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Should Aerial Drones Replace Flux Chambers and Wind Tunnels to Sample Odorous Atmospheres Emitted by Area Sources?

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Sampling is a key step in environmental analysis. For odorous atmospheres, mostly sample bags are used to carry out olfactometric or chemical analyses. Despite the description in some protocols, like VDI-3880 (2011) of how to sample area sources, it was demonstrated by the last version of European standard (EN-13725:2022) that it is impossible to fix a consensus about the sampling method for such emission sources. Studies showed that the type of device (Flux Chamber FC or Wind Tunnel WT) is highly influencing the sampling and thus also the expected result. This means that the real emission is hard to predict with these methods and the resulting value is probably either underestimated or overestimated. Comparison of results between sampling labs is a real challenge. The result of sampling with FC or WT is always linked to conditions and gives relative values, that are only comparable with the same device used in the same conditions for the same type of source. The uncertainty of FC and WT appears to be way too high. Moreover, these methods present lots of drawbacks: difficulty to place devices on a surface (without leaks on a solid surface or with acceptable floatability on a liquid source); difficulty for operators to place and move the device in different locations; necessity to have odourless flux air for inlet in the device, limitation in surface that is effectively sampled… So, without a clear method for sampling, without consensus about values obtained using FC and WT, the question of a paradigm shift using aerial drones is clearly posed to improve assessment of real emission rates from large area sources and their impact after dispersion.
This paper deals with all advantages and drawbacks of these approaches and illustrates that the shift is probably a significant step forward. First of all, operators can stay away from the emission source, which is a real improvement for safety conditions, without risk of falls or drowning and with less exposition to odorous pollutants. Secondly, the possibility in terms of sample numbers is increased with the easiness to change the sampling point and, it also gives a stronger flexibility to average emission from different points. Third, when using this method, we can measure the real windflow and thus the result is not dependent on the choice of the windspeed.

1. Introduction

In environmental science, the sampling step is always a key step to warranty a result as representative as possible. It's even more crucial for air samples (less easy to collect than liquid or solid samples) and the difficulty is increasing when air samples must reflect emissions from passive area sources, liquid, semi-liquid or solid sources. Such sources that need to be characterised in terms of odorous emissions are wastewater basins or lagoons, opened large tanks, landfills, composting piles, biofilters… The actual protocols for sampling passive sources are the use of a sampling device like Flux Chamber (FC) or Wind Tunnel (WT) and the diversity of devices demonstrate high variability of results (Guillot et al.2014). FC and WT are one part of sampling protocol dedicated to area sources (Duan et al., 2021). With such devices, the air sample is collected in a bag, but other types of samples could be imagined as for example sorbent tube sampling, canister…Technical aspects and improvements are discussed in this paper.

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During last years, several examples were given combining aerial drones and chemical sensor technologies such as Instrumental Odour Monitoring System (IOMS) previously named electronic noses (e-noses). It illustrates the great advantage of a drone to be equipped with different types of sensors/detectors. With a thermal camera, a drone can map a surface and help distinguishing active or non-active parts on e.g. composting piles or biofilters. An e-nose with a sampling line gives data about level of detected compounds over the surface. The drone also allows both vertical and horizontal profiles and so a three-dimensional characterization of the source while previous sampling methods only led to partial two-dimensional data. All types of sensors can be included in the sampling drone to improve the efficiency of emission assessment. To replace FC or WT, the drone must be able to collect air for analysis. A small canister (mini-can) with vacuum inside is enough to collect approximatively 1L of air for chemical analysis but for olfactometric analysis a vacuum box with a pump is needed to fill sampling bags of few liters. Some studies indicate that downdraft from wind drone rotors can be limited if the drone is at least 8 m from the source (L1 in figure 1) so future improvements concerns sampling lines, their warranty to be at controlled distance from the source and also the position of the vacuum box between the sampling inlet and the drone. Typically, figure 1 illustrates the use of drone with an IOMS (Burgués and Marco, 2020) or a vacuum box to fill a bag to characterise the odour emission as closest as possible from the source. It represents one sampling point and such measurement or sampling must be repeated in different location over the source. In all cases, the length of sampling line (L2) must be sufficient to avoid rotor impact on the surface, the internal volume of this line and the flow must be taken into account to start a measurement after a purge of this volume, and the line flexibility is necessary for take-off and landing, but the line must be as vertical as possible during sampling. Additionally, the distance D between the surfacic source and the sampling-line inlet must be identified and kept constant for all samples.

