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Odour Sampling on Passive Area Sources: Principles and Methods

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Despite a certain simplicity and a well-defined methodology for the assessment of odour emissions from point sources and active area sources, odour sampling on passive area sources is still a rather debated task, meaning that, up to now, there is not a codified sampling procedure allowing to give reproducible results among different laboratories. Three different kinds of area sources can be distinguished, i.e. liquid passive area sources, solid passive area sources, and landfill surfaces. These three different types of sources are characterized by different volatilization and/or emission phenomena, and shall thus be treated differently while sampling in order to assess a representative odour emission rate. This paper aims to give an up-to-date overview of the principles and methods for odour sampling on passive (or semi-passive) area sources as well as for the estimation of the odour emission rates relevant to those sources, most of which still require further development and validation. The considerations here proposed highlight how the understanding of the volatilization phenomena that constitute the odour emission are fundamental for the evaluation and quantification of odour emissions.

1. Background

Despite a certain simplicity and a well-defined methodology for the assessment of odour emissions from point sources and active area sources, whereby the emitted airflow is conveyed and measurable, odour sampling on passive area sources is still a rather debated task (Capelli et al., 2013). This means that, up to now, there is not a codified sampling procedure allowing to give reproducible results among different laboratories. Even though the principle of isolating a portion of the surface by means of a suitable sampling hood is currently universally accepted, some recent studies discuss how odour emissions assessments based on the use of different sampling devices as well as different operating conditions may differ significantly (Hudson and Ayoko, 2008; Leyris et al., 2005). Besides that, high discrepancies in the estimation of the Odour Emission Rates (OER) are due to the type of passive area source considered.

For this reason, in order to make more specific considerations about the principles and methods to assess OER from passive area sources, it is first necessary to identify and distinguish the different source types that require to be treated separately. The emission of odours depends on the phenomena that regulate the volatilization of the odorous substances from the surface into the atmosphere, and thus are different in the case of liquid (Capelli et al, 2009) and solid area sources (Capelli et al., 2012; Zhang et al., 2002).

Landfill surfaces have been historically considered as passive area sources (Frechen et al., 2004, Sironi et al., 2005). However, this approach does not account for the fact that landfill surfaces are crossed by a low yet not negligible flux of landfill gas (LFG) (Palmiotto et al., 2014). Moreover, the mechanisms that regulate volatilization from the surface into the atmosphere are not quite the same as for other solid passive area sources, since the main driving force is not forced convection, but rather the LFG emission rate, which is influenced by other meteorological parameters than wind speed (Rachor et al., 2013). For these reasons, more recent studies in this field provide to use static sampling hoods instead of wind tunnels for sampling over landfill surfaces, thus treating this kind of source as a sort of "semi-passive" area source (Capelli et al., 2014; Lucernoni et al., 2016; Rachor et al., 2013).

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According to this classification, three different kinds of area sources can be distinguished, for which the procedure for the assessment of the OER is still debated: i) liquid passive area sources; ii) solid passive area sources; and iii) solid "semi-passive" area sources (i.e. landfill surfaces).

These three different types of sources are characterized by different volatilization and/or emission phenomena, and shall thus be treated differently while sampling in order to assess an OER that is representative of the source itself.

The aim of this paper is to give an overview of the principles and methods that should be adopted in order not only to collect representative odour samples on the area source to be monitored, but also to express the OER – if necessary – as a function of meteorological parameters that affect the odour emission. This applies for instance to the OER relevant to passive area sources with respect to the wind speed, whereby this dependence has already been highlighted in previous studies (Capelli et al., 2009; Sohn et al., 2003). This step is fundamental when the application of dour dispersion models is required for odour impact assessment purposes, as provided by several national and local regulations.

