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"Experiment Analysis of Box Type Solar Cooker with and without Thermal Energy Storage Medium"

Anand Mohan[1], Amit Agrawal[2]
[1]M. Tech Scholar, [2]Assistant Prof., Department of Mechanical Engineering, Shri Ram college of Engineering & Management Banmore Gwalior, Madhya Pradesh 476444, India

***Abstract:** Energy plays a vital role for cooking purpose. This study is focused on the performance analysis of box type solar cooker at the climate conditions of Gwalior. Thermal energy storage materials provide better temperature and reducing cooking time as compared to without TES. In this thesis, two different types of TES material are used i.e. water and sand and the performance of solar cooker with TES and without TES are compared, the maxi mum temperature is attained by the solar cooker without TES was found 90.6°C when solar radiation was 1075 w/m^2 while using sand and water as TES the maximum temperature was found 81.3°C and 69.4°C respectively when solar radiation was found very low 496 w/m^2 and 365 w/m^2 .It seems that where radiation is low and off-sunshine, TES material is used for attaining maximum temperature. The sand gains the temperature faster than the water but it needs to be moisture free. The advantage of using water is that even though there occurs a sudden fall in solar radiation, the water temperature remains the same for a long duration, which is not possible in case of cooker without thermal energy storage.*

***Keywords:** Thermal energy storage (TES), conventional box cooker, solar cookers, phase change materials (PCMs), solar technology, black powder coated stainless steel.*

I. INTRODUCTION

Cooking is a heat treatment process of raw food, and depending on the temperature requirement, method of heating, and duration, cooking may be categorized as baking, roasting, boiling, blanching, etc. Besides, household cooking, it is performed in an institutional and community kitchen. This has given an opportunity for solar cooking to prove environmentally and economically beneficial. Various studies have shown that solar cooking and heating contributes to carbon mitigation [1,2]. Solar cooking is a part of India's energy expansion program in the energy security area. Energy consumption for cooking accounts for 36% of the total energy demand in India. The use of solar energy will reduce the burden on LPG and fossil fuel consumed. The main obstacle in the acceptance of solar energy is a convenience issue and high initial cost of solar cookers. The development in concentrated solar technology could overcome the limitations of the conventional box cooker [3]. Concentrated solar power has offered many benefits in large-sized kitchens where people take their meals. Steam at high temperature and pressure produced using the solar concentrators transferred to the kitchen for food cooking. Concentrated solar energy has proven the best clean and economical energy source for cooking; its use can be expanded to post-harvesting agricultural produce such as turmeric cooking/blanching [4].

II. RESEARCH GAPS IN SOLAR COOKERS WITH THERMAL ENERGY STORAGE

1) There have been limited research studies on solar cookers with TES systems using heat transfer oils. Heat transfer oils are particularly favorable since temperatures above the boiling point of water (100°C) can be achieved which are suitable for frying and baking. Besides this, storage tanks using oil are simplified since they do not have to be pressurized as with the case of water which is cheaper and readily available [5].
2) The use of locally available TES materials in a particular region or country for enhancing the performance of solar cookers is rather limited [6].
3) Packed bed storage systems using oil heat transfer fluids for domestic cooking applications have been rarely reported in recent literature. The packed bed storage configuration has better heat transfer characteristics than other types of configurations such as the shell and tube especially when latent heat thermal energy storage systems are considered [7].

4) Storage type of cooking vessels has been rarely reported. These vessels can store heat during periods of high solar radiation, and use it during non-sunshine periods.
5) Hybrid solar cooking and TES storage systems using another energy source have been rarely reported. These systems are more practical especially when there are extended periods of low solar radiations. The alternative energy source can be used for cooking [8].
6) TES applications of metallic phase change materials (PCMs) for higher volumetric storage densities and higher thermal conductivities that have appeared in recent literature are rather limited [10].

The box type solar cooker of dimensions 600mm × 600mm × 200mm facing south is used as shown in the Figure 3.1. The box is fitted with a 2cm thermocol sheet and a 2cm thermocol sheet. The absorber tray is made aluminum sheet of 0.5mm thickness, which is a black powder coated. Similarly, cooking utensils are made of black powder coated stainless steel. It consists of one reflector mirror and two transparent glasses. The experiment is performed in the summer at the terrace of Madhav Institute of Technology & Science, Gwalior. The setup is shown in Figure 1.

