Chemical Mass Balance model applied to an olfactory annoyance problematic

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* 1. Introduction and context

In many industrialized or emerging countries with high population density, odour problems are numerous and constantly increasing due to the proximity between residential areas and large industrial areas. To reduce the olfactory discomfort, it is necessary to identify the sources responsible for the problem. This question is all the more difficult to solve than most industrial areas have numerous industries, each containing many potentially odorous sources [1, 2]. The main techniques to identify and quantify odour [3- 4, 5] are the sensory method, the analytic method, the "senso-instrumental" method.

Sensory tools used for monitoring odours are mainly based on human resources (volunteers’ nose jury, collections of complaints from residents). They are time consuming, and in some cases, they require people specifically trained. Beyond the problems linked to the variability of odour perception from one individual to another, these tools rarely discriminate the main source of the annoyance when the smell is the result of a mixture of several complex matrices.

This is the reason why these odours’ monitoring tools are completed with scientific investigation tools able to identify the type of smell and associate it with a quantitative "index", independently from its hedonic nature. Although the dynamic olfactometry according to the EN 13725 is the most widely used technique for odour measurement, chemical analysis as well as senso-intrumental systems allowed to facilitate a real time monitoring of odours. Senso-instrumental systems (also called electronic noses) have the advantage to provide answers in real time. Their main role is to follow the time evolution of an odour emission clearly identified to trigger alerts and corrective actions in case of increasing levels of odour concentrations [6 *-*7 -8]. Chemical analyses focus on families of chemical compounds typically associated with odour (compounds containing sulphur, nitrogen, or oxygen functional groups), allowing a comprehensive identification, even at trace levels concentrations. Several uses of chemical analysis are possible: characterisations of emissions sources only, or environmental monitoring of source tracers [9]. These last methods are generally deployed at the source of the olfactory annoyance [10]. The issue is to supply datas to dispersion models in order to predict the impact of each emission sources on a receptor site, where the odour disturb people [11, 12]. Among these models, the most widely used at small-scale (in the case of odours, the scope of the nuisance is often a few hundred meters) are Gaussian puff models [6], because of their ease of use, the input data immediately available, the accuracy of the results, and their low cost. In the case of chemical analyses, meteorological data are introduced into the atmospheric dispersion model, and then, the simulation consists in adjusting the rate of emission of each compounds that induces, with the same weather conditions, an iso-chemical-concentration line in the field. [13, 14]

Therefore, these models have a major drawback: the emission rate has to be very well characterized, which is difficult in the case of non-point sources, i-e sources spread over a wide area. In such cases, the correspondence between the real and perceived olfactory prediction is often bad, with a high uncertainty. [15]

Few studies directly focus on geographic area where the annoyance is perceived: in this case, the issue is to estimate the contributions of each source responsible for the overall olfactory discomfort at the receptor site. Receptor models have been elaborated to solve this problem. These models also use linear combinations to determine the contribution of different sources on the impacted site, but are mainly based on measurements done at a receptor site. Scientific literature reports three main sources-receptor models: the CMB (Chemical Mass Balance), the PMF (Positive Matrix Factorization) and the UNMIX, and all of them share two main common principles:

* making the assumption that the sources signatures are still constant from the sources location to the receptor site
* optimising the linear combinations of different sources in order to minimize the difference between calculated values and experimental values.

PMF and UNMIX are used when the compositions of the sources are totally unknown but calculations take hundreds of measurements done on the receptor site [16].This point is a major drawback especially for chemical analyses that require bulky equipment, complex handling, and manual sampling [17]. By comparison, CMB is easier to implement, provided to that sources are clearly defined and quantified. Moreover, it can be calculated with only a few dozen measurements on the receptor site. In the case of odours, the sources and the receptor sites are generally distant from a few hundred meters, up to several kilometres, so the reactivity and the washing of the VOCs are negligible [18]. Furthermore, the sources are well known and their signatures are easy to establish. These are the reasons why we chose to use the Chemical Mass Balance (CMB) model for this study.

The CMB model is used and described in many scientific publications, especially for the VOC pollution of big cities, for example, in Mumbai and Delhi [19]. It is also used to study automotive exhaust gases and use of industrial solvents for example in Seoul [20], Columbus [21], and in 20 other urban areas of the United States [22]. Two other studies using two receptor models in parallel (respectively CMB and PMF and CMB and Unmix) showed minor variations between the results [23,24]. Finally, a study comparing CMB, PMF and Unmix, found a good homogeneity of the main contributors to the total content of VOCs in Beijing [25].

Thus, sources-receptor models are very common in the allocation of VOCs sources and lead to reliable results, but the CMB model was never implemented in specific measurements of odour nuisance, which justifies the innovative nature of this work.