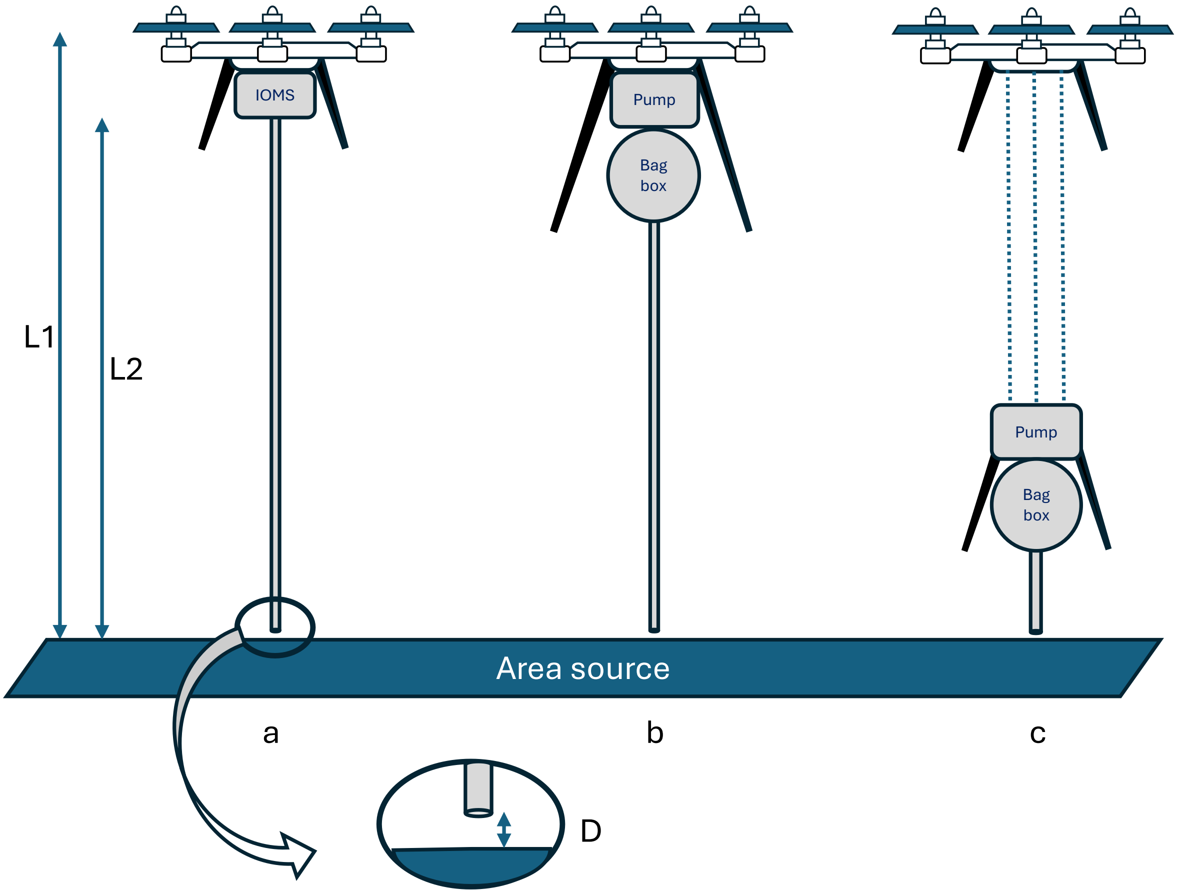

Figure 1: Three cases a) Drone with IOMS, b) drone with vacuum box to collect a bag, c) same equipment with a shorter sampling line - L1: Length from the source to rotors, L2: Length from the source to measurement device as IOMS, D: Distance from the source to the inlet of the sampling line

