Experimental Investigation of Thermal Performance of PCM based Heat Sinks of Different Fin Configurations & using Different Phase Change Materials Matrix

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Abstract

Thermal energy storage by Phase Change Material (PCM) is an effective way of energy storage for later use in many applications. As working of electronics components largely affected by temperature, it is necessary to reduce temperature of electronics components. This paper includes study of different heat sinks matrices containing PCM, fins and copper particles. Four matrices have been used. These are: Test section without fins without Cu particles, Test section without fins with Cu particles, Test section with fins without Cu particles and Test section with fins with Cu particles. Results indicated that analysis of heat capacity and thermal conductance evidence that a fin PCM filled heat sink with Cu particle has maximum heat capacity and thermal conductance. Also A uniform temperature distribution is found between heat sink and PCM (paraffin wax) which ensures equally melt fraction of PCM in spatial direction.

Keywords: Thermal Energy Storage, PCM, Heat Sinks, Fins, Cu Particles

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I. INTRODUCTION

Thermal energy storage (TES) is defined as the temporary holding of thermal energy in the form of hot or cold substances for later utilization. TES systems deal with the storage of energy by cooling, heating, melting, solidifying or vaporizing a material. Stored thermal energy makes available when the process is reversed.

In a number of applications like laptops, cellular phones, digital cameras and control systems in missiles, the thermal management solution needs to be reliable, safe, inexpensive, light, and durable and more importantly energy efficient. The reliability of equipment can be decided by expected frequency of failure as a function of time. Out of the various factors affecting the reliability of electronic equipment, temperature is one of the most important.

With the advancement in technology for large-scale integration of electronic circuits into compact form along with the continuous increase in power and performance requirements, the demand for greater heat dissipation in a more constricted space has grown tremendously. At the same time the reliability of an electronic component is defined as its ability to satisfy its desired purpose. An electronic component fails to assure its desired purpose when the environmental condition or its application exceeds its application limit. Investigations show that 55% of failures in electronic devices are related to high temperature.

Three types of TES systems are being investigated, especially for concentrated solar power (CSP) plants. Sensible heat thermal storage (SHTES) is the most frequently used and commercially available TES technology, however, LHTES is fast emerging as a viable alternative to SHTES. This is partly due to the fact that the LHTES has a higher energy storage density than the SHTES. The high energy storage density implies a smaller storage tank leading to a substantial decrease in the overall cost of the storage system. One of the major drawbacks associated with the LHTES is the longer charging and discharging times potentially leading to inefficient energy retrieval from the system. The main reason for this is the low thermal conductivity of the PCMs. various methods have been presented to increase the PCM thermal conductivity. Insertion of nano or expanded graphite mixture and metal particles into the PCM matrix increases the thermal conductivity of the PCM. Heat Sink with PCMs have also been shown to improve the heat transfer rate. Recently, in packed bed thermal storage systems, Heat Sink with metal particles has been considered as one of the heat storage approaches to encounter the low thermal conductivity problem of the PCMs.

II. EXPERIMENTAL SETUP

A schematic drawing of the facility used to determine heat capacity of PCM in heat sink is shown in Figure 1. The heat capacity of the Phase Change Material (PCM) is determined in this study. It consists of one power control panel. The dimmerstat is used to control the power supplied to the heater. The voltmeter and ammeter is connected in circuit to measure the amount of voltage and current supplied to the heater. The hater is used in this study is having square in shape with dimension of 200 mm. This heater is having the capacity of 250 watt.

