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Comparison of Field Inspections and Dispersion Modelling as a Tool to Estimate Odour Emission Rates from Landfill Surfaces

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This study has the final purpose to estimate the odour impact of a landfill located in Southern Italy, in the region of Puglia, by means of a field inspection that involves the direct assessment of odours in the field by trained assessors, which was carried out following the "plume method" described in the EN 16841:2016, Part 2. The primary aim of this work is to compare different methods for the estimation of Odour Emission Rates from the landfill surface in order to evaluate the method that allows to maximize the correspondence between the simulated odour impact and the outcomes of the direct assessment by field investigations. The motivation of this combined activity relies in the necessity to experimentally verify the hypotheses proposed in recent research work, which highlight the different mechanism determining odour emissions from landfill surfaces compared to the typical volatilization mechanism from passive area source, i.e. natural convection. As a consequence of this different volatilization mechanism, in the case of landfill surfaces, the recalculation of the OER as a function of the wind speed as it is done for other passive area sources may result in significant overestimation of odour impact. This study shows how the correspondence between direct field odour assessments and simulated odour impact is maximized by considering a constant SOER (Specific Odour Emission Rate) in the range of 0.07-0.25 $ou_E/m^2/s$. On the other hand, a variable SOER proportional to the square root of the wind speed results in an overestimation of about one order of magnitude of the landfill odour impact. This in turn proves the need to treat landfill surfaces as a particular type of source, requiring specific techniques for the estimation of odour emissions, which must account for the peculiarity of the mechanisms that affect landfill gas emissions into the atmosphere.

1. Introduction

As already discussed in previous works (Lucernoni et al., 2016a), 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). Especially in the case of landfills, the determination of odour emissions is particularly complex, giving that, up to now, no universally accepted methodology for sampling and assessment of emissions from landfill surfaces has been established. The most recent studies on the matter account for the fact that landfill surfaces are crossed by a low yet not negligible flux of landfill gas (LFG) (Palmiotto et al., 2014; Rachor et al., 2013), and thus propose to treat this kind of source as a "semi-passive" area source (Lucernoni et al., 2016a,b).
One of the main consequences of this is that, while for other types of passive area sources, such as non-aerated wastewater treatment tanks or non-ventilated solid heaps the emission rate has been proven to depend on the wind speed over the emitting surface (Lucernoni et al., 2017a; 2018), in the case of landfills a different mechanism applies. Indeed, the phenomenon that regulates emissions from landfill surfaces is not natural convection, but the presence of an endogenous gas flow due to the formation of LFG inside the landfill

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body, which is not directly affected by the wind blowing over the surface (Lucernoni et al., 2016b; Rachor et al., 2013).

Although this evidence, there are some cases in Italy in which the approach that treats the landfill as a fully passive area source, thereby considering the emission as a function of the wind speed blowing over the surface has been erroneously adopted. This was for instance the case for the previous regulation of the Region of Puglia, before the very recent publication of the new regulation in matter of odour emissions, in July 2018. For this reason, this study compares the outputs of odour dispersion modelling obtained with different Odour Emission Rate (OER) values and field assessments by human assessors with the technique of the plume inspection (Capelli et al., 2012) with the aim to evaluate the OER values resulting in a better correspondence between the two results. This in turn allows to evaluate the best way to estimate odour emissions from a landfill surface.

2. Materials and methods

2.1 The studied site

The study was conducted at a landfill in Southern Italy, close to the city of Taranto, in the Region of Puglia.

As already mentioned, for the specific scope of this study, the dynamic plume field inspection method was adopted to "validate" the outputs of the dispersion model outputs and thus to estimate the landfill OER. However, the standardized method described in the EN 16841:2016 - Part 2 had to be slightly modified and re-adapted to the specific geographical characteristics of the investigated area.

A preliminary inspection survey was organized inside the landfill and in the surrounding areas in order to map the investigation area and trace the paths that could be covered by the panel members for the identification of the presence of odours from the studied landfill (Figure 1).

