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Evaluation of odour impact from a landfill area and a waste treatment facility through the application of two approaches of a Gaussian dispersion model

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Abstract: Odour emission from landfill areas has a high potential to cause significant annoyance to people living in their surroundings. In order to avoid odour nuisance, it is crucial to select the best location in the project phase of these facilities. In the present work, two approaches of the Gaussian atmospheric dispersion model were employed to predict odour impact from a projected landfill area and a waste treatment facility. The first approach was a simplified bi-Gaussian Atmospheric Dispersion model developed by the authors. Calculated odour concentrations were represented using GIS tools (Esri ArcMap® software). Regarding the second approach, a commercial bi-Gaussian Atmospheric Dispersion one was used. The odour impact of the waste treatment facility is expected to be low, because of the high efficiency of air biofiltration treatments and the dispersion effect of the stack. The shape and the reach of odour percentile contours were quite similar, providing coherent results between two approaches. Concerning the landfill installation, odour concentrations were modelled for the prevailing winds. The results obtained by the simple dispersion model were 1.5 km, compared with the 3.3 km modelled by the commercial one. Both approaches seem to overestimate the distance reached by odour. Meteorological conditions in Mediterranean areas typically present a high proportion of calm winds, and in these situations Gaussian models may present high errors. Field measurements are required when landfill installation becomes operational, in order to determine the real reach of odour. Bi-Gaussian Dispersion Models may not be appropriate to quantify the odour impact from agricultural sources.

Keywords: Odour, Gaussian Dispersion Model, Landfill, Waste

1. INTRODUCTION

Unpleasant odours are emitted from landfill facilities and could become an important nuisance for local residents if the installation is located near to villages. In the present work, odour was evaluated through implementation of two Gaussian atmospheric dispersion approaches, in order to predict the affected areas in two different installations: a landfill area and a waste treatment facility both projected in the province of Valencia, Spain. The treatment facility is designed to treat 200,000 tonnes of municipal solid waste (MSW) annually. The operations which will be carried out in the facility are the reception and separation of wastes into different classes (organic and inorganic fraction, building wastes, refuse, etc) and the following treatment of the waste. Two principal treatments of waste are designed: the anaerobic digestion of the organic fraction of MSW and composting of the MSW organic fraction with garden wastes and digested residues. The installation will have mechanical extraction of air, which will be previously treated in two chemical scrubbers and two series of two biofilters. The equipment has a capacity to treat
455,000 m$^3$/hour. Concerning the release of clean air, three possibilities have been evaluated in the project: the emission of air at the ground level through two release points, the emission through two stacks of 5 m height; and the emission through two stacks at 10 m height. The storage of remaining wastes will take place in the projected landfill area. The landfill area will have an extension of 220,000 m$^2$ approximately, and will storage the inert solid wastes from the treatment plant. Leachates will be collected in two storage areas of about 8,700 m$^2$ which will be located in the sides of the landfill.

2. **MATERIAL AND METHODS**

2.1 **Weather conditions**

The projected facilities are located in a valley, where wind directions are strongly determined by the topography. The orientation of the valley is ENE-WSW direction, and the facilities are located in the centre of the valley. Data from two weather stations located at 5,267 and 5,620 m from the odour source were employed in this work. No important disturbing elements as hills or mountains were situated between weather measurement stations and the projected installation, so the meteorology data was considered to be representative of the studied area.

2.2 **Modelling odour evaluation**

Odour evaluation in the two studied planned facilities was done by two approaches of the Gaussian Dispersion Model. However, odour evaluation strategies were different, as follows. In both cases, odour modelling was performed considering the plant at a full capacity, in order to consider the worst perception situation.

a) **Waste treatment facility**

The 3 OUm$^3$ 98-percentile was employed in the waste treatment facility in order to evaluate odour impact in the surroundings for the three studied scenarios: the emission at ground level, at 5 m height and 10 m height. Annually hourly weather data was employed in this case.

b) **Landfill area**

Instantaneous odour concentrations were calculated for the prevailing wind direction, using average values of weather data. Percentile was not calculated in this case because calculations by the simple bi-Gaussian approach were difficult and required a lot of work and time.

