

Experimental Analysis of the Cooling of a Motorcycle Helmet by Using Phase Change Material with Forced Convection

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Abstract: *This paper presents an experimental analysis of the cooling of a motorcycle helmet with the help of phase change material (PCM) and using air flow circulation through the surface of the phase change material. The heat produced by the head of the wearer is absorbed and stored by phase change material and stored heat is thrown out with the help of air circulation in the helmet. In this PCM is placed between the head of the wearer and helmet metal shell. Thus the heat produced by head of the wearer and heat in the helmet metal shell due to atmospheric high temperature and expanded polystyrene foam (EPF) will be absorbed by the PCM but to increase the duration of working of the PCM, here we implement the method of forced convection by the installing two fan which removed the inside heat of the helmet and extend the working time of the PCM. This maintains the wearer head temperature nearly melting point of PCM temperature and protects the wearer head from discomfort and hot environment. If only PCM will be used then the cooling is achieved for few hours only when the PCM is completely melted.*

Keywords: Phase change material; Helmet metal shell; Expanded polystyrene foam; Melted

1. Introduction

The motorcycle helmet is used by motorcycle riders. The main objective of a motorcycle helmet is to provide safety to the rider's head during impact [1]. Modern helmets are generally made from plastics, reinforced with Kevlar or carbon fiber. Basically, helmet contains two layers of protection i.e. outer shell and inner shell, outer shell made of acrylonitrile butadiene styrene (ABS) plastic, fiberglass or Kevlar and inner shell contains inner liner about one-inch thickness made of EPS "Expanded Polystyrene Foam" and an outer shell which protects the EPS. An outer shell is used to prevent puncture of the helmet by any sharp object and to hold the EPS, it is used to absorb the crush during an impact. The acrylonitrile butadiene styrene (ABS) causes heating inside the helmet because it acts as insulation and restricts the transfer of heat from the interior to the outside of the wall. This causes discomfort and danger to the rider because the temperature in the interior of the helmet increases up to 37 to 38 C. Due to this, the physiological and psychological effect on the rider takes place. This causes the deadening of the senses and rider looses its ability to concentrate [2]. As compared to another body, the head has high skin temperature because it has highest skin temperature as well as large constant volume blood flow [3]. For the comfort of the head around 34.5 C temperature is required. In hot climate condition temperature inside helmet may reach up to 45 C if there is no wind and hypothermia can be induced [4]. Hence it is necessary to maintain the interior temperature of helmet around the body temperature. So for cooling of the head, additional features are provided in the helmet like ventilation for air flow, but this phenomenon is not very effective in ordinary motorcycle it is effective in racing motorcycle. Therefore an alternative is required for the cooling of the helmet in which using of phase change

material is also included. Phase change material is absorbing all the heat of head at a constant temperature by changing its phase and providing cooling to the wearer's head. The PCM is placed between the head and helmet. Initially, the PCM is in a solid state. When the temperature inside the helmet reaches above the melting point temperature of PCM it starts melting by absorbing the heat of the head. But the drawback of this system is that it is effective only for nearly two hours (Climsel C28) i.e. its capacity to store the heat is only for nearly two hours. After every two hours it's needed discharging of stored heat to the ambient. The PCM weight is also an important factor in cooling [7]. To overcome from this problem we installed two fans (inlet and exhaust) which increase the working duration of the PCM by removing the interior heat of the helmet [5].

2. Materials and Methods

For storage of heat, PCM is a very effective material which stores the heat by changing its phase because much higher energy is needed during the phase change. PCM have a specific phase change temperature for different uses. The use of PCM materials is depending upon its melting temperature, freezing temperature, latent heat, liquid thermal conductivity and solid thermal conductivity. In this experiment savE^R HS29 are used. savE^R Phase change materials are organic or inorganic chemical compounds that have a large amount of heat energy stored in the form of latent heat. The PCM retains its latent heat without any change in physical or chemical properties over thousand of cycles. Various specific temperatures PCM" are commercially available varying between -35 C to 90 C depending upon the applications.

