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Sugarcane bagasse as alternative packing material for biofiltration of benzene polluted gaseous streams: a preliminary study

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Abstract

Removal of benzene vapor from gaseous streams was studied in two identically sized lab-scale biofiltration columns: one filled with a mixture of raw sugarcane bagasse and glass beads, and the other one packed with a mixture of ground sugarcane bagasse and glass beads, in the same volume ratio, as filter materials. Separate series of continuous tests were performed, in parallel, under the same operating conditions (inlet benzene concentration of 10.0, 20.0 or 50.0 mg m^{-3}, and superficial gas velocity of 30.6, 61.2 or 122.4 m h^{-1}) in order to evaluate and compare the influence of the packing material characteristics upon the biofilter effectiveness. The maximum elimination capacities obtained, at an inlet load of 6.12 g m^{-3} h^{-1}, were 3.50 and 3.80 g $m^{-3}_{\text{packing material}}$ h^{-1} with raw and ground sugarcane bagasse, respectively. This was a preliminary study and the results obtained suggest only a limited application with more work needed.

Keywords: Sugarcane bagasse; Benzene vapor; Biofiltration; *Pseudomonas* sp.

1. Introduction

Biofilters are air phase bioreactors considered to be one of the most promising technologies for treating waste gases contaminated by VOCs. They consist basically of a simple packed bed column containing microbial populations immobilized on a porous solid support. These microorganisms organize themselves into something like a biolayer on the surface of the particles constituting the packing material. As contaminated air flows upward through the material, the air pollutants are transferred to the biolayer where they are transformed, by the microbes residing in it, into water, carbon dioxide, mineral salts, and new microbial mass.

The effectiveness of a biofilter for the treatment of gaseous streams largely depends upon several key operational parameters, among which is the filter material structure. The choice of the filter material is crucial in order to maintain long-term biofilter operational stability, in that it must (a) guarantee optimum environmental living conditions for the microorganisms which are the system workhorses; (b) constitute at the same time a nutritious reserve, a humidity reservoir, and a mechanical odorless support; and (c) provide the structural stability of the bed.

The packing media widely used in biofiltration are natural organic materials, such as peat, compost, soil, or mixtures of these materials with bark, leaves, wood chips, heather branches, humus earths, or brushwood (less than 10.0 mm in diameter), because they provide a high specific surface area (from 300 to 1000 m^{-1}), high retention capacities of water and nutrients, and favorable immobilization for the microflora involved. In practice, these packing materials have shown the common disadvantage of being strongly subject to aging phenomena, resulting in bed shrinkage. As is well known, this phenomenon, together with the natural unhomogeneity of the structure of these natural materials, may cause several problems, thus in turn strongly influencing biofiltration performance. In order to prevent these problems, inert materials, such as polystyrene spheres, lava particles, glass beads, porous clay, and ceramic are usually added to the natural filling materials (Zilli and Converti, 1999).

The aim of this study was to evaluate the feasibility of using sugarcane bagasse as an alternative filter material for the biofiltration of air streams contaminated by benzene.

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Sugarcane bagasse is an agricultural residue from industrial sugar extraction process. Although utilized in the sugar factories as fuel for the boilers, large quantities are accumulated in the mills, creating environmental problems. Recently, there is an increasing trend towards the utilization of sugarcane bagasse, as it represents a large and inexpensive source of raw material, which can be used as solid support also in several biotechnological processes (Pandey et al., 2000). Sugarcane bagasse is a residue composed approximately of 50% cellulose, 25% hemicellulose, and 25% lignin (Zandersons et al., 1999), therefore it is relatively resistant to biodegradation. In addition, the possibility of using a waste as packing material for off-gases treatment is particularly attractive.

