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Role of Phase Change Materials in Thermal Comfort Garments for BSF Jawans in Rajasthan and Kashmir

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Abstract –*Phase Change Materials (PCM) is emerging now as a Storage reservoir of Thermal Energyowing to its Latent Heat property during its change of phase. This PCM when incorporated with garments for BSF Jawans will definitely prove beneficial, as this property will keep them who wear the garment in a state of Thermal Comfort. This review focuses on the types and properties of various Phase Change Materials for Thermal Comfort Garments and also reviews on methodologies to incorporate this PCM with garments and also the nature of applicability for Border Security Force(BSF) Jawans in the Region of Rajasthan and in Kashmir in India where the weather is extremely rough. A CFD Analysis has also been conducted to check the behavior of the Phase Change Material with variation in temperature and the results have been discussed.*

Key Words:Storage Reservoir, Latent Heat, Thermal Comfort.

1. INTRODUCTION

Phase Change Materials are astounding materials that change its phase and store thermal energy. Whenever these PCMs are heated there occurs this change of phase and the input energy is stored as Latent Heat. When these PCMs are brought in contact with a lower energy product, it will return back to its original phase releasing the stored energy to the lower energy product. This property finds applicability in Thermal Comfort Garments (TCG). The main deciding parameter to choose the appropriate PCM is the required thermal comfort temperature range.

Rajasthan being in the eastern part of India hosts a destination for BSF Jawans owing to its India-Pakistan International Border. Substantial part of this region is a desert, the Thar Desert (453000 sq.km), where the maximum temperature reached is 35^{0}C - 40^{0}C on a summer day. 85% of the desert is located in India, the remaining in Pakistan. BSF Jawans in the desert will face severe hot temperatures. Conventional Garments (BSF Uniforms) will definitely stay non-beneficial in producing a cooling effect to the human body. When such garments are incorporated with PCM, it will definitely prove beneficial in making the human body cooler.

On contrast to Rajasthan, BSF Jawans in Kashmir will face extremely cold temperature, where the requirement is to keep the body warmer. The Kashmir region being on the Himalayan Range will face terribly cold temperatures upto -3^{0}C. Hence Thermal Comfort has to be chosen to make the body feel warmer.

Incorporating PCMs for both regions will definitely face challenges in the choice of the Phase Change Material and the nature of use. This research suggests suitable Phase Change Materials and also suggests methodologies to incorporate the PCMs into Garments.

2. CHOICE OF MELTING POINT OF PCM IN RAJASTHAN

The optimum thermal comfort required for the region can be chosen only after the determination of the temperature profile of the Region. Hence the maximum and minimum temperature that has occurred in Jaipur, Rajasthan has been measured.

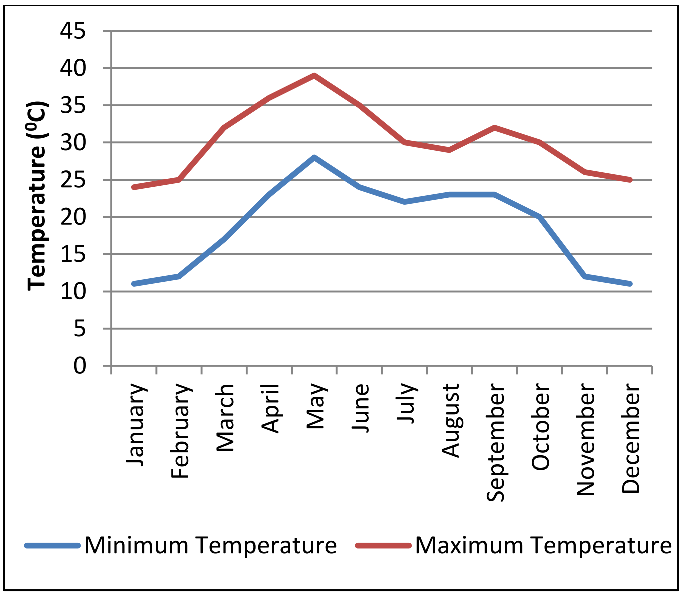

Chart -1: Variation of Temperature in Jaipur, Rajasthan

From the temperature profile, it can be inferred that a Thermal Comfort of 25^{0}C can be chosen. When the temperature is found to reach 25^{0}C, it would be better when the PCM starts to operate. Hence the melting point of the Phase Change Material must be around 25⁰C.

