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3

THE HEATING EFFECT OF PHASE CHANGE MATERIAL (PCM) VESTS ON A THERMAL MANIKIN IN A SUBZERO ENVIRONMENT

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Summary: *The heating effects of three PCM vests (T_{melt}=32, 28 and 24 °C) were tested on a thermal manikin with constant temperature at 30 ºC in a subzero environment (T_a=-4 °C, V_a=0.4 m/s). The results showed that the heating effects lasted about 3-4 hours. The highest heating effects reduced heat loss for 20-30 W/m² on the torso during the first two hours. The results also showed that the vest with higher melting/solidifying temperature had a greater and longer heating effect. Among the three wear scenarios, the PCM vest worn directly and closely over the stretch coverall without winter jacket revealed the highest heating effect on the torso.*

Keywords: *phase change material, vest, heating, thermal manikin, subzero environment*
Category: *thermal manikin application*

1. Introduction

Phase change materials (PCMs) have been used in clothing, fabrics, and vests in the forms of microcapsules and packs to create thermal comfort and/or to alleviate heat strain [1-9]. PCMs are latent heat storage materials. The PCM absorbs or releases heat when it changes phases, e.g. from solid to liquid (heat of fusion), and back to solid (heat of crystallization). Therefore PCM has two types of thermal effects: a cooling effect when it melts and a heating effect when it solidifies. The former has been more widely studied and reported in literature [1-9]. However, the latter has only been sparsely documented. The heating effects of PCM microcapsules in clothing and fabrics in cold environments (5-10 ºC) were observed as decreased heat losses (lasted only 12-15 minutes) and increased clothing temperature by the heat of crystallization of the PCM [1-2, 9]. The amount of PCM in the microcapsules is relatively small compared with vests. The thermal performance of a PCM depends not only on the amount of PCM, but also on the temperature gradient and the amount of energy it absorbs/releases during a phase change. It is therefore of interest to investigate the thermal effects of PCM vests with various phase changing temperatures in a colder environment, e.g. outdoor environment for winter sports.

Preheating the body has been reported to require less energy for skiers exercised on a cycle ergometer in the cold environment (5 ºC) [10]. Preheating the hand, torso, body using electrically heated gloves, vests, liquid conditioning garment (LCG) helps to maintain hand dexterity and other hand functions [11-12]. Using PCM vests to pre-heat or to keep the body warm before exercises in outdoor environments for winter activities is another alternative and convenient way to improve and maintain performance.

The objective of this study was to investigate and quantify the heating effect of PCM vests with different phase change temperatures during the process of solidification on a thermal manikin in a subzero environment (-4 ºC, e.g. temperature for skiing).

2. Method

2.1 PCM vests

The heating/cooling vest is made of polyester and separate pockets containing 21 PCM packs (70-80 g/pack). The main ingredients are salt mixtures including sodium sulphate, water and additives (Patent: PCT/SE 95/01309, 9404056-5). In this study, three PCMs were tested with phase change temperatures at 24, 28, and 32 °C, representing three levels of latent heat 108.0, 126.0, and 194.4 J/g respectively. The fabric and design were the same for the three vests. The total weight of each vest including clothing material and PCM was 2.2 kg. Before the tests, the vests were warmed up and PCMs were melted at about 40 °C.

2.2 Thermal manikin

A thermal manikin with 17 zones [13] and a constant surface temperature at 30 °C was used in order to assess possible low skin temperature in subzero conditions outdoors in winter. The climatic chamber air temperature (T_a) was kept at -4 °C, and air velocity (V_a) at 0.4 m/s for all tests. Heat losses, manikin surface temperature, manikin stretch coverall surface temperature, ambient temperature and PCM pack inner and outer surface temperature, and vest outer surface temperature were recorded at 10-second intervals. As the heating vest covered only torso part of the manikin, therefore chest, abdomen, upper and lower back zones were included in calculations for the heating effect on the torso. Each condition was measured twice. Average values were used for analyses.

