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FABRICATION AND ANALYSIS OF COOLING JACKET INCORPORATED WITH PHASE CHANGE MATERIAL

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Abstract- Phase change material (PCM) is a substance that absorbs and releases thermal energy during the process of melting and freezing. When a PCM freezes, it releases a large amount of energy in the form of latent heat at a relatively constant temperature. Conversely, when such a material melts, it absorbs a large amount of heat from its surroundings. PCM's ability to maintain constant temperature as the ambient temperatures fluctuate makes it ideal for a variety of everyday applications that require temperature control. Human body works fine when its temperature is maintained constant. The motive of this research is to develop a cooling jacket incorporated with phase change material which can maintain favorable body temperature. The study also focuses on calculating accurate mass of PCM required for the application. The PCM will also help to isolate the body from external temperature fluctuations thereby maintaining good health. These vests or jackets can be worn in factories subjected to high temperatures, armed forces in deserts, patients and can be used in many more applications.

Keywords – Phase change materials, Latent heat, Encapsulation, Cooling jacket, Melting Temperature.

I. INTRODUCTION

Due to growing global warming and increasing mercury level, it is predicted that future summers will be lot hotter than the present scenario. It is also proved that human body works efficiently when it is subjected to favorable ambient temperature. Cooling jacket incorporated with PCM will help to maintain this favorable temperature of the individual even when the ambient temperature is varying. These jackets will be very effective for people who do multiple short duration outdoor activities. It will also help to maintain thermal comfort of patients. Many researchers have tried experimenting with the usage of PCM's. PCM can be incorporated in the car ceiling to maintain constant temperature inside the cabin of the car [1]. Micro-encapsulation of PCM can be done in the fabric of the cloth to give the cooling effect [2][3]. Proper encapsulation techniques are needed to do so. Experiments were also carried out using human mannequin subjected to high temperatures [4]. Study on how heat flow through the body is affected with PCM has been carried out [5]. PCM's can also be used in buildings to eliminate temperature fluctuations throughout the day [6]. However, there was a disadvantage of using it inside the concrete. Life of the PCM's is short compared to the life of the buildings. Hence to remove the degraded material, walls need to be broken. Hence PCM panels can be set as false roofing to overcome the disadvantage. PCM also finds its application in electronics industries as heat sinks. Mobile device was incorporated with PCM and experimented for its feasibility [7]. Solar collectors are used from ages to cook food in many areas. Intensity of the sun changes with time and also the temperature developed in the solar collector. Thus, if these collectors are incorporated with high temperature PCM's, temperature can be maintained for longer time which will help food to be cooked faster [8].

A. WORKING OF PHASE CHANGE MATERIAL

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Phase change materials (PCMs) are substances which absorb or release large amounts of latent heat when they go through a change in their physical state, i.e. from solid to liquid and vice versa. When the PCM is heated or cooled, phase change starts as soon as the material reaches its specific phase change temperature. During the latent heat absorption or latent heat release, the temperature of the PCM remains constant or varies over a small range of temperature. Most of the phase change materials have high latent energy. Thus they can absorb and release large amounts of heat in a controlled way which can be utilized to improve the thermal performance of various end-use products to which the PCMs are applied. The latent heat absorbed by the PCM can be stored therein. Therefore, PCMs are considered to be highly efficient thermal storage material. The working cycle of the phase change material is shown below (refer Fig 1)

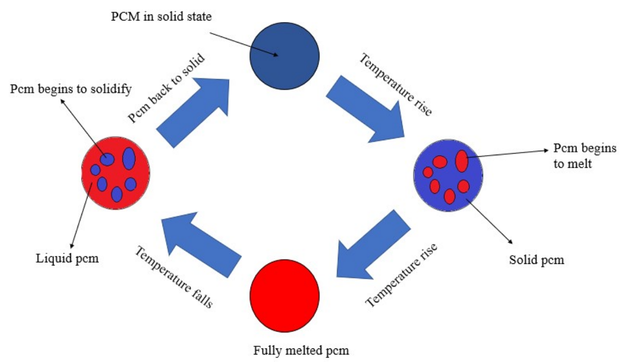

Fig. 1: Working cycle of phase change material

The concept never led to any practically applicable materials for use in the space program, but the basics of the technology were further developed into ‘terrestrial’ applications. Nowadays, textiles with PCM treatment are widely used in garments and home furnishing products. However, many other textile products utilizing the PCM technology are under development and will be introduced to the market soon. In order to incorporate PCM in a specific textile product, it is first microencapsulated or macro-encapsulated. The microencapsulated PCM is then added to a binder and applied to a textile substrate in the form of a coating. The macro-encapsulated PCM is either directly applied to a textile substrate by coating or it is formed into a thin film which could be laminated to a textile substrate.[9]

B. TYPES OF PHASE CHANGE MATERIALS [9]

- *Water based*

These PCM's contain mostly water. Cold storage systems or ice storage systems are mainly used in the air conditioning or process industry. The freezing point is reduced by adding glycol or ethanol, allowing storage temperatures up to -30 ° C. Example, water-Ice is known as the best form of water based pcm.

