Experimental Investigation of Heat Exchanger Using Phase Change Material

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Abstract— Phase change materials (PCMs) are considered widely as alternative cooling methods for transient electronic cooling. The uses of PCM's for heating & cooling applications for buildings have been investigated within the past decade. Experimental study of the performance of PCM incorporated of steel and copper heat exchangers for thermal management has been done. Two phase change materials (PCMs) OM32 and OM64 having melting points 28 to 37 °C and 60 to 70°C respectively are selected to be used to fill inside a heat exchanger which is made of copper. A round configuration is used and its effects of heat removal from heat source have been studied. The effect of PCMs on source, which enhance the operating time for different set points of temperatures and on the duration of latent heating phases, has been explored. Based on the findings, best solution that can be used in electronics cooling with PCM's has been studied.

Keywords: Thermal Energy Storage, Phase Change Material, Heat Exchange, Heat Transfer Enhancement

I. INTRODUCTION

Notable increase in density integration, clock rates, and upcoming trend of miniaturization are the advantages that have been resulted in modern electronics. In order to satisfy the junction temperature requirements in terms of performance and reliability, advanced improvements in cooling technologies are required. For electronics industry a thermal management is very important and increasingly critical. It is important task of the thermal engineers to maintain suitable junction temperature by dissipating the heat from the integrated circuit chips.

Advanced thermal architecture is required to meet these thermal requirements. Mechanical stresses, thermal de-bonding and thermal fracture are the thermal failures occurring at high chip temperatures. The percentage of failure during operations occurs mainly due to temperature as shown in fig. 1 [1].

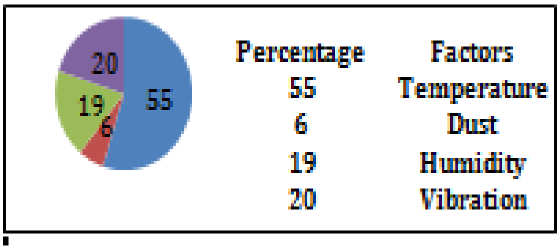

Fig.1 Elcectronic Failure Pie Chart

Lasance [3] mentioned three typical reasons, given below for the ever increasing importance of thermal management:

1. At the component level, designers reduced package dimensions while increasing power density, which create the problem to minimize the thermal resistance from junction to case, it is a crucial part of the package density,
2. Electronic industries thermal design tends to be an afterthought of the design process only if the prototype raises any thermal issues, and
3. The use of air cooling with heat sink and fan is expected some limitations in the coming years.

Therefore thermal management is an important technique in the development of advance electronics. It is part of competitive power density environment. The new tools and technologies employed for cooling; should have no asset change in the constraints and design requirements. Thermal management is not necessary for new designs. It must be discarding with other requirements and constraints. The cost is the main constraint for any thermal management. Therefore the cooling technology must be cost effective and keeping pace with the reduction in overall package and system cost per function. The cost of cooling is important factor, which plays an important role in maintaining competitiveness. [3]

Phase change material cooling is passive cooling technique, which has advantages such as high specific heat, high latent heat of fusion, small volume changes, availability of PCMs at appropriate melting temperatures and chemical properties such as non-toxicity, inertness and non- corrosiveness. Paraffin's and non-paraffin's and salt hydrates and metallic are organic and inorganic phase change materials respectively. PCMs can be used for a large number of cycles, so they are suitable for repeated use. PCMs are selected based on their heat of fusion and melting temperatures. The melting temperature of PCM should be below the maximum operating temperature of the equipment. Phase change materials have a very low thermal conductivity, because of this charging and discharging is slow during PCM melting. High thermal conductivity materials with fins are used of different geometry with PCMs which can outfit this challenge. [2]

II. THERMAL ENERGY STORAGE METHODS

There are many ways to store thermal energy. They can be divided into:

1. Sensible heat storage
2. Latent heat storage
3. Thermo-chemical storage

2.1 Sensible heat storage

In sensible heat storage, the thermal energy is stored due to increase in temperature of stored medium. The amount of energy stored depends on the specific heat, the change in temperature and mass of the material.

$Q = \int_{T_1}^{T_2} mC_p \, dT$

Sensible heat storage can be differentiated on the basis of storage media, *viz. (i)* liquids such as oil, water and molten salt, and (ii) solids such as rocks and metals.

