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Passive delivery of mixed explosives vapor from separated components

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ABSTRACT

Homemade explosive (HME) materials commonly take the form of binary, ammonium nitrate-based explosives, and are a challenge to detect due to the low volatility of ammonium nitrate, the great variation in fuel sources, and the complex environment in which detection takes place. Vapor detection in the form of detector canines overcomes these and other obstacles, and has proven to be a highly effective mode of detection. Due to inherent safety precautions associated with working with HMEs, experienced detector canines often lack the frequency of training on HME material necessary to remain proficient. For this reason, the Mixed Odor Delivery Device (MODD) was designed allowing canines to train on the odor of mixed explosives while keeping the HME components separate and unmixed, thus alleviating the safety requirements for handling, storing, and transporting explosives. Experiments across multiple investigative strategies were carried out to evaluate and characterize the vapor distribution in the MODD including computational modeling, analytical testing, and field trials. All testing indicated the MODD accurately provides uniformly mixed HME vapor at detectable levels from separated HME components.

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1. Background

Improvised explosive devices (IEDs) have been the leading cause of injury and death in recent Middle East conflicts. Approximately two-thirds of all American deaths in combat were by IED attacks, according to the Joint IED Defeat Organization (JIEDDO, now the Joint Improvised-Threat Defeat Organization). From 2003 to 2013 this equaled more than 3000 American military deaths and 33,000 injuries attributed to IEDs [1,2]. IEDs are not only threats abroad, but also pose a great threat to homeland security. Their prevalence at home and abroad is due to both the ease of acquiring the explosive components, as well as constructing the devices.

An IED can be defined simply as any non-industrially produced explosive weapon. The type of explosive material used can vary widely and tends to be made from materials readily available at that time/location [3]. Formerly, during the Iraq conflict, military and commercial explosives were more commonly used in IEDs. Withdrawing Iraqi forces left behind large amounts of unsecured munitions, which, in addition to demolition explosives, were acquired by insurgent groups, and used primarily in roadside IEDs and landmines [2,4]. In Afghanistan and other recent Middle East conflicts, the threat has shifted to homemade explosive (HME) materials most commonly composed of simple binary explosive mixtures, such as ammonium nitrate (AN) or potassium chlorate ($KClO_3$) mixed with various fuel sources [3,5,2].

Many detectors previously developed for the Iraqi conflict are inadequate for current military and homeland security needs. Previous detection capabilities were focused on landmine detection though, attention has broadened to the detection of a range of explosives, including HMEs, in complex and contaminated environments. Thus, versatility is the most important requirement for today's explosives detectors. Remote as well as proximate detection capabilities, detection through packaging or a container, and

Abbreviations: HME, homemade explosive; IED, improvised explosive device; MODD, Mixed Odor Delivery Device; AN, ammonium nitrate; CIS, cooled injection system.

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detection of both bulk and trace quantities are also necessary. Additionally, detection systems must be fast, robust, and selective with a low rate of false alarms [3,6,7].

Many current detection strategies for HMEs focus on the collection of explosive residues including direct irradiation of explosive residues, swabbing of residue followed by instrumental detection, or dislodging residue particles by air flow with instrumental detection. These methods are often fast, robust, and selective, but cannot be used or perform poorly in remote and non-contact sampling scenarios. For remote detection, spectroscopic methods, most commonly Raman spectroscopy, are utilized. These methods, however, suffer selectivity and sensitivity issues in complex environments or with certain substrates [6]. Alternatively vapor sampling systems, instrumental or biological (i.e. canines, plants, bees, etc.), may be employed [8]. Instrumental vapor detectors often do not have the sensitivity and selectivity needed for real-world scenarios. Vapor sampling by well-trained canine detectors fulfill all of the above-mentioned needs, and have, thus far, proven to be the most effective tool for HME detection.

