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Baseline levels of bioaerosols and volatile organic compounds around a municipal waste incinerator prior to the construction of a mechanical-biological treatment plant

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ABSTRACT

New waste management programs are currently aimed at developing alternative treatment technologies such as mechanical–biological treatment (MBT) and composting plants. However, there is still a high uncertainty concerning the chemical and microbiological risks for human health, not only for workers of these facilities, but also for the population living in the neighborhood. A new MBT plant is planned to be constructed adjacently to a municipal solid waste incinerator (MSWI) in Tarragona (Catalonia, Spain). In order to evaluate its potential impact and to differentiate the impacts of MSWI from those of the MBT when the latter is operative, a pre-operational survey was initiated by determining the concentrations of 20 volatile organic compounds (VOCs) and bioaerosols (total bacteria, Gram-negative bacteria, fungi and *Aspergillus fumigatus*) in airborne samples around the MSWI. The results indicated that the current concentrations of bioaerosols (ranges: 382–3882, 18–790, 44–926, and <1–7 CFU/m^3 for fungi at 25 °C, fungi at 37 °C, total bacteria, and Gram-negative bacteria, respectively) and VOCs (ranging from 0.9 to 121.2 μg/m^3) are very low in comparison to reported levels in indoor and outdoor air in composting and MBT plants, as well in urban and industrial zones. With the exception of total bacteria, no correlations were observed between the environmental concentrations of biological agents and the direction/distance from the facility. However, total bacteria presented significantly higher levels downwind. Moreover, a non-significant increase of VOCs was detected in sites closer to the incinerator, which means that the MSWI could have a very minor impact on the surrounding environment.

1. Introduction

Because of its increasing production tendency, the disposal of waste has become one of the most crucial problems in modern societies. Until recent years, landfilling was used as the prominent technique for waste management. Because it is probably the most economic route of solid waste disposal (El-Fadel and Massoud, 2000), landfilling is still the predominant treatment option for the EU's municipal waste (Mazzanti and Zoboli, 2008). However, the lack of recovery of materials and/or energy in waste landfills, together with the potential health risks associated to waste disposal, emission of greenhouse gases and leachate (El-Fadel et al., 1997), has led to consider other options. Among these, waste incineration, and specially waste-to-energy, has become a serious option in developed countries. It presents numerous advantages, such as energy recovery and volume minimization. However, public controversy is frequent at those locations where municipal solid waste incinerators (MSWI) are operating or planned. These facilities have been associated to emissions of toxic chemicals, such as polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs) and heavy metals (Domingo, 2002; Schuhmacher and Domingo, 2006), among others.

The public concern on waste incineration, as well as the importance of developing sustainable waste strategies, including the reuse and recycle of materials, has given place to a shift in waste management programs. As a consequence, some experts have pointed out that other waste treatment technologies, such as mechanical–biological treatment (MBT), anaerobic digestions, and composting might be paramount for achieving sustainable development (Sykes et al., 2007).

MBT seems to be a suitable alternative to reduce the organic fraction of municipal solid waste (MSW), prior to landfilling or incineration (de Araújo Morais et al., 2008). In addition, the emission of greenhouse gases during MBT processes is minor (Amlinger et al., 2008; van Praagh et al., 2009). In fact, the bio-mechanical treatment of MSW is an increasing option in the European Union,

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as well as in some developing countries of South America (Rada et al., 2005; Bezama et al., 2007; Pan and Voulvoulis, 2007). On the other hand, the composting of organic waste has been demonstrated to be an efficient way to reduce the material to be disposed/incinerated. In turn, compost may be potentially used in various agricultural applications (Hargreaves et al., 2008). Unfortunately, adverse health effects have been detected in individuals working in composting and MBT plants (Domingo and Nadal, 2009), making evident the potential human health risks. Apart from the evident occupational exposure, people living in the vicinity of such facilities may be potentially exposed to relatively high concentrations of airborne volatile organic compounds (VOCs) and microorganisms, due to the atmospheric dispersion of particulates (Déportes et al., 1995). In addition, both composting and MBT plants can result in significant odor releases, which may be of nuisance to the population surrounding the facilities (Canovai et al., 2004; Sironi et al., 2006).

The MSWI of Tarragona (Catalonia, Spain) has an annual capacity of 145,000 tones of waste, serving a total population of 350,000 inhabitants. Since 1995, a wide surveillance program has been carried out in order to get overall information on the environmental impact of the facility. This program was aimed at determining the PCDD/F and metal levels in soil and vegetation samples, as well as to assess the human health risks associated to exposure to those pollutants (Domingo et al., 2001; Mari et al., 2007). Recently, active and passive sampling devices were additionally used to measure PCDD/Fs and metals in air (Mari et al., 2008). The current waste management planning program of the Catalan government is enforced in implementing new pre-treatment processes to reduce the amount of waste to be incinerated, and to optimize the incineration process. Specifically, a modern MBT plant, with a treatment capacity of 185,000 tones/year, has been planned to be constructed adjacent to the MSWI of Tarragona. Due to the concern of the local population, as well as governmental regulators, a pre-operational survey focused on measuring the chemical and microbiological pollution was conducted in order to get baseline data for the evaluation of the planned facility.