Figure 1: Map of the studied landfill and the surrounding paths (coloured) identified for the field inspection. The black lines indicate the limits of inaccessible areas (private properties or other plants)

Since the aim of the study is the evaluation of the most suitable method for the characterization of odour emissions due to LFG emissions through the landfill surface, the surveys had to be programmed during the times of the day when the fresh waste conferred to the landfill is covered, and thus the emissions from fresh waste tipping is negligible. Thus, the surveys took place either in the early morning (before 8:30) or after 17:00. The panel members were trained to recognize the specific LFG odour by sniffing samples collected over the landfill surface before the surveys. The panel was divided into 2 groups, each composed by a minimum of 2 people, in order to make it possible to inspect 2 paths simultaneously during each measurement cycle. In total, 5 measurement cycles were carried out, as summarized in Table 1.

2.2 Olfactometric sampling over the landfill surface

In order to compare the two different approaches for the evaluation of odour emissions from landfill surfaces – i.e. the one that considers odour emissions as independent from the wind speed over the landfill surface, and the one that treats the landfill as a fully passive area source thus considering the OER as a function of the wind speed – specific sampling campaigns were organized simultaneously to the field inspection surveys.

Table 1: Summary of the measurement cycles

Cycle	Date	Time	Cycle start hour	Cycle end hour	WD (observed)
I	10/04/2017	Afternoon	17:00	19:00	SW
II	11/04/2017	Morning	7:00	8:30	N
III	11/04/2017	Afternoon	18:00	19:30	W
IV	12/04/2017	Morning	6:30	8:15	NW
V	12/04/2017	Afternoon	17:30	18:40	NE - _

As previously mentioned, in the case of landfills, no universally accepted methodology for olfactometric sampling has been defined up to now. One possibility is to use a flux chamber, similar to the one suggested by the US EPA (Capelli et al., 2014), which is typically operated at low sweep air flows, in the range of few hundreds litres per hour. On the other hand, if the landfill is considered as a fully passive area source, then also a wind tunnel can be used for the collection of odour samples over the surface (Capelli et al., 2013).
Since the final aim of this work is the evaluation of the best method for estimating odour emissions from landfills, both a flux chamber and a wind tunnel were adopted, operated at a flow rate of 200 l/h and 2500 l/h, respectively (Lucernoni et al., 2017b).
In both cases, the Specific Odour Emission Rate is obtained as:

$$SOER = \frac{c_{od} \cdot Q_{in}}{A_{base}} \quad (1)$$

Where c_{od} is the odour concentration measured at the hood outlet, Q_{in} is the sweep air flow rate, and A_{base} is the base area of the hood.

2.3 Odour dispersion modelling

The dispersion of odour emissions from the landfill surface was evaluated using the CALPUFF model (Scire et al., 2000).
The meteorological data used are 3D hourly data of April 2017 processed by means of the WRF (Weather Research and Forecasting) model with 1 km resolution relevant to the studied area. The meteorological domain and the simulation domain were set equal to an area of 6000 m x 6000 m, with a resolution of 100 m, including the closest receptors to the landfill. 10 cells were considered on the vertical plane, giving a total of 36000 cells.

