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Dewatering of saline sewage sludge using iron-oxidizing bacteria: Effect of substrate concentration

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HIGHLIGHTS

- *Acidithiobacillus ferrooxidans* is a potential biogenic flocculant producer.
- Bioacidification and dewaterability of saline sewage sludge was investigated.
- Optimum dose of Fe^{2+} to sludge solids was optimized to improve the dewaterability.
- Sludge CST and SRF were significantly reduced by biogenic flocculant.

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ABSTRACT

This study investigated the improvement in dewaterability of activated sludge (ACS) and anaerobically digested sludge (ADS) through bioacidification approach using iron-oxidizing bacterium, *Acidithiobacillus ferrooxidans*. ACS and ADS were treated with *A. ferrooxidans* culture with addition of different concentrations of energy substrate, in terms of Fe^{2+}:sludge solids ratio (0:1, 0.01:1, 0.05:1 and 0.1:1), and the dewaterability was assessed by determining the capillary suction time (CST), time to filter (TTF) and specific resistance to filtration (SRF) of the sludge. The results revealed that the levels of Fe^{2+} significantly influenced the sludge acidification ($pH \leqslant 3$). The CST, TTF and SRF values rapidly decreased in treated sludge, indicating that dewaterability of the sludge was significantly ($p < 0.05$) improved than untreated sludge. This investigation clearly demonstrates that *A. ferrooxidans* culture, as biogenic flocculant, can be potentially used for improving the sludge flocculation, stabilization and dewaterability.

1. Introduction

A large number of sewage treatment plants have been constructed in recent years especially in Asian countries to meet the increasing demand for better water quality. In Hong Kong, 30% of the wastewater is treated by secondary treatment using modified activated sludge process similar to many cities in the world, which effectively purifies the wastewater but at the same time generates a huge volume of waste activated sludge. Sludge volumetrically represents only 1–2% of the treated wastewater but contains around 50–80% pollutants of the waste stream that must be stabilized by proper treatment before disposal or land application. Sludge management is the major challenge in sewage treatment process as it requires appropriate methods for volume reduction, stabilization, dewatering and safe disposal. Sludge stabilization can be done by thermal, chemical and biological process. Anaerobic digestion (AD) is a generally adopted biological process as AD simultaneously stabilize waste activated sludge, and generate valuable biogas as by-product. In addition, AD process reduces the amount of final sludge solids for disposal. Digested sewage sludge generally contains up to 97–99% water content and remaining as organic and inorganic matters in the form of suspended and dissolved solids. In order to minimize the volume of sludge to be transported to the disposal site and the cost of the transportation, an effective dewatering of sludge is essential to separate the suspended solids from bulk volume of water. Furthermore, efficient dewatering can reduce the amount of leachate generated in landfills; enhance the energy efficiency during thermal treatment;

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or reduce the requirement for bulking agent when recycled through composting, depending on the mode of disposal employed.

Sludge dewatering is the most challenging and expensive step of sewage treatment process that covers almost 50% of the total operation cost of sewage treatment works due to huge consumption of expensive flocculants (Neyens et al., 2004). Sludge floc is composed of microbial aggregates and their extracellular polymeric substances (EPS), which exist in different layers such as slime, loosely bound (LB-EPS) and tightly bound (TB-EPS). EPS are responsible for the structural and functional integrity of the aggregates (Liu et al., 2010). The sludge EPS constitutes protein, polysaccharide, lipids and humic like substances that entrap the water and cause a high viscosity (Li and Yang, 2007). EPS change the particle size distribution of the sludge by binding cells and particulate matter together, which affects the sludge dewaterability. An increase in EPS content generally leads to lower sludge dewaterability, possibly due to the steric force generated by EPS which prevents the contact between sludge particles (Sheng et al., 2010). Thus, the sludge needs to be preconditioned with effective flocculant in order to neutralize the steric force and improve the dewaterability.

A number of physical (Lee, 2006; Xu et al., 2011), chemical (Shao et al., 2009; Zhai et al., 2012; Zhen et al., 2011, 2012) and physicochemical (Abelleira et al., 2012) pretreatment methods have been reported to improve the sludge dewaterability. Currently, commercial synthetic polymer flocculants are being used as sludge conditioner in sewage treatment works. Despite of their effectiveness in improving the sludge dewaterability, the high cost and consequent secondary pollution are the major issues. Besides, some polyacrylamide polymeric derivatives are recalcitrant and some degradation residues released are carcinogenic compounds and strong odors causing chemicals (Chang et al., 2005; Rudén, 2004). As an alternative to chemical flocculants, the use of biological flocculants is getting great interest in recent years due to the safe and non-toxic nature. Therefore, an intensive research has been progressing to develop an ecofriendly and cost effective biological flocculants using naturally occurring microbes.

