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Odour annoyance assessment around landfill sites: methods and results

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Assessing odour annoyance generated by landfill areas involves a number of difficulties due to the variable, diffuse and multiple characters of odour sources. Analyses of ambient air by GC-MS, spot FID measurements or the determination of the odour concentration by dynamic olfactometry on the basis of samples collected through flux chambers, while providing valuable results, do not allow to encompass the different odour emissions as a whole and unique source.
An alternative and interesting approach is applied to 9 landfill sites in Belgium. It is an adaptation of the method of sniffing team campaigns to the particular case of landfill site odours. The paper presents the main results of those campaigns, highlighting many advantages, but also different problems. One of the main advantages of the method is that the feeling of the observers is close to the resident one. However, as field inspection often occurs during the activity period it does not account for evening or night situations, when sometimes the atmosphere is quieter or when landfill gas could be preferentially emitted. Another problem arises from the fact that a model is used, with its hypothesis and its uncertainties due to the large sensitivity of some estimated parameters. If absolute value of the odour emission rate is necessary, then further validation of the method is needed, e.g. by using surveys and neighbour panellists. Anyhow, the method is particularly adapted to obtain relative results, for comparing different sites or for monitoring long term evolution of odour emissions.

1. Introduction

Unpleasant smells can cause serious annoyance in the neighbourhood of landfill areas. Various odours are released by the fresh deposits of municipal solid waste, by the landfill gas (LFG), by the leachate treatment plants, by flares and by some waste treatment works, like composting facilities. Besides stationary emissions, like the odour of waste at rest or the one of LFG collection piping or wells, specific activities liberate short-lived odours, such as active tipping of waste, waste transportation by disposal trucks, intermediate storage or handling process after the garbage deposit.

Consequently, the measurement of malodour generated by a landfill area is difficult.
Problems already emerge at the sampling level. When studying landfill site as a passive area source, it is rarely possible to sample more than 1% of the total area. Further

extrapolation to the whole site assumes that the distribution of the specific emission rate is homogeneous, which is not realistic.

Many authors mention also that the main odour problem of a landfill is caused by the handling of the fresh waste (Karnik and Parry, 2001; Stretch et al., 2001). Such an intermittent activity makes difficult the sampling of the gas emitted at the landfill working face.

Some additional problems arise at the measurement level. Analytical techniques, such as gas chromatography and mass spectrometry (GC-MS), while providing accurate concentration of each compound of the odorous mixture, are not able to provide directly the global olfactory perception. When using the GC-sniffing method (with an odour port at the end of the GC column), no individual compound indeed provides the typical and unpleasant smell of the fresh waste (Bradley et al., 2001).

Promising results are expected from emerging techniques, such as the electronic nose (Bourgeois et al, 2003), but routine field monitoring of landfill odour remains challenging.

One of the most representative and the most usual way to assess the global odour level still remains the sensory measurement using a panel of judges. Dynamic olfactometry EN13725 standard involves a panel of 4 to 6 assessors sniffing different dilutions of the odour sampled in the field. For area source, like landfill surface, the emitted odour is collected in Tedlar® bags through a dynamic flux chamber. The final outcome of this method is the specific odour emission rate in $ou_E/s.m^2$ (with subscript E if EN13725 is respected). But typical aperture size of such chamber is only 0.2 m^2, i.e. close to the size of the waste elements on the landfill area. So, the odour emission is highly dependant of the specific garbage material on which the chamber is placed. Moreover, air tightness is impossible to ensure with such uneven areas. So, olfactometry results characterize only a small part of the total odour emission.

The present paper illustrates and discusses the use of an alternative method, based on field inspection teams, in 9 landfill sites in Belgium. The method proves to be more adapted to cope with highly variable sources, such as waste handling and transportation.