2.3 **Atmospheric dispersion approaches**

The two approaches used in this study employ the same Gaussian model and, consequently, the same atmospheric dispersion equation. The main differences between them are the determination of the atmospheric dispersion coefficients and the possibility for using wind speed values lower than 1 m·s$^{-1}$. The implementation of the model is also different as is explained in the followed paragraphs.

a) **Simple bi-Gaussian Dispersion Model**

Two Gaussian atmospheric dispersion approaches were employed to evaluate odour impact from the waste treatment facility and landfill installation. The first one was a simple bi-Gaussian Dispersion Model, specifically the Pasquill Model, obtained from the universal equations of dispersion turbulence and convective transport (Figure 1 and Equation 1). Some hypothesis are assumed: the emission rate is constant with time, the conservation of the substance is supposed, the problem is analysed in stationary pattern where wind speed is uniform and independent from height, the dispersion coefficients are assumed to be constant, the longitudinal turbulence dispersion is negligible with respect to the convective transport and the axis x is related to the horizontal wind direction.
\[ C(x, y, z) = \frac{G}{2\pi U\sigma_y \sigma_z} \exp \left( -\frac{y^2}{2\sigma_y^2} - \frac{z^2}{2\sigma_z^2} \right) \]  

Where:
- \( C \): odour concentration (OU·m\(^{-3}\)) at the receptor location
- \( G \): odour emission (OU·s\(^{-1}\))
- \( U \): horizontal wind velocity (ms\(^{-1}\))
- \( \sigma_y, \sigma_z \): atmospheric dispersion coefficients (m)

As shown in Espert and López [1997] this is a suitable model for similar cases in Valencian region. Assuming that the behaviour of ground level is an impermeable barrier, the gas concentration can be calculated at the effective emission height (H) using the Equation 2.

\[ C(x, y, z) = \frac{G}{2\pi U\sigma_y \sigma_z} \exp \left( -\frac{y^2}{2\sigma_y^2} \right) \exp \left( -\frac{(z-H)^2}{2\sigma_z^2} \right) + \exp \left( -\frac{(z+H)^2}{2\sigma_z^2} \right) \]  

The concentration at ground level (\( z=0 \)), could be calculated with the Pasquill’s equation (Equation 3).

\[ C(x, y, z) = \frac{G}{\pi U\sigma_y \sigma_z} \exp \left( -\frac{y^2}{2\sigma_y^2} - \frac{H^2}{2\sigma_z^2} \right) \]  

In the present work we have assimilated the effective emission height to the source height, without considering any over elevation of the odour plume. The atmospheric dispersion coefficients were determined using the Equations 4 and 5, depending on atmospheric stability classes (A-F) (Table 1). According Tadmor and Gur (1969) in Espert and López [2000].

\[ \sigma_y = a \cdot x^p \]  
\[ \sigma_z = b \cdot x^q \]  

Table 1. Parameters used to determine atmospheric dispersion coefficients

<table>
<thead>
<tr>
<th>Stability class</th>
<th>( \sigma_y )</th>
<th>( \sigma_z )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.3658</td>
<td>0.9031</td>
</tr>
<tr>
<td>B</td>
<td>0.2751</td>
<td>0.9031</td>
</tr>
<tr>
<td>C</td>
<td>0.2089</td>
<td>0.9031</td>
</tr>
<tr>
<td>D</td>
<td>0.1474</td>
<td>0.9031</td>
</tr>
<tr>
<td>E</td>
<td>0.1046</td>
<td>0.9031</td>
</tr>
<tr>
<td>F</td>
<td>0.0722</td>
<td>0.9031</td>
</tr>
</tbody>
</table>

The model was implemented in a spreadsheet (Microsoft® Office Excel™ 2003). The simulated odour concentration was calculated in a grid whose dimensions were 4 x 4 km around the odour source, with a distance between points of 25 m.

In the case of treatment facility, this procedure was repeated using every hourly data of wind direction and wind speed of a year for the three studied scenarios: a ground level, at 5m and at 10m above ground level. Modelling was carried out with the meteorological data.
from the two weather stations, obtaining two odour concentrations profiles. Subsequently
odour concentrations at the facility’s location were obtained by averaging odour
concentration, inversely weighted to the distance of this location to the weather station. 98-
percentile for 3 OU m⁻³ was calculated for each point of the network, by addition of the
cases that exceed 3 OU m⁻³ and the percentage calculation. Spatial distribution of odour
levels obtained with the atmospheric dispersion model was represented using an ordinary
krigging of GIS (ESRI® ArcMap™ 9.1).
For the landfill facility, the calculation procedure was similar, but odour modelling only
included odour dispersion for the most frequent wind direction. In this case, a spreadsheet
was applied to the emission source, which dimensions were those of the projected landfill.
Total odour concentration around the facility was calculated in a spreadsheet as addition of
the odour concentrations from each emission point. The topography of the environment
was not taken into account in this study.