To apply this model on a case study, a municipal Solid Waste (MSW) treatment centre have been selected in order to conduct field measurement campaigns on a site representative of a smell annoyance. This site includes three different sources of odours, which potentially cause an annoyance to three villages under prevailing winds. The first objective was to establish the chemical profiles for each odours source of the emission site to be able to determine the contribution of the different odours in a air sample collected at the immission (also called “receptor site”). These composite samples, i.e. constituted by several mixed odours, were taken where an annoyance is perceived. To validate the CMB model predictions applied to the chemical analyses, characterisations of the odours were done both by dynamic olfactometry (European standard NF EN 13725) in a certified laboratory, and both by field olfactometry associated to an odour intensity, on a scale from 0 to 6, as defined by the German norm VDI 3940 directly in the field.

* 1. Material and Methods
     1. Chemical Mass Balance model

The CMB (Chemical Mass Balance) receptor model is based on the principle of mass conservation between the sources and the receptor site considered. It estimates the concentration Ci of a species i at a receptor site (in µg/m3). As it requires relatively few observations at the receptor site to be reliable, the CMB model is advantageous compared to other sources-receptors models, but the source profiles and the uncertainties must be established with high accuracy. The modelling is based on the equation 1:

*for*  (1)

*where Ci is the concentration of species i measured at the receptor site in µg/m3*

*aij is the mass fraction of species i in the profile of the source j (%)*

*n is the number of species*

*Sj is the mass concentration at the receptor site of all species assigned to the source j (µg/m3)*

* is the difference between real and estimated concentrations Ci*

The model aims to quantify the parameter Sj, which corresponds to the mass concentration of all species due to source j, by reducing the parameter  which corresponds to the difference between the measured value of the real concentration Ci and the value estimated by the model. Thus, Sj is the contribution of a source at the receptor site. This is the reason why it is absolutely necessary to characterise emission sources profiles with accurate chemical analyses. Furthermore, the number of selected compounds chosen to describe the sources profile must be greater than the number of sources. This defines the degree of freedom (DF) of the system:

DF = [number of compounds - number of sources] (2)

The modeling is usually done in seven steps described in the Protocol for Applying and Validating the CMB Model for PM2.5 and VOC by John G. Watson et al. [26]:

1 – Exhaustive identification of p uncollinear sources that influence the receptor site

2 - Knowledge of the VOC-compositions of each source by chemical measurements at the source areas

3 - Selection of n "targets" molecules or tracers which are useful to differentiate one source from another

4 – Determination of the mass ratio aij of each specie i for the n targets molecules with respect to the total mass of VOC of the source profile

5 – Measurements of concentration Ci of each of this n species perceived at the multi-influenced site

6 - Estimation of the uncertainty associated with both source profiles and concentrations of each of the “n” target molecule measured at the receptor site

7 - Evaluation of the performance criteria, which indicates the robustness of the model.

The robustness of the model is evaluated using different performance criteria, but the main ones are:

1 - %m or percent mass: percentage of the mass explained by the model.

It is defined as the sum of contributions of each species from the sources calculated by the model divided by the total concentration of VOCs measured at the receptor site. A value approaching 100% is expected with a reasonable range of 80% to 120%.

%m = SCE / ΣiCi  (3)

*with*

*Ci, measured concentration of species i at receptor site (µg/m3)*

*SCE,the Source Contribution Estimate (µg/m3)*

2 - Tstat: ratio of the total concentration of VOC calculated for a source divided by its uncertainty.

A Tstat greater than 2 indicates a significant contribution of sources.

Tstat = SCE / Std Err (4)

*with SCE, the Source Contribution Estimate (µg/m3)*

*Std Err, the standard deviation associated with the contribution of a source to the total concentration of VOC receptor site(µg/m3)*

3 – R² coefficient: measure of the variance of the ambient concentration explained by the calculated concentration. It is defined as the sum of the square of the differences between measured and calculated concentrations, divided by the sum of the measured concentrations. a low value of R² indicates that the profiles of selected sources did not explain the concentrations at the receptor site for the selected species. The value of R² can vary from 0 to 1 but a good model is characterized by a R² greater than 0.8.

(5)

*with*

*Ci = measured concentration of species i (µg/m3)*

*Fij = fraction of species i in the source j (in %)*

*and Sj = mass concentration at the receptor site from source j (µg/m3).*

4 – ² or chi square: goodness of fit model, defined as the sum of the squares of the differences between measured and calculated concentrations divided by the sum of the variances. A high ², beyond 4, means that the uncertainty associated to the sources profiles is not sufficient to explain the difference between measured and calculated concentrations.

