

# Coupling Composting and Biofiltration for Ammonia and Volatile Organic Compounds Removal

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Pre-print of: Pagans, E., Font, X. and Sánchez, A. "Coupling composting and bio-filtration for ammonia and volatile organic compounds removal" in Biosystems engineering (Ed. Elsevier), vol. 97, issue 4 (Aug. 2007), p. 491-500. The final version is available at DOI 10.1016/j.biosystemseng.2007.03.035

## **Abstract**

In this work, the efficiency of a compost biofilter for the simultaneous removal of ammonia and volatile organic compounds (VOCs) from the exhaust gases of the composting process of different organic wastes (source-selected organic fraction of municipal solid wastes and animal by-products) is studied. Average ammonia removal efficiency of 94.7% was obtained in the biofilter for an average loading rate range of 846 to 67100 mg NH<sub>3</sub> m<sup>-3</sup> biofilter h<sup>-1</sup>. However, a sharp reduction in NH<sub>3</sub>-removal was observed when the waste gas contained high (more than 2000 mg/m<sup>3</sup>) NH<sub>3</sub> concentration. Maximum VOCs removal efficiency was 82% when the biofilter worked at a loading rate range of 0.55 to 28.8 g C m<sup>-3</sup> biofilter h<sup>-1</sup>.

## 1. Introduction

At present, solid waste management, and particularly the organic fraction, is becoming a global problem in developed countries. Different technologies are being today applied to reduce landfilling destination of organic wastes. Among them, composting is an environmentally friendly technology that allows treating and recycling organic wastes. It is an extended technology for treating household wastes, but it is also applied to residuals coming from industrial activities. Municipal or industrial wastewater sludge (Gea et al., 2004) and animal by-products (European Compost Network, 2003) are examples of organic solid wastes susceptible to composting.

However, there are some problems associated with composting of organic wastes in large-scale facilities. Odour emissions and atmospheric pollution are the most common. Composting plants present numerous odour sources, including the reception and handling of materials, active composting, stock piling, etc. Gaseous emissions in composting facilities are normally composed of nitrogen based compounds, sulphur based compounds and a wide group named Volatile Organic Compounds (VOCs).

Among the nitrogen based compounds released to atmosphere, ammonia has received much attention as it can be easily identified from other composting odours, often represents the main nitrogen gas emitted during composting and it can be released in large amounts. Ammonia emissions are related to protein, urea or uric acid degradation during composting (Hansen et al., 1990). In this process, pH, temperature and moisture content determine the  $\text{NH}_3/\text{NH}_4^+$  balance and hence the ammonia emission. Ammonia emissions in a composting process of organic fraction

of municipal solid wastes varies between 18 to 150 g NH<sub>3</sub>/t waste (Clemens & Cuhls, 2003), while ammonia concentrations up to 700 mg NH<sub>3</sub>/m<sup>3</sup> have been reported in exhaust gases from sludge composting (Haug, 1993).

Another major group of gaseous pollutants emitted in composting facilities are VOCs, in reference to a wide group of organic compounds which vapour pressure is at least 0.01 kPa at 20°C (European Commission, 1999). VOCs are also characterised by their low water solubility. According to Eitzer (1995), most VOCs in aerobic composting plants are emitted at the early stages of process *i.e.* at the tipping floors, at the shredder and in the initial active composting area. Van Durme et al. (1992) identified dimethyl sulphide, dimethyl disulphide, limonene and  $\alpha$ -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 (Homas et al., 1992). Eitzer (1995) measured the highest concentration of almost all VOCs in composting plants at the early stages of the composting process.

To avoid atmospheric contamination, exhaust gases from composting should be treated before their release to atmosphere. Among the available technologies for gas treatment, biofiltration is an odour reduction technique (Sheridan et al., 2002) that can be adapted to reduce emissions from composting processes (Hong & Park, 2004). It is considered a suitable technology in terms of waste recycling, filtering effect, and low construction and operating costs (Lang & Lager, 1992). In a biofilter, a contaminated/odorous gas stream passes through a biologically enriched layer of a filter material such as soil, wood chips, compost or mixed materials, followed by a

biodegradation of the absorbed/adsorbed pollutant. The by-products of microbial oxidation are primarily water, carbon dioxide, mineral salts, some volatile organic compounds and microbial biomass (Nicolai & Jani, 2001). The quality of the filter media has been reported as one of the key factors in biofilter performance. Compost-based media have been extensively used in recent years because they are cheap and have several microbial communities capable of degrading various pollutants. Furthermore, additional nutrients are not usually required for biofilters based on compost because it has significant amounts of organic nitrogen and other micronutrients.

Biofilters permit a high removal of ammonia, usually around 95-98% on a wide variety of support materials, either organic or inorganic (Busca & Pistarino, 2003). Liang et al. (2000) investigated the long-term ammonia removal using a compost biofilter and achieving removal efficiencies above 95% with loads ranging from 0.33 to 16.25 mg NH<sub>3</sub> kg media<sup>-1</sup> h<sup>-1</sup> and empty bed retention time (EBRT) ranging from 31.8 to 78 s. Other studies on biofiltration of exhaust gases in composting facilities indicate reductions of 98% for an average loading rate of 10180 mg NH<sub>3</sub> m<sup>-3</sup> biofilter h<sup>-1</sup> and an EBRT of 16 s (Park et al., 2002).

VOCs biofiltration is being frequently studied using two or three mixed compounds or even a single compound. Studies are being 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 (Aizpuru et al., 2003; Torkian et al., 2003). Elimination capacities for benzene, toluene and xylene of 60 g C m<sup>-3</sup> biofilter h<sup>-1</sup> with a removal efficiency of 75% (Seed & Corsi, 1996) and 18 g C m<sup>-3</sup> biofilter h<sup>-1</sup> with a removal efficiency of 81% (Thomson et al., 1996) have been reported using organic

materials and compost respectively. However, biofiltration of a polluted gas with a complex mixture of VOCs is rarely reported.

This work studies the efficiency of a compost biofilter for the simultaneous removal of ammonia and volatile organic compounds (VOCs) from the exhaust gases of the composting of source-selected organic fraction of municipal solid wastes (OFMSW) and animal by-products (AP).

## **2. Materials and methods**

### *2.1 Organic wastes composted*

Both wastes (OFMSW and AP) were obtained from the municipal composting plant of Jorba (Barcelona, Spain). AP consisted of rejected parts of chicken and rabbit (viscera, carcasses, feathers, etc.). 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 3:1 was used 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 and AP were composted 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 l/min) through the compost mass and discharged the exhaust gas to a pilot-scale biofilter filled with mature compost as a biofilter medium (Table 2). Compost was selected as biofilter

material since it is naturally inoculated with a wide variety of indigenous microorganisms capable of degrading substrates in the exhaust gases of the composting processes. This fact will improve biomass adaptation by reducing the start up period. No replacement of the biofilter material was performed during the experimental period as this is the normal operation of full-scale biofilters.