2. Methods

2.1. Microorganism and culture conditions

The benzene-degrading strain of *Pseudomonas* sp. NCIMB 9688 was grown aerobically, at 25 °C, in 250 ml shaken Erlenmeyer flasks containing 100 ml of sterilized nutrient medium (1.0 g Lab-Lemco beef extract, 2.0 g yeast extract, 5.0 g peptone, and 5.0 g NaCl, per litre of tap water), and at pH 6.8 ± 0.2. After 24–48 h of growth, the cells were harvested by centrifugation at 5000 rpm for 20 min and re-suspended in fresh nutrient medium to be used as inoculum for the biofilters. Stock cultures of the strain were maintained by periodic subculture on the same nutrient medium and stored at 4 °C.

The mineral salts solution used for continuous tests had the following composition per litre of tap water: 5.0 g Na_2HPO_4, 4.0 g KH_2PO_4, 4.0 g K_2HPO_4, 1.0 g $(NH_4)_2SO_4$, 0.2 g $MgSO_4 \cdot 7H_2O$, 0.34 g $MgCl_2 \cdot 6H_2O$, 0.08 g $FeSO_4 \cdot 7H_2O$, 0.07 g $CaCl_2 \cdot 6H_2O$, 0.002 g $ZnSO_4 \cdot 7H_2O$, and 0.002 g $MnSO_4 \cdot H_2O$.

2.2. Analytical techniques

Influent and effluent benzene gas concentrations were determined using a Carlo Erba Model HRGC 5160 gas chromatograph equipped with a capillary column (25 m × 0.32 mm, Mega Laboratory) and a flame ionization detector connected with a computing integrator. The temperatures of injector, oven and detector were 170, 150 and 200 °C, respectively. The carrier gas was nitrogen. 0.5 ml of air samples were injected into the FID gas chromatograph with a 1.0 ml gas-tight syringe and the benzene concentration was quantified by comparison with standards. Vapor phase pollutant standard curves were obtained by injecting known volumes of benzene, using a 10 μl liquid-tight syringe, into a sealed calibrated glass bottle (1000 ml), equipped with teflon-faced rubber septa according to the methods described by Lodge (1989). The pollutant was allowed to evaporate completely at room temperature for 12 h within the bottles. Then, gas samples were withdrawn from the bottles with a 1.0 ml gas-tight syringe and 0.5 ml were subjected to gas chromatograph analysis.

Cell mass concentration for inoculum preparation and filter bed moisture content were both determined by the dry weight method (APHA, 1985).

2.3. Experimental equipment for continuous operation

Continuous experiments to study the removal of benzene were carried out in two identically sized lab-scale biofiltration columns. They consisted of 0.65 m long cylindrical glass columns, with an inner diameter of 0.05 m and a filter material height of 0.50 m, giving a packing volume of 0.98 l.

Two different preparations of sugarcane bagasse, kindly supplied by Usina Guaraní, Olímpia-SP, Brazil, were utilized as packing media: (a) raw sugarcane bagasse with non homogeneous structure, and (b) ground sugarcane bagasse. A mixture of raw sugarcane bagasse and glass beads (5 mm diameter) was used in a 4:1 volume ratio as filter material in one biofilter, while a mixture of ground sugarcane bagasse and glass beads was used in the same proportion in the other one. A fine perforated sieve plate of ceramic was fitted at the bottom of each column to ensure the uniform distribution of the inlet gaseous stream. The total dried mass of both materials used in each biofilter was about 500 g.

The moisture content of both filter materials was maintained at the desired level (50–70%) either by bubbling the influent synthetic polluted gas stream in a humidification unit, or by periodically distributing, by means of a spray nozzle at the top of the packing material, a mineral salts solution, flowing counter currently with the gas upward through the column. The leachate was collected at the bottom of the columns in a 200 ml vessel, periodically recirculated to the top with a closed water recirculation circuit by peristaltic pumps, and regularly supplemented with fresh salts solution.

Continuous experiments, in both columns, were performed at 20–22 °C and the pH of the filter bed was kept around neutrality by periodic addition of a 0.1 N NaOH solution in the leachate. Each biofilter was inoculated with a cell suspension of the *Pseudomonas* sp. NCIMB 9688 selected strain. The suspension was mixed with the sterilized dry packing material, in the proportion of 25% by volume. Cell density in the inoculum was 5.2 g l^{-1} (dry weight).

