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Experimental Study On Thermal Comfort Of Helmet Using Phase Change Material

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Abstract
Helmet is essential safety equipment for motorcyclist. Although helmet protects us form serious injuries, wearing helmet in hot ambient conditions makes the user uncomfortable. This paper mainly focuses on absorbing the heat produced inside the helmet using Phase Change Material (PCM). To achieve this, a suitable Phase Change Material is encapsulated inside an Aluminum pouch and placed between the helmet and the wearer head. Phase change material which is capable of storing and releasing large amount of energy, absorbs the atmospheric heat and heat generated from motorist head. The results prove that, helmet subjected to phase change material gives more thermal stability and cooling effect compared to the normal helmet. The heat absorbed by PCM is then subjected to cold water for a short period of time to solidify before reuse. Once the PCM is solidified, it can provide cooling effect for about 2 hours at an ambient temperature of 40°C approximately. PCM helmet is simple in design and effective, it can be used in practical as a solution for driving in uncomfortable hot ambient conditions.

Key words: Phase Change Material, Latent heat storage, Helmet cooling, Thermal comfort to riders.

INTRODUCTION

Helmet is important safety equipment for motorist riders. The National Crime Records Bureau reveals that, at least 13 people die every hour in road accidents in India. A study conducted at Victoria Hospital Mortuary, Bangalore on 245 cases of deaths due to two wheeler accidents, was reported for the autopsy. Riders constituted 76.33% and pillion riders 23.67%. Most victims were male 87.75%, skull fractures 67.75% were observed in two wheeler accidental deaths. Linear fracture 55.43% was the commonest pattern of fracture observed in these accidents. These surveys give knowledge about the importance of wearing helmet.

Although peoples are aware of helmet, tropical regions people feel uncomfortable to wear helmet under sunny weather. Uncomfortable individual protective devices may affect performance of drives and create disturbance that could lead to accidents. During the hot climate season, the temperature inside the helmet could reach 40-45°C and hypothermia can be induced. To avoid this problem, it is desired to maintain the helmet interior temperature to around the body temperature of 38°C. The temperature of helmet is affected by both solar radiation and heat generated from riders head. Heat could be transferred from outer layer of helmet to interior by conduction due to temperature gradient across the helmet layer.

A good solution to maintain the helmet interior temperature in a thermal comfort zone is to use Phase Change Material (PCM), which has high latent heat melting.PCM materials have high heats of fusion, so they can absorb and release large amount of energy by melting and solidifying. PCM temperature remains constant during the phase change, which is useful for keeping the subject at a uniform temperature. A PCM helmet absorbs all the heat generated from the head and solar radiation at a relatively constant temperature to provide thermal comfort to the riders.

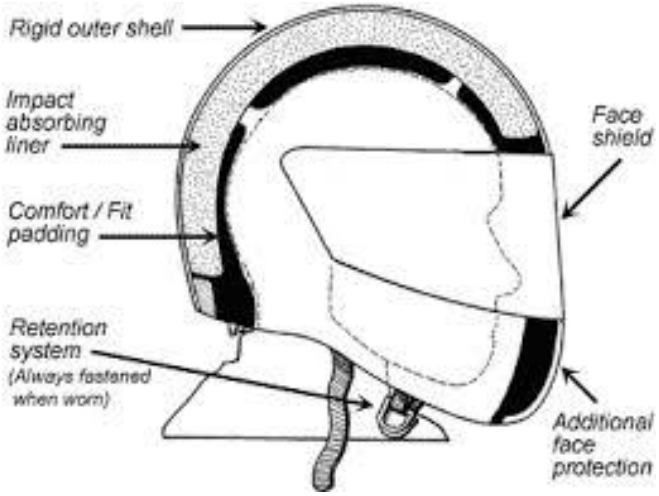

FIGURE 1.1 Various Parts of Helmet

PCM SELECTION

Since the ambient temperature of a normal climate is 27-30°C, the rider should be provided with a thermal comfort around that temperature. So, Thermal salt Latest 29T inorganic PCM which is a mixture of several ingredients is selected.

THERMAL SALT LATEST 29T PCM

It has an operating temperature of 28°C and it has relatively high storage capacity per unit volume. It has a density of 1490 Kg/m^3. It is also relatively inexpensive and Non-flammable. It has a thermal stability over 10,000 cycles. It is viscous semi-solid near Phase Change Temperature. It is Non-toxic and congruent in melting [12].