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. A scheme of the composting and biofiltration system is shown in Figure 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 l media<sup>-1</sup> h<sup>-1</sup> 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 minutes 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.

Experiments were carried out during a period of two months. Within this period exhaust gases from different successive composting batch processes were biofiltered. The inactive periods were not significant. Two runs were conducted for each waste composted, and each run lasted about 1 week. In addition to OFMSW and AP other wastes were composted (data not shown). OFMSW and AP were selected among the wastes composted because of the characteristics of these residues, such as N content and C/N ratio, are significantly different (Table 1). The biofiltration period (two months) was initiated with the OFMSW composting exhaust gases. AP composting exhaust gases were biofiltered at the end of the period.

Values of parameters presented in this paper are calculated including all the experiments carried out. In Figures 2 and 3 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  $\mu\text{l}$  of sample in a gas chromatograph (Perkin Elmer Autosystem XL), equipped with a flame ionisation detector (FID) and a HP-Innowax (Agilent Technologies) capillary column (30m x 0.25mm x 0.25  $\mu\text{m}$ , poliethylenglycol stationary phase). Column temperature was initially 50°C maintained for 2 minutes, and then increased to 200°C at 45°C/min, and maintained for 6 minutes. Injector and detector temperatures were 200°C and 250°C respectively. Samples were obtained using a syringe and immediately injected into the chromatograph. Sampling points are shown in Figure 1. Each data point, for both inlet and outlet concentrations, represents the average of three sequential samples collected during a period of 90 minutes being the variability in the range of 10-20%. N-hexane (Scharlau, 99.9% purity) was used to quantify the VOCs concentration in  $\text{mg C/m}^3$  (Spigno et al.,



2003). 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 (Torkian et al., 2003). Quantification of total VOCs concentration was based on total peak area (Spigno et al., 2003). A triplicate analysis was performed for each VOC concentration and the associated error to the method was below 10%.

Ammonia emissions were measured online by an electrochemical gas sensor (Bionics Instrument Co, Tokyo, Japan). Values of elimination capacity and removal efficiency are presented as an average of 6 values obtained during a period of 3 hours being the variability in the range of 10-20%.

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  $\text{NH}_4^+$ -N content, total 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 (Gea et al., 2004). These parameters were analyzed according to accepted methods (U.S. Department of Agriculture and U.S. Composting Council, 2001).

### **3. Results and discussion**

#### *3.1 Biofilter media: initial and final characterization*

Exhaust gases produced during different composting processes were treated using a compost biofilter. Biofiltration media was characterised before and after the entire period of two months (Table 2). The OM decreased as the effluent gas from the composting reactor was biofiltered. Although the loss of OM is high, it is expected

a stabilization of the final content of OM as it is typical in mature compost (Gea et al., 2004). The MC and  $\text{NH}_4^+\text{-N}$  increased because of the absorption of moisture and ammonia present in the exhaust gas. However, the ammonia increase detected in the biofilter media is not significant when compared the total ammonia treated by the biofilter. In the case of moisture, biofilter watering was not necessary as it is reported in other works (Haug, 1993), in which the water-saturated composting exhaust gases are biofiltered. 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<sub>2</sub>O 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.

### *3.2. Composting processes evolution*

During composting temperature was used as the most important indicator of the composting process performance. According to Stentiford et al., (1998), a maximum temperature of 55 to 65°C is necessary to destroy pathogen microorganisms, but temperatures of 45 to 55°C must be maintained for maximum biodegradation. Temperature profiles observed (Figures 2 and 3) correspond to a typical evolution of a laboratory scale composting process, reaching in all cases the

thermophilic range in one to two days. The maximum temperature achieved for OFMSW (5:1), OFMSW (1:1), AP were 52.2°C, 58.0°C, and 66.2°C, respectively.

### 3.3 Ammonia biofiltration

Ammonia emissions were quantified in the composting of the different wastes studied. Results are shown in Figures 2a, 2b, 2c. In all cases, a peak in the ammonia emissions was observed in coincidence with the thermophilic stage. Ammonia emissions and its relationship with composting process have been studied by the authors indicating that a direct correlation with temperature can be determined (Pagans et al., 2006a).

In reference to the biofilter start-up, no delay phase was observed for the removal of ammonia, probably due to the high ammonia adsorption and absorption capacity of the compost media and the large variety of adapted microorganisms capable of degrading products contained in the exhaust gases of the composting process.

In order to compare the obtained results, the experimental time sequence must be considered (see Materials and Methods section) since some differences in the adaptation of microorganisms could be found during the experimental period.

The ammonia inlet concentration ranges from 16 to 36 mg NH<sub>3</sub>/m<sup>3</sup> for OFMSW (5:1), from 5 to 530 mg NH<sub>3</sub>/m<sup>3</sup> for OFMSW (1:1) and from 60 to 3150 mg NH<sub>3</sub>/m<sup>3</sup> for AP. The highest ammonia emissions were observed during composting of AP due to their high initial nitrogen content (4.3% in comparison to those found in OFMSW which was 2.2%), especially proteins, that are easily biodegradable. The low ammonia losses obtained during composting of OFMSW (5:1) could be related to the high C/N ratio of the mixture, which is one of the main factors controlling NH<sub>4</sub><sup>+</sup> availability of the raw composting material (Peigné & Girardin, 2004).

The exhaust gases from the biofilter ranges from 0 to 1 mg NH<sub>3</sub>/m<sup>3</sup> for OFMSW (5:1), from 0 to 39 mg NH<sub>3</sub>/m<sup>3</sup> for OFMSW (1:1), and from 30 to 590 mg NH<sub>3</sub>/m<sup>3</sup> for AP. The comparison of cumulative ammonia emissions before and after biofiltration, loading rate and elimination capacity for the four composted wastes are shown in Table 3. Ranges corresponding to loading rate and, consequently, those corresponding to elimination capacity, are due to the evolution of ammonia emission during composting process. As it can be observed, removal efficiencies over 95% were obtained for OFMSW exhaust gases treatment. Concretely, a global removal efficiency of 98.8% was obtained at a global loading rate of 846 mg NH<sub>3</sub> m<sup>-3</sup> biofilter h<sup>-1</sup> (day 0-5 for OFMSW (5:1)) and a global removal efficiency of 95.9% was obtained at a global loading rate of 7500 mg NH<sub>3</sub> m<sup>-3</sup> biofilter h<sup>-1</sup> (day 0-6 for OFMSW (1:1)). Even increasing the global loading rate to 67100 mg NH<sub>3</sub> m<sup>-3</sup> biofilter h<sup>-1</sup> (day 0-4 for AP), the removal efficiency only slightly decreased to a global value of 89.5%. However, for AP from day 4 on, the removal efficiency in the biofilter strongly dropped to an average value of 46.7% (ranging from 90% at the beginning of this period to some values well below 30% at the end of this period).