The synthetic waste air stream was generated, for both biofilters, by injecting a low-flow laboratory compressed air stream into a storage vessel containing a controlled amount of liquid benzene, the stream becoming polluted by benzene evaporation. The air saturated with benzene vapor was then adequately mixed with a high-flow rate air stream, previously humidified

by bubbling it through a vessel containing water. By regulating the total air flow and the streams flowing in the vessels with two flow-meters, the desired concentration of benzene in the gaseous stream was obtained. Both biofilters were operated in up-flow mode and under non-sterile conditions.

3. Results and discussion

The range of benzene concentration in the air stream, selected in this study ($C_{go} = 10.0$, 20.0 and 50.0 mg m^{-3}), is close to the values detected in petrochemical industry emissions (30 mg m^{-3}) (Dragt and Ottengraf, 1987) and slightly higher than the TLV-STEL (8 mg m^{-3}) and TLV-TWA (1.6 mg m^{-3}) (ACGIH, 2001). The selected gas residence time range (60, 30 and 15 s) is near to the average value reported for biofilters treating different industrial emissions (Ottengraf and Dicks, 1992).

Figs. 1 and 2 show the experimental results of continuous tests carried out with both support materials during the whole experimental investigation. Each test at a given inlet benzene concentration and superficial gas velocity lasted a period of about 10–15 days.

The duration of the starting abiotic removal due to physical adsorption or absorption by the packed bed was evaluated during the start-up phase through control columns without biofilm. Under the same conditions of moisture content (50%), the breakthrough occurred after 1 and 2.5 h of operation with the raw and ground bagasse, respectively, thus demonstrating the lower water retention capacity of the former material. To evaluate the effect of the moisture content on the absorption capacity of the packed bed, a further test was done increasing the water content of the column packed with the raw medium up to 70%. A satisfactory breakthrough of 2 h was observed under these conditions which were consequently selected for the continuous runs with this material. To prevent an excess substrate shock to the microflora, the first series of tests was carried out, in both biofilters, operating at the lowest superficial gas velocity (30.6 m h^{-1}) as well as at the lowest influent benzene concentration (10.0 mg m^{-3}). Benzene removal, initially close to 100% regardless of the selected material, progressively decreased as a consequence of the preliminary benzene adsorption onto the support materials.

Only 3–5 days of continuous operation were needed to reach nearly constant values of degradation efficiency under these conditions, due to the progressive microflora adaptation to the operative conditions. The final average degree of conversion (η) settled again close to 1.00 as the result of the biological activity, which indicated biofiltration is a really efficient technique in the control of waste gases containing benzene at very low concentrations.

The second and third series of experiments were performed, in both columns, maintaining constant the inlet benzene concentration (10.0 mg m^{-3}) and increasing the superficial gas velocity (61.2 and 122.4 m h^{-1}). As regards the other series of continuous experiments carried out at benzene concentration of 20.0 and 50.0 mg m^{-3}, the same operative procedure was followed.

The average degree of conversion was satisfactory and the system proved very stable during the whole experimental investigation, thus demonstrating the high capacity of the cells to adapt themselves to large variations of pollutant concentration as well the relative