LATENT HEAT OF LATEST 29T PCM

The latent heat of fusion is 175 KJ/Kg (40 K.Cal/Kg). Most manufactures reports the heat of fusion in a temperature range, like 20°C to 35°C. The specific heat of PCM in this range will get added to the values. For this temperature range Latent heat of Fusion is 210 KJ/K (50 K. Cal/kg)

TABLE 2.3 Latent heat and sub-cooling for different cycles Ref. [12]

Cycle No.	Latent Heat KJ/Kg &Sub-Cooling
100	LH 196 KJ/Kg & Sub-cool 0.5°C
200	LH 188 KJ/Kg & Sub-cool 1°C
300	LH 188 KJ/Kg & Sub-cool 0.9°C
400	LH 192 KJ/Kg & Sub-cool 0.8°C
500	LH 185 KJ/Kg & Sub-cool 0.7°C
1000	LH 178 KJ/Kg & Sub-cool 1°C
1500	LH 172 KJ/Kg & Sub-cool 1.3°C
2000	LH 175 KJ/Kg & Sub-cool 1.2°C
2500	LH 178 KJ/Kg & Sub-cool 1.3°C
3000	LH 170 KJ/Kg & Sub-cool 1°C

The latent heat storage and sub-cooling temperature varies for different number of cycles. The table 2.3 shows the latent heat and sub-cooling for different cycle number.

PROPERTIES OF PCM LATEST 29T

TABLE 2.4 Properties of Latest 29T PCM [Ref.11]

DESCRIPTION	VALUE
Series	T-Series
Appearance	Translucent
Melting point	29°C
Freezing Point	28°C
Sub-Cooling	2°C Max
Specific gravity	1.5
Latent heat practically	175 KJ/Kg
Latent heat Theoretically	188 KJ/Kg
Specific Heat	2 KJ/Kg°C
Thermal Conductivity	1 W/m°C
Density	1490Kg/m^3
Maximum operating temperature	100°C

DESIGN OF PCM COOLED HELMET

The main component of helmet cooling system is the PCM pouch in which PCM is encapsulated. The PCM pouch or casing is made of thin flexible Aluminum foil. We choose Aluminum for its high thermal conductivity and light weight. The pouch dimension depends on the required mass of PCM. To reduce the heat discharge (solidification) time, the surface area of pouch is increased. When the PCM melts the liquid PCM will increase in volume, so the pouch should be given the required allowance. A flexible copper heat collector provides thermal path for conducting heat form the wearer head to PCM pouch. Gel cushion is attached with the heat collector which provides comfortable interior for the helmet. The PCM pouch is made thin, so that it doesn't increase the weight of helmet. The temperature inside the helmet will not cause overcooling, as the PCM will start melting when the temperature reaches29°C, when the temperature goes below 29°C, PCM will start solidifying which in turn gives warm effect to the riders.

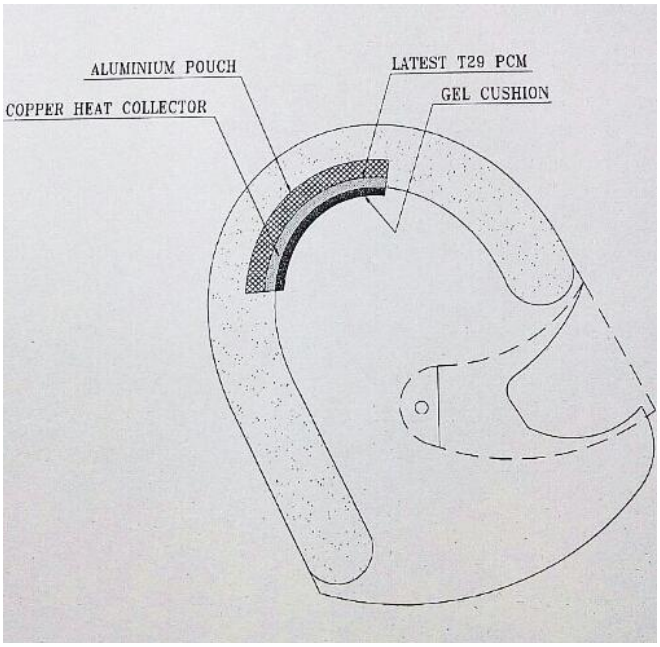

FIGURE 3.1 PCM setup on Helmet

The design problem with PCM-cooled helmet is the time constrain on usage. When the PCM absorbs all the heat and completely melts, it cannot absorber anymore excess heat. When more heat is given to liquid PCM from head and solar radiation, it will get more heated. The cooling time can be extended by using large amount of PCM, but it will increase the weight, volume and cost of helmet. However, the health and safety recommendation suggested that motorist should take rest at least once in every two hours when driving long distance.

CALCULATION

Thermal Properties of a black helmet

TABLE 4.1 Thermal Properties of Helmet. Ref. [4]

Description	Value
Outer shell	Thermal conductivity 50 W/m K
Outer shell	Emissivity 0.75
Foam	Thermal conductivity 0.01 W/m K

The PCM is receives heat by two means they are heat due to solar radiation and heat produced form wearer head. A study found that about 50% of heat produced in body is released through head. Clark and Toy; found that the heat loss from the

average size head is about 10W for a skin temperature of 33°C and ambient temperature of 23°C. The duration till which the PCM temperature remains constant depends upon the mass and volume occupied by PCM used. It also depends on the temperature around PCM and specific enthalpy. The duration index of a PCM is calculated by the following formula.

$$\text{Duration Index D.I.} = h_f \rho / \Delta T \ (J/cm^3 °C)$$

Mass of PCM required for 2 hrs. of cooling

The heat flow from head to PCM has thermal resistance of cushion and heat collector. Heat flow form hot ambient to PCM pouch has a thermal resistance of shell thickness and foam. The surface temperature of helmet is estimated as 48°C and PCM melting temperature is 29°C.