2. Strategies for odour sampling on passive and semi-passive area sources

2.1 Liquid and solid passive area sources

Liquid passive area sources are typically represented by wastewater treatment tanks or other pool bio-reactors. As already mentioned, direct measurements using an enclosure of some sort, i.e. so-called "hood methods", are actually being preferred over indirect measurements using micrometeorological methods, where emission rates are derived from simultaneous measurements of wind velocities and concentrations across the plume profile downwind of the source (Capelli et al., 2013). Therefore, the sampling strategies typically involve the use of specifically designed Wind Tunnel (WT) devices that isolate a portion of the surface to be monitored (Capelli et al., 2009; Hudson and Ayoko, 2008). The WT is flushed with a neutral airflow that can be obtained either from a neutral air cylinder or generated on site with ambient air and active carbon filters, with the aim of simulating the wind action over the covered portion of the emitting surface. The air velocity inside the hood is typically of few centimetres per second. The odour sample is then collected at the outlet of the WT by means of a suitable sampling bag and a vacuum pump (Figure 1).

Solid passive area sources are typically represented by contaminated soils. For such sources there are less widely accepted notions concerning sampling. However, the scientific community agrees that the sampling procedure should involve also in this case the use of specifically designed WT devices and follow the same steps as the case of liquid area sources (Capelli et al., 2012; Capelli et al., 2013; VDI, 2011). Nonetheless, since the real nature of the volatilization phenomena taking place inside the chamber is not yet fully understood, there is still a certain degree of uncertainty concerning both the optimal features of the sampling device and its operating conditions.

2.2 Landfill surfaces

The evaluation of odour emissions from landfill surfaces is complicated, due to the specific characteristics of this peculiar source, which is surely not active, but neither properly a passive area source. These surfaces present a minimal yet non-negligible emission flux generally in the range of L/m^2/h (Capelli et al., 2014; Palmiotto et al., 2014), and the emission is not directly affected by the wind action on the surface. The studies carried out so far show that there are two viable approaches for sampling on landfill surfaces.

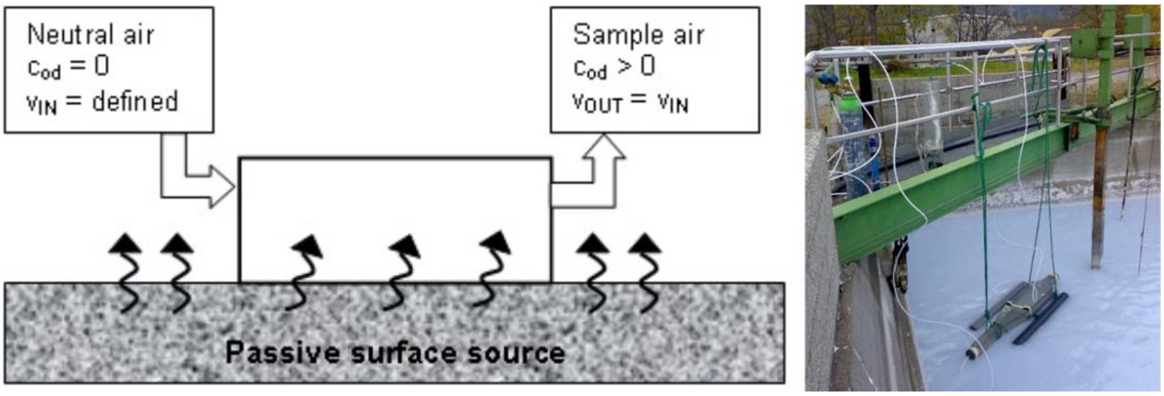

Figure 1: Scheme of the principle of hood sampling on a passive are source (left) and an example of WT on a wastewater treatment tank (right)

Figure 2: Examples of a static hood (left), a flux chamber (centre) and a device that can be operated both as static hood and flux chamber (right) for sampling on landfill surfaces

The first option involves the use of a flux chamber, as suggested for instance by the US EPA (Capelli et al., 2014; Klenbusch, 1986), at the outlet of which the odour sample can be collected. The second possibility, which is generally preferred for logistical reasons, as it doesn't require the use of a dedicated air tank for the sweep air supply, is a static hood. The hood should allow the LFG to diffuse in the internal volume undisturbed (i.e. no external flow) making it possible to measure the methane concentration over time and then estimate the LFG emission flux. There are several possibilities for the static hood design, as there are different proposals found for instance in the UK guidelines and in recent scientific papers (Rachor et al., 2013; Lucernoni et al., 2016). The drawback of the static hood is that, due to its limited volume, it doesn't allow the withdrawal of a 6 L bag for olfactometric analysis, and thus the direct assessment of the odour emissions on the landfill surface. It is possible to measure the methane concentration inside the chamber by means of a FID, which shall then be related to the LFG odour concentration in order to evaluate the OER. An example of these sampling devices is presented in Figure 2.

