Emission of volatile organic compounds from composting of different solid wastes: Abatement by biofiltration

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Abstract

Emission of volatile organic compounds (VOCs) produced during composting of different organic wastes (source-selected organic fraction of municipal solid wastes (OFMSW), raw sludge (RS) and anaerobically digested wastewater sludge (ADS) and animal by-products (AP)) and its subsequent biofiltration have been studied. Composting was performed in a laboratory scale composting plant (30 l) and the exhaust gases generated were treated by means of a compost biofilter. VOCs concentration in the composting exhaust gases for each composting process ranged from 50 to 695 mg C m^{-3} for OFMSW (5:1), from 13 to 190 mg C m^{-3} for OFMSW (1:1), from 200 to 965 mg C m^{-3} for RS, from 43 to 2900 mg C m^{-3} for ADS and from 50 to 465 mg C m^{-3} for AP. VOCs emissions were higher during the beginning of the composting process and were not generally related to the biological activity of the process. These emissions corresponded to an average loading rate applied to the biofilter from 2.56 to 29.7 g C m^{-3} biofilter h^{-1}. VOCs concentration in the exhaust gas from the biofilter ranged from 55 to 295 mg C m^{-3} for OFMSW (5:1), from 12 to 145 mg C m^{-3} for OFMSW (1:1), from 55 to 270 mg C m^{-3} for RS, from 42 to 855 mg C m^{-3} for ADS and from 55 to 315 mg C m^{-3} for AP. Removal efficiencies up to 97% were achieved although they were highly dependent of the composted waste. An important observation was that the compost biofilter emitted VOCs with an estimated concentration of 50 mg C m^{-3}.
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1. Introduction

Denomination of volatile organic compounds (VOCs) refers to organic compounds which vapour pressure is at least 0.01 kPa at 20 °C. VOCs are also characterised by their low water solubility. Processes involving solvents, paints or the use of chemicals are the most significant sources of VOCs, however waste and wastewater treatment facilities are also important VOCs producers. The environmental problem caused by the presence of VOCs in gaseous streams is due to the fact that many of them produce bad odours or are hazardous. For this reason VOCs are being subject to increasingly severe constrains; in Europe, for example, VOCs are controlled through the EU Directive 1999/13/EC [1] on the limitation of emissions of volatile organic compounds.

Composting is a technology widely used for the treatment of solid organic wastes. Composting allows wastes to be disposed of by reducing their size and volume. It is an extended technology for treating household wastes, but it is also applied to residuals coming from industrial activities. Municipal or industrial wastewater excess sludge [2] and animal by-products [3] are examples of organic solid wastes susceptible to be composted.

Composting exhaust gases are characterised by high flow rates and, normally, low pollutant concentration, in which VOCs can be found among the major pollutants. Van Durme et al. [4] identified dimethyl sulphide, dimethyl disulphide, limonene and α-pinene as the most significant odorous VOCs at a wastewater sludge composting facility. According to this work, the latter two compounds were released from wood chips used as a bulking agent. Incomplete or insufficient aeration during composting can produce sulphur compounds of intensive smell, while incomplete aerobic degradation processes also result in the emission of alcohols, ketones, esters and organic acids [5]. Eitzer [6]

Table 1
Properties of composted wastes (wb: wet basis; db: dry basis)

Parameter	OFMSW (5:1)	OFMSW (1:1)	RS	ADS	AP
Moisture content (% wb)	46.1	46.7	61.8	62.4	55.0
Organic matter content (% db)	51.5	67.3	57.7	52.5	69.1
pH	6.9	6.1	7.1	7.6	8.0
Electrical conductivity (mS cm^{-1})	2.7	3.0	1.8	2.1	5.6

measured the highest concentration of almost all VOCs in composting plants at the early stages of the composting process.

Among the available options for the treatment of polluted air, biofiltration is an odour reduction technique that can be adapted to reduce emissions from composting processes [7]. Moreover, biofiltration is a biological technique, and is both economically and environmentally viable. It is considered a suitable technology in terms of waste recycling, filtering effect, and at the same time, reduces costs in construction and operational work [8]. In fact, biofiltration is presently used as one of the newest technologies for odour abatement in composting facilities [9,10].

