Phase Change Material based Heat Withdrawal System (HWS) with Improved Heat withdrawing Capacity in Hot Environment for High Power Electronic Equipments / Devices

[1] Deepak Gupta
Defence Laboratory, Ratanada,
Defence Research & Development Organization,
Jodhpur (Raj.),INDIA

[2] Pramod Sharma
Defence Laboratory, Ratanada,
Defence Research & Development Organization,
Jodhpur (Raj.), INDIA

[3] Ravindra Kumar
Defence Laboratory, Ratanada,
Defence Research & Development Organization,
Jodhpur (Raj.),INDIA

[4] Akhil R. Garg
MBM Engineering College,
Jai Narayan Vyas University,
Residency road, Jodhpur (Raj), INDIA

Abstract: **Conventional heat sinks used with electronic devices are designed for normal ambient temperature. Performance of these devices gets degraded or device starts malfunctioning, when used in high temperature field environment conditions like desert. To improve their working or operational time, a Phase Change Material (PCM) based heat withdrawal system (HWS) having capacity to withdraw a significant amount of heat even in hot environment has been designed and tested on simulated heat source for its heat withdrawal capacity. Results indicate that under the harsh field environment conditions (like desert) the PCM HWS maintains the device steady state temperature below its healthy operational temperature (near 100˚C) for more than 5hrs (tested), while temperature of electronic devices with conventional heat sinks shoots above 150˚C in a very short interval of time with the conventional heat sinks. Hence, in this work we suggest that the PCM HWS may be helpful in place of conventional sinks during hot ambient conditions to improve the system reliability and operation time.**

Keywords: Phase Change Material, PCM, Ambient temperature, Heat withdrawal system, Cool plate, Cartridge, Heat exchanger, Coolant, Electronic equipment.

I INTRODUCTION

During field operations electronic systems have to withstand many typical environmental conditions like high ambient temperature, high rate of rise of temperature, dust storms and unbroken sunshine etc. One of these condition i.e. high ambient temperatures of desert severely affects the efficiency of existing cooling system (heat withdrawal system) of electronic equipments, causing their underperformance, malfunctioning or failure.

High temperature operation not only reduces the performance of electronic devices, but also greatly shortens their lifetime study published by Wallace T. Anderson[1]. Arrhenius equation shows that component life becomes half for every 10˚C increase in component temperature. As the ambient temperature increases, the heat transfer rate from junction to ambient reduces, which inturn increases the junction temperature and reduces device life as well as degrade its performance.

Electronic gadgets mostly use conventional cooling methods such as finned aluminum/ copper heat sinks, convection cooling by forced air, thermo electric coolers using Peltier effect [2], heat pipes [3] and fluid jets [4] for heat management and to maintain device junction temperature within its specified limit. All these technologies have their own merits and demerits, but one limitation is common in all, that's ambient temperature, which greatly affects their working efficiency or heat withdrawal capacity. To overcome this limitation phase change material based HWS may be used.

Phase Change Materials (PCM) absorb large amount of latent heat in narrow range of their phase transformation. These PCM based cooling technology may be helpful for improving efficiency of heat management system of electrical or electronic equipments in high ambient temperature conditions. Dong-won Yoo et al.[5] reported the incorporation of phase change materials in heat sink and reported that inclusion of PCM gives the possibility of size reduction of thermal management devices like heat sinks. Amy S Fleischer et al.[6] analyzed the performance of PCM with an embedded light weight carbon fiber heat sink to improve its thermal performance. Maurice J. Marongiu [7] describes in his paper on the design and development of a PCM heat exchanger, and reported that PCM plays active role for storage of energy during high load periods and release it during low load periods. Results indicate that PCM heat exchangers work relatively well in maintaining target temperatures. Esam M. Alawadhi [8] published a paper on thermal management of an electronics devices using PCM and reported that incorporating PCM package into an electronic system enhance heat removal capacity.

