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Study of removal efficiency of odorous compounds (NH_3) by peat and wood chips laboratory-scale biotrickling filters

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Biological treatment is an emerging technology for treating off-gases from wastewater treatment plants and for removing odorous compounds such as ammonia or hydrogen sulfide. This research aims to assess the removal efficiency of biofilters lightly packed with peat and wood chips. The inlet concentration of ammonia (60 ppm) was chosen considering the typical value of compost plan, the empty residence time (ERT) was 50 seconds. During the experiment operative conditions were varied in order to evaluate the filter response whereas parameters such as pH, outlet temperature and contaminant concentration were monitored in order to assess the filter performance. The peat shows much higher removal efficiency (RE) than wood chips even decreasing the ERT and either are quick to respond to intermittent loading scenario.

1. Introduction

Biofilter and biotrickling filter have been recently considered as the best available control technology for odor and waste gas treatment. The process involve biological oxidation: polluted air is supplied through a filtrating mean and pollutants are removed by transfer to liquid film and absorption on a solid support; then bacteria degrade contaminants producing energy and nutritional source. Contaminants are oxidized to dioxide carbon, water, biomaterial and energy. Biological processes are more convenient than others, treating high air flow rate and relatively low concentration of pollutants. The construction of these systems is generally not complicated and well-engineered systems require low managing costs and achieved high efficiency. This latter depends on important parameters such as the inlet concentration, retention time, bed temperature and moisture content.

Biofiltration has several applications in removing odorous contaminants. Especially researches focus on ammonia and hydrogen sulfide because they are produced and released from industrial processes such as leather manufacturing, rubber and food production processes, sewage treatment, agriculture activities and livestock cremation (Devinny et al 1999a).

Microorganisms can oxidize more efficiently low molecular weight compounds with simple bounds and high water solubility, producing energy water and oxidized compounds. This research focuses on the best way to project and set up a laboratory-scale biological filter and to assess the removal efficiency by varying operative parameters in order to compare the two different media.

2. Materials and methods

2.1 Experimental design

The biological filter **Fig 1.** consists in two vertical units placed in parallel on the same bench: each unit consists in a PVC, transparent cylindrical tube of one meter high, 20 cm of diameter and 3 mm of thickness. Each ending part of the filter is covered by a PVC, 8mm thick seal with a central hole. The upper one is useful to supply odorous contaminants or water in order to humidify the packing materials and the air stream; whereas the bottom one is used to collect leachate. Moreover each section is equipped with 5 holes of 10 mm of diameter drilled along the main length. The three central holes are equipped with termistore in order to assess the temperature profile along the filtrating bed, while the ending holes are utilized for the inlet and outlet gas flow. The filter was operated in downflow mode. Packing material was manually loaded and lightly packed until the desired height (90 cm). At the bottom of the filter a sieve plate with 3 mm diameter holes is placed in order to have enough space to drain leachate. Bioreactor is fed with a hot air stream coming from the outside line; air warming is accomplished flowing air in a copper coil pipe placed in a oven that allow to reach temperature around 25 - 40 °C at the top of each bioreactor. Nylon outlet line coming from the oven split into two pipes and feed either bioreactor separately. In order to reduce thermal dispersion, pipes were covered with a sponge isolate coaxial material (8 mm x 10 mm). After warming unit, the air flow rate is controlled and set using a controller and regulator Brooks® 5851S in a range of 0÷50 l/min. A dilute ammonia solution is fed at the top of each bioreactor to achieve either air and medium humidification either providing contaminants to the microorganisms growth. Every liquid stream is trickled directly on the bed using a peristaltic pump Gilson TM Minipulse Evolution III. An important parameter to control during the experiment is the pressure drop along the filter. This allows to compare the packing level and humidity content between the two mediums.