- *Salt based*

Salt hydrates contain inorganic salt and water. The melting point temperature range is between 8 °C and 90 °C. Benefits of salt hydrates are favorable material costs, high latent melting heat, good thermal conductivity and non-combustible. A disadvantage may be that poor crystal formation makes salty hydrates more sensitive to super-cooling. Examples: $NaCl\cdot Na_2SO_4\cdot 10H_2O$, $Mn(NO_3)_2\cdot 6H_2O$,$Na_2SiO_3\cdot 5H_2O$ etc.

- *Plant based*

These are organic PCM's because they come from plant oil or animal fat. The range of melting temperatures is wide and lie between -30 °C and 150 °C. The latent heat is good and most vegetable fats derived from fatty acids have better efficiency than salt hydrates and paraffins Example: Fatty acids, vegetable oil, corn fat oil, stearic acid etc.

- *Paraffin wax*

Paraffin or wax is a derivative of petroleum. The melting point temperature range is comparable to that of salt hydrates. The latent melting heat is reasonable and they do not have any problems with supercooling. The disadvantage is that the prices are linked to oil prices and are therefore not stable. he paraffin PCMs are either used in technical grades with a purity of approximately 95% or they are blended with one another in order to cover specific phase change temperature ranges. The paraffin PCMs are nontoxic, noncorrosive, and non-hygroscopic.

C. SELECTION CRITERIA OF PCM

- Melting temperature in the desired operating temperature range
- High latent heat of fusion per unit volume
- High specific heat, high density and high thermal conductivity
- Chemical properties & Chemical stability
- Complete reversible freeze/melt cycle
- No degradation after a large number of freeze/melt cycle, Non-corrosiveness, non-toxic, non-flammable and non-explosive materials
- Economic properties
- Low cost, Availability

Pluss advanced technologies Pvt. Ltd. is a materials research and manufacturing company involved in the field of specialty Polymeric Additives for enhancing polymer properties and Phase Change Materials (PCMs) for thermal energy storage.
Research and Innovation has been the cornerstone of the company since its inception and is the motto of the organization. The organization welcomes and motivates young minds and helps them to successfully implement their ideas. The company believes in developing products which are meaningful and relevant to the country and the world at large.
Table no. 1 shows various PCM's which were selected based on the application. Since the ideal temperature for human body to perform well is 26°C, HS24 was selected. Also it can be seen that HS24 has the highest latent energy. This indicates that it will absorb more amount of energy and will last for longer time.

TABLE-1:
SHORTLISTED PHASE CHANGE MATERIALS [13]

Type	Name	Solid density (kg/m^3)	Liquid density (kg/m^3)	Melting temperature (C)	Latent Heat (kJ)
Hydrated Salts	HS 22	1651	1540	22	167.66
Hydrated Salts	HS 24	1621	1510	26	199
Hydrated Salts	HS 29	1681	1530	29	190

II. CALCULATION [10]

Assuming,
Film temperature, T_f= 30^o
Corresponding to 30^{o}C, various properties of air from Heat & Mass Transfer Data Handbook [11] are:
Density, ρ= 1.165 kg/m^3
Dynamic viscosity, μ=18.63×10^{-6} Ns/m^2
Kinematic viscosity, ν=16×10^{-6} m^2/s
Absorptivity, α=22.861×10^{-6}
Prandtl no., Pr= 0.701
Specific Heat, c_p=1.005 kJ/kg.K
Thermal Conductivity, K=0.02675 W/m.K

