A comparative study of the characteristics and physical behaviour of different packing materials commonly used in biofiltration.

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ABSTRACT. In this study, the characteristics and physical behaviour of 8 different packing materials were compared. The materials were selected according to previous works in the field of biofiltration including organic and inorganic or synthetic materials. Results pre-selected those more acceptable support materials for the main function they have to perform in the biological system: high surface contact, rugosity to immobilize the biomass, low pressure drop, nutrients supply, water retentivity or a commitment among them. Otherwise, pressure drop have been described by means of the respective mathematic expressions in order to include phenomena in the classical biofiltration models.

1 INTRODUCTION

Biological treatment have become and effective and economical alternative to the traditional systems of gas treatment. However, several packing materials have been used in biofiltration without a global agreement about which one is the most adequate to immobilize biomass. Carrier materials may be organic, natural inorganic, or entirely synthetic. The nature of the packing material is a fundamental factor for successful application of biofilters because it affects the frequency at which the medium is replaced and other key factors such as bacterial activity and pressure drop across the bioreactor (Devinny et al., 1999).

Moreover, particles vary in size, which affects important medium characteristics such as resistance to air flow and effective biofilm surface area. If the size of the bed pellets is too small provides for large specific surface areas, available for essential mass exchange, but it also creates resistance to gas flow, while if it is too large, it favours gaseous flows but reduces the number of potential sites for the microbial activity (Delhoménie et al. 2002). Adu and Otten (1996) have reported that particle size is a parameter more influential to the performance than the gas flow rate.

Among the naturals carriers reported, compost, peat, soil and the wood derivatives are the most extensively used while GAC, perlite, glass beads, ceramic rings, polyurethane

foam, polystyrene and vermiculite are some of the several synthetic or inert carriers which have been studied (Kennes et al., 2001).
Specific surface area, porosity, density, water retention capacity and the nutrients availability are some of the most important characteristics of the filter media (Janni et al. 2001). In this work, a comprehensive study of physical parameters for different packing materials commonly used in biofiltration has been performed. Pressure drop was also determined for each packing material to determinate the inherent economical cost to flow the air through the bed. To this aim, pressure drop was evaluated in each case depending on the flow rate, the bed porosity and the water content circulating through the material media in countercurrent flow. Pressure drops have been described by means of mathematical expressions relating the effects of the studied factors in order to include this parameter in classical biofiltration models.

2 MATERIALS AND METHODS

2.1 Experimental setup

Pressure drop assessment experiments were carried out using a lab-scale plant consisting of a PVC column with an inner diameter of 4.6 cm and a height of 70 cm (Figure 1). The compressed air was conducted by 2 different circuits. In the former, the air stream was passed through a water column in order to increase the relative humidity and in the latter, the air stream arrived completely dry to the fixed bed. The inlet air pressure and the flow rate were controlled and measured by means of a pressure regulator (Norgren Excelon) and a flowmeter (Tecfluid 2100) respectively. Throughout this study, the gaseous stream was supplied in up-flow mode. Tap water was sprinkled continuously at the top of the fixed bed be means of a peristaltic pump (Magdos LT-10) and the water content was measured by an optical level sensor. Pressure drop was determined by means of two digital differential pressure meter used according to the limit detection and precision (Testo 512-20hPa and Testo 506-200 hPa).