Hence when the temperature reaches 25⁰C, the system must be designed such that the Phase Change Material melts and stored the heat energy, thus maintaining the body temperature in a comfort zone. When the temperature falls below 25⁰C, the PCM solidifies and releases the stored thermal energy, thereby still providing a nature of thermal comfort. This cycle repeats itself and the PCM melts and solidifies. The melting temperature of the PCM is the key parameter in the choice of the suitable PCM.

3. CHOICE OF MELTING POINT OF PCM IN KASHMIR.

The temperature profile of Kashmir is as shown in Chart 2. It is observed that Baramulla faces temperature upto -3⁰C.

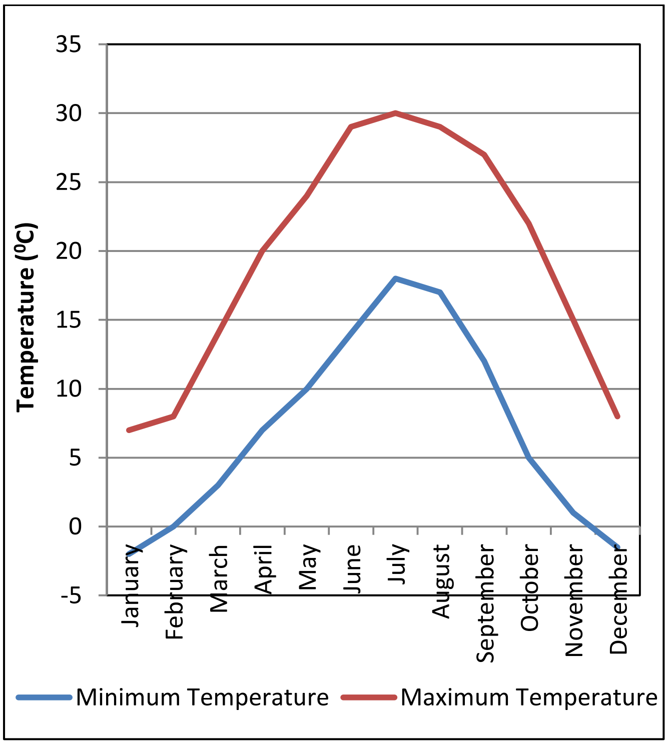

Chart -2: Variation of Temperature in Baramulla, Kashmir

Here, for BSF Jawans stationed in Baramulla, the maximum temperature reached is 30⁰C as shown in Chart- 2. Since the required thermal process in Kashmir is heating, the melting point can be even lower than that of Kashmir. Hence,the choice of Melting Point to be selected must be chosen purely to release heat energy to human body for heating purpose. Hence the solidification transition would be preferred than melting transition. Here the melting point of the Phase Change Material can be chosen as 15⁰C.

The Phase Change Material will start to melt when the temperature is above 15⁰C, thereby absorbing heat energy. When the temperature falls below 15⁰C, it will solidify and will release heat energy to human body. This melting point has been adopted by taking the average temperature of the region into consideration. This solidification and melting phenomena will repeat cyclically bringing about the required thermal comfort to the Jawans. Since heating is required the solidification phenomenon in Phase Change Material cycle is considered to be of utmost importance. However the charging and discharging phenomenon of Phase Change Materials has to be taken into account while incorporating the Phase Change Materials into Thermal Comfort Garments.

4. PHASE CHANGE MATERIALS FOR TCG

4.1 Classification of Phase Change Materials

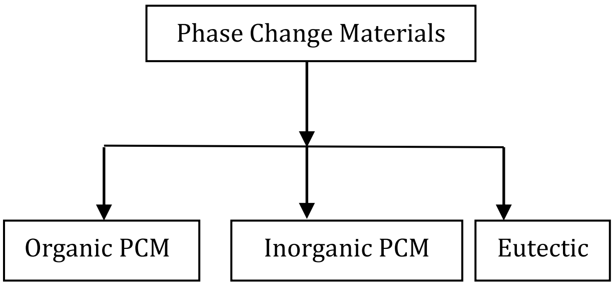

Fig -1: Classification of PCMs [1]

Sharma et al [1] classifies Phase Change Materials for Thermal Energy Storage. Out of the classification it is necessary to consider which type of PCM will suit for Thermal Comfort Garments.

Organic Phase Change Materials are generally Polyethylene Glycol, Fatty Acids, and paraffins. They have advantages of appropriate melting and are available in a wide range of melting temperatures. [2].