If the Figure 1 shows some equipment used with a drone, such a small radio-controlled aircraft can be adapted with different sampling technologies like for example SPME and adsorption with tubes for a concentration step in chemical analysis (Ruiz-Jimenez et al., 2019). The advantage is to allow the collection of multiple air samples and of course the flight time linked to battery charge must be considered if tubes need a relatively long period of sampling. It's an added parameter comparatively with sampling on the ground where battery size is not so limited or direct electric power can be used for pumping. The interest to use a drone is also obvious for mapping situation like wastewater plants (Burgués et al., 2021) and the discussion is based on air measurement even if drones can also be dedicated to sample liquids (Lally et al., 2019).

2. Limitations of Flux Chambers and Wind Tunnels

Sampling devices like Flux Chambers or Wind Tunnels can be used on solid or liquid areas to estimate emissions from the selected area. In both cases, the first limitation is the small sampled surface (generally <1 m^2) comparatively to large emission sites (thousands square meters or even more). It implies that a lot of points must be studied and that the chamber/tunnel and all connected systems have to be moved. The second limitation is that the device itself has a strong influence on the sample and then the measurement (Guillot et al., 2014). All results are then relative results (linked with the device used) and cannot be really compared with results obtained by another device. When a FC or a WT is always used in the same conditions, the results are useful to verify the evolution of a source or to compare different sources. FC and WT cannot be used with the obtention of getting true values of emission but only emission values within certain sampling conditions (type of device, inside flow and pressure, temperature of air and surface…).

2.1 Drawbacks for Solid Sources

Main drawbacks:

- Some solid sources present high heterogeneity so the selected area cannot warranty a representative sample and even with the multiplication of samples, the uncertainty can be significant.
- Depending on the solid area characteristics, the surface is not strictly flat, so FC or WT could present potential leaks. Typically, on a landfill or on a compost pile with high particle size, the sampling system is not airtight and the installation of flexible strips around it can limit leaks without any certainty of eliminating them.
- The complete device must be cleaned after operation; there is a need for additional equipment like a pump or a fan, activated charcoal filter, larges tubes for WT or bottle with pure air for FC.

2.2 Drawbacks for Liquid Sources

Main drawbacks:

- Area access for operators independently to description in paragraph 2.3.
- Disturbing source when moving.
- Floatability of FC and WT that must be adapted with source conditions for example liquid or semi-liquid (sludge) source.
- As for solid source, a cleaning procedure is needed for WT, FC, floating equipment and all additional parts in contact with the source.

2.3 Safety conditions for operators

In order to place FC or WT on area sources, operators must be very close to the source, at the border or above the surface to sample (walking on the solid surface or using a small raft on liquid sources). They must connect all additional equipment for WT or FC like fans or pumps, tubing to deliver odourless air and extract air with emitted compounds…They are at the level of the emissive zone and therefore exposed to strong nuisances or even toxic compounds for potentially a long period of time: to go to the selected locations on the surface, to place the device and all additional equipment, to start and stop sampling after the defined sampling time, and to repeat the operation for each point The risks of capsizing and drowning are not to be neglected.

3. Determination of the airflow

When having taken an air sample in a bag with one of the classic methods, it is possible to measure the odour concentration of the sample or the concentration of certain pollutants. However, if we need to define the impact of the emissions on the surrounding environment, we also need to determine the odour flow, by multiplying the concentration with a volumetric flow (in m^3/h). In a WT for example, an average windspeed is used to generate a flux through the tunnel, but the resulting odour flow appears to be highly dependent on the chosen speed.
This is not the case when using the method of the windward and leeward side. In this method, samples can be taken and concentrations can be measured in different points upwind and downwind the emitting source. The windward/leeward method uses the wind that carries the odour from the area source or diffuse source. Sampling