The purpose of the present study was to analyze the environmental concentrations of VOCs and bioaerosols (bacteria and fungi) in the vicinity of the MSWI of Tarragona. It is expected that the current levels can be used as reference values to assess the impact of the MBT after it begins to operate.

2. Materials and methods

2.1. Sampling and analysis

In November–December 2007, air samples were collected in the surroundings of the MSWI in Tarragona (Catalonia, NE Spain). Sixteen sampling points, situated at 4 different distances (300, 600, 900 and 1200 m) in 4 different directions from the facility (NW, NE, SW, and SE) were selected. Additionally, 4 samples were collected as reference (background) samples around the cities of Tarragona and Reus, as well as the villages of Constantí and Vilaplana (at a distance of 2.8, 9.6, 1.7 and 19.1 km from the MSWI, respectively). The locations of the sampling points are depicted in Fig. 1. To minimize the impacts of meteorological conditions (temperature, solar radiation, etc.) on the sampling, samples were collected as quickly as possible from all the locations. Thus, weather conditions could be assumed to be "stable" during the sampling window (typically hours).

Given the expected high variability of microbial concentrations, 5 replicate air samples were collected at each point in order to determine the average levels of microorganisms. The following bioaerosols were determined: total bacteria and fungi as general indicators, Gram-negative bacteria as indicators of opportunistic pathogens, and *Aspergillus fumigatus* (*A. fumigatus)* as fungus which may mean a potentially remarkable human heath risk. Sampling was carried out by means of a Sampl'Air Lite device (AES Laboratoires, Bruz, France), with an air-flow rate set at 100 L/min. Sampling time was 3 min for Gram-negative bacteria, and 1 min for the remaining agents. Triptyc Soy Agar (TSA) and MacConkey culture media were used to determine the levels of total and Gram-negative bacteria, respectively. In turn, the fungal growth was assessed on a PDA (Potato Dextrose Agar) culture medium. After collection, samples were incubated for 48 h at 37 °C for the analyses of total bacteria, and 24 h for the determination of Gram-negative bacteria. PDA was incubated at 25 °C and 37 °C for 5–7 days for the determination of fungi at environmental and body temperatures, respectively (Piecková and Kunová, 2002; Falvey and Streifel, 2007). This procedure differentiates the total number of fungi present in the environment (25 °C) and the amount of fungal agents which could potentially affect the human health (37 °C). Microbiological results were expressed as the total number of Colony-Forming Units (CFU) per m^3 of air. In 2 of each of the 5 fungi samples, a detailed study on the number of colonies of *A. fumigatus* was performed. If the total number of colonies exceeded 200 in a Petri dish, results were expressed, according to the ISO 8199:2005 standard, as too numerous to count, and were not included in the statistical analysis. However, none of the samples showed a value above that threshold.

On the other hand, the levels of the following VOCs were determined: benzene, toluene, *m*,*p*-xylene, *o*-xylene, styrene, naphthalene, methylene chloride, 1,2-dichlorethane, chloroform, trichloroethylene, tetrachlorethylene, 1,3-butadiene, 1,3,5-trimethylbenzene, 1,2,4-trimethylbenzene, ethylbenzene, *p*-isopropyltoluene, *n*-propylbenzene, isopropylbenzene, and formaldehyde. An AMBCPV device (Ambiental d'Enginyeria i Assessorament, Esparreguera, Spain) was used to sample air for the subsequent analysis of VOCs. Samples were collected by passing air through ORBO-32 activated carbon tubes (Supelco, Bellefonte, PA, USA), in which all compounds, with the exception of formaldehyde, were trapped. In turn, formaldehyde retention was done by using a 2,4-dinitrophenylhydrazine (2,4-DNPH) coated silica gel tube (ORBO-DNPH, Supelco, Bellefonte, PA, USA). Total volumes of air were approximately 150 L for most VOCs, and 40 L for formaldehyde.