Inorganic Phase Change Materials include Single Temperature Eutectics and Hydrated Salts. They are advantageous as they have high latent heat and high thermal conductivity. To prevent decomposition, several nucleating agents can also be added. [3]

Eutectic PCMs represent a class of mixture of materials to provide a minimum melting temperature. They melt and freeze congruently. Notable combinations in eutectics include:

1. Organic – Organic [1]
2. Inorganic – Organic [1]
3. Organic – Inorganic [1]

Phase Change Materials for Rajasthan and Kashmir are as shown in Table 1.

Table -1: Possible organic PCM for TCG

	PCM	Melting Temperature (^0C)	Heat of Fusion k J/kg
Rajasthan	Micronal5001	26	110 [2]
	RT25	25	147 [2]
	Eutectic Capric-stearic	24.7	179 [2]
	D-Lattic Acid	26	184 [2]
	Polyethylene Glycol	20-25	146 [1]
	$Mn(NO_3)_2.6H_2O$	25.5	148[1]
	1 - Dodecanol	26	200 [3]
	Climsel C24	24	108 [3]
Kashmir	$CaCl_2.6H_2O$ + $CaBr_2.6H2O$	14.7	140 [1]
	Triethylolethane + Water + Urea	13.4	160 [1]
	$K_2HPO_{4.}6H_2O$	14	109[1]
	$NaCl·Na_2SO_4·10H_2O$	15	286

4.2 Selection of PCM for TCG

The key factors that have to be considered in selecting the appropriate Phase Change Material for Thermal Comfort Garments are as follows:

1. Latent Heat of Fusion of Phase Change Material
2. Melting Temperature of the PCM
3. Garment Material and PCM Material Interaction
4. Safety in use.

From Table 1, the PCMs screened are subjected to further consideration. Considering the melting temperature, the PCM must be chosen that it has a congruent melting point. In Table 1, the PCMs considered are of a finite temperature range.

For selecting the optimum Phase Change Material for Rajasthan Region; considering the heat of fusion, 1-dodecanol has a higher heat of fusion. If the application had been for conventional solar water heaters or for buildings, the choice can be made on the above principles alone. This work focuses on PCMs for TCG. Hence the interaction of this material with the garment material has also to be studied. In this regard, Polyethylene glycol has lower segmental mobility property and also has a convenient geometrical orientation property [4]. Hence when it is packed between two layers of the garment it will definitely prove beneficial. Manganese (II) Nitrate Hexahydrate (Mn $(NO_3)_2.6H_2O$) has a latent heat of 226 × 10^3 kJ/kg. It also faces a disadvantage that the difference between solidification temperature and melting temperature is quite high.Hence we infer that Polyethylene glycol to be a suitable PCM for Thermal Comfort Garments for Rajasthan Region

Similarly, when comparing the alternatives $CaCl_2.6H_2O$ + $CaBr_2.6H_2O$finds suitability owing to its non-toxicity when used with Garments. And also the energy density and latent heat properties of this hexahydrate are satisfactory. Since the sole aim of Phase Change Material in Kashmir region is for heating, the PCM should have minimum sub-cooling issues. This $CaCl_2.6H_2O$ + $CaBr_2.6H_2O$is definitely a good choice of Phase Change Materials to be incorporated within Thermal Comfort Garments for Kashmir Region.

5.PREPARATION OF PCM FOR TCG

The properties of Phase Change Materials differ from that of properties of the Garments. Hence suitable method of to add the PCM into the Garment is necessary. This process consists of two phases:

1. Microencapsulation of PCM
2. Incorporation of PCM to the Garment

Microencapsulation of PCM refers to creating a capsule enveloping over the PCM such that the Phase Change that happens in the PCM is within the capsule. Several Microencapsulation techniques are available.

1. InsituPolymerization [5]
2. Interfacial Polymerization[5]
3. Complex Coervation[5]
4. Air Suspension Coating[6]
5. Sol-gel Technique[6]
6. Centrifugal Extrusion[6]

Out of the above key techniques, the sol-gel technique finds suitable for our TCG since, the capsule envelop will have a high thermal conductivity[5], and also required physical properties can be obtained in Sol-gel Technique.

A methodology to incorporate the Phase Change Materials to the garments is of utmost importance. Most important methodologies of incorporation are:

1. Spinning [5]
2. Coating [5]
3. Lamination [5]

Out of the three above methods, lamination method finds suitable, as a thin film of PCM gets incorporated in the garments such that a higher PCM Concentration can be obtained. Prepared microcapsules can be mixed with polyurethane foam and can be laminated and coated over the fabric. The Polymer film thickness is of 0.3mm [7].