This phenomenon may be explained by an inhibition of microbial activity by waste gases containing high ammonia concentrations (>2000 mg/m<sup>3</sup>). According to Hartikainen et al. (1996) toxification of the biofilter can cause a drop in the removal efficiency for ammonia at a waste gas concentration level exceeding 45-50 mg NH<sub>3</sub>/m<sup>3</sup>. On the contrary, Smet et al. (2000) reported no toxicity effect of ammonia on the nitrifying activity of the biofilter even at ammonia concentrations up to 550 mg NH<sub>3</sub>/m<sup>3</sup>. However, a recent study on the modelization of ammonia biofiltration, has reported that high concentrations of free ammonia in the support material can strongly inhibit the biological activity of a biofilter (Baquerizo et al., 2004).

Furthermore other causes should be considered, such as reaching the maximum adsorption and absorption capacity of the biofilter or ammonia mass transfer limitations (Kim & Deshusses, 2002).

The dependence of ammonia removal rate on loading rate is shown in Figure 4. The solid line indicates the total elimination of inlet ammonia, whereas experimental data are indicated by symbols. The maximum ammonia elimination capacity of the biofilter was  $85200 \text{ mg NH}_3 \text{ m}^{-3} \text{ biofilter h}^{-1}$  at a loading of  $96800 \text{ mg NH}_3 \text{ m}^{-3} \text{ biofilter h}^{-1}$ . The critical load was  $27000 \text{ mg NH}_3 \text{ m}^{-3} \text{ biofilter h}^{-1}$ . From this value there is a drop of the ammonia removal efficiency and the trend line of observation points flattens, relative to the diagonal, which is typical behavior of biofilters when operating above critical load conditions (Devinny et al., 1999). However, when the system became saturated or biological activity was inhibited (day 4-9 for AP), it was not capable of eliminating influent loads lower than the estimated critical load. This fact should be taken into account in the design of biofilters treating high ammonia loading rates, especially in composting plants, where operational conditions and wastes composted can be variable.

#### *3.4. VOCs biofiltration*

VOCs emissions were quantified in the composting of the different wastes studied. Results are shown in Figures 3a, 3b and 3c. VOCs concentration in the composting exhaust gases along each composting process ranged from 50 to  $695 \text{ mg C/m}^3$  for OFMSW (5:1), from 13 to  $190 \text{ mg C/m}^3$  for OFMSW (1:1) and from 50 to  $465 \text{ mg C/m}^3$  for AP. Average values are shown in Table 4. As it can be observed, VOCs emissions in composting were dependent on the waste to be composted. This fact has also been observed in the composting of other wastes (Pagans et al., 2006b). Also, the biofilter loading rate ranged from an average value of  $2.56 \text{ g C m}^{-3}$

biofilter  $\text{h}^{-1}$  to  $9.83 \text{ g C m}^{-3} \text{ biofilter h}^{-1}$  for OFMSW (1:1) and OFMSW (5:1) respectively.

VOCs concentration of the exhaust gas from biofilter ranged from 55 to 295  $\text{mg C/m}^3$  for OFMSW (5:1), from 12 to 145  $\text{mg C/m}^3$  for OFMSW (1:1) and from 55 to 315  $\text{mg C/m}^3$  for AP. Average values are shown in Table 4.

Figures 3a, 3b and 3c 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. 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 (2001) 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  $50 \text{ mg C/m}^3$ , 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 analyzing 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 was not able to remove all the VOCs produced during the composting process (i.e. composting AP at 70 h process time, Figure 3c). 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 et al. (2004) 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 Figure 5. 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  $50 \text{ mg C/m}^3$ . Efficiencies obtained were highly dependent of 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  $5 \text{ g C m}^{-3} \text{ biofilter h}^{-1}$ . 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. 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.

The compost biofilter studied in this work obtained a maximum elimination capacity of  $18.70 \text{ g C m}^{-3} \text{ biofilter h}^{-1}$  at a loading rate of  $28.83 \text{ g C m}^{-3} \text{ biofilter h}^{-1}$ . However, this value can not 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.

### *3.5 Simultaneous biofiltration of ammonia and VOCs*

Results presented in Figures 2 and 3 indicate that biofiltration of ammonia and VOCs can be performed simultaneously with different level of success. Removal efficiencies obtained for ammonia are higher and more constant than those obtained for VOCs (Tables 3 and 4).

Although microbial communities responsible of the degradation of ammonia and VOCs are different, results obtained do not discard the interaction between the degradation of both pollutants. Morales et al. (1998) observed higher toluene elimination capacities after gaseous ammonia addition and Malhautier et al. (2003) reported some negative effects on microbial communities when simultaneous  $\text{NH}_3$  and  $\text{H}_2\text{S}$  elimination occurred in biofilters. In the present study, VOCs removal efficiency for AP composting gases was low, and it was attributed to the complexity of VOCs emitted or to a lack of acclimation. However, a global analysis of the process shows that this low VOCs removal efficiency coincides with a high ammonia emission in the composting process, and so, with a high ammonia loading rate and a rise in pH, which could be inhibitory for both ammonia and VOCs degrading communities.

There are different possibilities to overcome the problems of low efficiency in industrial composting plants: firstly, to increase the gas retention time of the biofilter or, if there is no space available, to include a previous absorption process for ammonia removal. Nevertheless, the final selection of these options should be based on technical en economic considerations.



Although the coexistence of VOCs and ammonia is found in a large number of emissions, there is a lack of research concerning the interactions caused by these mixtures. Biofilter performance appears to be limited by competitive inhibition, product toxicity, pH changes, acclimation approach, etc. For instance, multicomponent inhibition has been observed in biofilters treating a mixture of different VOCs. Inhibition was attributed to the nature of the chemical components, suppression effects on microbial communities, or complex contaminant-contaminant interactions (Mohseni & Allen, 2000; Liu et al., 2002; Ikemoto et al., 2006). Therefore, more research is needed to study interactions between contaminant biodegradation and its effect on microbial communities when the gaseous effluent is a pollutant mixture (i.e. composting emissions).