is performed by simultaneously measuring the air upwind and downwind of the activity. The downwind samples are collected in a so-called flux window. This is an imaginary plane at a short distance from the activity, perpendicular to the wind direction, through which all odour emanating from the activity passes.
For determining the location and the size of the flux window, a predetermined scheme is followed. A mobile meteostation on site measures the wind direction and the wind speed on different heights. Perpendicular to the wind direction, the downwind measurement plane is established. The distance from the measurement plane to the source is dependent on the height of the source. The width of the measurement plane depends on the width and depth of the surface source. The width of the measurement line is calculated from the width of the source plus a 10-degree angle on both sides. The height of the flux window depends on the distance from the source, the roughness of the surface, wind speed and cloud cover. To calculate the height of the flux window, the vertical dispersion parameter of the short-term Gaussian plume model is used.
At a short distance from the source (a few metres), the measurement point stays relatively low; at larger distances (tens of metres) odour measurements can be carried out at several heights. In this methodology, the use of a drone which can hover from point to point and take samples or carry out measurements of single parameters like H_2S or NH_3, can be very helpful.
Measurements upwind can be carried out in one single point, in case there is a negligible concentration of the parameter to be measured, or otherwise in a similar flux window. To achieve reliable results, there must be a significant difference in the concentrations of the incoming and outgoing air.
The total OER (odour emission rate) or, in case of measuring chemical parameters the total mass flow coming out of the source, can be calculated as the surface (in m²) times the average velocity measured in the different points times the average concentration measured over the flux window.
Figure 2 beneath illustrates the schematic set-up of measurement positions of the windward/leeward method:

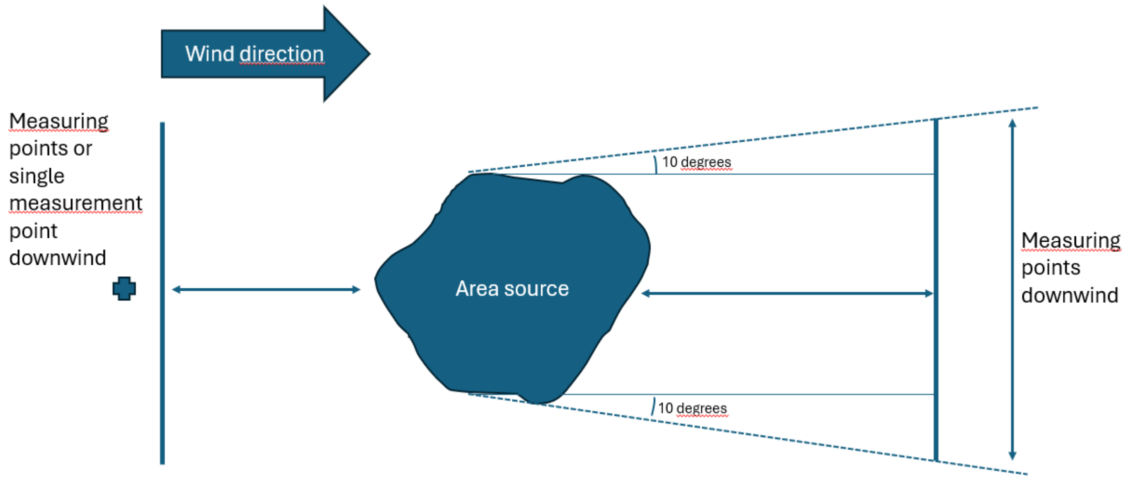

Figure 2: Schematic set-up of measurement positions of the windward/leeward method

4. Limitations of drones

4.1 Classical calculation of Odour Emission Rate (OER) and Specific Odour Emission Rate (SOER)

The result of an analysis with dynamic olfactometry is an odour concentration expressed in OU_E/m^3. The odour emission rate (OER) reflects the odour concentration per time by the product of odour concentration (OU_E/m^3) and flow rate (m^3/s) of the sampled source, so the OER is expressed in OU_E/s (Capelli et al.2014). The specific odour emission rate (SOER) reflects the odour concentration per time and per area by the product of odour concentration (OU_E/m^3) and flow rate into a sampling device (m^3/min) placed over the sampled surface and divided by the area determined by the device in (FC or WT). So, with previous units the SOER can be expressed in $OU_E/m^2/min$.
A key point is that some regulations request OER (or SOER) for sources and for area sources and that's the reason why FC and WT were used. With such devices, OER is determined in a small surface and even with different sampling location, the OER is then expressed based on selected parts of the surface. Considering a similar wind speed over the surface and integrating all the emission area, a global OER is then proposed.