3. Methods for the estimation of the OER from passive and semi-passive area sources

3.1 Evaluation of the Specific Emission Rate from passive area sources

From the odour concentration measured in the sample collected at the WT outlet, it is possible to calculate the Specific Odour Emission Rate (SOER), which is the odour emitted from the area source per unit of time and surface [ou/m^2/s] (Capelli et al., 2013). The OER can then obtained as the product of the SOER and of the emitting surface. This is valid both for liquid and solid passive area sources. The SOER obtained this way refers to the conditions of air velocity inside the hood corresponding to the sweep air flow adopted during sampling. In order to evaluate the "real" SOER, i.e. the SOER relevant to the open field and at the different wind conditions, it is necessary to scale the value obtained for the hood to the real situation, adopting a suitable correlation. The elaboration of the datum to get from the SOER at the sampling conditions to the real SOER is still an open issue. In order to assess the optimal correlation, it is necessary to be able to describe accurately the volatilization phenomenon inside the WT and to relate this volatilization model to the effective conditions that occur in the open field. For this reason, the elaboration methods adopted will have to be different in the case of liquid area sources with respect to solid area sources. Actually, the phenomena regulating volatilization of odorous substances into the atmosphere from a homogeneous liquid surface are different from those relevant to a solid, whereby for the latter it is not sufficient to consider only the diffusion from the surface into the gas phase, but also the diffusion inside the solid plays an important role.

3.2 Liquid area sources

The most widely adopted method for the re-calculation of the SOER for the open field, assuming that both the SOER and the OER are proportional to the square root of the sweep air velocity, is shown in Eq. (1) (Capelli et al., 2013; Sohn et al., 2003):

$$SOER_{u_2} = SOER_{u_1}\left(\frac{u_2}{u_1}\right)^{0.5} \quad (1)$$

In most applications that are found in the scientific literature, the re-calculation is carried out considering that the air speed inside the WT is equivalent to the wind speed - conventionally measured at a height of 10 m above the ground - which in the open field would cause the same emission as the one measured with the hood. This gives that u_2 is the wind speed at 10 m at which the SOER has to be recalculated, and u_1 is set equal to the sweep air speed inside the WT during sampling. This approach is clearly a big approximation of the reality, as the presence of the enclosure of the WT presence may affect the volatilization phenomenon with respect to the open field. Moreover, the vertical profile of the wind speed profile is typically not flat, but can be approximated by means of logarithmic laws or power laws. For this reasons, that the sweep air velocity inside the WT, which typically has a height of few centimetres, should not be considered equivalent to a wind speed measured at 10 m above the ground level.

Our most recent research in this field aims to investigate and evaluate the models describing the volatilization from liquid pools both in the open field and inside the WT. For this purpose, the models based on Prandtl's boundary layer theory have been considered and experiments were performed in order to evaluate their reliability and define the field of application. This allowed to make some considerations and devise a new correlation that allows, starting from the sweep air speed inside the WT, to calculate the wind speed in the open field at 10 m that would cause the same SOER. The correlation allows to scale the obtained datum of emission flow to the open field situation, accounting for the differences between the two scenarios.

As volatilization model for the open field, Eq. (2) was derived from the model adopted in the text "Methods for the calculation of physical effects" (Committee for the Prevention of Disasters, 1992):

$$SER = 2\ (10)^{-3}\ {u_{10}}^{0.78} X^{-0.11}\ M_i \frac{Pv\left(T_{pool}\right)}{RT_{pool}} \tag{2}$$

Where SER is the Specific Emission Rate in [kg/m^2/s]; M_i is the molar mass of the evaporating compound in [kg/mol]; $P_v\left(T_{pool}\right)$ is the vapour pressure of the liquid compound at the surface temperature in [Pa]; R is the universal gas constant equal to 8.314 [J/mol/K]; T_{pool} is the surface temperature of the pool in [K]; u_{10} is the wind velocity at 10 m in [m/h]; X is the characteristic dimension of the pool in the leeward direction in [m].

