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Treatment of xylene polluted air using press mud-based biofilter

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ABSTRACT

In the present work, biofiltration of xylene vapors has been investigated on a laboratory scale biofilter packed with press mud as filter material inoculated with activated sludge from pharmaceutical industry. Four various gas flow rates, i.e. 0.03, 0.06, 0.09 and 0.12 $m^3\ h^{-1}$, were tested for inlet xylene concentration ranging from 0.2 to 1.2 gm^{-3}. The biofilter proved to be highly efficient in the removal of xylene at a gas flow rate of 0.2 $m^3\ h^{-1}$ corresponding to a gas residence time of 2.8 min. For all the tested inlet concentrations, the removal efficiency decreased for high gas flow rates. For all the tested gas flow rates, a decrease in the removal efficiency was noticed for high xylene inlet concentration. The follow-up of carbon dioxide concentration profile through the biofilter revealed that the mass ratio of carbon dioxide produced to the xylene removed was approximately 2.52, which confirms complete degradation of xylene if one considers the fraction of the consumed organic carbon used for the microbial growth.

1. Introduction

The atmospheric emissions of volatile organic compounds (VOCs) represent a major contributor to the deterioration of air quality and pollution of the environment. Among these VOCs, xylene (or dimethylbenzene) is a hazardous chemical that can be found in many consumer products such as paints, lacquers, varnishes, adhesives, cements, inks and dyes, cleaners and degreasers, aviation gasoline, etc. It is also used in the manufacture of plastics and synthetic fibers, insecticides and pesticides, leather goods, and other chemicals. A considerable share (over 60%) of the total emissions of xylene into the atmosphere originates from industrial facilities. Biofiltration is a pollution control technique using living material to filter or chemically process pollutants. When applied to air filtration and purification, biofilters use microorganisms to remove pollution. The airflows through a packed bed and the pollutant transfers into a thin biofilm on the surface of the packing material. Microorganisms, including bacteria and fungi, immobilised in the biofilm, degrade the pollutant. VOCs transfer from the gas phase into the aqueous and solid phases where microorganisms biodegrade VOCs into environmentally harmless end products, such as carbon dioxide, water and biomass. During long-term operation of biofilters, especially with high VOCs load, biofilters might suffer from dryness of packing media, acidification and nutrient limitation, which reduce microbial activity to influence the removal of VOCs. Therefore, in long-term operation of biofilter with high VOCs load, high efficiency of biofilter is related to various performance parameters such as characteristics of packing media, water content of support media [1–3], pH of media [4], addition of nutrient [5,6] and temperature [7].

Xylene is a clear, colorless and hydrophobic liquid that has a characteristic pungent odor. It is an important chemical, and used widely as a solvent in the printing, rubber, leather, painting and varnishing industries. Xylene isomers have been listed as hazardous and toxic atmospheric contaminants under CAAA (Clean Air Act Amendments of 1990, USA). Many studies on removal of xylene and other VOCs by microorganisms have been reported [8–13]. Abumaizar et al. reported biofiltration of benzene, toluene, ethylbenzene and xylene (BTEX) contaminated air streams using compost-activated carbon filter media with inlet concentrations more than 200 ppm and a gas load rate of 17.6 $m^3\ m^{-2}\ h^{-1}$ and removal efficiencies of 90% were achieved [14]. Among the BTEX compounds, xylene is more difficult to biodegrade under mesophilic and thermophilic conditions in the toluene acclimatized biofilter [15]. Even though, a number of studies on biofiltration of xylene is available the removal results were not satisfactory.

Only few studies focused on the performance of biofiltration in the removal of xylene as the sole pollutant in the airflow [16–19]. Hasnaa Jorio, Louise Bibeau, Guy Viel1, Michèle Heitz [16] studied the biofiltration of xylene vapors on a laboratory scale biofilter packed with peat and concluded that maximum elimination capacity obtained were 67, 52 and 41 $g\,m^3\ h^{-1}$ for gas flow rates of 0.4, 0.7 and 1 $m^3\ h^{-1}$, respectively.

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An experimental study on the removal of xylene vapors from an air stream was conducted. During the experimentation, the biofilter response to steep and abrupt variations in the xylene inlet concentration and gas flow rate was investigated. The results obtained showed that the removal efficiency of the bioreactor regained its high values (above 96%) in less than 24 h following the change to low concentrations and gas flow rate [17].

The present paper describes the effects of various xylene inlet concentrations; gas flow rates and height of the biofilter on the performance of biofilter, using press mud as a packing media and evaluated the production of carbon dioxide during biofilter operation.

2. Materials and methods

2.1. Biofilter media and inoculum preparation

The commercial press mud (sugar industry waste) has been selected as the biofilter and chosen as a packing medium. The support material was ceramic berl saddle. The press mud was sieved to reject particles with a diameter less than 3 mm. The characteristics of the packing materials are given in Table 1. Chemical composition was determined using standard method, organic content was determined by calcinations at 550 °C, and specific surface area by the nitrogen adsorption–desorption method. The inoculum was obtained from a 2-month acclimatized culture seeded with activated sludge from the secondary clarifier of pharmaceutical industry. 200 mL of the concentrated sludge were placed in an aerated batch reactor and diluted with 1 L of nutrient solution containing N and P (3.84 g L^{-1} K_2HPO_4, 1.94 g L^{-1} KH_2PO_4, 3.00 g L^{-1} NH_4Cl, pH 6.97). Vitamins and trace minerals were added by diluting 3 g of Supradyn.

