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Short Communication

Characterization of five agricultural by-products as potential biofilter carriers

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Abstract

Biofiltration is the most commonly used biological gas treatment technology and is extensively used for the treatment of polluted air with gas flow rates of up to 2×10^5 m^3/h. It involves a filter bed of organic matter serving both as carrier for microorganisms and as nutrient supplier. Polluted gas passes through the filter bed and is cleaned by biological activity. Biofiltration is not being developed in Latin America as in the USA, Canada or Europe; the main reason probably being the absence of specific technology and of potential organic carriers locally available. Five different agriculture by-products available in Latin America: peanut shells, rice husk, coconut shells, cane bagasse and maize stubble, were chemically, physically and structurally characterized for their potential use as biofilter carrier. It was found that peanut shells could be used as biofilter carrier and therefore would have potential biological application.

Keywords: Agricultural by-products; Biofilter carrier; Gas treatment; Peanut shells; Pressure drops; Water activity

1. Introduction

Biofiltration is currently the most used biological gas treatment technology. It involves microorganisms immobilized in the form of a biofilm on a porous carrier, such as, peat, soil, compost, synthetic substances or combinations of them. The carrier provides to the microorganisms a favorable environment in terms of pH, temperature, moisture, nutrients and oxygen supply. As the polluted air stream passes through the filter bed, pollutants are transferred from the vapor phase to the biofilm developing on the organic substrate. The microorganisms metabolize the pollutants (Bohn, 1992; Wani et al., 1997; Morgan-Sagastume et al., 2001). Peat and related compounds are the main carriers used in biofilters (Kennes and Thalasso, 1998). Although characterized by a low pH (3–4, Dalouche et al., 1989; Hirai et al., 1990), peat has a large calculated surface area (270×10^3 m^2/m^3, Zilli et al., 1996), void fraction (50%, Zilli et al., 1996), water holding capacity (WHC; 85% wet basis, this work) and contains large numbers of different bacteria (1×10^5, Dalouche et al., 1989). Nevertheless, peat is generally found in delicate ecosystems, not always available in large quantities and costs about 100 US\$/m^3 (Molyneaux, 1998; Vigneron, 1998). The use of agriculture by-products available in large quantities would be a valuable alternative to peat.

According to Clark and Wnorowski (1991) almost all organic compounds can be used as biofilter carrier. Bohn (1996) listed 13 important physical, chemical and biological characteristics with the most important being (i) large specific surface area, (ii) low bulk density, (iii) a high void fraction, (iv) large number of different bacteria naturally present in the carrier, (v) sufficient nutrients, i.e. N, P and K, (vi) large WHC and (vii) a neutral or alkaline pH as well as buffer capacity.

In this paper, five different agricultural by-products were selected for their availability and apparent characteristics; namely rice husk, maize stubble, bagasse, and coconut and peanut shells. All agricultural by-products selected are locally available in subtropical and tropical regions of Latin America, where peat is usually unavailable. In this study they were characterized, and investigated as potential carrier material in biofilters.

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Maize stubble ~ corn fibre

2. Methods

2.1. Material and method

Untreated peanut shells were obtained from a peanut oil factory in the State of Chiapas (Mexico). Sun-dried coconut shells were obtained from a coconut plantation in the State of Guerrero (Mexico). Rice husk, ground bagasse and maize stubble were obtained from a central wholesale (State of Mexico, Mexico). They were analyzed for pH, particle size, density, bulk density, WHC, specific surface area, induction of pressure drops when an air flow is passed trough, ash and organic matter content. The most promising by-product (peanut shells) was selected and further analyzed for total N, P and K, total microorganisms and water activity versus water content.

The water, ash and organic matter content, pH and WHC were determined in triplicate according to methods 2.105, 2.107, 2.109, 2.110 and 2.151 of the AOAC (1975), respectively. Particle sizes of coconut and peanut shells were determined by direct measurement of 50 and 200 particles, respectively, while that of rice husk, bagasse and maize stubble were determined in triplicate through sieving. The specific surface area of peanut shells, rice husk and coconut fiber was calculated by measuring the area of 200, 200 and 50 particles, respectively.