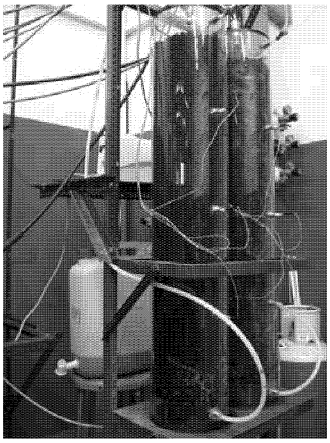


Figure 1: laboratory-scale biotrickling filters

2.2 Analysis

Headlosses across the biofilter were measured using a manometers. Pressure drop measurements were taken at the air sampling port at either the entrance or the exit of the biofilter column. The measurements were taken at the start and end of the experiment.

The effective porosity was calculated from the Ergun pressure drop equation as described by Janes (1995) and given below:

$$\Delta P = 150\frac{\mu u\,(1-\varepsilon)^2}{d_p^{\,2}\varepsilon^2}\,l + 1.75\frac{\rho u^2(1-\varepsilon)}{d_p^{\,2}\varepsilon^3}\,l \tag{1}$$

where, ΔP, pressure drop (Pa); μ, gas viscosity (1.8515×10⁻5 kg/m s); u, superficial air velocity (0,014324 m/s); d_p, particle diameter; ε, effective porosity; l, fluid path (assumed to be the same length as the packed column); ρ, gas density (1.184 kg/m^3) **Eq.(1)** is the sum of the Blake–Lozeny equation for laminar flow (the term multiplied by 150) and the Burke–Plummer equation for turbulent flow (the term multiplied by 1.75). Values of air density and viscosity were considered at 25 °C and 101.325 kPa. Superficial flow rate was calculated by dividing the volumetric airflow rate by the cross-sectional area of the vessel. A mean compost particle diameter of 2.0x10⁻3 m was selected. **Eq. (2)** as described by Hausenbuiller (1985) was used an alternate means to calculate the total porosity of the bed.

$$Porosity = \left[1 - \left(\frac{bd_{CB}}{pd_{CB}}\right)\right] \times 100 \tag{2}$$

where bd_{CB} , material bulk density (kg/m^3); pd_{CB} , material particle density (kg/m^3). The compost bulk density was determined by dividing the dry mass of the compost added to the biofilter by the volume it occupies.

pH of leachate was measured either by a pH-meter or pH test strips. The measurements of medium's pH were performed using the following method: a certain amount of packing material was withdrawn from the vessel and weighted; considering a water/medium ratio of 2.5, an exact amount of water was added to the material and the sample was stirred for 24h, reaching equilibrium condition. The solution's pH was determined by a pH-meter.

The moisture content of packing media was measured drying a weighted sample of material withdrawn from the filter in a oven at 120 °C for 24 hours. Whereas the outlet air humidity is controlled using a wall probe (ASW) by Carel ranging between 0 and 90%.

The outlet NH_3 concentration was measured using an analyzer with integrated recorder Drager CMS (Chip Measurement System) in a range from 0 to 50 ppm. The inlet concentration was previously known since it was chosen to feed a solution of commercial ammonia and tap water with desired concentration.

2.3 Packing material

Recently several new types of packing material have been introduced and experimented in biological filtration processes besides classical media. Therefore it's necessary to summarize briefly the different types according to their properties in order to understand our choice. Firstly, packing materials should have a high surface area, high air and water permeability, provide a good surface for microbial attachment and have good mechanical properties (Elias et al., 2002). It also plays an important role in air and water distribution, as well as mass transfer. Up to date it is used either natural (soil, compost, peat, wood chips) either synthetic mediums (ceramic saddles, polyethylene pall rings, polyurethane foam or activated carbon). Between natural materials, peat is considered the most interesting and effective in contaminants removal; it isn't prone to short circuiting and clogging like soil and his effectiveness is not decreased by aging effect as in the case of compost. Moreover it has good and uniform structural properties allowing a more uniform air and water distribution as well as synthetic media, though it doesn't need add of nutrient solution since it contains nearly all the mineral compounds useful in microbial growth. Nevertheless it suffers of water control problems due to his hydrophobic behavior (Leson and Winer, 1991). The second filter was packed with wood chips, medium commonly used in sewage treatment due to his cheapness. This material, a mixture of leaves barks and wooden sticks is less effective than peat; it suffers of clogging and channeling problems and offers less superficial area as well as porosity. Nevertheless it is economical and useful, considering the experimental aim, to compare the odor removal efficiency of different packing materials. In the **Table 1**. are listed the main properties of both media.