In this paper, study has been carried out to see the effect of PCM and circulating coolant on heat source temperature in the high ambient temperature conditions. A HWS (Indian patent application no 1913/DEL/2011 Dated 02-08-11) [9] consists of PCM incorporated cool plate to replace the conventional heat sink has been designed and fabricated. Results of heat withdrawing capacity using cool plate and conventional aluminum sink in term of source temperature rise has been compared. The details of study are given below:

II MATERIALS AND METHODS

Metal eutectic PCM are prepared by solid solutionising of low melting metals like Bi, Sn, Pb, cd, In. The melting point of PCM metal eutectic can be tailored by changing the composition of metals. In this study PCM having melting point 72˚Cwith enthalpy of fusion 20-25J/g [10] (Bi:50%, Sn:12.5%, Pb: 25%, cd:12.5%) has been used as the primary PCM in the cool plate of HWS. Another PCM have also been used in PCM cartridges termed as secondary PCM. The secondary PCM used in cartridges is multi transformation PCM developed at DLJ (Indian patent application No. ERIP/IP/0701014/M/01 dated 5th Dec 2007). The melting point of Secondary PCM is chosen slightly lower than that of primary PCM. It facilitates heat transfer from cool plate to PCM cartridges.

III DESIGN AND FABRICATION OF PCM HEAT WITHDRAWAL SYSTEM (PCM HWS)

PCM HWS consists of mainly four parts as described in fig 1:

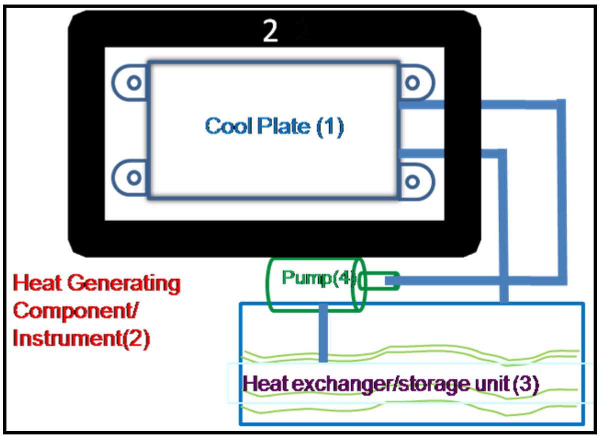

Fig. 1 Schematic diagram of PCM based heat withdrawal system

A. PCM Cool Plate
B. Heat Generating Source
C. Heat Exchanger Cum Heat Storage Unit and PCM Cartridge
D. Coolant and Coolant Circulating Pump

A. PCM Cool Plate

Cool plate used in heat withdrawal system, as shown in fig 2, is a small aluminum container (1) of Size (114 * 34* 16 mm) filled with primary PCM (2), hermetically sealed to avoid leakage of liquid PCM.

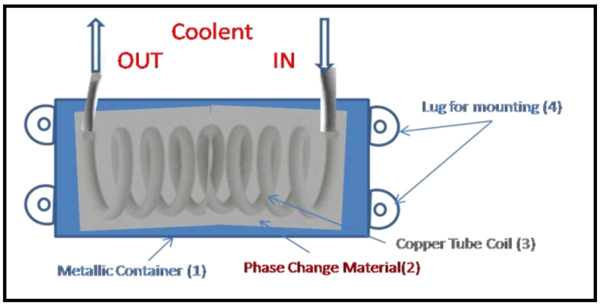

Fig. 2 Schematic diagram if PCM cool plate

A copper tube coil (3), of length 50 cm with 7 turns, is used as heat exchanger and submerged in PCM for coolant circulation. Lugs (4) have been provided on cool plate to facilitate mounting. The size and shape of the cool plate and tube heat exchanger can be tailored as per the space available for a particular application. The cool plate container material used are aluminum or copper, having property of high heat conduction and non reactive with liquid PCM.

The cool plate is mounted on the heat generating equipment / component from where heat has to be withdrawn and coolant is circulated through the tube heat exchanger.

B. Heat Generating Source

As explained in experimental setup, it is supposed to be the instrument on which cool plate is to be mounted for extraction of heat. For the experimental purpose dc heaters using nichrome wire are fabricated of different wattage.

C. Heat Exchanger cum Heat Storage Unit and PCM Cartridges

The HWS uses special heat exchanger cum heat storage unit (HEHSU) to feed almost constant temperature coolant to cool plate at high ambient temperature. The HEHSU is compact metallic unit of SS (size 30 X 12 X 10 cm) consisting of pump, PCM cartridges and coolant as shown in fig 3.

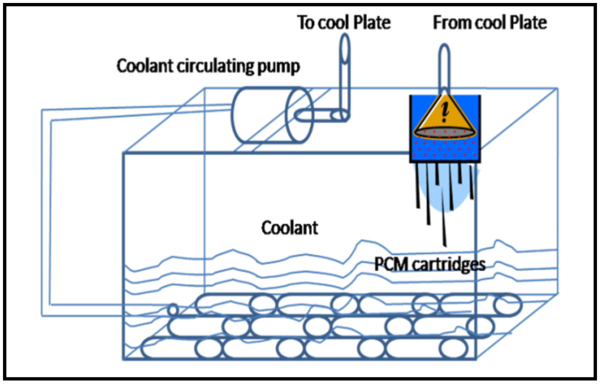

Fig. 3 Schematic diagram of heat exchanger cum storage unit.

