Science of the Total Environment 635 (2018) 699–704

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Enhancement of the sludge disintegration and nutrients release by a treatment with potassium ferrate combined with an ultrasonic process

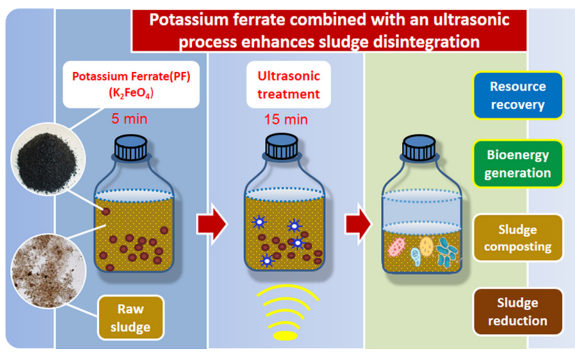
Wei Li, Najiaowa Yu, Qian Liu, Yiran Li, Nanqi Ren, Defeng Xing *

State Key Laboratory of Urban Water Resources and Environment, School of Environment, Harbin Institute of Technology, Harbin 150090, China

HIGHLIGHTS

- K_2FeO_4 combined with ultrasound process effectively disintegrated waste sludge.
- Potassium ferrate offers more safer and cheaper than ozone.
- The byproduct of potassium ferrate offered sludge superior flocculation and settleability.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 12 January 2018
Received in revised form 6 March 2018
Accepted 12 April 2018
Available online xxxx

Keywords:
Sludge pretreatment
Sludge biodegradability
Potassium ferrate (K_2FeO_4)
Ultrasound
Degree of disintegration (DD)
Waste activated sludge (WAS)

ABSTRACT

Sludge disintegration by ultrasound is a promising sludge treatment method. In order to enhance the efficiency of the sludge reduction and hydrolysis, potassium ferrate (K_2FeO_4) (PF) was used. A novel method was developed to improve the sludge disintegration-sludge pretreatment by using PF in combination with an ultrasonic treatment (PF + ULT). After a short-term PF + ULT treatment, 17.23% of the volatile suspended solids (VSS) were reduced after a 900-min reaction time, which is 61.3% higher than the VSS reduction for the raw sludge. The supernatant soluble chemical oxygen demand (SCOD), total nitrogen (TN), volatile fatty acids (VFAs), soluble protein and polysaccharides increased by 522.5%, 1029.4%, 878.4%, 2996.6% and 801.9%, respectively. The constituent parts of the dissolved organic matter of the sludge products were released efficiently, which demonstrated the positive effect caused by the PF + ULT. The enhanced sludge disintegration process further alleviates environmental risk and offers a more efficient and convenient method for utilizing sludge.

1. Introduction

The costs of waste activated sludge (WAS) management has become a dominant environment problems in municipal wastewater treatment plants (WWTP) as the greatly production of WAS continues to increase worldwide along with the increasing demand for urban environmental facilities and water treatment equipment (Kim et al., 2016). Moreover, the WAS treatment accounts for up to 60% of the wastewater treatment costs for sludge disposal (Low and Chase, 1999). The dewatering process is an effective treatment, reduces the sludge volume, and is promoted by the WAS disintegration (Kavitha et al., 2015). Sludge disintegration treatments have been used widely due to their advantages. These include (1) the reduction in the cost of sludge disposal, (2) the elimination of secondary sludge pollution, and (3) the enhancement of efficacy of subsequent processes for WAS recycling such as the

* Corresponding author at: School of Environment, Harbin Institute of Technology, P.O. Box 2614, 73 Huanghe Road, Nangang District, Harbin, Heilongjiang Province 150090, China.

E-mail address: dxing@hit.edu.cn. (D. Xing).

https://doi.org/10.1016/j.scitotenv.2018.04.174

production of biogas and nutrients including carbohydrates, proteins and volatile fatty acids (VFAs) (Yu et al., 2015). Because of the large disposal costs and the potential risks to the environment of the sludge, it is essential to develop an effective waste sludge pre-disposal technique that can accelerate the sewage hydrolysis process during anaerobic digestion (Liu et al., 2016); this is urgently needed for the greater amount of sludge production in the future. Cell-wall hydrolysis results in a massive release of all kinds of organic matters (Lu et al., 2016). When disintegration strategies are used for enhancing the hydrolysis, cells of microorganism are destroyed and the intracellular matter is released. The intracellular matter from the cells of the microorganism is utilized again, resulting in the reduction in the overall biomass yield (Chu et al., 2009). The increase in the extracellular polymeric substances (EPS) appears to have an important impact on the floc structure (Basuvaraj et al., 2015). The flocs' constituent variation may be partially responsible for the disintegration promotion (Yu et al., 2014).