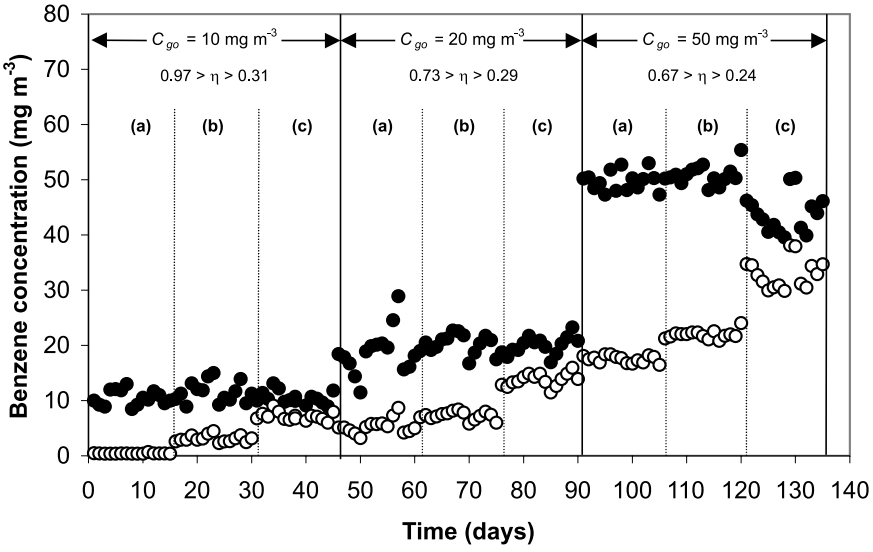

Fig. 1. Experimental results of continuous tests of benzene removal from air stream using raw sugarcane bagasse as packing material. Benzene concentration (mg m^{-3}): (●) inlet; (○) outlet. Superficial gas velocity, U_{go} (m h^{-1}): (a) 30.6; (b) 61.2; (c) 122.4.

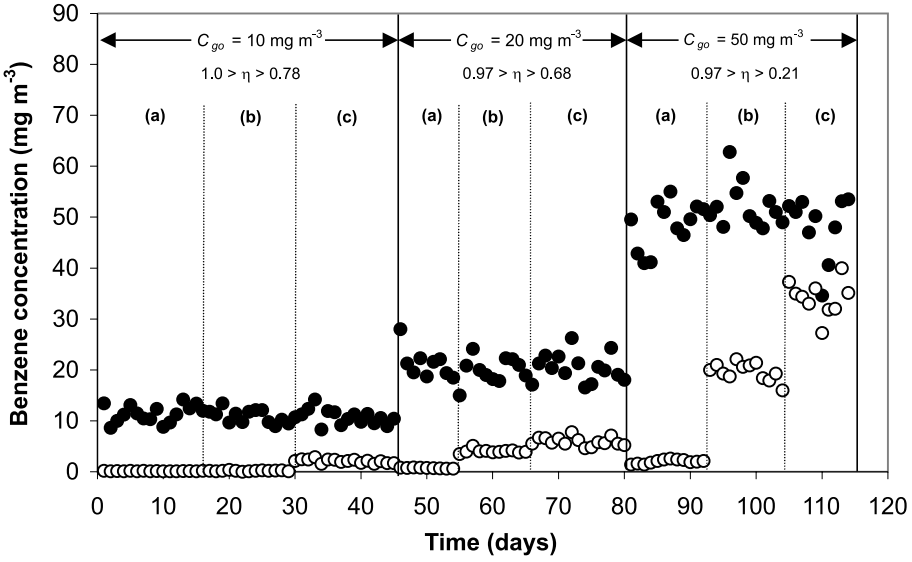

Fig. 2. Experimental results of continuous tests of benzene removal from air stream using ground sugarcane bagasse as packing material. Benzene concentration (mg m^{-3}): (●) inlet; (◯) outlet. Superficial gas velocity, U_{go} (m h^{-1}): (a) 30.6; (b) 61.2; (c) 122.4.

resistance of the selected *Pseudomonas* sp. strain to such a toxic pollutant.

Steady-state achievement was assumed to take place when the removal efficiency under given operating conditions kept nearly constant for at least five days.

The results obtained during the overall experimental study showed that benzene removal efficiency (η) of both materials decreased either with increasing C_{go} or with decreasing apparent gas residence time.