In a biofilter, a contaminated/odorous gas stream passes through a biologically enriched layer of a filter material followed by a biodegradation of the absorbed/adsorbed pollutants. The by-products of microbial oxidation are primary water, carbon dioxide, mineral salts, some volatile organic compounds and microbial biomass [11]. The performance of a biofilter is not uniform and it is influenced by several important variables. Microbial activity is affected by moisture content, pH, nutrient limitation, temperature and microbiology of the biofilter medium [12].

In recent years, a large number of studies have been conducted on VOC biofiltration with several support materials (compost, pine bark, wood chips, peat, inorganic supports or mixed materials) and some hydrophobic and hydrophilic compounds found in different industries [13–16]. Elimination capacities for benzene, toluene and xylene of $60\,\mathrm{g\,C\,m^{-3}}$ biofilter h^{-1} with a removal efficiency of 75% [17] and $18\,\mathrm{g\,C\,m^{-3}}$ biofilter h^{-1} with a removal efficiency of 81% [18] have been reported using organic materials and compost, respectively. However, these studies on biofiltration take only in account the presence of a couple or even a single compound, which is not the normal situation in composting plants, where the composted wastes are variable and heterogeneous.

This work studies VOCs emissions generated during the composting of different organic residues such as source-selected organic fraction of municipal solid wastes (OFMSW), raw sludge (RS), anaerobically digested sludge (ADS) and animal by-products (AP). The abatement of the VOCs generated during the waste composting using the biofiltration technology is also presented.

2. Materials and methods

2.1. Organic wastes composted

OFMSW was obtained from the municipal composting plant of Jorba (Barcelona, Spain); ADS was obtained from the urban wastewater treatment plant of La Llagosta (Barcelona, Spain); RS was obtained from the urban wastewater treatment plant of La Garriga (Barcelona, Spain); and AP, consisting of rejected parts of chicken and rabbit (viscera, carcasses, feathers, etc.), were obtained from the municipal composting plant of Jorba (Barcelona, Spain). All wastes were manually mixed with bulking agents (chopped pruning waste) to ensure an optimal porosity and moisture content. In the case of OFMSW two volumetric ratios of bulking agent:waste (5:1, 1:1) were tested. A volumetric ratio of bulking agent:waste of 1:1 was used for RS and ADS, which was previously found as optimal for sludge composting at laboratory scale [19], and 3:1 for AP, as this is the usual ratio used in the composting plant. The most important parameters of each waste are presented in Table 1.

2.2. Experimental set-up

OFMSW, RS, ADS and AP were composted in this order in a thermally insulated 30 l laboratory reactor. Air was supplied to the reactor intermittently by a suction-type blower (Sensotran, Spain, model GCYA/BA) to control the content of oxygen (Sensotran, Spain, model Sensox 6C) in the composting material to ensure aerobic conditions (oxygen concentration above 10%). The blower extracted the air ($5\,\mathrm{l\,min^{-1}}$) through the compost mass and discharged the exhaust gas to a pilot-scale biofilter filled with mature compost as a biofilter medium (Table 2). Each biofiltration run was performed with the same packing material, as this is the normal operation in a composting plant.

Down-flow direction was selected to improve moisture control in the biofilter and to prevent drying of the material. Since temperature of off-gases from the composting reactor was below 35 °C, it was not necessary to cool down the gas entering the biofilter and thus, it was operated within a mesophilic temperature range throughout the whole experimental period.

Table 2
Properties of biofilter medium before and after the biofiltration period (wb: wet basis; db: dry basis)