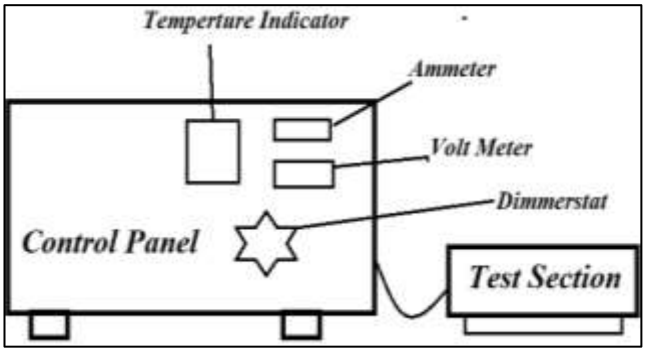

Fig. 1: Experimental Setup

The test section consists of base plate, heater, acrylic box and insulating base. The dimension of base plate is 200mm × 200 mm. The base plate is made up of from Copper as it is having good heat transfer rate with 10 mm thickness. The insulating box is having a cavity for base plate. The depth of cavity is 25 mm. The insulating box is made up of from wood. The insulating box consists of asbestos powder at base which reduces the heat transfer to the bottom side. Heater will placed on insulating powder, so that heat flow is restricted. The test section base plate is kept on heater. Test section is having two different plates i.e. with fins and without fins. Eight numbers of fins is used on fin test section having dimension of 100 mm length, 40 mm height and 3 mm thick. The acrylic box is used to hold the PCM in it. The capacity of acrylic box is 2 kg of PCM. The eight thermocouples are used to measure the temperature at various locations. Temperature measure at interference between heater and test section, test section at upper side, fins temperature and PCM temperature. The actual experimental setup is shown in figure 2.

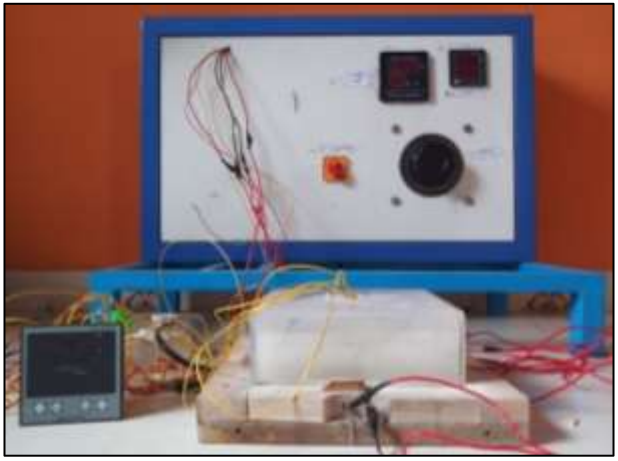

Fig. 2: Actual Experimental Setup

A. *Test Plate*

The test plate consists of base plate with or without fins along with PCM filled in acrylic box. Total four test section is required for this study purpose. The four test section is as follow:

a) Test section without fins without Cu particle
b) Test section without fins with Cu particle
c) Test section with fins without Cu particle
d) Test section with fins with Cu particle

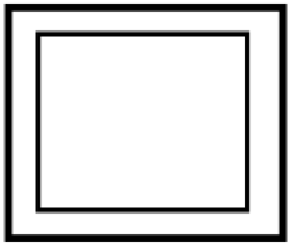

Fig. 3: Test section without fins without Cu Particles

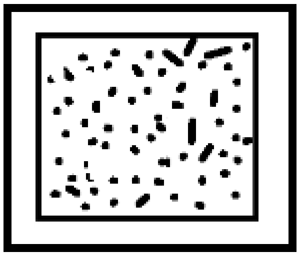

Fig. 4: Test section without fins with Cu Particles with Cu particle

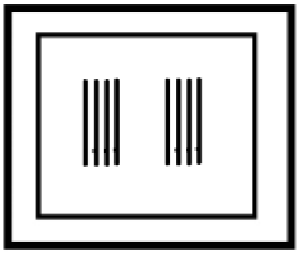

Fig. 5: Test section with fins without Cu particle

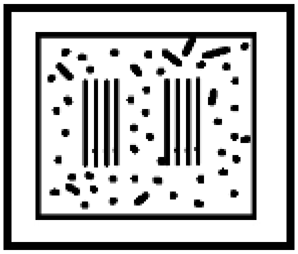

Fig. 6: Test section with fins with Cu particle

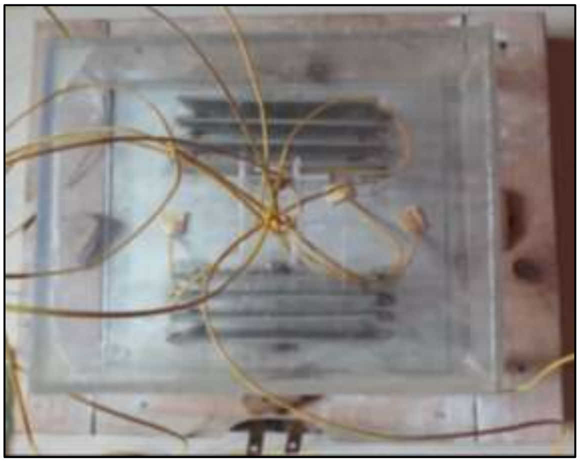

Fig. 7 Actual Test section with Fins having on base plate

III. EXPERIMENTAL PROCEDURE

Four tests are carried out during this study. These four tests are carried out as follow:

1) Base plate with fins and with Cu particles
2) Base plate with fins and without Cu particles
3) Base plate without fins and with Cu particles
4) Base plate without fins and without Cu particles

The test section is prepared before start of the test. The preparation is include selection of base plate i.e. with fins or without fins and PCM with or without copper (Cu) particles. The test section preparation is started with base plate then thermocouple is placed at different location like heater, base, plate, fins and PCM.

IV. RESULTS

The effect of Phase Change Material on latent heat recovery from heat source with and without fins section is studied along with the Copper particle is placed in PCM.

A. Base Plate with Fins, with & without Cu Particle Added in PCM

Fig.8 shows clearly, that at the beginning, the temperature of the heat sink t PCM increases, until reaching the melting temperature of the PCM. At this point, the PCM maintains its temperature while the temperature of the heat sink with PCM continues increasing until reaching the steady state temperature (72^0 C).

In the case with PCM without Cu particle, the heat sink base temperature increases slowly to reach a peak value of 72°C at the end of heating stage, while that with PCM with Cu particle it increases at a rapidly to reach a lower value than that of the case with PCM without Cu particle. This shows the clear advantage of using PCM where after reaching the melting point of the PCM, the heat sink is significantly cooler during the heating phase than the case without PCM. This is owing to the fact that the PCM absorbing large amount of heat (the latent heat) when it melts at the melting point resulting in better cooling of the heat sink. The solid PCM begins to melt at 60°C where latent heat is stored during this phase change process, but the heat sink temperature is not constant as anticipated and increased at a slow rate, which is caused by the poor thermal conductivity of PCM. By using the Copper particle into the PCM thermal conductivity is increases and the removal of sensible heat is also good in this case.