Samples were rapidly transferred to the lab, where they were kept at 4 °C until analysis. The target compounds, excepting formaldehyde, were extracted by liquid desorption with 1–3 mL of carbon disulphide for at least 60 min. Analysis was carried out by using a gas chromatograph coupled to a mass spectrometer (GC–MS) equipped with a Rtx-1 fused-silica capillary column ($30\ \mathrm{m} \times 0.32\ \mathrm{mm} \times 1.5\ \mu\mathrm{m}$). The oven temperature started at 40 °C, and kept for 1 min. Then, it was raised at 14.9 °C/min up to 220 °C, where a new ramp of 40 °C/min was initiated until 320 °C. Helium was used as carrier gas. Formaldehyde was desorbed from tubes with 2 mL of acetonitrile in an ultrasonic bath for 30 min. The analysis was done by high pressure liquid chromatography with UV detection (HPLC-UV), using a C-18 column ($5\ \mu\mathrm{m}$, $200\ \mathrm{cm} \times 4.6\ \mathrm{mm}$). The initial mobile phase was acetonitrile:water (50:50). The gradient program for acetonitrile, given as time–concentration percentage, was the following: min. 0.1–50%, min. 5–50%, min. 20–80%, min. 25–100%, min. 48–50%, min. 52–stop. The calibration was done by using reference standard solutions of VOCs in CS_2 and DNPH derivatives of aliphatic aldehydes in acetonitrile for the determination of VOCs and formaldehyde, respectively. Conventional procedures of quality assurance/quality control (QA/QC) were applied. Blank, replicate, and reference samples were analyzed in every batch of samples, showing a good repeatability for the method. Detection limits differed

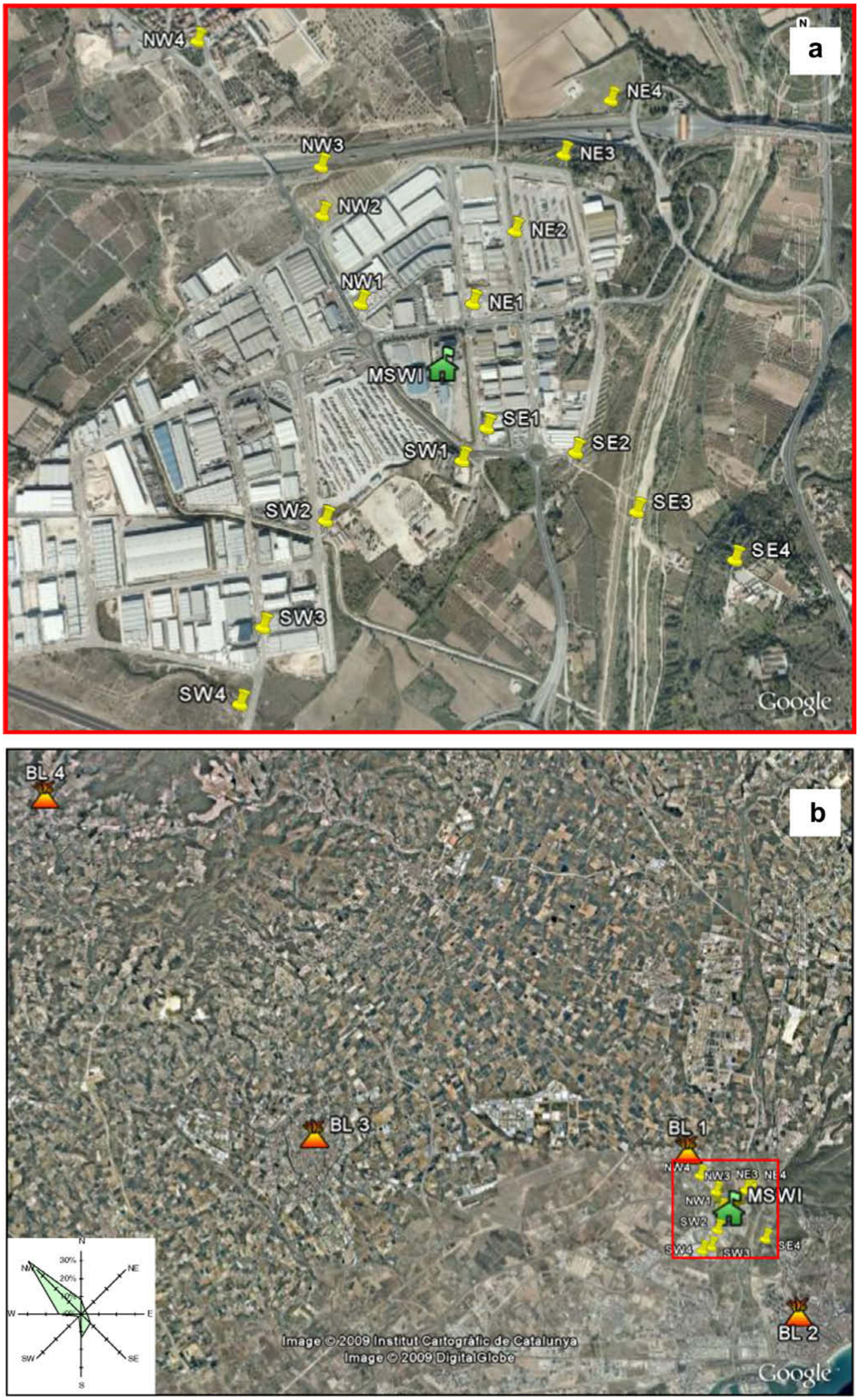

Fig. 1. Distribution of 16 sampling points around the MSWI of Tarragona (a) and 4 background sites, as well as wind rose (b).

according to each specific VOC, ranging from 0.1 and 10 μg/m^3. These were determined as three times the signal to noise ratio. As an additional measure of QA/QC, the analytical laboratory regularly participates in intercomparison exercises.