2.3 Clothing

The clothing worn on the manikin during the test included a Taiga stretch coverall, Ullfrotte pants (200 g/m^2), Ullfrote socks (400 g/m^2), sports shoes, Hestra fleece Windstopper gloves, and a Taiga hood on the head. A winter jacket (I_t=2.36 clo) was used in some of the test conditions, i.e. was worn over the PCM vest and under the PCM vest to simulate possible scenarios in winter activities, e.g. warming-up before skiing. Therefore there were three clothing combinations as below:

1). Manikin stretch coverall + PCM vest (Fig. 1);
2). Manikin stretch coverall + PCM vest + winter jacket;
3). Manikin stretch coverall + winter jacket + PCM vest.

Fig. 1. The thermal manikin, clothing and PCM vest

3. Results and discussion

The heating effects of the PCM vests (T_{melt}=32, 28 and 24 °C) worn over the stretch coverall on the manikin (Fig. 1) with ambient air temperature at -4 °C are evidenced by the reduced heat loss on the torso. The heating effects lasted about 3-4 hours (Fig. 2). The highest heating effects (20-30 W/m^2 on the torso corresponding to 6-10 W/m^2 on the whole manikin) were observed during the first two hours. During this period the heat loss on the torso was about 80-95 W/m^2. Upon the completion of PCM crystallization, the heat loss on the torso increased to 110 W/m^2. The heat loss on the torso with the same clothing but without the PCM vest was about 208 W/m^2. The heating effects were greater and lasted much longer than these reported in other studies using clothing with PCM microcapsules in a higher temperature environment (+5 °C) [1]. This most probably reflects the mass difference of used PCM. The results also showed that among the PCM vests tested, the vest with higher melting/solidifying temperature had a greater and longer heating effect due to a higher temperature gradient between the vest and the environment and a greater amount of latent heat of crystallization. Therefore the authors hypothesize that a PCM vest with a phase change temperature at about 36-37 °C will have even better heating effects.

The above heating effects were supported by the temperature change during the crystallization process of the melted PCM (T_{melt}=32 °C) on the manikin in the subzero environment (Fig. 3). As the manikin surface temperature was kept constant at 30 °C and the PCM vest was heated to about 40 °C, and the ambient air temperature was -4 °C, once the vests was put on the manikin, the PCM inner and outer surface temperature started dropping quickly below 32 °C until about 30 and 26 °C respectively in about 30 min.

Then the PCM started to crystallize and release heat. Therefore the PCM surface temperatures increased to a level which was even higher than the manikin stretch coverall surface temperature. When crystallization was finished after 3-4 hours, the PCM inner and outer surface temperatures were leveled off and stabilized about 22-19 °C. Meanwhile the heating effect was also completed. These temperature changes can explain the reduced heat loss on the torso.

When the PCM vest (T_{melt}=32 °C) was worn over the winter jacket, the reduced heat loss on the torso was about 10-15 W/m^2 during the first two hours period, which is two times lower than that worn directly on the stretch coverall. This is reasonable because the released heat by the solidifying PCM was mostly lost to the subzero environment (Fig. 4).

In the situation when the PCM vest (T_{melt}=32 °C) was worn under the winter jacket, no obvious heating effects were observed during 5.5 hours period. This is due to the very small temperature gradient between the PCM phase change temperature (32 °C) and the manikin surface temperature (30 °C), which is not sufficient for the melted PCM to effectively solidify within the period. It may be solidified slowly after very long time, but the heating efficiency on the manikin is very low.

Wear trials on subjects should be investigated to verify the results obtained in this study.