#### **4. Conclusions**

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

1. Biofiltration technology, using compost as biofilter media, can simultaneously remove part of the ammonia and VOCs contents of gases coming from the composting process of source-selected organic fraction of municipal solids wastes and animal by-products.
2. Emissions of ammonia and VOCs during composting process depend on the waste composted, which at the same time affects biofilter performance.

3. No start-up phase in the biofilter was observed for the removal of ammonia probably due to the high ammonia adsorption and absorption capacity of the compost media.
4. In the case of animal by-products, only a partial removal of ammonia was obtained due to the high ammonia emissions. This is an important observation with regard to the biofiltration of composting gases with high ammonia concentrations.
5. Compost biofilters are emitters of VOCs themselves. Approximately basal emission of 50 mg C/m<sup>3</sup> was measured in this study. 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.
6. Future research lines in this field should be focused on the interaction of microbial communities when different pollutants are being biofiltered.

### **Acknowledgements**

The authors wish to thank the financial support provided by the Spanish Ministerio de Ciencia y Tecnología (Projects REN2003-00823 and PPQ2000-0645-C02-01), with FEDER support.

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## TABLES

**Table 1:** Properties of composted wastes (OFMSW: Organic Fraction of Municipal Solid Wastes; AP: Animal by-products; wb: wet basis; db: dry basis).

Parameter	OFMSW	OFMSW	AP
	(5:1)	(1:1)	
Moisture content (% wb)	46.1	46.7	55.0
Organic matter content (% db)	51.5	67.3	69.1
pH	6.9	6.1	8.0
Electrical conductivity (mS/cm)	2.7	3.0	5.6
N-Kjeldahl (% db)	1.3	2.2	4.3
C/N ratio	22	17	8.8



**Table 2:** Properties of biofilter medium before and after the two months 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)	3.3	3.9
N-Kjeldahl (% db)	3.5	3.3
N-NH <sub>4</sub> <sup>+</sup> (% db)	0.3	0.9
C/N	8.7	6.4
Respirometric index (mg O <sub>2</sub> ·g OM <sup>-1</sup> ·h <sup>-1</sup> )	1.03	1.82
Pressure drop (mm of water column)	nd*	17

\*nd: not detected

**Table 3:** Cumulative ammonia emissions (before and after biofilter), average and maximum and minimum values (in parenthesis) of loading rate and elimination capacity and removal efficiency range for the three composted wastes (OFMSW: Organic Fraction of Municipal Solid Wastes; AP: Animal by-products).

	Cumulative NH <sub>3</sub> emissions (mg NH <sub>3</sub> /m <sup>3</sup> )		Loading Rate (mg NH <sub>3</sub> m <sup>-3</sup> biofilter h <sup>-1</sup> )	Elimination Capacity (mg NH <sub>3</sub> m <sup>-3</sup> biofilter h <sup>-1</sup> )	Removal Efficiency (%)
	Before biofilter	After biofilter			
OFMSW (5:1)	773	11.3	846 (669-1520)	829 (667-1480)	98.8 (96.4-100)
OFMSW (1:1)	6310	289	7500 (200-22000)	7170 (200-20300)	95.9 (88.6-100)
AP (day 0-4)	53400	4580	67100 (2650-140000)	61300 (1330-100000)	89.5 (50.2-97.9)
(day 4-9)	36100	15300	37500 (18000-72000)	21700 (0-62000)	46.7 (0-88.2)

**Table 4:** 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 three composted wastes (OFMSW: Organic Fraction of Municipal Solid Wastes; AP: Animal by-products).

	Average VOCs emissions (mg C/m <sup>3</sup> )		Loading Rate (g C m <sup>-3</sup> biofilter h <sup>-1</sup> )	Elimination Capacity (g C m <sup>-3</sup> biofilter h <sup>-1</sup> )	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
AP	150	100	6.25 (2.20-12.0)	2.29 (0-15.7)	0-82

## LEGEND TO FIGURES

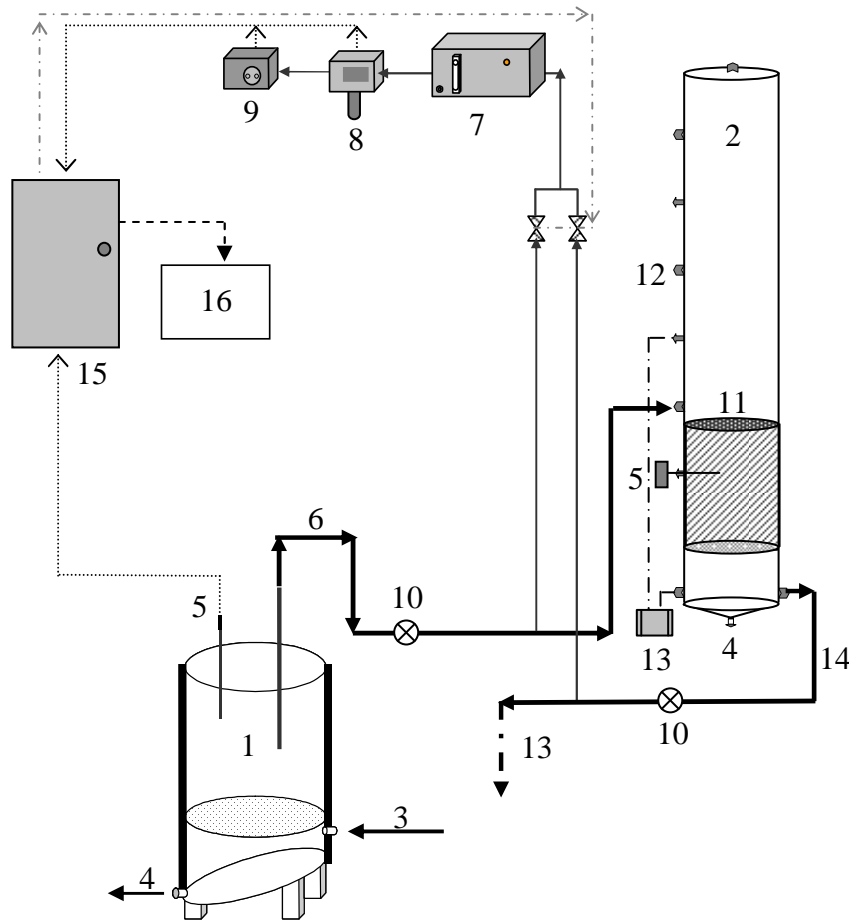
**Figure 1:** Scheme of the pilot scale composting and biofiltration system. 1-Composter; 2-Biofilter; 3-Air inlet; 4-Leachates outlet; 5-Temperature probe; 6-Exhaust gas from composter and inlet biofilter gas; 7-Suction type-blower; 8-Ammonia sensor; 9-Oxygen sensor; 10-VOCs sampling ports; 11-Compost media; 12-Biofilter sampling ports; 13-Manometer; 14-Outlet biofilter gas; 15-Data logger and control system; 16-Personal computer.