2.2. Statistics

Data analyses were performed by using the SPSS 15.0 statistical software package. The Levene test was applied to analyze the equality of variances. Because data followed a normal distribution, an ANOVA test was subsequently carried out. A probability of 0.05 or lower ($p < 0.05$) was considered as statistically significant.

3. Results and discussion

3.1. Microbiological concentrations

The mean concentration of airborne microorganisms in each sampling site is summarized in Table 1. Fungi, cultivated at 25 °C and 37 °C, were the microbial agents presenting the highest levels, with ranges between 382 and 3882 CFU/m^3, and between 18 and 790 CFU/m^3, respectively. Similar median concentrations of fungal communities incubated at 25 °C were observed near the MSWI in comparison to the background area at both temperatures (1673 vs. 1438 CFU/m^3). In contrast, an important difference in the levels of fungi at 37 °C was noted (236 vs. 119 CFU/m^3). Moreover, for those samples cultivated at 37 °C (median: 8 CFU/m^3; maximum: 25 CFU/m^3), higher levels of *A. fumigatus* were clearly (although non-significantly) observed in the background area with respect to the sampling sites surrounding the plant. Total bacteria concentrations ranged between 44 and 926 CFU/m^3, while those of Gram-negative bacteria were found to range from undetected to 7 CFU/m^3. Both, total and Gram-negative bacteria, showed similar levels independently on the sampling area (112 vs. 107 CFU/m^3 and 3 vs. 2 CFU/m^3, respectively).

In order to study any spatial pollution pattern, a study of the microbial concentrations in ambient air according to the wind directions and distances to the MSWI was carried out (Table 2). In general terms, no significant correlations between the levels of fungi and bacteria in ambient air and the distance from the facility were observed. In addition, no wind prevalence was noted when analyzing the concentrations of bioaerosols in relation to the wind direction. However, significantly higher concentrations of total bacteria were found at SW direction, in comparison to NW and background values. The highest levels of total bacteria were observed in SW (downwind) samples closest to the MSWI (926 and 380 CFU/m^3 at SW1 and SW2, respectively). That means that the collection and transport of waste in the incinerator might have a very minor impact on the surrounding environment in terms of microbiological contamination.

Waste management plants are considered as facilities with potentially very high concentrations of microbiological agents such as bacteria, fungi, protozoa and/or endotoxins produced by them (Tolvanen et al., 2005; Tolvanen and Hänninen, 2005, 2006). Some of these agents may lead to occupational exposure, especially for workers of composting plants of the MSW organic fraction (Domingo and Nadal, 2009). Concentrations of up to 10^5 CFU/m^3 have been observed on sampling sites within composting facilities (Fischer et al., 2008). Hryhorczuk et al. (2001) found important levels of bioaerosols (including total, Gram-positive and Gram-negative bacteria, as well as total and *Aspergillus* spores) in indoor air of a suburban yard-waste composting facility in northern Illinois, USA. Moreover, with the exception of fungi, outdoor levels were lower than on-site concentrations, while a clear reduction of the environmental values of microbial agents was registered during non-activity periods. The median off-site concentrations of fungi, total bacteria and Gram-negative bacteria were 3200, 2080 and 840 CFU/m^3, respectively. Those values mean higher levels, especially for bacterial agents, than those observed in 16 sites near the MSWI of Tarragona (1673, 112 and 3 CFU/m^3, respectively). These levels would be even lower than those found in ambient air during periods without activity at the compost pile (ranges of 960–1960 and 520–5920 CFU/m^3 for viable bacteria and fungi, respectively). The levels of *A. fumigatus* were also investigated in and near another yard-waste composting facility located in the USA (Long Island, NY) (Recer et al., 2001). The median concentrations of this biological agent in two different neighborhoods, used as reference sites, were 3–5 CFU/m^3, being the same concentration than that obtained in the vicinity of the MSWI. Recently, Lavoie (2006) reported a median concentration of 5900 CFU/m^3 of both, bacteria and fungi, in a mixed urban waste background scenario.