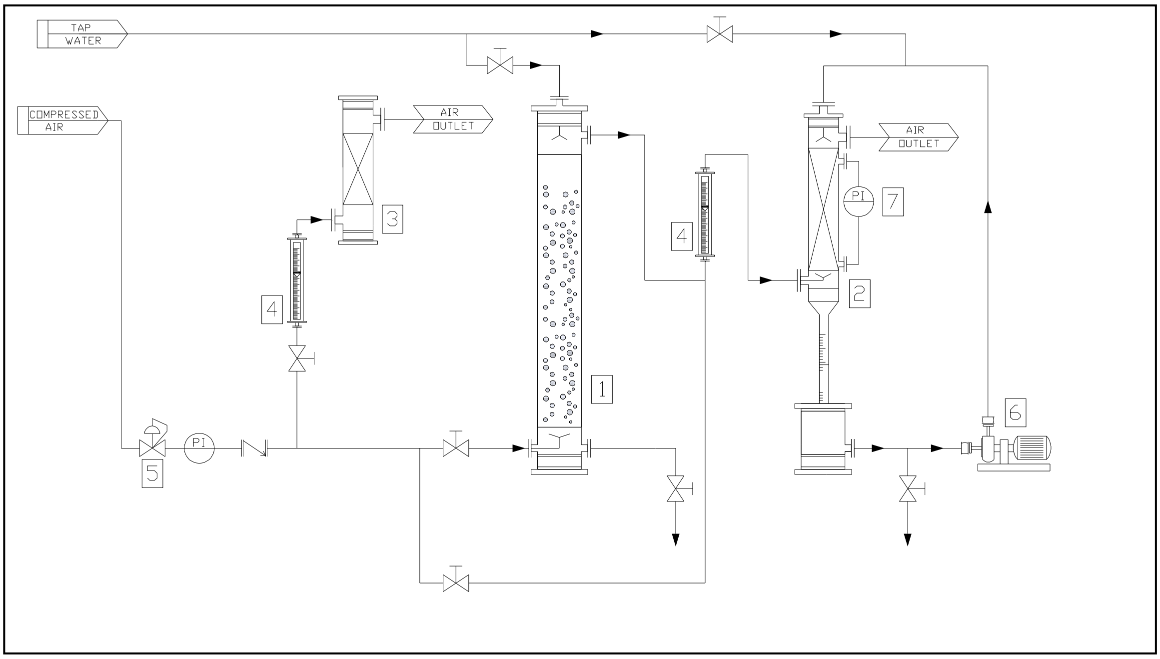

Figure 1. Schematic of the lab-scale setup. 1: humidification column; 2: fixed bed for pressure drop study; 3: fixed bed for water retentivity study; 4: flow meters; 5: pressure regulator; 6: peristaltic pump; 7: digital differential pressure meter.

2.2 Packing materials

A total of 8 common packing materials used in biofiltration were studied and compared by determining their main physico-schemical properties. Organic packing materials analysed were coconut fibre, pine leaves, peat and compost from sludge of a waste-water treatment plant. The inorganic or synthetic packing materials studied were polyurethane foam, lignite from Mequinenza mines (Spain), lava rock and an advanced material based on a thin layer of compost over a clay pellet.

2.3 Analytical methods

Characterization of packing materials were carried out according to standard methods (APHA, 1980; ASTM, 1990; TMECC, 2002). The following properties were compared in each case: specific surface area, elementary analysis, extractable phosphor content, organic matter, humidity, water holding capacity, retentivity, ph, conductivity and buffer capacity of the leachate.

Specific surface area and material density were determined by the BET technique in a Micromeritics, model Tristar 3000, apparatus.

Elementary analysis was realised by combustion in standard conditions using sulfanilamida as standard (EA-1108 ThermoFisher Scientific). Extractable phosphor was determined by the technique of ICP in a multichannel analyser in standard conditions (Thermo Jarell-Ash model 61E Polyscan) using Baker Instra as digester of the sample. Surface rugosity was observed by means of a Scanning Electron Microscope (Jeol JSM-840).

Humidity and organic matter were determined by drying and combustion standard procedures. Water holding capacity was measured keeping the material wet sparkling constantly tap water for 100 minutes and determining the weight changes. Water retentivity was measured by keeping wet material in constant contact with dry air flow circulating through the bed and measuring the loss of weight of the bed. Conductivity, pH and buffer capacity was determined for the materials leachate submerging them in water for 1 hour in controlled conditions of temperature and agitation.

3 RESULTS AND DISCUSSION

3.1 Characterization of packing materials

High nutrient, phosphorous, potassium and sulphate contents, as well as trace elements, are required for the establishment of a dense process culture. Regarding to the elementary composition of organic packing materials (Table 1), it is shown that the compost is the material with the highest content in nitrogen and phosphorus (2.7 % and 14.500 ppm, respectively. It must be pointed out that immature coal (lignite) studied showed a significant concentration of sulphur (8,8 %) which is related to the quality of the material. Also, presence of sulphur has been detected in compost as well. On the other hand, phosphorous concentration in lava rock (1800 ppm) is higher than expected probably due to the pre-treatment of this material to garden applications.

Among the organic material analysed, coconut fibre and pine leaves present the highest organic matter content (higher than 85% by weight). The organic matter detected in coal (next to 80%) is a reflex of the immature nature of this material.

Table 1. Elementary composition of packing materials.