(6)

*with: Ci = measured concentration of species i (µg/m3)*

*² = uncertainty on concentration Ci*

*Fij = fraction of species i in the source j (in %)*

*and Sj = mass concentration at the receptor site from source j (µg/m3)*

*DF = degree of Freedom*

* + 1. Field campaigns

The studied site is a Municipal Solid Waste (MSW) treatment centre located in Habay, southern Belgium. This is a rural area with only one town (Arlon) of 20,000 inhabitants in a radius of 30 km. Thus, the background pollution shows a relatively low level. Moreover, the MSW of Habay presents a flat topography without any buildings, hills or trees which could have induced disturbances in the dispersion of pollutants. It contains three potential sources of odour annoyance easy to identify: the hall for the storage and drying of the household wastes, which is referred “waste”, the green composting waste area, referred “compost”, and finally an old waste storage area developed for biogas production, referred “biogas”.

Figure 1 shows the configuration of the site, the location of the three sources plus a location noted "ambient air area" as a reference of non-odorous air. The figure 1 also illustrates the places chosen for the 15 measurements done at the immission, where the odour annoyance was perceived. These locations changed according to the wind orientation. As can be seen on figure 1, the measurement points are located a few hundred meters from the sources. First, it ensures odour levels high enough to be felt (intensity >1 according to the German vdi 3940 scale). Secondly, it ensures that the VOC compositions of odour sources keep constant from the place where they are issued to the area measurements. During the field campaigns, the winds were always upper than 1m/s, so the time between emission and reception of VOCs was around 15 minutes. Considering the most reactive VOC, its life time in presence of O3, or OH and NO3 radicals, is upper than 1h. Thus, the hypothesis that there are no changes in VOCs between emission site and immission site is credible. As explained on §2.1, these assumptions are necessary to use the CMB model in optimal conditions. Finally, the measurement locations are also relevant since they were specifically chosen for their multi-influenced behaviour.

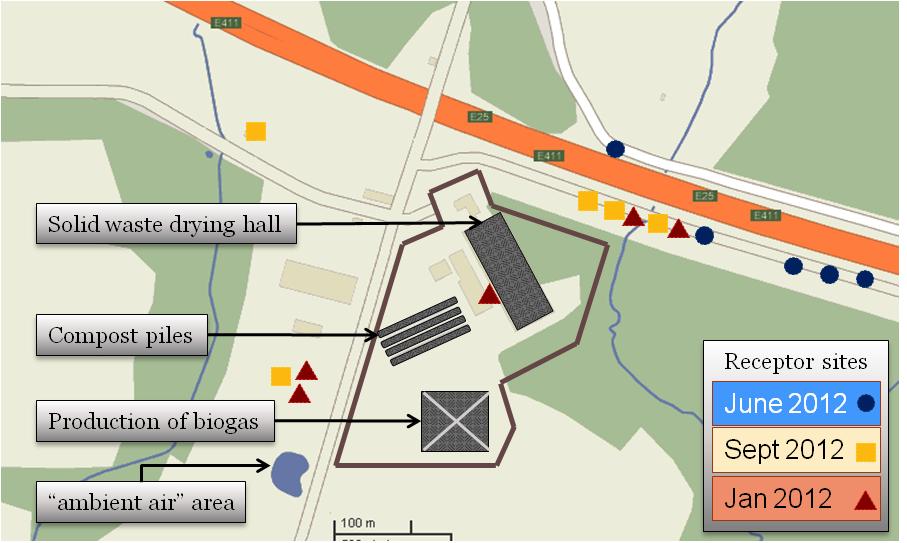


Figure 1: top view of the waste treatment site with the 3 emission sources plus the reference “ambient air” and 15 receptor sites.

The chemical profiles of the sources were established by collecting data during 18 months from January 2010 to May 2011. The data set for the sources is composed of 8 non-odorous samples “ambient air” and 25 odorous air samples: 8 samples for the source “compost”, 14 for the source “waste”, and 3 for the source “biogas”.

The profiles of odour annoyance **at the receptor sites** were established during 3 field campaigns from June 2011 to January 2012. 5 samples during summer 2011, 5 samples during autumn 2011 and 5 samples during winter 2011, in order to take into account the seasonality effect on the VOCs composition of odours. The locations of sampling sites shown on Figure 1 were carefully chosen based on wind directions and smell intensity: the optimal location is where the largest number of odour sources is perceived simultaneously and/or where the intensity of this smell is strong and stable. The intensity of the odour must be stable because the sampling for the chemical analysis is integrated over several minutes. This technique cannot take into account instant smell.