2.2 Latent heat storage

Latent heat storage system (LHS) uses the energy released or absorbed in the phase change region. When the material reaches the phase change temperature it absorbs or releases a huge amount of energy to carry out the phase change which is known as the latent heat of fusion or evaporation depending on the state and in this way the energy is stored. The materials used are known as phase change materials (PCM). They have very high energy density and hence they reduce the volume and hence the cost. Figure 2.2.1 explains the energy storage mechanism of a PCM. When a solid is heated, its temperature rises up to its melting temperature. After this point the temperature come to an end & increases and the phase change occurs. After the PCM has completely melted, the temperature rises again up till it reaches the boiling temperature. After this the temperature remains constant till everything is evaporated. In PCM application one can give and extract the energy within the phase change region and therefore without changing the temperature.

$Q = \int_{T_1}^{T_m} mC_{p\_solid} \, dT + mL_m + \int_{T_m}^{T_f} mC_{p\_liquid} \, dT$

1. The 1st term represents the increase in sensible energy stored by the increase in temperature of material from initial temperature to melting temperature.
2. The 2nd term represents the latent energy stored in the material by phase change.
3. The 3rd term represents the sensible energy stored by increase in temperature.

Most of the PCM suffer from a constraint of low thermal conductivity of around 0.2 and 0.5 W/mK for paraffin and inorganic salts respectively.

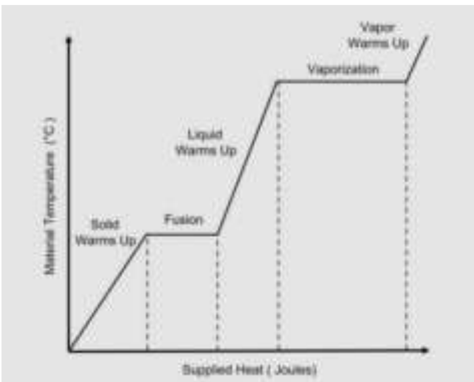

Fig. 2.2.1: Temperature profile of a PCM with heat supply

2.3 Thermo chemical heat storage

This is the most underdeveloped method of thermal energy storage. It contains the use of endothermic chemical reactions. When heat is supplied to an appropriate material, it is utilised in breaking the chemical bonds of the compound. Later all of this energy is recovered when the reaction takes place. This technology offers various advantages but it is in the early stages of development. The different types of PCMs are classified in figure 3

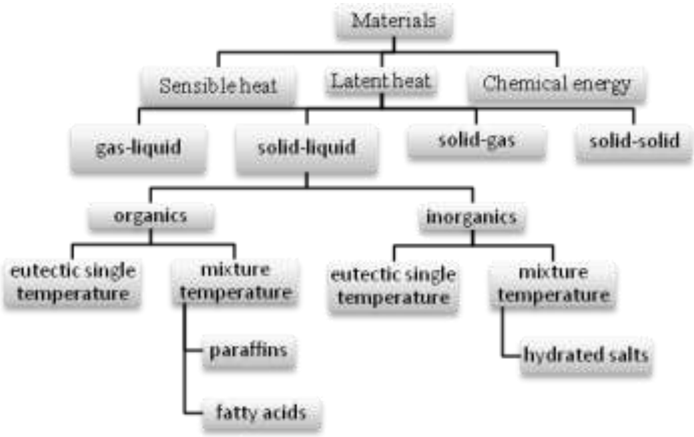

Fig. 2.2 Classification of TES materials

III. CLASSIFICATION OF PCM

The materials used in latent heat application are known as phase change material (PCM). They may undergo the following transformations:

1. Solid-solid (Ex. Cellulose diacetate)
2. Solid-liquid (Ex. Paraffin)
3. Liquid-gas (Ex. Water)

3.1 Solid-solid PCM

Solid PCM materials transform their crystalline structure at a particular condition.The transformation energy is comparable to solid to liquid PCMs. They are very easy to handle and cost effective because the absence of liquid state eliminates the problem of leakage and need for encapsulation. Research is going on for developing steel alloy for such application [3].

3.2 Liquid-gas latent heat storage

The transformation from liquid to gaseous state requires the highest amount of energy. But due to enormous amount of change in volume, the economic and practical feasibility becomes very difficult. Also, not much information is available on the gaseous state of materials.

