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POSITIVE PRESSURE AIR SUPPLY SYSTEM FOR WILDLAND FIREFIGHTER HELMETS

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SUMMARY: The size and severity of wildfires worldwide have increased since the 1980s. In the USA alone, over 66,000 wildland fires occurred during 2022. Thousands of firefighters were employed to control these fires. The occupational health and safety risks associated with wildland firefighting are significant and numerous. The most common are physical injury, exposure to smoke and heat stress. A prototype helmet ventilation system was developed that can reduce such exposures. The system uses multiple air ducts channeling filtered air into the firefighter's helmet while also directing the air over the firefighter's breathing zone. The two air supply systems can be operated independently of each other. The system is designed to provide a comfortable, discreet, and simple solution for reducing occupational exposure to smoke while also reducing the heat stress experienced by the wildland firefighters.

Key words: *wildland firefighters, occupational health and safety, respiratory protection, heat stress reduction, prototype technologye*

INTRODUCTION

Global warming patterns and changes in land use have increased the risk and frequency of wildfires worldwide *(Abatzoglou, Williams, 2016, Aldersley et al., 2011, Li et al., 2023)*. The size and severity of the fires have increased since the 1980s, with over 66,000 forest and wildland fires occurring in the USA during 2022 *(Burke et al., 2021, Earth Science data systems)*. Since the 1970s, western wildfire seasons in the USA have expanded in duration from five months to seven months annually *(Westerling et al., 2006)*. Thousands of wildland firefighters are required to protect local communities each year. Assuming that the current trend continues, the severity and duration of fire seasons are expected to increase globally *(Flannigan et al., 2013, Li et al., 2023)*.

The occupational health and safety risks associated with wildland firefighting are significant. The most common are physical injury, exposure to smoke, and heat stress. This project focused on the development of a prototype technology that may be able to protect wildland firefighters from excessive exposure to smoke while also reducing heat stress. The technology consists of a prototype system that is projected to meet current personal protective equipment safety and performance standards.

Wildland firefighters are exposed to smoke and ash consisting of particulates ≤ 2.5μm in size, and larger particulates ≤4μm in addition to multiple toxic gases *(Budd et al., 1997)*. The composition and concentration of wildland fire smoke can vary greatly from fire to fire and from one day to another No respiratory protection is currently

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mandated or used by wildland fire fighters. Nevertheless, the heavy workloads performed by wildland firefighters during extended periods of time may exacerbate the adverse health effects caused by the smoke. Innovative solutions are needed to address this shortcoming.

BACKGROUND

The occupational hazards associated with wildland firefighting are unique in many ways. Traditional respirator systems used in other work environments such as in structural firefighting are inappropriate in wildland firefighting *(Adetona et al., 2016)*. Wildland firefighters are often required to work 12-16-hour shifts for fourteen consecutive days with 48 hours rest between assignments. Additionally, wildland firefighters may work multiple fires during a 14-day period. In comparison, structural firefighters may respond to multiple incidents during a single shift, but resting or completing less arduous tasks between assignments *(Navarro et al., 2022)*. The long shifts associated with wildland firefighting make self-contained breathing apparatus used by structural firefighters unrealistic. Currently available respiratory systems either restrict the user's breathing, are vulnerable to the wildland fire environment, or are too cumbersome to be effective in wildland fire environments. The need for a practical respiratory protection system is clear.

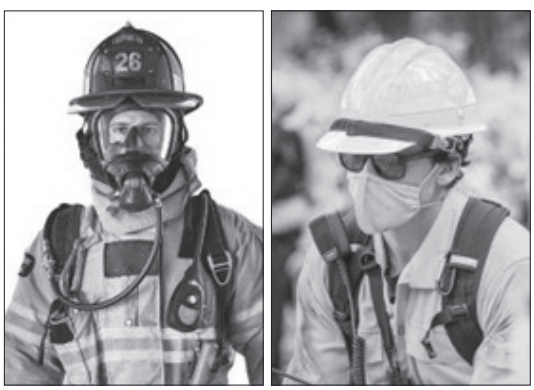
Currently, wildland firefighters rely on the use of standard construction hard hats and goggles. Light Nomex fire-resistant uniforms are provided for body protection. Boot requirements are also in place *(Garg et al., 2023, IAR, 2010, NIFC, 2024)*. Simple cloth facemasks and bandanas are occasionally employed to reduce exposure to smoke. A comparison of the personal protection equipment used by structural firefighters and wildland firefighters are shown below.

Structural Firefighting

Structural firefighting requires high intensity physical exertion. However, the exertion levels are generally shorter in duration but expose firefighters to known hazardous against which specialized respiratory protective equipment is usually provided *(Aisbett, 2012)*. Structural firefighters use a self-contained breathing apparatus (SCBA). The equipment is independent of the ambient atmosphere and requires a full-face mask. Depending on the firefighter's breathing rate, the air supply last about 45 minutes *(Kodros et al., 2021)*. While the system is effective for structural firefighting, it is not suitable for wildland firefighting.

