CHARACTERIZATION OF ORGANIC PACKING MATERIALS IN THE REMOVAL OF AMMONIA GAS IN AUTOMATED BIOFILTERS

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ABSTRACT

A fully-automated pilot-scale biofilter filled with coconut fiber as packing material was investigated for treatment of ammonia-containing off-gas streams. Coconut fiber was completely characterized for physical and chemical parameters and biological activity. Biofilter performance was assessed in a pilot-scale unit in a set of continuous experiments varying the inlet ammonia concentration in a range of 45 to 240 ppm_v at a gas contact time of 36 seconds. Samples taken along the bed height as well as inlet and outlet ammonia concentrations were used to determine a maximum elimination capacity of 12 g NH_3 $m^{?3}$ $h^{?1}$ at a 80% removal efficiency. Some features related to nitrification inhibition encountered in the experiments are also discussed.

INTRODUCTION

Biological waste air treatment techniques have become an excellent method for the control of low concentrations of odors and volatile organic and inorganic compounds in large air streams (Shoda, 1991). In addition, biofiltration is an inexpensive, environmentally friendly technique for waste air treatment compared with conventional techniques such as scrubbing or adsorption. Biofilters efficiency is highly dependant on the characteristics of the packing material. Proper packing material selection based on physical, chemical and biological parameters is a key factor in the reactor performance since biomass development and activity depends on the presence of a suitable support. Since operation of biofiltration units for waste gas treatment may require a set of routine tasks implementation of programmable logic controllers (PLCs) in addition to supervisory control and data acquisition systems (SCADAs) at pilot-scale levels is especially useful for avoiding routine tasks, and ensures repeatability, diminishes human mistakes and allows a deeper knowledge attainment.

The aim of this research was to characterize several physical and chemical properties of the coconut fiber, an organic material used as packing material in biofilters. Also, the material was tested in a pilot-scale reactor to assess its performance in ammonia removal.

MATERIALS AND METHODS

Biofiltration pilot-plant construction and operation

A biofiltration pilot-plant was constructed with special attention to automation (Figure 1). The main unit, the biofilter, is a 1.1 m long, 0.1 m internal diameter transparent PVC cylinder divided in four packed bed modules. Coconut fiber filled the 4 modules with an effective packing height of 80 cm (20 cm each). Gas sampling ports were located along the bed height, where electrovalves allowed for automatic sampling. The top was fitted up with an automated port for a nutrient solution addition while the bottom was fitted with a automated liquid drain, both controlled by the PLC. Gas flow rates for air and ammonia were measured and controlled using mass flow controllers. Prior to the mixture, air passes through a humidification column to ensure a 99-100% RH in the air entering the biofilter. A timer controlled electrovalve added water periodically to maintain a water level in the humidification unit. Continuously monitored parameters included temperature and relative humidity (Testo, Hygrotest 600 PHT), ammonia gas (Vaisala, AMT102) coupled with a log register of actuations to pumps and valves. A structured control system with a PLC (Siemens, S7-314C-2DP) and a commercial SCADA software (Siemens, WinCC v.5.2) were used to automate the pilot-plant

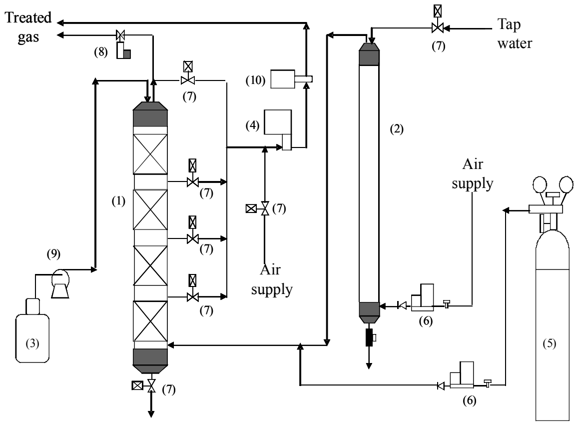

Figure 1. *Schematic of the biofiltration pilot-plant. (1) Biofilter, (2) Humidification column, (3) Nutrients reservoir, (4) Relative humidity and temperature sensor, (5) Ammonia gas cylinder, (6) Mass flow controllers, (7) Normally closed electrovalve, (8) Normally opened electrovalve, (9) Pump, (10) Ammonia gas sensor.*

Analytical methods for packing material characterization

Coconut fiber used as packing material in the pilot-scale biofilter was obtained from a full-scale biofilter at a municipal solid waste composting facility that mainly treats ammonia and volatile organic compounds from the foul air of the facility.