Once the odour emission rate of the source (in ou/s) is deduced from one of the above described measuring methods, the global exposition in the surroundings is deduced from percentiles calculated for average climatic conditions by an atmospheric dispersion model. When such global annoyance zone is the expected final outcome of the study, there is no need for very accurate measurement and modelling, especially when aiming at relative comparisons of different sites or operation conditions.

2. Case studies

Different odour investigation methods are applied to 9 solid waste disposal landfill areas in Wallonia (South of Belgium), which is a region characterised by quite homogeneous climatic conditions, with prevailing wind directions NE and SW. Generally, landfill sites are equipped with efficient landfill gas collection networks. So, although LFG odour is sometimes perceived on some sites, the measurement concerns chiefly the fresh garbage odour, which is, by far, the strongest odour during activity periods. It generally corresponds to the complaints of the neighbourhood. Two of the investigated landfill sites (Tenneville and Habay) include also organic waste composting facilities, with a specific odour which is mixed with the fresh waste one.

The study is made in the frame of a follow-up monitoring of all landfill sites in Wallonia, initiated by the Ministry of Environment and managed by ISSeP. Landfill sites are different in size (capacity from 0.8 to 5.3 millions of m^3), in topography (from almost flat environment to slight hills) and in neighbourhood (always in rural areas, but from almost none to about 500 dwellings in a circular zone of 1 km of radius around the active tipping area). Typically 100 000 m^3 of waste are deposited per year on the landfill areas. Table 1 shows the different investigated sites with period and number of measurements. Field observations were carried out during activity periods, i.e. generally between 10 am and 14 pm.

Table 1: Investigated landfill sites.

Site	Dates of investigation	Total number of field measurements
Mont-Saint-Guibert	Oct 03-Dec 03	8
	March 05-May 05	11
Hallembaye	Feb 03-Apr 03	7
	May 06-Oct06	10
Monceau-sur-Sambre	June 03-July 03	10
	March 04-June 04	12
Cour-au-Bois	Sep 03-Oct 03	11
	July 04-Oct 04	10
	May 07-Oct 07	6
Froidchapelle	March 03-June 03	11
Happe-Chapois	Aug 04-Oct 04	10
	Sep 05-Apr 06	10
Tenneville	Oct 04-Dec 04	11
Habay	July 05–Nov 05	12
Malvoisin	July 06-Jan 07	7

Most landfill sites predominantly receive municipal solid waste, which is immediately spread and compacted with suitable engines. There are no other odour sources in the immediate surroundings of the studied sites, except in the case of Hallembaye where a hen house is located at about 500 m from the landfill area. Its odour emissions cannot however be confused with those of the fresh waste of landfilling activities. A total of 146 field measurements were made covering various seasons and wind conditions.

3. Methods

The sniffing team measurement technique is inspired by a method originally developed by University of Gent (Van Langenhove and Van Broeck, 2001) and by German or

Dutch guidelines (VDI, 1993, Anzion et al., 1994). It is largely described and discussed in a previous paper (Nicolas et al., 2006). A small group of observers (1 to 3), previously checked against n-butanol odour standard are firstly familiarised with the odour of waste. Then, they detect the odour in the field, by a zigzag movement, downwind around the plume axis. The transitional stages from no odour perception to odour perception are recorded by GPS, so that the odour area can be plotted and the maximum odour perception distance can be determined. Assuming that observers identify exactly the perception threshold, by definition, the odour concentration at this maximum is 1 ou/m^3. As the size of the odour perception area also depends on the meteorological situation at the time of the measurement, the wind direction, the wind speed and the solar radiation (or cloudiness) are simultaneously recorded. The two last parameters allow determining the atmospheric stability using the Pasquill stability class system (Pasquill, 1974).
Then, an atmospheric dispersion model is used with the average values of these meteorological data. The emission rate is adjusted until the simulated average isopleth relative to 1 ou/m^3 (at about 1.5 m height, the height of the human nose) fits the measured maximum perception distance. For simple cases, bi-Gaussian model is sufficient. Tropos Impact from Odotech, Canada, is used for this study: it implements a special meandering algorithm to cope with odour dispersion. For more complex relief, 3D models are also applied.