Figure 1 Solar cooker setup without TES

Cooking capacity is about 1 kg at a time or 3-4 kg per day depending on the intensity of the radiation. The absorption tray material should have high absorption and low ventilation, to help block radiation inside the solar cell [10]. The dark cover of the absorber plate and the cooking vessel enhances absorption of the solar radiation by a type of solar cooker. The solar cooker cover is made using double-glazed glass, with long beams, and is exposed to high energy, short rays of the sun. The anchor is provided so that the display is properly positioned to allow for real tracking. The parallel rays from the coming from the sun are reflected by the reflector mirror towards the absorber plate via plane mirrors as shown in the Figure.2. The absorber plate is pain ted with black paint to absorb the heat energy to an optimum capacity.

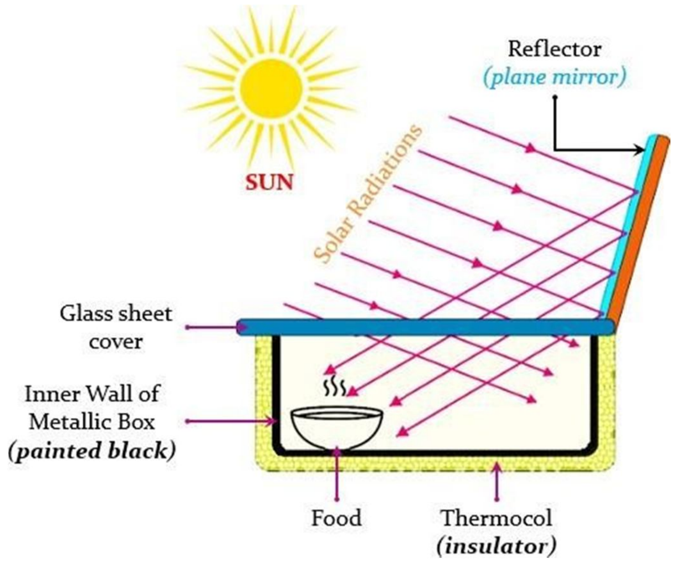

Figure 2 Box Type Solar Cooker

III. INSTRUMENTS USED

A. Solarimeter

A solarimeter is device used to measure solar radiations, a type of measuring device used to measure direct and indirect solar radiation. An integrated solarimeter measures the energy developed in solar radiation based on absorption of heat by a black person. Solarimeter used in thisexperiment is shown in Figure 3.

Figure 3 Solarimeter

B. Thermocouple

Thermocouple is a temperature measuring sensor. Thermocouples are connected to digital displays, which show the temperature reading directly. . The thermometer used in the experiment is shown in the Figure 4. Thermocouples are selected because of their wide temperature ranges, low cost, high-temperature limits, and their durability nature.

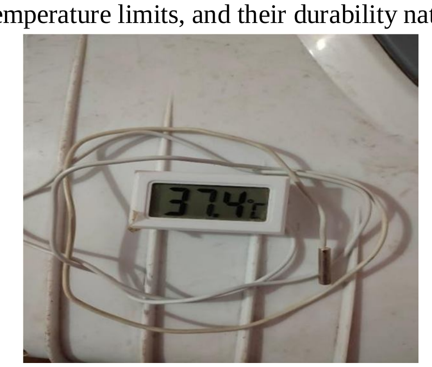

Figure 4 Thermometer

The type of solar cooking box used for experimental analysis is displayed. The solar cooker is made of UV-resistant UV glass. The performance evaluation of a solar cooker's box, the temperature of the suction plate, the temperature of the water in the cooking vessel, and the high and low gloss temperatures need to be measured. To measure the temperature at these points, a thermocouple of the appropriate diameter is installed. Five numbers of thermocouple are necessary for experiment. One thermocouple is inserted in the cooking vessel through a small opening, to measure the food temperature. Two thermocouples are attached to inner and outer glazing of cooker in order to measure the temperature of inner glazing and outer glazing of solar cooker respectively. To measure the ambient temperature one thermocouple is placed outside thesolar cooker and the remaining one can be used as per the experiment.

IV. EXPERIMENT USING CONVENTIONAL SOLAR COOKER WITHOUT ANY TES

In case of experiment, the temperatures measured are upper glazing temperature, lower glazing temperature, absorber tray temperature, ambient temperature as well as the food temperature, andthe corresponding solar radiation is to be measured using solarimeter.