3.3 Solid-liquid latent heat storage

The transition of materials from solid to liquid is studied and used widely in latent heat storage applications. Even though they have several times less latent heat compared to liquid-gas PCMs, they are acceptable as they do not present technical and economic difficulties of expansion. Normally their expansion is less than 10% of their original volume.

There are many problems associated with the use of solid-liquid PCM such as the complexity of the container, phase segregation and sub -cooling. But, the biggest hurdle to its application is the low thermal conductivity. It restricts the extraction and storage of the energy in a limited time period and also leads to wastage of PCM material by remaining unused.

IV. DESIRABLE PROPERTIES OF PCM

The properties of PCM are as follows

Thermal properties: Satisfactory phase-transition temperature, High latent heat of transition, Better heat transfer.
Physical properties: Favorable phase equilibrium, High-density, Minimum volume change, small vapor pressure.
Kinetic properties: No super cooling, sufficient crystallization rate.
Chemical properties: Durable chemical stability, Compatible with materials of construction, no toxicity, no fire hazard.
Economics: Huge, Easily available, low Cost.

V. PRESENT EXPERIMENTAL WORK

In this experiment study of phase change material using tube heat exchanger has been done. For that purpose OM32 & OM65 PCM’s are used.

5.1 Set up Experiment

Experimental set up consists of test section having tube in tube heat exchanger. Inside tube is of Copper and outside tube is of Stainless Steel. Six thermocouples are connected to the test section, one at the inlet and one at the outlet of hot and cold water & four thermocouples on the copper tube equidistant to each other.

Fig. 5.1Photographic view of experimental setup

One rota meter is connected at inlet of hot water to measure the flow rate. Also control valve and bypass valve are provided at inlet. One centrifugal pump is used to circulate the cold and hot water. Tank is used for storing the hot water and cold water. Electric heater is attached to the hot water tank of capacity of 1500watt. Inverted U-tube manometer is used to measure the pressure difference between inlet and outlet of hot fluid.

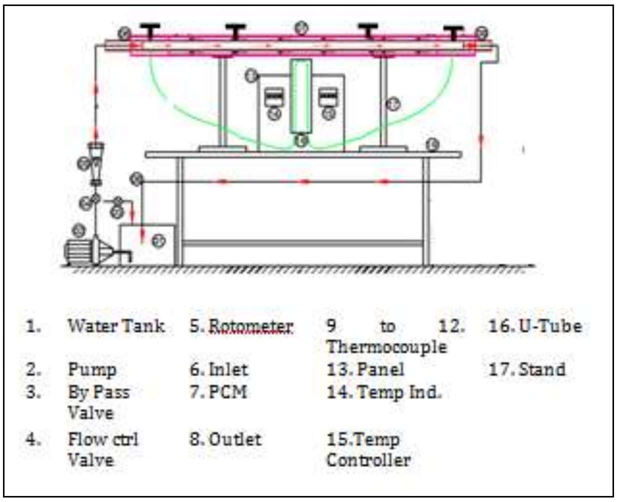

Fig. 5.2 Experimental Set-Up

1. All the cable connection has been done which are shown in figure 5.1

2. The water heater is on till temperature reaches 40°C.

3. To measure the readings switched on the temperature display.

4. The cold water pump is started.
5. The flow rate is maintained of cold water at 200 LPH.

6. The hot water pump is started.

7. Maintain the flow rate of hot water at 200 LPH and keep it constant.

8. Due to flow of hot water in the tube the temperature T1 & T6 remains constant, since there is no heat exchange taking place, so steady state is reached note the temperatures (T1 & T6)
9. Now Add PCM OM32 in the Copper tube through the opening & seal the ends

10. Step 7 and 8 are repeated to change the hot water flow rates at 300,400,500,600,700,800 and 900 LPH.
11. Record all the readings of the thermocouples from T1 to T6, in the chart provided
12. After completion of experiment switch off pumps, water heater and temperature display.

