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Waste activated sludge fermentation: Effect of solids retention time and biomass concentration

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ABSTRACT

Laboratory scale, room temperature, semi-continuous reactors were set-up to investigate the effect of solids retention time (SRT, equal to HRT hydraulic retention time) and biomass concentration on generation of volatile fatty acids (VFA) from the non-methanogenic fermentation of waste activated sludge (WAS) originating from an enhanced biological phosphorus removal process. It was found that VFA yields increased with SRT. At the longest SRT (10 d), improved biomass degradation resulted in the highest soluble to total COD ratio and the highest VFA yield from the influent COD (0.14 g VFA-COD/g TCOD). It was also observed that under the same SRT, VFA yields increased when the biomass concentration decreased. At a 10 d SRT the VFA yield increased by 46%, when the biomass concentration decreased from 13 g/L to 4.8 g/L. Relatively high nutrient release was observed during fermentation. The average phosphorus release was 17.3 mg PO_4-P/g TCOD and nitrogen release was 25.8 mg NH_4-N/g TCOD.

1. Introduction

Enhanced biological phosphorus removal (EBPR) processes are potentially the least costly methods to remove phosphorus from wastewater. The key to efficient EBPR performance is the presence of adequate volatile fatty acids (VFA) in the influent wastewater (Chu et al., 1994; Oleszkiewicz and Barnard, 2006). Influent wastewater often has low chemical oxygen demand (COD) and lacks adequate VFA to permit suitable P removal (Barajas et al., 2002) which forces the utility to seek carbon sources within the wastewater treatment plant (WWTP) itself. The addition of organic carbon from outside of the plant, unless it is a waste material, increases not only the plant's carbon footprint but also the operational cost of liquid treatment and sludge processing, since sludge production will increase as well.

The practice of primary sludge fermentation for on-site production of VFA is well established worldwide (Munch and Koch, 1999; Chanona et al., 2006; Bouzas et al., 2007), however the reliability of VFA generation is often not adequate, particularly in flat terrain large sewer systems such as in St Paul-Minneapolis USA, Winnipeg South CA or Gdansk PL. In a number of treatment plants the mass of VFA produced from primary sludge fermentation is frequently below that required to ensure efficient removal of both phosphorus and nitrate, for example in the Noosa AUS biological nutrient removal (BNR) WWTP (Thomas et al., 2003). The factors that affect VFA production from primary sludge fermentation include operational parameters such as solids retention time (SRT), hydraulic retention time (HRT), pH, temperature etc. Perot et al. (1988) conducted an experiment where the effects of pH, temperature and agitation speed were investigated with respect to VFA production. They concluded that optimal hydrolysis conditions appeared to be a pH of 6.8 at a temperature of 50 °C and an agitation speed of 545 rpm. Bouzas et al.

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(2002) reported that higher total volatile solids concentrations resulted in higher VFA production, but that SRT above 6 d did not significantly improve the VFA yields, however, an important decrease of VFA was observed with an SRT of 4 d.

The only other substrate available for VFA production within a wastewater treatment plant is waste activated sludge (WAS) generated from soluble organic matter removal. Waste activated sludge differs from primary sludge which contains higher concentrations of easily biodegradable organic polymers (proteins, lipids carbohydrates) than WAS, permitting shorter hydrolysis and fermentation times. WAS contains mostly bacterial mass, and cell lysis is therefore the rate-limiting step (Turoviskiy and Mathai, 2006). Fermentation of WAS is expected to release phosphorus and nitrogen into the liquid phase, as demonstrated during fermentation of primary sludge co-thickened with WAS by Danesh and Oleszkiewicz (1997) and McIntosh and Oleszkiewicz (1997). Because of the differences between primary sludge and WAS, operational conditions will have to vary accordingly. Few studies have been conducted on the operational parameters necessary for optimal WAS fermentation for VFA production.

