IOP Conf. Series: Materials Science and Engineering **377** (2018) 012188 doi:10.1088/1757-899X/377/1/012188

Development of PCM (paraffin wax) based Latent heat Storage type Solar powered Thermo-electric generator

P K Mahto[1], R Chaudhary[1], S Chowdhury[1], Md. Alham[1], S R Dutta[1]

[1] Mechanical Engineering Department, Sikkim Manipal Institute of Technology, Majitar, Rangpo, Sikkim – 737132

Corresponding Author , E-mail: premchand.m@smit.smu.edu.in/prem4es@gmail.com

Abstract. Solar energy is a renewable energy source, from that electricity can be generated. In response to increasing electrical energy costs, large number of thermal storage technology has been introduced by various researchers. The latent heat storage type system got a good response for the storage of solar energy in various applications. In the present work, an attempt has been made to showcase the utilization of solar energy to produce electrical energy using paraffin wax as phase change material and Peltier modules. In this experiment 5kg of paraffin wax has been used in a cylindrical absorber to store the thermal energy. The experimental results show that the time average minimum and maximum temperature of paraffin wax varies from 31.56 ^{o}C to 94.24 ^{o}C in day1, 29.59 ^{o}C to 88.12 ^{o}C in day2, 32.02 ^{o}C to 88.36 ^{o}C in day3 and also the minimum and maximum voltage generated by the peltier module varies from to 0.07V to 0.507V in day 1, 0.063V to 0.428V in day2, 0.072V to 0.428V in day3 of experimentation.

Keywords: latent heat storage type thermo-electric generator (LHSTTEG), phase change material (PCM), paraffin wax, Peltier

1. Introduction

Solar energy is the energy that is in sunlight. It has been used for thousands of years in many different ways by people all over the world. Solar radiation reaches the Earth's upper atmosphere with the power of 1366 W/m^2. Since the Earth is round, the surface nearer its poles is angled away from the Sun and receives much less solar energy than the surface nearer the equator. Center of the problem with solar energy is its availability so excess heat energy can be stored in some medium during daytime and stored heat can be used in the night time. The motivation of this experiment is to develop a heat storage type Solar powered Thermo-electric generator that can be used at night in rural areas. An efficient latent heat storage type Thermo-electric generator (LHSTTEG) can fulfil the demand of electricity after sunset in rural areas. Latent heat storage [5] type system required less weight and volume of material for a given amount of energy as compared to sensible heat storage type system. There are a number of PCM material that can store latent heat, in this experiment paraffin-Wax has been selected for the storage medium due to its high value of the latent heat of fusion [6].

Phase change materials (PCM) are ‘‘Latent’’ heat storage materials. The thermal energy transfer occurs when a material changes from solid to liquid, or liquid to solid. Unlike conventional (sensible) storage materials, PCM absorbs and release heat at a nearly constant temperature.

In many of the air heating systems reported in the literature, some form of energy storage is employed, ranging from sensible heat storage and chemical energy storage to latent heat storage systems [7]. Due to its high energy storage density and the isothermal nature of the heat storage and recovery processes, phase change material (PCM) energy storage is advantageous in certain applications [8, 9].

IOP Conf. Series: Materials Science and Engineering **377** (2018) 012188 doi:10.1088/1757-899X/377/1/012188

This project has used Paraffin wax [9] as a phase change material. The normal paraffin of type C_nH_{2n+2} are a family of saturated hydrocarbons with very similar properties. Paraffin between C_5 and C_{15} are liquids, and the rest are waxy solids. Paraffin wax is the mainly used commercial organic heat storage PCM [2,1]. It consists of mainly straight chain hydrocarbons that have melting temperatures from 23°C to 67 °C [3]. Commercial grade paraffin wax is obtained from petroleum distillation and is not a pure substance, but a combination of different hydrocarbons. In general, the longer the average length of hydrocarbon chain the higher the melting temperature and heat of fusion [4]. Paraffins are easily available from many manufacturers and are usually more expensive than salt hydrates [2,1]. Understanding the needs and benefits of renewable sources of energy (Solar energy) the objectives of the projects are as follows:

- To design and fabricate parabolic trough reflector and receiver system.
- To harness solar energy and store it efficiently in paraffin wax as thermal energy.
- To convert thermal energy into electrical energy with minimum losses using Peltier elements.