Leacheate conductivity and pH were measured with lab probes prior to filtering. Leacheate COD was measured according to Standard Methods (1995). Cl^-, NO_2^-, SO_4^{2-}, NO_3^-, PO_4^{3-} were determined by capillary electrophoresis in a Quanta 4000E unit (Waters). NH_4^+ was measured in a continuous flow analyzer (Baeza et al., 1999). Buffering capacity, water and organic matter content and water holding capacity (WHC) were determined according to Test Methods for the Examination of Composting and Compost (1995). Water retentivity of the packing material was determined according to Hirai et al. (2001). Coconut fiber porosity and specific surface area and elementary analysis for C, N, H and S content of the packing material were performed in outside laboratories.

RESULTS AND DISCUSSION

Physical and chemical parameters of coconut fiber from a full-scale biofilter

A complete characterization of the packing material was performed prior to setting up the pilot-scale biofilter (table 1). Coconut fiber was characterized for parameters that do not require a sample pre-treatment, while “water phase” parameters were determined by mixing water and coconut fiber in a proportion of 1:25 volumes, then stirred for 1h, and leacheate aliquots filtered in 0.22 µm cellulose filters prior to the analysis.

Some of the parameters determined are inherent to the material such us the pore size, the specific surface area, material density, CHNSP content and organic matter content and thus comparable to other materials characterized in the literature (Ramírez-López et al., 2003). In particular, a high specific surface area of the coconut fiber, similar to this of peat, is a favorable characteristic for biofiltration applications. In any case, low pore size of the material may lead to biomass growth over the surface of the coconut fiber, thus reducing the specific surface area available for pollutant degradation.

***Table 1**. Physicochemical characteristics of coconut fiber used in this study. Deviation reported as the standard deviation of a set of three replicates per sample.*

No pre-treatment methods		Pre-treatment required methods	
C (% dry weight)	47.32 ± 0.12	Buffering capacity ($g\ SO_4^{2-}\cdot kg\ material^{-1}$)	22 ± 1
H (% dry weight)	5.69 ± 0.12		
N (% dry weight)	0.52 ± 0.01	COD ($g\ COD\cdot kg\ material^{-1}$)	12.2 ± 1.2
S (% dry weight)	Not detected	pH	7.74 ± 0.01
P (% dry weight)	0.23 ± 0.00	Conductivity ($\mu S\ cm^{-1}$)	1047 ± 42
Water content (%)	72.8 ± 3.2	NH_4^+ ($g\ N\cdot kg\ material^{-1}$)	0.36 ± 0.05
Organic matter (% dry weight)	96.4 ± 3.0	Cl^- ($g\ Cl^-\cdot kg\ material^{-1}$)	0.5 ± 0.1
Pore size (Å)	109 ± 1	NO_2^- ($g\ N\cdot kg\ material^{-1}$)	1.93 ± 0.1
Specific surface area ($m^2.g^{-1}$)	0.75 ± 0.10	SO_4^{2-} ($g\ SO_4^{2-}\cdot kg\ material^{-1}$)	0.70 ± 0.03
WHC ($g\ H_2O\cdot g$ dry material^{-1})	5.5 ± 0.6	NO_3^- ($g\ N\cdot kg\ material^{-1}$)	0.49 ± 0.05
Water retentivity ($\%\cdot d^{-1}$)	- 31 ± 7	PO_4^{3-} ($g\ P\cdot kg\ material^{-1}$)	Not detected

Other parameters shown in Table 1 depend on the operating conditions of the biofilter. Compared to inorganic materials tested at the same space velocity (Hirai et al., 2001), 100 h^{-1}, 4 to 5 times lower water retentivity was found for coconut fiber. Also, coconut fiber at 70% water content is able to absorb up to 5.5 times its own dry weight in water, notably higher than a WHC of 2.8 $g\ H_2O\cdot g$ dry material^{-1} reported for peanut shells as suitable packing material for biofiltration applications (Ramírez-López et al., 2003). In any case, analyses were useful in order to gain knowledge prior to setting up the pilot-biofilter unit and to understand some operating conditions in the full-scale biofilter.

