A comparative study based on physical characteristics of suitable packing materials in biofiltration

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In the present work, 10 packing materials commonly used as support media in biofiltration are analyzed and compared to evaluate their suitability according to physical characteristics. The nature of the packing material in biofilters is an important factor for the success in their construction and operation. Different packing materials have been used in biofiltration without a global agreement about which ones are the most adequate for biofiltration success. The materials studied were chosen according to previous works in the field of biofiltration including both organic and inorganic (or synthetic) materials. A set of nine different parameters were selected to cope with well-established factors such as material specific surface area, pressure drop, nutrients supply, water retentivity, sorption capacity and purchase cost. One ranking of packing materials was established per each parameter studied to define a relative suitability degree. Since biofiltration success generally depends on a combination of the ranked parameters, a procedure was defined to compare packing materials suitability under common situations in biofiltration. Selected scenarios such as biofiltration of intermittent loads of pollutant and biofiltration of waste gases with low relative humidity were investigated. The results indicate that, out of the packing materials studied, activated carbons were ranked on top of several parameter rankings and showed as a significantly better packing material when parameters were combined to assess such selected scenarios.

Keywords: packing materials; biofiltration; Physical properties; Economical assessment

Introduction

Biological treatments have become an effective and economical alternative to traditional gas treatment systems. The correct selection of the packing material employed in a biofilter or a biotrickling filter is an important decision to achieve high removal efficiencies and to maintain an optimal performance in the long-term run [1]. Despite the widely recognized importance of the support media role, several packing materials have been used in biofiltration under a wide range of operating conditions without a global agreement about which one is the most adequate. Previous works studying packing materials are mostly based on a sole packing material case study [2-4] or on the

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comparison of the removal efficiency achieved by different packed biofilters under the same operating conditions [5,6]. In general, these studies concluded that high removal efficiencies in biofilters are strongly related to packing material properties although physical and chemical properties of the materials were not evaluated thoroughly. The nature of the carrier material, which may be organic, natural inorganic or entirely synthetic, is a crucial factor for the successful application of biofilters and biotrickling filters 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 [7,8].

Among the natural carriers reported, compost, peat, soil and wood derivatives are the most extensively used, while activated carbon (AC), perlite, glass beads, ceramic rings, polyurethane foam, polystyrene and vermiculite are some of the several synthetic or inert carriers which have been studied [9]. Specific surface area, porosity, density, water retention capacity and the nutrients content are some of the most important characteristics of the filter media from a biofiltration point of view [10]. A high specific surface area is needed to achieve high mass transfer velocities; high organic and inorganic nutrients content, water holding capacity and water retentivity are needed to keep an optimal activity of the immobilized microorganisms; a high adsorption capacity is recommendable to buffer intermittent loads; while a low purchase cost and a low pressure drop are directly linked with biofilter economical viability. Packing material particles vary in size, which affects important media characteristics such as the resistance to air flow and the effective biofilm surface area. If the size of the particles is small large specific surface areas essential for mass transfer are provided. However, smaller sizes also create a larger resistance to gas flow and, thus, larger operating costs due to the electrical power consumption of the blower. Conversely, large size particles favour gas flows but reduce the number of potential sites for the microbial activity [11]. Adu and Otten (1996) [12] have reported that particle size is a parameter even more influential to the performance than the gas flow rate. Thus, the relative importance of packing material properties can be different depending on the characteristics of the system and its operation.

The aim of this study is to study several relevant characteristics of 10 commonly used packing materials to evaluate their suitability in biofiltration. For this purpose, a comprehensive study of physical and chemical parameters for common packing materials used in biofiltration has been performed. Furthermore, since the economical viability is a key aspect to choose a suitable material, the purchase costs and operating costs related to pressure drop across the packed bed were also considered. In addition, a relative classification of the packing materials is provided per each parameter studied. Since packing materials selection is case specific, two case-studies such as the treatment of intermittent loads of pollutant and biofiltration of low humidity waste gases are analyzed. To this aim, a function is defined to classify packing materials by considering several parameters simultaneously.

