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Recovery of phosphorus and volatile fatty acids from wastewater and food waste with an iron-flocculation sequencing batch reactor and acidogenic co-fermentation

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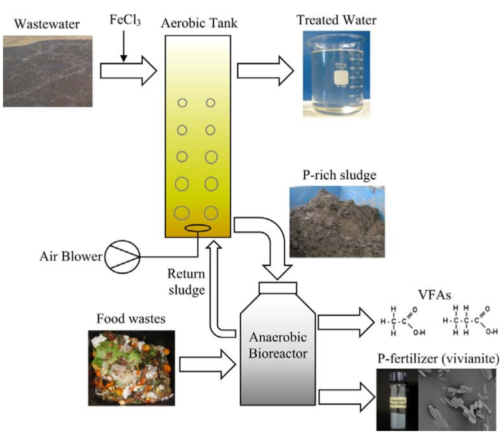
GRAPHICAL ABSTRACT



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ABSTRACT

A sequencing batch reactor-based system was developed for enhanced phosphorus (P) removal and recovery from municipal wastewater. The system consists of an iron-dosing SBR for P precipitation and a side-stream anaerobic reactor for sludge co-fermentation with food waste. During co-fermentation, sludge and food waste undergo acidogenesis, releasing phosphates under acidic conditions and producing volatile fatty acids (VFAs) into the supernatant. A few types of typical food waste were investigated for their effectiveness in acidogenesis and related enzymatic activities. The results show that approximately 96.4% of total P in wastewater was retained in activated sludge. Food waste with a high starch content favoured acidogenic fermentation. Around 55.7% of P from wastewater was recovered as vivianite, and around 66% of food waste loading was converted into VFAs. The new integration formed an effective system for wastewater treatment, food waste processing and simultaneous recovery of P and VFAs.

1. Introduction

Phosphorus (P) is a non-renewable and irreplaceable resource of fertilisers for food production. The global mineral phosphate reserves are limited and are predicted to be depleted by the end of this century (Cordell et al., 2009). The market price of phosphate rock increased by

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approximately four times in the past 10 years, and the demand for phosphate fertiliser continues to increase due to the growth of the global population and living standards (Mew, 2016). At the same time, phosphorus is a main pollutant in wastewater that causes eutrophication in natural waters. Chemical precipitation, such as by adding $FeCl_3$, has been commonly applied to remove P from wastewater (Nancharaiah et al., 2016). Every year, approximately 1.3 million tons of phosphorus are removed and lost in wastewater treatment globally. The recovery of phosphorus from wastewater should address the needs of water pollution control and resource reuse. It is anticipated that P recovery from wastewater will eventually be driven by both economics and legislations. For instance, in Germany, a new policy is formed that will require P recovery by all large wastewater treatment plants (BMUB, 2017).

Chemical acidification extraction is the current method that can be used to recover P from wastewater sludge or sludge ash (e.g., the Stuttgart process (Egle et al., 2016) and RecoPhos (Weigand et al., 2013)). This method adjusts the pH of sludge or sludge ash below 2 via the addition of strong acids, such as HCl or H_2SO_4, to dissolve metal salts and release phosphates into the acid leachate. However, the drawbacks of this method, such as the use of large amounts of strong acids, high operating costs and secondary pollution, limit the application of P recovery (Sartorius et al., 2012). In this study, we introduce a process of biological acidogenesis instead of chemical acidification to extract phosphorus from sludge. Acidogenic fermentation confines anaerobic organic digestion to the acidogenic stage and makes volatile fatty acids (VFAs) the main products. VFAs are considered to be value-added carbon sources for uses such as denitrification in wastewater treatment (Kim et al., 2016) and biosynthesis of polyhydroxyalkanoates (PHAs) (Frison et al., 2015). Suitable organics must be provided to achieve stable acidogenesis in fermentation. Food waste, with its high biodegradability, has been proved to be a desirable carbon source for acidogenic fermentation (Shen et al., 2017).

Approximately one third of global food is lost or wasted along the food supply chain to human consumption (Aschemann-Witzel, 2016). It is estimated that more than 97% of food waste in the United States is disposed by landfilling, which causes additional environmental problems, such as leachate contamination (Levis et al., 2010). Another disposal method is incineration (You et al., 2016), which wastes both energy and resources and emits air pollutants and greenhouse gases. There is a growing interest in the development of more sensible and environmentally friendly strategies for food waste processing and use. Unlike other types of waste, food waste consists of easily biodegradable organic matter, mainly carbohydrates and proteins, with few hazardous materials (Oh and Logan, 2005), so it can be readily processed by biological means of material and energy recovery, such as anaerobic digestion (Jiang et al., 2013, Thyberg and Tonjes, 2016).