Table 1 List of chemical – physical properties of peat and wood chips

	Peat	Wood chips
Mean diameter (m)	0.019	0.05
Weight (Kg)	14.7	4.3
Density (Kg/m^3)	513	149
pH	5.2	6.4

2.4 Media preparation and acclimatation

The packing means were supplied with an ammonia solution (around 60 ppmv) for a week to accomplish the material moisturizing, along with selection and acclimatation of microorganisms. During the two following days microorganism were added to the medium by addiction of a solution of yeasts (150 g), sawdust (150 g) and water (8 l) at the temperature of 30 °C to accelerate the acclimatation process. Leachate collected at the bottom of biofilter were recycled manually to the top for three times since the presence of those bacteria that have not enough time to attach to the packing media and to achieve a better distribution of organic material across the filtering beds. The latter was also accomplished by the addiction of supporting material such as sawdust. The freeze dried bacterial culture is a mixture of up to 21 microbial species including *Rhodococcus, Bacillus, Pseudomonas, and Trichoderma* species. The total viable count is approximately 10^9 cfu/ml. This bacterial culture product is non-pathogenic to humans and animals, non toxic, poisonous and flammable, thus it results completely safety for operators and workers. Moreover the mixture of bacteria is suitable to remove a wide sorts of contaminants.

The supply of nutrients was achieved feeding a solution of ammonia (around 60 ppmv) and mineral salts since microorganisms need further elements such as nitrogen, potassium and phosphorus to grow. The solution was prepared with the following composition: 2g of $KHPO_4$, 0.4g of NH_4Cl and 10g of glucose in one liter of distilled water.

The operative parameters of the filter during the acclimatation period were maintained around the followings values:

Temperature: 35 °C
Irrigation: 0.5 ml/min
Air flow rate: 17,3 l/min
Empty residence time (ERT): 90 sec
Outlet air humidity: 90%

It is interesting to focus on the motivation of these choices; a low air flow rate, thus high ERT, was selected in order to create suitable condition for microbial growth, since microorganism could be blown out the filter detaching from the packing material. The temperature was maintained in a range considered optimum for the microorganism's life. Unlike the air humidification systems quoted in the scientific literature, such as bubbling cylinder, it was considered more effective air humidification directly across the filter. Dry air strips nearly all the water introduced at the top of the filter during the first centimeters, promoted by dispersion on the packing material particles. The water flow rate was calculated accounting the air flow rate and mean temperature inside the filter in order to achieve an outlet saturated air stream. The saturation humidity is expressed by **Eq 3.**:

$$Umidity_{sat} = \frac{P^0_{H2O}}{P - P^0_{H2O}} \cdot \frac{PM_{H2O}}{PM_{Air}} \tag{3}$$

Where P^0_{H2O} is the vapor pressure at the filter temperature; PM_{H2O} is the molecular weight of water and PM_{Air} of the air. Now it is possible to evaluate the water flow rate using the **Eq 4.**:

$$Q_{H2O} = U_{sat} \cdot Q_{air} \tag{4}$$

Computations show a value of the water flow rate around 0.4 ml/min but it was decided to feed 0.5 ml/min in order to wet the packing material and maintain the moisture content.

The moisture content of the packing material is an important parameter since the removal of contaminants involves three steps; compounds diffusion across the liquid biofilm layer, absorption on medium and degradation by microbial oxidation. The contaminant diffusion in the active layer depends on the humidity of the material, thus the moisture content has to be control accurately. The level should be neither too high nor too low, since in the first case microorganisms have not enough water and nutrients to live; unlike the second case the thickness of the layer offer resistance to compounds diffusion, slowing the removal process velocity. Nevertheless the humidity is the most difficult parameter to deal suddenly and accurately.

