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Aerostat-lofted instrument and sampling method for determination of emissions from open area sources

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ABSTRACT

An aerostat-borne instrument and sampling method was developed to characterize air samples from area sources, such as emissions from open burning. The 10 kg battery-powered instrument system, termed "the Flyer", is lofted with a helium-filled aerostat of 4 m nominal diameter and maneuvered by means of one or two tethers. The Flyer can be configured variously for continuous CO_2 monitoring, batch sampling of semi-volatile organic compounds (SVOCs), volatile organic compounds (VOCs), black carbon, metals, and PM by size. The samplers are controlled by a trigger circuit to avoid unnecessary dilution from background sampling when not within the source plume. The aerostat/Flyer method was demonstrated by sampling emissions from open burning (OB) and open detonation (OD) of military ordnance. A carbon balance approach was used to derive emission factors that showed excellent agreement with published values.

1. Introduction

Air sampling from open area sources can be used to determine emission factors which allow calculation of source strength, atmospheric pollutant loading, and, with dispersion modeling, downwind exposures to assess possible harm to human health and the environment. Emission factors are significant for developing emission control strategies, permit applications, and for use in emission inventories. Open area sources include sources such as industrial plants, animal feed operations, and open burning. Typical sources of open burning include landfill or dump fires, structural fires, agricultural burns, and prescribed forest and grassland burns. Sampling emissions from open burning sources is particularly difficult due to the challenge of balancing the need for proximity to the undiluted source with safety issues for personnel. Furthermore, flame or explosion conditions which preclude sampling until onset of smoldering conditions may limit the representativeness of the emission sample.

Various methodologies and instrumentation have been used for open area sampling depending on the source characteristics and target analytes. Varying meteorological conditions, such as wind speed and direction may pose location challenges for ground-based point samplers. In addition, although ground-based samplers are often positioned on towers to improve their possibility for sampling, higher plumes and wind shifts may result in insufficient sample size to exceed detection limits. Optical remote sensing methods using "line of sight" measurements offer the benefit of path-integrated, rather than single point measurements. These sample methods are also ground-based and may be limited by their maneuverability as well as their applicability for some analytes, such as polycyclic aromatic hydrocarbons (PAHs). Aerial sampling methods, with capabilities for vertical and horizontal maneuverability, overcome concerns in sampling lofted plumes. These methods can employ airplanes, helicopters, miniature remote control helicopters, and unmanned airships/aerostats (Lund and Starkey, 1990; Laursen et al., 1992; Frick and Hoppel, 1993; Li et al., 1995; Imhoff et al., 1995; Fingas et al., 1996). While airplanes and helicopters can carry heavy payloads, pilots are often quite reticent to fly through combustion plumes due to visibility and turbulence concerns. The use of airplanes and helicopters often has high operating costs and, especially for airplanes, short times in the near-source plume, limiting the amount of sample that can be collected. Remote-controlled helicopters and airships/aerostats are slower, making it possible to achieve a long residence time in the plume, minimizing concerns of limited sample size. Remotely-controlled helicopters are generally limited in payload capacity and may not be suitable for use in turbulent or opaque plumes. It has also been found that larger remote helicopters are

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more difficult to operate than smaller (Li et al., 1995), which has the consequence of reduced payload weight. Tethered aerostats can be used to address many of these limitations by providing maneuverability, loft capacity, plume residence time, and safety. Aerostat-lofted instruments have been used for emission sampling with open detonation of military ordnance (Lindsay et al., 2000), and in situ burning of crude oil at sea (Fingas et al., 1996; Aurell and Gullett, 2010). Lindsay et al. (2000) sampled gas via summa canister and particulate matter collection by filter. They had partial success but experienced some difficulties with failure to trigger the sampling instruments and damage to the sampling equipment. Tethered blimp sampling of PAHs from oil burn plumes was conducted by Fingas et al. (1996) but was of insufficient sampling volume (30 L) to reach detectable levels of the analyzed PAHs. Recent advances in aerostat materials and miniaturization of samplers and batteries have improved the possibilities for lofted sampling. Use of continuous carbon dioxide (CO_2) measurements with wireless telemetry systems has allowed optimization sampler position to achieve the highest plume concentration.

This paper describes the development and demonstration of a method using an instrumented, tethered aerostat to characterize air emissions from open area sources. The method was demonstrated by sampling emissions from open burning (OB) and open detonation (OD) plumes during disposal of military ordnance. The resulting emission factors are used in dispersion models by the military to ensure that the emissions are not adversely affecting human and environmental health. The sampled emission factors were compared to literature values obtained from field measurements.