2.2. Experimental setup and monitoring of biofilters

The xylene biodegradation was carried out in laboratory-scale biofilter (Fig. 1) made of acrylic column with a total height of 1 m and an internal diameter of 0.05 m. A 0.01 m headspace was used for the waste gas inlet and for nutrient feed, while a 0.01 m bottom space was used for the treated air outlet and leachate. The biofilter was equipped with four sampling ports to measure VOC concentrations, located at 0 (inlet port), 0.25, 0.50 and 0.75 (outlet port) m of column height. Additional ports located at 0.125, 0.375 and 0.625 m were used for the measurement of temperature and to recover bed particles for humidity analyses. Berl saddles and press mud was filled up to the top of the reactor. First of all, compressed air was passed through the filtration device to remove moisture, oil and particulate matter. After purification, the filtered air stream was split into two sections: minor and major air stream. For producing loaded air stream of desired concentration, the minor air stream was passed separately through the glass bottles containing xylene solution (99% pure) and through the humidifier. The xylene loaded air stream and humid air were mixed in a glass bottle. Finally, this mixed humidified xylene loaded air stream was mixed with major stream and then fed to the bottom of the biofilter in up flow mode of operation. The airflow rates was controlled and measured by a Rotameter (Placka Purge Rotameter, India) for high flowrate (1–10 L min^{-1}) and for low flow rate (1–300 cm^3 min^{-1}). Finally, xylene concentration was maintained at the desired value by adjusting the fine brass control valves. In present study, the experiments was carried out at the range of 0.2–1.2 g m^{-3} for a different gas flow rate of 0.03, 0.06, 0.09 and 0.12 g m^{-3}. Pressure control valve was used for constant airflow to the reactor. The biofilter was operated at various inlet xylene concentrations and gas flow rates. Samples was collected at a regular intervals of time from the inlet, outlet and as well as from the sampling ports using an airtight syringe and analyzed for residual xylene.

Table 1
Physical and chemical characteristics of press mud before filtration

S. No.	Properties	Units	Values
Physical compositions			
1.	Average particle size (mm)	mm	2–4
2.	pH		6.2
3.	Electrical conductivity	(mS/cm)	1.53
4.	Moisture content	(%)	80
5.	Bulk density	(kg/m^3)	1825
6.	Porosity	(%)	78
7.	Pressure drop (mm of water)	mm Hg	2
8.	Dry matter	(%)	20
9.	Water holding capacity	(%)	45
10.	Organic substance	(%)	54
11.	Ash	(%)	45
Chemical compositions (dry basis)			
12.	Carbon content	(%)	48.35
13.	Hydrogen	(%)	2.5
14.	Nitrogen	(%)	1.9
15.	Sulphur	(%)	3.2

2.3. Chemicals and mineral medium

The nutrient solution (basal salts medium, BSM) was continuously sprayed two times in a day for 30 min on the top of the packing media through the nutrient distribution system. The BSM solution used for the continuous tests had the following composition per liter of water: K_2HPO_4, 0.91 g; $Na_2HPO_4{\cdot}2H_2O$, 2.39 g; KNO_3, 2.96 g; $(NH_4)_2SO_4$, 1.97 g; $FeSO_4{\cdot}7H_2O$, 0.2 g; $MgSO_4{\cdot}7H_2O$, 2.0 g; $MnSO_4{\cdot}7H_2O$, 0.88 mg; $Na_2MoO_4{\cdot}2H2O$, 1 mg; $CaCl_2$, 3 mg; $ZnSO_4{\cdot}7H_2O$, 0.04 mg; $CoCl_2{\cdot}6H_2O$, 0.04 mg. All the chemicals used were AR grade with more than 99% purity.

2.4. Microbial cell counts

Approximately 1 g of press mud was put into 9 mL of sterile extraction buffer (0.1% sodium pyrophosphate and 2% NaCl) and vigorously mixed for 3 min. The suspension was separated from solid particulates by sedimentation, serially diluted with 0.9% NaCl solution, plated in a nutrient agar for isolation of bacteria. The colonies on the plates were counted after 1 week of incubation at 28 °C in the dark. The bacteria were identified following [20] and fungi following [21].