Table 1 Observation table for temp. at various points of cooker for experimentwithout thermal energy storage medium dated on 25/05/2022

Time (hrs.)	Upper glazing temp. (°c)	Lower glazing temp. (°c)	Food temp. Within Pot (°c)	Absorber plate temp.	Ambient temp. (°c)	Solar radiations (w/m^2)	Wind velocity (m/s)
10:00	41.7	48.9	37.1	57.2	35.6	755	2
11:00	51.1	83.4	77.5	88.8	36.5	945	2.7
12:00	57.6	89.9	90.6	92.7	38.2	1010	1.8
01:00	63.2	95.8	90.6	101.9	42	1075	0.9
02:00	60.5	90.5	90.1	94.6	42	870	1
03:00	52.5	83.6	89.0	85.2	41.9	155	2.36
04:00	48.6	71.6	81.9	72.6	38	121	2.3
05:00	43.0	54.8	62.5	56.3	37.1	183	1.38

The average solar radiation for the whole day was only 639.2 W/m^2.

A. *Experiment Using Sand As Thermal Energy Storage*

During this experiment, the space surrounding the cooking vessel is filled with sand. In this experiment, 4 kg of sand has been used. When compared to the height of cooking vessel, sand level was around three-fourth the height of cooking vessel (as per size of solar cooker and cooking vessel). Solar cooker setup with sand as TES material is shown in Figure 5.

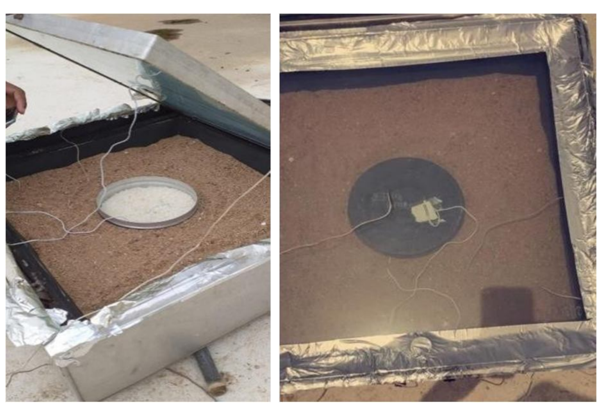

Figure 5 Solar cooker with sand as TES

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Table 2 Observation table for temperature at various points of cooker for experiment using sand as thermal energy storage medium dated on 27/05/2022

B	Upper glazing temp. (°c)	Lower glazing temp. (°c)	Food temp Within Pot (°c)	Sand Temp. (°c)	Ambient temp. (°c)	Solar radiations (w/m^2)	Wind velocity (m/s)
10:00	43.8	56.4	35.9	40.2	36.9	889	1.2
11:00	47.6	68.4	42.3	51.2	37.9	941	2.6
12:00	50.2	74.4	51.4	61.6	38.8	998	1.84
01:00	54.7	81.7	65.5	75.1	40.9	1015	4.2
02:00	53.7	85.4	75.1	82.5	44.1	916	1.9
03:00	54.4	83.6	79.9	84.6	43.9	722	0.8
04:00	51.0	79.1	81.3	82.2	43	496	3.5
05:00	42.0	63.1	76.7	82.2	36.5	53.5	5.8

The average solar radiation for the whole day was only 753.8 W/m^2

B. Experiment using Water as Thermal Energy Storage

During this experiment, the space surrounding the cooking vessel is filled with water upto the lid. in this experiment, 4 liters of water has been used (as per size of solar cooker and cooking vessel). Solar cooker setup with water as TES is shown in Figure 6.

Figure 6 Solar cooker using water as TES

Table 3 Observation table for temp. at various points of cooker for experiment usingwater as thermal energy storage medium dated on 28/06/2022

Time (hrs.)	Upper glazing temp. (°c)	Lower glazing temp. (°c)	Food temp. Within Pot (°c)	Water Temp. (°c)	Ambient temp. (°c)	Solar radiations (w/m^2)	Wind velocity (m/s)
11:00	43.6	48.6	34.4	35.5	39.9	942	4.4
12:00	48.9	63.5	45.2	47.5	42.0	998	4.10
01:00	52.8	69.9	55.6	57.5	43.6	929	1.61
02:00	54.3	73.6	64.0	65.3	44.6	736	0.9
03:00	52.9	73.1	68.2	68.9	43.4	544	1.53
04:00	51.9	70.3	69.4	69.6	43.6	365	1.92
05:00	48.6	65.6	67.7	67.0	41.0	188	2.06

The average solar radiation for the whole day was only 664.6 W/m2

C. Cooked Rice

The Food cooked using a solar cooker is nutritious. Protein retention is 10-20% more as compared to that in conventional cooking .Vitamin retention is also comparatively higher, thiamine vitamin retention is about 20 to 30% more whereas vitamin A is retained 5-10% more when food is cooked in solar cooker. Rice used 200gm with 250ml clean drinking water. The cooked rise is shown in Figure 7.