2. Experimental Setup

2.1. Reflector
A parabolic trough is a type of solar thermal collector that is straight in one dimension and curved as a parabola in the other two, lined with a polished metal (mirror) which concentrates light onto a receiver positioned along the reflector's focal line. The receiver is a tube positioned directly above the middle of the parabolic mirror and filled with a working fluid. The trough is usually aligned on a north-south axis, and rotated to track the sun as it moves across the sky each day. Alternatively, the trough can be aligned on an east-west axis; this reduces the overall efficiency of the collector due to cosine loss. Solar light waves essentially travel parallel to each other, this type of solar collector can be pointed directly into the sun and still achieve a total focal output from all parts of the trough shaped reflector.

2.2. Receiver Cylinder
The receiver is kept in the focal line of the parabolic reflector. The entire concentrated beam from the reflector falls onto the receiver so that higher temperatures can be achieved. The copper made cylindrical receiver [10] is painted black to increase the absorptivity. The central rod of receiver consist numbers of rectangular copper fins that helps to increase the transportation of heat during charging and discharging of paraffin wax. The cylindrical absorber is filled with 5kg of paraffin wax (PCM) which is acting as a thermal reservoir. Paraffin wax (PCM) gets heated as the heat is transferred from the receiver to the wax and its store sensible heat and latent heat, that heat is used to convert electricity using the set of peltier module. The receiver was chosen as cylindrical as the melting time of PCM was found to be less as compared to other shapes. Also, aspect ratio plays an important role in melting time of paraffin wax.

2.3. Peltier Module
Thermo-electric generators, function like heat engines, but are less bulky and have no moving parts. They could be used in power plants in order to convert waste heat into additional electrical power and in automobiles as automotive thermo-electric generators (ATGs) to increase fuel efficiency.
Peltier module is a circuit containing thermo-electric materials that generate electricity from heat directly by utilizing Seeback effect. It consists of two dissimilar thermo-electric materials joining in their ends: An n-type (negatively charged); and a p-type (positively charged) semiconductors through which a direct electric current will flow when there is a temperature difference between the two materials. Copper layer surrounds the P-N diodes which act as a good conductor of electricity. Diffusion barrier (Ni) layer is interposed between copper and diode to suppress, or at least strongly reduce, this undesirable transport of atoms. Copper layer interconnects on Ceramic Substrate (Alumina, Beryllium Oxide or Aluminum Nitride) which acts as an electrical insulator.

As the ceramic of Peltier is heated by solar heat flux, the electrons flow from electron rich n-type to electron deficient p-type. As p and n type diodes are electrically connected in series and thermally in parallel, the current will flow.

In this project, Tec1-12706 Peltier modules have been used.The project utilizes a total of 8 Peltier modules. 4 modules are mounted on either side of the receiver cylinder with 2 module on both surface of a copper plate.

2.4 Heat Sink

A heat sink is a passive heat exchanger component that cools a device by dissipating heat into the surrounding air. A heat sink is designed to increase the surface area in contact with the cooling medium surrounding it, such as the air. Approach air velocity, choice of material, fin (or other protrusion) design and surface treatment are some of the factors which affect the thermal performance of a heat sink. Heat sink attachment methods and thermal interface materials also affect the eventual die temperature of the integrated circuit. Thermal adhesive or thermal grease fills the air gap between the heat sink and devices to improve its thermal performance. The most common heat sink materials are Aluminium alloys. In this research aluminium fins are used as a heat sink.

2.5 Parameter Measurements

LM35 temperature sensors are used to measure the temperature. LM35 is a precision IC temperature sensor with its output proportional to the temperature (in °C). With LM35, the temperature can be measured more accurately than with a thermistor. All LM35 temperature sensors were connected to Arduino to record temperature. Voltage and current are measured by millivolt meter.