Canines can be thought of as an integrated sampling and detection system with the unique ability to follow a vapor trail to its source. Highly efficient sampling with preconcentration occurs in the mucus membranes of the nose. Data collection and processing take place at the olfactory receptors and in the olfactory bulb of the brain. Vapor concentration gradients are used to follow the vapor trail to its source [9]. Canine detection has the benefit of being non-invasive, and has demonstrated improved sensitivity and selectivity compared to most, if not all, field-deployable detectors and sensors [9–13]. With proper and consistent training, a canine detector can identify a wider range of explosives with lower false alert rates than any currently deployable detector [14].

The main challenges to training canines on HMEs are safety and cost. Mixed explosives are difficult and expensive to safely obtain, store, and transport; and for this reason, are frequently limited to same-day production with strict use and disposal oversight by explosives chemists. These safety measures are costly and time-consuming, limiting the frequency of training exercises. In addition, approved training locations are often not realistic to operational setting [15]. For these reasons, many canines are trained on the oxidizer (i.e. AN, $KClO_3$, etc.) alone instead of the explosive mixture. This is less than optimal, as training on single components of these mixtures has been proven inadequate. For example, while testing canines on the detection of AN mixed with aluminum powder (Al), it was observed that canines trained on AN alone did not reliably detect the mixture of AN and Al [16]. Another study testing canine detection of $KClO_3$ and fuel mixtures yielded similar results [17]. In addition to safety challenges, training canines on HMEs may be further complicated by component availability (variable by region), as well as differences in fuel/oxidizer ratios.

The Mixed Odor Delivery Device (MODD) [18] was designed to alleviate the above-mentioned training difficulties. The MODD safely contains and allows for accurate mixing and delivery of vapor from separated explosive components. It offers transportability and ruggedness for field use with minimal sample size requirement, and is easily adaptable for the varied components one might encounter in the field.

In this research, computational modeling of vapor distribution within the device was utilized to aid in developing the design, and laboratory analyses and field evaluations were carried out for confirmation of its efficacy. Also, to lay an analytical foundation for the use of the MODD, headspace analysis of HME components was carried out comparing the vapor signatures of the mixed and separated components.

2. Design

The MODD functions to safely separate up to four explosive components in removable vials. It is separated into upper and lower compartments held together with two metal latches on either side, and an o-ring placed between the upper and lower compartments to ensure an airtight closure (Fig. 1). The MODD is transportable weighing less than five pounds with dimensions $5'' \times 5'' \times 4.5''$. It was designed with a low internal volume to minimize sample size requirements. These features and its ruggedness make it amenable to use in diverse locations.

The goal of the design is for the vapors from the separated vials to meet and diffuse through the device to the outlet of the MODD where they are presented to the canine as a mixture. The pathway of the analyte vapors is shown in Fig. 2 by the white dotted lines. Analyte vapors disperse from the vials, through the neck where separate vapors meet and mix, and then continue to diffuse around a restrictor plug. The analyte vapor escapes as a vapor plume from around the restrictor plug to an area hereafter referred to as the MODD outlet, where the canine inhales a mixture of vapors instead of unmixed vapor.

Vapor diffusion beyond the MODD outlet was also considered in the design and material choice. The design further encourages pooling of the vapor in its bowl-shaped outlet to lessen the effect of large amounts of odor overwhelming the surrounding area. To minimize excessive vapor at the outlet while maintaining its compact size, and thus small internal volume, the MODD was fabricated from PVC with increased surface area to internal volume ratio. In a study of several suitable materials for fabrication, PVC was chosen from due to its ability to adsorb vapor, and the ease in which vapor deposits can be removed by simply cleaning with isopropanol (or similar) wipes [19].

In addition, the vapor plume is limited by the restrictor plug located between the upper and lower portions of the MODD. The restrictor plug (Fig. 3) creates a small gap that acts to limit vapor entering the MODD outlet, thus decreasing the analyte vapor concentration escaping the container. Multiple removable restrictor plugs with varied gap sizes allow different quantities of vapor to diffuse to the outlet of the device, allowing the user to adjust the vapor concentration available to the canine. Further alterations of component vapor concentrations can be made by simply adding or removing individual vials or by placing constricting lids on individual vials. Additionally, the restrictor plug can be removed to allow a greater concentration of vapor to reach the canine, if desired.

Fig. 1. An open MODD, with the interior portion holding a sample vial exposed.