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An internal carbon source for improving biological nutrient removal

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ABSTRACT

This study investigates the potential of mechanically disintegrated surplus activated sludge (SAS) to be used as an internal carbon source for biological nutrient removal (BNR) using two laboratory tests. In the phosphorus release test, the addition of disintegrated sludge as a carbon source was able to enhance phosphate (PO_4–P) release by 14.9 mg l^{-1} PO_4–P when compared with acetate (7.9 mg l^{-1} PO_4–P), considering the 4.3 mg l^{-1} PO_4–P released in the control vessel, without carbon addition. Similarly, in the denitrification test, the nitrate (NO_3–N) consumption rate was improved after the addition of disintegrated sludge (14.9 mg NO_3–N g^{-1} VSS h^{-1}) compared with acetate (7.0 mg NO_3–N g^{-1} VSS h^{-1}), taking in consideration the rate obtained in the control vessel (6.9 mg NO_3–N g^{-1} VSS h^{-1}). Two to five minutes of SAS disintegration time in the deflaker (2300–6200 kJ kg^{-1} total solids) is recommended for this application.

1. Introduction

The performance of biological nutrient removal (BNR) processes is directly connected to the availability of a carbon source. The most suitable carbon source for BNR is considered to be soluble substrates in the form of short-chain volatile fatty acids (VFA) (Abu-ghararah and Randall, 1991). In the past, several methods have examined means to increase the soluble carbon content in the wastewater and enhance BNR performance. Pre-treatments such as fermentation of wastewater (McCue et al., 2003) or primary sludge (Charlton, 1994) have been investigated as well as sludge disintegration technologies (Park et al., 2004). Another possible route to improve BNR performance is the addition of external carbon sources such as: methanol (Nyberg et al., 1996; Tam et al., 1992); ethanol (Hasselblad and Hallin, 1998); acetic acid (Naidoo et al., 1998); and glucose (Tam et al., 1992).

The addition of industrial wastes rich in soluble chemical oxygen demand (SCOD) such as food wastes and leachate from municipal solid waste have also proved to be suitable substrates for BNR process enhancement, with phosphorus removal and denitrification rates comparable to those obtained with acetic acid (Lee et al., 1997; Lim et al., 2000; Llabres et al., 1999; Pavan et al., 1998). In the UK many of the successful BNR plants have a strong industrial carbon input (Avendano, 2003).

Unfortunately, the addition of chemicals or industrial waste cannot be applied in every wastewater treatment plant (WWTP), as either the transportation of industrial wastes is not feasible or high operational costs are predicted. Therefore, internal carbon sources like the SCOD released during sludge disintegration needs to be examined. The suitability of internal carbon sources for phosphorus and nitrogen removal has been investigated using parameters such as carbon to phosphorus and carbon to nitrogen ratios with the carbon being measured as biochemical oxygen demand (BOD), chemical oxygen demand (COD) or VFA (Jonsson et al., 1996; Randall et al., 1992; Carlsson et al., 1996). According to these predictive parameters, when the ratio is above a specific value (e.g. 21.6 mg l^{-1} TCOD per mg l^{-1} PO_4–P, Llabres et al., 1999) the wastewater is suitable for BNR treatment and when it is below that value it is considered unsuitable. Unfortunately, these methods have sometimes been found to be unreliable indicators of the BNR potential of a particular wastewater, as in many cases there is no correlation between phosphorus (P) or nitrogen (N) removal and the respective predictive ratio (Avendano, 2003; Llabres et al., 1999). The methods used in this research to predict the biological P and N removal were the phosphorus release test (Park et al., 2001; Vale et al., 2005) and the denitrification test, a modification of the nitrate utilisation rate (NUR) test described by Kujawa and Klapwijk (1999). The P test is based on the release of phosphorus under anaerobic conditions for a specific period of time with the higher P release indicating a better P removal. Similarly, the N test is based on denitrification rates with high

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denitrification rates indicating good denitrification and hence good N removal.

This paper examines the suitability of an internal carbon source for BNR enhancement using the P release and denitrification tests. The additional carbon was obtained from mechanically disintegrated thickened surplus activated sludge (SAS) using a deflaker device.

2. Methods

For the completion of the phosphorus release test (P test) and the denitrification test (N test) samples of settled wastewater, after primary sludge sedimentation, were collected from different wastewater treatment plants (WWTPs): two BNR sites (site A – a Virginia Initiate Plant configuration and site B – a Modified University of Cape Town configuration) and one site with a standard nitrifying activated sludge process (ASP) (site C). To complete the P tests, return activated sludge (RAS) was collected from site A, which achieved a concentration of total P in the effluent of <1 mg l^{-1}. The RAS was used to ensure that phosphorus accumulating organisms (PAOs) were present in the P test vessels. The collection of the samples took place at different times over the period of one year. The samples were stored according to the method previously described by Kampas et al. (2006).

