Effect of Phase Change Materials on Temperature and Moisture Distributions in Clothing during Exercise in Cold Environment

Shu-Xiao Wang, Yi Li*, Hiromi Tokura, Jun-Yan Hu, Yi-Lin Kwok, Raymond Au

Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, People's Republic of China

Abstract: This paper reports a study on the effect of phase change material (PCM) in design of cold protective clothing. Two clothing systems with the same structural design, one was smart clothing (clothing C) was treated with PCM, the other one was moisture management clothing (clothing B), were tested in a climate chamber where was controlled at -15°C. Eleven young male students volunteered to take part in wear trial experiments. The experimental results showed that the ear canal temperature when subjects wearing clothing treated with PCM was significantly higher that when subjects wearing moisture management clothing. The results also indicated that subjects wearing the clothing treated with PCM felt more comfortable than wearing the clothing untreated with PCM.

Keywords: PCM, cold protective clothing, cold environment, temperature distribution, humidity distribution

1. Introduction

Wearing different clothing humans can live in different environments, normal, hot, cold and even outer space. The core temperature of humans is tightly steady, and is maintained by a number of temperature regulation mechanisms at 37°C [1]. Heat exchanges between human body with environment by conduction, convection, radiation and evaporation [2] [3]. In a cold environment, if heat loss from human body is larger than heat production, the inner temperature of human body will be decreasing. When the skin is cooled enough to lower the body temperature and consciousness is lost, hypothermia happens. Human will lose the ability to spontaneously return to the normal temperature when the rectal temperature reaches as low as 28°C. On the other hand, if heat loss from human body is less than heat production, the inner temperature of human body will be increasing. Insufficient heat loss leads to overheating, also called hyperthermia. Therefore, the careful regulation of body temperature is critical to comfort and health.

When human enters a cold environment from a warm environment, the temperature of the clothing microclimate decreases, if the heat loss is too fast, he feels cold. Reversible to the above, when human enters a warm environment from a cold environment, if the heat loss is too slow, he feels hot. In order to improve textile fibers' thermal performance, in 1987, scientists developed and patented the technology for incorporating microencapsulated phase change materials (PCM) inside textile fibers [4]. Material usually has three states, solid, liquid, and gas. There are four kinds of phase change, including solid to liquid, liquid to gas, solid to gas, solid to solid. Heat is absorbed or released during the phase change process. When phase change material is heated, its temperature increases and reaches the melting point, the PCM absorbs heat and changes from solid to liquid, during this process, the temperature is kept constant at the melting point until all material changes into liquid. When temperature decreases and reaches the crystallization point, the liquid phase change material releases heat and changes from liquid to solid, in this process, the temperature is kept constant at the crystallization point.

Different PCMs have different transition temperatures and latent heat. The ideal PCM would have the features such as high heat of fusion,

* Corresponding author's email: tcliyi@inet.polyu.edu.hk

reversible solid-to-liquid transition, high thermal conductive, high specific heat and volume change during phase change transition, low vapor pressure, etc [5]. According to the phase change material handbook, paraffins are ideal PCM used in textiles. Paraffins have a high heat of fusion per unit weight, a wide range of melting points (-5 to 66°C) and they are flammable, nontoxic, noncorrosive, chemically inert, stable below 500°C, and predictable. They also have properties of negligible super cooling behavior, low volume change on melting, low vapor pressure in the melt, reasonable cost, and high wetting ability. The density of paraffins ranges from 700 to770 kg/m^3 [5].

When PCMs are applied in textile, PCMs have to be put into microcapsules. Otherwise they will eventually drip off clothing when they melt. Microencapsulation is the process of enveloping microscopic sized droplets or particles in a shell material for the purposes of protection or controlled release, because PCM-containing microcapsules must be durable and safe through the finishing process [6].

Unlike traditional insulation that simply traps air, the encapsulated PCMs can dramatically increase the capacity of materials to store energy. The PCMs interactively respond to each individual's unique physiological condition, absorb, store and release heat to help the body remain comfortable. The PCMs help the body to maintain its natural temperature across hot and cold environments and during high and low activity levels.

Shim et al. (2001) reported that heat released by a PCM in a cold environment decreases body heat loss by an average of 6.5W for a one-layer suit and 13.2W for a two-layer suit compared with non-PCM counterparts [7]. Ying et al reported a study on the assessment of temperature regulating performance of textiles incorporated with phase change materials [8].

In summary, much research has been conducted on the relation between the temperature regulating effect and the level of PCM treated on a garment. There are very few reports on the effect of PCM on temperature distribution in a clothing system. This study focuses on the effect of an application of PCM on temperature distribution in a cold protective clothing system.

2. Methodology

2.1 Participants

11 healthy male students volunteered as subjects and gave informed consent to participate in the research. Their characteristics are provided in Table 1.

Table 1. Physical characteristics of participants (M±SD)

Age (years)	Height (m)	Weight (Kg)
21.4±0.8	1.73±0.04	61.9±6.7

Each subject was informed about the general purpose, procedure and possible risk involved with experiments.

2.2 Climate

In experiments, one climate chamber was used. The temperature of the climate chamber was controlled at -15.0±0.5°C. The air velocity was less than 0.1m/s. Before entering into the climate chamber, subjects changed clothing in a room in which temperature was about 23.0±1.0°C. The relatively humidity was about 65±5%.

2.3 Measurements

Heart rate was continuously measured by a chest electrode belt with a heart rate meter (S810i, Polar Electro Oy, Finland) for every 5 seconds. Blood pressure was measured for every 10 minutes in the right arm (DynaPulse® 5000AUTO).

Ear canal temperature was measured with a thermocouple probe (LT8A, Gram Co, Japan) for every 2 seconds. Skin temperature was measured on the left chest, left forearm, left thigh and left calf.

Thermistors (HEL-700-T-1-A, Honeywell, USA) were used for temperature measurement of each layer of the clothing system. Humidity sensors (HIH-3610-001, Honeywell, USA) were used for relative humidity measurement of the clothing system.