* + 1. Sampling techniques and analysis methods

The goal is to get a chemical composition of the sources as complete as possible. To reach this goal, several sampling couple with analytical techniques were used. For an exhaustive screening of compounds, cartridge-type adsorbents Tenax TA ®, were used as sampling technique, because of their good versatility. As Tenax retains poorly the lightest compounds, canisters were considered to analyse quantitatively the lightest hydrocarbons. To identify and quantify more specifically the carbonyl compounds, which are highly reactive compounds, we chose to use DNPH cartridges for their sampling and derivatization. All of the samples were then returned to the laboratory for analysis. The chemical analysis techniques depend on the type of sampling used in the field and on the trapped compounds: Tenax cartridges were analyzed using a GC-FID/MS system (Agilent 6890/5975 with a 100% PDMS column and a thermodesorber system Gerstel). Canisters were analyzed using a GC-FID system (Chrompack CP9001 with a Micro Purge & Trap Entech 7100 and dual columns CP-SIL-5CB and PLOT AL2O3/KCl). DNPH cartridges were analyzed using a HPLC system (Waters 2695 with a UV detector at λ = 365 nm and a reverse phase column C18) – Table 1.

*Table 1: chemical analysis methods versus sampling techniques.*



DNPH = 2,4-DiNitroPhenylHydrazine;

GC = Gas Chromatography;

HPLC = High Performance Liquid Chromatography;

IC = Ion Chromatography;

FID = Flame Ionization Detector;

MS = Mass Spectrometry;

To compare the results obtained by chemical analyses, and to validate the CMB model predictions, simultaneous measurements of odours by dynamic olfactometry [European standard EN 13725] in the lab, and field olfactometry associated to an odour intensity, on a scale from 0 to 6, as defined by the German norm VDI 3940, were conducted by operators. “0” corresponds to an imperceptible odour and “6” to an extremely strong odour. In our case, the odour intensity was rated from 1 to 3, ie from very weak to distinct.

For olfactometry according to the standard EN 13725, odour samples are collected in polymers bags (Tedlar) within a volume of about 60l with the principle of the “lung” technique. The bag, with a connecting tube between the bag and the outside air (in Teflon) is introduced in a sealed barrel. A vacuum pump decreases the pressure inside the barrel and the bag fills in with the outside odour air via the connecting tube. This technique insures the global sampling of odour without any contact with the pumping system. The odour samples are collected in the air near the source (above the compost piles, abive the waste, …)

* 1. Results and discussion

As seen in §2.1, to calculate the CMB parameters, the second step of the protocol requires to establish the sources profiles, and to chose judiciously compounds representative of the odour annoyance. During the chemical sources characterisations, 291 VOCs were identified and quantified in the sampled sources. To apply the CMB model, it was not necessary to use all of these VOCs, because many compounds present low concentrations not detectable at the receptor site (the limit was 10µg/m3). Thus, a list of 57 major compounds, characteristic of the sources, was established, with concentration levels high enough to apply the CMB model in good conditions. By themselves, these 57 VOCs represent an average of 77% of the total mass content of VOCs in the sample, which indicates a good representativeness of the total VOCs depending of the sources. They represent between 69% and 95% of compost source, between 53% and 95% of the waste source, between 61% and 66% of the biogas source. The results of all measurement campaigns, averaged source by source, are compiled in Table 2.

The results are consistent with previous studies conducted on the same types of waste treatment plants. For example, the “compost” source shows a majority of terpenes, followed by some aldehydes and ketones. This profile is similar to those obtained by Persoons et al. [27], Komilis et al. [28], Staley et al.[29], and Kumar et al. [30]. The chemical composition of the “waste” source depends on the maturation and the season, but there is a high presence of aromatic hydrocarbons, including a majority of BTEX, and oxygenated VOCs, mainly aldehydes, ketones, esters, alcohols, dioxolanes, and finally, a minority of aliphatic hydrocarbons and chlorinated compounds. In the literature, the amount of aromatic hydrocarbons (including BTEX) are generally equal or greater than to the quantities of aliphatic hydrocarbons [31323334353637-38], but in all these studies, samples were taken by adsorbent cartridges and/or SPME, which is a very bad trap for the lighter aliphatic hydrocarbons. Finally, three independent studies on the chemical characterization of “biogas” source conclude that in addition to methane, carbon dioxide and water vapor, which constitute most of biogas, the major compounds are aromatic hydrocarbons, aliphatic hydrocarbons, and terpenes [20,39-40], what is relevant to our own results.

To be sure that the sources are linearly independent as required by the CMB protocol, a correlation matrix of sources is calculated from the contents of these 57 individual VOCs. All correlation factors are below 0.7. Non-colinearity of the sources is crucial here: the CMB model has as premise that informed sources must be linearly independent. Otherwise, the model's performances are dramatically deteriorated. These results are good enough to apply the model in good conditions.