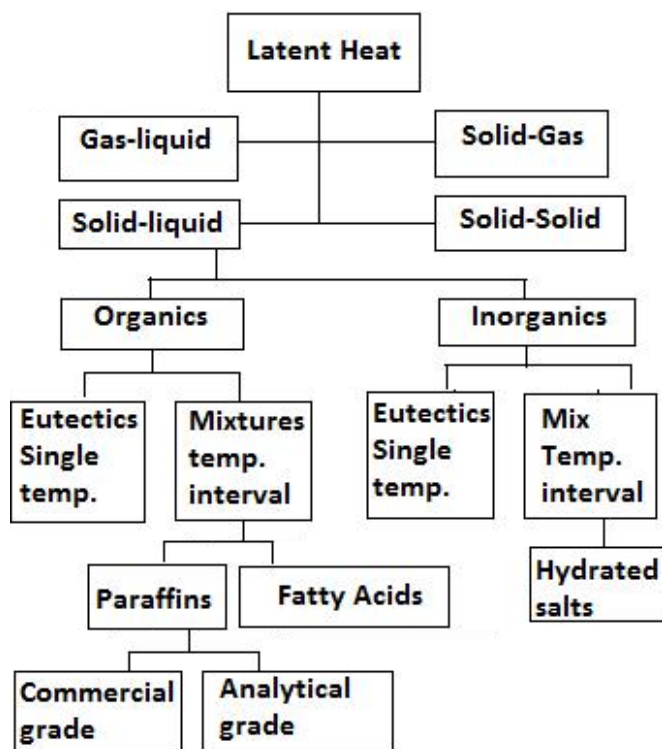


Figure 1: Classification of PCM

The major component of the PCM-cooled helmet includes: Copper heat collector, casing made of copper, PCM, copper pipe as outside/inside air channel, electric fan for an air pump, 12v battery and heat sink with built in electric fan. The PCM-cooled helmet is designed so that temperature of the head is maintained near about 30 C. It is designed to increase the working duration of PCM with transfer of heat by circulating air inside the casing where PCM is placed and for air flow we are using two fans, one is for suction of air and other for the exhaust [6]. The portion of heat collector which is made of copper for better heat transfer is in direct contact with the head and absorbing the heat produced by head and transfers it to the PCM. To hold the PCM, a casing of copper is fabricated so that transfer of heat takes place effectively to the PCM and some of the heat also removed by circulation of air through fan. For suction of air from outside to the casing of the PCM, double effect pipe is used to feed the air in and out with the help of suction and exhaust the fan. Both of the fans are installed at the back side of the helmet and it is connected with casing with the help of pipe for air circulation. 12 V batteries are used for running of the fan. It helps in the feeding of air directly into the helmet. Thus, a higher cooling rate is achieved.

2.1 Conceptual Design of PCM-cooled helmet

In a PCM-cooled helmet, basic component is PCM pouch. The problem of overcooling will not occur in a case of PCM cooling because it maintains the head temperature near the melting point of the PCM and the head skin temperature will never go below the melting temperature of the PCM. While in a case of thermoelectric cooling, it causes sensational overcooling on the head. Due to which rider losing his concentration and there is also chances of an accident. Hence for the cooling on the head selection of good PCM material is important. To avoid overcooling of the head select such a

PCM so that it's melting temperature is only 7 to 8 C below the body temperature and non-toxic in nature. One of the problems regarding the PCM is that when it solidifies it occupies more space than in liquid state. Hence the size of the PCM pouch should be large when PCM is in a liquid state. In this Solid to liquid PCM is used.

In this paper, the main focus is on how to increase the working time of the PCM by selecting suitable PCM and changing the interior design of the helmet. Casing of PCM pouch and heat collector is placed inside of the expanded polystyrene foam (EPF) between the helmet shell and head of the wearer.

2.2 Heat collector

For transfer of heat firstly collect the heat released by a head in a collector so that it is easy to transfer the heat from head to the PCM pouch. The collector is made up of copper wire so that it will transfer the maximum amount of heat which is released by head due to high thermal conductivity of copper as compared to other materials in respect of their cost. The heat collector is made of light flexible braided copper wire so that it is installed easily along the curvature of the helmet and head.



Figure 2: Heat Collector

So that it easily gets fitted on the head of the wearer and due to mesh like structure of light and soft copper wire provides a comfortable interior for the head to fit in.