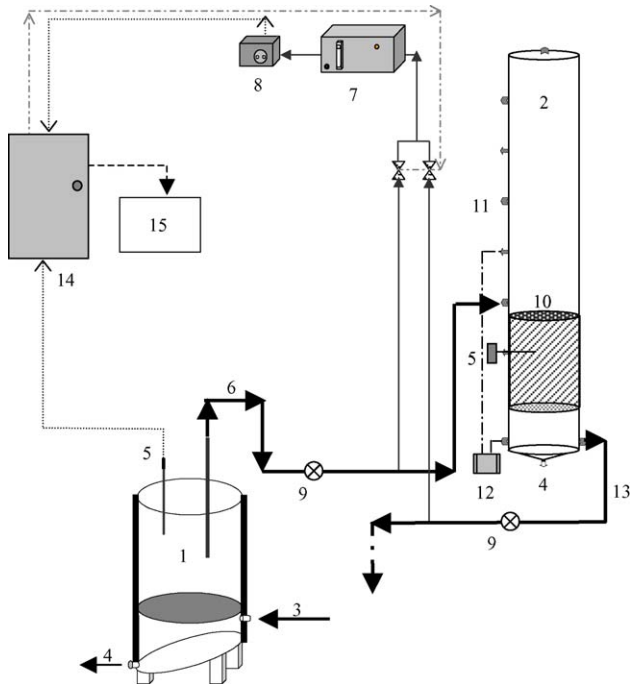| Parameter	Initial	Final
Moisture content (% wb)	40.4	60.8
Organic matter content (% db)	59.7	48.6
pH	8.7	9.0
Electrical conductivity (mS cm^{-1})	3.3	3.9
Kjeldahl-N (% db)	3.5	3.3
NH_4^+-N (% db)	0.3	0.9
C/N	8.7	6.4
Respirometric index (mg O$_2$ g OM^{-1} h^{-1})	1.03	1.82
Pressure drop (mm of water)	nd[a]	17

[a] Not detected.

Fig. 1. Scheme of the pilot scale composting and biofiltration system. (1) Composter; (2) biofilter; (3) air inlet; (4) leachates outlet; (5) temperature probe; (6) exhaust gas from composter and inlet biofilter gas; (7) suction-type blower; (8) oxygen sensor; (9) VOCs sampling ports; (10) compost media; (11) biofilter sampling ports; (12) manometer; (13) outlet biofilter gas; (14) data logger and control system; (15) personal computer.

A scheme of the composting and biofiltration system is shown in Fig. 1.

The biofilter was constructed with circular methacrylate pipe, and its dimensions were: height 1.2 m and diameter 0.2 m. The media depth was 0.23 m, resulting in a total bed volume of 7.2 l, a volumetric loading rate of 41.4 l media^{-1} h^{-1} and a gas retention time of 86 s. Initial properties of the mature compost used as biofilter medium are shown in Table 2.

Temperatures of the composting materials were monitored during the composting period with a Pt100 probe (Desin, Spain, model SR-NOH). All values were displayed and recorded with a personal computer every 30 min using a commercial data logger (Desin, Spain, DAS-8000).

Periodic measures of temperature and pressure drop across the medium were carried out manually using a digital thermometer (Hanna, mod. Checktemp) and a U-type water manometer. Moisture of the biofilter media was also periodically measured and maintained over 45% during all the experiments.

Two runs were conducted for each waste composted, and each run lasted about 1 week. Experiments were carried out continuously for about 2 months. Values of parameters presented in this paper are calculated including all the experiments carried out. In Figs. 2–6 only one replication for each waste is shown.

2.3. Analytical methods

The quantification of volatile organic compounds was obtained by direct injection of 250 µl of sample in a gas chro-
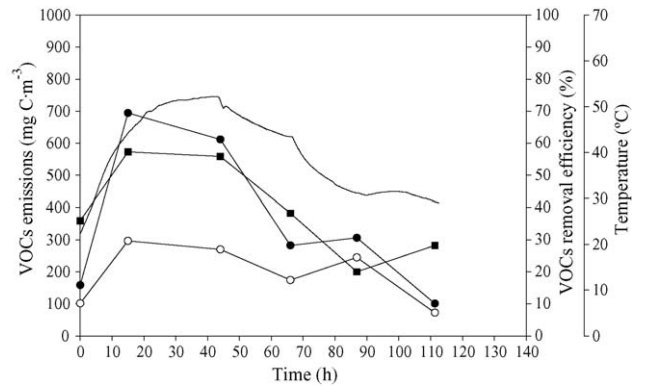