Materials and methods

The following parameters were evaluated: specific surface area, elementary analysis, extractable phosphorus content, organic matter, humidity, water holding capacity, water retentivity, pH, conductivity, buffering capacity in the leachate, purchase cost, toluene sorption capacity under dry and wet conditions and pressure drop across the packed bed.

Analytical methods

Characterization of packing materials was carried out according to standard methods [13-15]. Specific surface area and material density were determined by the BET technique in a Micromeritics, model Tristar 3000, apparatus. Elementary analysis was performed by combustion under standard conditions using sulphanilamide as standard (EA-1108 ThermoFisher Scientific). Extractable phosphorus was determined by the ICP technique in a multichannel analyser in standard conditions (Thermo Jarell-Ash model 61E Polyscan) using Baker Instra as digester of the sample. Surface roughness was observed by means of a Scanning Electron Microscope (Jeol JSM-840) to contemplate the potential capacity to immobilize the biomass according to the structure of the surface. However, surface roughness was not used numerically or quantitatively in the study of the suitability of materials. Humidity and organic matter were determined by drying and combustion according to standard procedures. Water holding capacity was measured keeping the material wet by 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 bed weight loss at a gas superficial velocity of 12 m h^{-1} (EBRT = 60 s) [5]. Conductivity, pH and buffer capacity were determined from leachate after submerging the packing material in water for 1 hour under controlled conditions of temperature and agitation (20ºC and 70 rpm).

Packing materials

A total of 10 common packing materials were studied. Natural organic packing materials analysed were coconut fibre, pine leaves, peat mixed with heather and compost from sludge of a wastewater treatment plant (WWTP)

(Manresa, Spain). The inorganic or synthetic packing materials studied were polyurethane foam (PUF), lignite from Mequinenza mines (Spain), lava rock and an advanced material based on a thin layer of compost over a clay pellet. Moreover, two different carbons were included in the study: a commercial activated carbon (CAC) supplied by Chemviron Carbon (UK) and a sludge-based carbon (SBC) provided by the Department of Civil and Environmental Engineering, Imperial College, London.

Experimental setup

Pressure drop and sorption capacity 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). 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 while 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 mass flow controller (Bronhorst F-201CV) respectively. Throughout this study, the gaseous stream was supplied in up-flow mode to the column. Tap water was sprinkled continuously at the top of the fixed bed be means of a membrane 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 range and detection limit required (Testo 512, 0-20 hPa and Testo 506, 0-200 hPa).

Pressure drop depends on gas flow rate, water content and porosity. Flow rate was selected to obtain a bed residence time commonly used to treat VOC's in biofiltration (60 seconds). Water content in the packed bed was obtained by continuous irrigation of the bed by means of a membrane pump coupled to a pressure nozzle and avoiding flooding episodes (differences in water content are related with the capacity of materials to keep water according to its structure and affinity). Materials sizes, and thus packed bed porosities, were selected to ensure a column diameter to particle diameter ratio above 10 (minimization of wall effects).

Adsorption capacity of packing materials was evaluated by the frontal analysis technique based on toluene measurements at the inlet and outlet of a fixed-bed according to the staircase method [16]. Isotherms were determined from the breakthrough times of step changes in the feed concentration. Inlet pollutant concentration was achieved dispensing toluene as model compound (Panreac 99.5%) by means of an automatic burette (Crison 2S-D) at different volumes and injection frequencies. Pollutant concentration was measured by an on-line photo ionization detector (Photovac 2020) connected at the inlet and outlet of the bed. This allowed continuous monitoring and data collection through RS-232 computer interface. Inlet toluene concentrations to evaluate the quantity adsorbed in materials were selected according to common VOC's concentration treated by biofiltration (between 100 and 1000 ppm) [7]. Studied support materials were previously sterilized using sodium azide (Sharlau) in a 10% (w/w) ratio to remove the interferences of biological activity during the adsorption measurements [17].

