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Thermal Performance Analysis and Comparison of Shallow Solar Pond Integrated With and Without Composite Phase Change Material

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Abstract- Excessive increase in the greenhouse gases emission level resulted in pollution due to the use of non-renewable energy resources caused driving forces for more utilization of renewable energy sources. One such alternative is solar energy emitted by the sun and is being received and stored in different thermal storage medium. Direct solar radiation incident on the earth surface can be considered as one of the most prospective sources of energy in all over the world. The main obstacle that prevents the complete utilization of this solar power is its fluctuation with time and the changes in the stored energy for night use. The enhancement of the energy storage system is necessary which reduces the mismatch between supply and demand of the energy. Also, it improves the energy system performance and reliability and plays a significant role in conserving the energy with least maintenance cost. In this paper, thermal performance analysis as well as comparison of a Shallow Solar Pond (SSP) for its thermal storage capability with and without composite PCM has been investigated experimentally.

Keywords— Shallow Solar Pond, Phase Change Material, PCM encapsulated Iron Pipe assembly, Composite PCM, Pyranometer, Temperature indicator.

I. Introduction

A Shallow Solar Pond (SSP) can be referred as a stagnant large body of water with bottom as well as side surface black which makes it capable of collecting and storing solar energy. The name shallow of the SSP itself implies that the depth of the pond is relatively small and ranges from 3 to 15 cm. The SSP has a capacity of heating a large volume of water to an appreciable high temperature. It is also one of the cheapest methods of harnessing the solar energy in a very easy way with a very low maintenance cost. In the shallow solar pond, the black Low-density poly ethylene (LDPE) liner was laid over the bottom surface of the pond which acts as a black body and absorbs the solar radiation in a very efficient way. As a result the stored water gets heated by absorbing solar radiation.

Various scientists have evolved some techniques to get more heated water for a long time even after sunset for domestic and industrial purposes. Like Sodha, et al [1], had purposed a very simplified design to measure the performance of a Shallow Solar Pond water heater which assorted both storage and collection in the same unit. The water heater was fabricated with a metallic Galvanized Iron (G.I.) tray, of which inside and bottom surfaces were painted with black color and the SSP was covered with the help of a transparent sheet at the top which prevents the water loss due to evaporation. The inside and bottom surface of the setup were perfectly insulated with the help of suitable material so as to minimize heat loss to the surrounding. The system had stored sufficient amount of heat energy for the next day morning purposes, when the top cover was properly insulated during the night time. Similarly Aboul-Enein et al. [2] have investigated the thermal performance of a shallow solar pond under the batch mode of heat effluence. He fabricated the setup with a baffle plate and a reflecting mirror with a suitable adjustable mechanism so as to get all time maximum solar radiation. From the experiment it has been concluded that the pond could be able to provide 88 litters of hot water with the maximum temperature of 60^{o} C at the sunset hours. The same amount water obtained at 47°C in the morning of the next day and which has been used for most domestic application. Zhongliang Liu et al., [3] have examined the thermal storage system, heat exchanger a heat pipe, with a suitable latent heat storage arrangement system. This was said to be one step ahead of the primitive methodology of heating process. The system was experimented in three basic different modes of operation for simultaneous charging/discharging and separate charging, discharging. The experimental results have been seen as that the heat exchanger performed the desired functions very well and has been found to hold and release the thermal energy efficiently. Basically a Thermal Energy Storage (TES) system consists of three different parts: a storage tank, heat exchanger and storage medium. Storage medium can be latent heat, thermo chemical or sensible storage material

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[4]. The main purpose of the heat exchanger is to provide or receive heat energy from the storage medium. The storage tanker contains the storage medium and insulates the system so as to minimize the heat loss to the surroundings. TES systems should be fabricated in such a way that it meets certain criteria, which are incumbent on the size, type and design of the application. [5]. Before selecting a suitable TES system a thorough explication of all requirements needed to be done. TES system must be suitable with all other units in the plant. It must also be durable to the overall operational performance of the plant like number of hours of storage required, integration with solar collection system operational temperature range, charging and discharging rate, etc. It must be confirmed its long-term stability, i.e. the total number of cycles that both storage medium and container can withstand without changing of their physical properties. The so called long-term stability of the system can be extricated by two different factors, poor stability of the properties of materials under excessive thermal cycling, chemical incompatibility and corrosion between the PCM and its container. Accordingly the perfect suitable storage material and heat exchanger between the heat transfer fluid (HTF) and thermal storage material and etc should be chosen.