Fig. 2. VOCs emissions in inlet (solid circles) and outlet (circles) gas streams of biofilter, average removal efficiency (squares) and temperature (solid line) of composting process of source-selected organic fraction of municipal solid wastes (5:1).
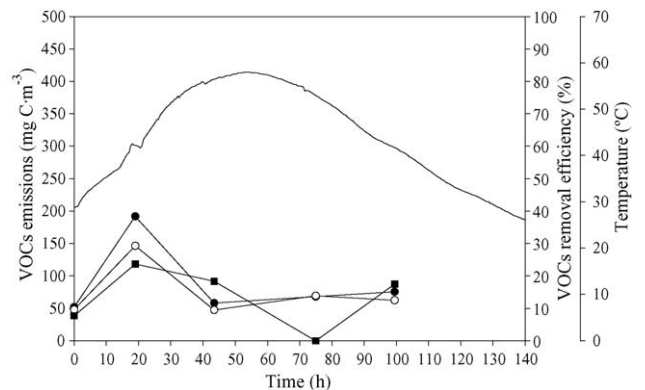

Fig. 3. VOCs emissions in inlet (solid circles) and outlet (circles) gas streams of biofilter, average removal efficiency (squares) and temperature (solid line) of composting process of source-selected organic fraction of municipal solid wastes (1:1).

matograph (Perkin-Elmer Autosystem XL), equipped with a flame ionisation detector (FID) and an HP-Innowax (Agilent Technologies) capillary column (30 m × 0.25 mm × 0.25 µm, poliethylenglycol stationary phase). Column temperature was initially 50 °C maintained for 2 min, and then increased to

Fig. 4. VOCs emissions in inlet (solid circles) and outlet (circles) gas streams of biofilter, average removal efficiency (squares) and temperature (solid line) of composting process of raw sludge.
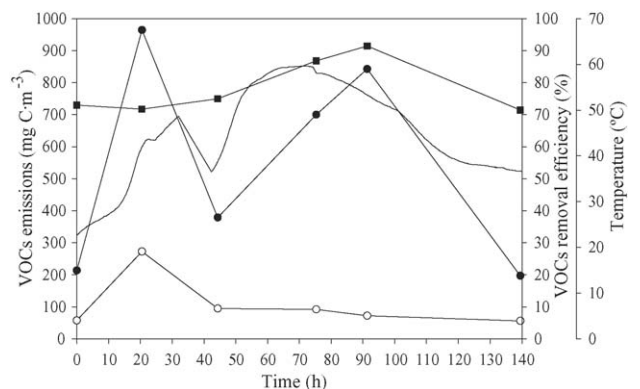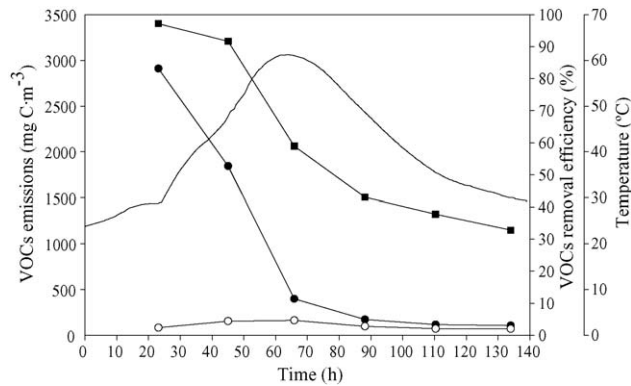
Fig. 5. VOCs emissions in inlet (solid circles) and outlet (circles) gas streams of biofilter, average removal efficiency (squares) and temperature (solid line) of composting process of anaerobically digested wastewater sludge.
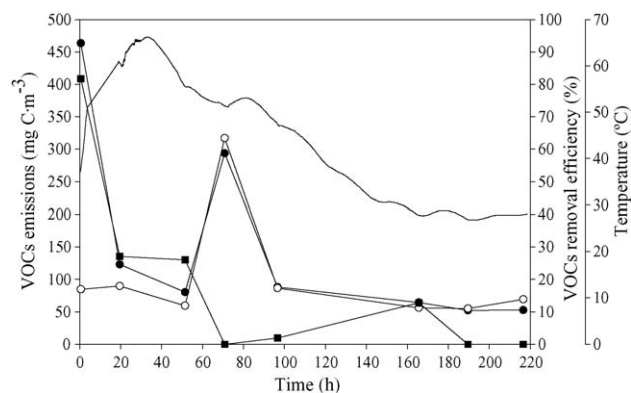

Fig. 6. VOCs emissions in inlet (solid circles) and outlet (circles) gas streams of biofilter, average removal efficiency (squares) and temperature (solid line) of composting process of animal by-products.