5.2 Specifica tions of PCM

Specifications of PCM have mention in table 5.1

Table 5.1 Thermo-physical properties of PCMs

Material	Density (g/cc)		Specific heat (J/g.K)		Latent heat (kJ/kg)	Melting point (^{0}C)
	Solid	Liquid	Solid	Liquid		
OM32	0.928	0.87	1.95	2.3	190	32.5
OM65	0.924	0.82	2.03	0.73	210	66-68

5.3 Advantages of OM32

- OM 32 is constituted of the right mix of various additives allowed the equilibrium between solid and liquid phases at the melting point. Also OM 32 is flowed in molten state and can be encapsulated in various forms.

Fig.5.3 OM 32

- It has a phase change temperature of 32 degrees C that makes it ideal for many cool / warm energy storage applications.
- Natural available energy is required to charge OM 32, which saved energy requirements and also reduced the carbon dioxide emission.
- They have a stability over thousands of cycles and can be used in very critical conditions

5.4 Advantages of OM65

- OM 65 is an organic chemical based PCM having melting temperature of 65 degrees. It stores thermal energy as latent heat in its crystalline form. This latent heat is released or absorbed when phase is changed , allowing the ambient temperature within the system to be maintained

Fig. 5.4 OM 65

- OM 65 is chemically and thermally stable
- This is mixture of organic fatty acids

5.5 Heat Exchanger Specifications

Type: -Pipe in Pipe Heat Exchanger

a. Inside Pipe Material: Copper

b. Outside Pipe Material: Mild steel
c. Length : 1.4 m
d. Inside Pipe Diameter : 0.0198 m
e. Inside Pipe thickness : 0.0028 m
f. Outside Pipe Diameter : 0.038 m
g. Outside Pipe thickness : 0.003 m

5.6 Instruments used for the Experiment

No.	Instrument	Range	Accuracy
1.	Temp Ind. Controller	0 to 200°C	1% F.S.
2	Temp Indicators	0 to 400°C	0.015°C
3	Manometer	0to250mmWc	+/-3mmHg
4	Rotameter	0to1000 LPH	8% of full scale

VI. RESULTS AND DISCUSSION

6.1 Result Analysis

The graph showed comparison between the outlet temperatures T6 of hot water without PCM & with PCM at initial flow rate of 600 LPH. The experiment is conducted for 60 minutes& readings recorded at an interval of 5 minutes.
The graph is plotted using the average of recorded temperatures. In general, the initial readings after an interval of around or up to 20 mins, gives a difference of 4.5 to 5 degrees at the inlet & outlet temperatures.

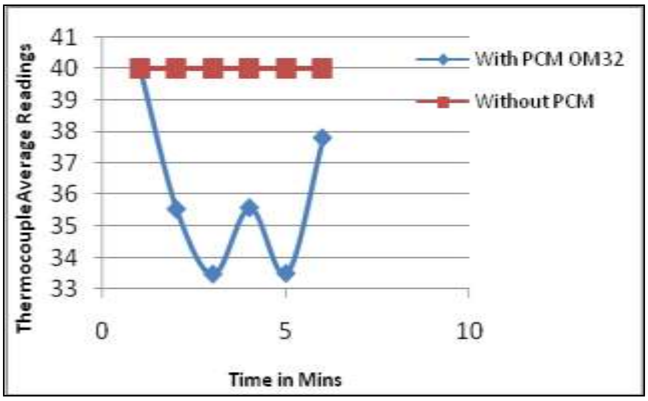

Fig. 6 Graph of Comparision between PCM

But as time progresses, the difference is reduced & it comes to a standstill. In the last 15 mins of the cycle, the readings remained constant to a difference of 0.4 degrees between inlet & outlet temperatures, which is very less. In the last few minutes of the experiment, there is no difference observed in the inlet & outlet temperatures of hot water.

6.2 Previous Literature Comparison

The initial results with the OM32 material and with previous experimental results in “Modelling of a Heat Exchanger utilizing a PCM for short term storage” by A.E. Ahmed [4] showed that the maximum temperature difference obtained was 2°C. The results have shown excellent between the predicted & the experimented outlet air temperature history.

VII. CONCLUSION

From the data gathered & the survey done, it is observed that very few experimental studies have been done on the heat transfer behavior of PCM’s in Heat Exchangers. The initial readings are not satisfactory & hence the parameters need to be modified. Readings in the second stage using OM65 are to be plotted & tested for miniature electronic cooling’s.

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