H.P.Garg et, al, [6] have discussed the effect of using organic phase change material as a thermal energy storage material. He found paraffin most qualified for its heat of fusion for thermal energy storage applications. Due to its availability in a large temperature range and with the desired thermo physical properties like non-corrosive, non-reactive with metal parts, non-toxic etc., so it is best suited for heating purposes for a very wide range of temperature. Some important thermo physical properties of paraffin wax have been shown in the table no.1below.

Latent heat of fusion (kJ/kg)	190
Melting temperature (°C)	44
Solid density (kg/cubic meter)	930
Liquid density (kg/m3) -	830
Thermal conductivity (W/m °C)	0.21
Solid specific heat (kJ/kg °C)	2.10
Liquid specific heat (kJ/kg °C)	2.10

Table 1: Thermo physical properties of paraffin wax

For any substance to become a good phase change material or thermal energy storage material it should have high value of latent heat of fusion as well as possessing less charging and discharging time. Although paraffin wax has some good thermo physical properties but it lacks in the above said properties. So in order to improve its physical parameters some additives like metal oxide powder was mixed to it. It has been seen in the past result that adding metal oxide to paraffin wax for making it a composite phase change material the amount of metal oxide is much important. It has been experimentally found that after adding approx... 5% of Titanium oxide to paraffin wax the composite mixture shows decease in charging and discharging time without affecting its latent heat of fusion [7]. In this case also in order to examine thermal performance of SSP composite phase change material having weight % of 5 was prepared and experiment was performed.

II. FABRICATION OF EXPERIMENTAL SETUP

In order to examine as well as compare the thermal performance of Shallow solar pond integrated with and without composite phase change material experimental set-up has been fabricated in the heat engine lab and installed on the terrace of the Department of Mechanical Engineering BIT Sindri Dhanbad 23.75^0 N, and 86.70 E.

As per report on the topic "Thermal conductivity enhancement of the phase change material" published in SAUSSUREA ISSN: 0373-2525 Vol. 5(6): PP 48-55, 2015**,** it has been concluded that by mixing 5 % Titanium oxide to paraffin wax thermal conductivity value of the composite PCM increases drastically and it decreases the charging time from 13 minute to 7 minute. Using this experimental data for further purpose composite PCM has been made for this experiment. In this experiment a total of 4.16 kg of paraffin wax has been used and 0.2 kg of titanium oxide powder wax mixed to it to make it a composite mixture. In the molten form of paraffin wax TiO_2 i.e. Titanium oxide powder as thermal conductivity enhancement was mixed and the mixture was stirred for about 15-20 minutes so that it could mixed well and gives us a homogeneous mixture.

III. DETAILS OF THE EXPERIMENTAL SETUP

A) Collecting Chamber: - It was composed of wooden rectangular box as shown in figure no.1 having dimensions 91.44 cm of length, 76.2 cm of width and 10 cm of depth. The collecting chamber was made in order to hold maximum of 80 to 85 liters of water. The reason behind selection of wooden box was to ensure self-insulation provided by collecting chamber itself.