Thermal resistance of foam

$R_{foam} = t_{foam}/A_{foam}.k_{foam}$
$R_{foam} = (2.1x10\text{-}2)/ (0.052x0.01)$
$R_{foam} = 40.3$ K/W

Thermal resistance of Shell

$R_{shell} = t_{shell}/A_{shell}k_{shell}$
$R_{shell} = (0.5 \times 10^{-2})/ (0.055x50)$
$R_{shell} = 1.81x10^{-3}$K/W

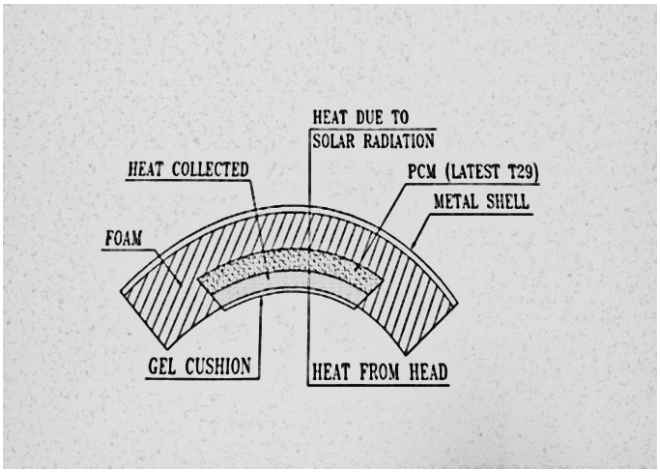

FIGURE 4.2 Cross section of helmet showing PCM pouch, Heat collector and Cushion

Thermal resistance of Heat collector

$R_{collector} = t_{coll}/A_{coll}k_{coll}$
$R_{collector} = (0.6x10^{-2})/ (0.04x385)$
$R_{collector} = 3.8x10^{-4}$K/W

Thermal resistance of cushion

$R_{cushion} = t_{cush}/A_{cush}k_{cush}$
$R_{cushion} = (0.6x10^{-2})/ (0.04x1.6)$
$R_{cushion} = 0.093$

Heat transfer (Q_{in})
$Q_{in} = (T_{surface} - T_{pcm})/ (R_{shell}+R_{foam})$
$Q_{in} = 0.47$ W
Heat transfer (Q_{Head})
$Q_{Head} = (T_{skin}\text{-}T_{PCM})/ (R_{collector}+R_{cushion})$
$Q_{Head} = 21.4$

Assume that, maximum amount of heat is absorbed form ambient air and head at about 2hrs.The massof PCM required for 2 hrs. of cooling is calculated by,
$(Q_{in}+Q_{head}) = m\ c_p\ \Delta T$
$21.8 = m_{PCM}x2\ (39 - 28)$
Mass M_{PCM}= 0.994kg.

RESULT AND DISCUSSIONS

It is clear that, with the use of PCM, the temperature inside the helmet can be maintained at a comfort zone for long time. From the above results it is clear that, the helmet subjected to PCM can absorb the heat produced by solar radiation and motorist head, and provide cooling effect for about 2hrs with approximately 1kg of Latest 29T PCM. When the skin temperature goes below 29°C the PCM starts solidifying and releases all its latent heat and provides warming effect, so the problem of overcooling is avoided.

Although theoretically it is proved that about 1kg of PCM can provide cooling effect for 2hrs approximately, practically the heat released from the head and the ambient temperature keeps varying. The above calculation is made with an assumption of 48C helmet surface temperature and 30C skin temperature. But in actual case if the helmet surface temperature is less than 48C, then the cooling period will increase. In rainy seasons, the PCM provides cooling effect for a longer time.

Salt hydrate PCM are generally corrosive as they absorb and loose water during phase change and tend to form partially hydrated crystals. Many salt hydrate PCMs have the disadvantage that during extraction of stored heat, the material super-cools before freezing. This reduces the utility of materials and in rare cases it can completely prevent heat recovery. They lose their heat storage property after some cycles [12].

However T-Series Latest 29T PCM has defied these restrictions. The packing material (Aluminum pouch) should conduct heat well and should be durable enough to withstand frequent changes in storage materials volume as phase changes occurs. It should also restrict the passage of water through the walls, so the materials will not dry out. Packaging must also resist leakage and corrosion [12]. Latest 29T PCM is not degradable with time and can be used for more than 10,000 cycles. It provides congruent melting on observing latent heat, and performs best in containers up to one inch. So, Latest 29T PCM overcomes the disadvantages on other salt hydrate PCMs and provide excellent cooling effect to the motorist by observing latent heat.

Once the PCM is completely melted, it must be cooled at a temperature below its melting temperature, say 28C. The PCM helmet can be simply subjected to a tap water for about 10 to 15 minutes for solidification of PCM. Again the solidification time depends on the tap water temperature and

the ambient conditions. If the water is very cool, the PCM solidification period may be limited to even 10 minutes.

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