The total nitrogen content was determined by Kjeldahl (Jackson, 1976), N–NH_4^+ by acidometric method (APHA, 1980), total P by spectophotometry (Jackson, 1976), and total K by atomic absorption after ashing and treating the sample with chloric acid (AOAC, 1975). All of these determinations were made in triplicate. The bulk density of the carrier material was determined in triplicate by filling a 20 l flask with the material and weighting it before and after. The void fraction of the carriers was determined submerging a known volume in water, the volume of water added per volume of material gives directly the void fraction while the density of the material is calculated by dividing the weight of the carrier used by its volume (total volume less volume of water added). The water activity of the material was determined in triplicate at 24.5 °C using a water activity measurer AquaLab CX-2 (Decagon Devices Inc., Pullman, WA). Pressure drops were determined during two independent experiments in a 20 l lab-scale stainless steel biofilter by passing an air-flow through the agricultural by-products. The biofilter was filled with a 0.8 m layer of each material and air with a superficial velocity from 0 to 140 m/h was led through the material in an up and downward way. These velocities are commonly used in biofilter systems (Ottengraf and Diks, 1991; Devinny et al., 1999). The pressure drops were measured using a U shaped differential manometer filled with water and calculated as Pa/m carrier.

For the determination of the number of microorganisms present in carrier, a 10 g sample of the selected agricultural by-product was added to a sterilized 500 ml flask with 100 ml sterile water and energetically shaken for 10 min. Dilutions ranging from 1×10^0 to 1×10^{12} were prepared with sterile water and an aliquot of 1 ml of each dilution was inoculated on potato-dextrose and yeast extract-malt agar in Petri dishes, incubated at 27 °C for 48 h and the colonies formed were counted.

2.2. Statistical analyses

The Ergun equation (1952) describe the pressure drop behavior in a bed with non porous regular shape particles (Eq. (1)). The pressure drops were measured during two independent experiments for each of the five agricultural by-products,

$$\frac{\Delta P}{LU_0} = \alpha + \beta U_0 \tag{1}$$

where ΔP is the pressure drop along the bed length L, U_0 is the superficial velocity, and α and β are the linear regression parameters. The relative dispersion of the results was determined by calculation of the mean absolute relative error (MARE) (Comiti and Renaud, 1989):

$$\text{MARE} = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{y_i - \hat{y}}{y_i}\right| \tag{2}$$

where

$$y_i = \frac{\Delta P}{LU_0}, \quad \hat{y} = \frac{\Delta P}{LU}.$$

3. Results and discussion

As presented in Table 1 coconut shells formed the largest particles followed by peanut shells, rice husk, maize stubble and bagasse. Coconuts shells had the lowest specific surface area; Maize stubble and bagasse the largest. The specific surface area for bagasse and maize stubble, taking into account the fraction of dust and small particles was higher than 10,000 m^2/m^3. This high value is a favorable characteristic but small particles could generate large pressure drops and clogging in biofilters. Additionally, micropores could fill up with growing microorganisms, reducing the surface area of the biofilm below the theoretical surface area of the carrier material. For instance, peat has a specific surface area of approximately 270,000 m^2/m^3 (Zilli et al., 1996) but the estimated surface of the biofilm is only between 40 and 85 m^2/m^3 (Baltzis and Androutsopoulou, 1994; Shareefdeen et al., 1993).

Bagasse and maize stubble gave the largest WHC (Table 1). They were able to absorb up to 9 times their

