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Performance Study of Solar Energy Charged Compact PCM Heat Exchanger

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***Abstract*: This paper presents the Experimental performance of compact (lab scale) solar energy charged PCM heat exchanger. It contains paraffin wax of Type –II with melting point 50OC as Phase change material. A conventional solar heat collector has the ability to extract / transfer only the sensible heat from the solar irradiance into it. The bulk latent heat cannot be stored in conventional system due to its simplicity. Therefore to utilize/ extract larger heat capacity, a substance inclusion is done in the form of PCM. Generally, PCM has high heat storage capacity but also experience low thermal conductivity. A box container with dimensions 280 mm X 28 mm X 450 mm is made to contain PCM material. The box container apart from the front, top and bottom sections is well insulated by thermal insulation material and kept as Adiabatic. To charge/melt PCM, Copper is chosen as the flat plate heat conductor. To enhance the heat transfer and to reduce Charging time of the PCM, the geometrical factor (surface area) is improved with help of fins. Fins are provided on the inner face of 1 mm thickness copper flat plate. Water as HTF flows through Copper tube is made as the discharging element.**

***Keywords*: Solar energy, Latent heat, Heat exchanger, Paraffin PCM.**

1. Introduction

A. General

Energy demand is increasing at a faster rate over the past few years. The energy consumption per capita decides the living standard of the people in the region. India's doubling time for per capita energy consumption is estimated to be in next 6 to 7 years and next doubling time is expected to be in 5 years (as per sources: RE-Invest 2017) at the present rate of economic growth. Therefore to meet the energy generation capacity with the energy demand capacity, engineers are keen to develop power systems capable of producing green power combined with energy storage capacities. Energy stored will be useful during peak load situations. The future green power generation greatly depends on renewable energy. The renewable energy resources are solar energy, hydro energy, wind energy, geothermal energy, ocean tidal energy, etc. since solar energy is renewable, free and largely available it finds a strong application in future power generation sectors. The large infinite amount of solar energy falling on the earth' surface is reflected back to the atmosphere or the majority of them are under-utilized. Heat energy is the prime source of energy and it can be converted to any other form of energy. Naturally, the latent heat from the sun is absorbed by the ocean water and is evaporated. The condensation of the vapour leads to the rain, thus providing hydropower. Due to the uneven heating of global air by the solar energy, expansion of air leads to pressure difference which further leads to kinetic energy driven wind power plants. Thermal power plants & Nuclear power driven steam power plants need heat energy for the steam generation. Thus all other forms of energy need thermal energy for their conversion. Solar energy provides both heat and light energy. Photovoltaic cell directly converts light energy into electrical energy. Based on the research, it is found that PV cell works more efficiently during moderate sunlight conditions. The high heat from the sunlight raises the temperature of the PV cell affecting the efficiency of the system. The high cost of the solar cell makes it difficult for commercial usage. The heat energy from the sun is generally used for heating purposes. Large size solar collectors are required for large scale heat extraction; thus the heat is stored and discharged using thermal storage systems.

B. Thermal Storage Systems

Heat from a source can be stored in two forms, one is sensible heat storage and another is latent heat storage. TES are useful in industrial application like aluminium, iron and steel, cement, glass, paper and food processing industries. A sensible heat storage system (SHSS) employs solid, liquid and water as storage medium. A solar heater stores sensible heat in the water medium. The storage density can be calculated by the product of density of the material and the difference in enthalpies. The heat storage capacity or storage density in a SHSS is low, whereas latent heat storage systems (LHSS) have high storage density. The storage density of LHSS is calculated by the product of the latent heat capacity and density of the storage medium. Here the energy is stored during the phase change of the material either liquefying of a solid or evaporation of a liquid. Latent heat value is higher than specific heat value, so it has high storage capacity. LHSS employs PCM's of organic, inorganic (salt hydrate) and eutectic type.

C. Need for the Study

The need is to develop an alternate energy solution. The ever renewable and free available solar heat source has to be utilized to compensate the energy demand. This analysis is keen to develop a heat storage combined with heat exchanger system.

A large quantity of heat storage is possible by extracting the latent heat and the same is to likely be exchanged to another useful medium with low loss. In recent years, Phase change material draws more attention in latent heat storage systems. Hence this study is done by integrating the solar heat storage with the PCM and is charged/ discharged by the use of heat exchangers.