Wildland Firefighting

Wildland firefighting involves exposure to sustained long-duration physical work. Wildland firefighter are also exposed to smoke, dust, and chemical fumes from vehicle exhaust. Wildland firefighters rely most frequently on bandanas, surgical masks, and N95 masks for respiratory protection. However, these have limited filtration efficiencies where bandanas provide the least protection while the N95 masks offer better protection *(De Vos et al., 2009)*. Figure 1. illustrates and example of a self-contained breathing apparatus worn by a structure firefighter “A” and use of a fabric facemask worn by a wildland firefighter “B”.



A B

Figure 1. Illustration of a self-contained breathing apparatus worn by a structural firefighter (A) and a cotton fabric facemask worn by a wildland firefighter (B)

Slika 1. Ilustracija samostalnog aparata za disanje koji nosi vatrogasac na objektima (A) i maske za lice od pamučne tkanine koju nosi vatrogasac u divljini (B)

PROTOTYPE

A prototype air filtration unit was developed to help improve respiratory protection for wildland firefighters. The system was designed to provide

an alternative to the respiratory protection options currently available such as covid facemasks and bandanas. Special attention was given to ensure that the system was practical yet effective in the appropriate occupational environments.

The prototype is a battery-powered. It contains a variable-speed air filter system that provides airflow to a firefighter's helmet. Air ducts direct filtered air to the firefighter's breathing zone while another set provides airflow into the space between the helmet suspension straps and the outer shell of the helmet. This airflow promotes sweat evaporation on the head. The two air supply options can be operated separately. The system design is shown graphically in Figure 2. The details of the air supply and air filter unit are illustrated in Figure 3. Figure 4. shows the air ducts connecting the air filter unit to the helmet.

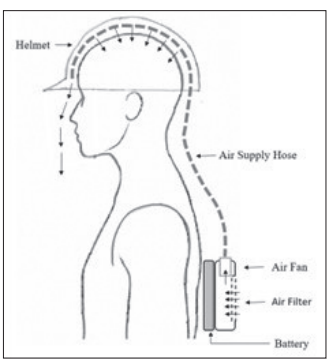


Figure 2. Graphic illustration of the prototype system
Slika 2. Grafički prikaz prototipa sustava

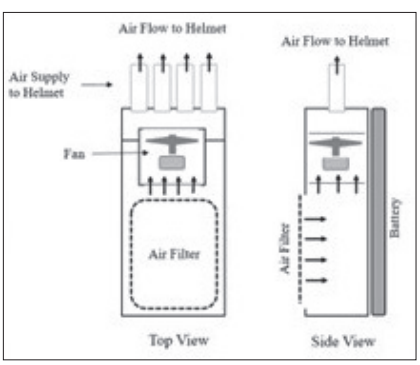
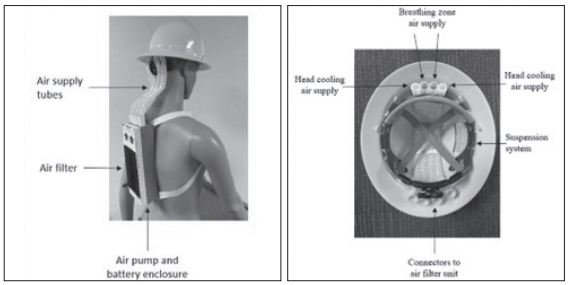


Figure 3. Design details of the air fan unit including the filter
Slika 3. Detalji dizajna jedinice ventilatora za zrak uključujući filtar



A B

Figure 4. Air supply unit including air filter (A) and the air distribution tubing inside the helmet (B)
Slika 4. Jedinica za dovod zraka uključujući filtar za zrak (A) i cijev za distribuciju zraka unutar kacige (B)

AIRFLOW ASSESSMENT

Airflow through the helmet air supply tubing was determined by employing a digital precision thermoanemometer probe which was placed inside the manifold chamber located upstream between the air fan and the tubing connector unit (Fig.3). Average airspeeds inside the tubing were based on three-minute sampling periods where the digital thermoanemometer recorded air velocities every second for a total of 180 individual measurements. To determine the airflow reaching the breathing zone only, the tubing for head cooling was blocked (Fig. 4B top). To determine the airflow for head cooling only, the tubing to the breathing zone was blocked (Fig. 4B side). To determine the combined airflow to both the breathing zone and head cooling, all tubing remained open. To calculate air volumes (l/min), the average air speed values determined by the digital thermoanemometer (cm/min) were multiplied by the cross-sectional area of the tubing (cm^2).

