drop for Hytherm 600 oil has found to be 79 ^{0}C in 12 hrs time period. It was found that, during 8th and 9th hour temperature of HDPE remains constant due to latent heat was dissipated from the heat storage system. Total temperature drop for HDPE has found to be 68 ^{0}C in 12 hrs time period.

It is found that drop in temperature of heat storage fluid is around 40 % for Hytherm 600 and around 34 % for HDPE.

Heat stored in heat storage system

When Hytherm 600 oil was used in the storage system, after every steam generation experiments, the amount of useful heat was stored in the storage system. After the 4 hrs experiment, 1938.15 kJ heat was available which is used for water heating purpose. And after 6 hrs and 12 hrs steam generation trial, 1996.29 kJ and 1550.52 kJ stored heat was available in the storage system respectively.

Table 3 - Heat stored in heat storage system

	Hytherm 600 oil			High density polyethylene HDPE		
	Expt. 1	Expt. 2	Expt. 3	Expt. 4	Expt. 5	Expt. 6
	After 4 hrs	After 6 hrs	After 12 hrs	After 4 hrs	After 6 hrs	After 12 hrs
Heat stored in shell fluid before steam generation (kJ)	2907.22	2713.41	1802.47	4859.7	4591.98	1879.86

Heat used in steam generation (kJ)	969.07	717.11	251.55	2979.64	2688.98	405.46
heat stored in shell fluid after steam generation (kJ)	1938.15	1996.29	1550.52	1880.06	1903	1474.4

When high density polyethylene (HDPE) was used in the storage system, after every steam generation experiments, the amount of useful heat was stored in the storage system. After the 4 hrs experiment, 1880.06 kJ heat was available which is used for water heating purpose. And after 6 hrs and 12 hrs steam generation trial, 1903 kJ and 1474.4 kJ useful heats were stored in the storage system respectively.[29]

Hot water after steam generation

In the kitchen, hot water also pays an important role in various cooking activity. It is most needed initial material for many processes during cooking. So, in this work, water circulated in tube was analyzed after each steam generation trial. For this, water temperature at the outlet of the tube was observed for next 40 min.

Table 4- Hot water analysis after steam generation

	Hytherm 600 oil			High density polyethylene HDPE		
	Expt. 1	Expt. 2	Expt. 3	Expt. 4	Expt. 5	Expt. 6
	After 4 hrs	After 6 hrs	After 12 hrs	After 4 hrs	After 6 hrs	After 12 hrs
Time at which hot water available (after how many hrs of heat storage)	4 hr 16 min	6 hr 12 min	12 hr 5 min	4 hr 24 min	6 hr 20 min	12 hr 10 min
Average temperature of hot water (^{0}C)	62	63	65	63	62	64
Mass flow rate of hot water (ml/min)	250	250	100	250	250	100

In case of Hytherm 600 oil, after 4 hrs steam generation trial, proposed heat storage system given a hot water of 62 ^{0}C average temperatures at the rate of 250 ml per min for 40 min. And in the trial after 6 hrs, system generates the hot water of 63 ^{0}C average temperatures at the same rate. Also, the heat storage system achieved the hot water of 65 ^{0}C average temperatures at the rate of 100 ml per min for 40 min after the 12 hrs steam generation experiment.

Similar experiment was conducted for High density polyethylene (HDPE), IN this case, after 4 hrs steam generation trial, proposed heat storage system given a hot water of 63 ^{0}C average temperatures at the rate of 250 ml per min for 40 min. And in the trial after 6 hrs, system generates the hot water of 62 ^{0}C average temperatures at the same rate. Also, the heat storage system achieved the hot water of 64 ^{0}C average temperatures at the rate of 100 ml per min for 40 min after the 12 hrs steam generation experiment.

CONCLUSION

Cooking energy plays an important role in sustainable energy management in Indian households. The use of solar energy is the best solution to meet the energy need for cooking. With the storage unit, food can be cooked even during night hours when sunlight is not available.

The performance of energy storage unit was analyzed by conducting experiments with two type of heat storing material; Hytherm 600 oil and high density polyethylene (HDPE). It was observed that, temperature drop for oil and HDPE was 6.5 ^{0}C and 5.6 ^{0}C per hour respectively.

The present study showed that, Performance of heat storage unit is better with the phase change material, HDPE as heat storage material as compared to Hytherm 600. The heat content in the system was around 67 % higher with HDPE as heat storage material. Correspondingly, the amount of steam generated at various intervals of time was found 50 % higher in case of HDPE.

It can be further concluded that even after enough steam is extracted from the system, the heat storage unit possesses sufficient potential to produce hot water at the temperature of around 63 ^{0}C, for both the fluids.

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