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A Methodological Framework for the Quantification of Odour Emissions from Covered Industrial Basins

Francesca Tagliaferri*, Giacomo D. Scolieri, Selena Sironi, Marzio Invernizzi

Politecnico di Milano, Department of Chemistry, Materials and Chemical Engineering “Giulio Natta” - Piazza Leonardo da Vinci 32, 20133 Milano, Italy
francesca.tagliaferri @polimi.it

Reliable estimation of odour emission rates is essential for environmental permitting and dispersion modelling. This study addresses the specific challenge of evaluating odour fluxes from industrial basins and inspection pits that are covered by metal grates, which prevent the direct application of conventional sampling hoods such as wind tunnels or flux chambers. In such configurations, the physical obstruction of the emitting surface makes direct sampling at the liquid–air interface unfeasible, thereby limiting the applicability of standard methodologies typically recommended for area sources. To overcome these constraints, this study proposes an alternative methodological framework that integrates in situ field measurements with theoretical estimations of mass transfer processes. The approach combines measurements of odour concentration within the air layer above the covered source with parameterizations of mass transfer coefficients derived from established formulations in the scientific literature and expressed as functions of meteorological and micrometeorological variables. The proposed method was evaluated through comparison with alternative approaches, including a headspace-based method coupled with mass transfer correlations and wind tunnel measurements performed on liquid samples. The comparison, carried out in terms of specific odour emission rates, showed consistent results between the in situ-based method and the wind tunnel approach, while the headspace-based method yielded lower SOER estimates. Notably, the proposed approach is the only one based on direct sampling performed under real field conditions, allowing emission estimates to be derived without the need for liquid collection or laboratory reconstruction of the source. This practical advantage, combined with the observed consistency with wind tunnel results, supports its applicability for the assessment of geometrically constrained sources under real operating conditions.

1. Introduction

Atmospheric dispersion modelling is widely applied to assess the impact of odour emissions from industrial activities, and its reliability largely depends on the accuracy of the emission input data (Dabberdt and Miller, 2000; Snoun et al., 2023). Among these, the estimation of odour emission rates (OERs) represents one of the most critical and uncertain steps, particularly in the case of diffuse sources (Invernizzi et al., 2025; Liu et al., 2024; Tagliaferri et al., 2024). In particular, passive area sources are characterized by the absence of a well-defined airflow and by strong variability driven by environmental and operational factors, making their quantification inherently complex. From a physical standpoint, odour emissions from liquid surfaces are governed by mass transfer phenomena occurring at the air–surface interface, which are influenced by both operational conditions and meteorological variables (Bellasio and Bianconi, 2022; Invernizzi et al., 2019; Tagliaferri et al., 2023). In practical applications, the absence of a well-defined airflow directly associated with passive area sources typically requires the use of enclosure-based sampling techniques, such as wind tunnels or flux chambers, which simulate the convective action of the wind over the emitting surface. However, the application of these methods relies on direct access to the emission interface, making them unsuitable for configurations in which the surface is physically obstructed (Carrera et al., 2025; Parker et al., 2013; Parker et al., 2009). These limitations become particularly relevant in the case of industrial tanks and inspection pits covered by walkable metal grates. In such configurations, the emitting surface is not directly accessible,

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preventing the correct deployment of conventional sampling devices and hindering the direct measurement of VOCs emission fluxes. In addition, the presence of the grating alters the airflow above the liquid surface, partially disrupting the flow and modifying the air–surface exchange conditions and the associated mass transfer processes. As a consequence, standard methodologies commonly adopted for area sources cannot be applied. Although indirect estimation approaches, such as inverse dispersion modelling, micrometeorological methods and optical remote sensing may in principle be considered, their application is often limited by methodological complexity, demanding data requirements and relatively high implementation costs, particularly in the context of odour assessment (Bénassy and Bilinska, 2008; Tagliaferri et al., 2023).
In light of these challenges, alternative approaches may be needed to estimate OERs from geometrically constrained or inaccessible sources. In the present case, the study focused on a wastewater collection basin receiving oily streams within an industrial processing plant, covered by a walkable grating that limits direct access to the emitting surface while still allowing air exchange through its openings. The study addresses this issue by proposing a novel methodological framework for the estimation of odour fluxes. The approach integrates *in situ* measurements of odour concentration above the liquid source with theoretical parameterizations of mass transfer processes. The results obtained with the proposed method are also discussed in relation to other approaches available in the scientific literature, in order to provide a broader perspective on its applicability and underlying assumptions.