Figure 1: Box with polyurethane foam insulation

The inside surface of the box was insulated with the help of polyurethane foam, so that it can prevent rapid heat dissipation to the surrounding. In order to capture the better solar energy a Low Density Polyethylene (LDPE) black sheet liner of 200 micrometer thickness was covered all along the bed side and inner sides of the shallow solar pond, and was made leak proof to hold the water after

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loading the SSP with known volume of fresh water. A clear transparent polyvinyl chloride (PVC) plastic sheet of 150 micrometer thickness was covered over the top surface of the pond as a evaporation suppressing membrane. A transparent glass cover of thickness 0.005m and dimension 91.44cm x 76.2cm was used to cover the pond.

(B) Aluminum Tube: - Having dimension 91 cm of length and 1.9 cm of diameter and 1mm of thickness as shown in figure was chosen for the encapsulation purposes. A total of 17 tubes as shown in figure 2 of such dimensions were taken for the experimental purposes.

Figure no 2: Aluminum tube

(C) Paraffin wax: - It comes under the category of organic thermal storage material. Due to its capacity of storing sensible as well as latent heat at desired working temperature range it is best suited for these purposes. Some of the important properties of paraffin wax are it is non-corrosive nontoxic and has a long life i.e. it is non-reactive with the metal in which it is kept

Figure no 3: Paraffin wax

(D) Temperature indicators : - As shown in figure , 4 it was mainly used to measure the temperature of water kept in the solar pond, ambient as well as normal water kept beside the SSP so as to compare the variation of temperature of different parameters with respect to time. A total of four temperature indicators were used for this purposes. Two temperature indicators were used to measure the temperature of pond water. One was kept at the center of the pond another was kept at one of the corners of the pond to measures the overall temperature variation of the pond water.

Figure no 4: Temperature Indicator

(E) Titanium Dioxide: - One of the main purposes of using any of the metal oxide powder was to increase the thermal conductivity of the phase change material. To serve this purpose we can choose copper oxide, aluminum oxide, or titanium oxide etc. powder. In this case I chose titanium oxide powder as shown in figure no. 5. since it is easily available in the market at a very low cost and with a good value of thermal conductivity.

Figure no 5: Titanium dioxide powder

(F) Pyranometer: - It is a device which is used to measure the solar irradiance on a planar surface and it is designed to measure the solar radiation flux density from the hemisphere above within a wavelength range 0.3um to 3um. The diagram of the pyranometer has been shown in the figure 6.

Figure no 6: - Pyranometer

IV. RESULTS AND DISCUSSION

The experiment has been performed to investigate the pond performance and thermal storage capability of the shallow solar pond when it was filled with 35 litters of water each time. The experiment was repeated every three times in three different mode of SSP in order to minimize the error occurred due to variation in solar intensity. The first mode contains the measurement of temperature variation of SSP without any PCM. The second mode contains the measurement of temperature variation of SSP with paraffin wax encapsulated aluminum tube. The third mode contains the measurement of temperature variation of SSP with composite PCM of paraffin wax and TiO_2 encapsulated in the aluminum tube. The tables and graphs below show the temperature (^{0}C) variation from the 1st day on 2nd May till the 9th day on 10 may 2018 at Sindri, Dhanbad 23.75^0 N, and 86.70 E.

(A)First mode of experiment

In order to minimize the error occurring due to variation of some natural physical parameters like wind speed, solar intensity, etc. the average value of the temperature for the first three days of the SSP without PCM has been considered as shown in the figure no 7. The average value of temperature is maximum at 2 pm having a value of 79.2^{0}C. The average value of maximum solar radiation is

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836.9 W/m^2 at 12 am. After 2pm the temperature of the pond is gradually decreasing and reached to a value of 55.8^{0}C for night use purposes. The above data of temperature has been obtained on all clear days with normal wind speed.