2.5. Water content of the media

Water content of the media is one of the most important factors that affect the performance of the biofilter [22–25]. According to Sun et al. [26,27], the optimal initial water content of the packing media treating xylene ranged from 50 to 70% and from 40 to 60%, respectively. The results of [23] showed that ethanol elimination capacity was relatively high for water contents ranging from 49 to 70%. In order to maintain the water content of the filter media in this work, the air streams were humidified above 95% relative humidity (the apparatus used for testing the relative humidity was not sensitive when the relative humidity was higher than 95%) and water was added into the bed from the top of the biofilter according to the condition of the packing media. During this project, the water content of the packing media in the first, the second and the

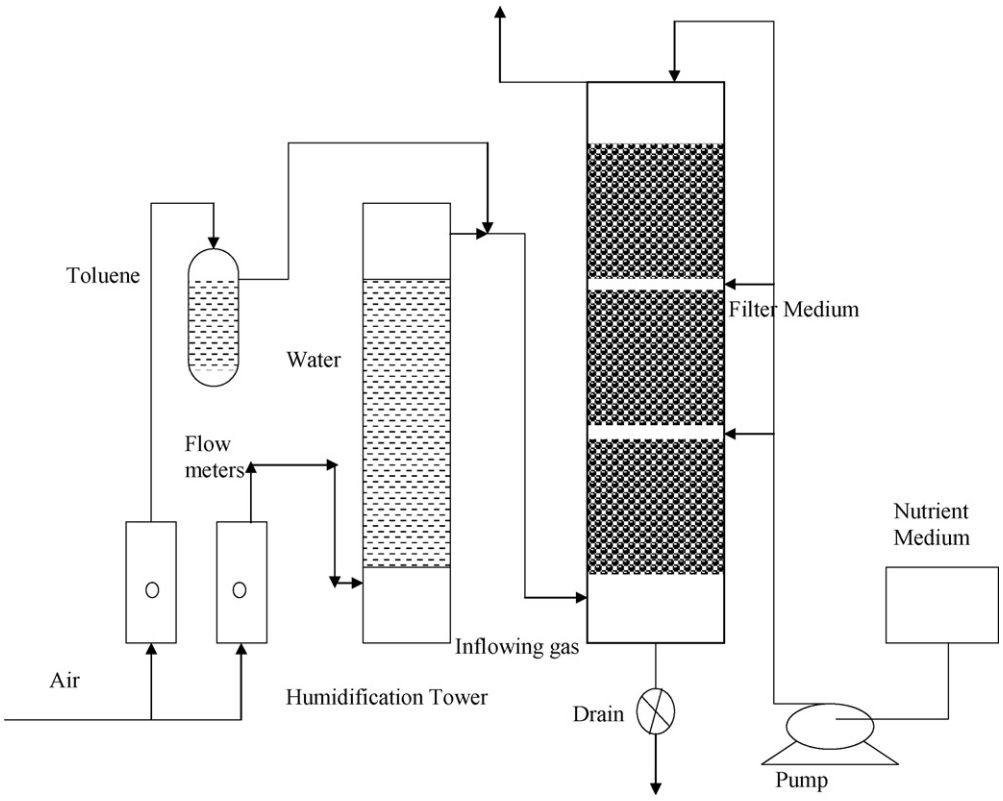

Fig. 1. Schematic diagram of up flow biofilter system.

third sections ranged from 50 to 60%, 55 to 60% and 55 to 65%, respectively.

2.6. Analytical methods

In order to examine the performance of the biofilter, inlet and outlet concentrations of xylene and carbon dioxide were measured daily. The xylene concentrations in the gas were measured using a Gas Chromatograph (Model 5765, Nucon gas chromatograph, Nucon Eng., India) with a poropak-Q column (1/80″ ID, liquid-10% FFAP, solid-Ch-WIHP, 80/100 mesh) and flame ionization detector. Nitrogen was used as the carrier gas with a flow rate of 0.06 mL min^{-1}. The temperatures of the injection port, oven and detection port were 250, 150 and 250 °C, respectively. The area of the chromatograms was determined using the Winacid Chromatography Software, Version 6.2. A 500 cm^3 glass bulb was connected to the outflow of each stage for taking gas samples. The calibration curve was prepared by injecting known amounts of the xylene into a sealed bottle equipped with a Teflon septum according to the standard procedure [28]. The injected amount of xylene was allowed to evaporate in the air space within the bottle at experimental temperature (30 °C). For the calibration, air samples were drawn from the bottle by a 1 mL gas tight syringe (Hamilton–Bonaduz–Schweiz, Switzerland) and analyzed by gas chromatograph. The air samples were drawn from the various sampling ports by using a gas tight syringe and analyzed.

Carbon dioxide (CO_2) concentration was determined by acid alkali titration method. The air streams containing CO_2 were collected and absorbed by 50 mL NaOH of 0.1 mol L^{-1}. Then the solution absorbed was titrated by HCl of 0.1 mol L^{-1}. Clean air and air prepared with various known xylene concentrations served as the calibration standards. The temperature of the filtering medium was recorded daily at three different levels of the biofiltration column using T type thermocouples.