The drone does not isolate a specific area but it is not a problem because the objective is to know the global surfacic emission from a source. As described in paragraph 3, the windward/leeward method can express an OER with another approach than the classical one with sampling devices.
In fact, a limitation of taking samples with a drone, is the time of flight with a single set of batteries. The lighter payload under the drone, the longer the flight time can be. When bag samples have to be collected, it is important to have a small pump and a light vacuum chamber for bags as shown in figure 1.

4.2 Conditions and regulations for operation of drones

It is obvious that drones must be used with some rules like the respect of:

- safety conditions over human beings,
- restricted area like airport areas,
- not trespassing privacy rules,
- …

Drones are submitted to regulation (existing rules are already defined considering the recent development of drones). Actually, without considering an exhaustive bibliography on the subject, two main regulations must be considered for Europe or United States:

- EU: European legislation pertaining to the operation of drones and drone strategy 2.0. Different texts are in progress and a first reference document exists since 2019 (Commission implementing regulation, 2019).
- USA: Code of Federal Regulations (Federal Aviation Administration, Part 107) about small unmanned aircrafts systems (CFR, 2024).

Besides of respecting the flight regulations and times, one also needs a skilled pilot to fly safely with the machine. Most of the time, two persons are necessary: a pilot and an observer who can always keep an eye on the drone with a different point of view. At the moment, it is possible to take samples with the drone, equipped with a long transfer line (in order to avoid disturbance through downdraught), care must be taken not to touch installations with the long transfer line hanging down the drone.

5. Case study

To illustrate the use of drone, a case study (De Baerdemaeker et al, 2021) is synthetised in the following paragraphs.

5.1 Location and objectives

At a wastewater treatment plant in Gent, Belgium, total NH_3-emissions had to be determined. The purpose was to calculate the N-deposition in a nearby natural reserve. A meteorological tower was placed on site to measure the meteorological conditions. The sensor unit of the tower was installed at a height of 10 meters, and allows for ultrasonic detection of wind speed, three vectors of wind direction, temperature, relative humidity and solar radiation in 30 second intervals. Based on these parameters, atmospheric stability is also directly calculated per 30 second interval.
Two imaginary flux windows were created, one downwind and one upwind. With a drone (OLFASCAN Flying Lab), concentrations of NH_3, CH_4 and H_2S were measured using a 8 m long suction line. By measuring the emission concentrations on different heights and lengths along the two fluxwindows, the difference in emission concentration can be determined. Multiplying with the flow rate across the fluxwindows derived from the determined meteorological windspeed, yields the emission rate of the source.

5.2 Results

The distance between the two flux windows was 20 m. Per window, 21 measurements were made, 3 points in width and 7 points in height. For NH_3, an average concentration was calculated of 1.56 ppm upwind, and 2.15 ppm downwind. The NH_3-flux concentration was calculated as the difference between the down- and upwind concentration and was equal to 0.59 ppm. Based on the average windspeed and the surface area of the fluxwindow grids, a flow rate of 149 105 $m^3.h^{-1}$ was obtained. Incorporating the measured air temperature and relative humidity with the determined flow rate and average NH_3-flux concentration, a NH_3-emission rate of 0.062 $kg.h^{-1}$ was calculated. With these values, the N-deposition caused by this source could be calculated.

6. Conclusions

Air sampling with drones, for both chemical and sensorial measurements, allows large-scale sampling strategies, quick and efficient collection of samples, reduces cost for such operations and proposes safer conditions for operators. But the approach with drones to sample emissions from area sources still presents drawbacks to solve like the right factor of flux estimation over the surface to obtain the OER, the limited capacity (volume of the vacuum box to fill bags), the distance of rotors from the surface to avoid perturbation, the length of the sampling line, all authorizations to use on sites to be studied. Even with such drawbacks, it seems than advantages can be more important. Sampling techniques with drones are already replacing classical techniques.

With developments and improvements, benefits should be important and if appropriate regulation for sampling could be defined, this new approach could become the standard.

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