Pilot-scale results on the impact of sludge alkaline fermentation liquid on nutrient removal from sewage

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Abstract
The use of sludge fermentation liquids to enhance denitrification and biological phosphorus removal from wastewater is becoming more attractive, following the growing concern on sustainability and greenhouse gas emissions. This work investigated the pilot scale production of the best mixture of short chain fatty acids (SCFAs) in terms of the subsequent biological valorization. Three major aspects are hereby presented and discussed: the alkaline fermentation of sewage sludge; the membrane filterability of the fermentation effluent; the impact of the fermentation liquid on nutrients removal.

Keywords
sludge alkaline fermentation; short chain fatty acids membrane separation; minerals

1. INTRODUCTION

Wastewater facilities are increasingly being asked to implement treatment process improvements to meet stricter discharge limits with respect to nutrients. Recovering short chain fatty acids (SCFAs) from sewage sludge is a challenge to optimize the operation of WWTPs. Fermenting sludge to generate SCFAs seems to be a sustainable process to produce external carbon source to be used in the subsequent biological nutrient removal (BNR) process. Recent research is focusing on the investigation of sludge alkaline fermentation (SAF) to produce a valuable external carbon source (Tong and Chen, 2007). It is still not well documented how key parameters can affect SCFA production. Furthermore, most applications of waste-derived SCFAs still remain in laboratory scale (Lee et al., 2014). To ascertain the transferability of the process from the laboratory to the market, pilot scale studies are 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. Recent studies have demonstrated enhanced SCFAs production under alkaline conditions since the inhibition of methanogenic activity resulted in less SCFAs consumption. The optimum pH range was 9-11 and was reached using chemicals (Wu et al., 2010; Su et al., 2013). The effective separation of fermentation liquid from the fermented sludge can enhance the sustainability and can lead to reduced production of wet sludge. Previous studies showed that the sludge dewatering ability was negatively affected by the use of caustic soda due to Na^+ release (Su et al., 2013). Separation may not be effective and the deteriorated filterability of sludge makes conventional dewatering methods unpractical (Tong and Chen, 2007). The application of an efficient separation method based on membrane filtration is examined. The use of a suitable mineral to enhance the fermentation process and the subsequent separation stage is also investigated. Finally, the produced SFL was tested for BNR from wastewater.

2. MATERIAL AND METHODS

The sewage sludge used for the fermentation experiments was collected from the municipal WWTP of Carbonera (Veneto Region, Italy). It consisted of mixed primary and secondary sludge. A pilot scale SAF unit was set up and was operated in the Carbonera WWTP. It was composed of the sewage SAF unit (reaction volume 500 L) and an ultrafiltration (UF) membrane filtration skid (MO P13U 1m, Berghof, Germany) for the solid/liquid separation of the fermentation effluent (Fig 1). Sludge screening through 50 mm was sufficient to prevent membrane clogging.

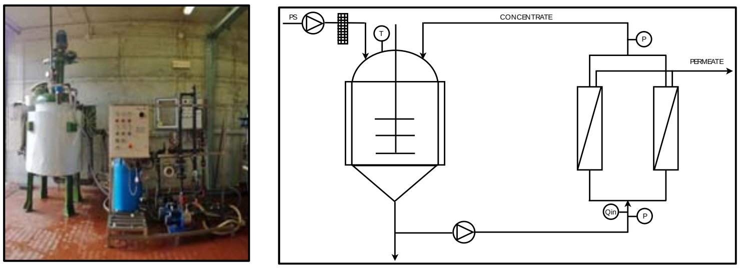

Fig 1 Integrated pilot scale SAF and membrane separation system

The impact of pH (8.0, 9.0, 10.0) and temperature (35, 40^{o}C) on the production of SCFAs was investigated in the SAF pilot (Fig. 1). The temperature was maintained by electric water heater and caustic soda was used to buffer the pH. The use of wollastonite was examined to increase pH without chemicals and enhance the dewatering characteristics of fermented sludge. Wollastonite was the mineral that was employed to control the pH and to improve the sludge dewatering characteristics. The mineral was supplied by Sigma Aldrich and was used in its natural form. Five batch reactors (1 L) were operated as follow: 1 batch reactor as blank and 4 having different wollastonite concentrations (1, 10, 20, 40 g/L). The temperature was maintained at 37^{o}C. In the pH and mineral experiments SCFAs, pH, total and volatile suspended solids (TSS, VSS), ammonium and phosphorous release were measured daily in the SFL. Capillary suction time (CST), time to filter (TTF) and step-flux tests were carried out at the end of every fermentation test to evaluate the sludge filterability and the critical flux. Batch experiments were also conducted to investigate the effect of the produced SCFAs on the specific nitrite and phosphate uptake rate (i.e. sNUR and sPUR) and on the specific phosphorus release rate (sPRR). The tests were carried out as reported by Alvarino et al. (2014) and Janssen et al. (2002). The pH, TSS, VSS, COD, soluble COD (sCOD), ammonium, CST, TTF were determined by standard methods (APHA, AWWA, WEF, 1998). NO_2-N, NO_3-N and PO_4-P were determined by ion chromatography (Dionex ICS-90 with AG14 and AS14 columns). SCFAs were analyzed by gas chromatography (Column: Nukol 15 m, 0.53 ID; temperature 85-125°C, 30°C min^{-1}; carrier: N_2, 5 mL·min^{-1})