3. Results & Discussion

3.1 Olfactometric evaluations and SOER calculation

Table 2 reports the results of the olfactometric analyses relevant to the samples collected on the landfill surface by means of the flux chamber (left part of the table) and of the wind tunnel (right part of the table).
The average odour concentration resulting from the flux chamber measurements is 56 ou_E/m^3, which corresponds to a SOER of 0.05 $ou_E/m^2/s$, calculated according to Eq. (1). With the wind tunnel, an average odour concentration of 56 ou_E/m^3 was measured, corresponding to a SOER of 0.25 $ou_E/m^2/s$.
As expected, the SOER resulting from the flux chamber measurements is lower compared to the one obtained based on the wind tunnel results. The reason for that is that, for area sources characterized by low emissivity, as it is the case for landfill surfaces, wind tunnels are known to overestimate the actual emission (Frechen et al., 2004; Lucernoni et al., 2017b).
As a general rule, the direct measurement of the odour concentration by means of hood methods for the evaluation of the SOER (or OER) from area sources that are not highly odorous is likely to lead to an overestimation of the OER related to the emission. This is typically the case for landfill surfaces.
In this specific case, the application of both hoods over the studied landfill surface results in a measure odour concentration of few tens of ou_E/m^3. For such low odour concentration values it is likely that at least a share of the sample odour concentration is given by the so-called "background odour". Here, the background odour could represent the odour of the landfill surface itself (e.g., soil, grass), which contributes to the overall concentration value of the collected sample, but is not necessarily related to the emitted LFG odour.

Moreover, it should be also considered that the intrinsic lower detection limit for Dynamic Olfactometry is typically in the range of 20-50 ou_E/m^3 (Capelli et al. 2013).

Table 2: Results of the olfactometric measurements of the samples collected on the landfill surface with the flux chamber (left) and with the wind tunnel (right)

Date	Sample no.	Description	c_{od} (ou_E/m^3)
10/04/2017	1	Flux I 8	29
10/04/2017	2	Flux I 5	72
11/04/2017	1	Flux H 1 ppm 300	40
11/04/2017	2	Flux H 7 ppm 150	54
11/04/2017	3	Flux H 15 ppm150	43
11/04/2017	4	Flux H 16 ppm 1000	72
11/04/2017	5	Flux H 18 ppm 400	54
11/04/2017	6	Flux I 23 ppm 1300	48
11/04/2017	7	Flux I 8 ppm 2500	72
11/04/2017	8	Flux I 3 ppm 450	40
11/04/2017	9	Flux I 5 ppm 400	40
11/04/2017	10	Flux I 20 ppm 1000	25
11/04/2017	11	Flux I 22 ppm 600	54
11/04/2017	12	Flux I 24 ppm 2000	24
12/04/2017	1	Flux H 1 ppm 400	57
12/04/2017	2	Flux I 3 ppm 1000	60
12/04/2017	3	Flux I 5 ppm 300	81
12/04/2017	4	Flux I 8 ppm 1050	64
12/04/2017	5	Flux H 15 ppm 400	85
12/04/2017	6	Flux H 16 ppm 200	85
12/04/2017	7	Flux H 17 ppm 150	76
12/04/2017	8	Flux H 18 ppm 150	91
12/04/2017	9	Flux I 20 ppm 200	76
12/04/2017	10	Flux I 22 ppm 2000	72
12/04/2017	11	Flux I 23 ppm 1000	91
12/04/2017	12	Flux I 24 ppm 800	51

Date	Sample no.	Description	c_{od} (ou_E/m^3)
10/04/2017	1	Wind I 3	29
10/04/2017	2	Wind I 5	18
10/04/2017	3	Wind I 8	483
10/04/2017	4	Wind I 24	18
11/04/2017	1	Wind H 1	40
11/04/2017	2	Wind H 7	48
11/04/2017	3	Wind H 16	36
11/04/2017	4	Wind H 18	30
11/04/2017	5	Wind I 3	25
11/04/2017	6	Wind I 5	34
11/04/2017	7	Wind I 8	30
11/04/2017	8	Wind I 20	17
11/04/2017	9	Wind I 22	32
11/04/2017	10	Wind I 23	40
11/04/2017	11	Wind I 24	20
12/04/2017	1	Wind H 1	76
12/04/2017	2	Wind H 15	76
12/04/2017	3	Wind H 16	96
12/04/2017	4	Wind H 17	68
12/04/2017	5	Wind H 18	68
12/04/2017	6	Wind I 3	68
12/04/2017	7	Wind I 5	60
12/04/2017	8	Wind I 8	57
12/04/2017	9	Wind I 20	40
12/04/2017	10	Wind I 22	76
12/04/2017	11	Wind I 23	60
12/04/2017	12	Wind I I 24	30

