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Biofiltration of methanol in an organic biofilter using peanut shells as medium

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ABSTRACT

Biofiltration consists of a filter-bed of organic matter serving both as carrier for the active biomass and as nutrient supply, through which the polluted gas passes. The selection of a suitable medium material is of major importance to ensure optimum biofilter efficiency. Peanut shells are an agricultural byproduct locally available in large quantities at a low price in most tropical and sub-tropical countries. A previous study showed that peanut shells are physically and chemically suitable for biofiltration. This paper presents the results obtained during a six month biofiltration experiment using peanut shells as medium and methanol as air pollutant. It is shown that peanut shells are potentially suitable as biofiltration medium, since degradation rates of up to 30 kg MeOH/m^3 d with an empty bed residence time of 19 s was obtained. The biofilter showed a good resistance to shock load and no operational problems were observed.

1. Introduction

Different cleaning technologies of gaseous effluents have been developed. Among these technologies, biological methods are increasingly applied for the treatment of air polluted by a wide variety of pollutants. Biofiltration is certainly the most commonly used biological gas treatment technology. Biofiltration involves naturally occurring microorganisms immobilized in the form of a biofilm on a porous medium such as peat, soil, compost, synthetic substances or their combination. The medium provides to the microorganisms a hospitable environment in terms of oxygen, temperature, moisture, nutrients and pH. As the polluted air stream passes through the filter-bed, pollutants are transferred from the vapour phase to the biofilm developing on the packing particles. Given enough residence time, the microorganisms metabolise the pollutants to their primary components (such as carbon dioxide and water in the case of carbonaceous pollutants) plus additional biomass and innocuous metabolic products (Ottengraf, 1987; Wani et al., 1997). The absorption and/or adsorption capacity of the filter media is thus continuously renewed by the biological oxidation of the sorbed pollutants (Wani et al., 1997; Kennes and Thalasso, 1998; Devinny et al., 1999; Pineda et al., 2004). Undoubtedly, biofiltration provides an economic, efficient, simple and versatile treatment method for a wide variety of both organic and inorganic pollutants, including numerous compounds classified as hazardous, odorous and/or toxic.

The selection of the medium material is of major importance to ensure biofilter efficiency. A large number of materials have been used (Kennes and Thalasso, 1998). Bohn et al. (1996) has listed 13 important physical, chemical and biological characteristics for good biofilter media. Additionally, as biofiltration is a low cost technology and because large amounts of medium material are usually needed, low cost materials locally available are preferred.

A previous study showed that peanut shells are potentially an interesting biofiltration medium (Ramírez-López et al., 2003). Peanut shells are locally available in large quantities at low price in most tropical and sub-tropical countries and have interesting physical and chemical characteristics: large specific surface area, neutral pH, large water holding capacity, nutrients for microbial growth and limited pressure drops when packed into a biofilter. In this context, peanut shells were selected as biofiltration medium material to study the treatment of a gaseous stream polluted with methanol. Methanol is an industrial solvent largely used in inks, resins, adhesives and dyes production, listed as one of the major Air Pollutants included in the EPA list of hazardous air pollutants.

This paper presents the main results obtained during a continuous six months biofiltration experiment. The study included the stability of the medium and the biofilter response to short-term shock loads.

2. Methods

Peanut shells were obtained from a peanuts oil factory located in the Chiapas State (México). The peanut shells were used as wasted without any previous treatment or inoculation. Peanut

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Table 1
Physico-chemical characteristics of peanut shells.

Water holding capacity (kg/kg dry weight)	2.8 ± 0.03
Specific surface area (m^2/m^3)	268 ± 6
Dry density	0.223 ± 0.022
Dry bulk density	0.052 ± 0.01
Void fraction (%)	74.02 ± 0.5
Number of particle per m^3	220×10^3
pH	6.8 ± 0.04
Ash (% dry weight)	3.5 ± 0.21
Organic matter (% dry weight)	95.7 ± 0.72
Total nitrogen (% dry weight)	2.3 ± 0.1
Total potassium (% dry weight)	0.31 ± 0.01
Total phosphorus (% dry weight)	0.025 ± 0.001
Total aerobic microorganisms (UFC/g)	1×10^8

shells were previously physically and chemically characterized (Table 1; Ramírez-López et al., 2003).

A stainless steel lab-scale reactor was built (diameter 0.25 m; height 0.86 m) with 42 L of total volume and an operating volume of 20 L. Air and water/nutrient solution were fed jointly on the top of the reactor using an atomising Venturi type nozzle. The atomising nozzle was the type 156.330.30.16 from Lechler (Fellbach, Germany). This atomiser was previously characterized (Thalasso et al., 1993). The gas flow rate was obtained from a compressed air distribution system and controlled by a valve and a flowmeter (Gilmon, Barrington, USA). The air flow rate was maintained between 1.95 and 3.90 m^3/h (98–195 m^3/m^3 h) and this stream was polluted with methanol as a model gaseous pollutant. Methanol was injected into the compressed air distribution line, through a vaporisation tank using a peristaltic pump (Masterflex pump C/L 6–60 rpm; Cole Parmer, Mexico). Methanol concentrations were regulated in order to reach volumetric loading rates from 2 to 55 kg MeOH/m^3 d. The liquid supply was maintained at approximately 0.07–0.13 L/d (3.5–6.5 L/m^3 d). Methanol degradation rates were determined from the inlet methanol gas concentration and the outlet gas and liquid concentrations.

