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Comparison of different approaches for the estimation of odour emissions from landfill surfaces

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A B S T R A C T

The aim of this study is related to the assessment of odour emissions from landfill surfaces. Up to now, there is not a widely accepted method to quantify odour emissions from this particular kind of source. Five different methods were developed and investigated. These methods can be considered as based on three distinct approaches, both experimental and computational. The first approach provides to use models for the estimation the landfill gas production, whereby the second and the third approach are based on direct measurement campaigns on the landfill surface: for the determination of the methane concentration or for the direct measurement of the odour concentration, respectively. The methods were then compared in terms of specific odour emission rates by referring to other literature data. Finally, dispersion modelling was applied in order to allow a further comparison of the resulting odour impacts with other olfactometric data from independent monitoring campaigns on the studied site.

1. Introduction

Olfactory pollution is the immission of polluting compounds in the atmosphere that, although if not directly dangerous for the human health, are nonetheless characterized by intense and/or unpleasant smell. Typical examples are gaseous emissions coming from landfill surfaces (Ying et al., 2012), intensive farming, etc. This kind of pollution is one of the most significant causes of environmental discomfort since it lowers the quality of the environment and it may lead to psychophysiological disorders and a general worsened life quality (Palmiotto et al., 2014), which brought several countries to adopt specific regulations for odour impact assessment and control (Sironi et al., 2013). In order to devise proper strategies to manage odour-related nuisance it is necessary to have specific methods for odour emission measurement and for odour impact assessment (Balling and Reynolds, 1980; Hobson, 1995; Stordeur et al., 1981), debunking the common belief, that odour characterization is more art than science (Koe, 1989; Jiang, 1996). While in the scientific community there is a satisfactory agreement regarding the analytical technique to be used for odour emission measurement – i.e. dynamic olfactometry for the determination of odour concentration (Sironi et al., 2014) – odour sampling is a quite more debated task, especially in the case of diffused emissions or area sources. The evaluation of odour emissions from landfills is even more complicated, due to the specific characteristics of this kind of source, which is surely not an active area source, but neither properly a passive area source, as the landfill surface is typically crossed by a – low – flux. As a consequence, there is currently no widely accepted method for odour assessment on landfills. However, landfills often represent a source of unpleasant odours and thus of complaints to the near-living population. For this reason, the development of specific methods for the quantification of such emissions and the definition of specific odour emission factors would be of great interest for environmental authorities, as well as for landfill managers and operators.

This work discusses different methods for the evaluation of odour emissions from landfills. Five methods were developed, which are all retraceable to one of three distinct approaches to the matter.

The first approach, which comprises methods 1 and 2, entails the usage of a model for the quantification of the landfill gas (LFG) production: the model used in the first method is the US-EPA LandGEM, while the second method exploited a second model that was specifically developed for the present project by improving some of the features of the US-EPA LandGEM.

The second approach, which includes the third method, relies on the direct measurement of the methane (CH_4) concentration

Abbreviations: LFG, landfill gas; OER, Odour Emission Rate; SOER, Specific Odour Emission Rate.

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on the landfill surface, which involved the necessity to define a sampling methodology tailored for this peculiar type of source.

The third approach, which comprises methods 4 and 5, involves the direct measurement of the odour concentration at the source. In the fourth method the concentration was measured by means of a flux chamber operated at 200 L/h (Capelli et al., 2014) and considered independent from the wind speed, while in method 5 the landfill surface was treated as a passive area source, thus using a Wind Tunnel (Capelli et al., 2009) operated at 2500 L/h for sampling and considering the concentration as a function of the wind speed on the surface (Sironi et al., 2005).

Since the first two approaches are based on the quantification of methane emissions, the Odour Emission Rate (OER) needs to be obtained indirectly by multiplying the emitted gas flow rate by the LFG odour concentration. The odour concentration (c_{od}) of the LFG emitted through the landfill surface was estimated by means of a correlation investigated between c_{od} and c_{CH_4}.

The OER and SOER (Specific Odour Emission Rate, i.e. the OER per surface unit) values obtained with these five methods were then compared and discussed referring to other – unfortunately few – data regarding odour emissions from landfills that can be found in the scientific literature. Moreover, an atmospheric dispersion model (CALPUFF) was run in order to compare the effect of the different OER values in terms of odour impact resulting on the territory surrounding the studied landfill. This allowed a more in-depth evaluation of the obtained results by comparison of the odour impacts resulting from the model application with some other indicators of the landfill odour impact, such as the presence/absence of complaints by population and the outcomes of other monitoring campaigns.

