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Effect of Configuration of Protective Fabrics on Thermal Protective Performance under Steam Exposure ⋆

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Abstract

A novel steam simulator was employed in this study to evaluate thermal protective performance of protective clothing while exposing to steam hazard. Single- and double-layer fabric systems were selected, and different configurations of moisture barrier were exposed to steam hazard for investigating the effect of configuration of protective fabrics on the thermal protective performance. The skin bio-heat transfer and Henriques burn integral models were used to predict the required times to reach 2nd and 3rd degree skin burn. The results demonstrated that the thermal protective performance of protective clothing under steam exposure was determined by the air permeability, the thickness, the mass, and the surface properties of fabric. Even though the moisture barrier provided excellent protective performance for steam exposure, the configuration of moisture barrier presented a decisive influence on the role of moisture barrier. The findings obtained in this study provide technical data for the performance improvement of protective clothing under steam hazard.

Keywords: Thermal Protective Performance; Steam Exposure; Protective Fabric; Configuration

1 Introduction

Industrial steam extensively used in oil and gas sectors presents a potential hazard for workers, such as steam burns and fatalities, since the surrounding ambient air can be heated rapidly in a confined space if steam leaks [1-3]. Thermal protective clothing can provide effective protection by resisting heat transfer under steam hazards. As stipulated in standard NFPA 1971 and EN 469, a typical thermal protective clothing can be a one-layer coverall or composed of three different fabric layers, i.e., an outer shell, a moisture barrier, and a thermal liner. The role of outer shell is to provide flame resistance, protection against heat radiation, resistance to water, and certain

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levels of abrasion. As a middle layer, the moisture barrier is designed to not allow liquid water to penetrate from outside but promote water vapor transport outwardly from the wearer [4, 5]. Therefore, the common thermal protective clothing is generally designed for protection against flash fire and high- or low-intensity radiant heat exposure and behavior of clothing against steam exposure should be further examined [6-9].

There is no international standard for characterizing the steam protective performance of clothing or fabric until now. Some preliminary explorations were carried out to characterize the performance of thermal protective clothing exposed to a pressurized steam condition. For simulating hot steam conditions, some researchers developed the bench scale tests [10-12] as well as the full-scale thermal manikin tests [3, 11] to measure the protective capacities of fabrics and clothing under hot steam conditions. The horizontal bench top tests developed by Liu et al. [10] and Murtaza [12] were used to investigate the performance of protective fabrics under hot steam exposures. Liu et al. selected different steam pressures (50.6 and 152 kPa) to expose the protective fabrics for a fixed period of 20 s while Murtaza evaluated the performance of protective fabrics under steam pressure of 210 kPa at 150 °C for 10 s exposure. The main difference between two kinds of test approaches was the steam flow directions: upward and downward, respectively. Because different steam flow directions could affect the rate of heat and moisture transfer in protective fabric system. However, the horizontal steam flow more conforms to the actual fire ground according to the body standing state. Therefore, a vertical test device under steam exposure was developed by Derscuell and Schimid [11]. The device could change the steam splash distance and steam pressure to simulate different experimental conditions, but the major limitation of Derscuell and Schimid's work was that the heat flux sensors have relatively large error for higher skin temperature. Su and Li [13] developed a vertical test device and investigated the combined effect of steam and radiant heat exposures on protective performance of clothing. Additionally, Sati et al. [3] presented a test device of cylindrical shape to evaluate the effect of body shape on steam protection of clothing in moderately high-pressure steam (69 and 207 kPa). The fabric could be mounted with or without a space to provide an air gap between the cylinder and the fabric that simulated the real wearing state. A thermal manikin in a steam climatic chamber was employed to evaluate the protective performance of protective clothing against steam exposure [11]. The results demonstrated that the steam penetration and the heat transfer in protective clothing depended on fabric's properties, such as resistance to water vapor diffusion, air permeability, thermal insulation and total heat loss, as well as fabric coating/laminate.

Additionally, our previous work evaluated the thermal protective performance of protective clothing under steam exposure [14]. Further study was to analyze the effect of configuration of moisture barrier on the thermal protective performance of protective clothing under a pressurized steam. Therefore, different configurations of moisture barrier for single- and double-layer fabric systems were exposed to steamy condition. The times to cause skin burn and heat transfer in various fabric systems were analyzed in order to provide proper suggestions to improve the thermal protective performance of protection clothing in a steamy condition.

2 Experimental Part

2.1 Materials

Four types of fabrics currently used in thermal protective clothing were selected as samples. Two kinds of composite fabric with different air permeability were used for outer shell. Two