(Figure 1)

Results and discussion

Physical properties of packing materials

Elementary analyses were performed to identify the capacity of support material to potentially provide macronutrients such as nitrogen and phosphorous necessary for biomass growth. Regarding to the elementary composition of packing materials (Table 1), SBC is clearly the material with the highest content in nitrogen and phosphorus (3.4 % and 6.6%, respectively), which is consistent with the origin of the raw material of SBCs obtained by pyrolyzing sludge from a WWTP [18]. Similarly, compost from WWTP sludge is the organic material with a highest content in nutrients. It is widely accepted that compost and most natural organic media have enough nitrogen and phosphorous content for developing a process culture [7]. However, external nutrients supply in organic media biofilters has been reported as a common way to improve biofilters performance [6,19]. Thus, bioavailability of nutrients for microorganisms growth may play a major role for optimizing biofilters performance. It must be pointed out that the immature coal (lignite) studied showed a significant concentration of sulphur (8.8 %), which is related to the quality of the material (formation of sulphur oxide by combustion). Also, a significant presence of sulphur was detected in compost as well. As it was expected, nutrients content in inorganic and synthetic materials was practically non-existent with the exception of a high content in phosphorus (0.13%) for the advanced material, due to the presence of compost fixed on its surface, and lava rock (0.18%), probably due to the pre-treatment of this material for garden applications.

On the other hand, organic matter content, i.e. the non-mineral matter content, constitutes an alternative substrate source for biofilter microorganisms which may be used during starvation periods such as process shut-downs, process rotation or intermittent loads [7]. Among organic materials analyzed, coconut fibre and pine leaves presented 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)

A high facility to keep appropriate wet conditions in packing materials is a desirable feature to avoid dry areas that would lead to poor growth and, thus, reduced removal efficiencies. The optimal moisture content for microbial activity is very close to the media's water holding capacity according to Bohn (1996) [20]. Thus, the water holding capacity has to be analyzed together with the material humidity, which depends on the wet conditions in which materials were collected. However, both parameters must be analyzed together with the water retentivity, which expresses how easily water is kept in the packing material independently of the amount of water retained. Table 2 shows that organic packing materials provide a water holding capacity inside the typical interval, being the higher values for coconut fibre, peat and pine leaves (Table 2). However, coconut fibre and pine leaves exhibit low water retentivities, which indicate that the amount of water retained may be easily lost if conditions inside the biofilter lead to high water evaporation rates, i.e. low relative humidity of the inlet gas. Among inorganic support media, it is interesting to notice that the relatively large water holding capacity found for PU foam coupled to a low specific surface area can be explained by its open-pore structure (10 pores per inch packing material), which permits water accumulation as macro droplets of water in the foam macro pores. This is consistent with the low water retentivity exhibited by PU foam. According to this, SBC and CAC offer the highest water retentivity, which is interesting in terms of water preservation in poorly watered biofilters but detrimental for adsorption and absorption of highly hydrophobic pollutants.

(Table 2)

Concerning the specific surface area, CAC was found to be the material with the highest value (950 m^2 g^{-1}) as expected, while compost is the highest among the organic materials (2,8 m^2 g^{-1}). Since no activation was produced during SBC production, the surface area of SBC (85,6 m^2 g^{-1}) is significantly reduced compared to CAC. However, it worth noticing that specific surface areas in Table 2 are referred to the total surface area including micro-pores, which may be hardly available in normal operating conditions of a biofilter due to the presence of water from irrigation and condensation and to biomass growth as a biofilm on the external surface of the packing material.