2.7. Performance evaluation

The performance of the biofilter was evaluated by the following performance parameters, xylene inlet load (IL), g m^{-3} h^{-1}, removal efficiency (RE), %, elimination capacity (EC), gm^{-3} h^{-1}. The definitions for these parameters are set out below:

$$\text{EBRT} = \frac{V}{F}(s) \tag{1}$$

$$\text{RE}\ (\%) = \frac{C_\text{i} - C_\text{o}}{C_\text{i}} \times 100 \tag{2}$$

$$\text{EC} = \frac{F(C_\text{i} - C_\text{o})}{V}(\text{g}\,\text{m}^{-3}\,\text{h}^{-1}) \tag{3}$$

$$\Delta CO_2 = C_{CO_2,\text{out}} - C_{CO_2,\text{in}}(\text{g}\ \text{m}^{-3}\,\text{h}^{-1}) \tag{4}$$

$$P_{CO_2} = \frac{Q(C_{CO_2,\text{out}} - C_{CO_2,\text{in}})}{V}(\text{g}\ \text{m}^{-3}\,\text{h}^{-1}) \tag{5}$$

where V is the volume of the packed bed section (m^3); F is the gas flow rate (m^3 h^{-1}); and C_i and C_o are the inlet and outlet concentration (g m^{-3}) of the pollutant, respectively. The carbon dioxide concentrations measured at the inlet and exit of the biofilter are denoted by $C_{CO_2,\text{in}}$ and $C_{CO_2,\text{out}}$ (g m^{-3}), respectively. Operational parameters such as the pollutant inlet concentration and the empty bed residence times (EBRTs) are in general not constant but fluctuate within certain ranges.

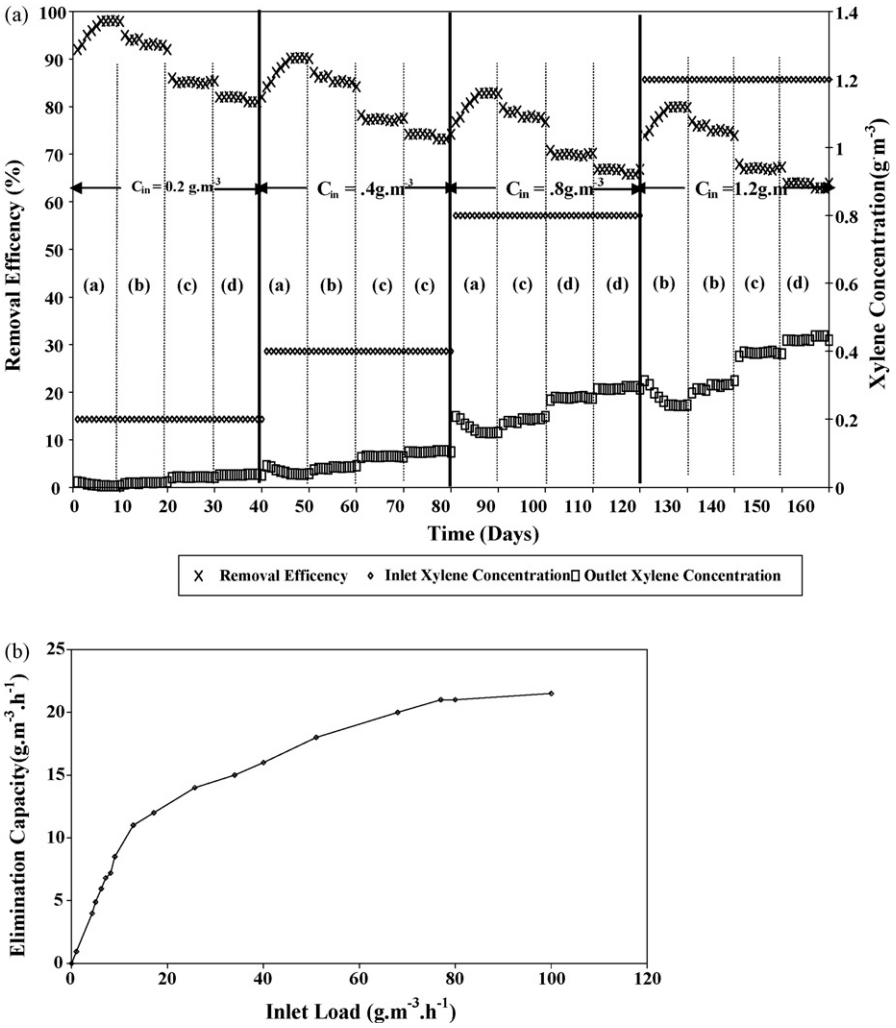

Fig. 2. (a) Experimental results of continuous tests of xylene removal from air stream using press mud as packing material. Gas flow rate of (a) 0.03 $m^3\ h^{-1}$; (b) 0.06 $m^3\ h^{-1}$; (c) 0.09 $m^3\ h^{-1}$; (d) 0.12 $m^3\ h^{-1}$. (b) Influence of xylene loading rate on the elimination capacity of the biofilter.

3. Results and discussion

3.1. Influence of xylene inlet concentration

Biofiltration of xylene vapors emissions was carried out over a period of 160 days at various operating conditions. Four various gas flow rates were tested: 0.03, 0.06, 0.09 and 0.12 $m^3\ h^{-1}$, corresponding to EBRTs of 2.8, 1.47, 0.93 and 0.7 min, respectively. The xylene inlet concentration was also varied in the range of 0.2–1.2 $g\ m^{-3}$. During the 160 days of operation, each set of operating conditions (gas flow rate and xylene inlet concentration) was tested at various discontinuous periods of time to insure the accuracy of the experimental results.