The presence of airborne microorganisms has been studied in residential areas around the world. In two neighborhoods near Berlin (Germany), the levels of Gram-negative bacteria were also detected at low concentrations, with a maximum of 7.9 CFU/m^3 (Zucker and Müller, 2004). Because samples were collected repeatedly, some seasonal differences were appreciated. However, the concentration of total viable bacteria in November (the same time of our study) was very similar to that found in Tarragona, with values of 159 and 178 CFU/m^3 in the meadow and the road, respectively. Recently, Guinea et al. (2006) studied the environmental

Table 1
Individual concentration (in CFU/m^3) of microbiological pollutants in air of the 20 sampling sites around the MSWI of Tarragona.

Sample	Gram-negative bacteria	Total bacteria 37 °C	Fungi 25 °C	*A. fumigatus* 25 °C	Fungi 37 °C	*A. fumigatus* 37 °C
NW1	3	76	1662	15	790	<2
NW2	2	68	1638	5	256	10
NW3	3	44	1488	<2	228	15
NW4	<1	78	1684	5	18	<2
SW1	1	926	1872	5	92	<2
SW2	7	380	2022	<2	90	<2
SW3	4	272	784	5	116	<2
SW4	2	116	1444	<2	122	15
SE1	5	54	1364	5	86	5
SE2	1	108	2522	<2	224	<2
SE3	3	142	1616	10	244	<2
SE4	3	310	3882	5	314	5
NE1	2	100	756	<2	306	<2
NE2	7	92	2126	<2	256	<2
NE3	7	208	2896	<2	334	5
NE4	4	336	2246	<2	442	5
BL1	2	102	948	10	114	25
BL2	5	92	3854	<2	332	10
BL3	2	112	1928	5	124	5
BL4	1	112	382	<2	39	<2

BL, background location; BL1, Constantí; BL2, Tarragona; BL3, Reus; BL4, Vilaplana.
NW, SW, SE and NE indicate wind directions. Numbers 1–4 refer to distances (300, 600, 900 and 1200 m) from the MSWI.

Table 2
Air median levels of bioaerosols (in CFU/m^3) and VOCs (in μg/m^3) according to the direction and distance from the MSWI of Tarragona.

	Direction					Distance				
	NE	NW	SE	SW	BL	300 m	600 m	900 m	1200 m	BL
Gram-negative bacteria	5	2	3	3	2	3	4	3	2	2
Total bacteria	154^{ac}	72^{b}	125^{abc}	326^{a}	107^{c}	88	100	175	213	107
Fungi (25 °C)	2186	1650	2069	1658	1438	1513	2074	1552	1965	1438
A. fumigatus (25 °C)	<2	5	5	3	3	5	<2	3	3	3
Fungi (37 °C)	320	242	234	104	119	199	240	236	218	119
A. fumigatus (37 °C)	3	5	3	<2	8	<2	<2	3	5	8
ΣVOCs	18.1	5.35	17.45	14.35	5.45	21.15	28.55	6.75	7.1	5.45
ΣBTEX	16.7	5.05	15.2	11.95	5.25	18.6	26.85	6.3	6.6	5.25

For each parameter, different superscripts (a,b,c) indicate significant differences at $p < 0.05$.

levels of some *Aspergillus* species in urban and rural samples of air and water collected in the Madrid region, Spain. A range of 0–30 CFU/m^3 of *A. fumigatus* air was found, with higher levels in urban than rural sites (0–30 vs. 0–5 CFU/m^3).

Currently, there are no standards set by the National Institute of Occupational Safety and Health (NIOSH) and the American Conference of Governmental Industrial Hygienists (ACGIH) regarding to the allowable amount of microbiological agents at the workplace. According to the ACGIH Bioaerosols Committee, an exposure threshold level for cultivable microorganisms has no scientific justification because bioaerosols are complex mixtures of particles whose health effects may vary according to the specific agent and the susceptibility inherent to each individual (ACGIH, 1989). However, some recommendations have been published for controlling indoor microbiological contamination (Tsai and Liu, 2009). For instance, the ACGIH established a guideline of 100–1000 CFU/m^3 for total fungi, while the NIOSH set a limit of 1000 CFU/m^3 for the total number of bioaerosols particles. With respect to the health risks derived from exposure to bioaerosols, limit values of 10000 and 1000 CFU/m^3 for total and Gram-negative bacteria, respectively, have been suggested (Heida et al., 1995; Marchand et al., 1995; Kiviranta et al., 1999). However, these recommendations are basically focused on workers of MSW management plants potentially more exposed to bioaerosols. No recommendations have been made for environmental levels of fungi and bacteria.