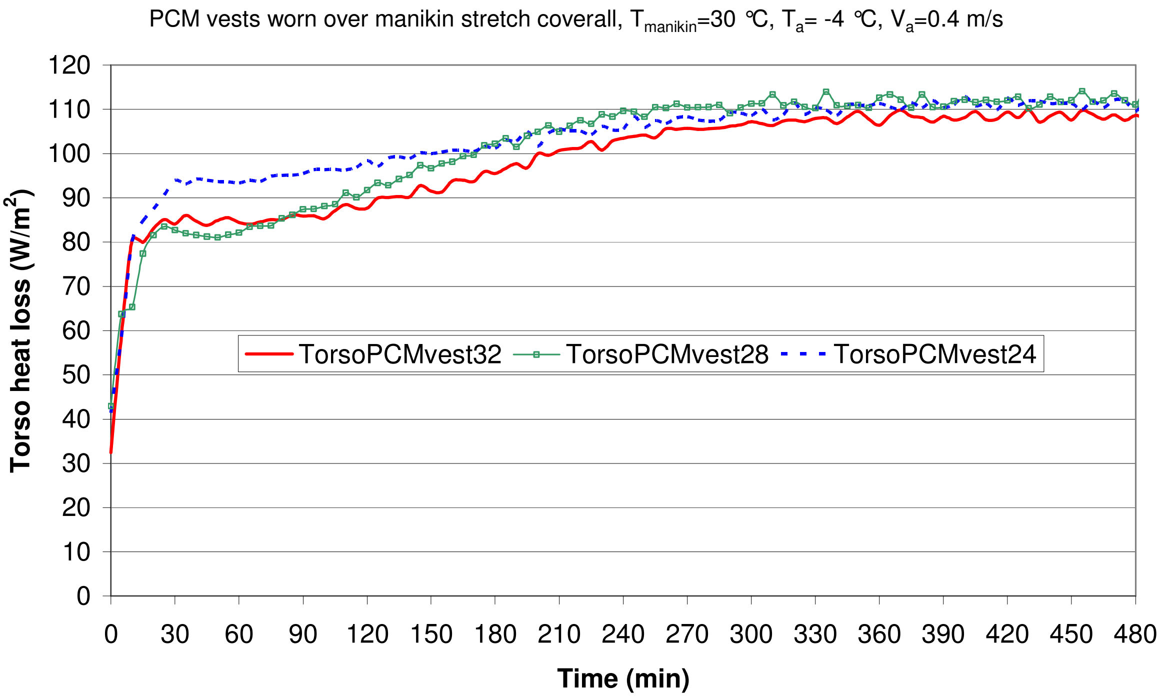

Fig. 2. Heating effects of the PCM vests (T_{melt}=32, 28 and 24 °C) on the manikin in the subzero environment.