2.6 Specifications:

Table Number 1: Specifications of parts

Specifications	
Cylindrical receiver:	**Parabolic reflector:**
Material: Copper	Material: Aluminium
Thickness: 1mm	Height:0.25m
Outer Diameter: 102 mm	Aperture: 1m
Inner Diameter: 100 mm	Focal length: 0.25m
Length: 700 mm	Area: 1.148×0.70 m^2
Length of Fins (inside the receiver): 700 mm	**Paraffin Wax:**
Height of Fins (inside the receiver): 40 mm	Composition: C_nH_{2n+2}
Number of Fins: 4	Carbon Range: $C_5 – C_{15}$
Length of Central rod: 800 mm	Melting Temperature: 23^0C- 67^0C
Peltier Module:	Density: 900 kg/m^3
Type: TEC1-12709	Specific Heat: 2.9 kJ/(kg K)
Max. Operating Temperature: 1380^0 C	Latent heat of fusion: 200 kJ/(kg K)
Max Voltage: 15 V.	Thermal conductivity: 0.25 W/(m K)
Internal resistance: 1.98 Ohm +/- 10%	Thermal resistance: 0.4 W/(m^2 K)
Imax (A): 6A.	**Temperature Sensor:**
Life expectancy: 200,000 hours	Type: LM 35
Size: 40mm x 40mm x 4mm	Temperature range: -55°C to 150°C
Operating voltage range: 0-15.2 V DC	Operating current: 60µA
Operating current range: 0-6A	Scale factor: 0.01V/°C.
	Heat Sink:
	Material: Aluminium
	Size: 8.3cm x 4.6cm x 1.6cm
	Number of Fins: 10
	Thermal Resistance: 0.6K/W