The elimination capacity of both biofilters was also evaluated. The results collected evidenced that this parameter increased regularly with the organic load, with scarce relevance whether such a dependence was due to an increase in C_{go} or a decrease in gas residence time. In particular, with ground bagasse the elimination capacity linearly increased up to an organic load of 3.06 g m^{-3} h^{-1}, while beyond this value it increased more slowly and reached a maximum (3.80 g $m^{-3}_{packing\ material}$ h^{-1}) at $C_{go} = 50.0$ mg m^{-3} and $U_g = 61.2$ m h^{-1}. Although the results collected with raw bagasse qualitatively followed a similar trend, the maximum elimination capacity was lower than that obtained with ground bagasse (3.50 g $m^{-3}_{packing\ material}$ h^{-1}) and poorer performances were obtained mainly at lower influent loads.

At loads higher than 7–8.0 g m^{-3} h^{-1}, benzene availability to the microbial system became inhibitory in both columns and the elimination capacity started to decrease. The poor results obtained with raw bagasse at low organic loads demonstrate that this system was never able to approach 100% benzene removal, likely due to its inadequate structure for biomass development. This means that grinding is a requisite that cannot be renounced to improve sugarcane bagasse immobilizing properties.

The maximum elimination capacities obtained in this work are lower than those reported by Zhu et al. (1998) for biofilters using compost-activated-carbon mixtures as packing material (9.0 g m^{-3} h^{-1}), likely due to reference to the empty bed volume, presence of well-adapted ubiquitous aerobic biomass in the compost, excellent adsorption properties of charcoal and higher working temperature (22–25 °C). However, in view of possible use of sugarcane bagasse as packing support for industrial application, a comparison with cheaper solutions is needed. To this purpose, in a pilot-scale study for treatment of soil venting emissions (medium blend not specified), average mass removal rates of 7.60 and 0.20 g m^{-3} h^{-1} and average degradation efficiencies of 82.5% and 80.0% were reported for BTEX and benzene (Swanson and Loehr, 1997), respectively. Although these preliminary results suggest only a limited application with more work needed, they demonstrate that sugarcane bagasse could actually be an effective and cheap alternative packing material for biofiltration systems.

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References

ACGIH, 2001. Guide to Occupational Exposure Values. American Conference of Governmental Industrial Hygienists, Cincinnati, OH, pp. 1–149.

APHA., 1985. Standard Methods for the Examination of Water and Wastewater. 16th ed., American Public Health Association, Washington, DC.

Dragt, A.J., Ottengraf, S.P.P., 1987. Fundamental aspects of biofiltration and some practical experiences. In: Proceedings of the Conference on Advanced Technologies and Biotechnology for the Pollution Prevention and Environmental Protection, SIBA-ISER, Genoa, Italy, pp. 243–258.

Lodge, J.P., 1989. Methods of Air Sampling and Analysis. Lewis Publishing Inc, New York, NY.

Ottengraf, S.P.P., Dicks, R.M.M., 1992. Process technology of biotechniques. In: Dragt, A.J., van Ham, J. (Eds.), Biotechniques for Air Pollution Abatement and Odour Control Policies. Elsevier, Amsterdam, pp. 17–31.

Pandey, A., Soccol, C.R., Nigam, P., Soccol, V.T., 2000. Biotechnological potential of agro-industrial residues I: sugarcane bagasse. Bioresour. Technol. 74, 69–80.

Swanson, W.J., Loehr, R.C., 1997. Biofiltration: Fundamentals, design and operations principles, and applications. J. Environ. Eng. 123, 538–546.

Zandersons, J., Gravitis, J., Kokorevics, A., Zhurinsh, A., Bikovens, O., Tardenaka, A., Spince, B., 1999. Studies of the brazilian sugarcane bagasse carbonisation process and products properties. Biomass Bioenergy 17, 209–219.

Zhu, L., Abumaizar, R.J., Kocher, W.M., 1998. Biofiltration of benzene contaminated air streams using compost-activated carbon filter media. Environ. Prog. 17, 168–172.

Zilli, M., Converti, A., 1999. Biofilters. In: Flickinger, M.C., Drew, S.W. (Eds.), The Encyclopedia of Bioprocess Technology: Fermentation, Biocatalysis and Bioseparation. Wiley, New York, pp. 305–319.