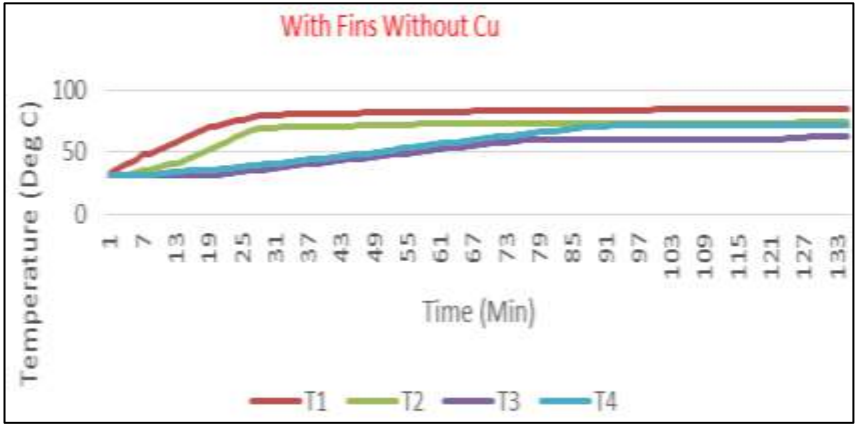

Fig. 8: Temperature Profile for Base Plate with Fins and without Cu particle

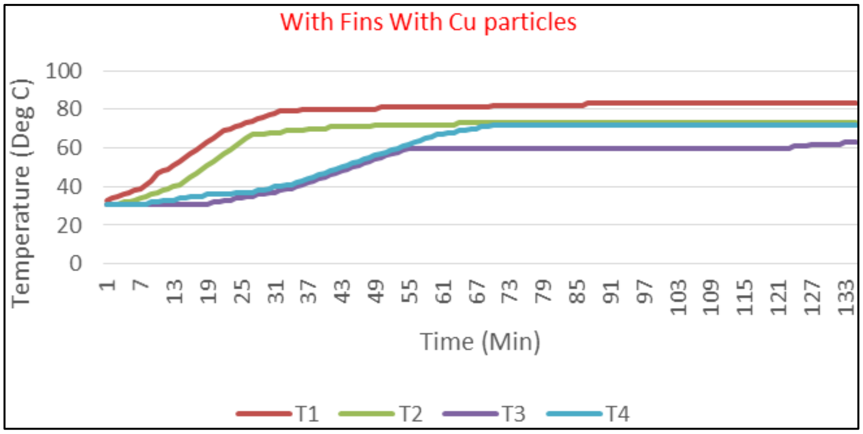

Fig. 9: Temperature Profile for Base Plate with Fins and with Cu particle

It is apparent from fig.9 that by adding the Cu particle in PCM height considerably reduces the maximum heat sink temperature. The addition of Cu particle in the PCM increases the thermal conductivity of PCM, and therefore increases the heat transfer to the PCM.

B. Base Plate without Fins, with & without Cu Particle Added in PCM

Fig.10 shows the variation of average temperature during the heating phases for the base plate without fins and without Cu particle in PCM at 125W. As depicted in fig.9, the absence of fins in both with and without Cu particle configurations results in lower heat transfer during the heating process than that of the PCM with fins. This is definitely due to the decreased in overall heat transfer rate of the heat sink as a result of the decreased contact area with the base plate as absence of fins.

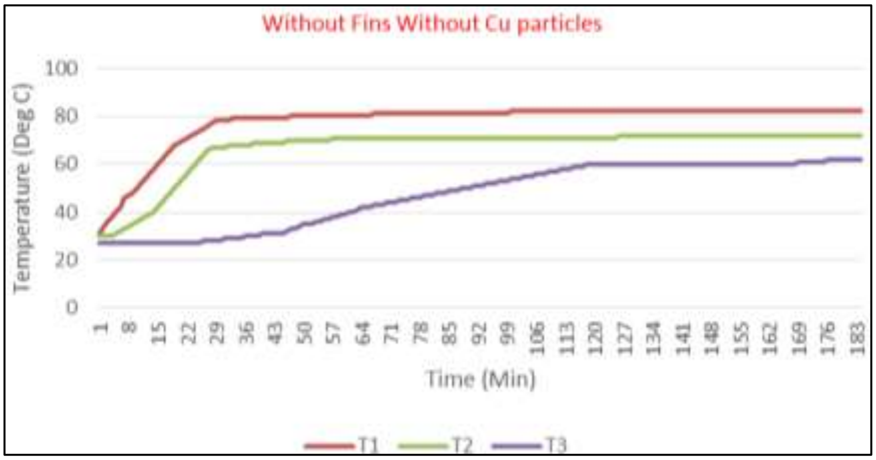

Fig. 10: Temperature Profile for Base Plate without Fins & without Cu Particles

The effect of Cu particle on the thermal performance of base plate with PCM is shown in fig.9. As can be seen, using the Cu particle in heat sink with a PCM the maximum heat sink temperature by about 71 ^{0}C, compared to a reduction 7 minute in the case without Cu particle in PCM. The thermal conductivity of Cu particle in PCM-based heat sinks is thus improved when using Cu particle in PCM based heat sinks.

As mentioned so far, a comparison between different heat sink designs is necessary to choose between alternatives with regards to best thermal performance. Having the same quantity of PCM, an attempt was made to study the effect of fin and Cu particle on the thermal performance of heat sink.