b) Tropos Model

The second atmospheric dispersion approach used the Tropos model ® (Odotech, Canada).
It implements a bi-Gaussian formula, which does not include topographic data into the
modelling. The program considers hourly meteorological data of a year of wind speed,
wind direction, stability classes and temperature. Equation 6 is implemented by the
program.

\[ C(x, y, z) = \frac{Gn}{2\pi U \sigma_y \sigma_z} \exp \left( -\frac{y^2}{2\sigma_y^2} \right) \]

Where:

\[ n = \exp \left[ -\frac{1}{2} \left( \frac{z-H}{\sigma_z} \right)^2 \right] + \exp \left[ -\frac{1}{2} \left( \frac{z+H}{\sigma_z} \right)^2 \right] \]

Where:

\[ z: \text{ point receptor height (m)=0} \]
\[ H: h_s + \Delta h; \Delta h=0 \]

The modelling program calculates the atmospheric dispersion coefficient with formulas that
have been developed to approximate the dispersion coefficients to the Pasquill-Gifford
curves for the rural environment. The coefficients are calculated depending on the stability
class and the distance in wind direction “x”, as is it shown in the Equations 7 and 8.
Dispersion coefficients for \( \sigma_x \) and \( \sigma_z \) have been considered by Tropos model as expressed
in tables consulted in reference [Odotech, 2005]. The over elevation of the odour plume
above ground level (\( \Delta h \)) was not taken into account in this work in order to compare the
results obtained by this way with the simple Gaussian Dispersion Model. The topography
was neither considered in the study.

\[ \sigma_x = 465.116 \cdot x \cdot \tan(TH) \]  
(7)

Where:

\[ TH = 0.017453293 \left[ c - d \cdot \ln(x) \right] \]

\[ \sigma_z = a \cdot x^b \]  
(8)

2.3 Odour emission rates estimation

a) Waste treatment facility

The odour emission rate of the treatment plant was calculated according to the type of
wastes and the surface taking up for each one, using the bibliographic data of Table 2.
According to the specific conditions given by the provider, the effectiveness of odour
abatement from each biofilter is around 97%.
Table 2. Bibliographic values of odour emission rates for the projected treatment waste facility

<table>
<thead>
<tr>
<th>Type of Waste</th>
<th>Odour emission rate</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Municipal Solid wastes</td>
<td>59.0 OU s⁻¹ m⁻²</td>
<td>Sironi et al., 2005</td>
</tr>
<tr>
<td>Active composting areas</td>
<td>150 OU s⁻¹ m⁻²</td>
<td>Boholt and Oxbol, 2002</td>
</tr>
<tr>
<td>Maturation areas of compost</td>
<td>42 OU s⁻¹ m⁻²</td>
<td>Boholt and Oxbol, 2002</td>
</tr>
<tr>
<td>Final Compost</td>
<td>5.5 OU s⁻¹ m⁻²</td>
<td>Sironi et al., 2005</td>
</tr>
</tbody>
</table>

The total emission rate was calculated with the Equation 9, adapted from Guo et al., [2005].

\[
E = \sum_{i=1}^{n} E_i = \sum_{i=1}^{n} (E_{ei} \times A_i \times f_{ci}) 
\]  

(9)

Where:
- \(E\) = total odour emission factor (OU·s⁻¹)
- \(E_i\) = odour emission from source \(i\)
- \(E_{ei}\) = odour flux of source \(i\) (OU·s⁻¹·m⁻²)
- \(A_i\) = area of source \(i\) (m²)
- \(f_{ci}\) = odour control factor of source \(i\)

b) Landfill area: Field measurements

Odour rates from the projected landfill were obtained from field odour measurements. In this work, a portable field olfactometer, Nasal Ranger® was used to measure and quantify odour in ambient air around a landfill site with similar characteristics of the proposed one. The field olfactometer dynamically dilutes the ambient air with carbon-filtered air in different dilution ratios known as ‘dilution-to-threshold’ dilutions factors (D/T), Pain et al., [2005]. The dilution to threshold ratio is equivalent to odour concentration, Sheffield and Thomson, [2004]. The Nasal Ranger olfactometer is an organoleptic measurement device which presents six prefixed D/T levels: 2, 4, 7, 15, 30 and 60 D/T. The measurement protocol is explained as follows: trained assessors places their nose into the nasal mask of the portable device, and breaths at a certain airflow rate (16-20 L/min). Firstly, filtered air is inspired by assessor as a blank measure and next the 60 D/T position was employed. After inspired one minute, if the panelist was not able to recognize odour source, he/she changes to the next D/T level, (30 D/T) and the same procedure was employed until odour was finally detected by the panelist. When odour concentration was not determined by Field olfactometers, assessors indicated if they perceived the odour without mask. If they did, odour concentration was considered to be 1 OU/m³. In the present work, two portable devices were used and measurements were simultaneously done by two expert panellists. At each field point, measurements were done at least by duplicate. Measurements were taken from the furthest downwind points to the facility to the nearest ones, in order to avoid the assessors getting used to the odour. At the same time, meteorological conditions (temperature, relative humidity, wind direction and wind velocity) were registered with a HOBO® Weather Station.