The number of PCM cartridge placed in HEHSU may be varying according to heat storage requirement. A sprinkle is used for the coolant circulating from cool plate to convey its heat to ambient.

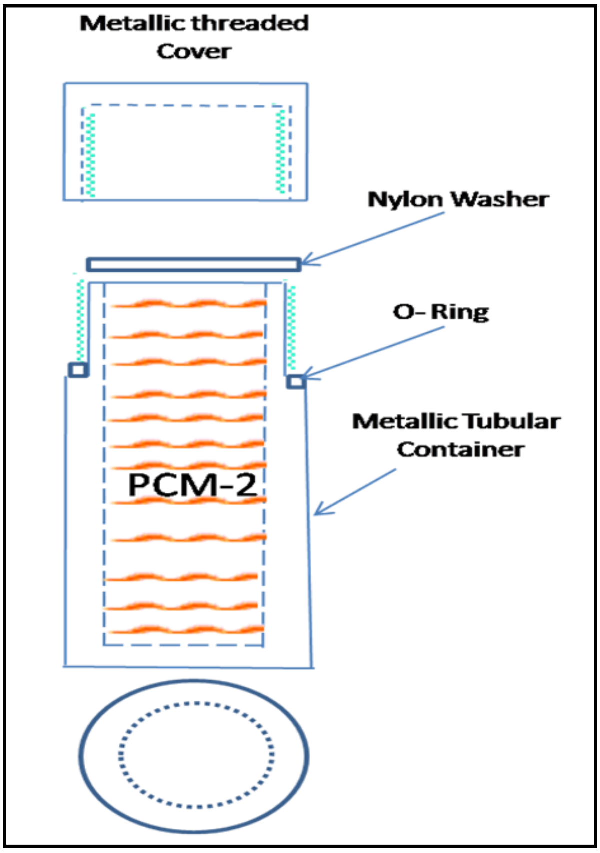

Fig. 4 Schematic diagram of PCM cartridge

The PCM cartridges used in heat exchanger are the aluminum tubes filled with secondary PCM. The tubes have special mechanically tightened lid (As shown in fig 4) which does not allow any leakage of liquid PCM after its melting. Aluminum is used for fabrication of tubes for PCM cartridges having characteristic of high thermal conductivity, light weight and chemically inert to liquid PCM and coolant. The secondary PCM has characteristics 00000 of high latent heat of fusion and is light in weight; its melting point is little degree less than primary PCM used in cool plate.

D. Coolant and Coolant Circulating Pump

In HWS coolant from the HEHSU circulates through cool plate with the help of pump and connecting tubing. The coolant used is concentrate coolant from M/s ac-delco Company. Approximately two liters of coolant has been used during the study to circulate in close loop. The pump may be of any type a.c. or d.c. placed in HEHSU and submerged in the coolant. A variable speed drive may be used to drive the pump, so that the pump output flow rate may be varied to meet coolant flow demand to extract heat over desirable range. The HEHSU work as a heat buffer as coolant temperature normalized in HEHSU by sprinkle and PCM cartridges.

The typical size of PCM cartridge is 150mm length and 25mm outer diameter. The inner diameter is 20mm and one cartridge contains approximate 50 grams of secondary PCM. The number of PCM cartridge may change according to temperature relief requirement.

The combination of all four parts makes the PCM HWS.

IV WORKING AND EXPERIENTIAL SETUP

This section describes the HWS working and the way; it improves the heat withdrawal from heat generating devices. It also explains the experimental setup used to evaluate the HWS.

A. Working

Initially cool plate mounted on the heat generating device withdraws heat as conventional heat sink and heat generating device temperature increases normally.

