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Recovery of volatile fatty acids from fermentation of sewage sludge in municipal wastewater treatment plants

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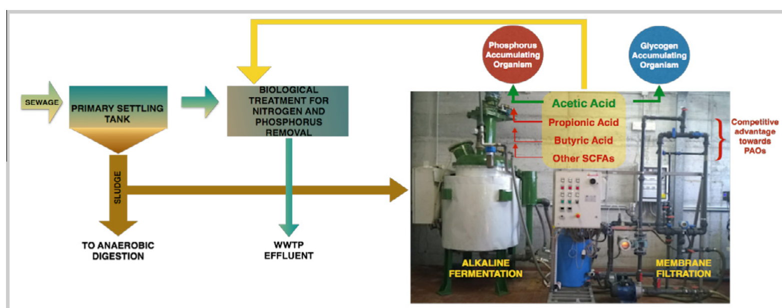
HIGHLIGHTS

- Wollastonite use during fermentation resulted in low nutrient release in the liquid.
- Higher SCFAs in the liquid phase with the use of caustic soda.
- Wollastonite enhanced the sludge dewatering characteristics and filterability.
- Fermentation liquid improved nutrient removal rates compared to acetic acid.

GRAPHICAL ABSTRACT



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ABSTRACT

This work investigated the pilot scale production of short chain fatty acids (SCFAs) from sewage sludge through alkaline fermentation and the subsequent membrane filtration. Furthermore, the impact of the fermentation liquid on nutrient bioremoval was examined. The addition of wollastonite in the fermenter to buffer the pH affected the composition of the carbon source produced during fermentation, resulting in higher COD/NH_4-N and COD/PO_4-P ratios in the liquid phase and higher content of propionic acid. The addition of wollastonite decreased the capillary suction time (CST) and the time to filter (TTF), resulting in favorable dewatering characteristics. The sludge dewatering characteristics and the separation process were adversely affected from the use of caustic soda. When wollastonite was added, the permeate flux increased by 32%, compared to the use of caustic soda. When fermentation liquid was added as carbon source for nutrient removal, higher removal rates were obtained compared to the use of acetic acid.

1. Introduction

Wastewater facilities are increasingly required to implement treatment process improvements to meet stricter discharge limits with respect to nutrients and at the same time want to maintain low operating expenses. Often commercially available organic carbon sources are used in wastewater treatment plants (WWTPs) for biological nutrient removal (BNR) from wastewater. However, the price of commercial synthetic carbon sources has significantly increased over the last years. Therefore, the use of non-conventional carbon sources seems to be an appealing alternative, considering their lower greenhouse gas (GHG) footprint compared to conventional ones. Fermenting sludge to produce short chain fatty acids (SCFAs) that can then be used in the subsequent BNR process

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Nomenclature

BNR	biological nutrient removal
COD	chemical oxygen demand
CST	capillary suction time
DNBPR	denitrifying via nitrite biological phosphorus removal
FL	fermentation liquid
GHG	greenhouse gas
HAc	Acetic acid
Hi-But	Iso-Butyric acid
Hn-But	n-Butyric acid
HPr	Propionic acid
HRT	hydraulic retention time
Hi-Va	Iso-Valeric acid
Hn-Va	n-Valeric acid
OFMSW	organic fraction of municipal solid waste
OLR	organic loading rate
S/L	solid/liquid
SCFA	short chain fatty acid
sCOD	soluble COD
SF	sludge fermentation
SFL	sludge fermentation liquid
sNUR	specific nitrogen uptake rate
soda-SFL	sludge fermentation liquid in which caustic soda is added
sPRR	specific phosphorus release rate
sPUR	specific phosphorus uptake rate
SRT	solids retention time
TMP	transmembrane pressure
TN	total nitrogen
TP	total phosphorus
TS	total solids
TSS	total suspended solids
TTF	time to filter
TVS	total volatile solids
UF	ultrafiltration
VFA	volatile fatty acid
VSS	volatile suspended solids
WAS	waste activated sludge
W	wollastonite
W-SFL	sludge fermentation liquid where wollastonite has been added
WWTP	wastewater treatment plant