Later, the odour emissions from odour sources were estimated using the methodology proposed by Nicolas et al., [2006]. Using the Tropos bi-Gaussian model and instantaneous meteorological data registered in the field, we estimated odour emission rate from the landfill site. The methodology consists on adjusting the emission rate by trial and error to approximate as much as possible the odour modelled concentrations to odour field measurements. The methodology proposed by Nicolas et al., [2006] was not employed with the simple dispersion model, because of the difficulty of applying the estimation procedure in the inverse sense.
3. RESULTS

3.1 Weather conditions

Preferential wind direction and wind speed patterns are shown in the Figure 2. The two wind roses are quite similar due to the proximity of the weather stations. In the first case, predominant winds during the day proceeds from the Northeast (17.5%) and Southwest (11.9%) directions and wind speeds are around $1.02 \pm 0.70$ ms$^{-1}$. In the second case, prevailing winds were similar to the weather station 1, with equal percentages in both origins (14%) and wind speed of $1.17 \pm 0.66$ ms$^{-1}$. In both cases, nocturnal wind comes preferably from the Southwest direction (34-43%) with a very high percentage of calms (53-56%). Meteorological conditions will determine to a large extend the locations and times where odour could be noticeable and becomes a nuisance. Due to the proximity of the villages and the considering the usual wind directions, odour annoyance are more likely to occur at night periods, when stable conditions are more frequent and residents remain in their houses.

![Wind Rose from Weather Station 1 (Top) and 2 (Bottom)](image)

Figure 2. Wind rose from the weather station 1 (top) and 2 (bottom)

3.2 Field Measurements in the existing landfill area with Nasal Ranger™ olfactometer

Odour fluxes were adjusted in the Tropos Model® by trial and error in order to obtain an odour plume that fits well with the measurements done in the field at 1.5m height (Figure 3). Resulting odour fluxes were 1.375 OU s$^{-1}$ m$^{-2}$ for the landfill facility and 10.50 OU s$^{-1}$ m$^{-2}$ for the collected leachates.

The results are coherent with the data found in the literature. Bowly [2003] measured odour emission fluxes from waste using dynamic olfactometry and an isolation flux chamber, obtaining values from 0.3 to 0.5 OU s$^{-1}$m$^{-2}$. Odotech [2001] measured odour emission from a landfill site in Canada and found odour fluxes of 2.6 OU s$^{-1}$m$^{-2}$. Odotech for old waste, 5.4 OU s$^{-1}$m$^{-2}$ for mixed waste and 3.5 OU s$^{-1}$m$^{-2}$ for the truck waiting area. Sironi et al. [2005]
found odour emission fluxes of 4 and 8 OU s⁻¹ m⁻² for exhausted and active landfill sites respectively, using the wind tunnel system. Romain et al. [2007] collected odours by a dynamic flux chamber from a waste disposal landfill area, obtaining values of 0.5 OU s⁻¹ m⁻². Nevertheless, only one odour measurement was done in the winter period so more field measurements would be recommendable to obtain a more precise odour emission rate.

Figure 3. Odour Concentration measurements with Nasal Ranger™ Field Olfactometer® and odour modelled concentrations predicted by Tropos Model®.

3.3 Odour modelling of Planned Waste Treatment Facility

The results obtained by the two Atmospheric Dispersion Models at ground level height are shown in the Figures 4 and 5 respectively.

Figure 4. 98-Percentile from the planned waste treatment facility obtained by the Simple Gaussian Dispersion Model for the three proposed scenarios: high emission at ground level, at 5 and 10 m above ground level.
Results from the two approaches are quite similar in contour form and reach of odour. 98-percentil contour of 3 OU m$^{-3}$ were predicted in the three alternatives with the simple Gaussian Model, whereas in Tropos Model the contour of 10 m emission height was not designed because odour concentrations were lower than 3 OU m$^{-3}$. The reach of odour in two cases was limited at the first 300 m from the odour source so no village or city was expected to be affected by the waste treatment facility. The best solution in terms of odour dispersion is provided by the emission of odours by the stack of 10 m.