2.3 PCM pouch and its casing

The PCM which is used in this research paper is save^R HS 29 is an organic chemical-based PCM having nominal freezing and melting temperature of 29 C. It stores thermal energy as latent heat in its crystalline form. On changing phase this latent heat is released or absorbed, allowing the ambient temperature within the systems to be maintained.

Technical specification of PCM
 Series: HS29

Description: Mixture of CaCl_2 and other salts
 Appearance: Grey liquid suspension above 30 C

HS29 is chemically and thermally stable by using proprietary additives. This is a blend of various organic fatty acids suspended in the matrix of polymers. The enthalpy graph of PCM HS29 in air bath with respect to temperature is shown in graph fig.3.

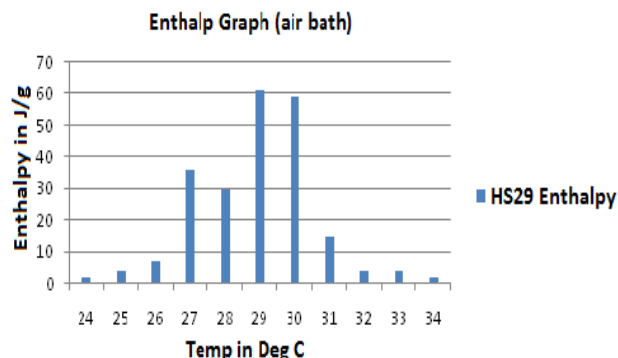


Figure 3: Enthalpy Graph of HS29

To hold the PCM with air flow circulation there is the requirement of such a casing which will carry the PCM with the hole in a casing so that air can be circulated by connecting the fan with the hole of casing through the pipe. The Casing is made of copper metal so that higher heat transfer rate can be achieved so that maximum heat can be transfer to the PCM for better cooling effect while a large area of the PCM surface is mainly in contact with the heat collector. In the figure, from the casing, the middle portion is cut out and removed so that direct contact of heat collector to the PCM can be made for increasing the rate of heat transfer from heat collector to PCM. PCM is placed in the casing in such a way so that air can circulate around the PCM effectively and prevent its leakage from the casing to heat collector because air resists the rate of heat transfer which reduces the effect of cooling.

2.4 Fan and its casing

PCM will the heat by changing its phase however the limitation of some of the PCM material like Climsel C28 is that they store heat only for about 2 hours [8] because after two hour its reaches at saturation state and further it will not absorb heat.



Figure 4: Set-up of fan with casing

Hence to increase the duration time of the PCM set up of inlet and exhaust fan is mounted on the helmet shown in fig.6. Due to transfer of air through the inlet fan, the air carries the heat from the PCM and rejects it through the exhaust fan. For running of fan 12 v battery is used which supplied the power to fan. As shown in fig. 4 it is exhausting fan and on reversing its direction it acts as inlet fan. In fig. 5 set up of inlet and exhaust fan which is connected to casing with the help of pipe for air flow.



Figure 5: Fan after mounting on helmet

3. Theoretical and Experimental Analyses of Cooling of Helmet

Analysis of motorcycle helmet can be done by following methods i.e. theoretical analysis and experimental analysis of cooling of the motorcycle helmet.

3.1 Theoretical analysis of cooling of motorcycle helmet

This helmet consist of three layers outer layer which is exposed to the atmosphere is the metal shell, foam, PCM pouch then heat collector are consequently the inner layer as shown in fig.8