Each experiment was run at a given inlet xylene concentration and gas flow rate for a period of about 10 days. The duration of the starting abiotic removal due to physical absorption or adsorption 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 h with the press mud, thus demonstrating the lower water retention capacity of the former material. To prevent an excess substrate shock to the microflora, the first series of tests was carried out, operating at the lowest gas flow rate (0.03 $m^3\ h^{-1}$) as well at the lowest xylene concentration (0.2 $g\ m^{-3}$).

Only 2–4 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 RE settled again close to 98% as the result of the biological activity, which indicated biofiltration is a really efficient technique in the control of waste gases containing xylene at low concentrations.

The second, third and fourth series of experiment were performed by maintaining constant inlet xylene concentrations of 0.4, 0.6, 0.8 and 1.2 $g\ m^{-3}$, with each inlet xylene concentration, four different flow rates of 0.03, 0.06, 0.09 and 0.12 $m^3\ h^{-1}$ were tried. The RE was satisfactory and the system proved very stable during the whole experimental investigation, thus demonstrating the high capacity of the cells to withstand a wide variation in pollutant concentration as well the relative resistance of the selected sludge to such a toxic VOC like xylene. Steady state was assumed to be achieved when the removal efficiency under given operating conditions kept nearly constant for at least 5 days. The result obtained during the overall experimental study showed that xylene removal efficiency, decreased either with increasing xylene inlet concentration or with decreasing EBRT, which is shown in Fig. 2a. The results collected evidenced that the elimination capacity increased regularly with the organic load. Similar observations were reported for benzene removal [29]. In this press mud-based biofilters, the

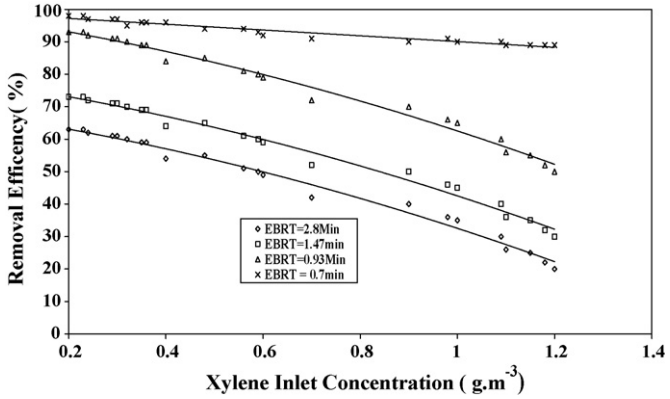

Fig. 3. Removal efficiency of xylene at the exit of the biofilter vs. xylene inlet concentration for various EBRTs.

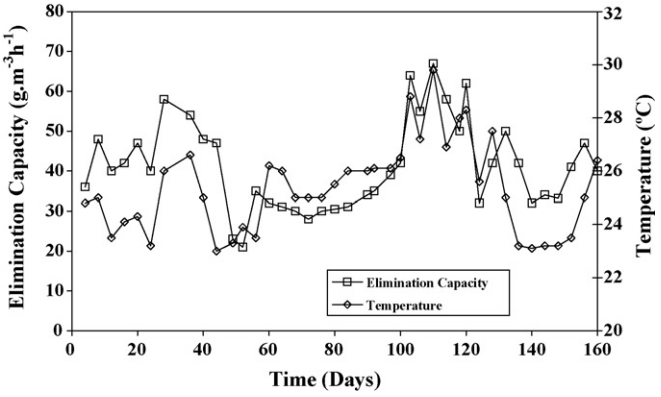

Fig. 4. Elimination capacity of xylene and the filter bed temperature vs. time.

elimination capacity linearly increased up to an organic load 17 g m^{-3} h^{-1}, while beyond this values it increased more slowly and reached a maximum. At loads higher than 17 g m^{-3} h^{-1}, xylene availability to the microbial system became inhibitory in biofilter column and the elimination capacity decreased as shown in Fig. 2b. The maximum elimination capacities obtained in this work are higher than the values reported earlier [29] using mixed compost and activated carbon as packing material.

3.2. Influence of gas flow rate

One of the important hydrodynamic parameters in the biofilter is input gas flow rate because it quantifies the amount of pollutant (xylene loading in the present case), which is to be treated per unit time. The gas flow rate is an important parameter in biofiltration process. In present study, four levels of gas rate, i.e. 0.03, 0.06, 0.09, and 0.12 m^3 h^{-1}, were investigated. Fig. 3 describes the removal efficiency of xylene versus inlet xylene concentration. As shown in Fig. 3, the removal efficiency was 98% at a gas flow rate of 0.03 m^3 h^{-1} at an inlet concentration of 0.2 g m^{-3}. When the inlet concentration of xylene was increased at constant flow rate of 0.03 m^3 h^{-1}, a decrease in removal efficiency was observed. At a gas flow rate of 0.06 m^3 h^{-1} and at an inlet concentration of 0.2 g m^{-3}, the removal efficiency was found to be 93%. But, when the inlet xylene concentration was increased to 1.2 g m^{-3} without changing the gas flow rate, significant drop in removal efficiency (i.e., from 93 to 50%) was observed. At higher gas flow rates 0.09 and 0.12 m^3 h^{-1} the maximum xylene removal efficiencies were found to be 73% and 63%, respectively at an initial xylene concentration of 0.2 g m^{-3}. With a higher inlet xylene concentration of 1.2 g m^{-3}, very low efficiencies (i.e. Less than 31%) were observed in the gas flow rate range of 0.09–0.12 m^3 h^{-1}, Thus, low values of gas flow rates (i.e. high values of EBRT) were favorable for degradation because the contact time between the microorganisms and xylene was increased. Thus, low values of gas flow rates (i.e. high values of EBRT) were favorable for degradation because the contact time between the microorganisms and xylene was increased. For high values of gas flow rates corresponding to low values of EBRT the contact time between the microorganisms and xylene was too low. Similar fluctuations in the biofilter performance for toluene removal have been reported [14].