### 3.4 Odour modelling of Exhausted Landfill

Figures 6, 7 and 8 represent the predicted odour concentrations for the prevailing wind from the landfill facility with the simple Gaussian model and the Tropos Model®. Significant differences were obtained from the two models, especially in the maximum distance of odour perception. The reach of odour was predicted in 1.5 km from the odour source with the simple model approach (Figure 6), whereas with the Tropos model® the odour reached 3.3 km (Figure 7). The differences can be explained by several reasons. Firstly, odour estimation rates were obtained with the inverse Tropos model. However, if the simple Gaussian Dispersion Model could be employed in the inverse sense, other emission rates would have been obtained, and the reach of odour achieved with the two approaches would probably have been more similar. Odour emission rates may have a significant error given the fluctuation of the odour source and the relatively high uncertainty of the odour measurement method.

Moreover, wind data employed in the modelling is close to 1 m s$^{-1}$, and both models are inversely dependent on this parameter. In addition, Tropos model only considers meteorological data higher than 1 m s$^{-1}$, so wind speed values lower than that limit were assumed to be 1 m s$^{-1}$. This assumption would be a strong source of error when faint wind speeds are considered, as occurs in the present work. Thus, odour dispersion might be overestimated because the worst conditions (low wind speed) were considered in the modelling. In addition, the methodology employed in the determination of the atmospheric dispersion coefficients was different. It seems that atmospheric dispersion coefficients employed by the Tropos model have been developed for the modelling for a stack emission and long distance pollutant dispersion, which would explain the high distance reached by odour. Furthermore, the emission at ground level could also be a source of error.

Comparing the results arisen in this study with other odour dispersion studies on landfill areas, we have concluded that the maximum modelled distance is too long. Nicolas et al [2008] measured maximum odour perception distance from 525 to 700 m for a landfill site with an emission of 67,000 OU s$^{-1}$. In the study conducted by Feliubaladó et al., [2009], the Gaussian Dispersion model employed overestimated the area affected by odours, compared with field measurements and with odour concentrations obtained by CALPUFF model.
Finally the Gaussian model seem to be unsuitable for odour modelling, because the human response to the odour perception is very fast, in the order of 1s, and odour modelling provide average hourly concentrations. The meandering model of Gifford considers an instantaneous plume that meanders between the limit of Gaussian plume, doing suitable corrections for odour dispersion modelling when it is applied with the Gaussian model, Nicolas et al., [2006]. Therefore, the Gaussian model may not be applicable to determine the reach of the odour plume. Odour field measurements would be done when facilities become operational in order to measure the real impact of these installations over the neighbourhood, as well as to verify the performance of the two studied models.

Concerning the applicability of the model, Tropos was easy to be implemented compared to the simple Gaussian approach developed by the authors. The introduction of a series of meteorological data in the second model is a hardworking procedure and demand much more time related to the commercial approach. In addition, Tropos presents a large number of possibilities, as different dispersion models, different modeling options, etc. The most important drawback of the commercial model is the impossibility to introduce topography data, which could be an essential point in some areas of the Mediterranean area.

4. CONCLUSIONS

Two Gaussian dispersion approaches were applied in order to quantify the odour potential impact in the environment of a projected landfill area and waste treatment facility in the Mediterranean area. Results from two methods for the waste treatment facility were similar in magnitude and shape contour, when 98-percentil 3 OU/m² was analysed. The scenario that provides better results in terms of odour dispersion is done by the emission height of 10 m above ground level. Related to the landfill facility, the two models seem to overestimate the odour reach, particularly the Tropos model. Gaussian models may be inappropriate for odour modelling from ground sources. Gaussian Dispersion Models seem to be unsuitable to determine odour dispersion in Mediterranean conditions, which are characterized by a high proportion of wind calms. In low wind speed situations, the Gaussian model overestimates the reach of odour in comparison with measured values. Field odour measurements are required in order to validate odour modelled concentrations and to know the real impact of the annoyance. The commercial model resulted easy to be implemented, with a high number of possibilities compared to the simple Gaussian model developed by the authors. Gaussian models may not be the most appropriate tool to estimate odour dispersion because the nature of the odour, which is commonly associated with particulate matter transport.

ACKNOWLEDGMENTS
The authors are grateful for their generous collaboration and helpful by the Environmental Monitoring group of University of Liège.

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