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A model to relate wind tunnel measurements to open field odorant emissions from liquid area sources

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HIGHLIGHTS

- Liquid area surfaces are significant sources of odours and VOCs emissions.
- Lawmakers concur that the emissions should be monitored.
- There are no widely accepted methodologies for emissions assessment.
- The paper tries to provide a method for evaluating liquid sources.
- The procedure entails also the recalculation of the emission in the field.

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ABSTRACT

Waste Water Treatment Plants are known to have significant emissions of several pollutants and odorants causing nuisance to the near-living population. One of the purposes of the present work is to study a suitable model to evaluate odour emissions from liquid passive area sources. First, the models describing volatilization under a forced convection regime inside a wind tunnel device, which is the sampling device that typically used for sampling on liquid area sources, were investigated. In order to relate the fluid dynamic conditions inside the hood to the open field and inside the hood a thorough study of the models capable of describing the volatilization phenomena of the odorous compounds from liquid pools was performed and several different models were evaluated for the open field emission. By means of experimental tests involving pure liquid acetone and pure liquid butanone, it was verified that the model more suitable to describe precisely the volatilization inside the sampling hood is the model for the emission from a single flat plate in forced convection and laminar regime, with a fluid dynamic boundary layer fully developed and a mass transfer boundary layer not fully developed. The proportionality coefficient for the model was re-evaluated in order to account for the specific characteristics of the adopted wind tunnel device, and then the model was related with the selected model for the open field thereby computing the wind speed at 10 m that would cause the same emission that is estimated from the wind tunnel measurement furthermore, the field of application of the proposed model was clearly defined for the considered models during the project, discussing the two different kinds of compounds commonly found in emissive liquid pools or liquid spills, i.e. gas phase controlled and liquid phase controlled compounds. Lastly, a discussion is presented comparing the presented approach for emission rates recalculation in the field, with other approaches possible, i.e. the ones relying on the recalculation of the wind speed at the emission level, instead of the wind speed that would cause in the open field the same emission that is measured with the hood.

1. Introduction

Waste Water Treatment Plants (WWTP) are known to have significant emissions of several pollutants from the different treatment phases (Capelli et al., 2009a; Prata. et al., 2016a; Santos et al., 2012). Among them, volatile organic and inorganic compounds, often having low odour detection thresholds, are typically a cause of odour nuisance to the near-living population (Capelli et al., 2009a; Parker et al., 2013; Prata et al., 2016a). Whereas

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point source, such as stacks (Bockreis and Steinberg, 2005; Capelli et al., 2013) are typically subject to periodical emission monitoring, this is not the case for area sources, such as WWTP tanks, which, however, often represent the main source of VOCs and odour emissions in this kind of plants (Capelli et al., 2008, 2009a). For this reason, area sources should be considered as well as point sources for odour emission characterization and impact assessment, as already provided by some regulations on the matter (D.g.r. n. IX/3018, 2012; VDI 3880, 2011). However, assessing odour emissions from area sources such as wastewater treatment tanks, i.e. the so-called "passive" area sources, which means without outward flow, is typically a rather complicated task, since there is no straightforward nor established procedure (Capelli et al., 2013). First of all, already choosing the most appropriate technology for sampling is difficult among the different ones that have been proposed and are currently applied for this scope (Muezzinoglu, 2003; Blunden and Aneja, 2008; Beghi et al., 2012; Rumsey et al., 2012; Hentz et al., 2013; Hudson and Ayoko, 2008; Bliss et al., 1995; Kim and Park, 2008). In recent studies there is evidence that so-called "hood methods", entailing an enclosure of some sort (e.g., wind tunnels), whereby emission rates are derived from the data regarding the concentration at the outlet of the sampling device combined with the dimensions of the device and the operating conditions, should be preferred for this purpose (Hudson and Ayoko, 2008; Capelli et al., 2013). There are different types of dynamic hoods, mainly distinguished between Flux Chambers (FC) (Klenbusch, 1986; Prata et al., 2016a) and Wind Tunnels (WT) (Smith and Watts, 1994; Jiang et al., 1995; Capelli et al., 2009b; Parker et al., 2010), the latter being considered for this study. With hood methods, the assessment of the odour emission rate (OER) involves 3 phases: on-site sampling (Capelli et al., 2009b; Koziel et al., 2005; Sironi et al., 2014a), sample analysis (CEN EN 13725, 2003) and data elaboration (Lucernoni et al., 2016; Ranzato et al., 2012). With the odour concentration it is possible to evaluate the Specific Odour Emission Rate (SOER), that is the odour units emitted from the source per surface and time unit [ou/m^2/s] referred to the neutral sweep air flow rate used during sampling (Capelli et al., 2009b).

