BIOFILTRATION OF WWTP SLUDGE COMPOSTING EMISSIONS AT CONTACT TIMES OF 2 TO 8 SECONDS

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ABSTRACT

The performance of a biotrickling filter for the abatement of composting emissions was evaluated at short contact times of 2 to 8 seconds. The effect of EBRT, pH control and water renovation rate were evaluated. The average elimination capacity was 13 and 3.3 g N/C $m^{-3}h^{-1}$ for ammonia and VOCs, respectively, and the maximum EC obtained during a doping process were 40 and 20 g N/C $m^{-3}h^{-1}$. Biotrickling filters appear as a better alternative than biofilters due to their controllability. However, water renovation becomes a critical parameter to avoid substrate inhibition by nitrite and ammonia accumulation. Not only ammonia absorption is negatively affected at low renovation rate but it is also affected the biological process. A decrease of 40 % was detected in the nitrification step when the hydraulic residence time increased from 2 to 5 hours. Results presented herein demonstrate that high removal efficiencies can be achieved for composting emissions in a biotrickling filter operated at short contact times which entails a substantial reduction of operational and investment costs in comparison to traditional techniques.

INTRODUCTION

Emissions from waste water treatment plants (WWTP) sludge composting are characterized by high flow rates and low concentrations of several compounds, mainly ammonia and volatile organic compounds (VOCs). The ammonia emission is the consequence of the undesirable nitrogen losses from composting material and the amount emitted is determined by the ammonia/ammonium balance, which depends on the temperature, pH and moisture content. While the ammonia concentration in a composting process of the organic fraction of municipal solid wastes varies between 18 and 150 g NH_3 Mg^{-1} waste, concentrations up to 700 mg NH_3 m^{-3} have been reported in exhaust gases from sludge composting (Haug, 1993). Even though these relatively low concentrations in the off gases, they can commonly be perceived even at very long distances from the source, due to their relatively low odour thresholds (Prado et al., 2009).

Several physical and chemical processes have been traditionally used to abate ammonia and VOCs from waste gas, including activated carbon adsorption, wet-scrubbing, incineration and air stripping. However, high costs associated to these technologies and the possibility of secondary pollutants emissions make them uncompetitive (Chung et al., 1997). The suitability of either biofilters (BF) or biotrickling filters (BTF) have been successfully tested for the abatement of ammonia and a wide range of volatile organic compounds and conditions in lab-scale studies (Pagans et al., 2007; Baquerizo et al., 2009; Hernandez et al., 2010). However, once these techniques are applied at pilot or industrial-scale, behavior can vary significantly from those previously tested mainly due to instant changes and perturbations difficult to control and commonly found in industrial environment. Indeed, the evaluation of BTF in industrial facilities for composting emissions is rarely reported. Prado et al. (2009) studied the performance of a BTF during 5 months at an empty bed residence time of about 0.9 s as a result of an industrial chemical scrubber conversion. Relatively low removal efficiencies were found for VOCs and NH_3 (around 10 and 25%, respectively), meaning an elimination capacity of 18 g C m^{-3} h^{-1} and 3 g N m^{-3} h^{-1}. Furthermore, it has been reported that microbial activity in biofiltration by waste gases containing ammonia can be inhibited mainly due to the accumulation of free ammonia (FA) and free nitrous acid (FNA) in the liquid phase (Baquerizo et al., 2005).

Regarding VOCs emissions, low removal efficiencies are commonly reported by biofiltration which is related to the complexity of the VOC mixture emitted and their variability throughout the composting process (Pagans et al., 2007). In this sense, Prenafeta-Boldú (2012) identified up to 48 different VOCs by gas chromatography–mass spectrometry (GC–MS) in a full-scale composting plant in an urban environment, and among them, alcohols, aldehydes, aliphatic and aromatic hydrocarbons, esters, ketones, terpenes, and organosulfur compounds were detected. Moreover, in the case of emissions from WWTP sludge composting (lower ammonia and VOCs concentrations than in MSW), the high volume to treat entails large bed volume of the bioreactors. Working at short contact times affects mainly to VOCs abatement due to the low solubility of these compounds and the corresponding mass transfer limitation.