2. Proposed methodological framework for odour flux estimation (Method 1)

In this study, a time-resolved framework for the indirect estimation of OERs from geometrically constrained area sources is proposed. The approach combines in situ measurements of odour concentration C_{od} in the air phase with the estimation of the corresponding emission flux based on gas-side mass transfer theory.
The OER [ou_E/s] is expressed as:

$$OER = C_{od} \cdot Q_{out} \tag{1}$$

where C_{od} [ou_E/m^3] is the odour concentration measured in the air layer above the source at the level of the covering structure (i.e. the grating) and Q_{out} [m^3/h] is the volumetric flow rate associated with the emission. The latter is expressed as the product of the effective emission area and a characteristic emission velocity v_{out}. In the absence of a well-defined bulk flow, v_{out} is approximated, by dimensional analogy, as a gas-side mass transfer coefficient k_g, thus linking the emission flux to the underlying transport processes. The estimation of k_g [m/s] is based on a resistance model in which the overall gas-side mass transfer resistance is expressed as the sum of two contributions in series:

$$\frac{1}{k_g} = R_{tot} = R_s + R_m \tag{2}$$

where R_s represents the resistance associated with molecular diffusion across the thin air layer immediately above the liquid surface (i.e. interfacial sublayer), and R_m accounts for turbulent transport between the interfacial sublayer and the sampling height. The interfacial contribution is described using the empirical formulation proposed by Brutsaert (Brutsaert, 1975; Prata et al., 2018):

$$\frac{1}{R_s} = k_{G,s} = c_s \cdot u_* \cdot Sc_G^{-\frac{2}{3}} \tag{3}$$

where c_s [-] is an empirical constant equal to 0.0735, u^* [m/s] is the friction velocity, and Sc_G [-] is the Schmidt number. The turbulent contribution is evaluated using a logarithmic profile formulation:

$$R_m = \frac{1}{k_{G,m}} = Sc_t \cdot \frac{1}{k \cdot u_*} \cdot ln\left(\frac{z_m}{z_s}\right) \tag{4}$$

where k [-] is the von Kármán constant, z_m [m] is the sampling height, z_s [m] is the thickness of the interfacial sublayer, computed according to the correlation proposed by Prata et al. (2018), and Sc_t is the turbulent Schmidt number. Within this framework, the friction velocity u^* can be considered as a time-dependent micrometeorological variable, allowing both resistances and, consequently, the overall mass transfer coefficient to be evaluated on an hourly basis. The resulting coefficient is then used to estimate a dynamic emission rate:

$$OER = C_{od} \cdot A \cdot k_G \tag{5}$$

where A [m^2] represents the effective emission area of the source.

3. Application and comparative evaluation of emission estimation methods

3.1 Method 2: headspace-based concentration coupled with mass-transfer correlation

The first comparison approach combines experimental determination of C_{od} with a literature-based formulation for mass transfer. A liquid sample collected from the basin was used to generate a gas-phase headspace under controlled conditions. In this procedure, a known volume of liquid is enclosed in a sealed container with a defined headspace, allowing volatile compounds to partition between the liquid and gas phases until equilibrium is reached under controlled temperature conditions. After a conditioning period, the gas phase, enriched with volatile odorants transferred from the liquid, is sampled and analysed by dynamic olfactometry to provide an estimate of the C_{od}.
The OER is then estimated consistently with Eq. (5), where the gas-side mass transfer coefficient is derived from an analytical formulation based on mass transfer theory, as proposed by Macias et al. (2025). In this framework, k_G is obtained through a Sherwood number correlation derived from an extensive database of CFD simulations of cavity-type geometries representative of wastewater basins.
The Sherwood number is defined as:

$$Sh = \frac{k_G \cdot L}{D_m} \tag{6}$$

where L [m] is a characteristic length scale of the source, and D_m [m^2/s] is the molecular diffusivity of the compound in air.
In this study, Sh is estimated through a parameterization derived from CFD simulations, expressed as a function of Reynolds number, Schmidt number and geometric aspect ratio, defined as the ratio between the characteristic depth and length of the basin (D/L):

$$Sh = 1.2 \cdot 10^{-3} \cdot Re^{0.85} \cdot Sc^{1/3} \cdot \left(\frac{D}{L}\right)^{-0.6} \tag{7}$$

This approach therefore combines experimentally derived concentration values with a CFD-based parameterization of gas-side transport processes. Full details regarding the CFD modelling approach and derivation of the mass-transfer correlation can be found in Macias et al. (2025).