2.7 Prototype Model:

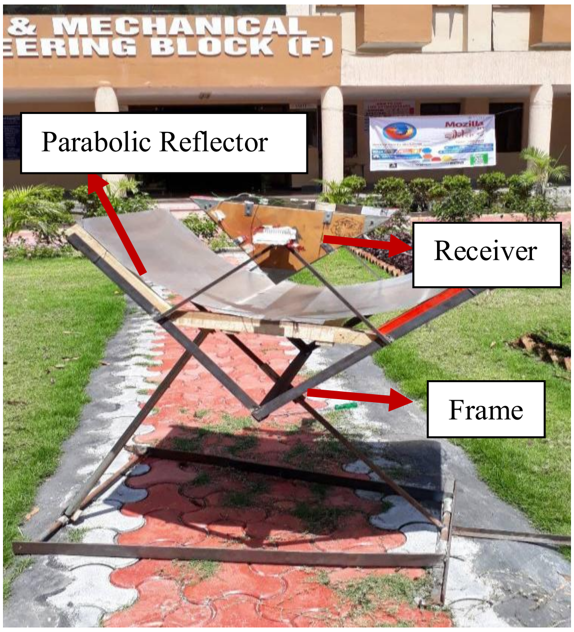

Figure 1: Experimental setup view1

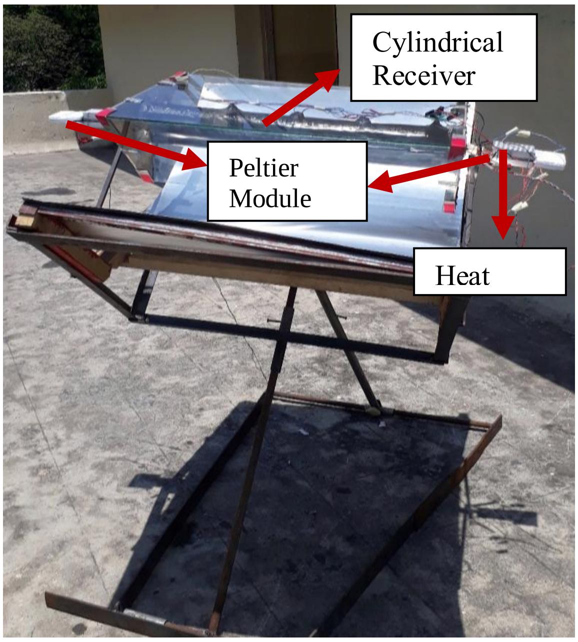

Figure 2: Experimental setup view2

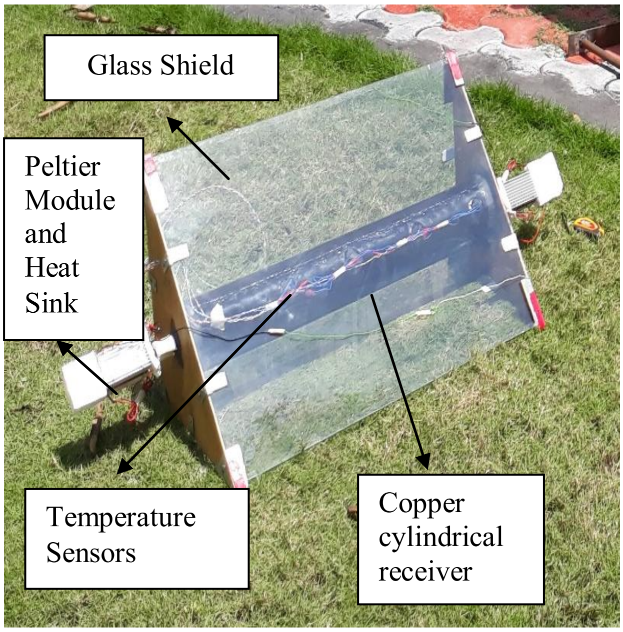

Figure 3: Experimental setup view3

IOP Conf. Series: Materials Science and Engineering **377** (2018) 012188 doi:10.1088/1757-899X/377/1/012188

3 Experimental Procedure:

In this project, the parabolic reflector focuses the sun rays onto the cylindrical receiver which stores by the paraffin wax (Phase change material) and is insulated from the surroundings with the help of the transparent glass panes and air pocket sandwiched in between. As the sun rays are concentrated on the receiver, it gets heated up which in turn heats up the paraffin wax. During the dark hours, wax releases the latent heat through copper rod and fin system within the receiver, carrying the heat to the eight Peltier elements placed on both sides of the receiver for the conversion of solar thermal energy into electricity. The experiment was conducted in SMIT Campus (latitude 27^{O}.18'N and longitude 88^{O}.49'E), Majhitar Sikkim India. The axis of parabolic reflector varies from 3.73^{O} to 50.63^{O} from the vertical to receive maximum solar radiation. The receiver is placed at the focal plane of the parabolic trough reflector, along the focal line so that all of the focused rays are made incident on it. The hourly variation of solar radiation flux on 5-8 April 2017 was taken from the website of the meteorological department [11]. Five numbers of LM35 temperature sensors have been used to measure the paraffin wax temperature and surrounding temperature. Once the unit was connected, it was left to run for about 2 days before the measurements were taken, in order to overcome the initial transient effects and to confirm reliable operation of the unit. Then, the experiment was run at steady state for a period of 3 days (from 5th April-8th April, 2017) at SMIT campus Sikkim.

4 Results and Discussion:

After conducting the experiment for three days on 06/05/17, 07/05/17, 08/05/17, the following data for temperature and voltages were obtained.