- As the cool plate temperature shoots above the primary PCM temperature PCM starts melting and absorbs heat continually equivalent to its latent heat of fusion.
- During this coolant from HEHSU also circulates through the coil plate's heat exchanger and withdraws heat from PCM and tries to maintain it in continuous absorbing state.
- During close loop traveling, coolant gather heat from partially molten primary PCM and carry it to HEHSU and convey to atmosphere by way of sprinkle.
- Thus the coolant temperature increase slowly and further its temperature decrease by absorbing heat by secondary PCM (melting point few degree less than primary PCM) of cartridge in HEHSU. Secondary PCM present in the PCM cartridges absorbs large amount of heat from hot circulating coolant and store it as latent heat of melting. This extraction of heat from circulating coolant, slow down its temperature rise rate or maintain the coolant efficiency of heat removal higher with time.
- This coolant continuously circulates through the cool plate and withdraws heat from cool plate. In this process it maintains the high rate of heat withdrawal capacity of HWS, which is more than the conventional heat sink. High rate of heat removal from heat generating component/ equipment, keeps their temperature below safe limit for longer duration even in high ambient temperature condition.

To validate the HWS effectiveness a test method and set up has been designed and experimental results are compared with conventional heat sink.

B. Experiment set up:

To study the performance of PCM HWS in hot climatic environment and its utilization with heat generated electronic or electrical instruments a experimental set as shown in fig 5 has been assembled. This set up is integration of climatic chamber, heating source, sensor, power supply etc. The details of different parts of set up are as follows:

- *Environmental (Climatic) Chamber [1]:* A climatic test chamber, CME make, has been used to provide the simulated ambient temperature for the test set up. The temperature range that can be simulated inside the chamber from -30 °c to 120 °c.

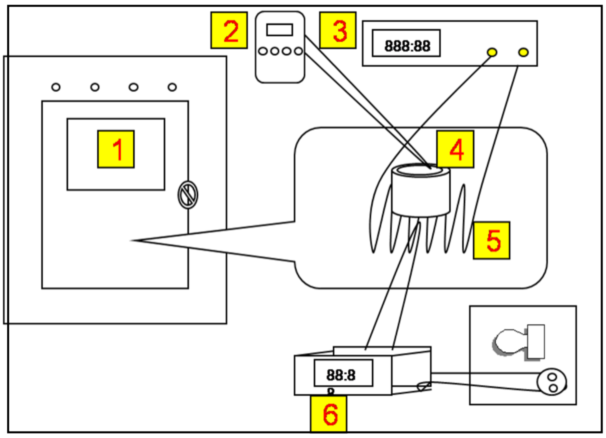

Fig. 5 Schematic diagram of experiment setup for thermal performance evaluation

- *Heat simulation source [5]:* Heat simulation source has been developed using Nichrome (80% nickel and 20% chromium) metal heating ribbon of required width and thickness. The heating element selected on the basis of power (heating) output requirement and size of heating source. Heat sources of 20, 40 & 60 watt capacity is designed and fabricated for our testing purpose
- *Sensor and Display [2,3,6]:* For temperature monitoring during performance evaluation of heat sink and PCM HWS different temperature sensors and indicators are used.
  i) For monitoring of heater source temperature a PT-100 sensor is used. This sensor is inserted in between the mica layer (just above the heating filament) and the copper plate (used for uniform distribution of the temperature). The two output control leads of the sensors are extended by using the thin wires of the cooper, to take out the connection to display unit of the PT-100 sensor. The range of this display is -50˚C to 400˚C.
  ii) For monitoring of coolant and heat sink temperature inside the climatic chamber digital thermo meter of Euro lab make are used. The probe of this thermometer is fixed on the heat sink fins and the display is set on the desk outside the chamber to monitor the temperature. The range of the thermometer is -50˚C to 200˚C.

V METHOD OF EVALUATION

To evaluate and compare of performance of PCM HWS and conventional heat sink following steps are performed:

- Assembled the test set up in the test chamber and Mount the conventional heat sink on the heater. Data are collected for source temperature with time for set of input power i.e 20,30,40,54 watts at ambient temperature 30˚C.
- The same sets of data are collected by changing the ambient temperature of climatic test chamber at 50˚C.
- The experiment was repeated by mounting the PCM HWS cool plate on heater for the same conditions, where source temperature using conventional sink cross the temperature limit i.e 140˚C.
- Another set of data are collected with PCM HWS for even more harsh condition of temperature at 55˚C.
- To show the PCM effectiveness for heat removal, the comparison also made by changing the PCM cool plate by same size aluminum casted cool plate with HWS.
- The different responses of source temperature with time are presented in next section.

VI RESULTS AND ANALYSIS

A. Effect of High Ambient Temperature on Source Temperature

Using the experiment setup, as shown in fig 5, source temperature data has been collected with conventional heat sink and PCM HWS at ambient temperature 30˚C and 50˚C with different input power. For this study, typical case, a heat sink used with solid state power amplifier (SSPA) attached in air born SATCOM system is studied for its heat withdrawal capacity. A result shown in fig 6 indicates that for low wattage (below 40 watt) and ambient temperature below 40˚C, the conventional heat sink performs well and source temperature remains within the operational limits.