2. Experimental work

The PCM heat exchanger is designed and fabricated for the purpose of solar heat extraction and hot water generation. Hence, the heat exchanger material, the PCM transition temperature, the heat exchanger capacity, heat transfer fluid (HTF) flow rate and inlet temperature are selected based on this application. To measure temperature, K-type thermocouples are used with the range and accuracy of -270 to 1250 ^{o}C and +/- 1.1 ^{o}C.

A. Selection of heat exchanger material

The Heat exchanger in this research is for solar heat extraction. Solar energy is intermittent; therefore a high thermal conductive material is required to quickly extract the heat. Already copper tubes are used in conventional solar heat collectors and so copper is chosen as heat exchanger material. Here both flat plate (charging) and tube material (discharging) is chosen to be copper. The purpose for the selection of copper material is due to its high thermal conductivity, high durability, high strength, corrosion resistance and high stability during the welding process.

B. Selection of phase change material

The selection of PCM is made based on its thermal, chemical, physical properties and mainly on economic factor. On the review of the previous literature, organic PCM's have shown satisfactory performance in charging and discharging process and is expected to be durable even for 1000- 2000 cycles of operation. Another desirable property of organic PCM is non-corrosive unlike salt hydrates and eutectics. The phase change material selected in this analysis work is organic paraffin of type II which has a melting point of 68^{o}C (as per manufacturer's data). But on experimental analysis, the PCM shows a melting point between 48 – 50^{o}C. The selection of this PCM & its melting point temperature was based on the following considerations: (i) the solar irradiance values observed for a two week time and analyse on NREL source (ii) economic criteria.

C. Selection of heat exchanger capacity

Heat exchanger selected is shell type. To determine the capacity of the heat exchanger shell container, the mass of phase change material has to be calculated. The following formula is used to calculate the mass of PCM, Minimum mass of PCM, $M = (A_s * I * T * E_f)/ L$ Where, A_s – surface area of flat plate collector, I – solar irradiance / insolation, T- Estimated time of solar absorption, E_f – fraction of energy absorbed by the flat plate collector, L- latent heat of PCM.

3. CAD model

The Fig. 1, shows a schematic assembled view of the physical model. It consists of an outer and inner container separated by a space of thermal insulation. The containers are made of 1mm thick mild steel sheet. The sheet is then carefully folded to the prescribed dimensions.

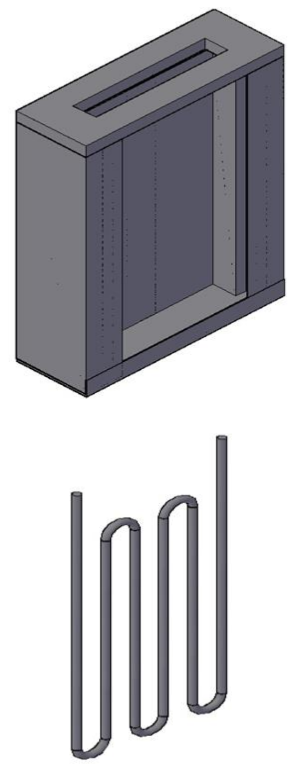

Fig. 1. Box container assembly and HTF discharge tube

4. Experimental procedure

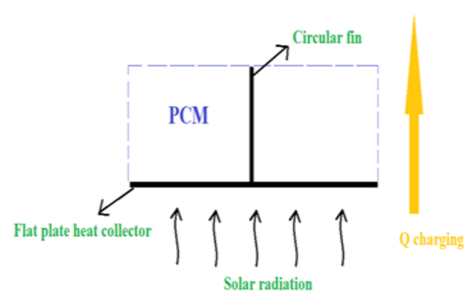

Fig. 2. PCM Charging process

The performance of the thermal storage system is found by two processes, (i) charging/ melting process of the PCM, (ii) discharging/solidification process of PCM. The experimental test rig is Non-concentrating type solar heat collector. It is placed at a tilted angle of 25^{o} to the sunrays. The beam of sunlight falling on the test rig passes through transparent glass cover and heats the copper flat plate collector behind it. The spacing between the outer and inner container is closely packed with thermal insulation material glass wool. This restricts heat transfer from the PCM material to the surrounding environment. The copper plate acting as the solar heat collector extracts the heat and transfers the heat to the Phase change material present in the adjacent side of the plate. A thermocouple is placed on the solar heat collector plate to measure the temperature increase of the plate over a time period. Another thermocouple is inserted into the PCM material bulk.