**Figure 2:** Ammonia emissions in inlet (circles) and outlet (triangles) gas streams of biofilter, average removal efficiency (squares) and temperature (solid line) of composting process of: **a)** source-selected organic fraction of municipal solid wastes (5:1); **b)** source-selected organic fraction of municipal solid wastes (1:1); **c)** animal by-products.

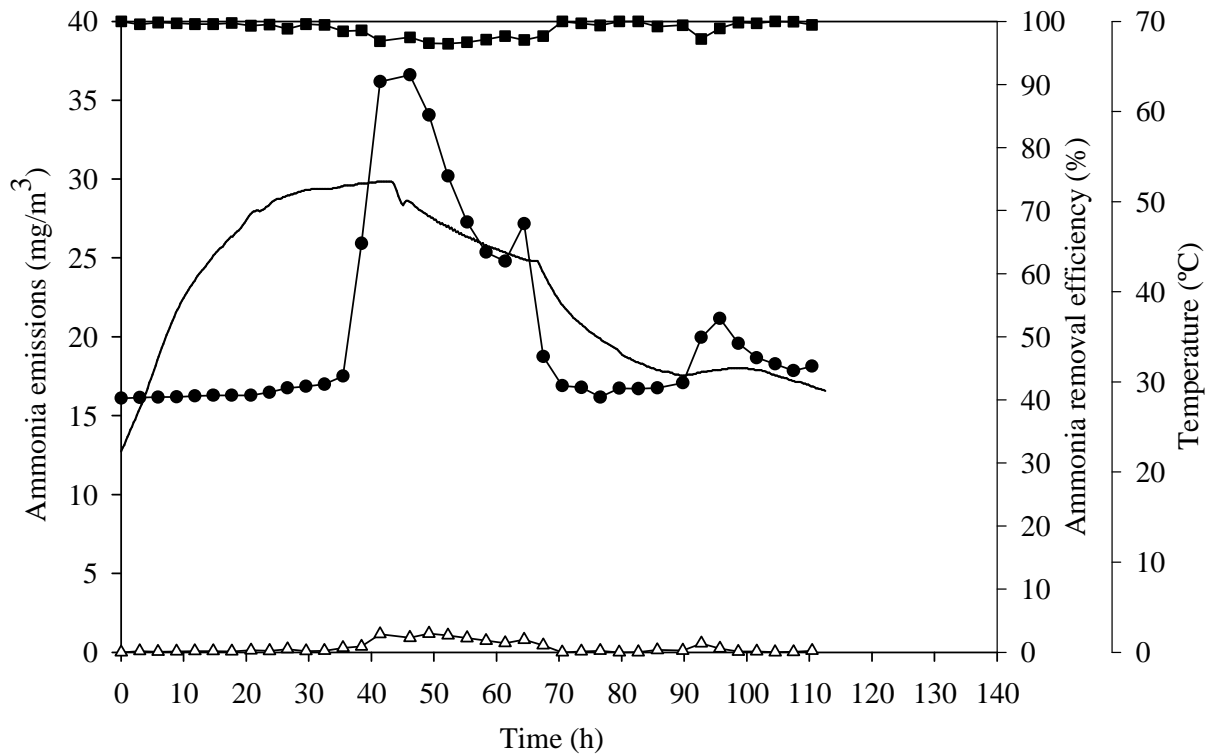
**Figure 3:** VOCs emissions in inlet (solid circles) and outlet (circles) gas streams of biofilter, average removal efficiency (squares) and temperature (solid line) of composting process of: **a)** source-selected organic fraction of municipal solid wastes (5:1); **b)** source-selected organic fraction of municipal solid wastes (1:1); **c)** animal by-products.

**Figure 4:** Average elimination capacity of the compost biofilter for different loading rates during composting of source-selected organic fraction of municipal solid wastes and animal by-products (day 0-4) (circles), and during composting of animal by-products (day 4-9) (triangles).

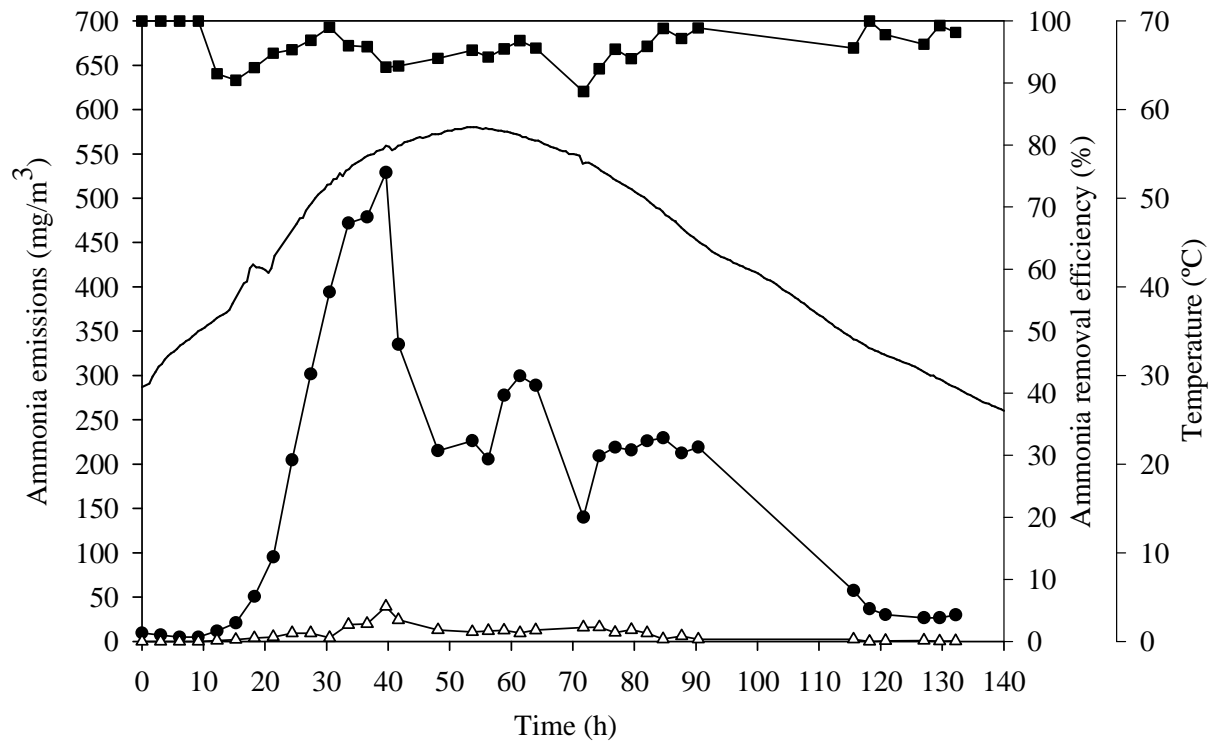
**Figure 5:** Average elimination capacity of the compost biofilter for different loading rates of VOCs during composting of source-selected organic fraction of municipal solid wastes 1:1 (squares), 5:1 (triangles) and animal by-products (cross).