2. Material and methods

2.1. The aerostat-borne sampling method

The sampling instruments were lofted by a 4.0 m × 3.1 m semi-spherical, helium-filled, two layer aerostat (Kingfisher Model, Aerial Products Inc., USA). The inner layer is made of polyurethane with additional ultraviolet and hydrolysis inhibitors and the outer layer consists of rip-stop nylon. The aerostat uses a tether attachment over the whole sphere that results in tension around the whole aerostat rather than at a single point of connection, thereby eliminating concerns regarding tether breakage. The maximum loft capacity is approximately 19 kg at sea level but was 11.8 kg at 1500 m elevation during this test study. The aerostat was tethered and maneuvered by using two 300 m long, 2.5 mm diameter Spectra lines (Cortland Cable Company, USA) attached to a pair of all-terrain vehicles (ATVs) equipped with electrically powered winches.

The aerostat carries a lightweight instrument sampling package termed "the Flyer", Fig. 1. The Flyer consists of multiple sampling instruments which can be added or removed to match the source pollutants or measurements of interest. In addition, the Flyer sampling method can be optimized to the source characteristics to effect sampling onset, duration, and volume. The Flyer is comprised of interchangeable instruments including total PM, PM_{10}, $PM_{2.5}$, CO, CO_2, semi-volatile organic compounds (SVOCs), such as PAHs and polychlorinated dibenzodioxins and dibenzofurans (PCDDs/PCDFs), black carbon, volatile organic compounds (VOCs), and HCl. In addition, filter analysis can be done for PM-borne metals. Additional measurements include temperature, humidity, GPS coordinates, wind velocity, and altitude.

This paper will describe the Flyer performance while measuring emissions from OB and OD. Sampling emissions from OB and OD of military ordnance is challenging as safety considerations limit source proximity. In addition, plume generation is very quick (<15 s) and transport by winds past the relatively stationary Flyer limits the available sampling time and, hence, the sample sufficiency. In order to determine emission factors for the target compounds of this test campaign, the Flyer was configured with a continuous emission monitor (CEM) for CO_2 measurements, a Summa canister for sampling of benzene (a VOC), a polyurethane foam/XAD-2/polyurethane foam (PUF) sorbent sampler for collection of PAHs, and a single stage PM_{10} impact sampler by filter (Fig. 1). CEM data and flow rate were logged every second to an on-board data acquisition system (HOBO U12-013, Onset Computer Corporation, USA) which also measured temperature. Furthermore, the Flyer also had a Geko 301 (Garmin, USA) global position system (GPS) and a Lead Acid 12 V 5 Ah rechargeable battery (BatteriesPlus, USA) on board, all resulting in a total weight of about 11 kg (Table 1), just below the 11.8 kg payload capacity at an elevation of 1500 m.

The carbon mass balance approach was used to derive emission factors, as is common for sources of open burning (Laursen et al., 1992; Gullett et al., 2006). It was assumed that all the carbon from the material burned was emitted to the atmosphere (Laursen et al., 1992) and that the plume was completely mixed (i.e. the pollutants and the carbon emitted were assumed to be proportionally distributed throughout the plume). Emission factors derived from the carbon mass balance have been shown to be in good agreement with emission factors derived from direct mass loss measurement methods (Gullett et al., 2006; Dhammapala et al., 2006). The major carbon product has been shown to be CO_2 in OB and OD combustion plumes 99% and 97%, respectively (Johnson, 1992a). Other minor carbon products were CO, CH_4, total hydrocarbons, and particle-bound carbon. The relative concentration of the carbon species and the power and weight cost of its measurement method

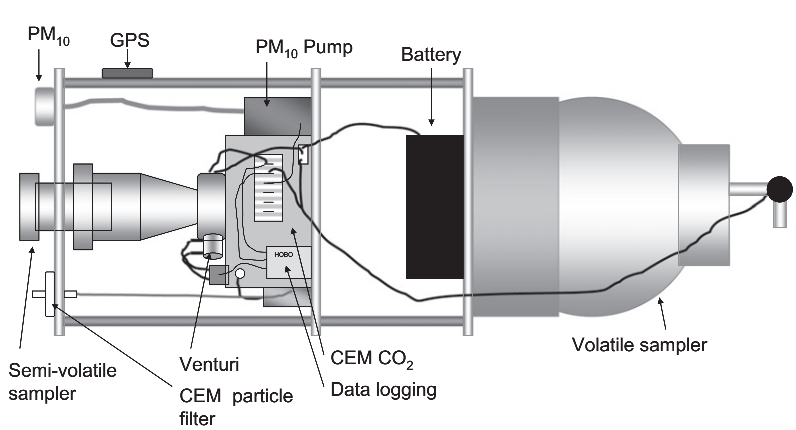

Fig. 1. Schematic illustration of the sampling package termed the "Flyer", not to scale.