Figure 7: Rice cooked with solar cooker

Table Cooking Time of Rice with and without TES Materials

S. No.	Without TES	Sand as TES	Water as TES
Cooking Time(Minute)	45	30	35

D. The Comparison Graph of Solar Radiations for the Three Cases Discussed

The average solar radiations for the day1, day2, day3 were 639.2 W/m^2, 753.8 W/m^2 and 664.6 W/m^2 respectively. For the whole experiment average solar radiations was 685.8 W/m^2. It is clearly seen from the graph that the intensity of solar radiations was highest for the day1 at 1:00 PM which is 1075 W/m^2. The graph is shown in Figure 8.

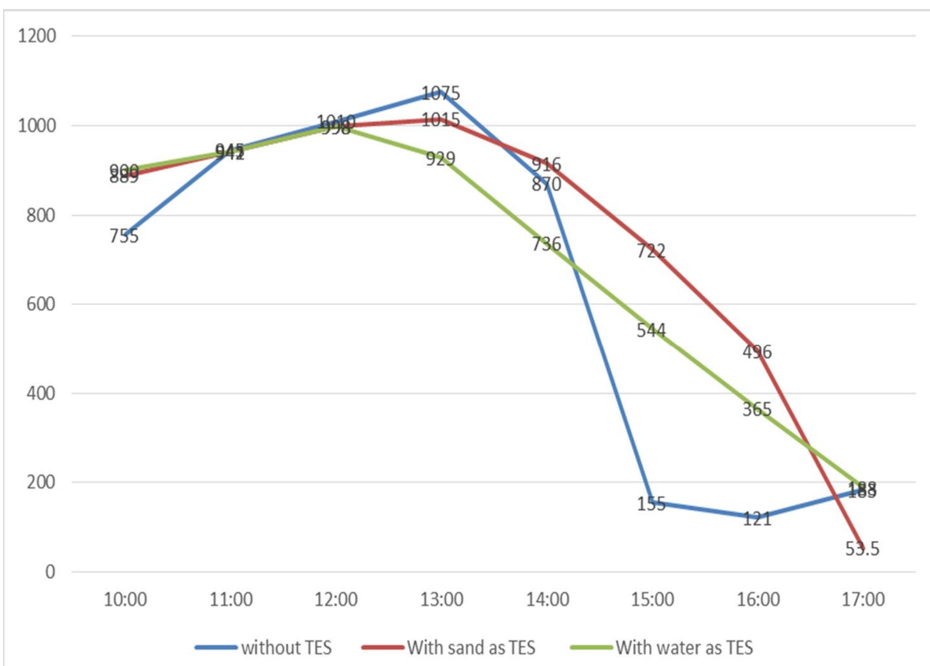

Figure 8 Variation in solar radiations with time for the three cases discussed

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E Variation of Temperature Recorded During the Experiment day for Solar Cooker withoutTES

The graph is representing the temperature at various points of solar cooker in the absence thermal energy storage medium. The highest temperature was attained in the afternoon 1:00 PM and it was 101.9°C. The highest temperature achieved by the food inside the vessel was 90.6°C at 1:00 PM. After that the temperature kept decreasing as shown in the Figure 9.