3. RESULTS AND DISCUSSION

3.1 Sewage sludge characteristics

The main sludge characteristics of the sewage sludge used as raw material in the fermentation process are presented in Table 1.

Table 1 Sewage sludge characteristics.

Parameter	Average ± standard deviation	Parameter	Average ± standard deviation
TSS (g/L)	19.1 ± 1.5	pH	6.4 ± 0.3
VSS (g/L)	15.6 ± 1.6	SCFAs (mg/L)	235 ± 142
sCOD (mg/L)	274 ± 56	NH_4-N (mg/L)	46.1 ± 13
Total COD (mg/gSS)	954.04 ± 45	PO_4-P (mg/L)	12.6 ± 2.7

3.1. Determination of the optimum sludge fermentation conditions

The highest production of SCFAs was obtained at pH=10, T=40°C at the 5th day of operation. The maximal conversion of VSS to SCFAs rate was 0.22 mgCOD/gVSS. The yield of SCFAs production was linearly dependent on the change of pH and T:

$$\Delta Y\left(\frac{\text{mgSCFAs}}{\text{gVSS}}\right) = (21\Delta pH + 2.4\Delta T)$$

When 20 g/L (pH 7.0) and 40 g/L (pH 8.0) of wollastonite were applied at 37°C, high production of SCFAs was obtained: 0.30 and 0.31 mgCOD/gVSS respectively. Wollastonite may optimize the economical and environmental sustainability of the fermentation, together with the solid-liquid separation properties of the fermented sludge.

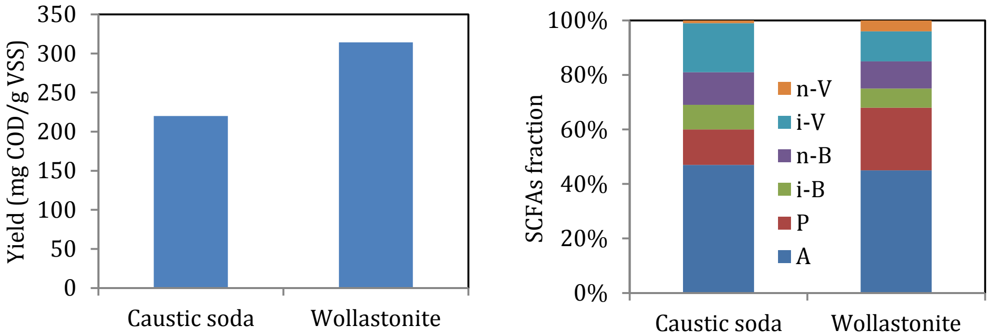

Fig 2 Comparison between caustic soda (pH 10.0 / 40°C) and wollastonite (40 g/L / 37°C) fermentation experiment: (a) SCFAs production; (b) SCFAs composition.

Acetic, propionic and butyric acids are the compounds of major interest as they enhance BNR (Frison et al., 2013). Acetic acid was the most prevalent acid and propionic acid the second one (13-23%). The use of wollastonite not only led to higher production of SCFAs, but also increased the percentage of propionic acid in SCFAs. Similar nutrient release was found when pH was controlled using caustic soda, the maximum release was at pH 10 and 40°C (521.0 mgN/L and 81.2 mgP/L). The effect of temperature on nutrients release diminished as the pH increased.

3.2 Filterability and membrane separation

The solid-liquid separation of fermentation effluent is often a bottleneck. The membrane process was employed as a sustainable option for the solid/liquid separation. The UF membrane module allows the complete retention of suspended solids within the reactor. However, the filtration performance decreased with time due to the deposition of soluble and particulate matter on the membrane. The temperature of the SFL was high (~35^{o}C), fact that is expected to benefit the filtration process. The filterability of the caustic soda fermentation effluent was evaluated by the step-flux filtration test (Fig 3a).

