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The use of organic wastes at different degrees of maturity as carbon sources for denitrification of landfill leachate

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ABSTRACT

In this study different garden refuses were investigated to ascertain their efficiency to act as carbon sources in a denitrification system. Six different garden refuse materials were studied: commercial and domestic garden refuse raw (CGR RAW, DGR RAW), immaturely composted domestic and commercial garden refuse (DGR 10 and CGR 10 respectively), commercial garden refuse composted by Dome Aeration Technology and by "turned windrow" technology (DAT and TW). Different concentrations of synthetic nitrate solution were used to assess the efficiency of each substrate. The results demonstrate that all substrates were able to sustain the denitrification process. However, due to its higher *C*/*N* ratio the CGR RAW was the better performing of the materials, reaching 100% removal after 8 and 12 h for the 100 and 500 mg L^{-1} respectively and after 11 days for 2000 mg L^{-1}. Kinetic studies revealed that the zero-order reaction better describes the process indicating a denitrification rate independent from the nitrate concentrations investigated when 100 and 500 mg L^{-1} of nitrate were used. The study demonstrated the suitability of organic municipal solid wastes to sustain denitrification, opening a new scenario towards a low cost and *in situ* solution for treatment of landfill leachate by using wastes, otherwise disposed of in landfill.

1. Introduction

Landfill leachate, due to the large presence of organic matter and ammonium, often exceeds the stipulated discharge limits and causes serious problems to both the environment and human health. The biological processes involved in nitrogen removal consist of nitrification and denitrification. During nitrification, under aerobic conditions, nitrifying bacteria such as *Nitrosomonas* and *Nitrobacter* convert ammonia to nitrite and nitrate. Denitrification instead occurs through an assimilatory or dissimilatory biological process and in both cases bacteria uses nitrate as electron acceptor. Assimilatory nitrate reduction leads to formation of ammonia for cell synthesis and is common when nitrate is the only source of nitrogen (Akunna et al., 1992). The dissimilatory nitrate reduction occurs under anoxic conditions through two types of reaction: in the first reaction nitrate is reduced to nitrite which is then further reduced to nitrogen gas or nitrous oxide by a process called nitrate respiration or denitrification (U.S. EPA, 1998). In the second reaction, nitrate is reduced to ammonia via nitrite by a process called ammonification.

As reported by other authors (Grady et al., 1999), denitrification can also occur through pre-anoxic operation where nitrate-rich wastewater is mixed with raw influent. However, the main drawback being that the final effluent is rich in nitrogen. Inversely, the post-anoxic denitrification process shows high nitrogen removal capacity, but a source of organic carbon is required to act as an electron donor. Therefore, the denitrification rate depends mostly on external carbon sources and the COD/NO_3–N ratio (Lucas et al., 2005). Currently, most of denitrification processes employ a supplemental carbon source such as acetic acid, methanol, sucrose, propionate, ethanol and molasses (Constantin and Fick, 1997; Najafpour and Shan, 2003; Tsui et al., 2007). These are high-cost solutions; hence solid carbon sources such as CGR, DGR, immature compost and tree bark can represent promising low-cost alternatives (Wiszniowski et al., 2006; Zhong et al., 2009).

Therefore, in order to develop an economical and environmentally sustainable process, a low-cost, readily biodegradable source of organic carbon is fundamental with a suitable *C*/*N* ratio. Studies have shown that high *C*/*N* ratios can affect the denitrification process because of dissimilatory reduction to ammonium, while low *C*/*N* ratios could lead to nitrate accumulation (Bandpi et al., 1999; U.S. EPA, 2006).

Currently, in South Africa, garden refuse as well as tree bark are disposed of in general waste landfills (Trois and Polster, 2007).

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In the region of KwaZulu-Natal (South Africa), a sequencing batch reactor at the Mariannhill Landfill site is currently used for nitrifying landfill leachate. The treated landfill leachate produced from the SBR displays nitrate concentrations up to 2200 mg/L. Further denitrification is required to reduce the high concentrations of nitrates in the nitrified effluents to below the discharge limits. Thus an ad-hoc treatment is required prior to the discharge of leachate into the natural environment.

In this context, the focus of the project is to determine the efficiency of using five different organic wastes at different stages of maturity as carbon sources for the nitrate removal from the treated Mariannhill landfill leachate, thus assessing the feasibility of each substrate, as a means to denitrify treated landfill leachate in an integrated waste management system.

Filter beds packed with commercial garden refuse raw (CGR RAW), commercial garden refuse composted for 10 weeks (CGR 10), domestic garden refuse composted for 10 weeks (DGR 10), organic substrate composted by Dome Aeration Technology (DAT) and organic substrate composted by "turned windrow" technology (TW) were simulated in dynamic batch tests. The kinetics of nitrate removal for the different substrates, as well as environmental conditions (pH, nitrate concentrations, temperature etc.) were determined for all tests.