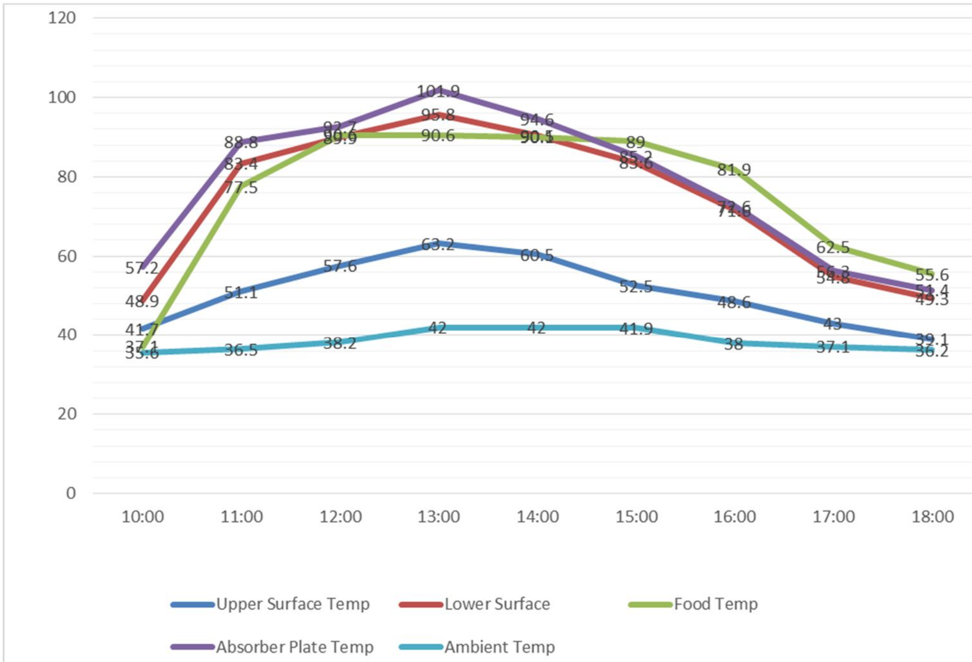

Figure 9 Temperature (°C) at various points v/s time of day for the cooker without TES

F. Variation of Temperature Recorded During the Experiment day for Solar Cooker withsand as TES

When sand is used as TES material the rise in food temperature was slow as the sand needs to get heat up initially then it transfers the heat to the vessel but in first case there was only air inside the solar cooker. The highest temperature achieved inside the vessel (food temp) was just 79.9°C and for the lower glazing it was 85.4°C as shown in the Figure 10. The maximum ambient temperature recorded at the experiment location was 44.1°C at 2:00 PMon 27thMay 2022.

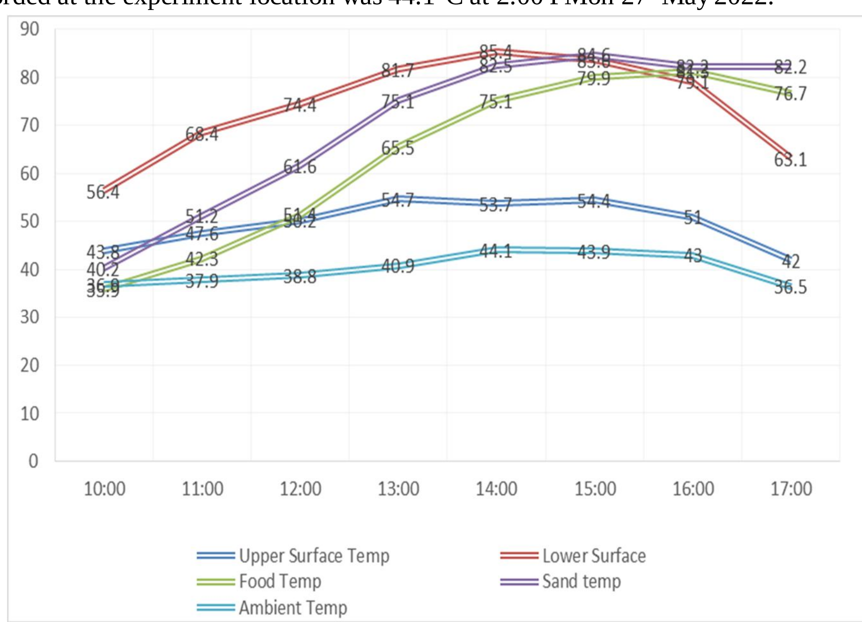

Figure 10 Temperature (°C) at various points v/s time of day for the with sand asTES

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G. Variation of Temperature Recorded During the Experiment day for Solar cooker with water as TES

In this case the temperature of food inside the vessel was approximately same as that of the water which is used as the TES medium, as shown in the Figure 11. In this case the efficiency was decreased as first water absorbs the heat and rise the temperature then heat transfer takes place via convection.