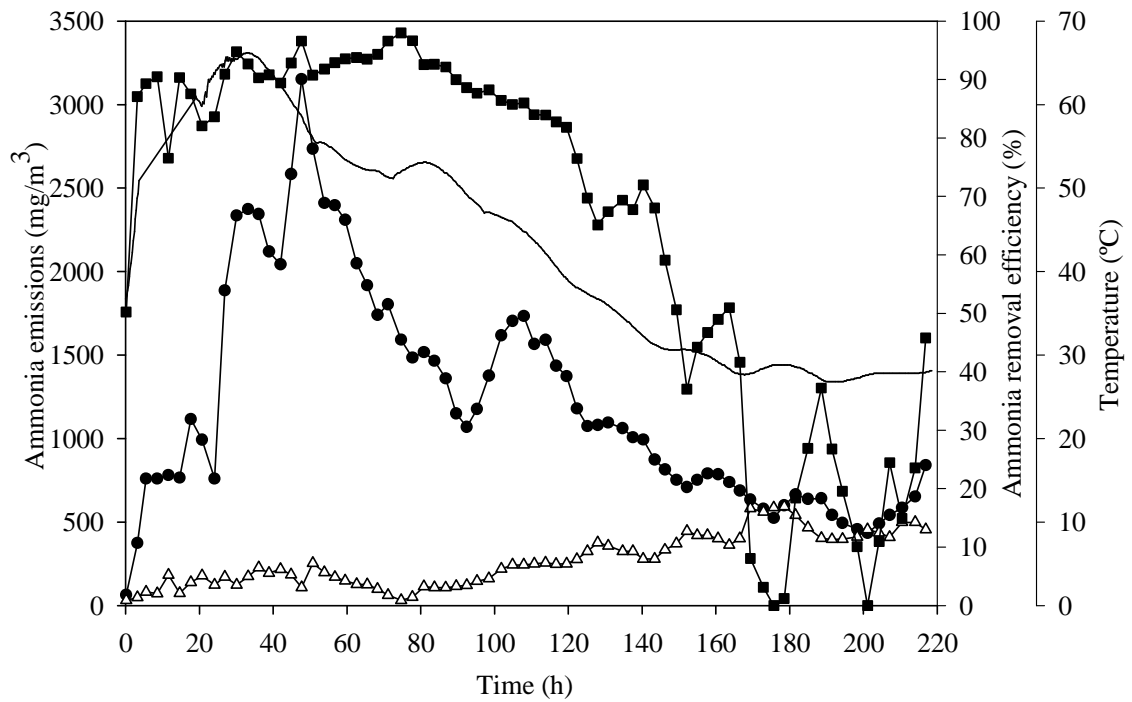
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**Figure 2a:** Ammonia emissions in inlet (circles) and outlet (triangles) gas streams of biofilter, average removal efficiency (squares) and temperature (solid line) of composting process of: **a)** source-selected organic fraction of municipal solid wastes (5:1); **b)** source-selected organic fraction of municipal solid wastes (1:1); **c)** animal by-products.

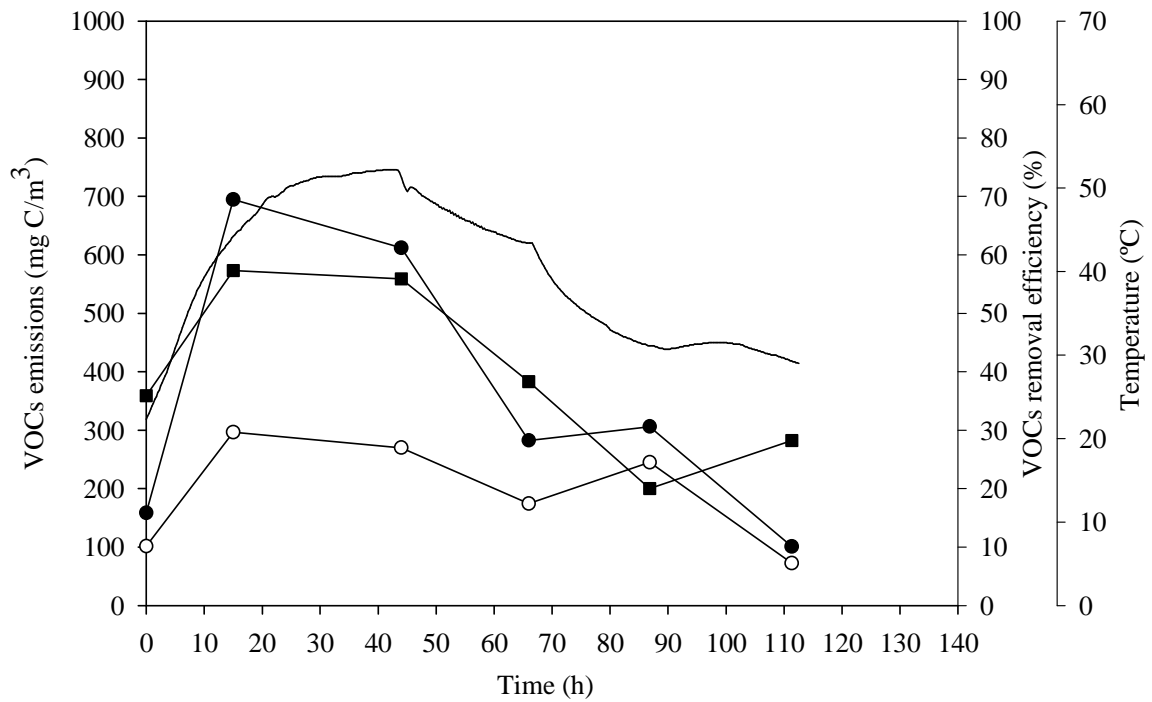


**Figure 2b:** Ammonia emissions in inlet (circles) and outlet (triangles) gas streams of biofilter, average removal efficiency (squares) and temperature (solid line) of composting process of: **a)** source-selected organic fraction of municipal solid wastes (5:1); **b)** source-selected organic fraction of municipal solid wastes (1:1); **c)** animal by-products.