200 °C at 45 °C/min, and maintained for 6 min. Injector and detector temperatures were 200 and 250 °C, respectively. Samples were obtained using a syringe and immediately injected into the chromatograph. Sampling points are shown in Fig. 1. Each data point, for both inlet and outlet concentrations, represents the average of three sequential samples collected during a period of 90 min. N-hexane (Scharlau, 99.9% purity) was used to quantify the VOCs concentration in mg C m^{-3} [20]. Calibration curve was obtained by injecting different amounts of liquid n-hexane in a sealed Tedlar bag of known volume and analysing the gas sample [14]. Quantification of total VOCs concentration

was based on total peak area [20]. A triplicate analysis was performed for each VOC concentration and the associated error to the method was below 10%.

Physico-chemical properties of the biofilter compost media and wastes composted were analysed before and after the biofiltration process for the determination of moisture content (MC), organic matter content (OM), Kjeldahl nitrogen and NH_4^+-N content, carbon/nitrogen ratio (C/N), pH, electrical conductivity, and biological activity measured as respirometric index (RI), which measures the rate of oxygen consumption of the biomass and is usually conducted to determine compost stability [2]. These parameters were analysed according to accepted methods [21].

3. Results and discussion

3.1. VOCs emitted during composting

Composting experiments were performed for a period of 2 months. Temperature profiles for each composting experiment are presented in Figs. 2–6. Temperature has been used as the most important indicator of the composting process performance. According to Stentiford et al. [22], a maximum temperature of 55–65 °C is necessary to destroy pathogen microorganisms, but temperatures of 45–55 °C must be maintained for maximum biodegradation. Temperature of the four wastes rose rapidly and reached the thermophilic range within 1 and 2 days. The maximum temperature achieved for OFMSW (5:1), OFMSW (1:1), RS, ADS and AP were 52.2, 58.0, 60.0, 61.2 and 66.2 °C, respectively.

VOCs concentration in the composting exhaust gases along each composting process ranged from 50 to 695 mg C m^{-3} for OFMSW (5:1), from 13 to 190 mg C m^{-3} for OFMSW (1:1), from 200 to 965 mg C m^{-3} for RS, from 43 to 2900 mg C m^{-3} for ADS and from 50 to 465 mg C m^{-3} for AP. Average values are shown in Table 3. As it can be observed, VOCs emissions in composting were highly dependent on the waste to be composted. Also, the biofilter loading rate ranged from an average values of 2.56 to 29.7 g C m^{-3} biofilter h^{-1} for OFMSW (1:1) and ADS, respectively.

As it can be seen in Table 3, there is a significant difference between VOCs concentration emitted by OFMSW (5:1) and OFMSW (1:1) composting. This is of special interest since the only difference between the two composting processes was the

Table 3
VOCs emissions average (before and after biofilter), average and maximum and minimum values (in parenthesis) of loading rate and elimination capacity and removal efficiency range for the five composted wastes

	Average VOCs emissions (mg C m^{-3})		Loading rate (g C m^{-3} biofilter h^{-1})	Elimination capacity (g C m^{-3} biofilter h^{-1})	Removal efficiency (%)
	Before biofilter	After biofilter			
OFMSW (5:1)	237	155	9.83 (2.10–28.8)	3.52 (0–16.5)	0–57
OFMSW (1:1)	61.7	50.7	2.56 (0.55–7.95)	0.61 (0–2.90)	0–60
RS	550	110	22.9 (8.20–40.0)	18.3 (5.84–31.9)	71–91
ADS	716	192	29.7 (1.85–120)	21.7 (0–117)	0–97
AP	150	100	6.25 (2.20–12.0)	2.29 (0–15.7)	0–82