The increase of TMP caused an increase of the permeate flux. However, beyond a certain TMP the flux decreased. This indicates that there is an optimum operating TMP. Moreover, it is evident that the increase of the pH negatively affected the permeate flux probably due to the release of Na^+. The sludge dewatering characteristics and the separation process can be adversely affected from the use of caustic soda (Su et al., 2013). Furthermore, caustic soda reduces the efficiency of the separation process. In this study wollastonite was added to increase the pH without chemical use and to favor the dewatering characteristics of the sludge and maximize the separation performance. In the light of that high-energy demand, better dewatering characteristics need to be investigated in order to reduce energy consumption. When wollastonite was added significantly lower NH_4 and PO_4 release occurred (Fig 3c). Also, a better solid-liquid separation properties of the fermented sludge was measured by CST and TFF when alkaline fermentation is conducted adding the mineral compared to soda. CST and TTF were clearly lower (37% and 60%) when the mineral was used (Fig 3b). Compared to the use of soda, the alkali silicates may optimize the economical and environmental sustainability of the fermentation, together with the solid-liquid separation properties of the fermented sludge.

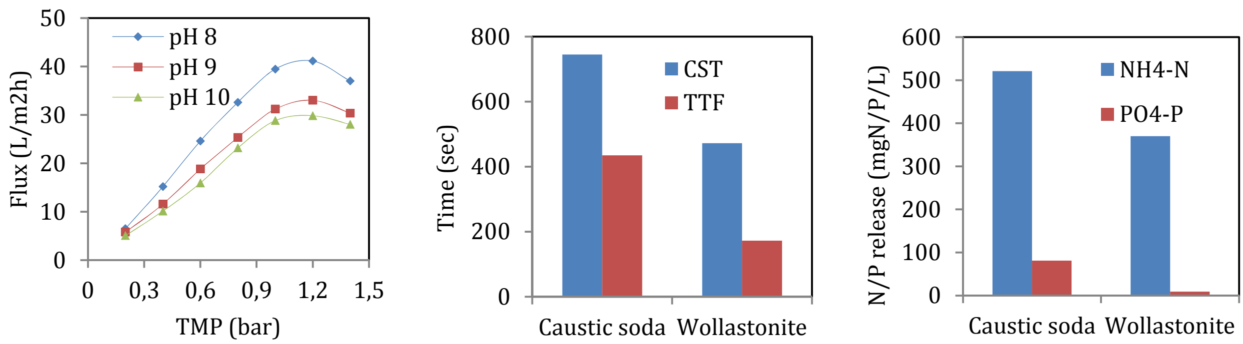

Fig 3 (a) Effect of pH and TMP on flux (20°C); (b) CST and TFF (dilution 1:5) of SFL for caustic soda (pH 10.0, 40°C) and wollastonite (40 g/L, 37 °C) addition; (c) ammonium and phosphate release for caustic soda (pH 10.0, 40°C) and wollastonite (40 g/L, 37°C)

3.4 Impact of sewage sludge fermentation liquid on nutrient removal

The use of SFL using caustic soda for pH buffering enhanced the sNUR by 26% by and sPUR 53% compared to the rates obtained with the use of acetic acid. Wollastonite addition changed the quantity and composition of the SLF, as it increased the content of propionic acid. Therefore, improved nutrient kinetics are expected; kinetic batch test are planned for the months February-May 2014. The full presentation of this work will include mass balances considering the full scale plant of Carbonera and cost comparison to evaluate the economic feasibility of the process.

Table 2 Comparing nutrient uptake in municipal wastewater for different carbon sources

External carbon source	sNUR mgN/(gVSS·h)	sPRR mgP/(gVSS·h)	sPUR mgP/(gVSS·h)
Wastewater	2.3	n.a.	n.a.
Acetic acid	4.6	1.9	2.1
Fermentation liquid using caustic soda	5.8	3.0	3.2
Fermentation liquid using wollastonite	Test ongoing	Test ongoing	Test ongoing

CONCLUSIONS

The use of SFL using caustic soda for pH buffering enhanced the sNUR by 26% by and sPUR 53% compared to the rates obtained with the use of acetic acid. The use of wollastonite (20 g/L and 40 g/L) was beneficial as it maintained the pH at 7.0 and 8.0 respectively increased the SCFAs production and enhanced filterability.

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