Many researchers studying disintegration treatments have devoted their efforts to develop potential sludge pretreatment technologies including oxidation(Dytczak et al., 2007), ultrasound pretreatments (Khanal et al., 2007), mechanical disintegration (Kampas et al., 2007), thermal hydrolysis (Bougrier et al., 2008), alkaline treatments (Dogan and Sanin, 2009), and the biological treatment (Ponsa et al., 2008). Furthermore, the increasing degradability results in a higher energy recovery and lower residual energy in the digested sludge. Proteins and polysaccharides and the main organic components in sludge, account for 75–90% of activated sludge (Tsuneda et al., 2003), and are very important for retaining the fundamental property of sludge flocks. Apparently, an improvement in the activated sludge destruction increases the release of proteins and polysaccharides, which then have to be treated. In addition, the potential recovery of nitrogen and phosphorus has been observed consistently (Wang et al., 2010). Potassium ferrate (PF) is a powerful oxidant reagent that can oxidize noxious substances and disintegrate sludge efficiently (He et al., 2009). It is worth noting that PF is an environmental protection reagent that is applied during the waste treatment process and does not produce harmful substances or polluting byproducts. It was observed that a PF pretreatment resulted in negative effects on the ability to filter of the sludge based on capillary suction time (CST) results; the sludge particles and viscosity were reduced. In addition, the settleability of the sludge was enhanced by 17% because a large amount of floc was resized into tight flocs depending on the production of flocculants, Fe(III) (Ye et al., 2012b; Ye et al., 2012a). It was demonstrated that PF (VI) was capable of removing 50% or more color (Vis400-abs) and 30% or more of chemical oxygen demand (COD) (Jiang et al., 2006) and the final biogas production increased by approximately 44% compared with the control (Wu et al., 2015). Moreover, the sludge dewatering was improved after a PF treatment regardless of pH, whereas the sludge conditioning efficiency was enhanced by decreasing the pH value (Zhang et al., 2016b). Specifically, a PF pretreatment at pH 3 is an effective method for enhancing the sludge dewatering ability (Zhang et al., 2012).

Previous studies have mainly focused on the changes in the sludge shape and properties and the effects of different acidity/basicity conditions. Nevertheless, less is known about the release and recovery of nutrients during the reduction of waste sludge although this is important for understanding the internal mechanisms of sludge disintegration and for providing nutrients strategies. Therefore, in this study, an intensive pretreatment method using PF (K_2FeO_4) combined with an ultrasonic treatment (PF + ULT) is investigated, The objective of this study was to investigate (1) the performance of the PF + ULT co-treatment to disintegrate the WAS; (2) the influence of the PF + ULT co-treatment on the release of soluble proteins, and polysaccharides; (3) the influence of the PF + ULT co-treatment on the VFAs concentration and the pH; (4) the influence of the PF + ULT co-treatment on the concentrations of the total nitrogen (TN), NO_3═N, and PO_4^-.

2. Materials and methods

2.1. WAS source

The WAS used in this study was collected from the secondary sedimentation tank in the Wenchang WWTP in Harbin, China. After an absolute-rest precipitation for 24 h, the sludge supernatant was discarded and the remaining sludge was stored at 4 °C and was used as the raw WAS (R-WAS). The initial index values of the R-WAS and the sludge after co-pretreatment are shown in Table 1.

2.2. Pretreatment with PT + ULT

Two liters of the R-WAS was divided evenly into four 500-ml silk-mouth bottles, which were numbered 1–4. The sludge in bottle 1 was not pretreated and served as the blank control. The PF was added to bottles 2, 3, and 4 and then the sludge samples were treated ultrasonically using an Ultrasonic Cell Disrupter System (JY92-IIDN ultrasonic cell crusher, Ningbo Scientz Biotechnology Co., Ltd.). The sonication was conducted at frequencies of 25 kHz and the power output was 150 W. The probe diameter was 20 mm and the probe was immersed 150 mm into the sludge during disintegration.

After disintegrated for 20 min, the bottles were placed in an incubator shaker with a speed of 180 rpm and were maintained at 35 °C during the entire test period. Ultra-high purity nitrogen gas was purged for 10 min into the bottles to remove the remained air to create an anaerobic environment. The sludge in each bottle was sampled at 0, 10, 20, 30, 40, 50, 60, 90, 120, 180, 240, 480, and 900 min after ultrasonic processing. All the experiments were performed in triplicate.

2.3. Analysis methods and calculation

The total chemical oxygen demand (TCOD), soluble chemical oxygen demand (SCOD), total suspended solids (TSS), and volatile suspended solids (VSS) were determined using standard methods (American Public Health Association) (APHA, 1998). The sludge samples were first centrifuged and then filtered through a 0.45-μm sponge filter prior to determining the SCOD. Eq. (1) was used to determine the degree of SCOD disintegration, which indicates the effects of different kinds of pretreatments had on the solubilization of the particle substances.

$$\text{Disintegration degree} = \frac{SCOD_{after} - SCOD_0}{TCOD_0 - SCOD_0} \quad (1)$$

where $SCOD_{after}$ is the SCOD of the pre-treated sludge at each sampling point, $SCOD_0$ is the SCOD of the untreated sludge, and $TCOD_0$ is the TCOD of the untreated sludge.

The pH was measured using a Shang Hai Lei Ci PHS-2F type pH meter and the VFAs were analyzed using a gas chromatograph (GC4890, Agilent, America) (Lu et al., 2012). The polysaccharides and proteins were also examined in this experiment. The phenol sulfuric acid colorimetric method was used to test the carbohydrate concentration

Table 1
Characteristics of the buffered R-WAS and the pretreatment sludge.

Parameter	0	0.5	1.0	1.5
Volatile suspended solids (VSS) ($g\ L^{-1}$)	9.38	9.16	8.7	8.11
Soluble chemical oxygen demand (SCOD) (mg/ L)	280	2580	4210	5290
Soluble protein (mg/ L)	34.9	645.8	1114.5	1435.7
Soluble carbohydrate (mg/ L)	44.7	269.4	386.6	408.6
TN (mg/ L)	75	890	986	1062
PO_4^- (mg/ L)	380	347	220	196
NO^{3-}-N (mg/ L)	15	169	594	806
pH	6.66	8.26	9.76	10.6

0.5, 1.0, and 1.5 represent 0.5 g, 1.0 g, and 1.5 g potassium ferrate added to a sludge concentration of 1 g VSS.