Finally, with 57 target molecules to describe 4 sources, the degree of freedom is then equal to 53, which is more than enough according to the CMB protocol.

*Table 2: list of the 57 major compounds of target molecules constituting the sources profiles.*



* + 1. Receptor sites results

Results of CMB modelling on VOC concentrations :

Performance criteria for the 15 multi-influenced samples collected during June 2011, September 2011 and January 2012 data are given in Table 3:

*Table 3: CMB performance criteria on physico-chemical analysis of 15 receptor sites*



The CMB model has similar criteria for data from June 2011 to September 2011 or January 2012. We note that the percentage of mass is generally acceptable with values between 70% and 130%: plus or minus 30%, we recover the total mass of all volatile organic compounds. The chi square is also always satisfactory, with a value less than 1 in most cases. This means that the uncertainty associated with the determination of profiles of sources is low enough for a good modelling. In contrast, the correlation coefficient R² is always poor. This can be explained by the range of very low concentrations measured at the receptor sites, which introduces a significant relative difference between calculated and measured values, although the absolute difference is small.

Tables 4-a, 4-b and 4-c identify the concentrations in µg/m3 corresponding to the contribution of each source to the overall concentration of VOC measured on each receptor site. The values used are those whose level is greater than the uncertainty associated to them, ie those with an index Tstat greater than 1.

*Table 4: CMB results on VOC measurements of 15 sampling on receptor sites*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| *Table 4-a : Measurements of June 2011* | | | | | | |
|  |  | 17 June | 18 June | 21 June | 22 June | 23 June |
| [VOC] (µg/m3) | ambient air | 42 | 17 | 8 | 25 | 22 |
| compost | - | **5** | 7 | **6** | **6** |
| waste | **13** | 4 | **16** | 4 | - |
| biogas | - | - | - | - | - |
| **TOTAL** | **55** | **26** | **31** | **35** | **28** |
| *Table 4-b : Measurements of September 2011* | | | | | | |
|  |  | 12-sept | 13-sept | 14-sept | 15-sept | 16-sept |
| [VOC] (µg/m3) | ambient air | 13 | 22 | 30 | - | 46 |
| compost | 26 | - | - | **113** | - |
| waste | **51** | **50** | **37** | 17 | **76** |
| biogas | - | 2 | - | - | - |
| **TOTAL** | **90** | **74** | **67** | **130** | **121** |
| *Table 4-c : Measurements of January 2012* | | | | | | |
|  |  | 10 Jan | 11 Jan | 13 Jan | 16 Jan | 17 Jan |
| [VOC] (µg/m3) | ambient air | - | 31 | 48 | 29 | 41 |
| compost | - | - | - | - | - |
| waste | **316** | **51** | **91** | **4** | **15** |
| biogas | - | - | - | - | - |
| **TOTAL** | **55** | **26** | **31** | **35** | **28** |

In the case where CMB pointed out ambient air as the most important contribution, we considered that the odour annoyance was the second most important contribution evaluated by the model. If “ambient air” is detected, it means that the odour intensity is low or it could warn us on an unidentified source. For 11 of the 15 measurement of sampling on receptor sites, the majority odour source is the source of "waste". In the other 4 samples, it is the source of "compost". Source of "biogas" is never pointed out by the model at the receptor site, with the exception of a very small presence (~ 2µg/m3) in a sample of the September campaign. We also note that the samples collected at the receptor site in June have extremely low concentrations, in the same order that ambient air samples and therefore, contributions of odour sources are very low in June. In addition, for 4 samples out of 5 measured in june 2011, ambient air is identified as the main source. For example, on the 21st of June, the main source is "waste", but at a level of only 16µg/m3. To explain such discrepancies with samples from September and January, it will be necessary to compare these values with the olfactometric data over these periods.

Cross-comparison with olfactometric data:

To determine if chemical approach is consistent with olfactometric data or not, the results are compared to the olfactometric methods. In the column “olfactometry”, the table 5 indicates firstly the nature of the odour sampled into bag and tested in laboratory, according to standard EN 13725 and, secondly, the intensity of the odour felt on the field according to the German vdi 3940 scale. The column “chemical analyses + CMB” represents the relative contribution of each of the two main sources determined by CMB applied on chemical data for the 15 samples at the receptor sites.