Many bacteria have been demonstrated to produce bioflocculants having sludge flocculation, sludge settling and dewatering capacity (More et al., 2012). The microbial bioflocculants are mainly the secretary extracellular polymeric compounds (More et al., 2012). During the growth in complex organic medium these microbes produce bioflocculant. Although microbial bioflocculant produced by the heterotrophic bacteria are useful for sludge flocculation, the flocculant should be isolated from the medium, but it will cover additional processing cost. Besides, for effective flocculation the bioflocculants requires additional metal cations as flocculant aiders (More et al., 2012) to increase the adsorption of bioflocculants on the surface of suspended sludge flocs by decreasing the negativity of the charged particles.

Sludge acidification by the addition of sulfuric acid has been shown to increase the dewaterability. Bioacidification of sludge using acidophilic microbes could also improve the sludge dewaterability. However, dewaterability could be worsened due to dissociation of sludge flocs and release of EPS when sludge become strongly acidic. Liu et al. (2012a,b) also found that in a sludge bioleaching study conducted using combined *Acidithiobacillus ferrooxidans* and *Acidithiobacillus thiooxidans*, the dewaterability was deteriorated as the acidification progress. This suggests that bioleaching with above combination may not be effective for sludge flocculation and improve the dewaterability but effective for metal leaching from sludge (Liu et al., 2012a,b). On the other hand, the use of pre-grown *A. ferrooxidans* culture as flocculant can improve the sludge flocculation. Sludge stabilization can also be achieved by bioacidification during further incubation due to production of *in situ* biogenic flocculant. *A. ferrooxidans* mediated sludge metal leaching and sludge stabilization have been proved in our previous studies (Gu and Wong, 2004; Wong and Gu, 2008). Our investigation indicated that feasibility of biogenic flocculant derived from *A. ferrooxidans* for sludge conditioning and this biogenic flocculant can be a potential alternative to the synthetic flocculants (Murugesan et al., 2014; Wong et al., 2015, 2016). However, the production of biogenic flocculant by iron-oxidizing bacteria might vary depending on the dosage of Fe^{2+} supplemented to the sludge and this has not been fully investigated.

The production of biogenic flocculants by iron-oxidizing bacteria might vary depending on the dosage of Fe^{2+} supplemented to the sludge. In addition, the total solids of the sludge can also affect the sludge dewaterability. As the total solids content of sludge varies time to time, it is important to keep iron content in a fixed ratio to achieve uniform effectiveness. Therefore, the objectives of this study were (i) to investigate the influence of different Fe^{2+}:sludge solids ratio on *A. ferrooxidans* culture mediated flocculation, dewaterability, and bioacidification of saline water sewage sludge (activated sludge and anaerobically digested sludge). (ii) production of *in situ* biogenic flocculant and how that improve the dewaterability, (iii) to find out the minimum concentration of the iron for effective dewaterability.

2. Materials and methods

2.1. Sludge sample

Saline activated sludge (ACS) and anaerobically digested sludge (ADS) samples were collected from the Sha Tin Sewage Treatment Works; Hong Kong which receives seawater flushed sewage. The sludge samples were quickly transferred to laboratory and stored in clean plastic cans at 4 °C until further use. Selected initial physicochemical and dewaterability properties were characterized according to the standard methods (APHA, 2005) and the data are shown in Table 1.

2.2. Preparation of biogenic flocculant

Active culture of an indigenous strain of iron-oxidizing bacteria *A. ferrooxidans* ANYL-1, previously isolated from anaerobically digested sludge (Gu and Wong, 2004), was regularly maintained in modified 9K medium (Silverman and Lundgren, 1959), which contained: $(NH_4)_2SO_4$ 3 g, $MgSO_4{\cdot}7H_2O$ 0.5 g, K_2HPO_4 0.5 g, KCl 0.1 g, $Ca(NO_3)_2{\cdot}2H_2O$ 0.01 g, and 44.2 g $FeSO_4{\cdot}7H_2O$ as the energy substrate in 1 L of distilled–deionized water. The culture was incubated at 30 °C and 180 rpm on a rotating shaker before filtered through Whatman No. 1 filter paper to remove the culture solids containing salt precipitate. The filtrate contained the bioferric iron as well as the *A. ferrooxidans* cells and its EPS. The filtered culture containing *A. ferrooxidans* cells (10^7–10^8 cell/ml) was used as

Table 1
Selected physicochemical and dewaterability characteristics of the activated and anaerobically digested sludge samples.

Parameter	Activated sludge	Anaerobically digested sludge
pH	6.7	7.7
ORP (mV)	−89.6	−117.1
Total solids (%)	2.08	2.1
CST (s)	12.6	19.5
SRF (m/kg)	1.0×10^{13}	8.3×10^{12}
Salinity (ppm)	11,044	8335

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