Table 4
VOCs emissions during the composting process

Process stage	Average VOCs concentration (mg C m^{-3})				
	OFMSW (5:1)	OFMSW (1:1)	ADS	RS	AP
Rising to 45 °C	426	122	2910	519	463
Above 45 °C	612	63	804	771	46
Decreasing from 45 °C	229	76	111	197	56

amount of bulking agent used. In both cases the maximum VOCs concentration was achieved in the initial 20 h (Figs. 2 and 3). Since the temperature profile was similar in both processes, the higher emission of VOCs for OFMSW (5:1) can be attributed to the higher content of bulking agent (chopped pruning waste). Some authors [4,10,23,24] have found that terpenes are primarily released from the biodegradable vegetable material used as a bulking agent in composting facilities. Therefore, it can be concluded that a high bulking agent ratio provokes a high VOCs emission.

VOCs emissions are also different when comparing RS and ADS (Table 3). Since in both cases a similar temperature profile was observed (Figs. 4 and 5) and the bulking agent ratio was identical (1:1), sludges can be compared in terms of VOCs emissions. Results obtained indicate high concentration of VOCs emitted during ADS than RS composting (average value of 716 and 550 mg C m^{-3} for ADS and RS, respectively). According to Van Durme [4], VOCs emissions during composting of raw sludge are greater or equal to VOCs emitted during digested sludge composting. However, in our case, higher VOCs concentration was detected for ADS composting. Probably, other factors such as anaerobic digestion efficiency or sludge characteristics may affect VOCs emissions in waste sludge composting. In both cases, the maximum VOCs concentration was achieved in the initial 20 h. However, whereas RS VOCs concentration was maintained around 700 mg C m^{-3} within the initial 90 h, ADS composting VOCs concentration clearly decreased from 3000 to 170 mg C m^{-3}. The causes of these results are not clear, we can either hypothesise that ADS might contain a low amount of VOCs (as the content of organic matter is expected to be low) or that VOCs might be released during the first stage of composting.

Finally, for AP composting (Fig. 6), two peaks of VOCs emission were detected, one at the beginning of the composting process and a second one after 70 h of process time. It should be noted that high temperatures in AP composting were maintained for a longer period and this fact may be the cause of a sustained VOCs emission.

Temperature in a composting process is an indicator of biological activity [25]. For this reason a longer thermophilic period (temperature above 45 °C) implies high biological activity. It is interesting to note that VOCs emitted in the composting of the five wastes investigated do not reveal a dependence on biological activity. According to temperature profile, AP is the waste with the highest activity, followed by RS, OFMSW (1:1), ADS and OFMSW (5:1). However, VOCs concentration emitted during composting of AP were lower than those emitted when compost-ing OFMSW (5:1), ADS or RS. This is an important result since the dependence of emissions of other gases, such as ammonia, with temperature and biological activity has been shown [26].

For each composted waste the VOCs maximum production was obtained in the first 48 h. The composting process can be divided in three stages: rising to 45 °C, above 45 °C (thermophilic range) and decreasing from 45 °C to ambient temperature. Maximum VOCs emissions were detected in the first or second stage (Table 4), but always during the first 48 h. There was no coincidence between maximum VOCs emission and maximum process temperature, which is the period of maximum activity. These results agree with several studies showing that emission of volatile compounds already starts upon arrival of the fresh biowaste to the composting plant [27]. According to Eitzer [6], most of the volatile organic compounds in aerobic composting plants are emitted at early stages of processing, i.e. in the tipping floors where the wastes are discharged, in the shredder, and in the initial active composting area where the temperature increases to 55 °C. It was also observed a decreasing concentration of almost all VOCs from fresh to partially composted material and to cured compost. Other authors [23] found that VOCs emissions during composting of organic fraction of municipal solid wastes decreased along the thermophilic range of temperatures.

