Local thermal resistance of chemical protective clothing: effect of material and clothing fit

Liwen Wang, Rui Li, Mengying Zhang, Yulin Wu, Chunhui Xiang, & Guowen Song
Iowa State University, USA

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Introduction Chemical protective clothing (CPC) is designed to protect individuals from exposure to any potential chemical hazards. While it can prevent damages to the body from chemicals, it also causes significant issues of heat illness/injury by limiting heat dissipation of the body especially in hot environments (Sawka et al., 2003). Heat stress in CPC has been well recognized and the reasons for that are mostly because of the materials used and the design of clothing (Levine et al., 2001; Nunneley, 1989). Even though there have been different materials developed and applied (Anna, 2003), the heat stress issue remains unsolved (Slabotinský & Bernatíková, 2016; Taylor, 2015; Wang, Li, & Wang, 2019). The design of CPC has been very limited to loose-fit coveralls in general to accommodate body movement and inclusion of rebreathing apparatus and body armor when necessary. However, the large air gap created can cause significant increase in thermal resistance (Havenith, Heus, & Lotens, 1990; L. Wang et al., 2017). And because of the surface geometry of human body, clothing may drape/lie over the body differently at local body sections. Therefore, the purpose of this study is to investigate the thermal properties of typical CPC with a focus on the effect of clothing material and fit on local thermal resistance. The information and knowledge obtained from this study will assist the material selection and design improvement especially in local body area of CPC, as well as the evaluation and modeling of thermal strain in CPC.

Method and Analysis A total of six ensembles were studied: Three CPC of different materials and protection levels but the same coverall design and large size including MG—double-layer (active carbon embedded foam/woven shell), permeable and high protection; D—single-layer DuPont® Tyvek®, low permeability and protection; BL—single-layer DuPont® Tychem®, impermeable and high protection; Nomex—a duplicate of CPC style with common workwear material Nomex® as control, high permeable; BM, BXL—medium and extra large sized BL for the study of clothing fit. Their thermal resistance was measured per standard ASTM F1291-16 (2016) using a sweating thermal manikin. Both whole-body and local thermal resistance of the surface air layer (Ra, Ra,l) and clothing ensembles (Rct, Rct,l) (only one side of symmetrical parts were analyzed) were reported. Effects of clothing material and fit/size were analyzed using one-way ANOVA and post-hoc Tukey tests at a significance level of 0.05.

Results and Discussion It was found that clothing material had a significant effect on Rct ($p<.05$), specifically, MG had higher Rct than the others, while CPC D and BL, and Nomex had similar Rct. This could be caused by the much thicker material of MG which created larger air gap under clothing. Clothing fit/size was also found to significantly affect Rct with Large sized

BL having higher Rct than the medium and extra-large sized BM and BXL. It agreed with previous finding that increasing air gap under certain limit would increase Rct.

Local thermal resistance varied a lot among local body sections even though the surface air layer had generally consistent Ra,l. Material was also found to significantly affect local thermal resistance. The variation of Rct,l depended on specific ensembles and could be as large as from 0.19 °C·m^2/W to 1.8 °C·m^2/W (highest value in Fig. 1) for MG. A similar pattern of Rct,l distribution was found where higher values were found at the torso with the highest value at the Stomach. This explained the severe heat stress issue in CPC and indicated an urgent need of redesigning and constructing current CPC. Compared to single-layer clothing ensembles, the increase of Rct,l for CPC MG at the Stomach was much higher. This could be because the thick and rigid material of MG created larger air gap at the stomach. The post-hoc Tukey test also identified a significant difference of Rct,l only between MG and all the other ensembles. Although clothing fit/size was found to significantly affect Rct, no significant effect was found on Rct,l. The reason for that could be the small sample size of the study—only one type of CPC was studied.

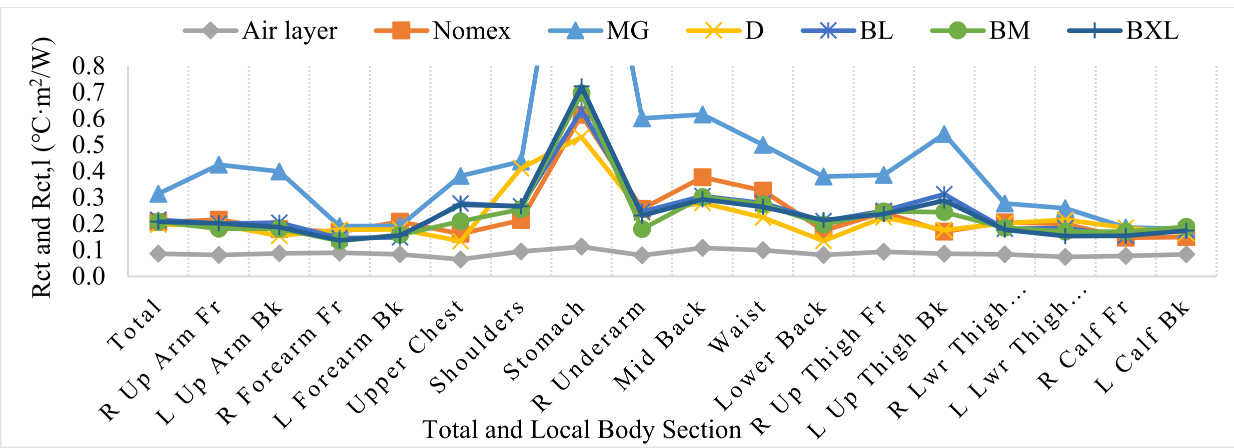

Figure 1. Total and local thermal resistance of air layer, Nomex, and five CPC

Conclusions The material used can significantly affect both whole and local thermal resistance of CPC, and material thickness and stiffness are two determining factors. Local thermal resistance can provide more and detailed information about the thermal properties of clothing such as higher thermal resistance at the torso, and hence a more accurate and thorough evaluation of the heat strain for users. It should always be reported and considered for better evaluation and modeling of the heat stress in CPC, and for the design and development of next generation CPC with higher protection and less compromised thermal comfort. Inconclusive effect of clothing fit/size was found on thermal resistance because of the small and simplex sample studied. In future studies, more CPC of various materials and different sizes will be included, and the air gap thickness and distribution in the microclimate under clothing will be quantified to further investigate the effect of clothing fit.

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