Table 1
Physical and chemical characteristics of the agricultural by-products

	Peanut shells	Rice husk	Coconut shells	Maize stubble	Bagasse
WHC (kg/kg)	2.8 ± 0.03	1.1 ± 0.01	3.3 ± 0.03	7.3 ± 0.29	10.1 ± 0.57
Specific surface area (m^2/m^3)	268 ± 6	997 ± 25	58 ± 1	>10,000	>10,000
Dry density	0.223 ± 0.022	0.653 ± 0.019	0.161 ± 0.005	0.403 ± 0.172	0.221 ± 0.085
Dry bulk density	0.052 ± 0.012	0.104 ± 0.013	0.069 ± 0.002	0.116 ± 0.011	0.052 ± 0.002
Void fraction (%)	7402 ± 0.5	84.3 ± 1.6	57.5 ± 1.3	71.2 ± 2.2	76.8 ± 2.5
Number of particles per m^3	220×10^3	28×10^6	1.4×10^3	$>120 \times 10^6$	$>290 \times 10^6$
pH	6.8 ± 0.04	6.3 ± 0.05	5.0 ± 0.3	5.9 ± 0.2	5 ± 0.5
Ash (% dry weight)	3.5 ± 0.21	24.2 ± 1.2	6.1 ± 0.1	8.4 ± 0.1	5.3 ± 0.3
Organic matter (% dry weight)	95.7 ± 0.72	74.4 ± 0.53	94.8 ± 0.89	92.3 ± 0.75	94.9 ± 0.15
Total nitrogen (% dry weight)	2.3 ± 0.1	ND	ND	ND	ND
Total potassium (% dry weight)	0.31 ± 0.01	ND	ND	ND	ND
Total phosphorus (% dry weight)	0.025 ± 0.001	ND	ND	ND	ND
Total aerobic microorganisms (#/g)	1×10^8	ND	ND	ND	ND

ND: not determined.
*: at 70% WHC.

dry weight in water but were compacted during measurement making these estimates less reliable. Coconut and peanut shells absorbed up to 3 times their own dry weight while rice husk was able to absorb only the equivalent to its dry weight. The five agricultural by-products possessed a low dry density and dry bulk density indicating in all cases a void fraction higher than 50% (Table 1).

The pH levels of the agricultural by-products ranged from 5.0 ± 0.3 (coconut shells) to 6.8 ± 0.04 (peanut shells). A neutral pH, as found for peanut shells, rice husk and maize stubble, would be considered a suitable characteristic for biofiltration although lower pH values can be compensated by adding a buffer or a compound with an alkaline pH. The organic matter content of each agricultural by-product was higher than 90% except for rice husk due its large silicate content (Table 1). An organic content higher than 55% is considered as the minimum acceptable for biofiltration applications (Leson and Winer, 1991; Eitner and Gethke, 1987), although successful biofiltrations have been obtained in soil biofilters with a lower organic content.

Pressure drop in biofilter media is a function of the moisture content of the packing material and de superficial velocity (Shoda, 1991; Van Langenhove et al., 1986). For that reason, pressure drops were measured at 100% of WHC except for maize stubble and bagasse, for which pressure drops were measured at 60% of WHC as they showed clogging at water contents of approximately 70% of WHC. The pressure drops measured with a superficial gas velocity of 100 m/h (down-flow) ranged from 100 to 800 Pa/m and were inversely proportional to the mean particle size (Fig. 1, Table 1). The pressure gradient as a function of the superficial velocity (U_0) for the five different agricultural by-products is shown in Fig. 1. A correlation coefficient superior to 0.99 and with a MARE from 0.02 to 0.1 were obtained (Table 2). The pressure drops observed with peanut and coconut shells were lower than those observed for peat and compost (Ottengraf and Van den Oever, 1983; Van Langenhove et al., 1986; Martin et al., 1979; Ottengraf and Diks, 1991; Smit and Derber, 1987). Pressure drops were similar in up-flow direction except for bagasse and maize stubble; they were close to zero as channels were formed.

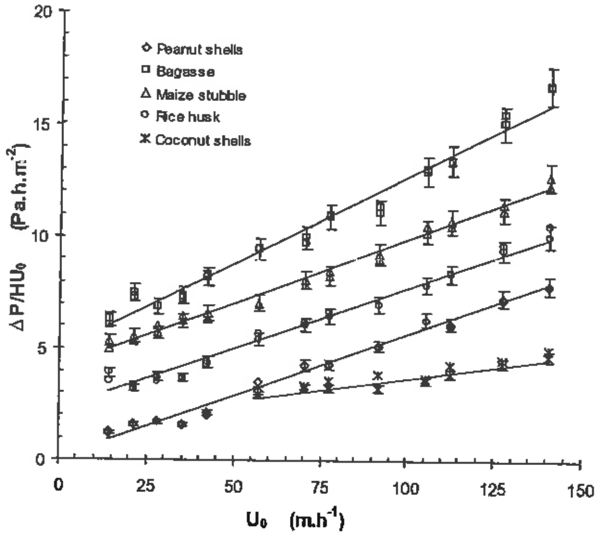

Fig. 1. Pressure gradient for five different agricultural by-products.