	Nitrogen (%)	Carbon (%)	Hydrogen (%)	Sulphur (%)	Phosphorus (ppm)	Organic matter (%)
Coconut fiber	1,17	45,05	6,18	0,12	256	91,62
Pine leaves	0,56	45,18	6,10	0,05	191	86,71
Peat	1,26	21,99	2,56	0,15	455	66,23
Compost	2,68	33,86	4,63	0,63	14487	53,56
Advanced material	0,34	2,45	0,18	0,19	1259	2,57
Lava rock	0,00	0,40	0,00	0,00	1821	0,63
Coal	0,85	44,37	4,06	8,81	98	79,69

In general, it is desirable to have media with a high water-holding capacity. Organic media are 40 to 80% water (by weight) when they are saturated (Devinny et al. 2002). Packing materials studied keep a water holding capacity inside the typical interval, being in the higher values for coconut fibre, pine leaves and peat (Table 2). The humidity of the materials is similar in all the studied cases but there are appreciable differences in water retentivity.

Regarding to the specific surface, coal is the material with the highest value (6 m^2 m^{-3}), while compost is the highest among the organic materials (2,8 m^2 m^{-3}).

Table 2. Physical characteristics of packing materials.

	Surface area (m^2 m^{-3})	Humidity (%)	Water holding capacity ($g \cdot g^{-1}$)	Water retentivity (% dia^{-1})	Conductivity (µS)	pH	Buffer capacity (ml $SO_4^{2-} \cdot l^{-1}$)
Coconut fiber	1,68	6,62	3,90	192,24	315	5,93	33
Pine leaves	0,50	7,79	1,51	422,78	216	6,90	120
Peat	1,43	6,97	1,80	66,38	338	5,13	20
Compost	2,82	7,83	0,68	57,89	470	7,24	128
Advanced material	0,76	37,62	0,58	41,90	226	5,72	13
Lava rock	0,62	0,06	0,18	23,33	33	7,21	33
Coal	5,99	4,85	0,28	41,62	205	6,51	45
Polyeurethane foam	0,02	-	-	416,45	-	-	-

Packing materials studied showed a pH close to the neutrality or slightly acid (pH ≈ 5 for peat) and a buffer capacity inferior to 150 ml SO_4^{2-} l^{-1} in all the cases. Leachate conductivity of the materials was similar among them (excepting lava rock), being 470 µS the highest value determined in compost.

The surface rugosity of the materials has been observed and compared by means of Scanning Electron Microscopy. As a sample of organic materials, coconut fibre shows an important surface rugosity which could aim to fix the microorganisms to the surface (Figure 2). Conversely, polyurethane foam shows the opposite situation where the surface observation at 1000 magnifications shows a completely flat surface.

a) b)

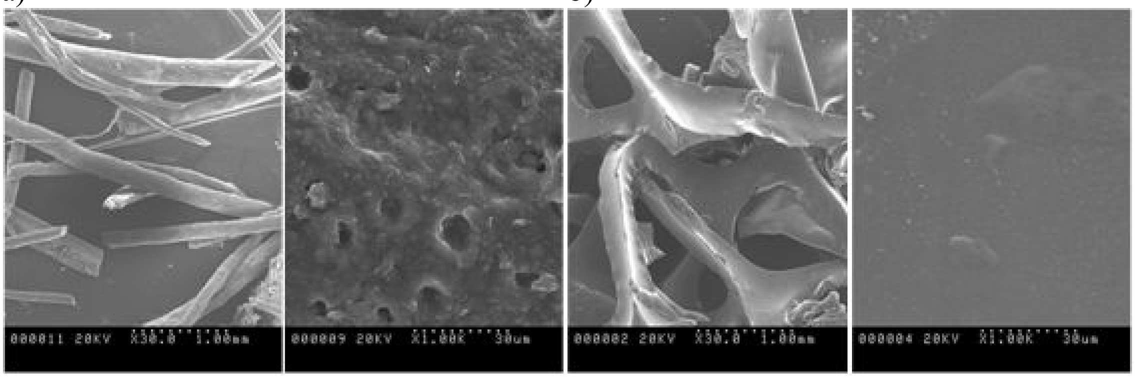

Figure 2. Microscopic observation of the rugosity of a) coconut fibre at different magnifications by SEM (x30, x1000) and b) polyurethane foam (x30, x1000).

3.2 Parameters influence in pressure drop

Pressure drop tests were carried out at 7 different flow rates, 5 different water contents and 3 different bed porosities. Flow rates were selected in the range to obtain empty bed residence times commonly used in biofiltration (from 5 to 40 seconds). Water content circulating through the bed was regulated by means of the peristaltic pump avoiding flooding episodes. Porosity was selected through different particle size or different degrees of compactation depending on the materials as for instance, coconut fibre or pine leaves. Results were represented in surface plots to observe simultaneously the parameters influence pressure drop.

Figure 3 shows the effect for coconut fibre and compost as examples of organic packing materials behaviour. Regarding water content, the influence is very similar for both materials in opposition to empty bed porosity influence where results do not show significant differences.