6.CFD ANALYSIS OF PCM BASED TCG

A 1m×1m garment has been taken for analysis to observe the temperature effects, and it is assumed to be laminated with Polyethylene glycol for 0.3mm. The model has been simulated using Computational Fluid Dynamics

(CFD) Approach. This analysis is used to observe the cooling effect of the PCM incorporated TCG

Dimensions of Phase Change Material: 1m×1m×0.3mm
Dimension of Garment: 1m×1m×2cm
Chosen Phase Change Material: Polyethylene Glycol

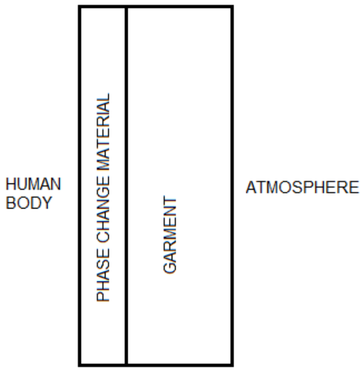

Fig -2: Cross section of the garment PCM Arrangement.

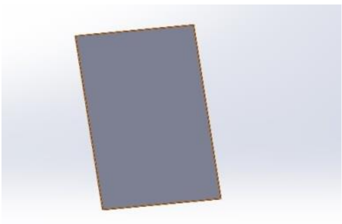

Fig -3a: 3D Model of PCM – Garment Arrangement

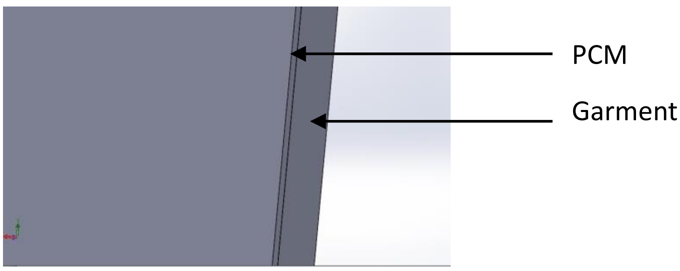

Fig -3b: 3D Model of PCM – Garment Arrangement indicating the components

CFD Analysis has been performed using ANSYS-FLUENT 17.0 Facility and the results of the analysis has been shown in Fig. 4 and Fig 5

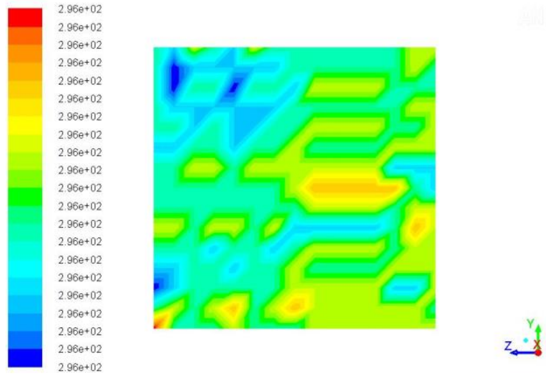

Fig-4a: Temperature of the Garment at Atmospheric Temperature of 23^{0}C

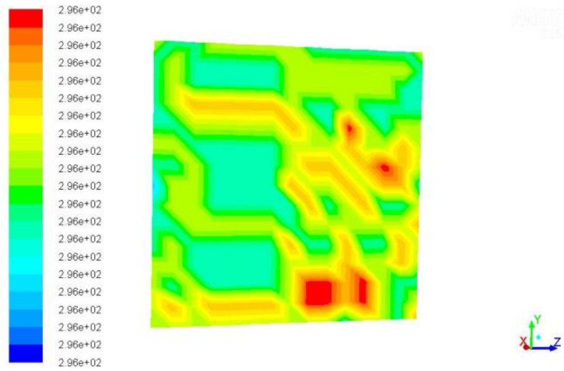

Fig-4b: Temperature of the Phase Change Material at Atmospheric Temperature of 23^{0}C

From the Fig.4a and 4b, it can be observed that, below the melting point of the Phase Change Material, the temperature of the garment is transferred to the Phase Change Material and hence the Phase Change Material will also face a raise in its temperature. This process continues till the melting point is reached. Once the melting point is reached, the Latent Heat of the Phase Change Material comes into consideration. The PCM remains solid at 23^{0}C and it is show in Fig. 4c