Finally, it is important to mention that, due to the logistic difficulties connected to the collection of experimental data on area sources of big dimensions such as landfills, the investigation was limited to the odour emissions from the exhausted landfill surface. As a matter of fact, due to its large extension compared to the other sections of the plant (e.g., fresh waste tipping, torches), as well as to the offensive odour character of the landfill gas (Dincer et al., 2006), this is often recognized to be the main source of malodours from landfills (Saral et al., 2009; Sarkar and Hobbs, 2003).

2. Materials and methods

2.1. The studied site

The chosen landfill is located in Northern Italy, and it is classified as "Landfill for Non-Hazardous Municipal Solid Waste Disposal".

The site was chosen because it is object of repeated olfactometric monitoring campaigns by the Olfactometric Laboratory of Politecnico di Milano since several years. This is of course not mandatory for the aim of the study, nonetheless, the experience with the studied landfill site and the access to a great amount of emission, olfactometric and meteorological data, as well as the results of the monitoring campaigns are very useful in order to evaluate the outcomes of this study (SOER and OER values obtained with the different methods). The landfill is operational since the early 1990s and has a waste processing capacity of several millions cubic meters, and a surface of about 205,000 m^2, making it one of the biggest landfills in Northern Italy. The site is subdivided in six allotments: currently only one allotment is still active, all the others are closed.

The campaigns for the collection of the experimental data (CH_4 and odour concentration measurements) were carried out from 1/3/2014 to 30/10/2014 on allotment No. 1, which is the oldest one. The limitation of the investigation domain was due to the high cost- and time-consumption associated with the retrieval of experimental field data, for which it was decided to focus only to the exhausted part of the landfill, and especially on one allotment. Nonetheless, the methods here proposed are methodological approaches that can be analogously applied to the other landfill parts.

2.2. Modifications to the LandGEM model

As a first attempt, in this study the US-EPA LandGEM model (Alexander et al., 2005) was used in order to assess the methane production. One of the novel aspects of this study was the modification of the LandGEM models in order to improve some of its features.

The fundamental equation of the LandGEM emission model is reported in Eq. (1).

$$Q_{CH_4}^{gen} = \sum_{i=1}^{n}\sum_{j=0.1}^{1} kL_0\left(\frac{M_i}{10}\right)e^{-kt_{i,j}} \tag{1}$$

where $Q_{CH_4}^{gen}$ is the annual methane generation $\left[\frac{m^3}{y}\right]$, i is the one year time increment, n is the number of years considered, j is the 0.1 year time increment, k is the methane generation rate $\left[y^{-1}\right]$, L_0 is the potential methane generation capacity $\left[\frac{m^3}{t}\right]$, M_i is the waste accepted in the i-th year [t], $t_{i,j}$ is the age of the j-th section of waste M_i accepted in the i-th year, in decimal years [y].

The improvement concerns the input parameters, which the model is very sensitive to. More in detail, one main flaw in the default model is that, although the waste inflow can be set changing year by year, the other parameters, i.e. the methane generation rate (k) and the methane generation potential (L_0), must be considered constant for the whole simulation (Alexander et al., 2005). This makes it impossible to account for the variations that may occur because of a change in the processed waste quality, given that both (k) and (L_0) are strongly dependent on the bio-degradability of the landfilled waste.

As a matter of fact, the quality of the landfilled waste depends on the national regulations regarding waste management and disposal. The recent European Directives on the matter (the last one being the Directive 2008/98/EC) have brought to a progressive modification of the characteristics of the landfilled waste, i.e. to a reduction of its bio-degradability due to the obligation of waste pre-treatment before landfilling, thereby greatly affecting the values of the two input parameters (k) and (L_0). It is therefore clear that considering those parameters as constants over the whole landfill life is often an unacceptable approximation. For this reason, in this work, the possibility of setting these two key parameters varying year by year was implemented. The modified LandGEM emission model maintains the same Graphical User Interface (GUI) in MS Excel as the standard US-EPA LandGEM but allows to consider the parameters (k) and (L_0) as changing yearly.

2.3. Design and development of specific sampling procedures

In order to justify the necessity to design specific equipment and procedures for sampling on landfill surface, it is first important to clarify the peculiarities of this source type. The landfill surface can be treated as an area source, but it doesn't fall into the category neither of "active" nor "passive", as defined by the German guideline on olfactometric sampling VDI 3880 (VDI, 2011), which states that area sources with an outward flow below 30 $dm^3/m^2/h$ are to be considered as passive. In facts, landfill surfaces are crossed by a – typically very low – emission flow, which nonetheless cannot be neglected. Moreover, the emission flow is not determined by forced convection, as it is the case for passive area sources