3.2. Biofiltration of composting exhaust gases

Exhaust gases produced during different composting processes were treated using a compost biofilter. Biofiltration media was characterised before and after the whole period. Properties of the compost media after filtering operation are shown in Table 2. The OM decreased as the effluent gas from the composting reactor was biofiltered, while the MC and NH$_4^+$-N increased because of the absorption of moisture and ammonia present in the exhaust gas. In the case of moisture, biofilter watering was not necessary as it is reported in other works [25], in which the water-saturated composting exhaust gases are biofiltered. The NH$_4^+$-N increase was also observed in similar experiments where biofilter ammonia loading rate ranged from 0.85 to 67.10 g NH$_3$ m^{-3} biofilter h^{-1} [28]. The value of pH and electrical conductivity did not change significantly. The biological activity of the compost (measured as RI) slightly increased throughout the biofiltration process probably due to a compost reactivation or to the formation of new active biological colonies. This can provoke a simultaneous degradation of the biofilter organic media as it is observed in the decrease of its organic matter content (Table 2).

During the course of the experiments, the biofilter operated at a temperature range from 15 to 26 °C and the pressure drop exhibited an increase of 17 mm H_2O due to the gradual compaction of the packing material. However, the value of the pressure drop did not increase to a critical value during the whole experimental period and no channelling phenomena were visually observed.

VOCs concentration of the exhaust gas from biofilter ranged from 55 to 295 mg C m^{-3} for OFMSW (5:1), from 12 to 145 mg C m^{-3} for OFMSW (1:1), from 55 to 270 mg C m^{-3} for RS, from 42 to 855 mg C m^{-3} for ADS and from 55 to 315 mg C m^{-3} for AP. Average values are shown in Table 3.

Figs. 2–6 describe VOCs concentration in the inlet (composting exhaust gas) and outlet gas stream of biofilter, as well as the resulting removal efficiencies for the five wastes composted. As it can be observed, higher VOCs reductions were obtained during the initial stages of the composting processes, when VOCs emissions reached its maximum value.

Although removal efficiencies above 90% were reached, there were periods in which lower removal efficiencies were obtained. In relation to removal efficiencies, it can be observed that on one hand, poor removal efficiencies were obtained at the final period of the composting processes, when the lowest VOCs emission concentrations were detected. This inefficiency can be due to the fact that the biofilter emitted VOCs by itself. Nicolai and Janni [11] also observed that some VOCs can be produced as by-products of microbial oxidation in biofilters. It was found that at the end of the whole biofiltration period, the compost biofilter released about 50 mg C m^{-3}, as a constant VOCs emission concentration measured during 15 days. This emission level is similar to the VOCs production measured at the final stage of composting processes. This fact must be considered when analysing the performance of VOC biofilters (calculation of operational and design parameters), especially in the case where complex gas samples are treated. On the other hand, during certain periods the biofilter clearly was not able to remove all the VOCs produced during the composting process (i.e. composting AP at 70 h process time, Fig. 6). In this case, low removal efficiencies should be related to the complexity of VOCs mixture emitted and their variability throughout the composting process, affecting their elimination in the biofilter. Removal efficiency reductions were observed by Kim [29] after interchanging the feed VOCs to the biofilter. According to this work, it is commonly observed that microorganisms exposed to a new substrate may require a period of acclimation before they begin vital degradation. This fact is of special interest in the design and operation of compost biofilters for treating exhaust gases in composting plants where different wastes are treated.

The influence of loading rate on elimination capacity and the calculation of the critical loading rate is shown in Fig. 7. The solid line indicates the total elimination of inlet VOCs, whereas experimental data are indicated by symbols. For the calculation of the critical loading rate, experimental points were determined considering the VOCs emissions from biofilter itself and assuming that they were constant with a value of 50 mg C m^{-3}. Efficiencies obtained were highly dependent of
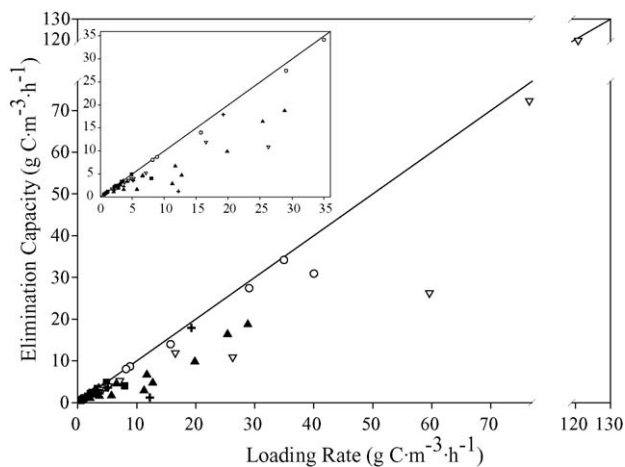