*Table 5: Comparison between physico-chemical analyses coupled with CMB model and olfactometry*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| major odour source | | | | |
| date | olfactometry  odours nature/intensity | | Chemical analyses + CMB odours nature/ (µg/m3) | |
| June 2011 | waste | 2 | waste | 13 |
| waste | 2 | compost/waste | 5 |
| waste | 2 | waste | 16 |
| waste | 3 | compost/waste | 5 |
| waste | 2 | compost | 6 |
| September 2011 | waste | 3 | waste | 51 |
| waste | 2 | waste | 49 |
| waste | 3 | waste | 37 |
| compost | 3 | compost | 113 |
| waste | 2 | waste | 75 |
| January 2012 | waste | 3 | waste | 316 |
| waste | 2 | waste | 51 |
| waste | 3 | waste | 91 |
| compost | 3 | waste | 4 |
| compost | 2 | waste | 15 |

Regarding the “chemical analyses + CMB”, in 10 cases out of 15, the major identified source is identical to the one identified by olfactometric methods. In the remaining 5 cases, the difference can be explained by the low levels of VOC’s concentrations. Indeed, for these 5 cases the sources contributions are below 20µg/m3, which is too low to conduct a significant interpretation. In contrast, among the measures whose contributions are higher than 20µg/m3, there are 100% match between the CMB modelling and the odour felt on the receptor site.

Among the 8 samples for which sources contribute for more than 20µg/m3 at the receptor site, the majority sources are identified unambiguously. But during the field campaign, the receptor sites were especially chosen for their multi-influenced characteristics. Most of time, the odour perceived is a mix of 2 or 3 odours. It is then possible to compare the results of olfactometry and chemical identification for the 2nd and 3rd odours underlying the main source – table 5

*Table 6: Cross-comparison physico-chemical analyses+CMB vsd olfactometry: underlying sources*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | field olfactometry | | | physico-chemical analyses + CMB | | |
|  | waste | compost | biogas | waste | compost | biogas |
| 12 Sept 2011 | 3 | 2 | 2 | 51 | 26 | 0 |
| 13 Sept 2011 | 2 | 0 | 0 | 49 | 0 | 2 |
| 14 Sept 2011 | 3 | 1 | 0 | 37 | 0 | 0 |
| 15 Sept 2011 | 1 | 3 | 0 | 17 | 113 | 0 |
| 16 Sept 2011 | 2 | 1 | 1 | 75 | 0 | 0 |
| 10 Jan 2012 | 3 | 3 | 0 | 312 | 0 | 0 |
| 11 Jan 2012 | 2 | 1 | 0 | 51 | 0 | 0 |
| 13 Jan 2012 | 3 | 0 | 0 | 91 | 0 | 0 |

Underlying sources of 12 and 15 September are correctly identified by the CMB model. On September 13th, a single odour was felt at the receptor site, and the 2nd source identified by the CMB model is biogas, but with a contribution of only 2µg/m3. Therefore, we can assume that this contribution, although statistically different from 0, is so small that it remains below the threshold of olfactory perception. On January 13th, only one odour was perceived, in the same way as the CMB does not identify any other contribution of the sources. These four results show a good correlation between olfactometry and analytical methods.

In contrast, for the 4 remaining dates, we observe a constant problem: the 2nd odour identified by olfactometry is always the source "compost", which is never detected by the CMB. This can be explained by the time difference between the two methodology: olfactometry is an instantly perception, done in real time, as opposed to VOC’s sampling, which need an integration during 30 minutes. With unstable weather conditions, the feeling of "hot scent" may seem high for a few seconds, while negligible on the total duration of sampling.

To conclude, in this work, we demonstrated the feasibility of applying the receptor CMB modelling, usually used in the general context of air pollution, to determine the major contributors to the odour annoyance perceived at a receptor site. First the model gives an indication on the level of olfactory intensity detected, and then it designates the source(s) that prevail(s).

Regarding the chemical analysis approach, the results obtained in this study can be considered as having achieved the goals that were initially set. However, the cost and time of analysis were very important. The working time spent collecting data for chemical analysis, and to interpret them was much greater than the time spent working to collect and interpret data for the measure by the e-nose. To make the "chemical" approach viable, it is imperative to reduce these costs (expensive equipment, time-consuming analyses ...). Alternatives to chromatographic techniques are recently proposed, including for example the analysis by PTR-MS (Proton Transfer Reaction Mass Spectrometry), which despite having a very high initial cost is much cheaper on a day-to-day basis, less time-consuming, and also allows lower detection limits [41]. It is however necessary to keep in mind that the methods do not need to be that heavy in relatively simple problems, looking for some specific tracer compounds sources could provide good results. If the goal is to identify the source of a nuisance, the calculation of ratios in 16 VOCs is enough to convincingly identify the source of "waste" as generally predominant in the olfactory nuisance receptor sites.