The present study evaluates the performance of a biotrickling filter operated at short contact times (2 to 8 seconds) for the abatement of composting emissions. The effect of EBRT, pH control and water renovation rate were evaluated in a biotrickling filter set up at the WWTP of Manresa (Barcelona, Spain) during 110 days.

MATERIALS AND METHODS

The biotrickling filter (Figure 1), with a total bed height of 0.6 m and a volume of 0.5 m^3, was packed with a structured synthetic support media (FKP 158, Ecotec, Spain). The packing material was inoculated by recirculating for 24 h sludge from the nitrifying activated reactor of the same plant with an initial concentration of 1 g L^{-1}. With a flowrate between 200 and 1200 m^3 h^{-1} the average inlet concentration was 40 ppm for ammonia and very variable (from 5 to 250 ppm) for VOCs, meaning an inlet load up to 5.5 and 15 gN/C $m^{-3}h^{-1}$, respectively. At these flowrates the empty bed residence times (EBRT) were varied between 2 and 10 s which correspond to gas velocities between 250 and 1500 m h^{-1}. The liquid phase was recirculated with a hydraulic residence time (HRT) from 4 to 22.5 h.

A structured control system with a supervisory control and data acquisition (SCADA) software was used to automate the pilot plant and for data acquisition. Temperature, humidity (Testo, 605-H1) and carbon dioxide (Vaisala, GMP343) was registered continuously at the inlet and outlet gas stream, while ammonia (Industrial Scientific, Ibrid MX6), hydrogen sulfide and VOCs concentration were measured daily by means of portable electrochemical (Industrial Scientific, Ibrid MX6) and photoionization detectors (RAE, MiniRae 3000). Pressure drop across the fixed-bed reactor was measured by a water-filled U-tube manometer. For the liquid phase, temperature, pH, dissolved oxygen and reduction potential (Crison) were analyzed online and registered continuously, while the ionic species concentrations were determined off-line by ion chromatography (Dionex, ICS1000). The SCADA system was also used for controlling the aqueous phase pH to a value within 7.4 and 7.6 by means of either industrial water (i.e. WWTP effluent) until day 48 or reactive addition (NaOH/HCl 0.1M) from day 49 onwards. An auxiliary tank of 0.4 m^3 was installed for adding additional nutrients if necessary.

From day 85 additional VOCs with different grades of solubility (ethanol, hexane and toluene) were supplied in the influent at a concentration of 20 ppm to evaluate the performance for these compounds under more steady conditions. To evaluate the performance of the BTF, the nitritation percentages were calculated as the ratio of the mass of nitrite and nitrate respect the sum of all nitrogen species. In addition, the nitratation percentages were determined as the fraction of nitrate respect the sum of nitrate and nitrite. Nitritation (R_1) and nitratation (R_2) rates were calculated according to Baquerizo et al (2009).