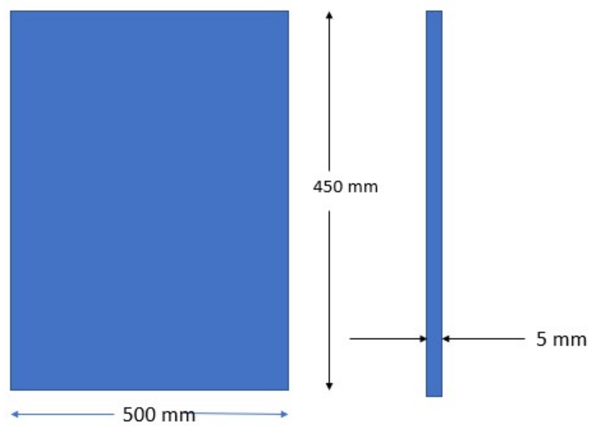

Fig 2: Profile of the phase change material used for calculation

A. DETERMINATION OF FLOW OF THE AIR

Coefficient of expansion,

$$\beta = \frac{1}{T_f}$$

$\beta = 1/(273+30) = 1/303 = 3.303\times10^{-3}$

$$\text{Grashoff number, } G_r = \frac{g\times\beta\times x^3\times\Delta T}{\nu}$$

Where x is the characteristic length, hence the Grashoff 's number is

$$G_r = 168467321.6$$

$$\mathbf{G_r\times Pr = 118095592.4 < 10^9}$$

Hence, the flow is **laminar.**

B. DETERMINATION OF HEAT TRASNFER COEFFICIENT

So,
Local Nusselts no,

$$N_{ux} = C\times(G_r)^{.25}$$

By substituting the value of C and Gr,
Therefore,

Local Nusslet's number is

$$N_{ux} = 36.37$$

$$\text{Average Nusselts no.} = \frac{4}{3}\times N_{ux}$$

Average Nusselts no $= \frac{4}{3}\times 36.37 = 48.505$

The **Nusselt number** is defined as the ratio of convection heat transfer to fluid conduction heat transfer under the same conditions

$$N_{uL} = \frac{hL}{K}$$

By substituting the values of N_{uL}, L and K , we get the value of h to be

$$\mathbf{h = 2.3591\ W/m^2.^oC}$$

C. DETERMINATION OF MASS OF THE PCM REQURIED

Heat absorbed by the PCM per second is given by,

$$Q_a = Ah(T_s - T_\infty)$$

The area of was taken to be 0.45 m^2, [refer the profile for dimensions.]

$$\mathbf{Q_a = 8.49276\ Watts}$$

By applying Heat Balance,

$$Q_a + Q_{body} = m.C_p.dT + mL$$

By substituting the values, we get

$$m = 5.033 \times 10^{-3} Kg/s$$

The total mass of the PCM required can be given as,

$$M = m \times t$$

where, "t" is the time up to which the PCM will be exposed to the heat source.

$$M = 1.8\ kg$$

The mass of the PCM encapsulated in the jacket is 1.8kg.

III. ENCAPSULATION OF PHASE CHANGE MATERIAL

The phase change material was encapsulated in small pouches of multilayered nylon material. [12]

- This is the most flexible method of encapsulating PCMs. The material used is multilayer films (Nylon/Nylon laminates) to provide good strength and Durability.
- They find most of their utility in transporting pharmaceutical goods (at desired temperatures), temperature back-up for refrigerators, deep freezers and ice boxes. (Refer fig 3)

Fig 3: Multilayer Nylon pouches

The jacket was stitched with pockets of dimensions 50mm X 30mm in order to incorporate the encapsulated pcm for the application. The pcm in encapsulated form was incorporated inside the jacket. (Refer fig 4).