seems to be a sustainable process, having the additional advantage of decreasing the amount of sludge to be disposed (Li et al., 2011; Tong and Chen, 2007; Ucisik and Henze, 2008; Zheng et al., 2010). Recovering SCFAs from sewage sludge is currently a challenge in WWTPs. Depending on process conditions of the sewage sludge fermentation, the concentration of SCFAs can be satisfactory (i.e. >2 g/L), with favorable proportions of acids for the subsequent BNR process (i.e. ~40% acetic acid (HAc), ~15% propionic acid (HPr), ~25% butyric acid (HBut)) (Jiang et al., 2009; Lee et al., 2014; Li et al., 2011). The results of recent studies have shown that the use of sludge fermentation liquid (SFL) decreases the production of nitrous oxide (N_2O) and nitric oxide (NO) during the BNR processes accomplished via the nitrite pathway (Zhu and Chen, 2011). Despite the extensive work on sludge fermentation, there is still a gap of knowledge about how process parameters (i.e. pH, temperature, solids retention time (SRT), hydraulic retention time (HRT)) can affect the efficiency of sludge fermentation in terms of the composition and the quantity of SCFAs. Most applications of waste-derived SCFAs still remain at laboratory scale (Lee et al., 2014). To ascertain the transferability of the process from the laboratory to the market, pilot scale studies are also required.

The pH is an important factor that controls the hydrolysis and acidification during sewage sludge fermentation. Alkaline conditions are expected to lead to more soluble protein and carbohydrate generation. At the same time, the methanogenic activity is inhibited resulting in enhanced SCFAs production (Wu et al., 2009). The optimum pH has been found to be in the range of 9–11 and can be maintained with the use NaOH and $Ca(OH)_2$ (Su et al., 2013; Wu et al., 2009). However, this practice is not desirable in full-scale plants, since it increases the cost and the environmental impact of the process. The addition of alkaline silicate minerals to control the pH can increase the sustainability of the fermentation process. The economic evaluation concerning the use of biowaste derived external carbon sources revealed that the organic fraction of municipal solid waste (OFMSW) fermentation liquid (FL) is a less expensive option compared to the use of synthetic HAc for the treatment of high strength nitrogenous effluents (Katsou et al., 2014). Considering the complex physicochemical nature of fermented effluents, the separation of SCFAs from fermented sludge is not a straightforward process. There are very few studies examining the solid/liquid (S/L) separation of fermented effluents. The effective and straightforward separation of FL from the fermented sludge can enhance the sustainability of the process and can lead to reduced production of wet sludge. In previous studies, the sludge dewatering ability was negatively affected by the use of caustic soda due to the release of Na^+, which impaired the separation of the FL from the fermented sludge (Su et al., 2013). One commonly applied technique for S/L separation is filtration. Nevertheless, membrane filtration is energy demanding, which limits its applications (Zhang et al., 2009). S/L separation is not always effective and the deteriorated filtration capability of the sludge makes the conventional sludge dewatering methods not practical (Tong and Chen, 2007; Yuan et al., 2006).

Within this context, the application of an efficient separation method based on membrane filtration is examined, aiming at the optimization of the whole treatment scheme. Membrane technology has been studied for the separation, isolation, recovery and utilization of volatile fatty acids (VFAs) (Zacharof and Lovitt, 2012). Membrane filtration is expected to allow the selective separation and retain the VFAs within the liquid stream, while rejecting the suspended solids. To apply this technology effectively, pretreatment of the fermented effluent is necessary since membrane fouling can be the major operational deficiency limiting the wider adoption of the process for the S/L separation.

This work studied the integration of the sewage sludge fermentation–membrane separation (SF–MS) process in order to recover SCFAs from sewage sludge and subsequently use them for nutrient bioremoval in a WWTP. The use of a suitable alkaline silicate mineral (wollastonite) was studied to enhance the performance of the fermentation process and the subsequent S/L separation stage. Finally, the feasibility of using the SFL as carbon source for enhanced BNR was assessed.

2. Methods

2.1. Source of sewage sludge and reasons for wollastonite selection

The sewage sludge used for the fermentation experiments was collected from the municipal WWTP of Carbonera (Veneto Region,