Fig. 7. Average elimination capacity of the compost biofilter for different loading rates of VOCs during composting of source-selected organic fraction of municipal solid wastes 1:1 (solid squares) and 5:1 (solid triangles up), raw sludge (circles), digested wastewater sludge (triangles down) and animal by-products (cross). In-box graphic corresponds to a scale enlargement.

the waste composted and of the type of VOCs emitted during composting. VOCs emitted during OFMSW (1:1) composting were removed with efficiencies above 90% for loading rates up to 5 g C m^{-3} biofilter h^{-1}. However, for OFMSW (5:1) at the same loading rate, only efficiencies up to 80% were obtained, indicating that VOCs emitted were more recalcitrant to degradation. For VOCs emitted during biofiltration of RS, efficiencies above 88% were obtained for loading rates up to 34.0 g C m^{-3} biofilter h^{-1}. However, for ADS exhaust gases biofiltration at loading rates up to 34.0 g C m^{-3} biofilter h^{-1} efficiencies lower than 80% were obtained. This fact can again indicate that the composition of VOCs mixture obtained during the composting of each organic waste has a dramatic effect on the performance of the biofilter. Finally, efficiencies achieved in the biofiltration of exhaust gases from AP composting were generally lower than 30% except from the first points. It is probable that this low efficiency is due to the low inlet VOCs concentration or a lack of acclimation of microorganisms.

Deshusses et al. [30] observed that most of biofilters reached a maximum elimination capacity below 50 g C m^{-3} biofilter h^{-1}. In a similar study, a maximum elimination capacity of 75 g C m^{-3} biofilter h^{-1} was determined by Aizpuru [31], treating an artificial complex VOCs mixture. The compost biofilter studied in this work obtained a maximum elimination capacity of 119.5 g C m^{-3} biofilter h^{-1} at a loading rate of 120.8 g C m^{-3} biofilter h^{-1} (Fig. 7). However, this value cannot be defined as a real maximum elimination capacity for this biofilter. This is due to the fact that elimination capacity is highly dependent on the biofiltered VOCs, which are related to the composted waste and the composting stage.

More research is needed to determine the effect on the biofiltration process when treating complex and variable VOCs coming from different composting processes. Acclimation of microorganisms to variable air streams (in composition and concentration) should be the objective of future works on this field.

4. Conclusions

A compost biofilter was operated during 2 months treating real gases from a laboratory scale composting plant. The overall conclusions from the obtained data can be summarized as:

(1) Biofiltration of VOCs from exhaust gases of composting processes can be performed achieving different efficiencies depending on the waste composted. More sustained removal efficiencies were obtained in the composting of RS.

(2) Significant differences on biofiltration of OFMSW (1:1) and (5:1) were detected. The best results were obtained in the biofiltration of exhaust gases from OFMSW (1:1) composting. This may indicate that the ratio bulking agent:waste affects the VOCs emitted during the composting process and their elimination in the biofilter. The ratio bulking agent:waste should be an important parameter to control VOCs emissions for OFMSW. This parameter will permit to reduce VOCs emissions to be treated in the biofiltration process.

(3) Compost biofilters are emitters of VOCs themselves. Approximately basal emission of $50\,mg\,C\,m^{-3}$ was measured. This fact must be taken into account when calculating the removal efficiency of a biofilter treating complex samples of VOCs, and to evaluate the overall performance of the biofilter.

(4) The highest concentrations of VOCs in the exhaust gases of composting processes were detected during the first 48 h of process time. VOCs emission during composting is not generally related to the biological activity of the process. The maximum VOCs concentration emission did not coincide with the maximum temperature achieved during composting.

(5) Future research lines in this field should be focused on the identification and quantification of single VOCs and the differences found in the VOCs profile from different wastes and composting stages.

Acknowledgement

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