Maize stubble and bagasse were not further investigated as channeling and clogging were observed. Coconut shells were not further considered since they had the lowest pH (5.0 ± 0.3) and specific surface area (58 ± 1 m^2/m^3). From the two remaining products, peanut shells were chosen for further analysis since the WHC of peanut shells was 1.4-times larger than that of rice husk, its organic matter content was 1.3-times larger and its dry and wet bulk density were smaller. Although its specific surface area was only 25% of that for rice husk, it was still within values reported for synthetic carrier used in trickling filters.

Table 2
Regression parameters for each of five agricultural by-products

Agricultural by-product	Experimental values (Pa h/m²)		Correlation coefficient, r	MARE
	α	β		
Peanut shells	0.055	0.128	0.993	0.09
Bagasse	0.077	4.931	0.988	0.04
Maize stubble	0.057	4.167	0.994	0.02
Rice husk	0.054	2.271	0.990	0.04
Coconut husk	0.020	1.642	0.960	0.18

As presented in Table 1, the peanut shells contained a significant amount of nitrogen, phosphorus and potassium and N/K/P ratio of 100/13/1. The microorganisms normally contain 5%, 1% and 0.6% dry weight of N, P and K, respectively, or a N/K/P ratio of 100/20/12 (Schlegel, 1993). The K and P content of the peanut shells would be considered too low for optimum microbial biomass growth but the P concentration is enough to yield about 200 kg of dry biomass/m^3 of peanut shells, sufficient for a biofilter (Schlegel, 1993).

The number of total aerobic microorganism found in the peanut shells was approximately 1×10^8 organism/g dry peanut shells; significantly larger than numbers reported for peat (Dalouche et al., 1989). Most microorganisms need a water activity higher than 0.98 (Atlas, 1989; VanDemark and Batzing, 1987). The relationship between the water content of the carrier and the water activity is therefore important, especially in gas biofiltration, as the gas passing through the carrier has a large drying potential. The results obtained are presented in Fig. 2. According to Fig. 2, peanut shells have a water activity higher than 0.98 at a water content above 30%, i.e. 40% of WHC (Fig. 2). So a moistened filter bed of peanut shells can lose up to 88 kg H_2O m^{-3} before a lack of H_2O will inhibit microbial activity.

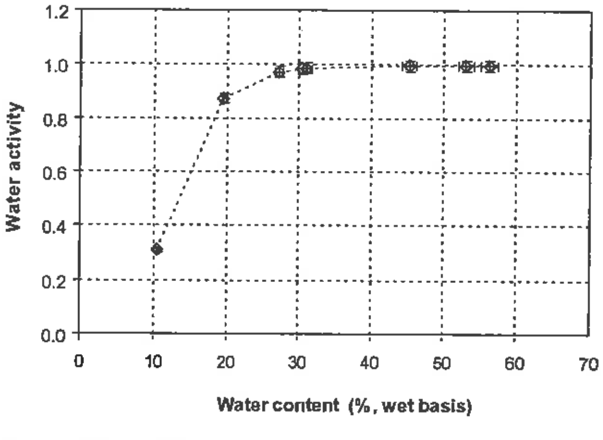

Fig. 2. Water activity versus moisture of selected agricultural by-products.

4. Conclusion

Peanut shells constitute a potential alternative to peat in biofiltration applications, especially in regions where peat is not available at a low price and/or in large quantities. They have a regular particle size, a large specific surface area, a low bulk density, a neutral pH, a large number of microorganisms, a large WHC, sufficient nutrients for microbial growth, no significant clogging risk, and they showed limited pressure drops.

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