Prior observations about specific surface area and pores structure were confirmed through surface roughness observation of the materials by means of Scanning Electron Microscopy. As a sample of organic materials, coconut fibre shows an important surface roughness which could aim to fix the microorganisms to its surface (Figure 2). Conversely, polyurethane foam shows the opposite situation where the surface observation at 1000 magnifications shows a completely flat surface. Although the flat structure does not favour biomass immobilization on its surface, the macroscopic structure of PUF with open pore helps to capture water and biofilm between synthetic fibres to achieve high removal efficiencies as it has been reported in industrial applications [21].

(Figure 2)

Optimum pH values of the biofilter media depends on the contaminant being treated and the characteristics of the microbial ecosystem. However, pH changes generally stress the microorganisms affecting the correct operation of the biofilter. Episodes of inhibition can be controlled by using a biofilter medium with a high buffer capacity, i.e. high ability of the medium to face pH changes [7]. Packing materials studied showed a pH close to the neutrality or slightly acid (pH ≈ 5 for peat) except for sludge based carbon (close to 8) and a buffer capacity below 2350 mmol SO_4^{2-} l^{-1} in all cases. Low pH values of peat are explained by the organic acid compounds produced during the natural decomposition of organic matter. In all cases, buffering capacities are not enough for biofiltration of waste gases containing significant loads of pollutants such as H_2S that produce acidic by-products from microbial oxidation.

Moreover, leachate conductivity of the materials is significantly lower for carbons and lava rock, which indicates that extractable compounds such as a diversity of ions that may act as micronutrients are not present in large amounts. Instead, most organic materials or these provided with a layer of organic compounds such as the advanced material showed significantly higher conductivities. Such results confirm that organic packing materials may be more favourable for biofiltration with no external nutrients addition. Additionally, bulk density of materials has been included in Table 2. However, this value could change depending on the particle size and the degree of compactation of materials.

Characterization of pressure drop

Pressure drop (ΔP), i.e. the difference of pressure between the inlet and outlet of a biofilter, can be used as an indirect measurement of compaction and biomass or water accumulation since it rises as permeability is reduced. ΔP is an important operating parameter related to the energy requirements to drive air through the bioreactor, which is a substantial part of the operating costs and the majority of the electrical costs in bioreactors [22].

In the present study, ΔP tests were initially performed under dry conditions to evaluate the ΔP due to packing materials structure, size and shape, which in turn lead to a particular bed porosity. Afterwards wet conditions tests were also performed to study the effect of water absorbed and retained on the surface of materials as in biofilter operating conditions. Intrinsic ΔP for dry packing materials was below 3 cm water column per meter of bed height in all cases (Table 3). Results are according to typically ranges for pressure drop through biofilter beds [7] and correlated well with bed porosity except for PU foam, the advanced material and CAC. PUF exhibits a high bed porosity due to its open pore structure but it has been related previously to intrinsically high bed ΔP [23]. Oppositely, CAC and the advanced materials showed low bed porosities and significantly low ΔP, probably because of their rounded shape which offer a lower resistance to air circulation through the bed.

Interestingly, intrinsic ΔP values were only slightly increased with the presence of water inside the bed (Table 3) except for SBC, which retained high amounts of water due to the low bed porosity and high water retentivity. ΔP increases between 5 and 30% over dry conditions does not have a significant impact in terms of energy consumption costs as shown in Table 3. The electricity consumption was calculated considering a kilowatt-hour cost of 0.08 €/kWh (local prize) and by means of the empirical expression $P(kW) = 3.64 \cdot 10^{-4}$ x $Q (m^3 \cdot h^{-1})$ [24]. The increase of electrical consumption due to the pressure drop measured is estimated according to a mechanical balance: $P(W) = \Delta P (N \cdot m^{-2})$ x $Q(m^3 \cdot s^{-1})$. However, estimated annual material cost and economical consumption demonstrate that the correct election of support media have important implications in the economic assessment. As an example, treating an air flow of 100.000 $m^3 \cdot h^{-1}$ in a biofilter packed with CAC instead of SBC means an annual saving of 36.000 €.