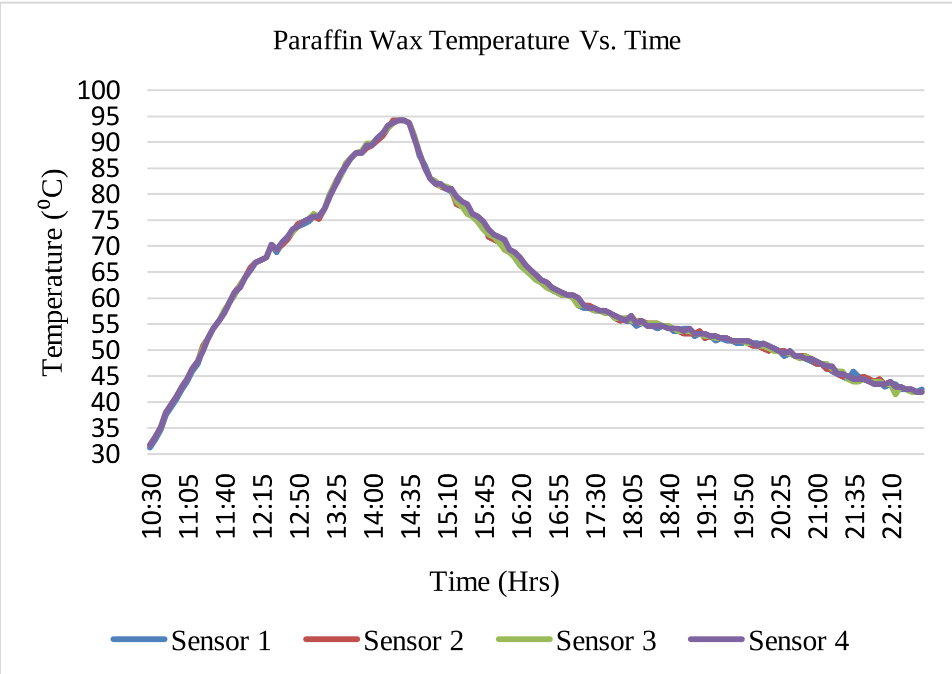

Figure 4: Temperature variation of Paraffin Wax with Time (Day 1)

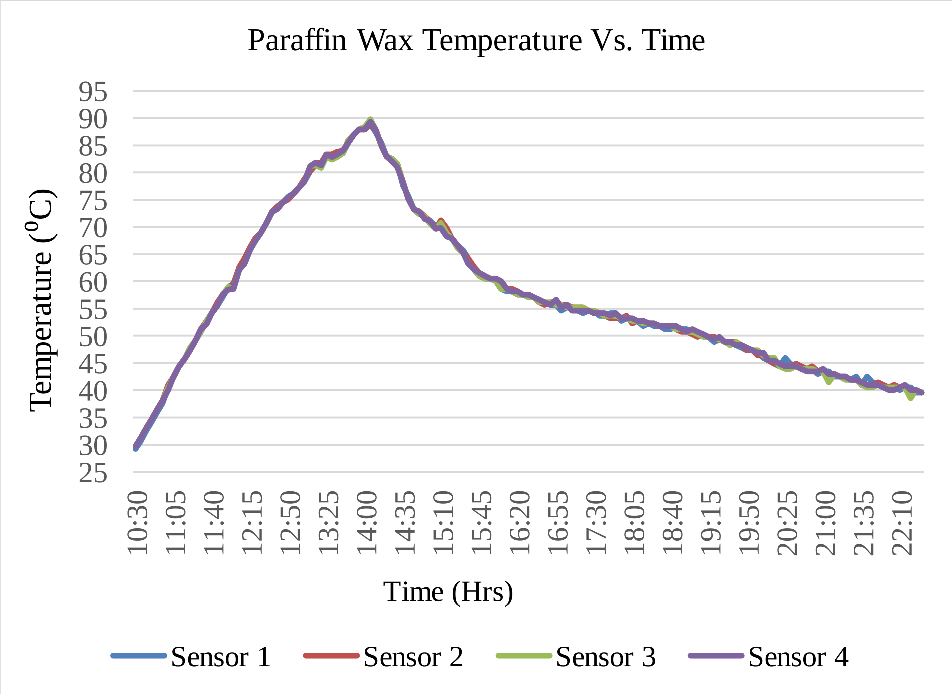

Figure 5: Temperature variation of Paraffin Wax with Time (Day 2)

