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Influence of sludge solids content on sludge dewaterability using bioleaching

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Abstract. Dewatering is an extremely important step in wastewater treatment process to reduce the final sludge volume in order to minimize the cost of sludge transportation and disposal. In the present study, the effect of different sludge solids content (1, 2 and 3.8%) on the dewaterability of anaerobically digested sludge using *Acidithiobacillus ferrooxidans* and *A. thiooxidans* was studied. The rate of pH reduction was higher during initial process in the sludge having low solids content, but after 48 h of bioleaching, similar pH of below 3 was observed in all the treatments with different solids content. Bio-oxidation rate of Fe^{2+} was initially higher in sludge with low solids content, but complete oxidation was observed within 60 h in all the three treatments. Compared to the control, specific resistance to filtration was reduced by 75, 78 and 80% in the sludge with a solids content of 1, 2 and 3.8% respectively, showing improvement in dewaterability with an increase in sludge solids content. Sludge effluent quality and sludge settling rate were also improved in treatments with higher solids content after the bioleaching process.

Keywords: *Acidithiobacillus ferrooxidans*; *Acidithiobacillus thiooxidans*; sludge dewaterability; bioleaching

1. Introduction

Anaerobic digestion is most commonly used method for sludge digestion and stabilization in the conventional activated sludge process as it considerably reduces the organic matter content and pollution load of the sludge, as well as provides additional benefits of valuable energy recovery. However, the disposal of the huge bulky sludge generated after anaerobic digestion is still a subject of concern. The discharging of sludge into the water body leads to rise of metal concentrations in water. It can directly affect the aquatic organisms and human bodies due to heavy-metal accumulation (Hegazy *et al*. 2012). Improper disposal of the large amounts of sludge generated during wastewater treatment poses a significant threat to the ecological systems (Rai *et al*. 2004). However, removing the excessive amount of water in sewage sludge is difficult (Neyens and Baeyens 2003) because conventional organic or inorganic-flocculants and mechanical

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dewatering systems used for sludge dewatering always give sludge with high moisture content (> 80%) depending on the effectiveness of the dewatering process that affects its disposal by landfilling, incineration and composting.

From the last decade, bioleaching has gained a lot of attention as an attractive method for the removal of heavy metals from sewage sludge, sediments and soils (Wong and Gu 2004, Wong *et al*. 2004, 2008). But not only limited to heavy metal leaching, this bioleaching process is recently found as an effective tool for dewatering the sewage sludge (Song and Zhou 2008, Shi *et al*. 2013). Bioacidification may play a critical role in sludge dewatering during bioleaching process. Bioacidification is governed by bio-oxidation of energy substances during bioleaching. The two mainly studied microbial species, *Acidithiobacillus ferrooxidans* and *A. thiooxidans* carry out biooxidation as,

$$S^0 + H_2O + 1.5O_2 \longrightarrow H_2SO_4 \ldots\ldots\ldots\ldots\ldots \textit{A. thiooxidans}$$
$$4Fe^{2+} + O_2 + 4H^+ \longrightarrow 4Fe^{3+} + 2H_2O \ldots\ldots\ldots\ldots \textit{A. ferrooxidans}$$

Bioleaching improves sludge dewaterability by at least 4-10 times as compared to control sludge by solubilizing the extracellular polymeric substances (EPS) of sludge that impedes the dewaterability; hence the dewatering efficiency has always been sacrificed. The current study focused on investigating the effect of solids content of the sludge on bioacidification and dewatering performance using *A. ferrooxidans* and *A. thiooxidans*. It is expected that this bioleaching process can improve the dewaterability through altering the sludge properties suitable for dewatering (Song and Zhou 2008, Shi *et al*. 2013). However, the recent approach did not focus on detailed investigation of effects of sludge properties on dewatering performance of the bioleaching process. It is well known that the solids content of wastewater sludge varies with effluent loading. Bio-oxidation of Fe^{2+} was monitored for 3 days of sludge incubation with mixed bacterial species (*A. ferrooxidans* and *A. thiooxidans*) and sludge dewaterability was monitored by SRF.

2. Materials and methods

2.1 Sludge sampling

Anaerobically digested sludge samples were collected from Shek Wu Hui wastewater treatment plant, Hong Kong, in clean 10 L polyethylene containers, quickly transferred to laboratory and stored at 4°C for subsequent experiments. When the sludge was collected, the initial pH of the sludge was 7.1, solids content 3.8% and organic matter 77%.

2.2 Microorganisms and inoculum

A. ferrooxidans LX5 (AF) and *A. thiooxidans* TS6 (AT) were obtained from China General Microbiological Culture Collection Center and cultivated in modified 9K medium [$(NH_4)_2$-SO_4 3.5 g, KCl 0.119 g, K_2HPO_4 0.058 g, $Ca(NO_3)_2·4H_2O$ 0.0168 g, $MgSO_4·7H_2O$ 0.583 g, H_2O 1000 mL, pH 2.5] and SM [$(NH_4)^2SO_4$ 0.4 g, KH_2PO_4 3.0 g, $CaCl_2·2H_2O$ 0.25 g, $MgSO_4·7H_2O$ 0.5 g, H_2O 1000 mL, pH 3.0). The modified 9K and SM media were adjusted to pH 2.5 and 3.0, respectively using sulfuric acid, and then spiked with 44.2 g/L $FeSO_4·H_2O$ and 10 g/L of elemental sulfur (S^0) as the energy sources, Both the cultures were grown in 500 mL Erlenmeyer flasks containing 250 mL of 9K or SM medium at 30°C and 180 rpm on a rotating shaker. The inoculum was prepared by transferring 10% v/v of 72 h old culture to fresh medium. *A*. *ferrooxidans* and *A*. *thiooxidans* cell counts were about 10^8 cells/mL after 72 h of growth.