Some spot samples were also collected in Tedlar bags through dynamic flux chamber for olfactometric analysis. We used a circular chamber with a cross section of 0.2 m^2, very similar to the EPA/600/8-86/008 one, and a sampling flow rate of 10 l/min, equal to the controlled flow of the carrier gas (nitrogen) released into the chamber . The subsequent analysis is made in the lab with Odile olfactometer (Odotech, Canada).

For two cases (Malvoisin and Cour-au-Bois in 2007), those odour emission assessment methods were compared to results of surveys in the surrounding resident population and repeated brief questioning of neighbour panellists. Both methods aim at determining annoyance parameters and are inspired by German VDI guidelines (VDI 3883, parts I and II). Surveys involved 23 and 96 persons for Malvoisin and Cour-au-Bois, respectively. Brief questioning results presented below originate mostly from observations of a couple of residents of Cour-au-Bois.

4. Results and discussion

Figure 1 shows a typical result after adjustment of 1 ou/m^3 isopleth by Tropos model. The measurement took about 40 minutes during which 5 trucks tipped waste on the working area, which is represented at the bottom-left by a shaded polygon. The maximum distance of odour perception in the wind direction is about 450 m from the centre of the tipping area. By trial and error, using the TROPOS model, we adjusted an odour emission rate of 44 352 ou/s to surround nearly all the "odour" points and avoid the "no-odour" points. The five digits of the emission rate just result from an accurate evaluation of the computer model, but the adjustment is carried out with an approximate margin of 100 uo/s.

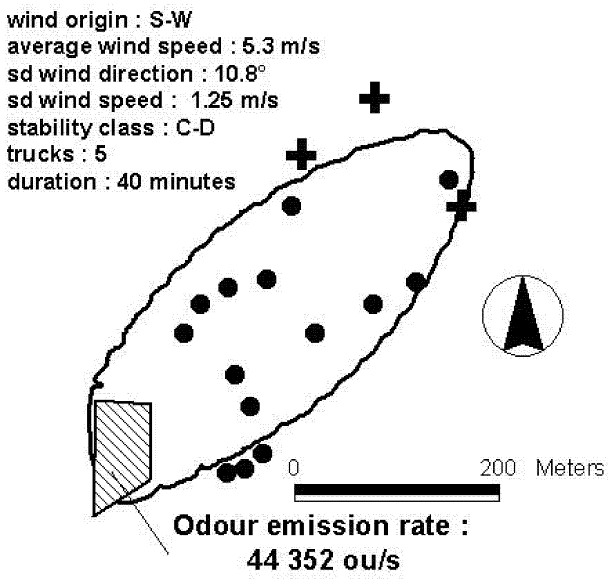


Figure 1: 1 ou/m3 isopleth as estimated by the TROPOS model for Froidchapelle landfill and including at best the odour points identified in the field (black circle) and not the points where the odour is not perceived (cross).

The confidence interval of maximum odour perception distance for all 146 field measurements is [525 m, 700 m] around the mean 612 m. For the estimated odour emission rate, the confidence interval is [57 000 ou/s, 79 000 ou/s] around the geometrical mean 67 000 ou/s.
However, it is observed that installations with composting facilities generate much more odour than standard landfill areas, especially when turning windrows. Removing those cases from table 1 leads to a geometrical mean value of 61 000 ou/s with a confidence interval of [52 000 ou/s, 70 000 ou/s] and an average distance of 540 m.
Low correlation is found between estimated odour emission rate and the number of trucks arriving on the site during the measurement period, showing that odour is mainly generated by bulldozers and scrappers handling the deposited waste.