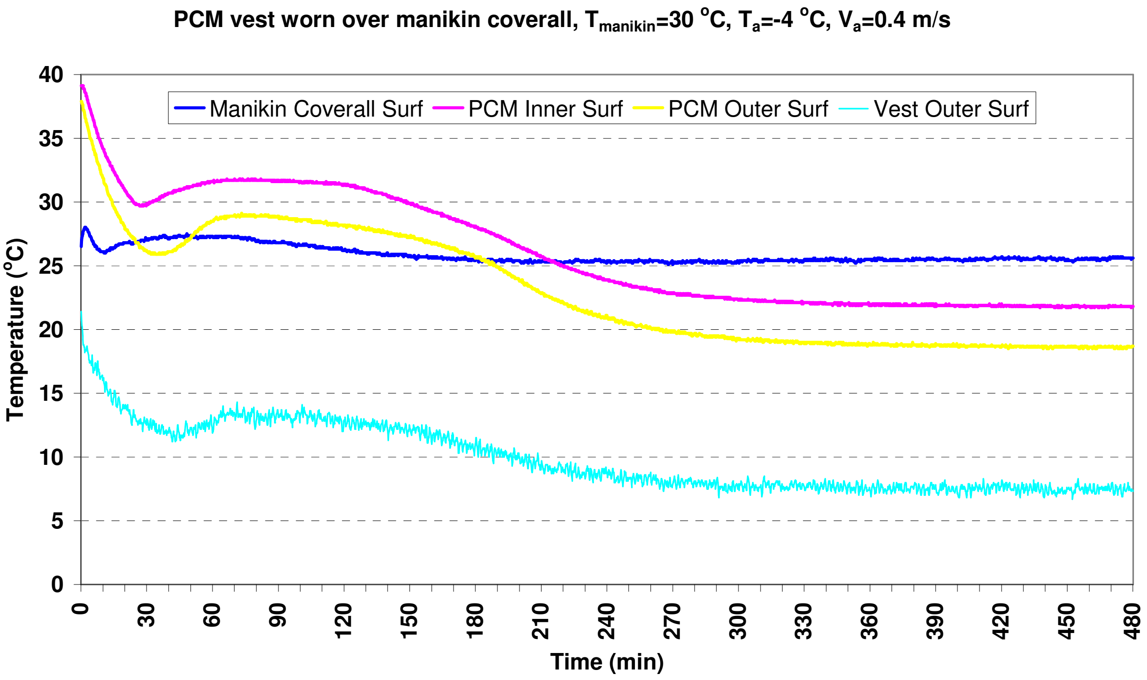

Fig. 3 Typical temperature change during the crystallization of the PCM (T_{melt}=32 °C) on the manikin in the subzero environment.

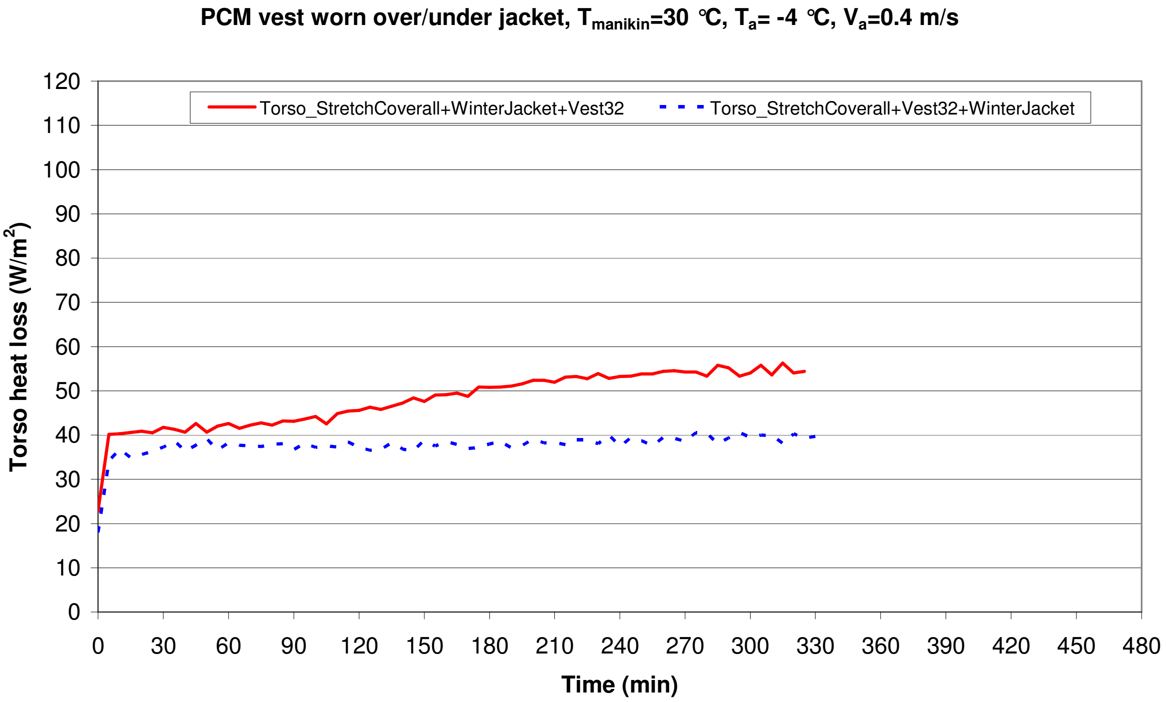

Fig. 4. Heating effects of the PCM vest (T_{melt}=32 °C) in the combination of the winter jacket on the manikin in the subzero environment.

4. Conclusions

Among the three wear scenarios, the PCM vest worn directly and closely on the manikin stretch coverall (similar to skintight ski suit) revealed the highest heating effect on the torso of the manikin. The heating effects lasted about 3-4 hours. The highest heating effects reduced heat loss for 20-30 W/m^2 on the torso during the first two hours. The PCM vest with a higher phase change temperature and a greater amount of latent heat of crystallization showed better heating effect.

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