(Table 3)

Purchase cost of packing materials

Additionally to operating costs, the purchase cost of packing materials has a significant impact in overall costs, not only because of the high volumes usually required for biofilter construction but also because of packing materials replacement due to limited durability. Table 4 shows the purchase price of packing materials according to prices of year 2009, Spanish market. As expected, synthetic materials are more expensive than naturals materials, e.g. 475 €·m^{-3} of bed for CAC and 35 €·m^{-3} for pine leaves. However, their estimated durability is generally larger than organic packing materials because of a superior mechanical and chemical resistance which avoids bed compaction and degradation in short periods of time. Special attention has to be paid to the packing materials selected, as it is the main parameter influencing the medium replacement cost, and one of the main factors affecting investment costs [24]. Accordingly, estimated annual material cost proves that the cheapest supports media to operate in a biofiltration unit are (in this order) PU foam, compost, lava rock and lignite (from 2 to 5 €·m^{-3}·$year^{-1}$).

(Table 4)

Adsorption capacity tests

The effects of adsorption on biofilter performance are complex, since simultaneously depend on different factors such as the medium, contaminant and microorganisms [24]. The adsorption capacity of the medium tends to smooth changes in concentrations and to reduce stress on the microbial population. Sorption capacities were determined for both dry and wet materials to obtain information regarding to the interactions nature between the contaminant, packing materials and the aqueous phase.

Adsorption capacities of dry materials allow to describe the behaviour in the non-colonized patches in an operated biofilter or to characterize the materials suitability as a buffer to smooth intermittent pollutant loads using the materials previously to the biofilter inlet. As expected, dry adsorption capacities (Table 5) correlate perfectly with the specific surface area (Table 2) with maximum adsorption capacities found in CAC (244 mg·g^{-1} of material). SBC and lignite showed reasonable high values despite being far from those for activated carbon (0,72 and 0,74 mg·g^{-1} of material respectively). However, most materials showed a dramatic decrease in their adsorption capacities (an average of 80%) under wet, common operating conditions in biofilters. Thus, the drastic loss of capability to adsorb intermittent pollutant loads of hydrophobic compounds when the media supports are used in steady conditions of operation is an important operational limitation for that must be taken into consideration during packing materials selection. It's worth noticing that in the case of CAC the decrease under wet conditions was only 8% with respect to the dry material capacity which can be related with its lower water holding capacity, i.e. lower water competition for adsorptives sites [25]. Strategies such as these developed by Moe and Li (2005) [26] focusing on the use of a separate carbon column placed before a biofilter might be useful for preventing sorption limitations due to water presence.

(Table 5)

Suitability of packing materials

The determination of the parameters described in previous sections permitted to rank packing materials from the most to the least suitable material according to a single critical parameter (Table 6). The classification permits to examine the relative position of a support media between a value of 0% (the least adequate) and a value of 100% (the most adequate) for each property. In general, percentages of suitability of materials are quite homogeneously distributed in the whole range except for the specific surface area and the sorption capacity, in which the percentage between CAC and the rest of packing materials is extremely different. The suitability index for specific surface area, water holding capacity and wet sorption capacity have been expressed per volume of packing material according to the bulk density shown in Table 2. According to the results, SBC is the most suitable material based on the nitrogen and phosphorus content, while CAC is the most suitable material considering to the specific surface area, water retentivity, pressure drop and sorption capacity. Thus, carbons seem to be the most suitable packing material although they are the most expensive material by far, which may hinder their use at industrial scale with respect to cheaper materials such as compost. Results demonstrate that the most suitable material to pack a biofilter depends on the characteristics of a specific operation and site meaning that a material may be suitable in some conditions but inappropriate in others.