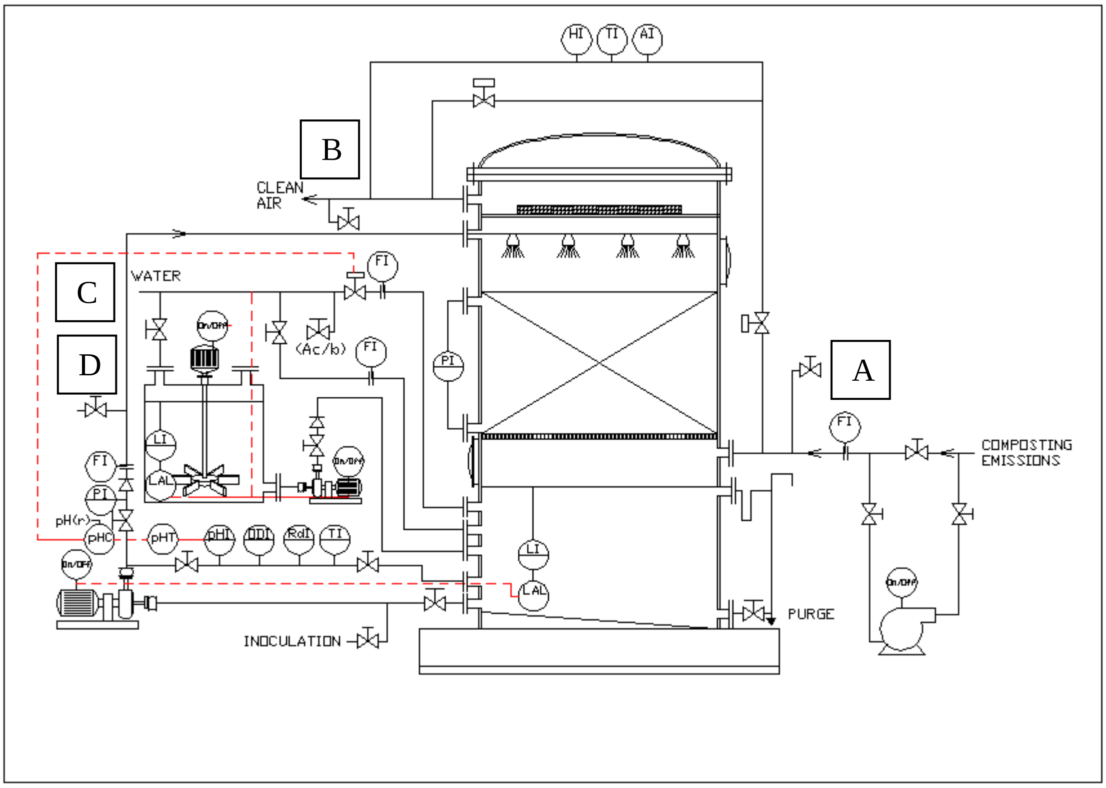

Figure 1. Diagram of the pilot plant. A and B are the sampling ports for gas phase at the inlet and outlet stream and equivalently, C and D for the liquid phase. Red lines represent electrical signal.

RESULTS AND DISCUSSION

The BTF performance was evaluated during almost 4 uninterrupted months of operation (Figure 2). The average removal efficiency (RE) for nitrogen was 82%, meaning an elimination capacity (EC) of 13 g N $m^{-3}h^{-1}$. In the case of volatile organic compounds, the average removal was inferior (around 46%) with a EC of 3.3 g C $m^{-3}h^{-1}$, which was significantly affected by the high fluctuations registered at the inlet for these compounds. The complexity of VOCs emitted, which are not generally related to the biological activity of the process (Pagans et al., 2006)**,** and the lack of acclimation due to the continuous fluctuations limited the removal efficiencies achieved. Considering data of the doping process, from day 85, the system showed a maximum EC of 20 g C $m^{-3}h^{-1}$ under steady conditions. The critical and the maximum EC for ammonia was not reached at the operation conditions of the plant, but it can be affirmed was over 45 g N $m^{-3}h^{-1}$. A critical EC of 45 g N $m^{-3}h^{-1}$ and a maximum EC between 50-100 g N $m^{-3}h^{-1}$ have been previously reported for BTF in ammonia abatement (Sakuma et al., 2008), although contact times used (13.5s) were higher than those tested in the present study (between 2 and 10s).