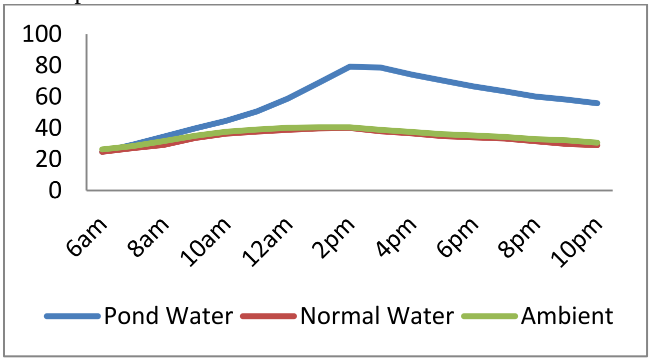

Figure no 7: Average of temperature profile of SSP without any PCM for the first three days from 02/05/2018 to 04/05/2018.

(B)Second mode of experiment

With the loaded water capacity of 35 litters and after the installment of paraffin wax as PCM encapsulated in aluminum tubes the temperature reading for the three days has been taken and plotted in the graph as shown in the above figure 8. In this case the maximum of average value of temperature achieved by the pond water is 75^{0}C which is lower than the previous case of SSP without any phase change material.

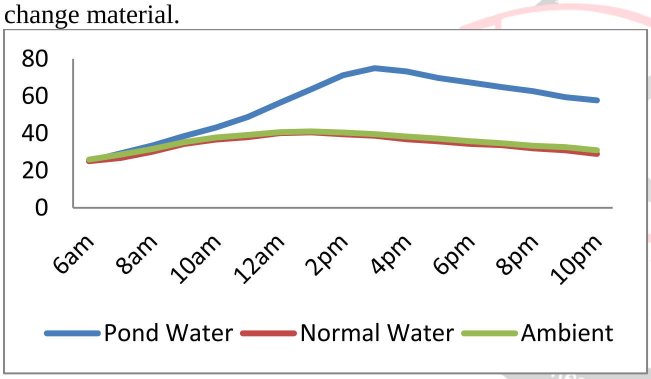

Figure no 8: Average value of temperature curve of the SSP with only Paraffin wax as PCM taken from 05/05/2018 to 07/05/2018

But due to installation of PCM encapsulated aluminum tubes the temperature gradient during cooling process is lower than the first case which result in the increase in the temperature value at night at 10 pm having value 2-3^0 C more than that in the first case. This increase in temperature obtained due to heat released from paraffin wax which it has stored in the form of latent heat during heating process

(C)Third mode of experiment

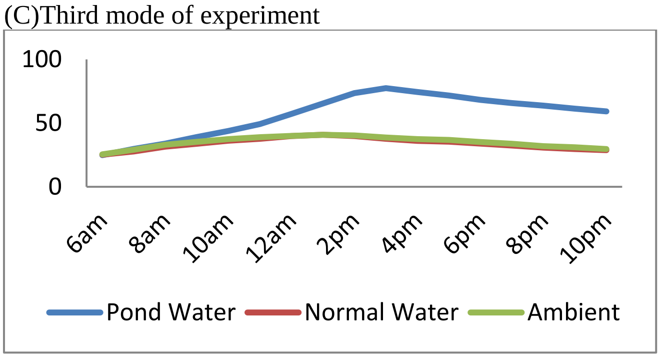

Figure no 9: Average of temperature value curve of SSP installed with composite PCM taken form 08/05/2018 to 10/05/2018.

The above temperature curve as shown in figure no 9 is the last mode of experiment in which SSP was installed with composite phase change material. The loaded water capacity was kept same as 35 litters and temperature reading has been taken from 6am to 10pm of three consecutive days. The benefits of using composite PCM can be seen from the above curve that the maximum value of average temperature has increased significantly. This increase in the value of the temperature has been obtained due to increase in the value of thermal conductivity value of composite PCM after mixing of Titanium Oxide to it. The mixing of TiO_2 with paraffin wax resulted in less charging and discharging time of the composite PCM which in turn helps to gain more temperature.