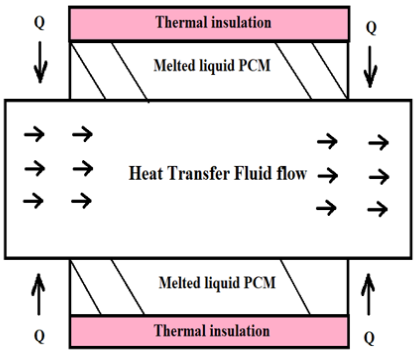

Fig. 3. PCM Discharging process

5. Experimental results

The following Table 1, is an observation of temperature readings for charging and discharging process over a time interval of 5 minutes. Thermocouples, Remainder stop watch, Discharge motor pump, flow rate controller equipment are used in this process,

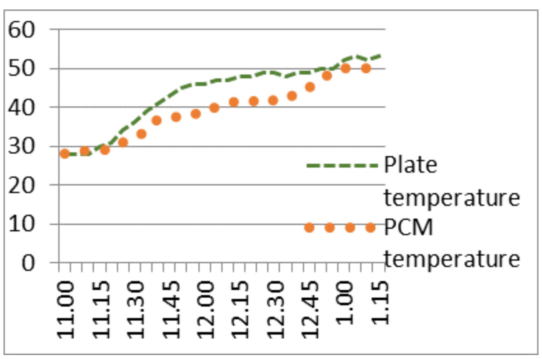

Fig. 4. PCM Heating curve

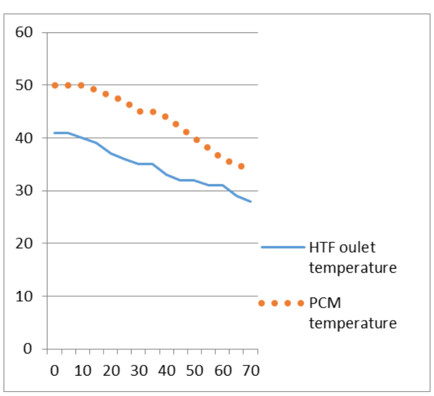

Fig. 3. PCM Cooling curve

Table 1
Charging process observation

Time interval	Plate temperature	PCM temperature	Observation of PCM state
11.00	28	28	solid state
11.05	28	28	solid state
11.10	28	29	solid state
11.15	30	29	solid state
11.20	31	29	solid state
11.25	34	31	solid state
11.30	36	32	solid state
11.35	39	34	solid state
11.40	41	37	solid state
11.45	43	37	solid state
11.50	45	38	solid state
11.55	46	38	solid state
12.00	46	40	solid state
12.05	47	40	solid state
12.10	47	41	solid state
12.15	48	42	solid state
12.20	48	42	solid state
12.25	49	41	solid state
12.30	49	42	solid state
12.35	48	42	solid state
12.40	49	44	solid state
12.45	49	45	solid/liquid state
12.50	50	47	solid/liquid state
12.55	50	49	begins to melt
1.00	52	50	partial melting
1.05	53	50	partial melting
1.10	52	50	partial melting
1.15	53	50	partial melting

Table 2
Discharging process observation

Time interval	HTF outlet temperature	PCM temperature	Observation of PCM state
0	0	50	partial melting
5	41	50	partial melting
10	40	50	partial melting
15	39	49	solid/liquid state
20	37	48	solid/liquid state
25	36	47	solid/liquid state
30	35	45	solid state
35	35	45	solid state
40	33	44	solid state
45	32	42	solid state
50	32	40	solid state
55	31	38	solid state
60	31	36	solid state
65	29	35	solid state
70	28	34	solid state

6. Conclusion

The experiment was performed to analyze the charging and discharging performance of paraffin PCM in a compact (prototype) flat plate and tube heat exchanger. Non concentrated direct sunlight is allowed to heat the flat plate. It is assumed that the solar irradiance incident on the flat plate is distributed uniformly across the surface. For heat transfer enhancement, fins are provided on the copper plate touching the PCM side. Water as heat transfer fluid at room temperature is used for discharging process. It is concluded from the following results:

- Melting begins in the region close to flat plate and PCM interface.
- Only partial melting of about 20-25 % is observed. Based on Hakeem Niyas, et al. [9] partial melting/discharging is efficient than complete melting/discharging.
- During charging process, initially for a certain minute's heat transfer rate is faster.
- The observed Charging time is 135 minutes and discharging time is 70 minutes.

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