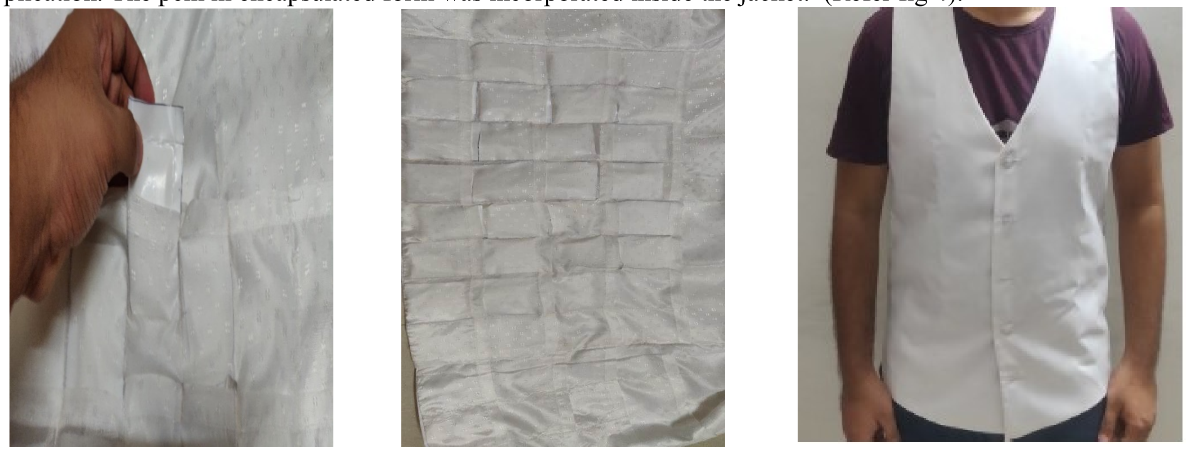

Fig 4: Cooling jacket incorporated with phase change material

IV. TESTS CONDUCTED

TABLE-2
VARIOUS TYPES OF TESTS CONDUCTED ON THE COOLING JACKET

Serial Number	Tests	Description
1	Test of cooling jacket in House	The cooling jacket was worn in house and the time taken for the pcm to melt was measured and also the cooling effect was observed.
2	Test cooling jacket during early morning hours	The cooling jacket was worn during early morning hours and the time taken for the pcm to melt was measured and also the cooling effect was observed.
3	Test of cooling jacket during evening	The cooling jacket was worn during evening hours and the time taken for the pcm to melt was measured and also the cooling effect was observed.
4	Test of cooling jacket in car when air conditioner of the car is switched ON	The cooling jacket was worn during travelling by car when the air conditioner of car is switched ON and the time taken for the pcm to melt was measured and also the cooling effect was observed.
5	Test of cooling jacket in car when air conditioner of the car is switched OFF	The cooling jacket was worn during travelling by car when the air conditioner of car is switched OFF and the time taken for the pcm to melt was measured and also the cooling effect was observed.

V. RESULT

VI. TABLE-2
RESULTS OF THE TESTS

SR.NO	TEST PERFORMED	DATE	TEST START TIME	TEST END TIME	DURATI-ON OF TEST
1	Test in house	29 May 2020	10:00 AM	11:28 AM	1 hour 28 Minutes
2	Test during early morning hours	30 May 2020	7:30 AM	9:05 AM	1 hour 35 Minutes
3	Test during evening hours	30 May 2020	4:30 PM	5:44 PM	1 hour 14 Minutes
4	Test in Car with Air conditioner switched ON	31May 2020	3:00 PM	4:40 PM	1 hour 40 Minutes
5	Test in Car with Air conditioner switched OFF	31 May 2020	5:00 PM	6:27 PM	1 hour 27 Minutes

It was observed that when the jacket is worn in house it provides a comfortable environment to the human body for 1 hour 28 minutes. During this time, there was no body sweat observed on the cloths. After 1 hour 28 minutes, the PCM begins to melt and slight discomfort is felt. The sweat begins to form at the back side.
When the jacket is worn during early hours of the day, it was observed that the melting rate of the PCM is slow and it sustains for a longer period of time. It was also observed that the cooling effect enhances while riding bike. The PCM took 1-hour 35 minutes to begin melting, but comfort of the body wasn't disturbed. However, after 1 hour 43 minutes, the jacket was slightly uncomfortable to wear and sweating had started.
The jacket was worn in the evening hours. It was observed that the melting rate is much faster as compared to early morning hours, the reason was increase in ambient temperature. The pcm proved to provide cooling comfort for 1 hour 14 min. After 1 hour 20 Minutes, the jacket was very uncomfortable to wear and sweat was formed at a much faster rate compared to other tests.
A test was also conducted in car under two circumstances:

- **When Air Conditioner is switched ON**
  When air conditioner of the car is switched on , the pcm took the longest time to melt and was able to provide comfort . The test duration lasted for 1 hour 40 minutes. It was possible because of the low car cabin temperature.
- **When Air Conditioner is switched OFF**
  In another test, the car ac was switched off and the time of comfort was recorded. It was observed that the pcm could provide a comfortable environment for the body for about 1 hour 27 minutes. It was evident due to the increase in cabin temperature as compared to the previous test. After 1 hours 27 minutes, sweat had begun to form as a result, the jacket was getting uncomfortable to wear.

VII. CONCLUSION

The 21^{st} century is said to be an era of technological and industrial revolution. Many new technologies as well as industrial expansion are taking place around the world. However, due to this there is a great negative impact on environment. It is predicted that the coming days will be warmer and hotter as compared to the present scenario due to increase in global warming. The cooling jacket incorporated with phase change material is an attempt to provide thermal comfort to a human in warm and hot conditions. The human body temperature comfort body range is said to be 25-29^{0}C. It can be concluded from the results that the PCM incorporated jacket could maintain favorable temperature of 26 ^{0}C for more than an hour considering all scenarios. The encapsulations prepared were also air tight and leak proof. Person wearing the jacket was at comfort throughout the time it was worn. The jacket becomes ideal for people working in hot environments for short time.

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