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Technical note

Fluorescent aerosol leakage quantification for protective clothing with an entropy-based image processor for industrial and medical workers

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ABSTRACT

Correct procedures for donning and removing protective clothing are critical for preventing transmission of hazardous particulates in industrial and medical settings. The purpose of this study is to examine the levels of airborne particulate leakage of personal protective clothing after a series of exercises performed by volunteers who simulated industrial and medical workers. The fluorescent aerosols were employed as airborne particulates in a controlled chamber with ultraviolet (UV) light-detectable stickers. After an exposure-and-leakage test, the protective clothing was removed and photographed with UV-scanning to evaluate areas where fluorescent aerosols had adhered to the body through the clothing. An image processor installed with an entropy-based algorithm was developed to segment the fluorescent area and calculate its relative leakage ratio (L_r) in real time. This study addresses an optimal technique to confirm the safety of protective clothing removal and decontamination policy formulated for aerosol-transmitted situations.

1. Introduction

Clothing surface safety has been a consideration in many studies. Most regulations and performance standards have focused on the fabric structure capability to withstand liquid and gaseous chemicals (Stull & White, 1992; NFPA 1999, 2003; CNS 14798, 2004). When motions are performed, the air exchange increases and results in a functional loss of clothing insulation. This phenomenon is called the pumping effect (Havenith & Nilsson, 2004), or clothing ventilation. In addition, this phenomenon occurs at the collar, cuff, waistline, and hemline body-clothing boundaries. Several studies have simulated or estimated the pumping effect on thermal insulation loss of workwear and cold-weather clothing in wind conditions (Havenith & Nilsson, 2004; Aoyagi, McLellan, & Shephard, 1994; Havenith, Heus, & Lotens, 1990; Vogt, Meyer, Libert, Sagot, & Candas, 1983). However, there has been little research into the pumping effect on leakage of airborne pollutants.

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Chemical, biological, or medical processes can produce and suspend various hazardous particulates. For the past decade, bioaerosol propagation has become an issue for medical hygiene and occupational health. Infectious and contagious bioaerosols, such as tuberculosis, SARS and H1N1 virus, are transmitted by suspended droplet nuclei with diameters of 1–20 μm (Yang, Lee, Chen, Wu, & Yu, 2007; Chao et al., 2009) through coughing, laughing, talking, and singing. In factory manufacturing, erosive dust, particles of heavy metals, organic aggregates of polymers and dyes, bituminous coal, and epoxy resin are concerns. Protective clothing, gloves, and masks are used to insulate related staff from contact transmission between skin and hazardous particles when operations and first aid are processed. The pumping effect, mentioned above, affects protective clothing rather than gloves and masks, because the boundary between the body and clothing is the most difficult to make airtight.

Unknown particulate leakage is an underestimated risk of hazard exposure for front-line factory and healthcare center workers. Because of complicated steps for donning and removing protective clothing, self-contamination risks from particulate leakage should not be ignored. The purpose of this study is to determine if particulate leakage into protective clothing worn by volunteer simulated workers would happen after a series of designed exercises. An image processor installed with an entropy-based algorithm was used to quantify the segmented images of boundary leakage areas adhered to by fluorochrome aerosols, the aerodynamic imitators of airborne particulates. Finally, a leakage ratio was introduced to assess the pumping effect on protective clothing in various conditions, such as exposure time and body parts.

2. Designed action sets for volunteers

For simulating the intensity and range of activities in hospitals and factories, simplified and disciplined exercises were taught to volunteers wearing protective clothing before exposure-and-leakage tests. The designed exercises included squatting, standing, raising elbows, turning left and right, holding arms across the chest, and stooping. All action sets were performed and finished successively in 1 min, and repeated for the next minute if necessary. Therefore, the ten-repetitions of designed exercises lasted 10 min. Volunteers wearing protective clothing performed designed exercises in a stabilized chamber, described below, for two- and ten-repetitions.

3. Functional requirements of protective clothing

Protective clothing was a one-piece coverall of high-density polyethylene fibers, registered as Tyvek® of DuPont. The functional requirements of protective clothing include breaking strength (vertical orientation ≧50 N, horizontal orientation ≧40 N), bursting strength (≧200 kPa), sewn seam strength (≧40 N), tearing strength (vertical and horizontal orientations ≧20 N), water vapor transmission rate (≧1500 g cm^{-2} day^{-1}), hydrostatic pressure (140 cm H_2O), and impact penetration (≦0.5 g). Finally, no surface penetration of virus and synthetic blood must be confirmed. The above specified requirements have been declared by the Committee for Conformity Assessment of Accreditation and Certification on Functional and Technical Textiles, Taiwan (http://www.ftts.org.tw/images/fp103E.pdf). Pre-delivery inspection of protective clothing used in this study must have been carried out.

4. Exposure-and-leakage test

For controlling the physical conditions, a closed chamber 360 cm (length) × 213 cm (width) × 180 cm (height), was fanned with a wind velocity of 1.3 m/s to simulate an indoor environment. The temperature was set at 21(± 3) °C by an air conditioner, and relative humidity was controlled at 50(± 3) by a dehumidifier. The aerosol solution was prepared by a mixture of SiO_2 powders, an ethanol solution of 20% (v/v), and the Hoechst 33258 fluorescent dye ($C_{25}H_{24}N_6O \cdot 3HCl$, Aldrich Inc.), a non-toxin used in flow cytometry. Ethanol can help the fluorescent dye combine with SiO_2 powders in an aqueous solution. A nebulizer consists of an air-extractor and a flow-presser was used to disperse the aerosol solution to produce challenged aerosols with fluorescence. The fluorescent aerosols with a count median diameter of 0.15 μm were dispersed into the chamber through a nozzle (model 8012/1010L, Natural Fog®, Taiwan) with a caliber of 0.80 mm. The concentration detected by a portable aerosol spectrometer (model 1.109, Grimm Aerosol Technik GmbH & Co., Germany) was 10^5–10^6 particles/cm^3. Total stabilization time for reaching steady temperature and relative humidity in the chamber was 4 h minimum for each exposure-and-leakage test. Fig. 1 depicts the experimental setups.

5. Image processing with entropy-based algorithm

After a series of designed exercises, volunteers left the chamber, removed the protective clothing, and stood in a darkroom. If boundary leakage of protective clothing happened, the selected boundary parts deposited by challenged aerosols presented fluorescence in a UV scanner of 365 nm. Fluorescent pictures were taken with a digital camera (Nikon D3000) equipped with a manual and automatic focusing lens (Nikon AF NIKKOR 50 mm 1.8D, Japan). Its charge-couple device's (CCD) picture quality is 3872 × 2592 pixels. The camera shutter was set to 1/60, and the camera's diaphragm and ISO value was F2.0 and 800, respectively. Before photographing, the response of the CCD was checked with a standard multicolor chart (a digital image file). In an enclosed environment, the camera took a picture of the standard chart lit by an electric bulb with a color temperature of 5000 K. A digital comparison of the photograph of the chart and the chart confirmed the constancy of the CCD