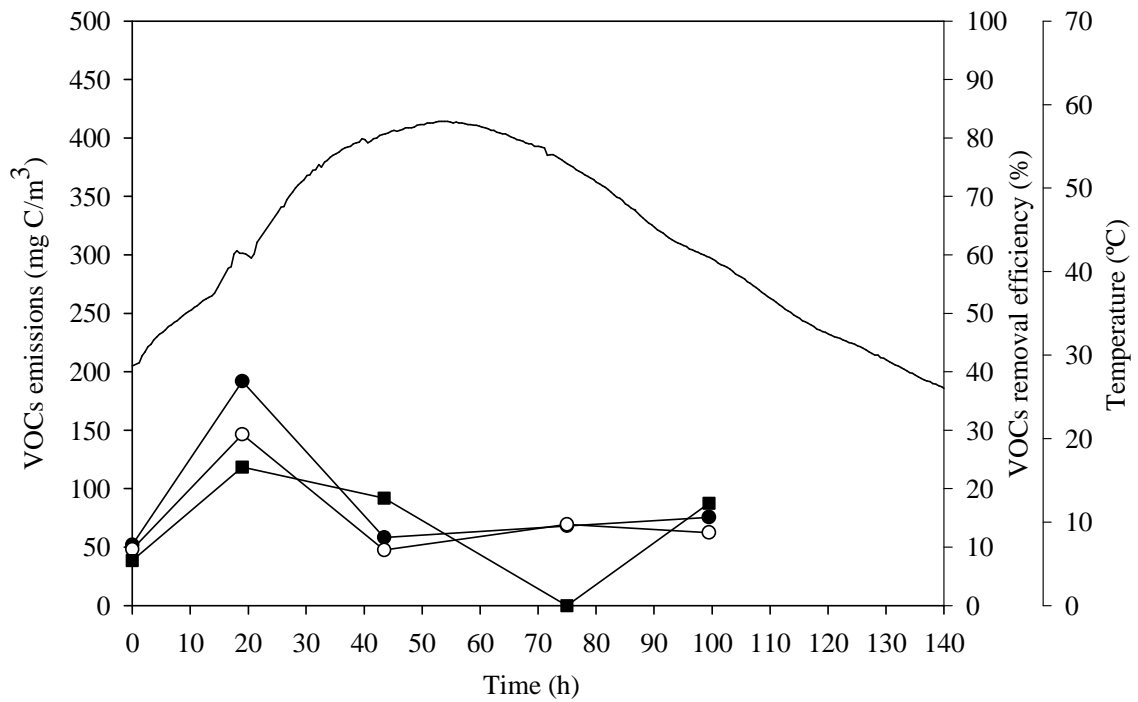


**Figure 2c:** Ammonia emissions in inlet (circles) and outlet (triangles) gas streams of biofilter, average removal efficiency (squares) and temperature (solid line) of composting process of: **a)** source-selected organic fraction of municipal solid wastes (5:1); **b)** source-selected organic fraction of municipal solid wastes (1:1); **c)** animal by-products.