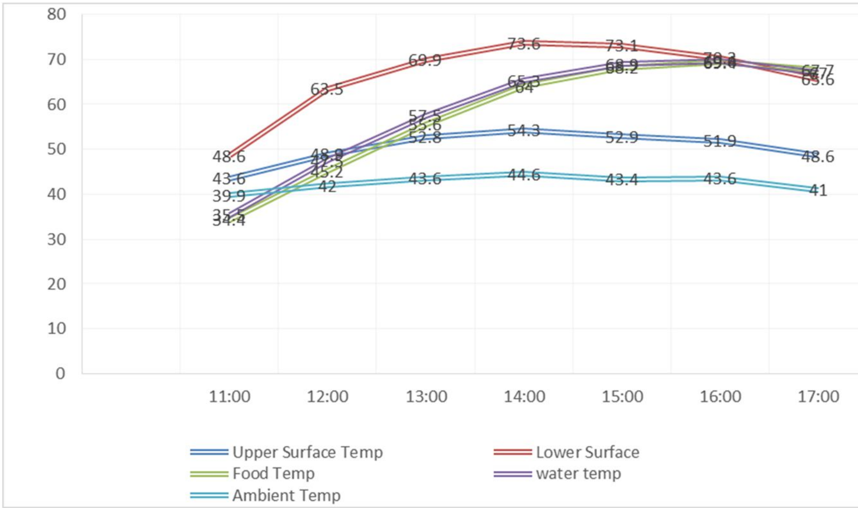

Figure 11 Temperature (°C) at various points v/s time of day for the cooker with water as TES

H. The Comparison Graph Of Food Temperature During The Three Cases

This graph represents the temperature of food achieved in the three cases discussed, from the graph it is clearly seen that the highest temperature was achieved when there is no thermal storage medium used. The temperature rise was slow when TES medium used as compared to first case. Variations in food temperature inside the cooker in three cases are given in Figure 12.

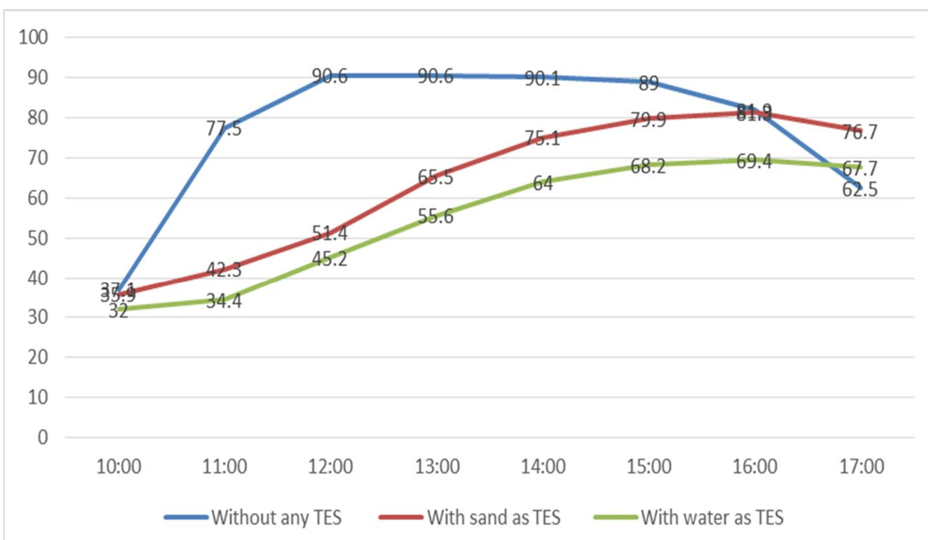

Figure 12 Variation in food temperature inside the cooker in three cases

V. CONCLUSION

In this project, three set of experiments we performed, which are,

1) Solar cooker without any TES,
2) Solar cooker with water as TES and
3) Solar cooker with sand as TES.

a) When the solar cooker with TES and without TES are compared, the maximum temperature is attained for the one with finned absorber plate and the value is 81.3°C, whereas for without TES material, it is 90.6°C.

b) The sand gains the temperature faster than the water but it needs to be moisture free. The advantage of using water is that even though there occurs a sudden fall in solar radiation, the water temperature remains the same for a long duration, which is not possible in case of cooker without thermal energy storage. The problem encountered in this experiment was the evaporation and leakage of water and the time for the water ton get heat up.

c) As the solar radiation increases, the evaporation of water in absorber tray occursat a faster rate. Due to imperfections in insulation, water may escape as water vapor, resulting in severe evaporation losses. Also, due to the cooker design imperfections, the water gets escaped through the edges/joints.

d) Thermal energy storage materials provide better temperature and reducing cooking time as compared to without TES.