3. Results

The first purpose was the assessment of the breakthrough point of the media. This task was accomplished packing the vessels with sterilized peat and wood chips, directing an high air flow rate to the filters and feeding a concentrated NH_3 solution (20000 ppm) to decrease the breakthrough time.

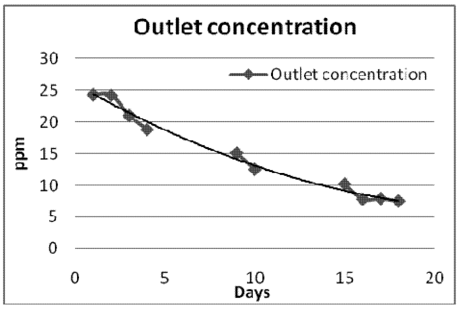
The run period of the experiment was different considering the two packing materials, due to their different features such as weight and porosity. Moreover the wood chips offers a less uniform air and water distribution, since the different dimension size and density of particles, leading to a not complete utilize of the medium volume. The breakthrough time was measured until the outlet concentration approached the inlet value; whereas the breakthrough load was calculated by the **Eq 5.**:

$$Load_b = C \cdot Q_{liq} \cdot t_b \tag{5}$$

Where C is the known inlet NH_3 concentration; Q_{liq} is the water rate (0.5 ml/min); t_b is the breakthrough time. In the case of peat the experiment lasted 9 days whereas the breakthrough time of wood chips packed filter was 4 days. Critical load for peat was around 500 ml and for wood chips 200 ml. The following step was the releasing of the absorbed ammonia flowing an high air flow rate at high temperature (45°C) across the filter and tricking water without contaminants to maintain the medium humidity. Even during this phase, the desorption time of the peat packed filter necessary to obtain an outlet concentration below 50 ppm was shorter than wood chips filter's time due to the different amount of NH_3 absorbed.
The following experiment was performed with fresh sterilized packed materials. The media preparation and acclimatation was accomplished following the method previously described. During the run period several parameters were monitored in order to understand the mechanism of odor removal. The first part of the experiment aimed to assess the efficiency of the two different filters. The operative parameters were maintained around the following values:

Temperature: 35 °C
Irrigation: 0.8 ml/min
Air flow rate: 31.2 l/min
Empty residence time (ERT): 50 sec
Outlet air humidity: 90%
Inlet concentration: 60 ppm

Temperature, water flow rate and outlet air humidity were chosen considering the same criteria expressed in 2.4. The air flow rate was increased to accomplish a more tough condition for microbial degradation; in this case the time available for the removal process is less than during the acclimatation phase. Hence the compounds diffusion through the active biofilm layer is the limiting parameter. The inlet concentration figure was chosen based on the typical off-gases ammonia concentration exiting from sewage and compost treatment. The measurements of outlet concentrations and removal efficiency during 18 days is illustrated in **Fig. 2** and **Fig. 3.**



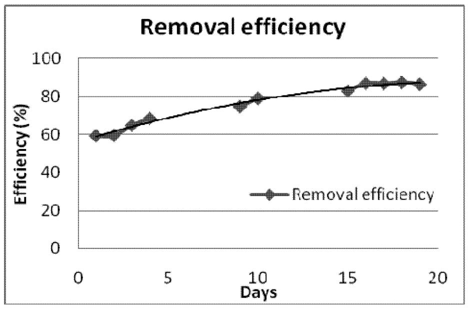


Figure 2: Outlet concentration (OC) of a wood chips packed filter
Figure 3: Removal efficiency (RE) of a wood chips packed filter

The plots represent the outlet concentration (OC) and removal efficiency (RE) profile of wood chips packed filter whereas the RE of the peat packed filter remains above 99% and OC was below 0.2 ppm since the first day.

