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Short Communication

Stability and efficiency of biofilms for landfill leachate treatment

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ABSTRACT

The objective of this work was to assess the feasibility of a fixed-film biological aerated filtration process for the treatment of the leachate produced at Harnhill landfill site (South Gloucestershire, UK). The laboratory scale plant consisted of four identical biological aerated filters (a triplicate and a "control" column) packed with small brick fragments. Biofilm formed within 24 h of immersion of the support material in the reactor, and had a high resistance to antibiotics and other toxic agents. The plant maintained a stable operation in the 20–45 °C temperature range, showing the best results (35.4 ± 6.6% COD removal and 73.9 ± 5.5% BOD_5 reduction) at 40 °C. The lowest COD and BOD_5 values obtained at the outlet of the columns were 7067 mg/L and 1050 mg/L, respectively.

1. Introduction

One of the greatest environmental problems associated with the disposal of wastes at landfills is the generation of leachate. It is heavily polluted wastewater of complex composition, including refractory and toxic components such as heavy metals and xenobiotic organic compounds (Alkalay et al., 1998).

Unless it is properly managed, leachate can cause surface water, groundwater and soil pollution (Haq, 2003). Among the biological processes for leachate treatment, fixed-film systems offer some advantages compared to the suspended growth systems, such as a higher resistance to toxic agents and a lower sensitivity to low temperatures. Biological aerated filters are an example of this type of system and have been widely used for the treatment of leachates with satisfactory results (Kalyuzhnyi et al., 2003; Stephenson et al., 2004). They provide good removal efficiencies, even with effluents with the low BOD_5/COD ratio commonly found in many leachates. Also, they are resistant to toxic substances and tolerate many of the inhibitors usually contained in leachates (Pujol et al., 1994).

As with any biological system, this treatment process is affected by temperature. Hence, it is an important operational parameter to be considered for a good performance of the process. If the plant is able to work at a wide range of temperatures, any process for temperature control would be avoided, which would lead to considerable savings.

The objective of the present work was to study the feasibility of biological aerated filtration for the treatment of leachate produced at Harnhill landfill site (UK). This landfill site is located in South Gloucestershire, approximately 10 km north of Bristol (UK). It developed in four phases from 1966 to 2003 in a former limestone quarry. Leachate is routinely abstracted from different leachate towers and tankered off-site to Avonmouth sewage treatment works. The overall cost of dealing with this leachate in 2008 was about £28 per tonne. The landfill operator has been looking for a potential alternative leachate treatment based on cost and environmental considerations. This study tried to assess if a biological aerated filter would be a useful alternative treatment option for Harnhill leachate. A laboratory scale plant was set up in order to study the formation of biofilm on the support material, its stability and the efficiency of the process at different temperatures.

2. Methods

2.1. Sampling

Leachate samples were collected from tower 3 (located in phase 4 of the landfill) in plastic carboys and transported to the laboratory for analysis.

2.2. Laboratory scale plant description

The laboratory scale plant consisted of four cylindrical columns (a triplicate and a control column) of 41.7 cm in height, with a bed height of 30 cm and internal diameter of 6 cm. All the columns contained pieces of bricks (6.7–10 mm) as support material for biofilm growth. This ceramic material can be obtained from industrial brick waste and it is catalogued as residue by European legislation. Hence this would be a way of recycling this type of waste. This material had an apparent density of 1.18 g/cm^3, a real density of

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2.68 g/cm^3 and a porosity of 56.1%. The effective bed volume of the columns was 3.73×10^{-4} m^3. The four columns were placed inside a temperature controlled unit (Stuart® Scientific). A peristaltic pump (Watson Marlow® 205U) was used for leachate feeding and recirculation, and air was supplied by fish pumps.

2.3. Experimental conditions

For the system start up, three of the columns were inoculated with mixed liquor from a domestic wastewater treatment plant (Avonmouth treatment works, UK) whereas the 4th column was fed only with leachate. This was done to test whether the preliminary inoculation step with mixed liquor was needed.

The development of the biofilm on the support material was investigated by sampling individual brick shards at different times throughout a two week period. Biofilm formed on each brick shard sampled was extracted and microbial counting for aerobes and anaerobes was performed.

One of the three identical columns inoculated with mixed liquor, column 3, was randomly selected as the "control" column. Aliquots of chloroform and the antibiotic Gentamicin (SIGMA® G1397, 50 mg/ml) were added to this "control" column in order to inactivate the microorganisms.

The other three identical aerated columns were used to carry out experiments in triplicate under the same operating conditions: an inlet flow rate of 0.6 l/d (hydraulic load = 0.21 m^3/m^{2}d, hydraulic retention time = 15.95 h), a COD volumic loading rate of 23.51 ± 6.31 kg COD/m^{3}d, an internal recirculation rate of 200% and an air flow rate of 33.96 m^3 air/m^{3}d. The temperatures tested were 20 °C, 30 °C, 40 °C and 45 °C.