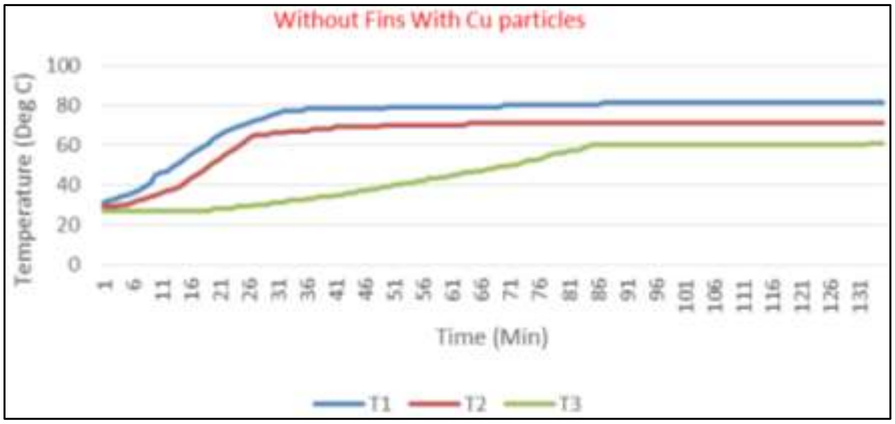

Fig. 11: Temperature Profile for Base Plate without Fins & with Cu Particles

In the current case, however, this behavior is minimal due to mainly because of the heat sink with Cu particle in PCM used and also owing to the difference in temperature between heat sink walls and ambient air. The heat sink without fin showed poor thermal performance than the one with fin. This is actually due to the large contact area between heat sink walls and the ambient air in case of heat sink without fin.

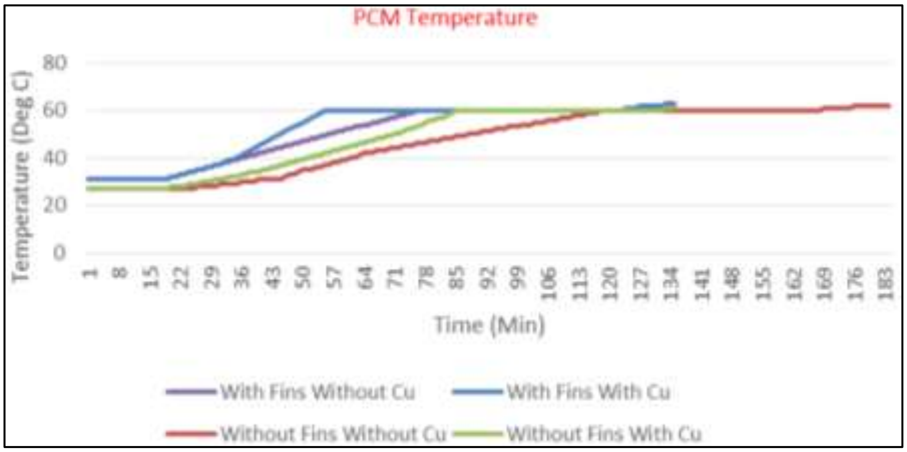

Fig. 12: PCM Temperature in all Cases

In order to compare between with and without fins, the simulation results of the temperature profiles of the heat sink under the three heat fluxes are depicted in fig.9. As shown in fig.9 we can clearly notice that at the beginning, the graphs have the same variation, until reaching the melting temperature for the PCM (60^0 C) starts to melt. At this point, the PCM starts to absorb energy until reaching the liquids temperature for each PCM (60^0 C) which indicates that the PCM is completely melted then the temperature continues to increase until reaching the steady state temperature.

The time needed to reach steady state is varying because of presence of fins and in some study Cu particle. Note that the two PCM condition (with and without Cu particle) used in this study have approximately the same heat capacity and the same latent heat of fusion. Also, the melting time of the two PCMs is approximately the same (the time from solidus to liquids status), thus is due to the difference in the in term of thermal conductivity. PCM without Cu particle has a smaller thermal conductivity than PCM with Cu particle so it can absorb smaller amount of heat by conduction and can consequently melt slowly.

V. CONCLUSION

The present experimental study with basic objective is to analyze the performance of heat sink with and without fins and also the effect of the Cu particle in PCM containing fin and without fin heat sinks for efficient working. Some contributions from this analysis are as following;

1) It is concluded that a heat sink with fins and Cu particle filled within PCM has more tendency to store more heat than that of other cases.
2) It is concluded that base plate with fin heat sink filled with PCM is more efficient and has significant thermal performance in comparison of non-fins heat sinks.
3) A uniform temperature distribution is found between heat sink and PCM (paraffin wax) which ensures equally melt fraction of PCM in spatial direction.
4) A time required for melting the PCM is less in case of heat sink with fins and Cu particle in PCM as compared to other cases.
5) Finally, analysis of heat capacity and thermal conductance evidence that a fin PCM filled heat sink with Cu particle has maximum heat capacity and thermal conductance.

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