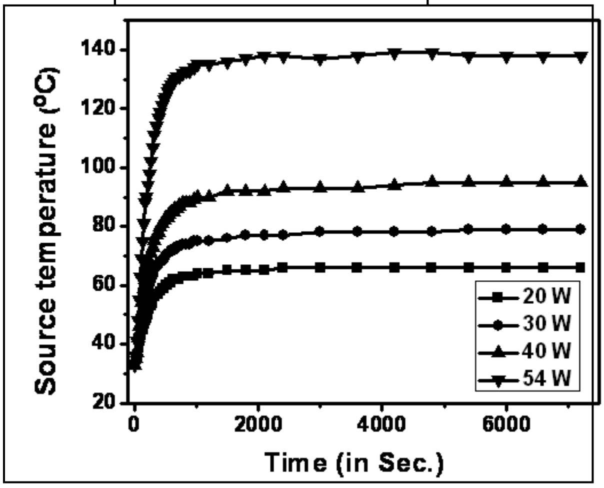

Fig. 6 Performance of conventional heat sink at ambient temperature 30˚C with different input power

As the ambient temperature in the vicinity of conventional heat sink increases near to 50˚C its capacity to withdraw heat degraded rapidly as it depend upon the ambient temperature as shows in fig 7. Graph shows that at high ambient temperature, because of the low temperature gradient between heat sink and ambient temperature, the source temperature increase rapidly as I/P power increase.

Conventional sinks attached with power devices can maintain the device temperature below their normal operating temperature i.e. 140˚C at ambient temperature 30˚C, but as the ambient temperature increase from 30˚C, because of low temperature gradient, heat withdrawal capacity of conventional sinks reduces drastically causes higher source temperature. The conventional sinks are in adequate at higher ambient temperature and high applied wattage.

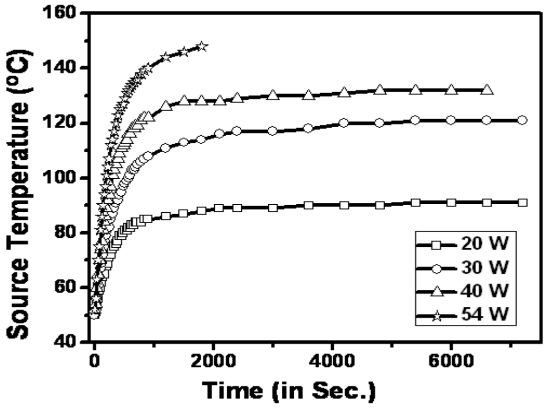

Fig. 7 Performance of conventional heat sink at ambient temperature 50˚C with different input power

B. Performance Comparison of HWS and Conventional Sink at High Ambient Temperature:

Comparison of source temperature with conventional and PCM HWS at high ambient temperature and high input power is presented in fig 8.

Comparison data shown for temperature rise for the conventional heat sink at ambient temperature 30˚C and 50˚C and HWS performance at ambient 50˚C. Curve indicates that at 50˚C ambient temperature heat generating source temperature with conventional heat sink increases above 140˚C the operational safe limit of electronic equipments, but with PCM HWS source temperature remain below 100˚C with 54watt I/P power and same operational conditions. Thus HWS withdraws higher amount of heat compare to heat sink and maintains source temperature below safe level consistently.

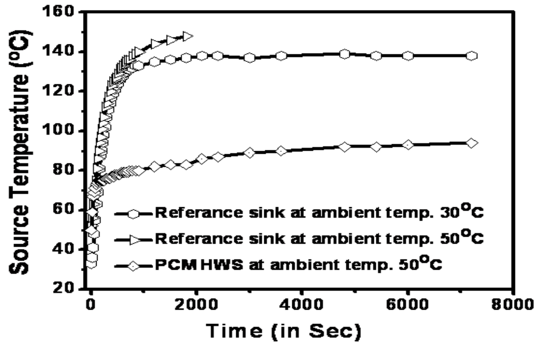

Fig. 8 Comparison of HWS and conventional heat sink performance at ambient temperature 50˚C with 54watt input power

C. Performance Comparison of HWS with PCM and Aluminum Cool Plate

Fig 9 shows the typical conventional heat sink, Aluminum cool plate HWS and PCM cool plate HWS at ambient 55˚C for their heat withdrawal capacity in terms of rise in source temperature with time. It shows that with conventional (reference) sink source temperature boost to 130˚C within 5 minutes time, whereas, with PCM HWS it remain within 100˚C tested for 4 hrs at I/P power of 54watt, in the similar conditions. Further to show the active involvement of PCM for improvement of the heat withdrawal capacity of cool plate comparisons have also been done with aluminum cool plate HWS system. It confirms that rate of rise in source temperature is comparably less in PCM HWS than other two, also the steady state source temperature is down by around 20˚C than the Al cool plate HWS.