3.3. Effect of bed height

In order to understand the dynamics of xylene removal, the normalized xylene concentration profiles at a different flow rates of 0.03,0.06, 0.09 and 0.12 m^3 h^{-1} for different xylene inlet concentration of 0.2, 0.4, 0.8 and 1.2 g m^{-3} were obtained as a function of the biofilter height. The results presented in Fig. 4 indicates that the removal is more efficient in the lower part of the biofilter than in the upper part of the filter. Nearly 60% of the xylene was removed in the first 25 cm of the bed height, while the rest of the 50 cm removed only an additional 20–25%. This may be due to a higher concentration of microbial population and higher moisture content in the lower section of the filter bed. Similar dynamics reported in the benzene removal using municipal sludge as a filter medium [30].

3.4. Temperature effect on biofilter

The filter bed temperature was monitored at three different levels of the biofiltration column. The temperature (T) variations along with the elimination capacity of the biofilter for different flow rates and inlet xylene concentration are shown in Fig. 5. The plot shows that T is an increasing function of EC, and as the temperature is increased from 23 to 29.8 °C, the elimination capacity increases from 4 to 67 g m^{-3} h^{-1}. As one can see, when the temperature rises or diminishes, the elimination capacity tends to follow the same trend of variation. In fact, the reaction of biodegradation of xylene in the wet biofilm is exothermic. Thus, an increase in the intensity of the biodegradation activity gives rise to a higher yield in the elimination of the contaminant and an augmentation of the filter bed temperature, simultaneously. Hence, the intensity of the microbial activity in the filter bed strongly depends on the biofilter temperature. Similar situations were obtained in xylene removal [16,31].

3.5. Carbon dioxide production on biofilter performance

In the biofiltration process, the organic pollutants are aerobically degraded to water and carbon dioxide and used as the essential carbon source for the microbial growth. Hence, the carbon dioxide concentration profile in the gas phase at the inlet and the outlet of the biofilter provides useful information on the biofilter performance. A positive gradient of CO_2 concentration in the gas phase through the biofilter indicates that there is CO_2 production due the biodegradation of the organic pollutants. Fig. 6 shows the outlet carbon dioxide concentration versus the xylene inlet concentration for various gas flow rates. In all tested operating conditions, the outlet CO_2 concentration is always higher than the inlet CO_2 concentration (0.50 g m^{-3}) indicating biodegradation of xylene in the biofilter. The concentration of CO_2 at the exit of the biofilter increases as the gas flow rate decreases. This result confirms the better performance of the biofilter at smaller gas flow rates. For a gas flow rate of 0.03 m^3 h^{-1} and inlet xylene concentration smaller than 1.2 g m^{-3}, the outlet CO_2 concentration increases with increasing

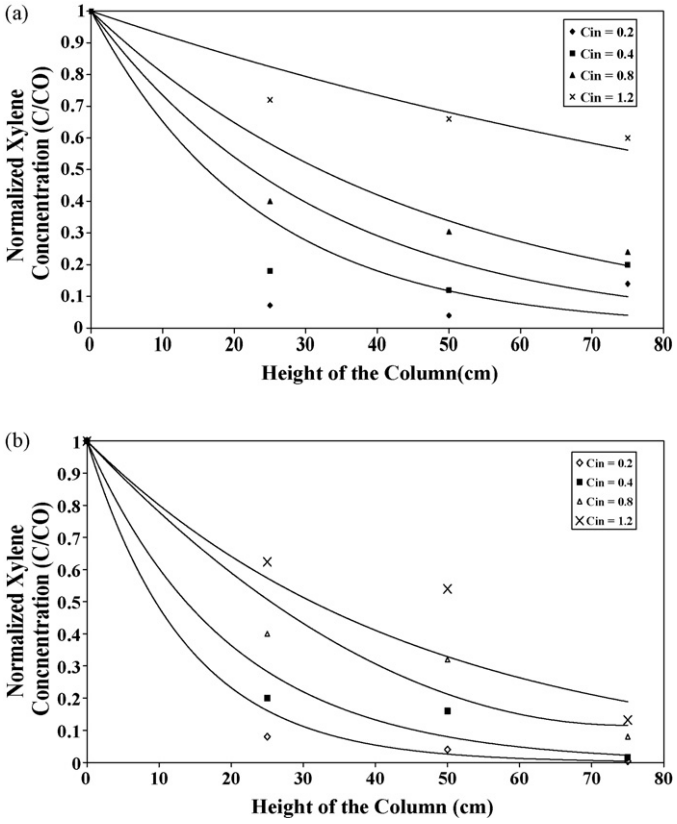

Fig. 5. Axial variation of normalized concentration at different initial concentration of pollutant: (a) flow rate = 0.03 $m^3\ h^{-1}$, (b) flow rate = 0.06 $m^3\ h^{-1}$, (c) flow rate = 0.09 $m^3\ h^{-1}$ and (d) flow rate = 0.12 $m^3\ h^{-1}$.