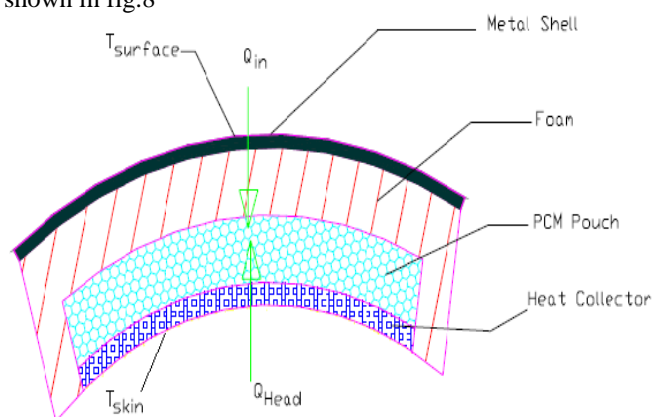


Figure 6: Cross-section of the helmet showing the PCM pouch and heat collector

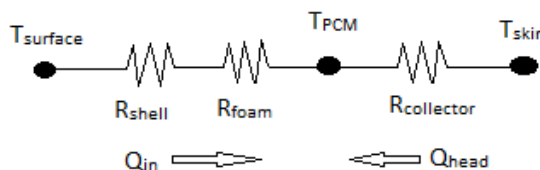


Figure 7: Heat flows through thermal resistance

Fourier law of heat conduction is used to evaluate the value of the temperature of wearer's head theoretically. First,

second and third equation shows the resistance of the shell (metal shell), foam and collector while fourth and fifth shows the heat transfer.

$$R_{shell} = \frac{T_{shell}}{K_{shell}} \times A_{shell} \quad (1)$$

$$R_{foam} = \frac{T_{foam}}{K_{foam}} \times A_{foam} \quad (2)$$

$$R_{collector} = \frac{T_{collector}}{K_{collector}} \times A_{foam} \quad (3)$$

$$Q_{in} = \frac{T_{surface} - T_{pcm}}{R_{shell} + R_{foam}} \quad (4)$$

$$Q_{head} = \frac{T_{skin} - T_{pcm}}{R_{collector}} \quad (5)$$

From equation (5) the temperature of the wearer's head after using the PCM can be determine [8].

3.2 Experimental analysis of cooling of motorcycle helmet

In the experimental set-up, PCM is absorbing the heat of wearer's head as well as the hot ambient air around the helmet which get heated up due to heating of metal shell which is direct exposed to sun rays. Testing of helmet is completed in three phase:-

3.2.1 In first phase temperature of wearer's head is measured without PCM inside helmet and fan. For measuring the temperature four thermocouples are placed, one of the thermocouples is placed at the top of the helmet to measure surface temperature (T_1) of the helmet while the other three are placed on the head of the wearer to measure the temperature of head when he wears the helmet i.e. T_2 , T_3 and T_4 . Atmospheric Temperature measured is C. After wearing of helmet Temperature is measured from readings of the thermocouples are:

$T_1 = 29.5$ C placed on the surface of the helmet.
 $T_2 = 36.4$ C, $T_3 = 36.5$ C, $T_4 = 37$ C

Table 1: Thermocouple reading without PCM and fan

Thermocouple Placed on top surface of helmet with PCM and without fan	Thermocouple placed on the head of the wearer without PCM and fan		
T_1 (C)	T_2 (C)	T_3 (C)	T_4 (C)
29.5	36.4	36.5	37

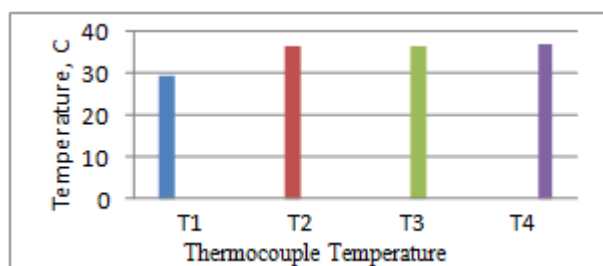


Figure 8: Helmet outer surface (T_1) and inner surface temperature (T_2 , T_3 & T_4) without PCM and the fan

3.2.2 After completing the first stage we placed the PCM inside the helmet and took the readings without starting the fan. Now recorded the value of the inside thermocouple placed on the wearer's head by increasing the temperature of the thermocouple placed on the top of the outer surface of the helmet when the intensity of heat is increasing by increasing the power of the halogen with the help of regulator.