As far as the volatilization model inside the WT is concerned, it can be derived from Prandtl's boundary layer theory. However, based on a set of experimental tests carried out with acetone and butanone as target compounds, it was possible to evaluate a new averaged proportionality coefficient that best fits with the experimental data, and therefore applies to the specific case of the adopted WT, which is equal to 0.315 instead of 0.664, giving:

$$K_{c,ave} = 0.315 \left(\frac{D_i^4}{{L_{WT}}^3\ \nu}\right)^{\frac{1}{6}} u_{WT}^{1/2} \tag{3}$$

Where $K_{c,ave}$ is the convective mass transfer coefficient, averaged over the exchange length, in [mol/m^3], D_i is the compound's molecular diffusivity in air in [m^2/s]; L_{WT} is the length of the WT central body in [m]; ν is the air's kinematic viscosity in [m^2/s]; h is the height of the WT in [m]; u_{WT} is the air velocity inside the hood in [m/s].

Finally, by combining the two models for the open field and for the WT, i.e. Eq. (2) and Eq. (3), and equalling the SER values, it is possible to obtain Eq. (4), which expresses a correlation between the air speed inside the WT and the wind speed at 10 m above the ground:

$$U_{10,re} = \sqrt[0.78]{157.5 \frac{L^{-0.39}\ \nu^{-\frac{1}{6}}\ U_{WT}^{1.5}\ h}{U_{WT}\ h\ D_i^{-0.67} + 0.158\ L^{0.5}\ \nu^{-\frac{1}{6}}\ U_{WT}^{0.5}}} \tag{4}$$

Where $U_{10,re}$ is therefore the wind speed at 10 m above ground that gives the same emission (SER) as the sweep air speed inside the WT (U_{WT}).

Based on these considerations, it is possible to express a new model for the recalculation of the SOER relevant to the sampling conditions to the effective SOER in the open field:

$$SOER_{u_2} = SOER_{u_1} \left(\frac{u_2}{u_1}\right)^{0.78} \tag{5}$$

For a correct use of the model, This gives that u_2 is again the wind speed at 10 m at which the SOER has to be recalculated, but u_1 is not the sweep air speed inside the WT during sampling, but instead the $U_{10,re}$ corresponding to this sweep air speed (U_{WT}) calculated according to Eq. (4).

Of course, this new proposed model still needs to be validated, but it already clearly represents an improvement with respect to the "traditional" model.

3.3 Solid area sources

The accurate description of the volatilization phenomena from a solid area source is quite more complicated, because the diffusion inside the solid needs to be considered as well, which depends on a lot of different factors, such as the soil porosity, its interaction with the diffusing compounds, the thickness of the layer interested by diffusion, etc. For this reason, despite an extensive research in this field, it was not yet possible to propose a suitable volatilization model, as it was the case for liquid area sources.

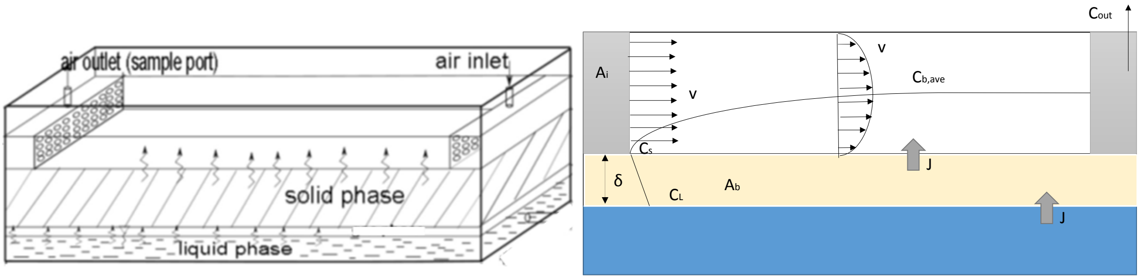

Figure 3: Scheme of the WT (left) and of the gaseous emission from a solid source with imbued lower levels exposed to a sweep air flow at speed v inside the WT (right)

The experimental work in this field was carried out to simulate the odour emitting solid as a layer without discontinuities, having the deeper levels wet with liquid acetone (used as target compound) and the upper levels dry. The solid layer is made of glass microspheres with diameters ranging from 400 μm and 800 μm. Glass was chosen as it is inert and odourless, and microspheres in order to have a good porosity. The experimental setup can be schematized as shown in Figure 3.