With the adjusted emission rates, the dispersion model calculates percentile 98 corresponding to the limit of perception of 1 ou/m3 for the typical climate of the region, on an hourly basis. For typical 60 000 ou/s emission rate, the resulting area for percentile 98 (C98, 1-hour = 1 ou/m^3) is a kind of ellipse with a major axis of 2000-2500 m oriented along the prevailing wind direction and with a minor axis of about 1300-1600 m. Figure 2 shows such typical percentile which can be drawn on a digitalised site map in the background. The figure is just an example and illustrates the "Monceau-sur-Sambre" landfill area. If the buildings are highlighted on such graphical view, it is possible to count the number of residents who are potentially annoyed by the odour. In our studies, we considered this area as the odour nuisance zone.

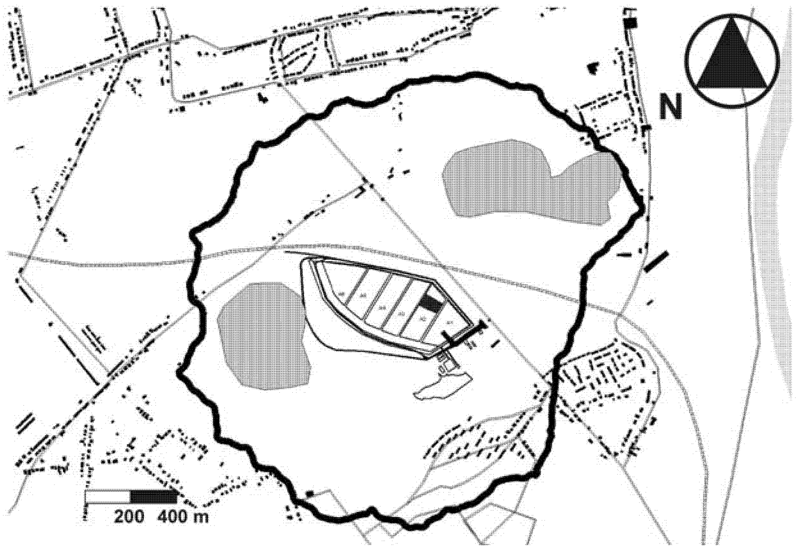
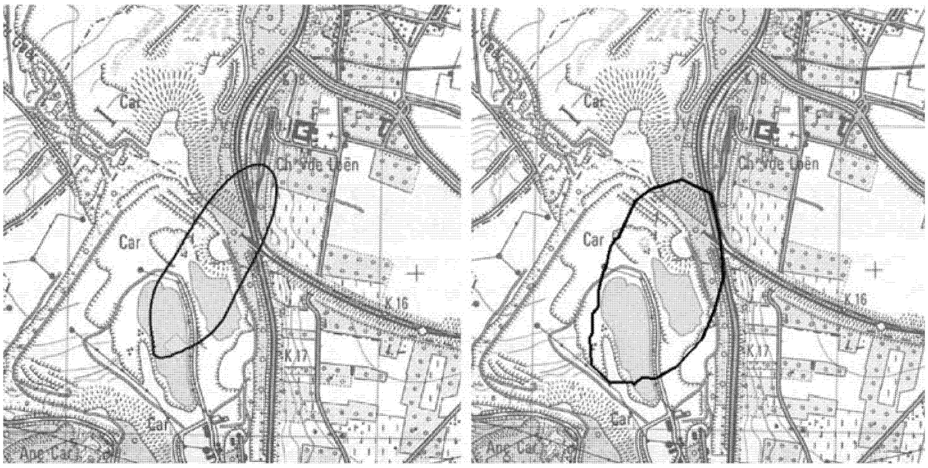


Figure 2: Typical percentile 98 for 1 ou/m3 resulting from TROPOS simulation with average climatic conditions and illustrating the "Monceau-sur-Sambre" landfill site.