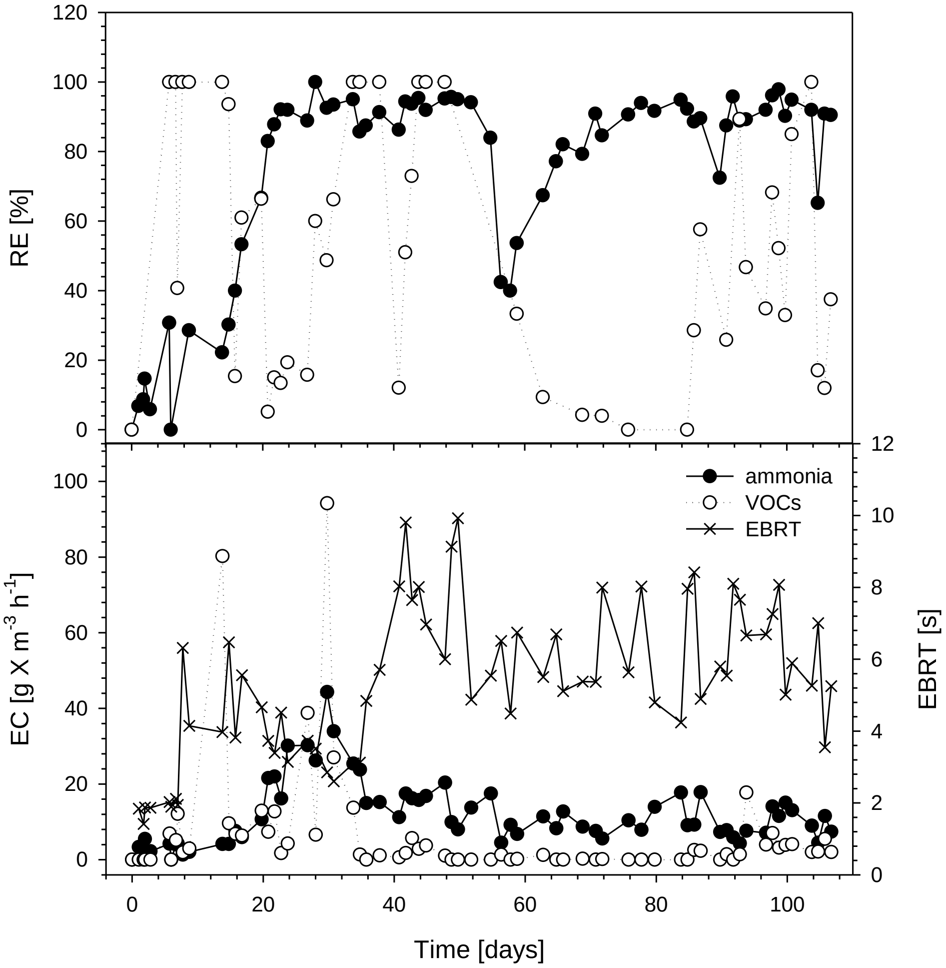

Figure 2. Removal efficiency (RE) and elimination capacity (EC) along time for the whole studied period where X is nitrogen or carbon.

Removal efficiencies increased during the first weeks until achieve, 20 days after the startup, a maximum value of 95% for ammonia, which showed a more stable inlet load than VOCs. ECs for ammonia were increasing progressively during the first month of operation up to 45 g N $m^{-3}h^{-1}$, which was also related with an enhancement of the inlet concentration (from 15 to 90 ppm) according to air temperatures during the seasonal changes. When the impact of potential emissions, derived from the low bioreactor performance during startup phases, are not permitted the use of selective inoculum can reduce this phase. Hernandez et al. (2010) reported a shorter startup of 14 days for the biofiltration of ammonia and a mixture of VOCs inoculating the material with an enriched microbial population at an EBRT of 25s. Xue et al. (2010) obtained an increase in RE of 15% when the BTF was inoculated with nitrifying bacteria in a BTF treating NH_3 emitted from the exhaust gases of cattle manure compost.

Reducing the contact time is an interesting option to reduce the bed volume and, consequently, the investment cost of the plant. However, mass transfer limitation can reduce the suitability of the BTFs for specific scenarios. Results presented herein show that moderately high efficiencies can be achieved for ammonia and VOCs removal with contact times between 2 and 10 s. However, the effect of EBRT becomes critical below 2 seconds where the mass transfer becomes limiting and the elimination decreases drastically. Figure 3a shows the effect of contact time on RE for ammonia. For VOCs (data not shown) a clear relationship with the EBRT was not observed, mainly due to the high variability at the inlet load during the operation. However, REs of 100% were registered for VOCs at contact time between 2 and 10 s, which entails that with a more stable inlet conditions and time to acclimate the biomass, high RE values could be achieved. The use of packing materials with higher specific surface area, e.g. polyurethane foam, could improve this limitation as it has been reported previously for contact times of the same magnitude (Gabriel et al., 2002).