Prior to the biofiltration experiment and in order to distinguish the biological degradation from the abiotic sorption of methanol, wet peanut shells (41% moisture content) were sterilised at 120 °C for 30 min and placed into the biofilter. The reactor was fed with a specific gas and water flow rate of 100 and 3.5×10^{-3} m^3/m^3 h, respectively. The methanol loading rate was maintained at 2.25 kg/m^3 d. Influent and effluent gas samples were frequently analysed.

Except during the first period of the biofiltration experiment (day 0 to day 30), the liquid flow injected to the biofilter contained buffer and nutrients solution in order to promote a higher biological activity. The nutrient solution contained (in mg/L): KH_2PO_4 5120; $Na_2HPO_4{\cdot}2H_2O$ 2720; $(NH_4)_2SO_4$ 876; $MgSO_4{\cdot}7H_2O$ 400; EDTA 20; $FeSO_4{\cdot}7H_2O$ 10; $MnCl_2{\cdot}4H_2O$ 2.4; $CoCl_2{\cdot}6H_2O$ 0.9; $ZnSO_4{\cdot}7H_2O$ 0.5; $CuSO_4{\cdot}5H_2O$ 0.4; $CaCl_2{\cdot}2H_2O$ 2.0; $Na_2MoO_4{\cdot}2H_2O$ 0.4; Inositol 4.0; pyridoxine chloride 2.0; thiamine chloride 2.0; pH 7.0. The water/nutrient solution was injected continuously using a Masterflex pump (model 755-05, Masterflex pump C/L System; Cole Parmer, México). The experiment was run at ambient temperature. Effluent gas temperature and humidity were frequently measured using a thermohygrometer controller (Taylor 5368, Taylor, Mexico). Pressure drops through the column were continuously measured using a water column manometer. pH of the influent and effluent liquid solution were measured using a pH meter (Consort C835, Consort, Belgium).

Methanol concentration of the influent and effluent gas phase as well as the liquid effluent was determined by gas chromatography using a Perkin–Elmer GC chromatograph equipped with a 2 m Porapak Q column and a FID detector.

From time to time, samples of peanut shells were taken for analysis. Apart of visual observation, the moisture content of the medium was measured according to the 2.166 method (AOAC, 2002) and the water holding capacity (WHC) was measured according to 2.181b method (AOAC, 2002). At the beginning and the end of the experiment, total nitrogen and total phosphorus content of the peanuts shell were measured according to Jackson's methods (Jackson, 1976). Total potassium was also measured by atomic absorption after ashing the sample at 550 °C (AOAC, 2002). Total aerobic microorganisms were counted using the plate count technique (Benson, 1985).

At the beginning and at the end of the biofiltration experiment a drying test of the peanut shells was carried out using a drying computerised tower at Celaya Institute of Technology (Celaya, Mexico). Prior to the drying test, the peanut shells were washed three times with tap water in an ultrasonic bath (150T, VWR, USA) for 5 min and then saturated with water for 48 h. Peanut shells were then put on a tray (0.18 by 0.27 m and 0.015 m height) and introduced into the drying tower. An air flow of 2 m^3/h at 90 °C was maintained through the peanut samples up to constant weight (4–8 h). The influent and effluent air temperature and humidity as well as the sample weight and temperature were continuously monitored. From the results obtained, the drying velocity versus the moisture content was plotted.

3. Results and discussion

The biofilter was first loaded with sterilized peanut shells to evaluate the abiotic methanol absorption. At the onset of this experiment, the effluent methanol concentration was close to zero. Twenty-four hours later, the influent and effluent concentrations were close enough to consider that the sorption equilibrium was reached. Considering the complete sorption curve (data not shown), the sorption capacity of the filter-bed was estimated to about 0.5 kg MeOH/m^3 of medium, this value being obviously proportional to the influent methanol concentration.

After the abiotic methanol sorption experiment, the reactor was filled with fresh, peanut shells (47% moisture content) and the biofiltration experiment was started. During the first period (Table 2), water was injected instead of nutrient solution and the gas flow rate and the volumetric loading rate were maintained at 100 m^3/m^3 h and 2.76 kg MeOH/m^3 d, respectively. As presented in Fig. 1, the apparent degradation rate started close to the loading rate, due to the sorption mechanisms, and rapidly decreased to an elimination efficiency of 45%. After few days, methanol removal efficiency increased and remained around 80%.

At day 30, assuming that the removal efficiency was limited by nutrients, the liquid feeding was changed from water to nutrient solution. During the following 42 days of operation, the removal efficiency increased and reached 90% (Fig. 1). From day 72 to 104 the inlet methanol concentration was increased to 0.66 g/m^3, while the air flow rate was increased to 191 m^3/m^3 h, maintaining the loading rate at 3 kg MeOH/m^3 d. This caused a continuous increase in the removal efficiency, up to values close to 100% (Fig. 1). At day 104, the loading rate was duplicated to 6 kg/m^3 d. This increase had a direct negative impact on the elimination efficiency, decreasing for few days to around 85%. Progressively, the degradation rate returned to higher values and stabilised at around 95%. At day 135, the loading rate was increased to 15 kg/m^3 d and the degradation rate increased in the same proportion. Nevertheless, after a few days the elimination efficiency started to decrease. Up to the end of the experiment, the loading rate was increased three times to reach a maximum value of 45 kg/m^3 d. During this period, the degradation rate increased proportionally to the loading rate applied up to 30 kg/m^3 d. Nevertheless, during the same period of time,