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TECHNICAL NOTES

Development of real-time particulate and toxic gas sensors for firefighter health and safety

EXECUTIVE SUMMARY FOR REPORT BY:

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August 2019

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FOREWORD

Removal of respiratory protection during activities such as fire overhaul and wildland fire fighting can expose firefighters to unknown toxicants. The preliminary study indicates evidence to justify the needs for simultaneous monitoring of particulates (including ultrafines), aldehydes (formaldehyde, acrolein), and hydrocarbons (benzene) in addition to the CO levels, as they frequently exceed the exposure limits and lead to severe health issues in firefighters. This project will focus on developing prototypes of compact, highly sensitive, real-time particulate/gas detection systems to reduce the number of firefighter fatalities and injuries. The sensors will alert the firefighters of hazards in the air.

Case Western Reserve University (CWRU), in close collaboration with NASA Glenn Research Center and Makel Engineering Inc., conducted this three-year, study in partnership with multiple fire service partners, and the Fire Protection Research Foundation. The purpose of this project is to design, develop and test prototypes of real-time sensors to detect particulates and toxic-gases, so as to protect firefighters from respiratory damage and illness.

This study endeavors to: (1) combine the NASA-developed compact particulate and gas (O_2, CO, and hydrocarbons) sensors, (2) micro-fabricate and integrate new sensitive aldehyde sensors, and (3) test prototypes in the laboratories, burn rooms, fire overhaul, and wildland fire environments in cooperation with the fire services.

This work was performed under a grant from the U.S. Department of Homeland Security, Federal Emergency Management Agency, Assistance to Firefighters Grant Program, Fire Prevention and Safety Grant (No. EMW-2014-FP-00688), following a preliminary study grant (EMW-2012-FP-01284), awarded to Case Western Reserve University.

The Fire Protection Research Foundation expresses gratitude to the research team report author Dr. Fumiaki Takahashi, who is with Department of Mechanical and Aerospace Engineering at Case Western Reserve University, Cleveland, Ohio, USA. The Research Foundation appreciates the guidance provided by the Project Technical Panelists, the funding provided by the project sponsor, and all others that contributed to this research effort.

About the Fire Protection Research Foundation

The Fire Protection Research Foundation plans, manages, and communicates research on a broad range of fire safety issues in collaboration with scientists and laboratories around the world. The Foundation is an affiliate of NFPA.

About the National Fire Protection Association (NFPA)

Founded in 1896, NFPA is a global, nonprofit organization devoted to eliminating death, injury, property and economic loss due to fire, electrical and related hazards. The association delivers information and knowledge through more than 300 consensus codes and standards, research, training, education, outreach and advocacy; and by partnering with others who share an interest in furthering the NFPA mission.

All NFPA codes and standards can be viewed online for free.

NFPA's membership totals more than 65,000 individuals around the world.

Keywords: sensors, firefighter, exposure, acrolein, formaldehyde, gas sensor, real-time, particulate.

Report number: FPRF-2019-18

FPRF Project Manager: Sreenivasan Ranganathan and Casey Grant

PROJECT SPONSORS

This work was performed under a grant from the U.S. Department of Homeland Security, Federal Emergency Management Agency, Assistance to Firefighters Grant Program, Fire Prevention and Safety Grant (No. EMW-2014-FP-00688), following a preliminary study grant (EMW-2012-FP-01284), awarded to Case Western Reserve University.

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EXECUTIVE SUMMARY

A technical endeavor has been made to develop prototypes of real-time particulate and toxic-gas sensors for firefighter health and safety in collaboration between Case Western Reserve University (CWRU), NASA Glenn Research Center, and Makel Engineering Inc. (MEI). Removal of respiratory protection during post-fire overhaul activities can expose firefighters to unknown toxicants, but current practice generally relies on the carbon monoxide detection. Wildland firefighters do not wear respiratory protection despite long-term exposure to smoke at varying levels. Various consecutive and partially overlapping tasks have been conducted.

In the early stage of the project, the Project Technical Panel was formed with the assistance of the Fire Protection Research Foundation, and telephone conferences were held to review the project scope, tasks, timetable, and other pertinent project details.

Two types of micro-fabricated sensors for sensory irritant gases, i.e., acrolein and formaldehyde, were studied at CWRU and NASA. In the meantime, miniaturization of the existing multi-parameter aerosol scattering sensor was completed at NASA. The particulate and gas sensors, together with the control electronics, were integrated into prototypes at MEI. Prototype I units include the sensors for particulate, low-level CO, O_2, and hydrocarbon sensors, and Prototype II units include those for particulate, high-level CO, O_2, hydrocarbon, acrolein, and formaldehyde.

The smoke generation and toxicity characteristics of pyrolyzing or flaming materials were studied using the smoke density chamber and the cone calorimeter at CWRU. Main findings include: (1) the non-flaming pyrolysis of wood generated much more (~3×) CO than the flaming condition, (2) the formaldehyde concentration was an order of magnitude higher than acrolein, and (3) both formaldehyde and acrolein concentrations were correlated well with the CO concentration. The results were informative for the device development.

In addition to initial laboratory testing of the prototypes, a brief attempt was made to test the first Prototype I unit in the wildland fire in California by the USDA Forest Service. Further field fire testing and debugging efforts are needed for Prototype II to implement the technology into a commercial product in the future.

The full final report shall be accessed from the Case Western Reserve University Website:
https://engineering.case.edu/sites/default/files/Final%20report-Sensors-FY2014.pdf