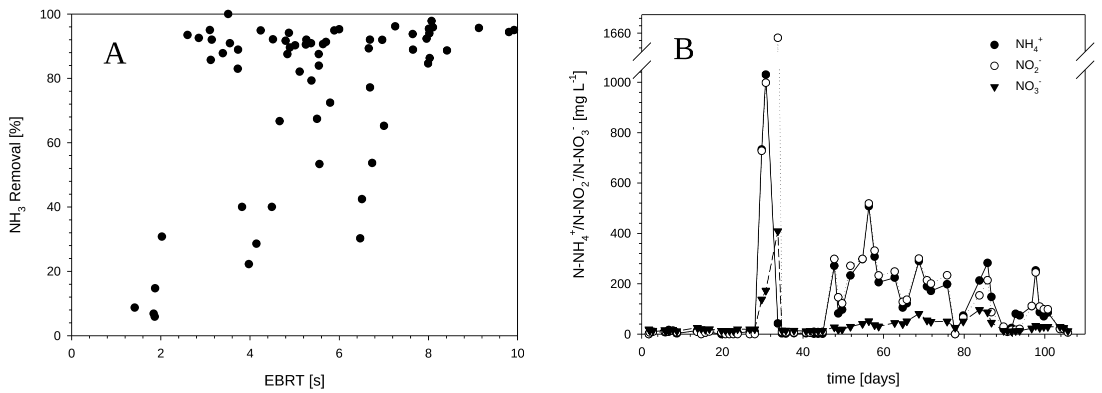

Figure 3. Effect of the empty bed residence time on ammonia removal efficiency (A) and ammonium, nitrite and nitrate concentrations in the liquid along operation time (B).

The high concentrations of nitrite and nitrate detected in the aqueous phase (up to 1600 and 400 ppm, respectively) denote that ammonia is not only being absorbed but it is also bio-oxidized (Figure 3B). Mass balances showed that the average nitritation and nitratation percentages are 72.5% and 46%, respectively. A high accumulation of ammonia and nitrite occurred between day 30 and 34 corresponding to a low aqueous phase renovation due to low water requirements for pH control. From day 34, when ammonium and nitrite were accumulated, the ammonia EC decreased progressively from 30 g N m^{-3} h^{-1} until reaching a steady removal of 15 g N m^{-3} h^{-1}. From day 48 a constant water flowrate was kept around 90 L h^{-1} and the pH was controlled by means of chemical reagents subsequently obtaining a slightly recovery of the removal efficiency. The drop in ammonia RE observed in Figure 2 between day 56 and 60 also correlated with higher concentration of ammonium and nitrite in the liquid phase (above 500 ppm N for both species).

Baquerizo et al. (2009) monitored ammonia removal in a biofilter packed with coconut fiber observing low nitratation rates in relation with large amounts of ammonium and nitrite accumulated in the packed bed, thus causing inhibition episodes on nitrite-oxidizing bacteria. Similarly, Hernández et al. (2010) detected inhibition by nitrogen species in the biofiltration of a gas mixture containing ammonia and different VOCs (DMDS, α-pinene, hexanal and MIBK). At the present operation conditions of temperature and pH the free ammonia concentration calculated in the liquid is 1.98 ppm. It has been stated that this form causes microbial inhibition, rather than total ammonia (Anthonisen et al., 1976). Jubany et al. (2008) reported inhibition thresholds of 7.0 and 0.95 ppm free $N\text{-}NH_3$ for ammonia- and nitrite-oxidizing biomass, respectively. Results clearly show that inhibition is taking place in these conditions, especially for the nitratation step, which should be avoided to guarantee an optimal long term operation.

Figure 4 shows the effect of the hydraulic residence time (HRT) on EC for ammonia, the nitritation rate (R_1) and the ratio nitratation/nitritation (R_2/R_1). The R_2/R_1 parameter represents the ratio between the amounts of nitrate and nitrite produced in the reactor per unit of reactor volume and time. Hence, values close to 1 indicate full nitrification (to nitrate), while values close to 0 represent predominance of partial nitrification (to nitrite). Results show how at low short hydraulic residence time the ammonia EC achieved in gas-phase comprise the wide range from 2 to 45 g $m^{-3}h^{-1}$. However, as higher HRTs are considered, the range is reduced and the obtained ECs are lower. Ammonia absorption is negatively affected at low renovation rate and so is the biological process. A decrease of 40 % was detected in the ratio R_2/R_1 when the residence time increases from 2 to 5 hours and a minimum value of 22% when the HTR overcomes 20 hours. Simultaneously the nitritation rate decreases exponentially as the water phase renovation decreases. Therefore, nitritation is even higher affected than nitratation for high hydraulic residence time.