V. CONCLUSION

In the figure as shown in figure no. 10 comparison of temperature profile of all the three different mode of experiment with SSP has been done. The reading has been started from 02/05/2018 to 10/05/2018 at Sindri, Dhanbad 23.75^0 N, and 86.70 E. The temperature curve shown with blue, red and green color represents the temperature variation of SSP without any PCM, SSP with only paraffin wax as PCM and SSP with composite PCM respectively.

❖ Temperature gradient during cooling period

In the cooling phase i.e. after 2-3 pm the temperature gradient is less for the curve shown in green color which represents SSP with composite phase change material and more for the curve shown with blue color curve representing SSP without any phase change material. This happened due to the PCM which while cooling liberates its latent as well as sensible heat to the surrounding water and helps to maintain its temperature. The composite PCM system took less charging time and succeeded to gain more temperature in comparison with paraffin as PCM alone.

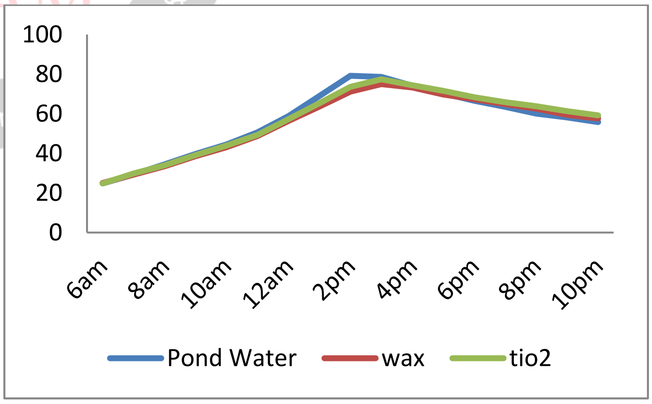

Figure 10: Comparison of temperature curve for all three different batch mode of experiment

❖ Maximum temperature obtained

From the above graph as shown in figure no. 10 SSP without any PCM achieved maximum temperature of 79.2^{0}C at 2pm w.. hich is more than the other two mode of experiment. Whereas maximum temperature achieved by mixing of metal oxide i.e. Titanium Oxide to paraffin wax helped to increase the thermal conductivity of the composite PCM. This in turn resulted in consuming less charging time and worked

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efficiently to gain more temperature for thermal energy storage than that of paraffin as PCM alone.

- **Temperature of SSP at 10pm**
  This is one of the main comparisons which are also an objective of this experiment to obtain relatively more temperature while using composite PCM. As shown in the figure no 10, temperature value at late night at 10pm is more for the composite PCM system then for the paraffin as PCM system and then for the non PCM system. Instead of gaining more temperature the SSP without any PCM could not maintain more temperature after sunset and liberated its stored heat rapidly. Whereas SSP with composite PCM gained more temperature than that of SSP with paraffin wax as PCM and hence could maintain more temperature at 10 pm.

V (1). COMPLEXITY INVOLVED

(i). Composite phase change material should be well mixed so as to form a homogeneous mixture. In order to obtain this, size of the metal oxide should be near to macro or nano particles. Otherwise it will settle down at the bottom of the aluminum tube.

(ii). After filling the aluminum tube it should be closed at both the end with tight cap. So that molten PCM should not come out of it.

(iii). While filling the aluminum tube it should be kept in mind that molten paraffin wax has more density than that of the solid paraffin wax. So it should not be filled completely inside the metal tube. Otherwise it may result into outflow of molten paraffin wax from the tube as shown in the figure below.

Figure 11: Surface solidification of paraffin wax due to outflow from the aluminum tube.

VI. FUTURE SCOPE

1. There is a vast range of PCMs together with vast range of metal oxide available to us which can be used to increase the potential of composite PCM. So we need to go ahead in the making of composite PCM so that it would be able to achieve more temperature and store more heat.
2. Besides synthesizing composite PCMs, there can be some changes in the design of SSP like, application of baffle plates which will increase the surface area of the combined SSP system.
3. Use of copper tube which has high thermal conductivity value as compared to aluminum tube or iron tube to store PCM and composite PCM.

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