Figure 4 shows an example of the behaviour of non-organic materials, concretely polyurethane foam and the advanced material. Polyurethane foam showed more important pressure drop in the range of study, presenting significantly differences for the different bed porosities tested. Water content is a parameter less influencing in comparison to organic samples. Drop pressure in advanced material, in the only possible porosity allowed by its shape and structure, shows a strong dependence on water content, being more important at high flow rates.

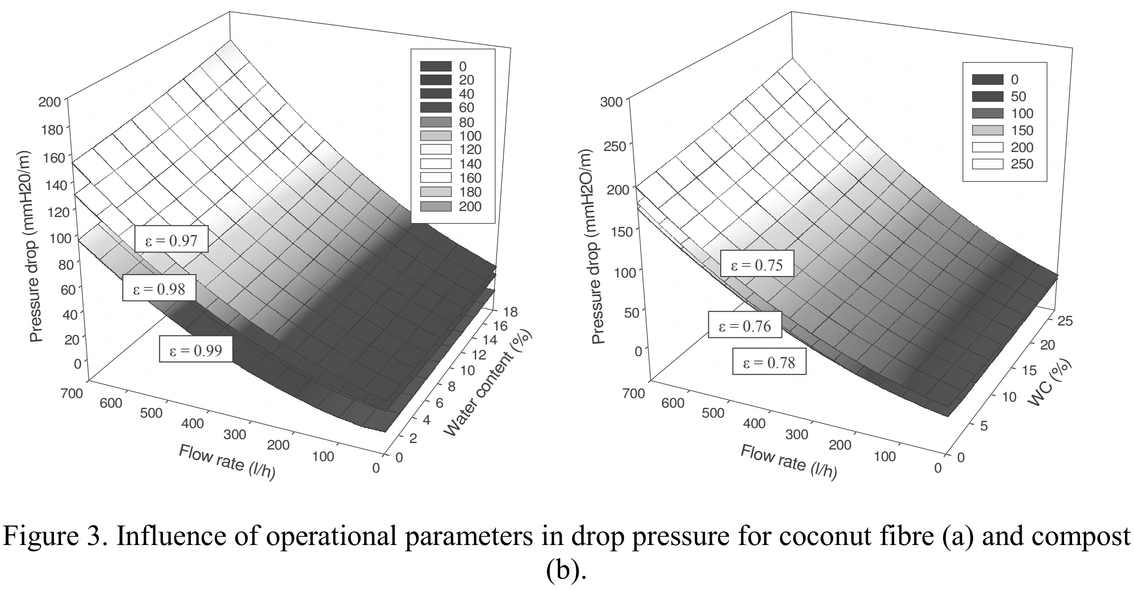

Figure 3. Influence of operational parameters in drop pressure for coconut fibre (a) and compost (b).

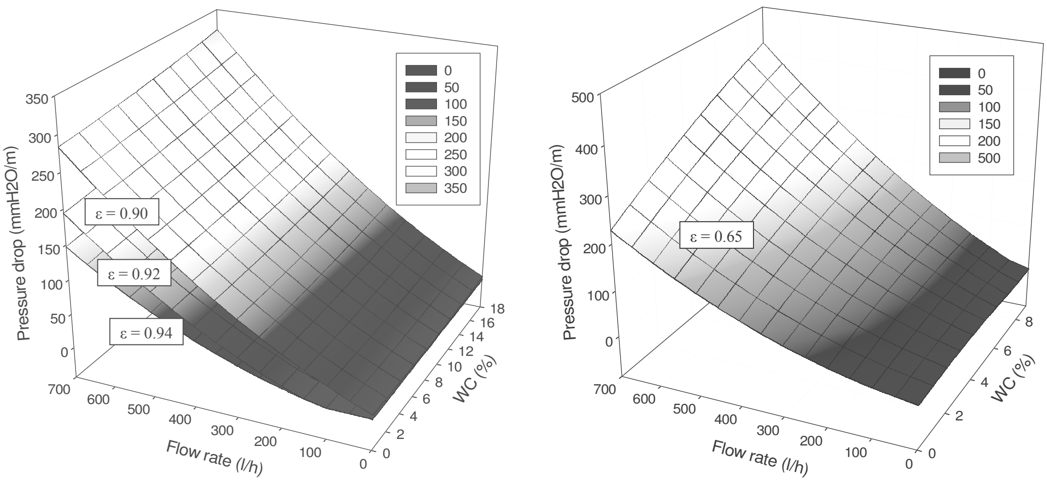

Figure 4. Influence of operational parameters in drop pressure for polyurethane foam (a) and advanced material (b).