The mathematical description of this scheme leads to the following expression for the C_{out}, which is the outlet concentration – in this case of the acetone – in the gas phase [kg/m^3]:

$$C_{out} = \frac{A_b * \frac{\mathcal{D}_{eff}}{\delta} * (C_L - C_b^{ave})}{A_i * \frac{v}{k_L} * (k_L + \frac{\mathcal{D}_{eff}}{\delta})} \tag{6}$$

By highlighting the velocity-depending terms it is possible to make some interesting considerations: for k_L>>$\mathcal{D}_{eff}\backslash\delta$, i.e. high values of v and/or high values of δ, C_{out} will be proportional to the speed v to an exponent of -1. On the contrary, k_L<<$\mathcal{D}_{eff}\backslash\delta$, i.e. low values of v and/or minimal values of δ, C_{out} will be proportional to the speed v to an exponent of -0.5, thus resembling the "liquid only" case.

Although it is not possible up to now to formulate a more elaborated model to describe the emission from a solid area source, it is clear from the previous consideration that it will have the following expression:

$$C_{out} = a' * v^{\alpha} \tag{7}$$

Where the exponent will be $-1 \leq \alpha \leq -½$.

3.4 Landfill surfaces

Based on the description of the sampling methods given in section 2.2, it appears clear that the methods for the estimation of the OER will be different in function of the type of sampling device used, i.e. flux chamber vs. static hood.

As already mentioned, the use of a flux chamber allows the direct determination of the odour concentration over the landfill surface. Then, the SOER relevant to the landfill surface can be obtained as:

$$SOER = \frac{c_{od} \cdot Q_{air}}{A_{hood}} \tag{8}$$

The OER is finally obtained by multiplying the SOER by the landfill surface. The drawback of this approach is that is intrinsically affected by the odour of the landfill soil itself ("background" odour). Moreover, it should be considered that odour concentration measurement entails greater uncertainty than CH_4 concentration measurement.

On the other hand, the static hood isn't suitable for the withdrawal of bags for olfactometric analyses, but the variation of the CH_4 concentration inside the hood can be measured over time by means of a FID, thereby allowing to evaluate the CH_4 flux according to the following mass balance (Lucernoni et al., 2016):

$$Q_{CH_4} = \frac{V_{hood}}{S_{hood}} \cdot \frac{\partial c_{CH_4}}{\partial t} \tag{9}$$

Once the CH_4 flow rate is known, it is possible to calculate the LFG emission by considering the LFG composition (i.e. the CH_4 content). The OER relevant to the landfill surface can then be evaluated indirectly by multiplying the LFG flow (Q_{LFG}) by the LFG odour concentration ($c_{od,LFG}$):

$$OER = c_{od,LFG} \cdot Q_{LFG} \tag{10}$$

The main problem related to this approach is that $c_{od,LFG}$ is the odour concentration of the LFG emitted from the landfill surface, which is hardly measurable, and similar values are not easily found in the scientific literature. Actually, some studies refer to the odour concentration of the pure LFG, which is typically measured directly in the LFG extraction wells or collection system. These odour concentration values are typically around 900’000 ou/m^3 (Sironi et al., 2005), but such values are likely to be significantly higher than the odour concentration of the LFG emitted through the landfill surface. This is because the LFG crossing the landfill cover will likely undergo partial degradation/oxidation, thereby reducing its odour concentration, which generally depends on the type of cover and its thickness (Capanema et al., 2014).

4. Conclusions

This paper gives an up-to-date overview of the principles and methods for odour sampling on passive (or semi-passive) area sources as well as for the estimation of the OER relevant to those sources. Of course, this is only a rough overview, based on our most recent research activities in this field, most of which still require further development and validation. However, the considerations proposed in this work point out on one hand the necessity of distinguishing the different area source types at least in liquid and solid area sources, thereby treating landfill surfaces differently as they cannot be considered properly as passive. Moreover, it is highlighted how the understanding and the description by means of suitable models of the volatilization phenomena that constitute the odour emission are fundamental for the evaluation of representative OER values to be used for odour dispersion modelling purposes.

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