(Table 6)

As a consequence, a simple function is defined to account for several properties simultaneously to compare packing materials suitability under common situations in biofiltration. The present study proposes a function defined by the degree of suitability values found in Table 6 of 4 parameters being 2 of them common in all the proposed cases of study: ΔP in wet conditions and the annual material cost. A material could be very interesting to use in a specific application for their properties but economically expensive to operate due to its cost or the pressure drop associated. Economical feature is a consideration that always has to be present in the selection of the most suitable material. The other two parameters are decided based on existing knowledge consisting in a main parameter, the one that has a larger impact in the case study, and a secondary parameter which may play an important role in the case of study. Function values are obtained by adding 45% of the degree of suitability value for the main parameter, 25% of the secondary parameter, 15% for ΔP and 15% for the annual material cost. Logically, the value of the percentage of each parameter depends on a subjective decision. Nevertheless, a study of the sensibility of these percentages in the final results confirms that the classification is not modified in a wide range of percentage values (data not shown). For instance, conferring the same importance to the first two parameters (35%), the final value obtained by each material varies an average of 9% but the positions in the classification are kept identically equal than in the previous consideration.

As an example, two common situations were studied: 1) a biofilter operating at intermittent loads of pollutant and 2) a biofilter fed with air containing low humidity values. However, the same methodology could be applied to other common situations in biofiltration as the treatment of hydrophobic pollutants (mainly influenced by the specific surface area), the acidification due to the by-products generation from microbial metabolism (high capacity to buffer pH changes), or watering with tap water without extra nutrients feeding. All these cases contemplate a wide range of situations where a material can be suitable to a specific application but poorly apt in others.

Biofiltration of intermittent inlet loads

Fluctuations in pollutant inlet concentrations adversely influence the effectiveness of bioreactors for waste gas treatment. Therefore, the application of an adsorbent to buffer the negative effect of such fluctuations improves the overall process. High contaminant concentrations can be toxic for the microorganisms immobilized in the reactor, causing the inactivation of the system. A rapid desorption may keep the microorganisms healthy and degradation rates high even when concentrations are falling besides reducing stress on the microbial population when concentrations rise [7]. It has been reported that fluctuations between 0 and 1000 mg toluene m^{-3} are decreased to an average inlet value of about 300 mg m^{-3} using activated carbon which is subsequently completely degraded in a biofilter [27].

As a result, a high sorption capacity of the support media is a critical parameter to achieve a constant supply of contaminant to the biofilter. Similarly, materials with high specific surface area achieve high adsorption capacities due to several physical or chemical interactions between the contaminant and the surface of the material. Thus, adsorption capacities in wet conditions and specific surface area are the main and secondary parameter, respectively, to consider in the case of intermittent inlet loads of pollutant. CAC was found the most suitable material to pack a biofilter where fluctuations of inlet load may be present despite its high purchase cost (Figure 3). Although SBC is ranked in second position based on its adsorption capacity and specific surface area (Table 6), SBC appears in the last part of the classification in Figure 3, mainly due to its high ΔP. Figure 3 also points out that most of studied materials show a similar degree of suitability in the present case. However, specific surface area include micro-pores that are hardly available for biomass growth. Thus, in a full colonized biofilter specific surface area should receive less attention.

The authors clearly indicate that the

(Figure 3)