inlet xylene concentration to a maximum of 4.3 g m^{-3}. For higher inlet xylene concentrations, a slight decrease in the CO_2 concentration at the exit is observed. This behavior is in agreement with the observed variations of EC with the inlet xylene concentration at a gas flow rate of 0.03 $m^3\ h^{-1}$. The same remark is also valid for the results obtained with the gas flow rates 0.06, 0.09 and 0.12 $m^3\ h^{-1}$. The variation of PCO_2 as function of EC for the various tested operating conditions of xylene inlet concentration and gas flow rates is presented in Fig. 7. In this figure, the mean experimental data lie reasonably around the line $y = 2.53x$. This indicates that the ratio between PCO_2 and EC, i.e. the mass of CO_2 produced per mass of xylene removed, is on average equal to 2.53 for all tested conditions with a R^2 values of 0.88. In fact, this ratio should be 3.3 in the case of complete oxidation of xylene to water and carbon dioxide according to the following stoichiometric reaction:

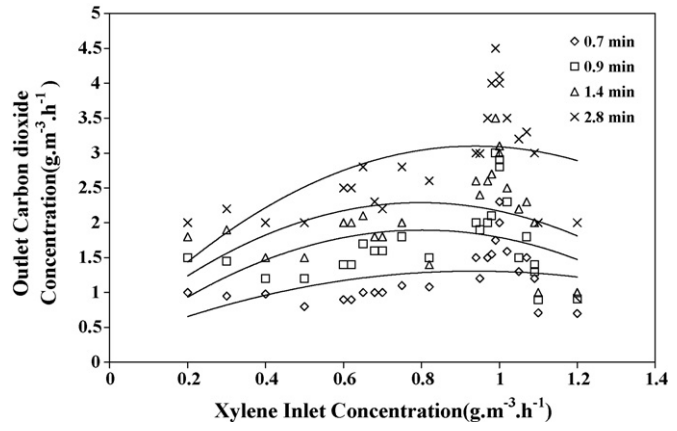

Fig. 6. Outlet carbon dioxide concentration vs. inlet xylene concentration for various gas flow rates.

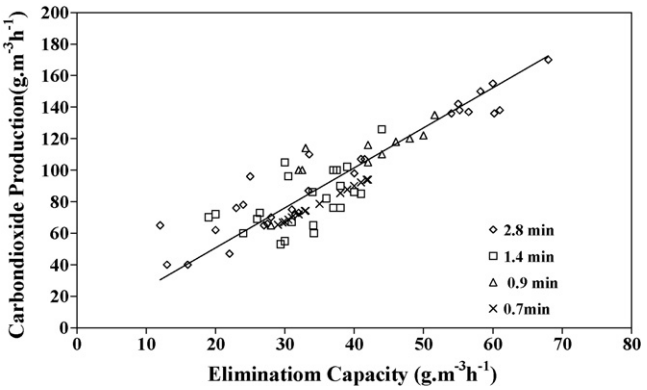

Fig. 7. Quantity of carbon dioxide produced at the exit of the biofilter vs. elimination capacity.

$$C_8H_{10} + 10.5O_2 \rightarrow 8CO_2 + 5H_2O$$

However, in case of biodegradation of organic pollutants, a fraction of consumed organic carbon is used for the microbial growth according to the following metabolism:

$$\text{organic pollutant} + \text{oxygen} = \text{carbon dioxide} + \text{water} + \text{cellular material}.$$

This explains the observed deficit in CO_2 production in comparison with the case of complete chemical oxidation of xylene. In addition, in the biofiltration process, the biodegradation of pollutants occurs in the liquid phase (the wet biofilm), and the CO_2 produced may partly accumulate in biofilm as one of its solute species, HCO_3^-, $H_2C\ O_3$ or $CO_3\ 2^-$ that can cause a deficit in CO_2 in the gas phase. This may also partly explain the fluctuations of the experimental ratio. Interestingly however, the small difference between the experimental ratio and the ratio evaluated from the stoichiometric reaction of complete oxidation is evidence of the removal of xylene exclusively by aerobic degradation and eliminates any option like adsorption or incomplete oxidation of xylene in explaining the decrease of xylene concentration through the biofilter. Also, this analysis reveals that the follow-up of the CO_2 concentration profile through the biofilter can be efficiently used for describing the biofilter performance.