3.2 Model outputs vs field assessments

The results of the field inspection surveys were processed by combining the information in the forms filled by the assessors with the data relevant to the paths covered registered by means of portable GPS systems.
For each measurement cycle, the significant measurement points were reported on a map indicating with different colours the points where the presence of LFG odour from the landfill was recognizable, not recognizable, or uncertain. Then the transition points were determined as the points halfway between an odour absence point and an odour presence point. Finally, the transition points were connected by means of a interpolation polyline that identifies the plume extent area, i.e. the extent of the area in which the presence of landfill gas odour from the landfill was recognizable by the assessors (Figure 2).
The results of the field inspection surveys were compared with the outputs of the dispersion modelling applied to the odour emissions referred to the same periods of execution of the measurements cycles (Table 1). This comparison was made by superimposing the lines defining the limits of the plume extents resulting from each measurement cycle (as the one shown in Figure 2) on the maps resulting from the odour emission dispersion simulations.
As an example, Figure 3 shows the comparison of the plume extents determined by field inspection with the corresponding maps resulting from dispersion modelling for the II measurement cycle. The left part of the figure shows the comparison with the model map obtained considering a SOER of $ou_E/m^2/s$ variable with the wind speed, i.e. proportional to $v^{1/2}$ as for fully passive area sources, while the right part of the figure represents the model map obtained using a constant SOER of 0.25 $ou_E/m^2/s$.
It is clearly visible from this comparison that considering the landfill SOER as a function of the wind speed significantly overestimates the landfill odour emissions, giving that the simulated odour impact results in odour concentrations that are almost one order of magnitude higher than those determined in the field by a panel of trained and expert assessors.

On the contrary, the comparison of the model simulations based on a constant SOER shows a better correspondence between model outputs and field assessments, in terms both of shape and extension of the determined odour plume extents.

Figure 2: Example of map of the plume extent limits resulting from the II measurement cycle

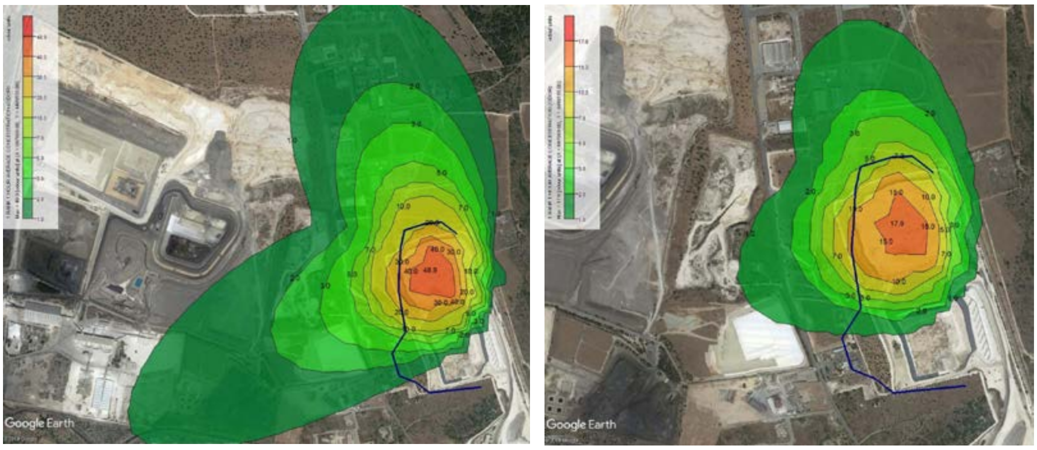

Figure 3: Comparison between plume extent determined by II field inspection (violet line) and model map obtained with a SOER of 0.25 $ou_E/m^2/s$ variable with wind speed (on the left) vs constant SOER (on the right)

