Chemical protective clothing comfort study: thermal insulation and evaporative resistance from fabric to garment

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Keywords: chemical protective clothing, thermal comfort, thermal insulation, evaporative resistance

Introduction

Chemical protective clothing (CPC) is designed to prevent harm to human body and fatalities from the exposure to chemical and biological substances (Raheel, 1994). The critical issue associated with CPC is the conflict between effective protection and wearer's thermal and movement comfort due to its bulky structure and poor permeability of fabric (Shishoo, 2002). Specifically, encapsulated CPC impairing heat and moisture transfer from human body to environment can cause severe thermal discomfort, even heat stress. To evaluate the thermal properties of clothing, thermal insulation (Rct) and evaporative resistance (Ret) have been widely used. However, few research has been done on thermal properties of CPC fabric and garment systematically. Rct and Ret are critical thermal properties for both CPC fabric and garment. However, the garment Rct and Ret can be influenced by various factors other than fabric properties, such as garment structure and air gap size (Chen, Fan, Qian, & Zhang, 2004; Li, Zhang, & Wang, 2013). Therefore, the purpose of this study is to investigate the relationship between the Rct and Ret of textile material used in CPC and that obtained from CPC garment. The finding in this study will help improve the structure design of CPC.

Method and Analysis

Seven CPC were evaluated in this study: one single layer Nomex® woven fabric (common industry workwear) as control; four non-woven w/o coating CPC from Dupont® with one for each protection level: A, B, C, and D; and two double-layer (woven shell and nonwoven lining) military CPC. They were denoted as Nomex, A, B, C, D, M-G, M-C, respectively. The Rct and Ret of fabrics were tested on a sweating guarded hot plate with/without air gap according to ASTM F1868 standard. Two spacers were applied to create 3mm and 6mm air gap under the fabric respectively. A 35-segment Newton-type sweating thermal manikin was used to measure the Rct and Ret of the garments as per the standard ASTM F2370. The correlations among the Rct and Ret of fabrics and garment, fabric thickness and air permeability, and air gap thickness were analyzed.

Results and Discussion

The Rct and Ret of fabrics without air gap underneath were significantly lower than that of garments, which could be explained by the large amount of air trapped under the bulky garment. Apparent difference was observed for the Rct and Ret of fabrics and garments among various types of CPC (Fig 1), which is probably because of the different fabric properties, such as

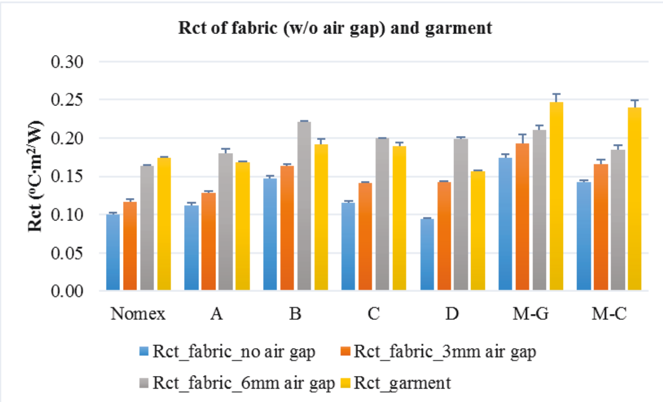

Fig 1. Rct of fabrics and garments

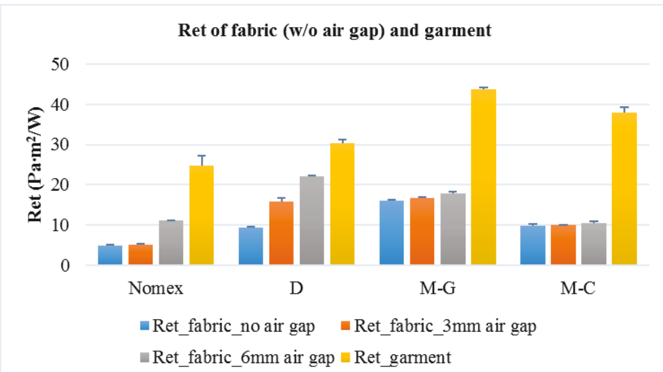

Fig 2. Ret of fabrics and garments (CPC A, B, and C are water vapor impermeable)

thickness and air permeability. Specifically, the extremely high value of Ret for CPC garment A, B, and C than other CPC indicated their water vapor impermeability because of the coating on fabric (Fig 2). The analysis results of Pearson's correlation showed that there was significant, positive correlation between the Rct of fabrics and that of garments ($p < 0.01$), indicating that the Rct of garments could be reliably predicted from that of fabrics. There was a strong but not significant positive correlation ($r = 0.938$) between the Ret of fabrics and that of garments for permeable Nomex, D, M-G, and M-C, which maybe due to the small sample size. A significant positive correlation was found between the Rct of fabric and air gap size, indicating the thicker the air gap, the larger the Rct. However, the Ret of neither fabrics nor garments was found significantly correlated with air gap size, which was inconsistent with previous studies (Chen, 2004). This could be due to the small sample size.

Conclusions

The Rct and Ret of CPC fabric are reliable predictor for the Rct and Ret of CPC garments respectively. Air gap contributes significantly to the increase of the Rct of CPC garments and fabrics. Heat dissipation by water vapor transfer through CPC is a complex process and different from other kinds of clothing due to its low permeability or impermeability. Further studies on the influential factors of Ret of CPC garments are needed.

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