3.2. VOC concentrations

The results corresponding to the VOC sampling are shown in Table 3. For calculations, a concentration of zero was considered for non-detected pollutants (ND = 0). Only BTEX (benzene, toluene, ethylbenzene, *m,p*-xylene and *o*-xylene) were detected in almost all samples. In contrast, naphthalene, methylene chloride, 1,2-dichlorethane, trichloroethylene, 1,3-butadiene, and formaldehyde showed concentrations under their respective limits of detection in all samples. Chloroform was detected only in one sample (SE1), while styrene, *p*-isopropyltoluene and isopropylbenzene were found to be above the detection limit in two samples (SE1 and NE1 for styrene, SE1 and SW3 for *p*-isopropyltoluene, and SW3 and NE1 for isopropylbenzene). Total VOC levels ranged from 0.9 to 121.2 μg/m^3, whereas those of BTEX presented minimum and maximum values of 0.9 and 117.9 μg/m^3, respectively. The concentration of benzene, a known carcinogenic chemical, ranged between 0.1 and 3.2 μg/m^3. The highest levels were observed in SE1 and SE2 sites (3.2 and 2.4 μg/m^3, respectively), which correspond to the two closest sampling points (300 and 600 m, respectively) downwind from the plant. In the EU, the benzene concentration is regulated by the Directive 2000/69/EC (EC, 2000). According to that, by the year 2010, the annual average levels of benzene in ambient air should not exceed 5 μg/m^3. Anyhow, none of the samples exceeded the EC threshold value of 5 μg/m^3 of benzene in ambient air, being similar to those previously reported in various European cities (Gonzalez-Flesca et al., 2007). The levels of toluene and styrene in Tarragona were notably lower than the WHO recommended guideline of 260 μg/m^3 as a weekly average for the protection of human health WHO,2000. To the best of our knowledge, the MSW incinerator is not currently being a cause of nuisance for bad odors for workers and local residents. In fact, during the sampling an increase of the presence of odors, linked to VOCs, was not observed. This suggests that the current levels of VOCs are not sufficient to impact human health in the vicinity of the plant.

As for microbial pollution, the potential correlation of the levels of VOCs and BTEX in relation to the wind directions and distances from the facility was also investigated (Table 2). Higher concentrations of VOCs were found at the downwind directions (SW and SE) in comparison to the NW and the background sites. That correlates with the predominant wind direction in the area, NW at a mean wind speed of 1.8 m/s (Fig. 1). NE presented also higher levels, which was very probably due to the important concentration noted in NE1, located in a roundabout 300 m from the plant. On the other hand, although not statistically significant ($p > 0.05$), the concentrations of VOCs near the MSWI (300–600 m) were higher than those of further sites (900–1200 m, and backgrounds). It must be taken into account that an important amount of MSW, with a varied percentage of organic content, is daily introduced in the plant for its incineration. The waste accumulation, together with the traffic of transporting trucks, could result in increased levels of VOCs in the immediate area.

To assess the degree of VOCs pollution near the MSWI of Tarragona, as well as to establish background levels of these pollutants, the current concentrations of VOCs were compared with reported data for urban and industrial areas. Currently, there is an important lack of information concerning the number of compounds which must be evaluated when carrying out environmental monitoring studies of VOCs in air (Jia et al., 2008; Özden et al., 2008). In fact, benzene is the only compound for which a maximum concentration in outdoor air has been established (EC, 2000). Because of the number of chemicals considered greatly depends on the criterion of each investigator, the comparison between different areas is rather difficult. However, BTEX are the most analyzed compounds in most studies, being also the most abundant VOCs in urban air (Baroja et al., 2005; Ras-Mallorquí et al., 2007)

In Spain, Baldasano et al. (1998) reported a mean airborne concentration of BTEX of 36.2 μg/m^3 in the city of Martorell (Barcelona Province, Spain). The authors stated that VOCs air quality in Martorell did not stand out for being neither among the worst nor among the best. More recently, similar concentrations of BTEX were reported in Vitoria-Gasteiz and A Coruña (Spain) (Fernandez-Martinez et al., 2001; Baroja et al., 2005). Very recently, Ras-Mallorquí et al. (2007) carried out a comprehensive study by analyzing 54

Table 3
Individual concentration and sum of VOCs (in μg/m^3) in ambient air of 20 sampling points around the MSWI of Tarragona.