As described in section 3.1, the SOER of 0.25 $ou_E/m^2/s$ is the one resulting from the olfactometric measurements carried out over the landfill surface using the wind tunnel system.
Furthermore, in order to optimize the correspondence, considering that the odour concentration at which the assessors recognize the presence of odours in the field corresponds to the so called “odour recognition threshold”, which lies around 2-3 ou_E/m^3 (Capelli et al., 2014), the SOER used as input for dispersion modelling was varied from the value of 0.25 $ou_E/m^2/s$ as to best fit the field inspection results.
As can be seen from the map on the right part of Figure 3, the use of a constant SOER of to 0.25 $ou_E/m^2/s$ results in a slight overestimation of the modelled odour impact, since the lines delimiting the plume extents determined by field inspection fall over odour concentrations of about 5-7 ou_E/m^3. Therefore, the SOER used for dispersion modelling was reduced to 0.07 $ou_E/m^2/s$ in order to obtain a “best fit”, as shown in Figure 4.
This SOER values is more similar to the one relevant to the olfactometric sampling carried out with the flux chamber instead of the wind tunnel, which resulted in a SOER of 0.07 $ou_E/m^2/s$. This observation seems to point out that the flux chamber might be a more suitable method for odour sampling over landfill surfaces instead of the wind tunnel, as already observed in other studies (Lucernoni et al., 2017b). However, other experiments are needed in order to confirm such observations, especially in consideration of the high degree of uncertainty that affects this kind of field determinations.

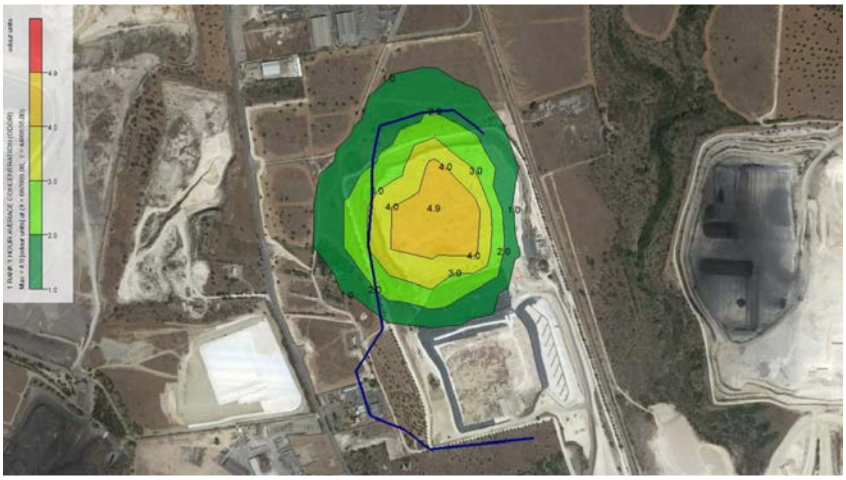

Figure 4: Comparison between plume extent determined by II field inspection (violet line) and "best-fit" map resulting from dispersion modelling obtained considering a constant SOER of 0.07 $ou_E/m^2/s$

4. Conclusions

The comparison of field assessments and model outputs obtained considering the landfill SOER as a function of the wind speed clearly highlights that this approach significantly overestimates the landfill odour emissions. On the contrary, the comparison of the model based on a constant SOER, independent from the wind speed, results in a good correspondence between model outputs and field assessments, both in terms of shape and extension of the determined odour plume extents. Correspondence between simulated and experimentally assessed plume extents is optimized for constant SOER values comprised between 0.07 and 0.25 $ou_E/m^2/s$, thus pointing out that flux chambers might be preferred over wind tunnels for direct odour assessment on landfill surfaces. However, further research is still required in order to identify the best practice for odour emission estimation from landfills.

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