References

[1] ADEME (2005). "Pollutions olfactives - Origine, Legislation, Analyse, Traitement." Dunod

[**2**] Nicolas, J., Cors, M., Romain, A.-C., Delva, J., ”Identification of odour sources in an industrial park from resident diaries statistics”, Atmospheric environment, 44, 13 (2010) 1623-1631.

[**3**] Gutiérrez, M. C., Chica, A. F., Martín, M. A., Romain, A. C., “Compost Pile Monitoring Using Different Approaches: GC–MS, E-nose and Dynamic Olfactometry”, Waste and Biomass Valorization, (2013) 1-11.

[**4**] Romain, A.-C., Delva, J., Nicolas, J., Complementary approaches to measure environmental odours emitted by landfill areas, Sensors and Actuators B: Chemical, 131, 1 (2008) 18-23.

[**5**] Gostelow, P., S. A. Parsons, et al. "Development of an odorant emission model for sewage treatment works." Water Science and Technology 44(9): 181-188.

[**6**] Nicolas, J. and A.-C. Romain (2004). "Establishing the limit of detection and the resolution limits of odorous sources in the environment for an array of metal oxide gas sensors." Sensors and Actuators B: Chemical 99(2-3): 384-392.

[**7**] Sohn J. H., Pioggia G., Craig I. P., Stuetz, R. M., Atzeni M. G., (2009), Identifying major contributing sources to odour annoyance using a non-specific gas sensor array, Biosystems Engineering 102(3): 305-312.

[**8**] Romain, A. C., “Monitoring an odour in the environment with an electronic nose: requirements for the signal processing, in Biologically Inspired Signal Processing for Chemical Sensing”, Vol. 188 (Ed.: A. M. Gutiérrez, Santiago ), Springer Berlin

(2009), p. 210.

[**9**] Kleeberg, K. K., Y. Liu, et al. (2005). "Development of a simple and sensitive method for the characterization of odorous waste gas emissions by means of solid-phase microextraction (SPME) and GC-MS/olfactometry." Waste Management 25(9): 872-879.

[**10**] Jing-Jing JJ Fang, Na N Yang, Dan-Yan DY Cen, Li-Ming LM Shao, Pin-Jing PJ He., “Odor compounds from different sources of landfill: Characterization and source identification”, Waste Management, Volume 32, Issue 7, (2012), Pages 1401-1410

[**11**] S. Sironi, L. Capelli\*, P. Centola, R. Del Rosso, S. Pierucci, “Odour impact assessment by means of dynamic olfactometry, dispersion modelling and social participation”, Atmospheric Environment, Volume 44, Issue 3, (2010), Pages 354-360

[**12**] L. Capelli,\*, S. Sironi, R. Del Rosso, J.-M. Guillot. “ Measuring odours in the environment vs. dispersion modelling: A review”, Atmospheric Environment, Volume 79, November 2013, Pages 731-7

[**13**] Romain, A.-C., “8.3 Landfill of Solid Waste, in Odour Impact Assessment” Handbook (Ed.: Wiley), V., Belgiorno, Chichester, England, (2013), pp. 232-250.

[**14**] Collard, C., Lebrun, V., Fays, S., Salpeteur, V., Nicolas, J., Romain, A.-C., “Air survey around MSW landfills in Wallonia: feedback of 8 years field measurements”, ORBIT 2008, Wageningen, Netherlands, 13th to 15th october, (2008).

[**15**] Barnéoud, P. P., T., M. Héroux, et al. (2012). "Évaluation de l'impact odeur d'un centre de compostage en milieu urbain à l'aide d'un réseau d'observateurs et comparaison avec des modèles de dispersion atmosphérique." Pollution Atmosphérique n°213-214 (Janvier-Juin 2012).

[**16**] M Viana, TAJ Kuhlbusch, X Querol, A Alastuey, RM Harrison, PK Hopke, W Winiwarter, A Vallius, S Szidat and Ash Prevot, et al. (2008) “Source apportionment of particulate matter in Europe: A review of methods and results”, Journal of Aerosol Science. 39(10). p.827-849

[**17**] Badol C., N. Locoge, et al. (2008). "Using a source-receptor approach to characterise VOC behaviour in a French urban area influenced by industrial emissions: Part II: Source contribution assessment using the Chemical Mass Balance (CMB) model." Science of The Total Environment **389**(2-3): 429-440.

[**18**] Ralf Koppmann, “Volatile Organic Compounds in the Atmosphere” (2007), ed. Wiley-Blackwell, ISBN: 978-1-4051-3115-5.

[**19**] Srivastava, A., B. Sengupta, et al. (2005). "Source apportionment of ambient VOCs in Delhi City." Science of The Total Environment 343(1-3): 207-220.