Samples (50 ml) were collected every 24 h from the inlet and the outlet of each column. Chemical Oxygen Demand (COD), total suspended solids (TSS), pH, redox potential (Eh) and conductivity were monitored on a daily basis whereas Biochemical Oxygen Demand (BOD_5) was determined three times a week.

The biofilter was washed manually every 7 days by emptying the content of the columns into a beaker with treated leachate and shaking it in order to eliminate the excess of biofilm and solids retained on the filter that could cause filter clogging.

2.4. Analytical methods and statistical analysis

COD was determined according to the Closed reflux method (colorimetric) while BOD_5 followed the dilution method (iodometric, azide modification) (APHA, AWWA and WPCF, 1989). TSS were separated by centrifugation (5 min at 2500 rpm) and then dried at 50 °C for 24 h. Both pH and Eh were monitored with a pH meter (Sartorious® PT-10) while conductivity was measured with a conductivity meter (HANNA Instruments® HI 9033).

Heavy metals and main cations were determined by Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) (Varian® VISTA-PRO CCD). Anions were determined by ion chromatography (Dionex® QIC). Microbial counting followed the method of serial dilutions and plate counting.

The data obtained were statistically analysed using SPSS for Windows 14.0. An analysis of variance (ANOVA) test with a significance level of 5% ($p < 0.05$) was used to determine any significant differences between the data sets of the variables tested.

3. Results and discussion

3.1. Harnhill landfill leachate characterization

The leachate showed high COD (18,283 ± 1909 mg/L) and BOD_5 (8150 ± 3323 mg/L) concentrations and an intermediate biodegradability (BOD_5/COD = 0.44 ± 0.14). TSS was 829 ± 172 mg/L. The ions measured at highest concentrations were Cl^- (2270 ± 2173 mg/L), Na^+ (2868 ± 302 mg/L) and K^+ (1437 ± 243 mg/L). The measured pH was 8.15 ± 0.21, the Eh −(53.2 ± 11.2) mV and the conductivity 31.25 ± 3.61 mS/cm. The most abundant heavy metals detected were Fe, Cr, Zn, Ni, As, and Mn. The leachate also contained high ammonia concentrations (2200–3800 mg/L) and different xenobiotic organic compounds, which can lead to inhibitory or toxic effects.

3.2. System start up. Biofilm formation and microbial diversity

The system start up needed a stable biofilm on the surface of the support material. This can be achieved by inoculation of microorganisms, though this can be expensive. An alternative, cheaper approach is to make use of the microorganisms already present in the leachate. In our system, three of the columns were inoculated with mixed liquor while the fourth column was fed with leachate only. No statistically different datasets were obtained from this experiment which means that it is not necessary to inoculate the columns with mixed liquor as the biofilm can also be formed with the microorganisms contained in the leachate.

Prior to leachate submersion in the columns, the microflora of each brick shard was very low (around 10^3 cfu/g for aerobes/facultatives and 10^2 cfu/g for anaerobes). After 10 min of immersion, aerobes/facultative species increased to $2.86 \pm 2.00 \times 10^7$ cfu/g and anaerobes to $3.64 \pm 1.44 \times 10^6$ cfu/g, thereafter stabilising between $1.0 \times 10^8 \pm 5.59 \times 10^7$ and $3.05 \pm 2.59 \times 10^8$ cfu/g, and between $7.56 \pm 5.12 \times 10^6$ and $1.51 \pm 1.49 \times 10^7$ cfu/g, respectively. The number of colonies recovered from anaerobic plates was always about 10% the numbers counted on the aerobic plates.

These results show that bacterial colonization of the support material is very rapid, with a stable biofilm developed on the support material after 24 h of immersion.

The diversity of the flora recovered by viable count was high; 8–15 different colonial morphotypes were observed in total. Landfill leachate is known to contain a high diversity of microorganisms (Huang et al., 2003), though the vast majority of landfill leachate microbial diversity is still uncharacterized. All this leachate microbial diversity increases the pollutant removal capacity of the biofilm.

3.3. Stability of the biofilm

Attempts were made to establish a "control column" free of microorganisms with the aim of determining removal efficiencies not attributed to biological processes. Among the different options available to achieve this objective those methods that did not contribute to increase leachate COD or that did not react with leachate compounds were preferred. Hence chloroform and the antibiotic Gentamicin were selected and added to the column. The COD removal efficiencies obtained after the addition of these reagents to column 3 were compared to the results obtained with the other columns (Fig. 1).

Initially, chloroform was added at doses ranging from several drops (μl) to several millilitres. As a result, COD removal efficiencies decreased from 30% to 2% (Fig. 1). However, after a few days of intermittent additions of chloroform, microorganisms became resistant and the addition of more chloroform became less and less effective. Therefore, chloroform was replaced by 1 ml doses of the antibiotic Gentamicin. Its effect (a drop of COD removal efficiency from more than 20% to 0%) could be observed only after repeated additions of this antibiotic. After a few more days, despite further additions of antibiotic, the microorganisms became resistant and the removal of COD returned to its initial levels.