The internal carbon sources tested in this study were thickened SAS (collected from the same site as the wastewater, i.e., site A, B, or C, respectively) and an industrial wastewater (brewery effluent) with a SCOD of 680 mg l^{-1} which was being used as carbon source in a successful BNR WWTP. The thickened SAS was disintegrated with a deflaker (equipment used in the paper industry) at different retention times (2–15 min) (Kampas et al., 2007). The deflaker was previously demonstrated to be able to release some of the organic matter locked in the sludge to the liquid phase (Kampas et al., 2006).

Replicates of the P release and denitrification tests were not completed due to the requirement of fresh wastewater and RAS (samples had to be used within 1–2 h after collection) to perform the tests (Kampas et al., 2006).

2.1. Phosphorus release test

To assess the impact of the disintegrated thickened SAS as the internal carbon source, a series of experiments were designed to investigate the phosphorus release and compare it with other carbon sources such as acetate and brewery effluent. Four vessels made of clear plastic (2.5 l) contained 1 l of wastewater collected from either site A, B, or C and 1 l of RAS (site A). The vessels were sealed, the wastewater was kept in suspension and homogenised by magnetic stirrers and a nitrogen blanket was maintained over the headspace of the mixture to maintain anaerobic conditions. Moreover, all the vessels were inside a water bath with a heater and circulation pump to keep the temperature constant at 20 °C. During the experiment the pH and dissolved oxygen (DO) were monitored continuously and liquid samples were taken every 30 min throughout the 2 h test period. The samples were filtered immediately with a syringe filter (0.45 μm) and the concentration of PO_4–P was measured.

The P tests were conducted using three different wastewaters supplemented with carbon according to the objective of each experiment. The goal of the first series of experiments was to investigate if the carbon addition had an effect on the P release using wastewaters from sites A, B, and C. The suitability of the internal carbon produced for phosphorus release was compared to other carbon sources (acetate) and no carbon addition (control) and the P test took place as follows: the first vessel had no addition of external carbon; the second and third were operated with the addition of disintegrated SAS; and the fourth one with the addition of sodium acetate. The same amount of carbon was added in the three vessels (excluding the control), as all the carbon sources were matched in terms of either VFA or SCOD content (23.4 mg l^{-1} VFA as acetic acid or 25 mg l^{-1} SCOD).

The second series of experiments aimed to investigate the source of the additional phosphorus that was measured during the first tests. In particular, it was investigated if the phosphorus originated from the RAS or from the disintegrated sludge. In order to meet the new objective the P test took place using the same carbon source (disintegrated SAS by the deflaker, 10 min retention time), adding the same amount of carbon in all vessels in terms of VFA (3.5 mg l^{-1}), but with the difference that in one vessel the biomass had been removed and the solid free fraction of sludge, obtained from centrifugation at 8800×g for 20 min, was added, instead.

Finally, it was examined how disintegration retention times of the SAS affected the phosphorus release process. The P test was again conducted in four vessels with the addition of sludge disintegrated in the deflaker matched in volume (100 ml) at four different retention times (2, 5, 10 and 15 min). According to Kampas et al. (2007) the carbon source quality is dependent on the disintegration time, and this third series of tests took place to investigate how the disintegration time influenced the suitability of the carbon source to promote phosphorus release.

2.2. Denitrification test

The same experimental rig was used for the denitrification tests with the difference that 2 l of settled wastewater from either site A, B, or C were used in the reaction vessels. Again, the first vessel was unamended with carbon source, the second and third with the addition of the solid free fraction of disintegrated sludge and the fourth with acetate. The carbon was again matched in terms of VFA or SCOD (23.4 mg l^{-1} VFA as acetic acid and 25 mg COD l^{-1}). The same amount of nitrate (133 mg l^{-1} NO_3) in the form of KNO_3 was added to all vessels. Samples were taken every 30 min, filtered immediately with a syringe filter (0.45 μm) and the concentration of nitrate (NO_3–N) was measured. The volatile suspended solids (VSS) were also measured from the solution of each vessel. Similar to the P test, the N test was also conducted to investigate the dependence of the carbon source quality on disintegration time. For this purpose four vessels were operated with the addition of the solid free fraction of sludge matched in volume at 50 ml, which was disintegrated in the deflaker for four different retention times (2, 5, 10 and 15 min).

2.3. Analytical methods

The concentration of SCOD, VFA, total solids (TS), VSS, and PO_4–P were measured according to APHA Standard Methods (1998). Analysis of NO_3–N was carried out using an ion chromatography (IEC) system, (Dionex, DX500 series, UK).

For VFA determination, 9 ml of filtered sample was placed in 10 ml plastic tubes and acidified with 10 μl of sulphuric acid 98% and frozen until HPLC analyses were carried out. The HPLC system Shimadzu VP Series (Milton Keynes, UK) was equipped with a Biorad column (cat 125-0115) (105 mm × 7.8 mm) and guard column (cat 125-0131). The UV detector was set at 208 nm and the column oven temperature was 65 °C. The mobile phase used was sulphuric acid 1 mM, prepared with ultra pure water and pumped at a flow rate of 0.8 ml min^{-1}. A solution of VFA at known concentrations was used as an external standard to quantify the VFA concentration in the samples.