Performance of coconut fiber in biofiltration of ammonia

An experiment was undertaken in the pilot biofilter once the coconut fiber withdrawn from a full-scale biofilter was fully characterized for physicochemical parameters. No inoculation was needed since the full-scale biofilter had been running for more than 2 years at averaged ammonia inlet concentrations of 40 ppm_v. Four step increases were performed to the ammonia inlet concentration (0-45, 45-120, 120-240, 240-180 ppm_v) to reach a new steady-states after a minimum of 3 days. Empty bed retention time was always 36 seconds at a gas flow rate of 10.47 L min^{-1}. Watering was performed once per day at 0.383 $L\cdot d^{-1}$.

Gas samples were taken automatically from inlet and outlet streams, as well as from the three sampling ports along the bed height of the biofilter. Figure 2a shows the profiles at the steady-state for ammonia gas concentration along the bed height. Inlet ammonia concentrations up to 120 ppm_v were completely removed, but in all cases a sharper decrease is observed in the lower module of the biofilter, which indicates a major biological activity in this zone of the reactor. Also, notice in Figure 2a that a decrease in the ammonia removal percentage was found in the lower module for an inlet ammonia concentration of 180 ppm_v. This was related to a nitrification inhibition since leacheate analysis for ammonium, nitrite and nitrate showed a progressive increase in the nitrite and ammonium concentration coupled to a decrease in the nitrate produced after the experiment of 120 ppm_v (data not shown). Performance was assessed in terms of elimination capacity (EC) and removal efficiency (RE) against the ammonia loaded (L) to the reactor (Figure 2b), where EC= $Q \cdot (C_{in}-C_{out})/V$, RE=$((C_{in}-C_{out})/C_{in}) \cdot 100$ and L=$Q \cdot C_{in}/V$. The maximum elimination capacity was around 12 g $NH_3 \cdot m^{-3} \cdot h^{-1}$ at a 80% removal efficiency, thus loads higher than 12 g $NH_3 \cdot m^{-3} \cdot h^{-1}$ would not enhance the efficiency of the biofilter. Although the full-scale biofilter where the packing was withdrawn was operated at the same gas contact time than the pilot-scale biofilter, 36 seconds, the EC_{max} found in the pilot-scale unit is notably higher than the value found in the full-scale reactor (4,3 g $NH_3 \cdot m^{-3} \cdot h^{-1}$).

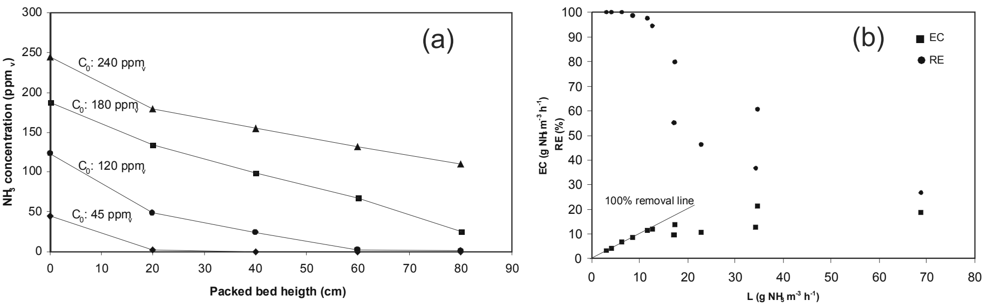

***Figure 2**. a) Ammonia concentration along the bed height; b) Elimination capacity and removal efficiency profiles for ammonia inlet concentrations of 45, 120 and 240 ppm_v.*

CONCLUSIONS

A complete characterization in terms of physical, chemical and biological properties of coconut fiber as packing material in ammonia removing biofilters was performed. Coconut fiber has some interesting properties such as high specific surface area, high WHC and a balanced C/N/P ratio in order to be used as carrier material in biofilters. Experiments performed with the coconut fiber in a fully automated pilot-scale biofilter showed reasonable ammonia elimination capacities of up to 12 g $NH_3 \cdot m^{-3} \cdot h^{-1}$ at a 80% removal efficiency. Results found herein may be improved if higher biomass activity could be achieved in the upper modules of the biofilter that would enhance ammonia removal, even if nitrification inhibition by nitrification by-products requires further research.

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