Figure 9: Experimental set-up of testing of helmet

Table 2: Thermocouple reading with PCM and without fan

Thermocouple Placed on top surface of helmet with PCM and without fan	Thermocouple placed on the head of the wearer with PCM and without fan		
T_1 (C)	T_2 (C)	T_3 (C)	T_4 (C)
35.7	31.3	31.4	32.1
40.1	31.9	32.4	32.9
45.0	32.0	32.7	33.1

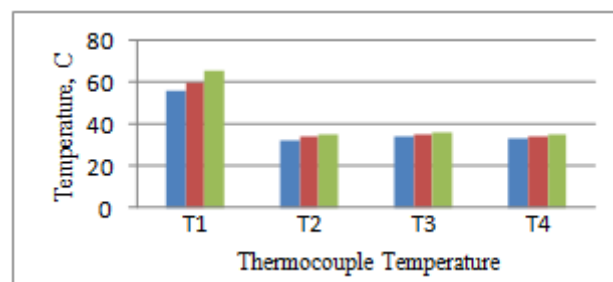


Figure 10: Helmet outer surface (T_1) and inner surface temperature (T_2 , T_3 & T_4) with PCM and without fan

The result shows that when PCM is used then inside temperature of the helmet is less than without PCM.

3.2.3 In this we switched on the fan and record the reading. As shown in the table temperature is nearly constant means increasing with the little margin with increasing the outer temperature at large scale.

Table 3: Thermocouple reading with PCM and fan

Thermocouple Placed on top surface of helmet with PCM and fan	Thermocouple placed on the head of the wearer with PCM and fan		
T ₁ (C)	T ₂ (C)	T ₃ (C)	T ₄ (C)
56.0	32.5	34.4	33.2
60.2	33.7	35.1	34.1
65.7	34.9	35.8	35.1

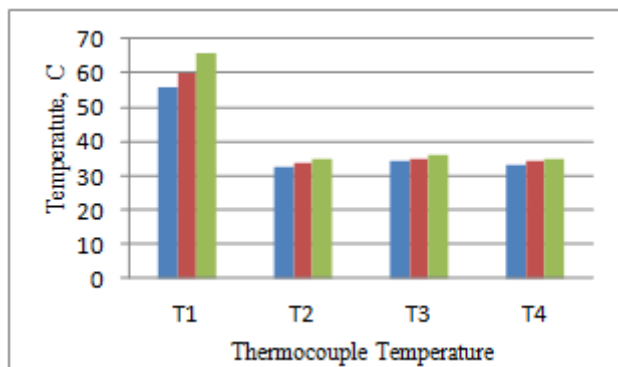


Figure 11: Helmet outer surface (T1) and inner surface temperature (T2, T3 & T4) with PCM and the fan

4. Result

This paper presented the experimental analysis of testing of the helmet in three stages

- First testing is completed without PCM and the fan, which shows that inside temperature of the helmet, is increases from 6 to 7 C shown in fig. 8 than atmospheric temperature which is also the surface temperature of the helmet.
- When PCM will be installed inside the helmet then the temperature of the wearer's head increases at very low rate as shown in fig. 11 while the temperature in inner surface is also lower than if we compared it to the previous testing this shows that PCM is absorbing the heat and maintaining the temperature close to the melting point of the PCM due to its phase change capacity. PCM will absorb the heat by changing its phase at constant temperature. In the result of the experiment, it shows that the temperature of the wearer's head inside helmet in which PCM is placed is lowered up to 5 to 6 C than that of the helmet without PCM.
- When the inlet and exhaust fan is started then it removes the inside heat of the helmet with forced convection process resulting in that wearer head temperature increases only 2 to 3°C when the surface temperature of the helmet reaches 55 to 65°C.

On comparing the temperature of thermocouples in fig. 8, 10 and 11 it shows that the thermocouple temperature T₁ is lower than other thermocouple temperature T₂, T₃ & T₄. While in fig. 10 and 11 value of T₁ is greater than other thermocouple which are T₂, T₃ & T₄, and they measure the temperature of the thermocouple which is placed on the wearer head. From the fig. 11 it shows that the working duration of the PCM will increased.

5. Conclusion

An analysis has been carried out to study the effect of PCM

with forced convection on the cooling of the helmet. PCM material having melting temperature of 29 C is used for controlling the inside temperature of the helmet. However to extend the working duration of PCM here forced convection phenomenon is used by with the help of inlet and exhaust fan. Which will extract the heat from inside of the helmet and it will increases the melting duration of the PCM.

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