Biofiltration of inlet air with low relative humidity

The necessity of water in a biofilter is one of the most important parameter to avoid a poor system operation. Around the 75% of all reported problems with biofiltration are caused by poor humidity control [28]. Thus, industrial biofilters are generally designed with a humidification unit prior to the inlet of the biofilter to ensure inlet air saturation with water. The rationale behind this case study is related to the humidification unit failure or malfunction and to the potential biofiltration without humidification towers. In all cases, proper control of the water content inside the packed bed is one of the most critical aspects of biofilter operation. Microorganisms immobilized on the support media need a minimum water content to keep active and to abate the pollutant. Moreover, the presence of water affects the gas-to-liquid or biofilm mass transfer of contaminant and oxygen [7]. Thus, packing materials must retain considerable amounts of water, that is high water holding capacities, and make water readily available during periods of drying, that is high water retentivity. However, excessive water content can hinder biofilter performance due to increased ΔP across the filter bed and increasing mass transfer resistance [29]. Thus, water holding capacity and water retentivity were considered the main and secondary parameter, respectively, in the case of biofiltration of inlet air with low relative humidity. Figure 4 shows that coconut fibre and peat with heather are the most adequate materials in this scenario. However, several materials can be considered similarly suitable to pack a biofilter (compost, advanced material lava rock, lignite and activated carbon). Also, some organic materials like compost, which are initially hydrophilic, can become hydrophobic when dried, making rewetting difficult or even impossible [7]. Figure 4 shows that the maximum punctuation for materials is around 75%. This data shows that materials with high water holding capacity could have difficulties to keep the water in dried conditions, that is, low water retentivity.

(Figure 4)

The suitability of coconut fibre for this specific case study is explained by the high water holding capacity of the material while the suitability of peat is in concordance with the high water retentivity to hinder the moisture content loss by the circulation of dry air. SBC and pine leaves are the worst considered materials to pack a biofilter where the water supply can be critical due to the low water holding capacity of SBC and the low water retentivity of pine leaves.

Conclusions

A wide characterization of 10 packing materials used in biofiltration has been performed. Physical and chemical properties and cost related parameters were used for ranking packing materials from best to worst materials according to a single parameter. Data was analyzed and compared for a better knowledge of their advantages and drawbacks. Organic materials, especially compost and coconut fibre, showed suitable to potentially release inorganic nutrients and are able to keep water content at optimal levels for microorganisms. A commercial activated carbon and a sludge-based carbon were ranked in first position for several parameters rankings mainly because both offer higher contact surfaces. In addition, pressure drop and sorption capacities were determined for each packing material in dry and wet conditions. Results showed that watering of packing materials notably diminished their adsorption capacity of a hydrophobic compound such as toluene, which has important implications in the design of buffering systems for load equalization.

Since the election of the most suitable material is completely related to the importance of physical and chemical properties according to the main function they have to develop in a specific operation, a simple function based on four selected parameters was defined to examine selected case studies as example. Materials were classified according to physical properties from the least suitable (0%) to the most (100%). Commercial activated carbon is a 60% more suitable to pack a biofilter with intermittent loads than the rest of supports media and coconut fiber is the better selection in the biofiltration of inlet air with low relative humidity. Results showed that a packing material can be perfect in a certain case operation but poorly apt in others.

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TABLE CAPTIONS

Table 1. Elementary composition of packing materials expressed in percentages by weight.

Table 2. Physical properties of packing materials.

Table 3: Pressure drop and electrical cost for dry and wet packing materials at a certain bed porosity and water content.

Table 4. The current estimated prices of packing materials, estimated durability and annual material cost.

Table 5: Adsorption capacities for dry and wet packing materials

Table 6. Degree of suitability of studied packing materials according to the main parameters evaluated, being 0% the minimum value of the property and 100% the maximum value.

FIGURE CAPTIONS

Figure 1. Experimental setup of the lab-scale plant; 1: mass flow controller; 2: humidification column; 3: mixing chamber; 4: toluene injection; 5: VOC’s detector; 6: fixed bed; 7: membrane pump; 8: storage tank; 9: data acquisition and control computer; 10: differential pressure meter. A: sample port for gas inlet; B: sample port for gas outlet.

Figure 2. Microscopic observation of the roughness of coconut fiber at different magnifications by SEM a) x30, b) x1000 and polyurethane foam c) x30 and d) x1000.

Figure 3. Degree of suitability of packing materials when intermittent loads of pollutant are present.

Figure 4. Degree of suitability of packing materials when the inlet air presents low humidity.