	LOD	SW1	SW2	SW3	SW4	SE1	SE2	SE3	SE4	NE1	NE2	NE3	NE4	NW1	NW2	NW3	NW4	BL1	BL2	BL3	BL4
Benzene	0.1	0.2	1.3	1.1	0.9	3.2	2.4	0.6	0.8	1.9	1.5	0.3	0.8	0.9	0.5	0.6	1.3	0.1	1.2	0.5	1.0
Toluene	0.1	1.1	8.6	5.3	5.6	12	13	1.2	1.6	21	15	4.3	5.5	6.0	2.7	3.3	1.7	0.4	8.8	2.9	3.0
m,*p*-Xylene	0.1	0.3	13	3.7	2.9	5.2	13	0.7	0.9	63	4.9	1.1	1.4	2.4	ND	1.3	0.6	0.3	5.3	0.9	0.9
o-Xylene	0.1	ND	2.1	1.2	0.6	1.7	2.5	0.1	0.3	13	1.3	0.3	0.5	0.9	ND	0.4	0.1	ND	1.8	0.3	0.2
Styrene	0.1	ND	ND	ND	ND	ND	0.2	ND	ND	0.4	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Naphthalene	0.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Methylene Chloride	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-Dichlorethane	1.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chloroform	1.0	ND	ND	ND	ND	1.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Trichlorethylene	0.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Tetrachlorethylene	5.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,3-Butadiene	5.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,3,5-Trimethylbenzene	0.1	ND	0.4	1.1	0.2	0.6	0.5	ND	ND	0.7	0.5	0.1	0.2	0.2	0.1	0.1	ND	ND	0.5	ND	ND
1,2,4-Trimethylbenzene	0.1	0.2	1.1	2.6	0.4	1.4	1.1	0.2	0.1	1.4	1.1	0.3	0.4	0.5	0.3	0.3	ND	ND	1.3	0.3	0.1
Ethylbenzene	0.1	0.5	4.4	1.3	1.3	4.2	5.5	0.3	0.5	19	1.6	0.4	0.9	0.7	0.4	0.6	0.2	0.1	4.5	0.4	0.4
p-Isopropyltoluene	0.1	ND	ND	ND	ND	0.4	ND	ND	ND	ND	ND	ND	0.2	ND	ND	ND	ND	ND	ND	ND	ND
n-Propylbenzene	0.1	ND	ND	0.3	ND	0.3	0.3	ND	ND	0.5	0.3	ND	0.1	ND	ND	0.1	ND	ND	0.2	ND	ND
Isopropylbenzene	0.1	ND	ND	0.2	ND	ND	ND	ND	ND	0.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Formaldehyde	2.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ΣVOCs		2.3	30.9	16.8	11.9	30.7	38.5	3.1	4.2	121.2	26.2	6.8	10	11.6	4.0	6.7	3.9	0.9	23.6	5.3	5.6
ΣBTEX		2.1	29.4	12.6	11.3	26.3	36.4	2.9	4.1	117.9	24.3	6.4	9.1	10.9	3.6	6.2	3.9	0.9	21.6	5.0	5.5

LOD, limit of detection; ND, not detected.

VOCs in air of urban and industrial areas of Tarragona, very close to our zone of sampling. BTEX were found to be the most abundant VOCs in urban air, with levels ranging from 12 to 270 μg/m^3.

Because of the potential release of a broad range of organic pollutants of chemical and microbiological characteristics, waste management facilities may have an important influence on the environment (Müller et al., 2004; Fischer et al., 2008). Leach et al. (1999) found a VOC concentration of 100–1300 μg/m^3 in sampling sites adjacent to a MSWI, a waste collection and processing centre, and a sewage treatment plant. Moreover, important reductions of VOC levels in air were noted after the closure of the incinerator. The mean concentration of aromatic compounds in airborne samples ranged 66–285 and 27–127 μg/m^3 pre- and post-incinerator shutdown, respectively. However, especially high contents of a wide variety of VOCs in indoor air of composting facilities can be found in the literature. Eitzer (1995) performed the very first important study on the levels of VOCs in composting plants. It was stated that VOCs could be released during composting, especially at early stages of processing. In the meantime, Kiviranta et al. (1999) found VOC levels of up to 2850 μg/m^3 in a waste processing room in a Finnish plant.

3.3. Overall pollution of bioaerosols and VOCs

To assess the environmental impact of the MSWI as a result of the joint concentrations of VOCs and microbiological pollutants, a Kohonen's Self-Organizing Map (SOM) was executed. SOM is a kind of unsupervised artificial neural network (Kohonen, 1982), with a great capability to handle great amounts of data and allowing to obtain a friendly visualization system (Nadal et al., 2004). It is being applied to a varied number of environmental studies concerning different topics, such as chemical pollution or ecological modeling (Brosse et al., 2007; Alvarez-Guerra et al., 2008; Nadal et al., 2008). In the current study, the map was a rectangular grid of 6 × 5 hexagons, getting a 30 virtual units grid. The learning phase was broken down with 10,000 steps, while the tuning phase consisted on 10,000 additional steps. The Kohonen's map and the component planes (c-planes) of the concentrations of bioaerosols and VOCs in the vicinity of the MSWI of Tarragona are depicted in Fig. 2. It can be clearly observed that NE1 shows the highest concentrations of BTEX, and especially of xylene and ethylbenzene. Other samples (SE1 and SE2) collected near the facility also showed relatively higher levels of VOCs. Therefore, it seems quite evident that, although very minor, the MSWI of Tarragona has a certain impact on the surrounding regarding to the release of VOCs. On the other hand, the pattern of the microbiological and chemical pollution was substantially different. No correlation was observed between the levels of VOCs and bioaerosols, as well as among the different studied microbiological agents.