SYSTEM PERFORMANCE

The prototype technology provides a positive pressure airflow into the helmet which directs filtered air into the firefighter's breathing zone. The air volume is such that a face shield is not needed to protect against incursion of smoke into the breathing zone. The system is designed to also be compatible with all current firefighter protective equipment safety and performance requirements. The unit operates on batteries used for standard

firefighting communication technologies. The air volumes directed into the firefighter's breathing zone, and separately into the helmet, were measured at flow volumes of 222 l/m and 680 l/m. The tests evaluated three ventilation configurations: Airflow to the breathing zone only, airflow to the head only, and airflow to both the breathing zone and the head simultaneously. All tests were conducted using a surgical face mask as the filter. Table 1. summarizes these results. Figure 5. illustrates the results graphically.

Table 1. Summary of airflow rates for the breathing zone only, for the helmet only, and for the combined breathing zone and helmet airflow

Tablica 1. Sažetak brzina protoka zraka samo za zonu disanja, samo za kacigu i za kombiniranu zonu disanja i protok zraka kacige

Filtered Air Supply (l/min)	Airflow to face only (l/m)	Airflow to head only (l/m)	Air Flow to Face + Head (l/m)
222	135	94	174
385	240	215	305
475	300	283	384
555	363	326	420
608	393	372	489

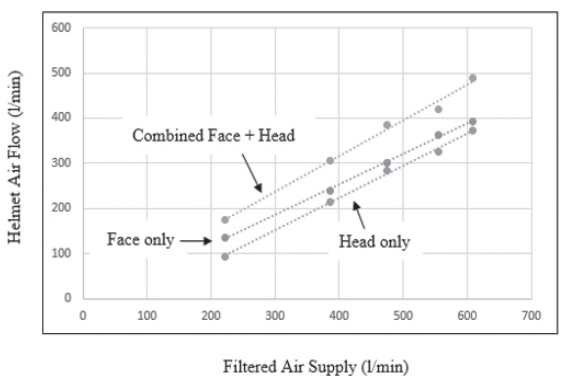


Figure 5. Summary of airflow rates observed for the inside of the helmet, the breathing zone, and the combined breathing zone and the helmet

Slika 5. Sažetak stopa protoka zraka opaženih za unutrašnjost kacige, zonu disanja i kombiniranu zonu disanja i kacigu

DISCUSSION

The number of firefighters exposed to smoke and heat stress is expected to increase in the future *(Abatzoglou, Williams, 2016, Navarro et al., 2022)*. Repeated inhalation of wildfire smoke is known to increase the risk of lung cancer and cardiovascular diseases. The development of the prototype system represents an opportunity to address this challenge. Also, providing effective respiratory protection in the future can help wildland fire management better retain their workforce, spend less on healthcare costs, and protect those who put themselves at risk. The ability of the proposed system to integrate with the current protective equipment can facilitate its adoption by fire services internationally. Field testing and performance evaluation will be the next step. Unintentional side effects resulting from repeated use may be identified. However, feedback from wildland firefighters will be critical in order to be able to optimize the new design for long-term field use.

CONCLUSION

The development and testing of the prototype respiratory system have shown the potential for improving the health and safety of wildland firefighters in the future. Although the tests were conducted inside a laboratory, the fundamental principle of providing fresh air to a firefighters' breathing zone displacing smoke while also reducing heat stress appears feasible. The demand for wildland firefighter personnel is increasing throughout the world. Therefore, providing better respiratory protection is a common-sense solution. Applications of this technology to other occupations such as construction work and industrial work will be possible.

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SUSTAV DOVODA ZRAKA S POZITIVNIM TLAKOM ZA VATROGASCE S KACIGOM NA OTVORENOM PROSTORU

SAŽETAK: Veličina i ozbiljnost šumskih požara diljem svijeta povećali su se od 1980-ih. Samo u SAD-u tijekom 2022. godine buknulo je više od 66.000 požara na otvorenom području. Tisuće vatrogasaca bile su angažirane na kontroli tih požara. Rizici za zdravlje i sigurnost na radu povezani s gašenjem požara u prirodi su značajni i brojni. Najčešće su tjelesne ozljede, izloženost dimu i toplinski stres. Razvijen je prototip ventilacijskog sustava za kacigu koji može smanjiti takvu izloženost. Sustav koristi višestruke zračne kanale koji usmjeravaju filtrirani zrak u kacigu vatrogasca, dok također usmjeravaju zrak preko zone disanja vatrogasca. Dva sustava za dovod zraka mogu raditi neovisno jedan o drugom. Sustav je dizajniran da pruži udobno, diskretno i jednostavno rješenje za smanjenje profesionalne izloženosti dimu, a istovremeno smanjuje toplinski stres koji doživljavaju vatrogasci na otvorenom području.

Ključne riječi: *vatrogasci na otvorenom prostoru, zdravlje i sigurnost na radu, zaštita dišnog sustava, smanjenje toplinskog stresa, prototipna tehnologija*

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