A hazard simulation study for PPE contamination and decontamination

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Adverse effects on long-term health associated with firefighters' occupational exposures have been recognized as a critical issue of firefighter's health and safety (Keir et al., 2020; Navarro et al., 2019). Numerous studies have demonstrated a higher incidence rate of several chronic diseases (e.g., cancer, cardiovascular disease (CVD), and reproduction problems) among firefighters (Casjens, Brüning, & Taeger, 2020; Daniels et al., 2014). Long-term exposure to the contaminated personal protective equipment (PPE) system is evidenced to be the potential trigger of these diseases (Gill & Britz-McKibbin, 2020; Harrison et al., 2018). Contaminated PPE that contains harmful substances such as small particles, organic compounds, plasticizers, and heavy metals are believed to be a major contamination source (Fent et al., 2020). Specifically, fine particles with other contaminants attached to them can re-suspend from contaminated PPE and can be inhaled or absorbed by firefighters around. It has been reported that a detectable level of contaminants was found from the air and dust of several fire stations (Shen et al., 2018). While the application of cleaning and decontamination provides a certain level of contaminant removal, their efficacy and the impacts of residuals have never been systematically evaluated.

Studies showed that the regular laundering approach could not adequately remove the special contamination containing numerous particles and semi-volatile compounds (Mayer et al., 2019). The mechanism of interaction among the nature of chemical compounds, concentration of contaminants, and PPE composites is not fully investigated. So far, only some laundering factors such as washing cycle, detergent type, and water temperature were explored of their effects on cleaning effectiveness (Stull, Dodgen, Connor, & McCarthy, 1996). Currently, the contaminant simulant applied (i.e., NFPA 1851 method) does not represent real contamination situations found on fire grounds with high temperature, humidity, and air velocity. Rather, it utilizes physical doping methods such as dripping chemical solution and rubbing into swatches (NFPA, 2020). Therefore, a controlled lab contamination/smoke simulation that represents a realistic exposure condition is in urgent need. Such a tool is crucial not only in sample preparation to evaluate decontamination methods but also in investigating the underlined mechanisms of contaminants absorption, transmission, desorption in PPE textiles.

In this study, a modified cone calorimeter test will be applied to study the material combustion process, analyze the emission components, and characterize and simulate a fire-scene smoke emission. The cone calorimeter has long been considered the most significant bench scale instrument in the field of fire testing. It can provide ignition time, mass loss, heat and smoke release, and other parameters associated with the material burning properties. Robust heat and air flow rate control can maintain a high level of test stability. A schematic map using a cone calorimeter as the combustion device is shown in figure 1.

The whole process involves three parts: smoke generation, environment monitor, and smoke collection and analysis. For the smoke generation, the major controllable factors, including material composition and concentration, moisture content, and exposure heat flux intensity, may affect the particle size and distribution and chemical compounds properties. To simulate a structual fire scene, several typical materials used in the modern building will be selected, such as wood, plastic, and textile. Mixture along with various moisture contents of these materials, will be accounted to investigate their relation with the smoke emission. The heat flux intensity, which affects the smoke emission, will also be explored. The variations of these factors and their effects on both the emission and the combustion process stability will be analyzed.

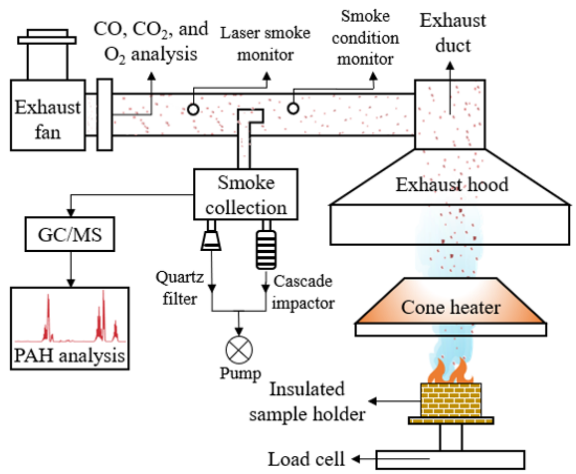

Figure 1. Smoke simulation using a cone calorimeter

To validate the smoke emission, part of the smoke flow will be collected using a quartz fiber filter and a cascade impactor. The smoke flow rate will be recorded and used for complete mass analysis. The whole particle mass and particle size distribution measured by filter and impactor will be used for contaminant emission and whole process stability validation. Furthermore, the filter will be processed by several steps such as extraction, concentration, and final chemical analysis for measuring chemical compound type and concentration within the particles. The major chemical compounds such as semi-VOCs and PAHs will be compared with the previous smoke investigation of the actual fire scene.

The stability and repeatability of the whole burning process will be emphasized and validated for future test standard development. Parameters such as particle distribution and chemical compounds will be used for validating the robustness of the entire system.

Future outlook. Smoke hazard simulation is critical for PPE contamination and decontamination studies. With a controlled hazard simulation, accurate evaluation of advanced decontamination methods, self-cleaning material, and contaminant-proof design of PPE can be achieved. Furthermore, more complete data and AI powered modeling of PPE contamination process and decontamination efficacy can be realized.

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