During the run period the stream of either ammonia and water were interrupted for 5 days between 10 and 15 day. The startup after the inactivity period was uneventful and removal efficiency return to their original levels since the first time. The fast recovery suggested the microorganisms are able to survive and quick to respond to intermittent loading scenario.
Different measurements were taken during the run period; pressure drops across each biofilter were measured and successively the values were used to compute both the total bed porosity and the effective porosity by using the **Eq. (1)** and **Eq. (2)**.

	Peat	Wood chips
l (m)	0.85	0.85
d_p (m)	0.019	0.05
ΔP	20,5	109,0
ε (effective)	13%	4%
ε (total)	58%	86,5%

The effective porosity represents the obstacles the air stream face when being forced through the biofilter. The effective porosity accounts for the void space that is filled by water and unavailable for the passage of the air stream. Hence, moisture and compaction of the bed affected the porosity of the bed. The higher the moisture content and compaction, the higher the pressure drop and thus the lower the porosity calculated from **Eq. (2)**.
The pH of leachate were around 8 for wood chips filter and 6.4 for peat filter. PH is one of the most important parameter that allow to assess the removal process efficiency; indeed the products of microbial degradation (nitrite and nitrate) tend to reduce the pH of leachate.
The temperature of the bed is lower than temperature of the inlet stream; this is due to the physical phenomena of stripping and leads to have a lower temperature at the bottom. In case of peat packed filter the temperature was almost constant at 21 °C (± 0.2 °C) whereas the outlet temperature of wood chips packed filter increased from 19 °C to 21 °C. The increasing temperature is linked to the RE profile and this scenario is due to the always higher degradation rate of ammonia; indeed one of the oxidation products is energy, responsible of the increasing temperature. Therefore temperature together with pH is also used to evaluate the process performance. Humidity of the exiting stream was monitored once a day and the following plot in **Fig 4.** depicts the humidity profile during the run period.

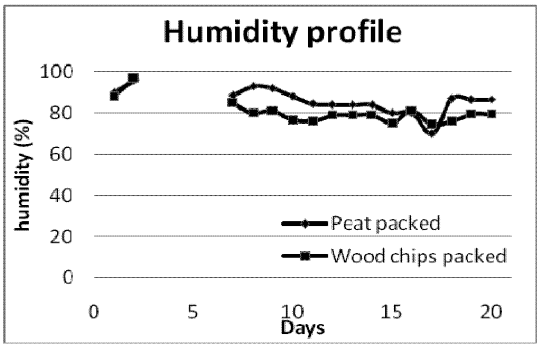


Figure 4: Humidity profile of peat and wood chips packed filters during the run period

The humidity level maintained high during all the experiment, also during the interruption of water supply. This phenomena is due to medium buffer capacity to adapt to water flow rate variations since water present in packing medium micro pores is difficulty reachable by air stream.

The humidity of the wood chips bed was around 11% and it did not increase even by soaking the material in 2 liters of water for 3 days. The water temporary adsorbed by the packing material was released only few hours later. On the other hand humidity of peat bed could reach higher level, and it was maintained around 20%.

Successively it was reduced the ERT (hence increased air flow rate) of the peat packed filter, in order to evaluate the RE with more tough operative conditions and establish the critical load available. The OC remain below 0.2 ppm also when the ERT was reduced to 30 seconds, rather less than ERT law limit fixed at 36 seconds.

4. Conclusion

The experiment was successfully in demonstrating that biofilter packed with peat is more effective in odorous compounds removal than wood chips packed filter. The filter performance was also evaluated monitoring pH and outlet temperature, since during the oxidation process some reaction products, such as nitrite nitrate and energy, affect this parameters.

Peat packed filter showed an overall removal efficiency nearing 100% whereas wood chips filter's efficiency approached 97%, supplying the same ammonia concentration (60 ppm).

It was demonstrated that biofilters can operate uneventfully also during intermittent loading scenario. Indeed for three days the water and contaminant supply was interrupted and after the successive startup the outlet humidity and RE maintained nearly the same values.

The decreasing of ERT did not influenced the RE of peat packed filter, always maintaining the same inlet concentration of 60 ppm.

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