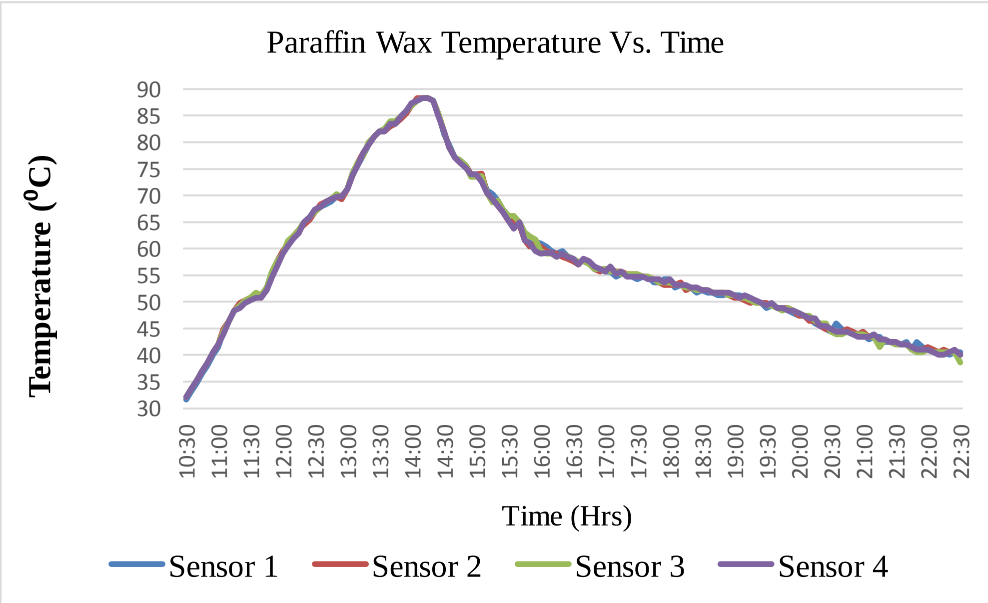

Figure 6: Temperature variation of Paraffin Wax with Time (Day 3)

Figure 4, 5 and 6 shows the temperature variation of paraffin wax (energy storage material) at four different sections with time in three observation day. From figure 4 it is observed that the average minimum and maximum temperature of paraffin wax varies from 31.56 ^{o}C to 94.24 ^{o}C in day 1, 29.59 ^{o}C to 88.12 ^{o}C in day2, 32.02 ^{o}C to 88.36 ^{o}C in day3. The total average temperature (for one cycle from 10:30AM to 22:10PM) of paraffin wax in day1, day2 and day 3 are 60.30 ^{o}C, 56.47 ^{o}C and 56.71 ^{o}C respectively. It is also observed that the total average temperature is highest in day1, this is because of the higher value of global solar radiation in day1 (200.75W/m^2) as compared to day2 (192.97W/m^2) and day3 (195.63W/m^2).

From the above data it has been noted that the total average temperature of paraffin wax is higher than the melting temperature of paraffin wax. So the paraffin wax can store huge amount of thermal energy in the form of latent heat, and that thermal energy can be converted into electrical energy using the peltier module.

It is also found that the rate of increase in temperature during charging (heating of paraffin wax) is much faster than the drop in temperature during discharging (cooling of paraffin wax). As at the time of charging the large amount of direct and reflected solar radiation falls on cylindrical receiver and that is transmitted through the fins to the paraffin wax, due to higher temperature difference and proper conduction of heat through copper fins, the rate of increase in temperature is faster during charging. The rate of drop in temperature is slower during discharging, because of degradation of energy in less temperature difference.