3.6. Effect of microbial count

Aerobic heterotrophic bacteria and fungal Counts in the filter material were regularly achieved for the follow-up of the microbial growth intensity inside the biofilter. Fig. 8a and b presents the aerobic heterotrophic bacteria and fungal counts in the raw non-inoculated filter material and in the samples withdrawn from each section of the filter bed, respectively. These results show the attainment of a stable bacterial and fungal density, higher than the bacterial and fungal density measured in the raw material, few days after the start-up. During all the operating period, an average value between 10^8 and 10^{10} CFU/g of humid filtering material was reported for the various sections of the filter bed. However, except for the day 5 after the start-up, the aerobic heterotrophic bacteria and fungi counts were always slightly higher in the first section of the filter bed, which can be related to the higher removal of xylene at this section in comparison with the two other sections.

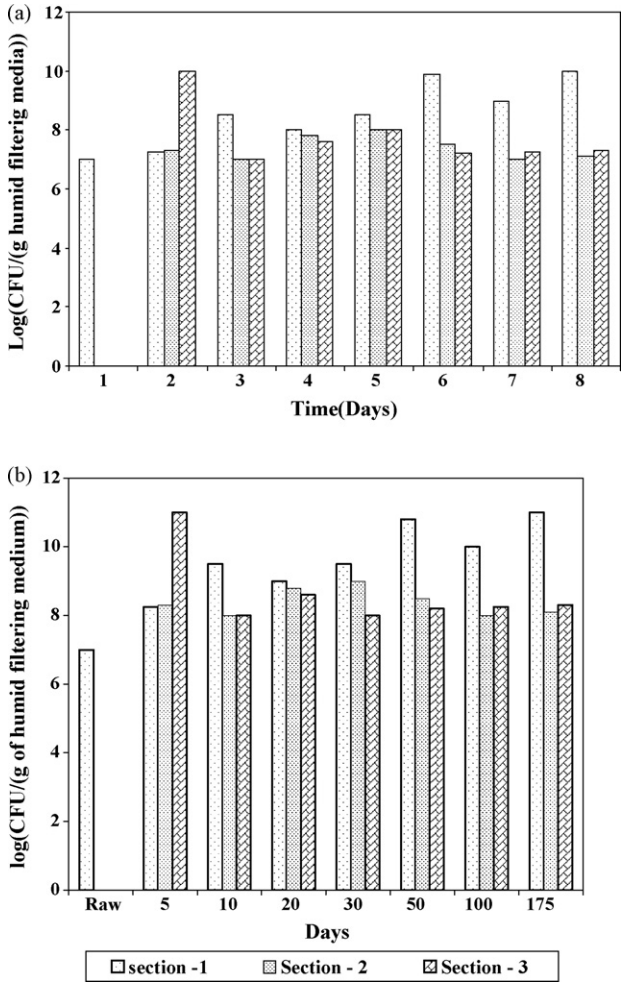

Fig. 8. (a and b) Microbial count of heterotrophic aerobic bacteria and fungi at the three sections of the filter bed vs. time.

This behavior is probably due to the higher inlet xylene load at this section.

4. Conclusion

An experimental study on the removal of xylene vapors from an air stream was conducted on an upflow laboratory scale biofilter using press mud as filter media over a period of 160 days. In this study, the biofiltration column was fed with an air stream characterized with a xylene inlet concentration range of 0.2–1.2 g m^{-3} and the different empty bed residence time of the injected air stream was 2.8, 1.47, 0.93 and 0.7 min. The maximum removal efficiency obtained was 98, 82, 75 and 65% for gas flow rates of 0.03, 0.06, 0.09 and 0.12 m^3 h^{-1}, respectively. The result concluded during the overall experimental study showed that xylene removal efficiency decreased, either with increasing inlet xylene concentration or with decreasing EBRT.

In order to understand the dynamics of xylene removal, steady state normalized concentration versus bed height plots at different initial concentrations was given. It was found to be nearly linear at lower flow rate and slightly exponential at higher flow rate.

Temperature measurements revealed that the biofilter temperature strongly depends on the intensity of the microbial activity in the filter bed. Increase from 23 to 29.8 °C in the average temperature of the filter bed was accompanied with an increase from 4 to 67 g m^{-3} h^{-1} in the elimination capacity. A sensitive dependence between the temperature of the filter bed and the biofiltration performance was noticed. Higher filter bed temperature was recorded for tests at a gas flow rate of 0.03 m^3 h^{-1} for which the highest biofiltration performance, in terms of elimination capacity, was obtained.

The important data collected on carbon dioxide concentration profile through the biofilter revealed that the follow-up of the carbon dioxide production provides a reliable means for monitoring the biofiltration performance. The carbon dioxide concentration in the gas phase was measured at the inlet and exit of the biofiltration column. For all the experimental conditions, the quantity of carbon dioxide produced was approximately 2.52 times the xylene elimination capacity. The stoichiometric ratio for complete oxidation of xylene being 3.3, the small deficit in carbon dioxide production can reasonably be attributed to the use of a fraction of consumed organic carbon for the microbial growth in the biofilm.

The bacterial count performed on filter material samples withdrawn regularly from the filter bed shows the establishment of a stable bacterial density only few days after the start-up. A slightly higher bacterial density was observed at the bottom section of the filter bed. The experimental results revealed that the biofiltration performance in terms of removal efficiency was higher for smaller gas flow rates for all the tested xylene inlet concentrations.

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