In this study, a sequencing batch reactor (SBR) was used with Fe(III) dosing for enhanced P removal in municipal wastewater treatment. A side-stream anaerobic reactor was integrated with the aerobic SBR for co-fermentation of the activated sludge with food waste. Instead of chemical acidification, acidogenic fermentation was realised to create a reduced and acidic condition to extract P from the solid phase of the sludge into the supernatant for recovery, and VFAs were produced in the solution for potential use. Various types of food waste were selected to investigate their effects on acidogenic co-fermentation. Continuous operation of the new system – Fe-flocculation SBR and side-stream co-fermentation with food waste – was conducted to evaluate its effectiveness in wastewater treatment, food waste processing and simultaneous recovery of P and VFAs.

2. Materials and methods

2.1. Raw wastewater

Municipal wastewater was collected from a local wastewater treatment plant, Stanley Sewage Treatment Works (SSTW), Hong Kong, for the experimental study. The raw wastewater was typical domestic sewage in nature, and the main water quality parameters of the wastewater influent are summarised in Table 1. If the wastewater collected was not used on the day it was collected, it was stored for no more than 6 d in a refrigerator at 4 °C for later use.

Table 1
Summary of the reactor and process parameters of the aerobic SBR and anaerobic fermentation system for simultaneous P and VFAs recovery.

	Aerobic SBR	Anaerobic fermenter
Temperature (°C)	25	25
Working volume (L)	4	1.6
DO (mg/L)	4–5	0
Alkalinity (mg-$CaCO_3$/L)	275	304
ORP (mV)	–	-105
Flow rate (L/d)	8	0.4
HRT (d)	0.5	4
SRT (d)	10	4
SS (g/L)	3.2 ± 0.3	5.6 ± 0.4
VSS (g/L)	2.4 ± 0.2	4.5 ± 0.4
Influent COD (mg/L)	171 ± 8	2500
Influent TN (mg/L)	25.0 ± 0.8	–
Influent TP (mg/L)	7.19 ± 0.19	69.4
COD: N: P	24:3:1	–
Organic loading rate (g COD/L/d)	0.342	0.625
F/M (g COD/g SS/d)	0.107	0.112
Effluent COD (mg/L)	17.5 ± 0.9	1991 ± 36
Effluent TN	6.4 ± 0.2	–
Effluent TP (mg/L)	0.51 ± 0.04	106.5 ± 1.4
Effluent SS (mg/L)	33 ± 3	–
Circulation sludge ratio (%)	20	–

2.2. The Fe-coagulation sequencing batch reactor and sludge fermentation system

The integrated units of the system consisted of an aerobic SBR for biological wastewater treatment and a side-stream anaerobic reactor for sludge fermentation (Fig. 1). The aerobic SBR was a cylindrical Plexiglass column with inner dimensions of 50 × 800 mm (diameter × height) and a working volume of 4 L. The SBR column was filled with seed activated sludge obtained from the SSTW, and the mixed-liquor suspended solids concentration was maintained at around 3.2 g/L in the SBR. For enhanced one-step P removal from wastewater by the SBR, $FeCl_3$ was dosed into the wastewater for pre-flocculation, and the flocculated influent without sedimentation was pumped into the SBR

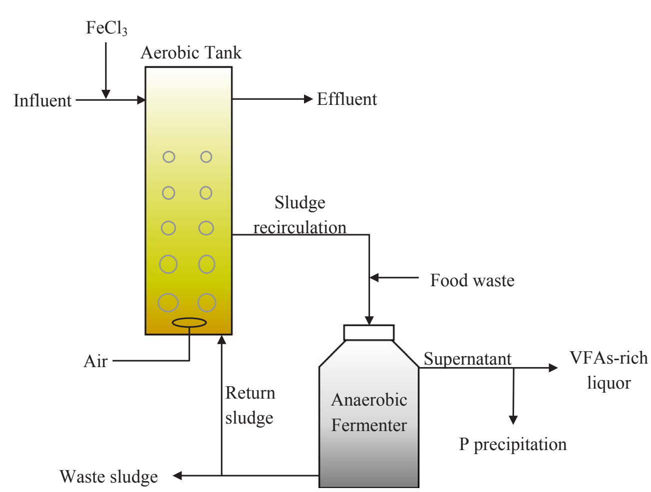

Fig. 1. Schematic flow chart of the SBR-based system with Fe(III)-dosing and side-stream anaerobic sludge co-fermentation with food waste for simultaneous recovery of P and VFAs.