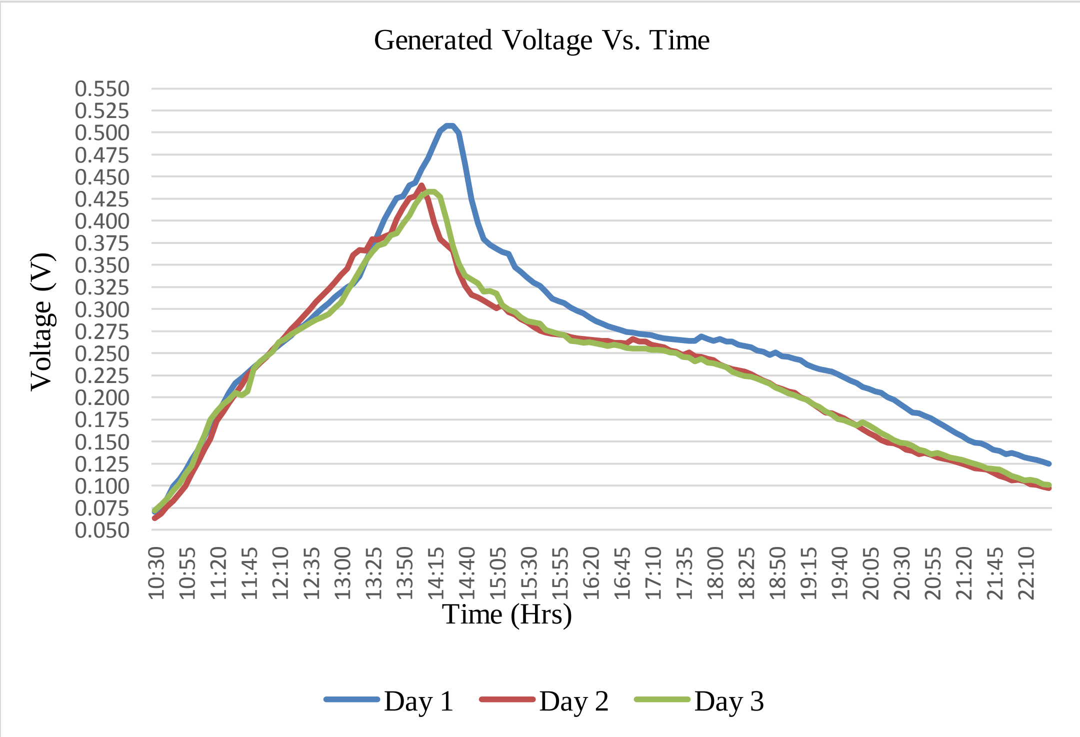

Figure 7: Time variation of generated voltage

Figure 7 shows the Time variation of generated voltage in all three days of experimentation.

It is observed that the minimum and maximum voltage varies from 0.507V to 0.07V in day 1, 0.428V to 0.063V in day2, 0.433V to 0.072V in day3. The time average voltage in day1, day2, day3 is 0.258V, 0.232V and 0.239V respectively. The variation of generated voltage follows the same nature as the temperature variation; this is because the generation of voltage or current is the function of temperature difference between source and sink.

5. Conclusion:

From the above results, the following conclusion can be drawn:

- Concentrated Solar Power technology can be used to achieve higher temperatures than Flat plate solar collectors, depending upon their shape and other parameters. The designed parabolic reflector had an aperture area of 1.0m×0.70m and it helped in achieving a maximum temperature of around 95 ^{O}C.

- Paraffin wax can be used as a heat tank or heat storage material as it behaves as Phase Change Material and hence can store a large amount of heat in the form of latent heat.
- The generation of voltage is proportion to the temperature difference between the heat source and sink.
- Large bank of Peltier module can be used to generate more electrical energy.

It can be concluded that the proposed model in large scale can be effectively used for generating electricity. This model can be act as a source of power bank for generation of electricity at night in rural areas. The large scale of proposed model may be fulfilled the electricity demand.

References

[1] A D.V. Hale, M.J. Hoover, and M.J. O'Neill, 1971" *Phase change materials*", Hand Book, Marshal Space Flight Center, Alabaa,
[2] G. Lane, 1983, "Latent heat materials", CRC Press, Boca Raton, Florida, Vol 1.
[3] A. Abhat, 1983 "Low temperature latent heat thermal energy storage: heat storage materials", *Solar Energy*, Vol. **30**, 4, pp. 313-331.
[4] S. Hiran, A. Suwondo, G. Mansoori, 1994 "Characterization of alkanes and paraffin waxes for application as phase change energy storage medium", *Energy Sources*, Vol. **16**, pp. 117-128.
[5] S.O. Enibe, 2003 "Thermal analysis of a natural circulation solar air heater with phase change material energy storage" *Renewable Energy* **28** ,2269–2299
[6] Duffie JA, Beckman WA. 1980, "Solar engineering of thermal processes" New York: John Wiley and Sons.
[7] Conti M, Charach Ch. 1996, Thermodynamics of heat storage in a PCM shell-and-tube heat exchanger in parallel or in series with a heat engine, *Solar Energy*, 57:59–68.
[8] Kerslake TW, Ibrahim MB. 1993, Analysis of thermal energy storage material with change of phase volumetric effects. *ASME Journal of Solar Energy Engineering*,115:22–31.
[9] A.Agarwal, R.M.Sarviya, 2017, characterization of commercial grade paraffin wax as latent heat storage material in solar dryer, *ICMPC 2017, proceedings* **4** , 779-789.
[10] Zhiwei Wang, Hengyun Zhang , Xin Xia, 2017, Experimental investigation on the thermal behavior of cylindrical battery with composite paraffin and fin structure, *international journal of heat and mass transfer*, **109**,958-970.
[11] India Meteorological Department, *www.imd.gov.in*.