Bioresource Technology 217 (2016) 179–185

Contents lists available at ScienceDirect

Bioresource Technology

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

Sludge conditioning using biogenic flocculant produced by *Acidithiobacillus ferrooxidans* for enhancement in dewaterability

Mayur B. Kurade[a], Kumarasamy Murugesan[a,c], Ammaiyappan Selvam[a,b], Shuk-Man Yu[b], Jonathan W.C. Wong[a,b,*]

[a] *Sino Forest Applied Research Center for Pearl River Delta Environment, Hong Kong Baptist University, Hong Kong Special Administrative Region*
[b] *Department of Biology, Hong Kong Baptist University, Hong Kong Special Administrative Region*
[c] *Department of Environmental Science, Periyar University, Salem 636011, India*

HIGHLIGHTS

- *A. ferrooxidans* was used to produce a novel composite biogenic flocculant.
- Rapid bioacidification triggered improvement in sludge dewaterability.
- Sludge moisture content can be reduced to 70% after biogenic flocculant treatment.
- Biogenic flocculant reduced odor, improved the calorific value and effluent quality.

ARTICLE INFO

Article history:
Received 11 December 2015
Received in revised form 24 February 2016
Accepted 25 February 2016
Available online 3 March 2016

Keywords:
Biogenic flocculant
Acidithiobacillus ferrooxidans
Sludge dewaterability
Sewage sludge
Bioflocculation

ABSTRACT

Biogenic flocculant produced by *Acidithiobacillus ferrooxidans* was used for sludge conditioning to improve the dewaterability of anaerobically-digested sludge, and its efficiency was compared with commercial cationic polyacrylamide (PAM). Biogenic flocculant rapidly reduced the pH and increased the oxidation–reduction potential of sludge. Capillary suction time (CST) and specific resistant to filtration (SRF) of sludge was decreased by 74% and 89%, respectively, compared with control; and the reductions were 58% CST and 67% SRF higher when compared with commercial polymer. Biogenic treatment improved the sludge calorific value by 13%, and also reduced the unpleasant odor. The small-scale mechanical filter press study showed that the biogenic flocculant can reduce the moisture content of sludge to 70%, and improve the clarity of the filtrate in terms of removal of total suspended solids and total dissolved solids when compared with synthetic polymer treatment.

1. Introduction

Sludge dewatering is an important process in wastewater treatment plants (WWTP), used for the reduction of sludge volume that helps to reduce the cost of transportation and disposal of dewatered sludge to either incineration or landfill (Feng et al., 2009). Large WWTPs utilize up to 50% of the total wastewater treatment cost for sludge handling and disposal (Abelleira et al., 2012). Anaerobic digestion is the most commonly used method for sludge digestion and stabilization in conventional activated sludge process. It involves a considerable reduction in the organic matter and pollution load of the sludge, and provides additional benefits of valuable biogas production. However, the anaerobic treatment adversely affects the sludge dewaterability (Dewil et al., 2006; Novak et al., 2003). This deterioration has been attributed to the presence of extracellular polymeric substances (EPS) in the sludge that are released into the bulk solution as a result of digestion (Murthy et al., 2000), and disintegration of organic debris causing changes in particle size distribution (Nellenschulte and Kayser, 1997). The extent of deterioration is also related to the reduction of iron concentration in anaerobically digested sludge (Nielsen and Keiding, 1998).

Various potential pretreatment strategies have been reported to enhance the dewaterability of sludge, such as the addition of calcined aluminum salts, alkaline pretreatment, ultrasonication, electrolysis and microwave irradiation (Feng et al., 2009; Li et al., 2009; Yu et al., 2009; Yuan et al., 2011a,b; Zhen et al., 2011). Despite the high dewatering potentials of these technologies, their

---

* Corresponding author at: Department of Biology, Hong Kong Baptist University, Kowloon Tong, Hong Kong Special Administrative Region. Tel.: +852 3411 7056; fax: +852 3411 2355.

E-mail address: jwcwong@hkbu.edu.hk (J.W.C. Wong).

http://dx.doi.org/10.1016/j.biortech.2016.02.113
0960-8524/

application in practical scale is limited due to high operational cost, high energy consumption and operational complexities. Moreover, these pretreatment approaches substantially reduce the organic matter content in dewatered sludge or produce highly organic and ammonia loaded wastewater, which is difficult to treat (Montusiewicz et al., 2010; Neyens and Baeyens, 2003). Currently, addition of polyelectrolyte such as, cationic polyacrylamide (CPAM, commercial name-FLOPAM) to sludge is the most widely accepted method for sludge dewatering. However, it not only increases the treatment cost, but also responsible for secondary environmental pollution, as the polymers used in this process pose serious threats due to its toxicity (Ho et al., 2010). The conventional dewatering methods, which utilize organic or inorganic flocculants followed by mechanical dewatering always give a dewatered sludge having high moisture content (>80%), and sometimes high concentration of heavy metals depending on wastewater sources. These problems severely affect subsequent disposal and reutilization of sewage sludge through incineration, landfilling, and composting; thus failing to meet the increasingly stringent regulations. Therefore, there is an immense need to develop new ecofriendly methods, which could enhance sludge dewaterability and simultaneously reduce the operational cost.