[**20**] Na, K. and Y. Pyo Kim (2007). "Chemical mass balance receptor model applied to ambient C2-C9 VOC concentration in Seoul, Korea: Effect of chemical reaction losses." Atmospheric Environment **41**(32): 6715-6728.

[**21**] Mukund, R., T. J. Kelly, et al. (1996). "Source attribution of ambient air toxic and other VOCs in Columbus, Ohio." Atmospheric Environment 30(20): 3457-3470.

[**22**] Lee S., Liu W., Wang Y., Russell A. G., Edgerton E. S., (2008), Source apportionment of PM2.5: Comparing PMF and CMB results for four ambient monitoring sites in the southeastern United States, Atmospheric Environment 42(18): 4126-4137.

[**23**] Wohrnschimmel, H., C. Marquez, et al. (2006). "Vertical profiles and receptor modeling of volatile organic compounds over Southeastern Mexico City." Atmospheric Environment 40(27): 5125-5136.

[**24**] Latella, A., G. Stani, et al. (2005). "Semicontinuous GC analysis and receptor modelling for source apportionment of ozone precursor hydrocarbons in Bresso, Milan, 2003." Journal of Chromatography A 1071(1-2): 29-39.

[**25**] Song, K., Q. Wang, et al. (2009). Design and Implementation A Real-time Electronic Nose System. I2mtc: 2009 Ieee Instrumentation & Measurement Technology Conference, Vols 1-3. New York, Ieee**:** 570-573.

[**26**] Watson John G. et al, Protocol for Applying and Validating the CMB Model for PM2.5 and VOC, EPA-451/R-04-001, (2004)

[**27**] Persoons, R., S. Parat, et al. (2010). "Critical working tasks and determinants of exposure to bioaerosols and MVOC at composting facilities." International Journal of Hygiene and Environmental Health 213(5): 338-347.

[**28**] Komilis, D. P., R. K. Ham, et al. (2004). "Emission of volatile organic compounds during composting of municipal solid wastes." Water Research 38(7): 1707-1714.

[**29**] Staley, B. F., F. Xu, et al. (2006). "Release of Trace Organic Compounds during the Decomposition of Municipal Solid Waste Components." Environmental Science & Technology 40(19): 5984-5991.

[**30**] Kumar, A., C. P. Alaimo, et al. (2011). "Volatile organic compound emissions from green waste composting: Characterization and ozone formation." Atmospheric Environment 45(10): 1841-1848.

[**31**] Zou, S. C., S. C. Lee, et al. (2003). "Characterization of ambient volatile organic compounds at a landfill site in G

[**32**] Davoli E., Gangai M. L., Morselli L., Tonelli D., 2003, Characterisation of odorants emissions from landfills by SPME and GC/MS, Chemosphere 51(5): 357-368.

[**33**] Dincer, F. and A. Muezzinoglu (2006b). "Chemical characterization of odors due to some industrial and urban facilities in Izmir, Turkey." Atmospheric Environment 40(22): 4210-4219.

[**34**] Dincer, F., M. Odabasi, et al. (2006a). "Chemical characterization of odorous gases at a landfill site by gas chromatography-mass spectrometry." Journal of Chromatography A 1122(1-2): 222-229.

[**35**] Sadowska-Rociek A., Kurdziel M., Szczepaniec-Cieciak E., Riesenmey C., Vaillant H., Batton-Hubert M., Piejko K., (2009), Analysis of odorous compounds at municipal landfill sites." Waste Management & Research 27(10): 966-975.

[**36**] Gallego, E., F. J. Roca, et al. (2012). "Characterization and determination of the odorous charge in the indoor air of a waste treatment facility through the evaluation of volatile organic compounds (VOCs) using TD/GC/MS." Waste Management(0).

[**37**] Ying, D., C. Chuanyu, et al. (2011). "Characterization and control of odorous gases at a landfill site: A case study in Hangzhou, China." Waste Management 32(2): 317-326.

[**38**] Fang, J.-J., N. Yang, et al. (2012). "Odor compounds from different sources of landfill: Characterization and source identification." Waste Management 32(7): 1401-1410.

[**39**] Takuwa Y., Matsumoto T., Oshita K., Takaoka M., Morisawa S., Takeda N., (2009), Characterization of trace constituents in landfill gas and a comparison of sites in Asia, Journal of Material Cycles and Waste Management 11(4): 305-311.

[**40**] Sadowska-Rociek, A., M. Kurdziel, et al. (2009). "Analysis of odorous compounds at municipal landfill sites." Waste Management & Research 27(10): 966-975.

[**41**] Biasioli, F., F. Gasperi, et al. (2004). "PTR-MS monitoring of odour emissions from composting plants." International Journal of Mass Spectrometry 239(2-3): 103-109.