Addition of TES materials increases the weight of the solar cooker that makes it heavier,water and sand which are used as TES medium takes time to get heat up.

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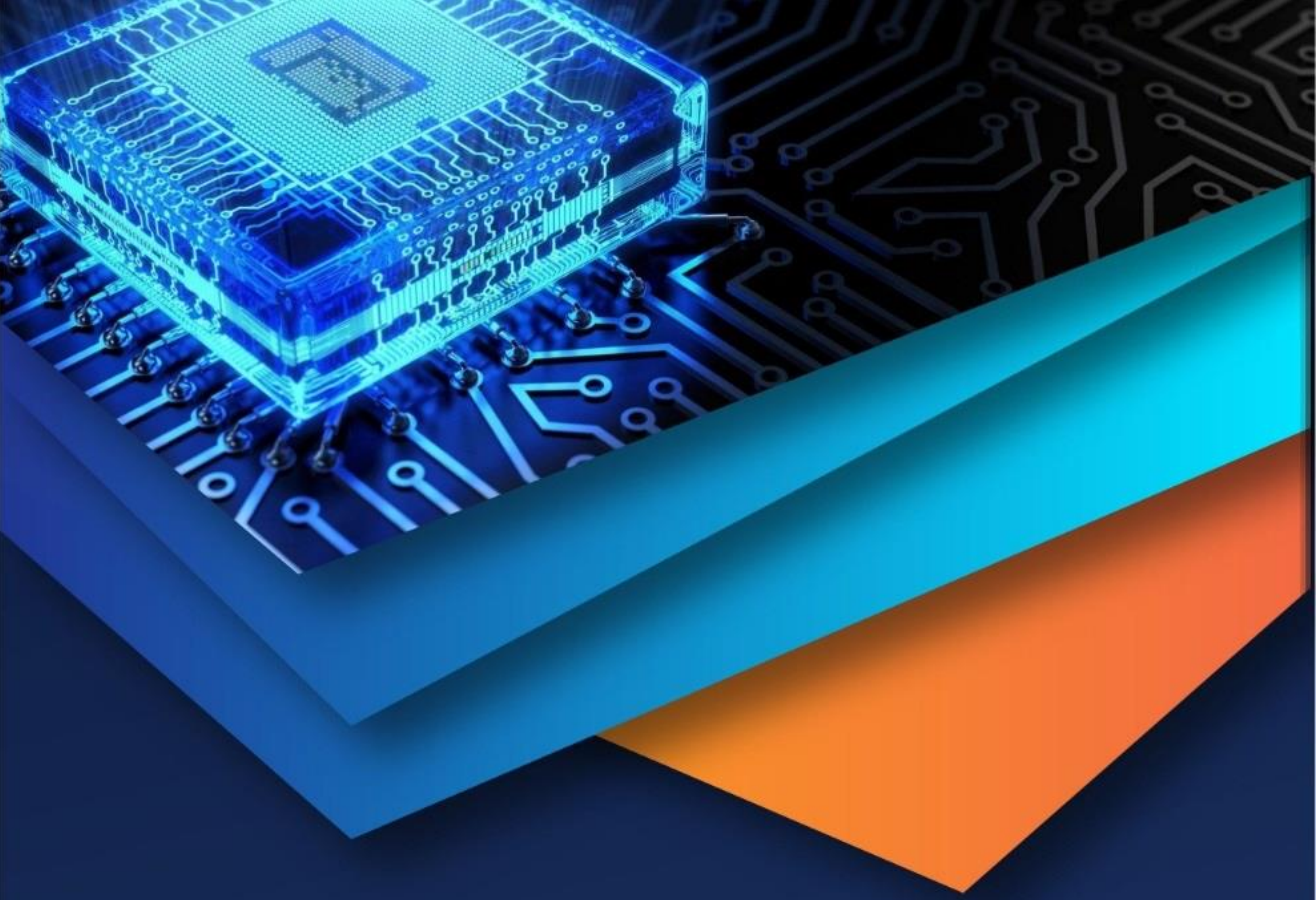

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