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Mechanical sludge disintegration for the production of carbon source for biological nutrient removal

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ABSTRACT

The primary driver for a successful biological nutrient removal is the availability of suitable carbon source, mainly in the form of volatile fatty acids (VFA). Several methods have been examined to increase the amount of VFAs in wastewater. This study investigates the mechanism of mechanical disintegration of thickened surplus activated sludge by a deflaker technology for the production of organic matter. This equipment was able to increase the soluble carbon in terms of VFA and soluble chemical oxygen demand (SCOD) with the maximum concentration to be around 850 and 6530 $mg\,l^{-1}$, for VFA and SCOD, respectively. The particle size was reduced from 65.5 to 9.3 μm after 15 min of disintegration with the simultaneous release of proteins (1550 $mg\,l^{-1}$) and carbohydrates (307 $mg\,l^{-1}$) indicating floc disruption and breakage. High performance size exclusion chromatography investigated the disintegrated sludge and confirmed that the deflaker was able to destroy the flocs releasing polymeric substances that are typically found outside of cells. When long disintegration times were applied ($\geqslant$10 min or $\geqslant$9000 $kJ\,kg^{-1}$ TS of specific energy) smaller molecular size materials were released to the liquid phase, which are considered to be found inside the cells indicating cell lysis.

1. Introduction

Biological nutrient removal (BNR) is widely used in modern municipal and industrial wastewater treatment plants (WWTP). A significant factor in the success of the BNR process is the availability of a suitable carbon source. Many authors have reported a specific ratio of carbon to phosphorus (P) and carbon to nitrogen (N), which can indicate the suitability of the wastewater for BNR treatment (Jonsson et al., 1996; Randall et al., 1992; Grady et al., 1999; Curto, 2001). The most common methods for increasing these ratios and hence make the wastewater treatable by a BNR process, are the pre-treatment of the wastewater (McCue et al., 2003) or the addition of extra carbon. The extra carbon can either be organic carbon in the form of methanol, ethanol, acetic acid and glucose, hydrolysed primary and secondary sludge or industrial wastes rich in readily biodegradable organic matter and volatile fatty acids (VFAs) (Charlton, 1994; Llabres et al., 1999).

The online fermentation of wastewater is able to increase the concentration of VFAs (by 25%) and improve the performance of the process (McCue et al., 2003). Likewise sludge fermentation can increase the available carbon and improve nutrient removal (Hatziconstantinou et al., 1996; Charlton, 1994). Unfortunately, the application of these methods is not a straightforward procedure, since site enlargement is required and usually the fermenters are prepared for permanent use without being flexible to any modifications (flows, retention times etc.) (Munch and Koch, 1999). In addition, nutrients are

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also released from sludge during the fermentation process, increasing the overall amount of nutrients that have to be removed. Industrial wastes, such as the fermented organic fraction of municipal solid waste, fermented leachate of food waste and nightsoil have been shown to contain rich organic substrate in terms of VFA and soluble chemical oxygen demand (SCOD) (Llabres et al., 1999; Bolzonella et al., 2001; Choi et al., 1996). The addition of the above wastes in BNR process has been reported to have a positive impact increasing the removal of nitrogen (~28–109% increase) and phosphorus (~97–410% increase) (Lim et al., 2000; Lee et al., 1997). For instance, in the UK the WWTP in Derby and Reading in Severn Trent Water and Thames Water areas, respectively, are successful BNR sites with domestic sewage being mixed with industrial effluent. When the additional carbon is in the form of methanol or acetic acid, there is an improvement in BNR performances (Tam et al., 1992; Fass et al., 1994). The only and important disadvantage of the addition of direct organic carbon is the high operational cost. Similarly, industrial wastes are not always applicable to a given WWTP since transportation requirements may result in extra costs. Moreover, the content of nutrients in some industrial wastes is high, increasing the load to the process.

Researchers investigating alternative carbon sources, which can easily be used without high operational cost, observed that sludge disintegration used in sludge treatment processes is able to increase the SCOD and VFA content. The ultimate goals of these methods are foam control, increase in biogas production and sludge mass reduction (Muller, 2000b). However, there is little information about the application of the disintegrated sludge to BNR in order to improve P and N removal. Muller (2000a, b) made a comparison of mechanical, thermal and chemical sludge treatment. The highest degree of disintegration was reached by the chemical (ozone) treatment (52%) with the mechanical methods reaching medium degrees of disintegration (20–37%) with a relatively low energy input (1000–10000 $kJ\,kg^{-1}$). Stirred ball mills (SBM) and high pressure homogenizers were used for sludge disintegration by Muller (2000a, b), to produce a carbon source for denitrification. According to their experiments the maximum denitrification rate was up to 15 $mg\ NO_3–N\ g^{-1}\ VSS\ h^{-1}$. Chiu et al. (1997) reported that the combination of alkaline treatment with ultrasound vibration brought an increase in SCOD and VFA at 41.5 and 28 times, respectively. The maximum increase in SCOD was reported by Wang et al. (1999) at 50 times with ultrasound equipment of 400 W treating 100 ml of surplus activated sludge (SAS) for 40 min.

This study examines mechanical sludge disintegration using a deflaker, a technology designed for processing the pulp in paper industries. The main goal of this study was to examine whether this equipment is capable of producing extra carbon from SAS and to investigate the mechanisms of disintegration. The suitability of the carbon produced for improving BNR will be investigated in further research.

2. Material and methods

The SAS used in this study was collected immediately after the belt thickener with the total solid (TS) concentration in the range of 4–7%, from WWTPs that operate in BNR (BNR SAS) or standard activated sludge mode (non BNR SAS) (Table 1).

2.1. Disintegration

The equipment used for sludge disintegration was a 10″ Pilao DTD Spider Deflaker with a 30 kW motor fitted with 230 mm discs with 3 active cell layers (Fig. 1). The gap distance between stator and rotor was 0.6–0.9 mm and the rotation speed 3000–3600 rpm, (Withey, 2003). The disintegration process was conducted as a batch with 5 l of thickened SAS to be treated each time at 4 different retention times, 2, 5, 10 and 15 min. The maximum monitored temperature of disintegrated sludge was 35 °C and considered to have negligible effect on disintegration (Wang et al., 2006). To quantify maximum carbon release in SAS a thermal extraction method was established, which was a modification of a method reported by Zhang et al. (1999) for the extraction of extracellular polymers. This method was used only for comparative reasons as it was assumed that thermal extraction could indicate the absolute carbon release causing cell lysis. During that method thickened SAS was left for an hour under the conditions of 1 bar and 105 °C.

Table 1 – Summary of the samples collected from different WWTPs with different solid contents

	Solid concentration (%) for different samples of thickened SAS						
BNR WWTP	5.8	5.9	4.3	6.3	5.2	7.2	6.1
Non-BNR WWTP	4.3	6.2	5.6	5.2			

Fig. 1 – Pilao 10″ spider deflaker.