3.3 Mathematical expressions in drop pressure

Drop pressure in a fixed bed has been described through several semiempirical mathematical expressions. In most of works, the pressure drop is described by the well-known Ergun equation (Ergun, 1952), which may be written as (Eq. 1):

$$\frac{\Delta P}{H} = a \cdot \frac{\mu v_0}{d_p^{\,2}} \frac{(1-\varepsilon)^2}{\varepsilon^3} + b \cdot \frac{\rho v_0^{\,2}}{d_p} \frac{(1-\varepsilon)}{\varepsilon^3} \qquad (1)$$

Where:

ΔP is the pressure drop in Pa; H is the height of the fixed bed in m; μ is the viscosity of the air in Pa s; v_0 is the superficial velocity in m s^{-1}; ε is the porosity of the bed; d_p is the equivalent spherical diameter of the particle in m; a is the first parameter of the Ergun equation, b is the second parameter of the Ergun equation.

Parameters a and b are related to the friction factor. In addition the expression term related to parameter a is significant for flow under very viscous conditions while the parameter b term is only significant when viscous effects are not as important as inertia. Some authors have fitted satisfactorily experimental data to a modified Ergun equation adapting the coefficients of the expression be means of a correction factor (Delhoménie et al. 2003). Other authors have used a specific relation due to the heterogeneity of the material and the difficulty to model pressure drop with the classical Ergun equation (Comiti and Renaud, 1989). In this study, parameters a and b from Ergun equation have been fitted as a function of the material, the porosity and the water content. Pressure drop (ΔP/H) as a function of the empty bed velocity has been fitted by a lineal regression. In all cases the correlation coefficient R^2 was superior to 0,990 indicating the correct linearity between operational parameters and pressure drop.

This experimental study incorporated the effect of water content in pressure drop although this parameter is not present in Ergun equation. For this reason, parameter a and b were fitted as a function of water content in the bed in order to find a relationship which describes this effect in the pressure drop estimation.

Table 3 shows the final results of this systematic study in order to compare the water content effect in each material. Water content for compost, lava rock and the advanced material biofilter showed the strongest effect in parameter a. In the case of parameter b the dependence on water content was markedly lower.

Thus, it is possible to express a modified Ergun equation incorporating the water content effect in the pressure drop predictions for some packing materials. These results may be useful to incorporate pressure drop phenomena in classical biofilter models.

Table 3. Ergun equation parameters as a function of water content in biofilters.

	ε	*a ordinate*	*a slope*	*b ordinate*	*b slope*
	0,70	12,634	-0,069	0,250	0,003
Compost	0,76	132,370	0,720	0,595	0,009
	0,79	432,090	4,077	1,199	0,004
	0,94	0,626	0,004	0,062	0,001
Coconut fibre	0,96	2,145	0,019	0,090	0,000
	0,99	9,130	0,750	0,333	-0,011
	0,73	75,398	0,340	0,512	0,005
Lava rock	0,76	115,150	0,384	0,531	0,001
	0,77	234,900	2,276	0,766	0,002
	0,58	14,618	0,212	0,176	0,001
Immature coal	0,63	35,182	0,387	0,248	0,002
	0,64	100,830	0,270	0,466	0,007
	0,91	1,885	0,014	1,146	0,058
Pine leaves	0,92	2,524	0,016	2,517	0,144
	0,96	9,378	0,059	11,196	0,000
Advanced material	0,65	12,342	1,458	0,160	0,009

4 CONCLUSIONS

Commonly used packing materials in biofiltration have been characterized and compared for a better knowledge of their advantages and drawbacks. Coconut fibre, pine leaves, peat, compost, polyurethane foam, coal, lava rock and an advanced material have been studied. Organic materials, especially compost and coconut fibre, are suitable to release extra inorganic nutrients. Moreover, these materials are able to keep water content at optimal levels for microorganisms and show the highest specific surface. Surface observation by Scanning Electron Microscope shows a better condition to fix the biomass in organic materials. On the contrary, inorganic or synthetic materials offers higher contact surface and produce cleaner drainage water. Otherwise, pressure drop have been determined for each packing materials as a function of flow rate, water content and bed porosity in order to represent the several effects simultaneously and obtain a mathematical expression to include phenomena in classical biofilter models. A water content dependence has been found through a modified Ergun equation for several packing materials.

5 ACKNOWLEDGEMENTS

This work was supported by the Spanish CICYT project CTQ2006 – 14997-C02-02. A.D. Dorado received a predoctoral fellowship from the M.E.C. (Ministerio de Educación y Ciencia).

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