3.2 Method 3: wind tunnel measurement on liquid sample

The second comparison method is based on the wind tunnel (WT) technique, which is widely adopted for the direct estimation of emission fluxes from passive liquid surfaces. Due to the presence of a metal grating covering the basin, the WT could not be directly deployed on the liquid surface. Therefore, a representative aliquot of liquid was collected from the basin surface and transferred into a dedicated container. The WT device was then applied to the liquid sample, allowing the determination of C_{od} in the outlet airflow and the corresponding OER.
In this framework, the emission is first expressed in terms of Specific Odour Emission Rate (SOER), which represents the odour emission per unit surface area and unit time [$ou_E/m^2/s$] for passive area sources without induced airflow:

$$SOER = \frac{C_{od} \cdot Q_{out,WT}}{A_{WT}} \tag{8}$$

where C_{od} [ou_E/m^3] is the odour concentration measured at the outlet of the WT, $Q_{out,WT}$ [m^3/h] is the airflow rate through the system (typically equal to the neutral air inflow), and A_{WT} [m^2] is the base area of the hood.
The OER is then obtained by scaling the specific flux to the emitting surface:

$$OER = SOER \cdot A \tag{9}$$

where A [m^2] represents the effective surface area of the basin under investigation.
This approach enables the direct quantification of emission fluxes, providing a reference estimate for comparison with model-based methods, although the measurement is performed under free-surface airflow conditions that may differ from the specific aerodynamic configuration of the basin, which is covered by a grating. Nevertheless, this method has been included in the comparison as it represents a widely adopted reference technique in current regulatory frameworks.
The emission estimates obtained with the two alternative approaches described above are compared with those derived from the proposed method (Section 2), which is based on the direct measurement of C_{od} in the air layer above the covered basin, at the level of the grating, combined with a micrometeorology-based mass transfer model.

3.3 Comparative estimation of SOER

The SOER obtained with the three approaches described above were estimated and compared on the basis of an experimental dataset collected at an industrial facility. The study focused on a wastewater collection basin receiving oily streams within an industrial plant, characterized by an effective emitting surface area of 40 m².
The comparison was carried out using C_{od} measurements obtained through the three different methodologies, namely: (i) in situ sampling of the air layer above the basin at the level of the grating (Eq. 5), (ii) headspace technique (Eq. 7), and (iii) WT measurement on liquid sample (Eq. 8).
Table 1 summarizes the C_{od} values obtained from the three sampling approaches, together with the corresponding input parameters required for the estimation of SOER according to each method. These include, depending on the approach, geometrical characteristics of the basin, airflow conditions, and parameters related to mass transfer formulations. For clarity, the three estimation methods are hereafter referred to as: Method 1, based on in situ concentration measurements and micrometeorology-driven mass transfer modelling; Method 2, corresponding to the headspace-based concentration coupled with mass-transfer correlation; and Method 3, corresponding to the WT measurement on liquid sample.

Table 1: C_{od} obtained from the three sampling methods together with the corresponding input parameters used for the estimation of SOER

Method 1					Method 2					Method 3		
C_{od} [ou_E/m^3]	u* [m/s]	$k_{G,s}$ [m/s]	$k_{G.m}$ [m/s]	k_G [m/s]	C_{od} [ou_E/m^3]	L [m]	D [m]	$u_{ref,1m}$ [m/s]	k_G [m/s]	C_{od} [ou_E/m^3]	Q_{WT} [L/h]	A_{WT} [m^2]
120	0.1	$5.61 \cdot 10^{-3}$	$9.52 \cdot 10^{-3}$	$3.53 \cdot 10^{-3}$	720	7	2	1	$2.13 \cdot 10^{-4}$	95	2500	0.125

For comparison purposes, the emission estimates were expressed in terms of SOER, which normalizes the emission flux with respect to the emitting surface area and allows a method-consistent evaluation independent of source size. The resulting SOER values are reported in Table 2.