Bioleaching is one of the biological methods, which is recently gaining attention for the treatment and dewatering of the sludge (Chan et al., 2003; Wong et al., 2004, 2015a). The sludge stabilization and mass reduction is enhanced, when the pH of sludge is reduced during bioacidification. In addition, bioacidification solubilizes the EPS of sludge that impedes the dewaterability. It is expected that, the bioleaching process can improve the dewaterability through altering the sludge properties, which are suitable for dewatering. It is recently reported that, dewaterability can be improved by 4–10 times, using the bioacidification process compared with untreated control sludge (Liu et al., 2012; Murugesan et al., 2014a).

The earlier approaches to enhance dewaterability by biological means include addition of Fe^{2+}/S^0, and allow the indigenous microflora in sludge to initiate bioacidification, which is time consuming (>48 h); thus limiting its application at real scale operations. Enhancement in dewaterability by directly adding the microbial flocculant could be an appropriate alternative strategy. Therefore, the major objective of this study was to reduce the treatment time for dewaterability using a novel biogenic flocculant produced by *Acidithiobacillus ferrooxidans*. *A. ferrooxidans* is a chemolithrotrophic iron-oxidizing bacterium, which generates biogenic ferric iron during its growth that can oxidise a variety of minerals, including metal sulphides and release the toxic heavy metals from sewage sludge (Wong and Gu, 2008). A well-grown culture of *A. ferrooxidans* contains biogenic Fe^{3+}, cell bound and released EPS and biogenic secondary minerals from iron oxidation. The acidic nature (pH 2.0–2.2), high oxidation potential (>600 mV) and presence of inorganic and organic constituents make the biogenic flocculant as a composite flocculant. The biogenic flocculant could exhibit both charge neutralization and bridging mechanism to achieve faster and maximum coagulation; and thus it could be used as an alternative to the commercial flocculants for dewatering of the sludge.

The production and maintenance of microbial inoculum is very difficult and uneconomical; however, in case of *A. ferrooxidans*, highly acidic nature and limited raw energy sources containing only salts in the medium for its growth makes this culture 'contamination free' and very easy and economical to maintain. During preliminary studies, bioacidification treatment was monitored for 6 days, and it was observed that *A. ferrooxidans* enables rapid bioacidification of anaerobically digested sludge (ADS) within first 2 days along with the improved dewaterability (Murugesan et al., 2014a; Wong et al., 2015b). The present study investigates the rapid effect of biogenic flocculant on ADS dewaterability, and its efficiency was compared with a cationic polymer, which is currently being employed in WWTPs for sludge conditioning. The improvement in dewaterability of AD sludge was assessed using capillary suction time (CST) and specific resistant to filtration (SRF). The effectiveness of biogenic flocculant in mechanical dewatering using a small scale filter press unit was also evaluated.

2. Methods

2.1. Sludge sampling

Anaerobically digested sludge (ADS) was collected in clean polyethylene containers (10 L) from the Shatin Sewage Treatment Works in Hong Kong, quickly transferred to laboratory and stored at 4 °C for further use.

2.2. Microorganism and inoculum

An indigenous strain of iron-oxidizing bacterium *A. ferrooxidans* ANYL-1, previously isolated from anaerobically digested sludge (Gu and Wong, 2004), was used in this study. The active culture of *A. ferrooxidans* was regularly maintained in 500 mL Erlenmeyer flasks, containing 200 mL modified 9 K medium (pH 2.5), amended with 44.2 g L^{-1} $FeSO_4{\cdot}7H_2O$ as the energy source (Gu and Wong, 2004). The inoculum was prepared by transferring 10% (v/v) of 72 h old culture to fresh medium. A well-grown culture of *A. ferrooxidans* (cell density – 1.0×10^8 cells mL^{-1}) was filtered through Advantec No. 1 filter paper and used as the composite biogenic flocculant.

2.3. Dewaterability experiments using commercial polymer and biogenic flocculant

A well-mixed 270 mL of sludge was transferred to a 500 mL Erlenmeyer flask together with 10% (30 mL) of *A. ferrooxidans* biogenic flocculant (cell density – 1.0×10^8 cells mL^{-1}). In a different set of experiment, commercial cationic polymer (Cationic Polymer FLOPAM FO4290, SNF (China) Flocculant Co. Ltd.) obtained from the sewage treatment plant was added at 0.2% concentration (based on the dry solid content of the sludge). In addition, control sets without biogenic flocculant or commercial cationic polymer were also included. These flasks were incubated at 30 °C and 180 rpm on a rotary shaker. Samples were collected from each flask at regular intervals to determine the dewaterability.

2.4. Dewaterability analyses

At each sampling point, the pH and oxidation reduction potential (ORP) of the sludge were measured using an Orion 920A pH meter (USA). To assess dewaterability, capillary suction time (CST) and specific resistance to filtration (SRF) were determined. CST was measured using a capillary suction timer (Triton Electronics Type 304 M, UK) with 18 mm reservoir (sample holding capacity – 6 mL) resting on standard CST filter paper (7 × 9 cm). SRF was determined by filtration in a Buchner funnel (Murugesan et al., 2014a). Briefly, 30 mL sludge sample was added into a Buchner funnel placed with a filter paper (Advantec No. 1), and suction filtration was performed using a vacuum pump with 0.07 MPa constant pressure. Morphology of sludge flocs was observed and images were captured using light microscope (Leica, M165, Germany). Total suspended solids (TSS), total dissolved solids (TDS), and chemical oxygen demand (COD) were measured as per the standard methods (APHA, 2005 – method 2540-C, 2540-D and 5220-B, respectively). Calorific value of sludge was