2. Materials and methods

2.1. Materials

2.1.1. Nitrate solution

The study was conducted by using a synthetic solution resembling the characteristic of a landfill leachate to operate the denitrification process in controlled conditions and to eliminate disturbances during the nitrate (NO_3^-) analysis. A synthetic solution was prepared by using potassium nitrate (KNO_3^-) and distilled water, diluted to obtain 3 different nitrate concentrations: 100, 500 and 2000 mg/L.

2.1.2. Organic wastes

For this study 6 different organic wastes were used as carbon sources to sustain the denitrification process. The substrates used were as follow:

– Fresh Commercial Garden Refuse (CGR RAW), collected from Bisasar Road Landfill site soon after the size reduction phase (4–5 cm length).
– Immaturely composted Commercial Garden Refuse (CGR 10), fresh CGR collected from Bisasar Road Landfill site was composted in troughs at the University of KwaZulu-Natal campus, using forced aeration technology for 10 weeks.
– Fresh Domestic Garden Refuse (DGR RAW), collected from curbside in the area of Hillcrest (Durban, South Africa).
– Immaturely composted Domestic Garden Refuse (DGR 10), consisted of domestic garden refuse collected from the Bisasar Road Landfill site and composted in troughs at the University of KwaZulu-Natal campus, using forced aeration technology for 10 weeks. Forced aeration is a Mechanical Biological Pretreatment technique used in the composting of organic waste. Air is introduced into the composting system through the use of pipes and an air compressor. The assisted aeration provides bacteria with ample oxygen while the material can remain static, preventing the need for routine turning. The practice allows for high rates of decomposition, whilst allowing for the control of the temperature and oxygen levels required to achieve effective aerobic conditions.
– Mature Commercial Garden Refuse (DAT), collected from Bisasar Road Landfill which had been composted for over 4 months in open windrows using the Dome Aeration Technology (DAT). The windrow test operated at Bisasar Road Landfill (30 m long, 10 m wide, 2 m high) consisted of five domes and 6 pairs of channels. An average dimension of the waste was a 15 cm length and 3 cm width (Trois and Polster, 2007). DAT is an advanced composting process for the aerobic biological degradation of garden refuse and general waste. It is a non-reactor open windrow composting process, where input material does not need to be turned periodically. The DAT method uses the passive aeration achieved through thermally driven advection in open windrows which is caused by the temperature differences between the degrading material and the outside environment.
– Mature Commercial Garden Refuse (TW), collected from Bisasar Road Landfill which had been composted for over 4 months in traditional turned windrow composting. The "turned windrow" composting process consists of rows of long piles of organic waste known as "windrows", that are turned on a regular basis using either manual or mechanical means, to allow for aeration to occur, causing degradation/stabilisation of the material into compost (U.S. EPA, 1998).

2.2. Methods

2.2.1. Characterisation tests

Characterisation tests were conducted on the five solid substrates and their respective eluates, using conventional testing methods of American Society for Testing and Materials (Eaton et al., 2005). The Moisture Content (MC), Total and Volatile Solids (TS at 105 °C for 24 h and VS at 500 °C for 4 h), Carbon to Nitrogen Ratio (C/N) and the Dynamic Respiration Index at 7 days (RI_7) were determined for each solid substrate.

Eluates were tested to establish pH, conductivity (C), TS, VS, COD, BOD_5, NH_3 and NO_3^-. The eluates were prepared by mixing a representative sample of each substrate with distilled water at a liquid to solid ratio of 10:1 for 24 h, before being filtered through a 63 μm sieve to obtain the eluate. All characterisation tests were conducted in triplicate to ensure accuracy and repeatability.

2.2.2. Analytical methods

Moisture Content (MC) of the solid substrates was calculated using the following equation:

$$W_{\text{total}} = \frac{w_w - w_d}{w_w} \quad (1)$$

where w_w = wet sample mass (g) and w_d = dried sample mass (g).

Total Solids (TS) and Volatile Solids (VS) were determined by Standard Methods 2540 G, D (Eaton et al., 2005). Respiration Index (RI_7) was determined using a respirometric system type OxiTop® and expresses the rate at which oxygen is consumed in the biodegradation of organic matter. It is often used as a means to define the level of stability and biodegradability of fresh and composted garden refuse (Adani et al., 2006). The test was performed by adding five drops of allylthiourea (ATH) to 25 g of solid material and distilled water to achieve field capacity in an airtight 1500 mL vessel. Five drops of potassium hydroxide was then added to a rubber thimble before an electronic pressure sensor head was screwed on. As biodegradation of the material occurred, oxygen was consumed and carbon dioxide produced. The potassium hydroxide added in the head of the vessel along with the ATH, absorbs the carbon dioxide (CO_2) to prevent nitrification. The apparatus was then placed in an incubator at 20 °C for seven days. The Oxitop bottles equipped with a pressure sensor lid records the change in gas