Table 2: SOER estimated with the three methods

Method 1 [$ou_E/m^2/s$]	Method 2 [$ou_E/m^2/s$]	Method 3 [$ou_E/m^2/s$]
0.42	0.15	0.53

As expected, the C_{od} obtained from the headspace method is approximately one order of magnitude higher than those measured with the other techniques, due to the equilibrium conditions established in a confined system, which promote the accumulation of volatile compounds in the gas phase. In contrast, the concentrations measured by the WT and by in situ sampling at the grating level are comparable. Consistently, Methods 1 and 3 provide similar SOER estimates, whereas Method 2, despite the higher Cod values, yields lower SOER results. This behaviour may be related to the estimation of the gas-side mass transfer coefficient in Method 2, which may not fully reflect the actual transfer conditions in the presence of the grating.

4. Discussion and conclusions

The comparison of the SOER values obtained with the three methods provides insight into both the consistency of the estimates and the influence of methodological assumptions on the resulting emission rates. Although the approaches differ substantially in terms of experimental setup and modelling assumptions, the resulting SOER values for Methods 1 and 3 are similar and, when considering the intrinsic uncertainty associated with olfactometric measurements, can be regarded as practically equivalent. This suggests that these two methods converge toward a consistent estimate of the emission rate for the investigated source. In contrast, Method 2 provides lower SOER estimates, despite being based on higher measured odour concentrations. This behaviour may be related to the estimation of the gas-side mass transfer coefficient. The Sherwood correlation adopted in this approach was developed for free liquid surfaces in open cavity configurations and does not explicitly account for the presence of a covering structure such as a metal grating. In the investigated case, the grating may alter the air exchange and mixing conditions above the liquid surface, including the possible generation of local turbulence, leading to differences in mass transfer compared to the assumptions underlying the correlation. As a result, the k_G value estimated with Method 2 may not fully represent the actual transfer conditions. Although Method 1 also relies on parameterizations for the estimation of the mass transfer coefficient and is therefore subject to the assumptions inherent in the adopted formulations, these are based on established interfacial

mass transfer formulations and make use of micrometeorological variables (i.e. u*) representative of near-surface conditions, and from a theoretical perspective are expected to reflect the local exchange conditions.
A key difference among the methods emerges in the measured C_{od}. As expected, the concentration derived from the headspace method (Method 2) is approximately one order of magnitude higher than those obtained with the other techniques. This reflects the partitioning conditions in a closed system, which promote elevated gas-phase concentrations of volatile compounds. In contrast, the concentrations measured using the WT (Method 3) and by in situ sampling at the grating level (Method 1) are comparable.
An additional aspect concerns the location and representativeness of the concentration measurements. In the proposed approach (Method 1), Cod is measured directly in the air layer at the level of the grating, i.e. in correspondence with the actual emission interface as modified by the presence of the cover. In contrast, Methods 2 and 3 rely on measurements performed under controlled or simplified conditions (headspace equilibrium and WT on liquid sample), which may not fully reproduce the geometrical and physical configuration of the source. From a practical perspective, the feasibility of sampling also represents a relevant aspect. In some cases, it may not be possible to collect representative liquid samples for headspace analysis or to transfer them into dedicated containers for wind tunnel measurements. In such situations, the proposed approach based on in situ air sampling combined with micrometeorological parameterizations enables direct field sampling in proximity to the emission source.
Overall, the results highlight the intrinsic difficulty in estimating OER from geometrically constrained and partially obstructed sources, particularly in cases where standardized methods are not available and existing approaches are not explicitly addressed in current regulatory frameworks. The approaches considered are inherently influenced by method-specific assumptions, related either to the representativeness of the sampling configuration or to the parameterization of transfer processes. In this context, the agreement between Methods 1 and 3 provides a certain degree of confidence in the obtained estimates, while the differences observed with Method 2 suggest that the adopted mass transfer formulation may have limitations in fully representing the exchange processes in configurations characterized by covering structures such as grates.
Future work should aim to extend this comparative analysis to a broader range of case studies, in particular including sources characterized by higher odour emission potential, in order to assess the robustness of the different approaches under varying conditions. In addition, given that Methods 1 and 2 rely on parameterizations for the estimation of mass transfer coefficients, further investigation should address the sensitivity of the OER estimates to the selected input parameters and correlations. In this context, extending CFD-based analyses to configurations including covering structures, such as grates, would be particularly relevant to improve the representativeness of mass transfer formulations under real operating conditions.

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