Since 1996, the MSWI of Tarragona is carrying out a scheduled surveillance program to estimate the environmental impact of the facility concerning to the potential emission of PCDD/Fs and heavy metals, as well as to assess the health risks for the population living nearby (Domingo et al., 2001). In 2007 and 2008, the PCDD/F concentrations in air in different points around the incinerator were determined by using active and passive air sampling devices, respectively (Mari et al., 2008). Mean PCDD/F levels in air were 12.0 and 15.2 fg WHO-TEQ/m^3 in 2007 and 2008, respectively, which mean a non-significant increase of 26% ($p > 0.05$). However, these levels are in the lowest part of the range, in comparison to those reported worldwide in industrial, urban and even unpolluted sites. As for VOCs, no preferential tendency of the PCDD/F concentration was observed according to the distance and direction of sampling to the facility. These low concentrations indicate that the MSWI of Tarragona is not currently a significant source of PCDD/Fs for the surrounding environment and the people living nearby.

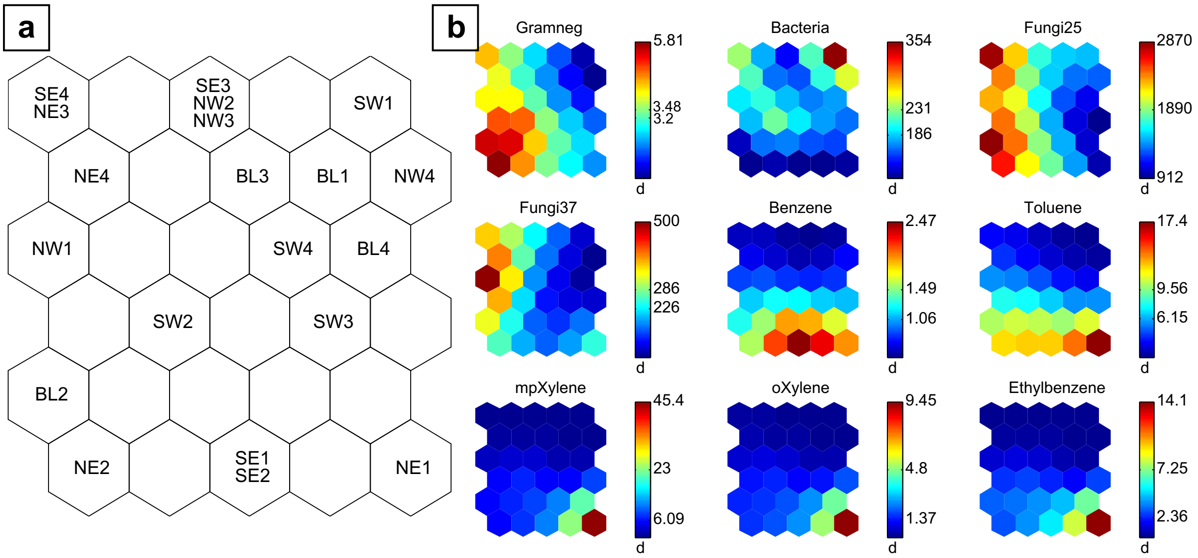

Fig. 2. Kohonen's map (a) and c-planes (b) of the levels of VOCs and bioaerosols in the vicinity of the MSWI of Tarragona.

4. Conclusions

The current concentrations of bioaerosols and VOCs in ambient air of the vicinity of the MSWI of Tarragona are very low in comparison to reported levels in indoor and outdoor air of composting and MBT plants. In addition, these values are in the lower part of the ranges found in ambient air of several urban and industrial zones. No correlations were observed between environmental concentrations of biological agents and the distance from the facility. However, total bacteria showed significantly higher levels downwind. Moreover, a slight non-significant increase of VOCs was detected in sites closer to the incinerator. As above commented, it means that the MSWI could have a very minor impact on the immediate environment. This increase is probably a consequence of the accumulation of waste together with the heavy traffic in the zone. In the future, the seasonal and temporal trends of the airborne pollutants here evaluated will be assessed. In addition, the analysis of odorous VOCs, such as short-chain carboxylic acids and terpenes, as well as skatole, a selective odorous indicator of human feces, will be taken into consideration. Therefore, a complete set of data on baseline levels of VOCs and bioaerosols will be obtained before the MBT plant adjacent to the MSWI starts its regular operations. The compilation of these data, together with those concerning to PCDD/Fs and heavy metals, should allow to carry out a complete human health risk assessment.

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