Excepted for some specific cases, it seems that 2D-modelling approach is often sufficient to globally assess the odour plume or odour annoyance zone. Figure 3 illustrates odour plume calculation with 2D-Gaussian model (fig. 3a-TROPOS Impact) and with 3D-Eulerian model (fig. 3b-FLUIDYN Paneia from TRANSOFT International).



a *b*

Figure 3: Comparison of odour plume at 1 ou/m^3 for 100 000 ou/s emission rate, wind from 210°, speed 4.7 m/s, Hallembaye site

a. Gaussian 2D model – b. Eulerian 3D model.

Conditions are similar for both simulations: point emission source of 100 000 ou/s, wind from 210° at a speed of 4.7 m/s, neutral atmospheric stability, uneven topographic area of Hallembaye. Gaussian simulation does not take relief into account while a complete terrain modelling was entered into the Eulerian model, on the basis of contour levels. Hallembay site is surrounded by quite broken relief with level gradients up to 8% on the East side of the landfill area.
As seen on figure 3, the two odour plume sizes (at 1 ou/m^3) are very similar, only the global shapes are slightly different. Same conclusions may be drawn when comparing percentile curves. Further tests with 2D and 3D approaches show that the relief influence is chiefly marked in the immediate surroundings of obstacles, but it does not modify considerably the size and the shape of the calculated plumes or percentiles.

One of the main advantages of the sniffing team method is that the feeling of the observer is about the same as the resident one. So the calculated odour impact zone is not deduced from measurements at the emission level, but corresponds to the real sensitive perception in the environment.
Obviously, final outcomes depend on model type and parameters. However differences between models lessen when the same model is used both to adjust the emission rate and to calculate the percentile for the typical climate of the region.

Moreover, odour studies often aim at comparing different sites or at monitoring long term evolution of odour emissions. So, as long as the same protocol is applied for each study, the method is suitable to provide relative results.

However, if absolute value of the odour emission rate is necessary, then further validation of the method is needed.
There are huge differences when comparing odour emission rates deduced from sniffing team method and from dynamic flux chamber sampling and olfactometry. Three spot samplings were carried out in Happe-Chapois and Malvoisin. Measured specific odour emission rates were 0.5, 0.4 and 0.2 ou_E/s.m^2, resulting in 2000 to 13 000 ou_E/s for the global odour emission rate when extrapolated to whole landfill areas. Emission rates provided by sniffing team method in the three cases are 10 times more. But, as above mentioned, odour generated by waste at rest is not representative of real global odour emissions and dynamic flux chamber sampling is not adapted for uneven surface. So, such method cannot be considered as a reference for the specific case of landfill odour.

A rough assessment of the robustness of sniffing team method could be verifying the correspondence between the percentile deduced from the measured odour emission rate and continuous observations of resident panellists. The couple of observers at Cour-au-Bois, living at about 500 m from the tipping area, smelled the odour of fresh garbage 18% of time during one year in 2004-2005. From our estimation, the percentile running through their house is C85, 1 h = 1 ou/m^3, corresponding to a waste odour perceived during 15% of time. The agreement between both percentages could be a first indication of method reliability.

Further analyses of survey and questionnaire outcomes confirm the fact that fresh waste is indeed the chief contribution to the global landfill odour. However, annoyance occurs particularly late in the evening, during the night or soon in the morning. Hence, as field inspection is always carried out within activity periods, it does not account for evening or night situations, when sometimes the atmosphere is quieter or when landfill gas could be preferentially emitted. That finding suggests broadening the field inspection period to the whole day.

5. Conclusion

Sniffing team inspection coupled to dispersion modelling is an attractive technique to assess global odour emission for diffuse and highly variable sources like landfill areas. However, its reliability must still be proved against reference methods. Repeated brief questioning of neighbour panellists, although providing a first way of testing the robustness of the method, is not sufficient to completely validate it. There is firstly a real need of reliable field data for more simple sources (stacks or homogeneous surface emissions) to compare standard olfactometry and field inspection approaches.

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