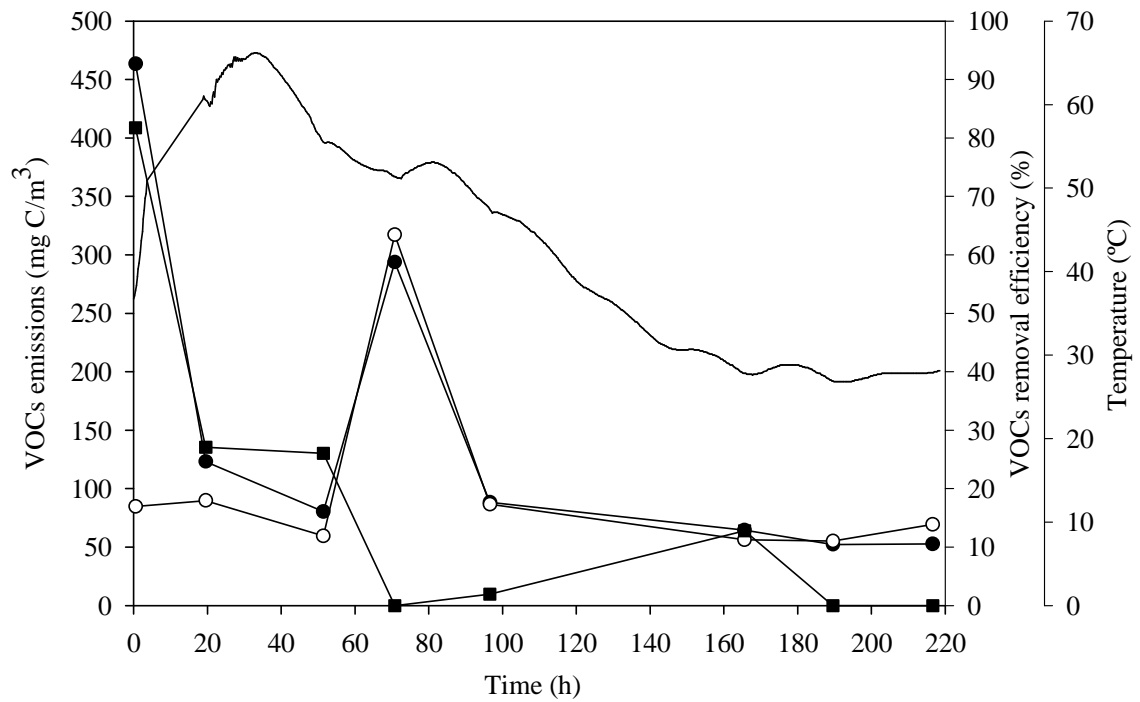




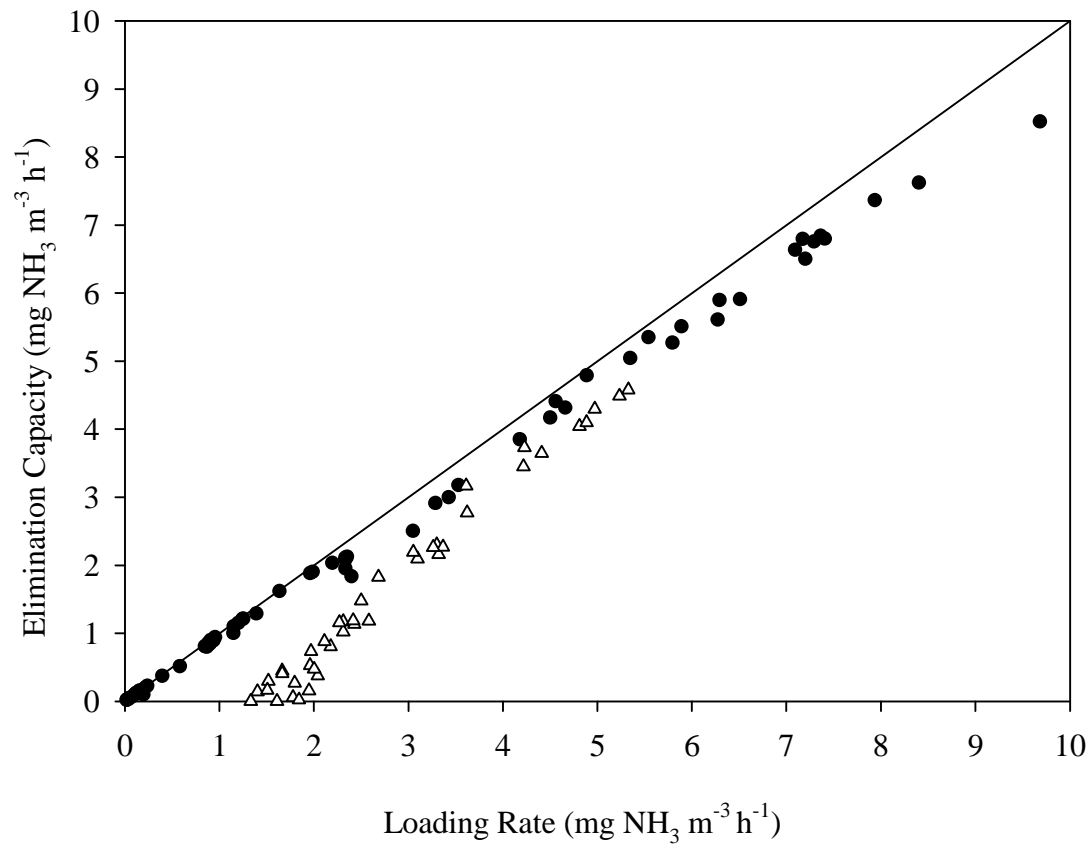
**Figure 3a:** VOCs emissions in inlet (solid circles) and outlet (circles) gas streams of biofilter, average removal efficiency (squares) and temperature (solid line) of composting process of: **a)** source-selected organic fraction of municipal solid wastes (5:1); **b)** source-selected organic fraction of municipal solid wastes (1:1); **c)** animal by-products.



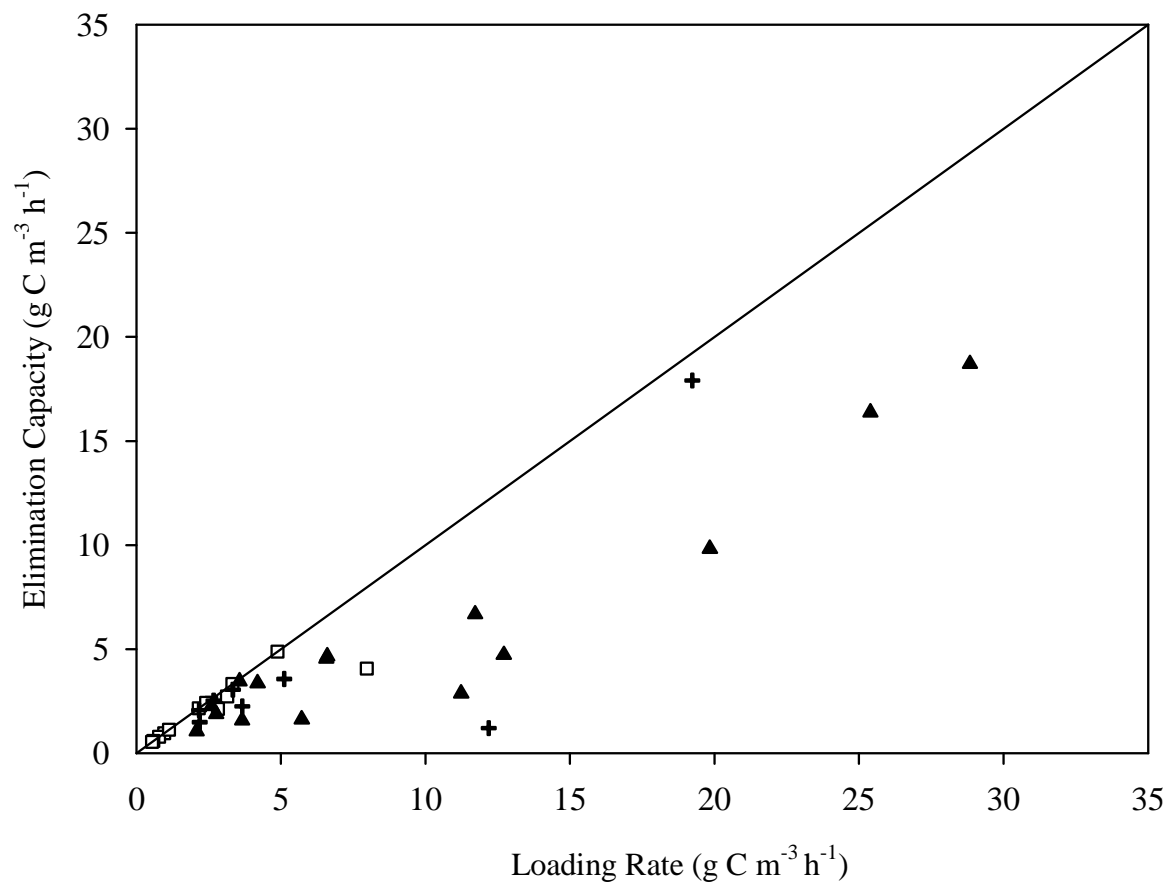
**Figure 3b:** VOCs emissions in inlet (solid circles) and outlet (circles) gas streams of biofilter, average removal efficiency (squares) and temperature (solid line) of composting process of: **a)** source-selected organic fraction of municipal solid wastes (5:1); **b)** source-selected organic fraction of municipal solid wastes (1:1); **c)** animal by-products.



**Figure 3c:** 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: **a)** source-selected organic fraction of municipal solid wastes (5:1); **b)** source-selected organic fraction of municipal solid wastes (1:1); **c)** animal by-products.



**Figure 4:** Average elimination capacity of the compost biofilter for different loading rates during composting of source-selected organic fraction of municipal solid wastes and animal by-products (day 0-4) (circles) and during composting of animal by-products (day 4-9) (triangles).



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