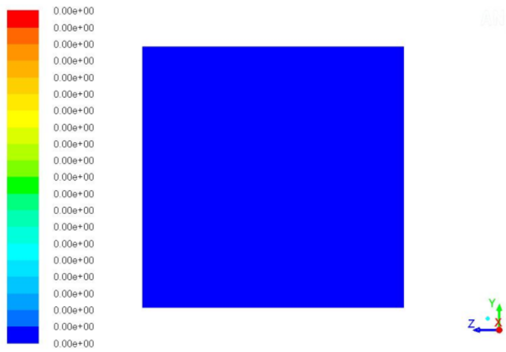

Fig-4c: Liquid Fraction of Phase Change Material at Atmospheric Temperature of 23^{0}C

Similar CFD Analysis has been performed to check the performance of the PCM Based Thermal Comfort Garment at a temperature higher than the melting point of the PCM.

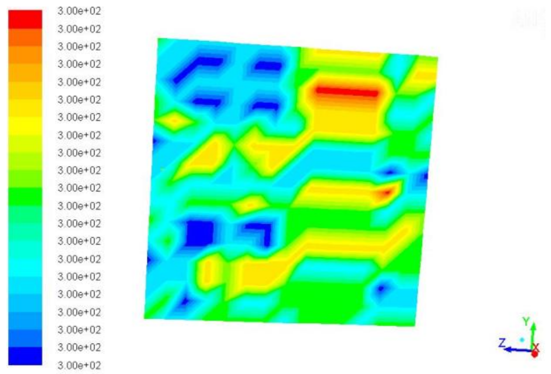

Fig-5a: Temperature of the Garment at Atmospheric Temperature of 27^{0}C

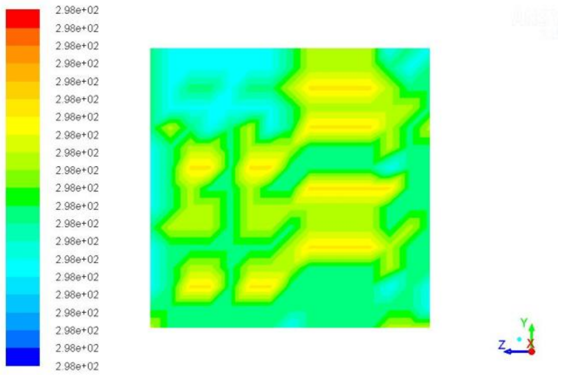

Fig-5b: Temperature of the Phase Change Material at Atmospheric Temperature of 27^{0}C

From the simulation results it can be inferred that, amidst the temperature of the atmosphere being higher than the melting temperature of the Phase Change Material, the Latent Heat Property of the PCM allows storage of heat energy, thereby making the temperature to the Phase Change Material to remain at 25^{0}C. Complete solidification of the Phase Change Material has taken place and the liquid fraction is shown in Fig.5c

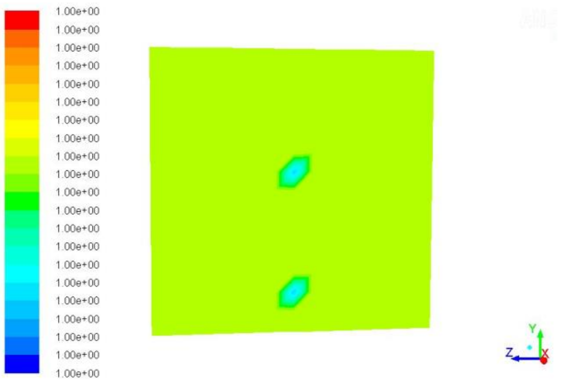

Fig-5c: Liquid Fraction of Phase Change Material at Atmospheric Temperature of 27^{0}C

7. CONCLUSIONS

Phase Change Materials are smart materials that definitely finds applicability in Garments for to maintain the Thermal Comfort of human body. When incorporated with Garments for Defense Jawans it will prove beneficial. It will also positively improve the working condition of such Jawans living in the wildernesses of extreme temperature. Analysis shows that the choice of PCM is of utmost importance as the choice is proportional to its performance. Also the charging and discharging cycles must be considered to ensure economical and efficient Phase Change Material based Thermal Comfort Garment.

ACKNOWLEDGEMENT

The authors dedicate this work to all Indian Border Security Force (BSF) Jawans who spend their life protecting people amidst extreme climatic zones.

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BIOGRAPHIES

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