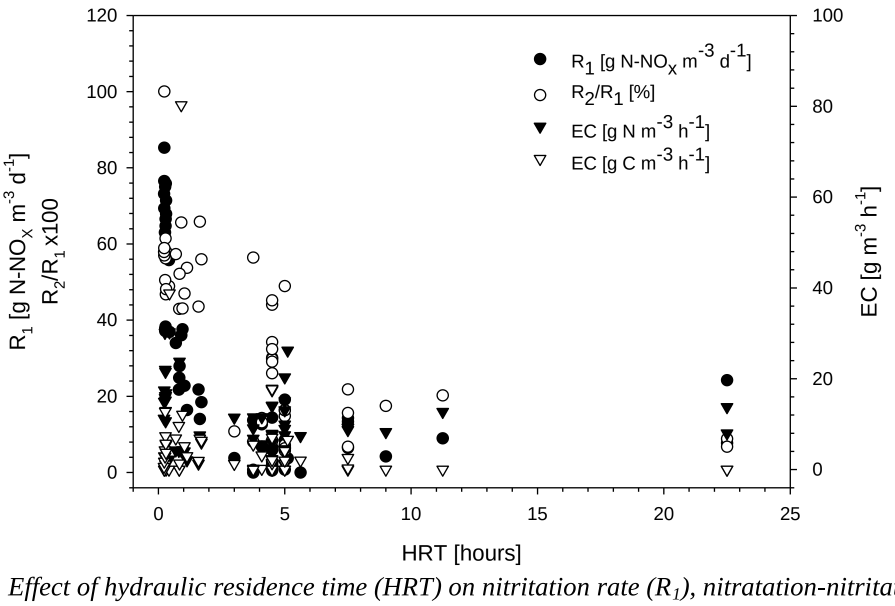

Figure 4: Effect of hydraulic residence time (HRT) on nitritation rate (R_1), nitratation-nitritation rate (R_2/R_1) and elimination capacity (EC) for ammonia and VOCs.

Most of studies focusing on ammonia biofiltration show that pH control together with the maintenance of an optimal water content in the filter bed arise as key operating parameters in order to keep a stable operation (Baquerizo et al., 2009). Due to their configuration and controllability, biotrickling filters appear as a better alternative than biofilters when ammonia is the main pollutant to be treated (Sakuma et al., 2008). As in biotrickling filters water content is assured with the continuous recirculation of a liquid phase, pH control is the key parameter to guarantee the optimal operation. However, among different control strategies to keep an optimal pH, present study entails how the use of industrial water can arise negative consequences in the biological system in relation to episodes of low water renovation and the consequently accumulation of inhibitory species.

CONCLUSIONS

In the biofiltration of WWTP sludge composting emissions, water renovation becomes a critical parameter to avoid inhibition by nitrite and ammonia accumulation. pH control by means of industrial water addition can become counterproductive when low water flow is needed to keep the optimal pH of operation. To avoid this strong dependence, it is desirable to keep a water renovation rate and to control the pH by means of acid/basic solutions addition. Present results underline how the aqueous phase renovation directly affects the grade of ammonia removal and the nitrification achieved in the system. On the contrary, VOCs removal did not show a clear relation with this operational parameter which is consistent with their higher hydrophobic character.

Results presented herein demonstrate that moderately high removal efficiencies can be achieved by a biotrickling filter at short contact times for treating composting emission. With these results, biotrickling filters becomes a promising alternative to the traditional combination of chemical scrubber and conventional biofilter where ammonia is abated in the former, and VOCs are degraded subsequently. The use of biotrickling filters entails a substantial reduction of operational and investment costs for composting emissions treatment. Present study will enable the design and fixation of the optimal conditions to a future conversion of a chemical scrubber to a biotrickling filter at an EBRT of 2.5 seconds to be done in the WWTP of Cubelles (Barcelona, Spain).

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