A study by Liu et al (2009) investigated various WAS pre-treatment methods (thermal, alkaline, ultrasonic) used to reduce the impact of the rate-limiting step of hydrolysis. They reported that during a 252 h fermentation period, total VFA concentration increased by 68.2% by using a combination ultrasonic-alkaline pre-treatment method. A conversion ratio from volatile solids into VFAs of 0.23 g VFA/g VS was obtained. Feng et al (2009) investigated WAS fermentation under alkaline condition and found that at a pH of 10 and an SRT of 12 days, the short chain fatty acid production increased to 933.5 mg/L. It was also reported by Chen et al (2007) that VFA production under alkaline conditions was significantly higher than under other pH conditions. Ucisik & Henze (2008) studied the effect of sludge type on the production of VFA and concluded that although primary sludge produced higher yields of VFA than activated sludge, the latter could generate substantial overall amount of VFA during fermentation because of the larger mass of activated sludge produced in wastewater treatment plants. The objective of this study was to investigate the effect of SRT and biomass concentration on VFA production in terms of quantity and composition from WAS (biomass) fermentation. The potential for nutrient recovery using the end-products of WAS fermentation, nutrient release (N and P) from cell lysis during the fermentation was also studied.

2. Materials and methods

2.1. Experiment set-up

Bench-scale experiments were performed with two semi-continuous reactors. The reactors were initially seeded by adding 50% of the volume with the sludge (approximate TSS of 16 g/L) from a mother WAS fermenter. One reactor was operated at an SRT of 10 d, and the other at an SRT = 7 d. When the tests in the latter reactor were finished, the SRT of this reactor was changed to 5 d. The reactors were operated under a complete mixing condition; therefore, hydraulic retention

Table 1 – Synthetic wastewater composition.

Synthetic wastewater		Mineral solution	
Ingredients	Concentration (mg/L)	Ingredients	Concentration (g/L)
NaAc	255	$FeCl_3 \cdot 6H_2O$	1.5
Beef extract	65	H_3BO_3	0.15
Yeast extract	65	$CuSO_4 \cdot 5H_2O$	0.03
$MgSO_4 \cdot 7H_2O$	170	KI	0.03
$CaCl_2 \cdot 2H_2O$	14	$MnCl_2 \cdot 4H_2O$	0.12
P (K_2HPO_4)	9	$Na_2MoO_4 \cdot 2H_2O$	0.06
TN (organic)	14–15	$ZnSO_4 \cdot 7H_2O$	0.12
		$CoCl_2 \cdot 2H_2O$	0.15
Mineral solution	0.3 ml	EDTA	10

time (HRT) was same as SRT. For each biomass concentration test at the designated SRT, the reactor was operated with three SRT to reach steady state followed by a one SRT sampling period. The results from this sampling period are reported here. Nevertheless, sampling was regularly performed during each of the three SRT periods to monitor the reactor performance and to assure that the reactor reached steady state before the final reported sampling period.

Each reactor was fed daily with WAS obtained from two lab-scale sequencing batch reactors (SBR) which were maintained for biological phosphorus removal. Synthetic wastewater (Table 1) was used as the feed for the SBRs which were operated with 3 cycles per day. For each cycle, it went through a 20 min filling period, a 1.5 h anaerobic period, a 3 h aerobic period, a 1.5 h anoxic period followed by 1 h of settling and finally a 40 min decant and idle period. The waste activated sludge was withdrawn from the SBR at the end of the anoxic period and then settled in a cylinder. The supernatant was discarded through a siphon and the concentrated WAS was used in this experiment. In order to provide the reactor with constant and desired mass feed, the biomass concentration of the sludge was measured (TSS = 18.89 g/L, VSS = 15.48 g/L and alkalinity = 190 mg/L) and adjusted to the desired value prior to feeding, by diluting with de-ionized water. Each reactor had a working volume of 0.5 L. Magnetic stirrers were used to maintain solids in suspension. The pH was monitored throughout the experiment. The experiments were conducted at room temperature (20–22 °C).

2.2. Analytical methods

Mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS) measurements were performed according to Standard Methods (APHA, 1998). Hach COD digestion vials were used to measure COD. Dissolved phosphate and ammonium were measured using a Lachat Instrument Quik Chem 8500, following the Quik Chem orthophosphate method 10-115-01-1-O, and Quik Chem ammonia method 10-107-06-1-I. The analysis of VFA composition was conducted by means of a Varian CP-3800 Gas Chromatograph using a flame ionization detector (FID) and HP-FFAP capillary column (inner diameter of 0.25 mm and length of 25 m). VFA concentration was converted to COD concentration by using the following conversion factors: 1.07 gCOD/g acetic acid, 1.51 gCOD/g propionic acid, 1.82 gCOD/g