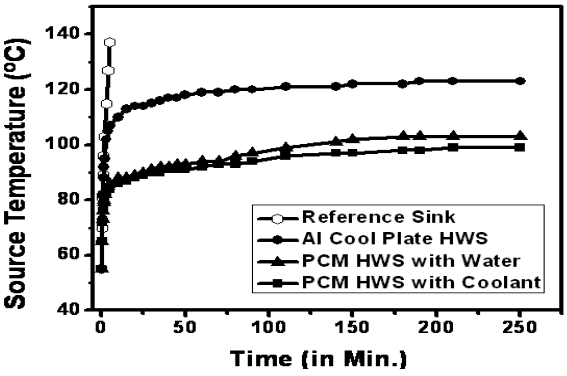

Fig. 9 Comparison of PCM HWS and aluminum cool plate HWS performance at ambient temperature 55˚C with 57watt input power

VII CONCLUSION

The high ambient temperature always adversely affects the performance of the conventional cooling system attached with electronic equipments. The PCM HWS can be one of the better alternative, as PCM absorption capacity is not affected by ambient temperature, its depends upon solution melting point and its latent heat of fusion. So as the temperature of the heater plate (simulation of the heat generated electronic devices) increases above the PCM melting point, PCM cool plate starts absorption of heat by phase transformation of the PCM and stops the further sharp rise of temperature. At the same time circulating coolant withdraw heat from the PCM cool plate, keeps the PCM in absorbing state.

Hence, phase change material based HWS enhances heat withdrawal capacity from the heat generating source, keeps its temperature within operational safe limit. It also concludes that PCM HWS can helps to operate the power devices in sever hot (desert) field condition without malfunctioning or failure. Also, for the same input power the size of the conventional sink available on board can reduce by use of small size PCM cool plate.

VIII ACKNOWLEDGEMENTS

All the experiments are conducted at Defence Laboratory, Jodhpur and authors are acknowledge the support provided by DLJ to complete the all necessary experiments.

REFERENCES

[1] Anderson, W.T., "DC Semiconductor device reliability in extreme high temperature space environments", IEEE Proceedings Aerospace Conference, VOL. 5, 2001, pp. 2457 - 2462.

[2] Julian H. Goldsmid, Introduction to Thermoelectricity, Publisher Springer, ISBN: 978-3- 642-00716-3, 2009.

[3] Eugene R. Hnatek 2003, Practical reliability of Electronic Equipment and Products Hand Book, Publisher Marcel Dekker Inc., ISBN: 0-8247-0832-6.

[4] Arik M., Todd W. G., Stephen S.A., "Cooling system employing fluidic jets, methods for their use and methods for cooling", Feb' 2008, US patent no. 0041574.

[5] Dong-won Yoo and Yogendra K. Joshi, "Energy efficient Thermal Management of Electronic Components using Solid-liquid Phase Change Materials", IEEE Transactions on Device and Materials Reliability, VOL. 4, NO. 4, December 2004, pp. 641-649.

[6] Amy S Fleischer, Randy D Weinstein, Thomas Kopec, " Analysis of transient Thermal Management characteristics of PCM with an Embedded carbon fiber heat sink", IEEE Transactions 0-7803-9524-7/06/2006, pp. 1265-1268.

[7] Marongiu, M. J., “Issues in the Thermal Management of Outdoor Telecommunications Cabinets/Enclosures”, TELESCON 97, Budapest., Hungary, April 1997, pp. 22-24.

[8] Esam M. Alawadhi, " Thermal Management of Blocks in a Channel using Phase Change Material, IEEE transactions on components and packaging technologies, VOL. 32, NO. 1, March 2009.

[9] DLJ Patent (Indian patent application No. ERIP/IP/0701014/M/01 dated 5th Dec 2007).

[10] Mehling H., Cabeza L.F., Heat and cold storage with PCM, Publisher Springer, ISBN 978-3-540-68556-2, 2008.