Determination of Buffering Capacity of Hygoscopic Fabrics Under Subzero Conditions by Using Man-Clothing-Environment Simulator

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Abstract

In order to understand the buffering behavior of hygroscopic fabric under subzero conditions, microclimates of the wool and PET clothing system were measured and compared. Vertical type Man-Clothing-Environment simulator was used to measure the microclimate at the environmental temperature of −10°C. Buffering capacity was quantified by calculating from the depth and width of the hyperbolic curve of the graph. Hydrophilic wool fabrics showed better buffering capacity at the transient state than hydrophobic PET fabrics; which is attributed to the heat of sorption.

Introduction

In our previous studies the reproducibility and accuracy of the vertical type Man-Clothing-Environment simulator has been reported. The vertical type is also advantageous in terms of the prediction of the thermal comfort properties of the clothing system under the wide ranges of environmental conditions at the faster speed and less expenses than traditional skin model. Umbach[1)] and Yoo et al.[2)] have reported the buffering capacity of the fabrics under the static standard condition.

In our real life, however, for example, because of the activity of the human, they often times go in and out of the room temperature and humidity to the various environmental conditions. So far, for the clothing system that is wearable at extreme conditions, many researches have been performed for their total thermal insulation values mostly at the static conditions. However, their dynamic or transient effect, especially when sweating occurs which is critical to the comfort sensation and safety of the subjects, has not been clearly investigated. In this study, by measuring the microclimate of the air layers formed by either wool or PET fabrics, buffering capacity of the hygroscopic fabric at the transient state from warm to cold and vice versa were examined and compared to that of the hydrophobic fabric.

Experimental

The test was conducted at a cold environment set at -10±0.5°C to simulate cold winter season condition. The hot plate temperature was set at 33±0.5°C to simulate human body's skin temperature at comfortable condition, and the plate was covered with the absorbent fabric. In order to simulate sweating, 5ml distilled water was spread over the surface of the absorbent fabric. 5ml of water covered around 60% of the test area. Wool fleece and PET fleece with comparable structural characteristics were mounted at the 1st and 2nd layer and the micro porous membrane was added as the outer layer. Somewhat less amount of clothing for the environmental temperature was used to maximize the transient effect at the micro climatic layers. Once the clothing system was completed, it was stabilized at warm environment (25°C, 50% R.H.), and quickly moved to the cold environment (-10°C) and measured the microclimate for 30 minutes and moved back to the warm condition and measured another 30 minutes. The data on the temperature and the relative humidity inside each garment layer were collected and recorded every 10 seconds through the data logging system. The depth and width of the well of the graph formed by the initial state of the transient period was analyzed. Time to reach to peak (t_{max}), time to recover (t_r), decrease in relative humidity (Δh_{max}) and slope of the peak were considered in the equation.

Results

1. Transient effect

As the thermal insulation value of the two fabrics were similar, the first layer temperature of the two clothing systems maintained around 33°C in the warm environment and decreased when the samples were moved to the cold environment. The second layer temperature showed same trend but with wider range of temperature difference between the samples. It is influenced by the air temperature, thermal insulation and buffering capacity of the two fabrics. Larger amount of sweat pulse may result higher microclimate temperature due to the specific heat energy of water vapor. When the clothing system was moved back to the warm environment, temperature increased back to the original temperature.

The relative humidity inside garment layer decreased rapidly right after the sample was moved to the cold environment. And it bounced up to level out and reached to the steady state. If the absolute amount of water vapor inside garment layer stayed constant in the cold environment, the relative humidity reading would increase because the vapor pressure at saturation decreases as the temperature decreases. This phenomena was not observed in the graph, which means the phenomena occurs so instantaneously that it can not be recorded by reading every 10 seconds. The steady state relative humidity in the cold was about the same as in the warm environment. It is assumed that the water vapor was condensed when it was met the temperature gradient due to the outer air temperature changes. The dew point was reached within the clothing system. The condensation caused decrease in the actual vapor pressure more drastically than the saturation vapor pressure change, resulting decrease in the relative humidity. The condensed water will evaporate again to reach to the equilibrium to the condition. Thus the relative humidity increased and finally the well-shaped curve was obtained. It may be the buffering capacity of the materials for the specific transient condition.

When the clothing system was moved to the warm environmental condition, a bump was obtained. This was an expected phenomenon because when the fabric has sufficient amount of moisture in the fabric and the vapor pressure is low at the environment, it will release moisture to the environment until it reaches to the equilibrium. This phenomenon was clearer with the hygroscopic fabric. The diagram of water vapor transport and condensation of the two clothing systems are compared. In the PET clothing system, water vapor can pass through the garment layers better than the wool because the PET does not absorb into the fiber and passes through the surface of the fibers whereas the wool fabric absorbs moisture inside the fiber and release heat of sorption which delays the water vapor transport prominently. This difference between the two fiber types was also shown in the second layer. Since the third layer microclimate temperature was low, the vapor pressure was higher than expected. This resulted the driving force for the vapor transmission trough both the first and the second layers reduced. For this reason, the vapor pressure inside the clothing system stayed high in the cold environment.

2. Buffering Capacity

As a result of condensation, fabrics can release heat of sorption by the hydroxyl groups of the amorphous region and the surface of the crystals combining with water molecules. The benefit of the heat of sorption of wool fiber is a well-known phenomenon. However, the efficacy of this heat of sorption has not been quantified to predict the comfort properties of the fabrics due to the lack of instrument to measure this. The depth of the well and the length of the time until it reaches to the steady state were analyzed. In this study, the sharper and deeper well with longer duration was obtained with the wool clothing system than that of PET. In other words, with wool clothing system, when the fabric is exposed to cold environment less temperature decrease will occur than with wool clothing system, which is explained with the buffering capacity. Similar phenomenon was obtained when the clothing system was moved from cold environment to warm environment as the wool fiber holds moisture at the cold environment and releases to the air layer when exposed to the warm environment where the vapor pressure is lower. With the equation, the capacity of the wool was higher than PET but this number cannot be used as the absolute value of the capacity. We need further study with various types of fabrics to standardize these figures.

Conclusions

By using Man-Clothing-Environment simulator, microclimate formed by wool and PET fabrics clothing system where the environmental temperature was -10°C was compared. Difference in transient effect between the hygroscopic and hydrophobic fabric was observed. Buffering capacity was calculated from the temperature humidity graph. As the clothing system moves from warm to cold condition, wool showed better buffering capacity than PET, which is attributed to the heat of sorption. Same trend was obtained when the clothing system moved to the warm environment.

References

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2. Yoo, H. S., Hu, Y. S., and Kim, E. A., *Textile Res. J.* 70(1), 542-549 (2000).