The main problem is that emission rates, calculated as abovementioned (Capelli et al., 2013), refer solely to the specific sampling conditions inside the hood, and therefore are not representative of the effective emissions from the source in the open field when subject to natural ventilation (Hudson and Ayoko, 2009; Leyris et al., 2005). In order to evaluate the SOER occurring in the open field at different wind conditions, it is necessary to scale the value obtained for the hood to the real situation, thereby adopting a suitable correlation. While sampling and analysis methodologies are fairly established (analysis more than sampling, as previously discussed), the elaboration of the datum is still an open issue. The studies of Sohn et al. (2005) and Sironi et al. (2014b) propose to use a correlation for the re-calculation of the SOER for the open field based on the Prandtl's boundary layer theory for laminar flow, assuming a proportionality of the SOER measured at the sampling conditions (i.e. sweep air velocity) and the SOER at the actual wind speed with the square root of the ratio between actual wind speed and sweep air velocity:

$$SER_{field} = SER_{WT} \left(\frac{U_{10}}{U_{WT}}\right)^{0.5} \quad (1)$$

The adoption of a dependence with the square root of the air velocity – typical of the laminar flow – does not account for the fact that in real situations the flow above a liquid area surface is typically turbulent (Sutton, 1934). Moreover, this approach clearly entails a big approximation of the real situation, since by relating the actual wind speed – conventionally measured at a height of 10 m above ground – with the sweep air speed inside the wind tunnel, on one hand it is assumed that the wind profile is constant with the height – which is typically not the case, the wind profile can be described by means of specific mathematical relationships (Bonan, 2005; Cook, 1997; Drew et al., 2013; Tieleman, 2008), and on the other hand it doesn't consider the difference between open-field conditions and forced convection inside an enclosure (WT). For these reasons, this work aims to investigate a suitable model to relate the datum obtained from the WT to the real situation. For this purpose, a suitable model based on Prandtl's boundary layer theory accounting for the volatilization inside the hood (Perry, 1997; Incropera et al., 2007) was experimentally verified and then related to a model describing the volatilization in the open field, thereby referring to the semi-empirical models existing for the estimation of emissions from liquid pools as a function of the wind speed. This relationship allowed to establish a new correlation for the recalculation of the SOER to the actual wind speed in the open field, thereby discussing reliability and field of application of this new proposed model.

2. Materials and methods

2.1. The wind tunnel device

The WT adopted for this work was designed and developed by the Olfactometric Laboratory at Politecnico di Milano. The structure of the hood is described in detail by Capelli et al. (2009b) and is depicted in Figs. 1 and 2. The central body has a 25 × 50 cm base section and is 8 cm high. The hood is open at the bottom and is laid on top of the emissive surface. The body has two converging sections at the extremes, connected to the inlet and outlet of the chamber that can be closed with specific fittings allowing to feed the neutral air at the inlet and collect the sample at the outlet. The WT is made of PVC and is equipped with buoyant parts that allow sampling on liquid sources.

2.2. Volatilization model for the open field

In the scientific literature there are several models that have been proposed in order to describe the volatilization phenomena of chemical compounds from liquid pools in the open field. Such models, typically developed in the field of industrial safety, for the most part rely on the theory developed by Sutton (1934). Sutton for his research (1934) considered a pool of a pure liquid volatile compound, subject to the wind action in the open field and he evaluated the dependence of the emission rate on the major factors that can influence the phenomenon. The resulting correlation can be expressed as:

$$SER = KU_h^{0.78} a^{0.89} x_0^{-0.11} \quad (2)$$

Where: SER is the Specific Emission Rate; K is the proportionality constant; U_h is the wind speed at the considered height; a is a

Fig. 1. The LabOlf wind tunnel.