2.3 Effect of sludge solids content on dewaterability

Experiments were carried out in 500 ml Erlenmeyer flasks. Sludge, 270 ml, was transferred into each flask. The solids content of the sludge were adjusted to 1, 2 and 3.8% to investigate their effect on dewaterability. Sludge was inoculated with AF + AT (5% each) together with the energy substrate. The experimental design was as follows

Treatment 1 : sludge solids content 1% + 1.25 g/L Fe^{2+} + 10% (AF+AT)
Treatment 2 : sludge solids content 2% + 2.5 g/L Fe^{2+} + 10% (AF+AT)
Treatment 3 : sludge solids content 3.8% + 4.75 g/L Fe^{2+} + 10% (AF+AT)

The mixtures were incubated at 30°C and 180 rpm on a rotary shaker for 3 days. Samples were collected from each treatment at different time intervals to determine the dewaterability. Three replicates were included for each treatment. Samples were collected from each treatment at different time intervals to determine the dewaterability.

2.4 Analyses

Samples collected were analyzed for pH using an Orion 920A pH meter. To assess the dewaterability of sludge, specific resistance to filtration (SRF) was determined using 30 mL of well-mixed sludge sample by suction filtration in a Buchner funnel with Advantec No. 1 filter paper (Lo *et al*. 2001) and the SRF was calculated according to Lo *et al*. (2001). Samples were centrifuged at 12,000 g for 15 min, filtered through 0.45 micrometer membrane filter and used for the determination of Fe content using the 1,10-phenanthroline method as per the standard methods (APHA 2005). All the data presented are the mean and standard error of three independent samples.

3. Results and discussion

3.1 Effect of different solids content on bioacidification during bioleaching

When anaerobically digested sludge was treated with AF + AT for 72 h, the pH of the sludge was reduced to acidic condition in all the solids content used. The drastic reduction in pH was recorded during the initial 12 h period (Fig. 1). It is well documented that pH decrease in bioleaching system is an indication of the high activity of *acidithiobacilli* bacteria (Sreekrishnan *et al*. 1993, Gu and Wong 2004, Zhang *et al*. 2009). It has been reported that, the co-inoculation of AF and AT together with energy substrates Fe^{2+} and S^0 can facilitate rapid bioacidification of sludge (Chan *et al*. 2003). Hence, the reaction time for bioleaching may be sharply reduced by the co-addition of Fe^{2+} and S^0. This decrease in pH during bioleaching may be due to the generation of sulfuric acid due to bio-oxidation of S^0 by *A*. *thiooxidans* (Chen *et al*. 2005) and the release of H^+ resulting from the formation of iron oxyhydroxysulfate mineral due to the hydrolysis of Fe^{3+} from the bio-oxidation of Fe^{2+} by *A*. *ferrooxidans* (Daoud and Karamanev 2006). The pH reduction rate

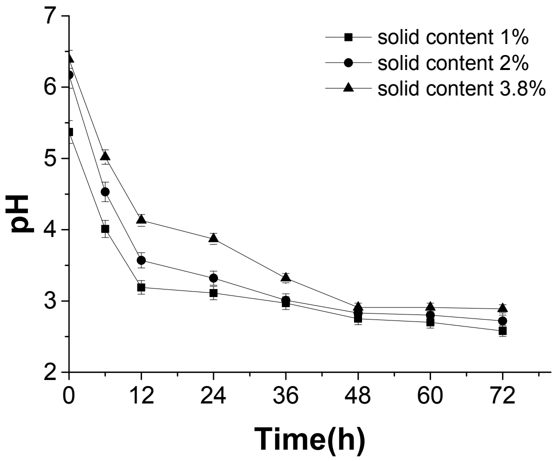

Fig. 1 Effect of different sludge solids content on the bioacidification during treatment with *A. ferrooxidans* and *A. thiooxidans* (AF+AT)

was higher during initial bioleaching period in the sludge having low solids content, indicating the strong buffer provided by sludge solids against the acidity resulting from the iron oxidization, but after 48 h of bioleaching the pHs of the sludge with different solids content did not differ significantly. Hence, it can be concluded that the overall reduction in pH is not dependent on the solids content of the sludge. The acidic pH could facilitate the dewaterability of sludge due to solubilization of sludge EPS that hold substantial amount of water (Yang and Li 2009).

3.2 Bio-oxidation of Fe^{2+} during bioleaching

The concentration of the energy source i.e., Fe^{2+}, was increased as the solids content of the sludge was increased with total addition corresponding to 1.25, 2.5 and 4.75 g/L for 1, 2 and 3.8%

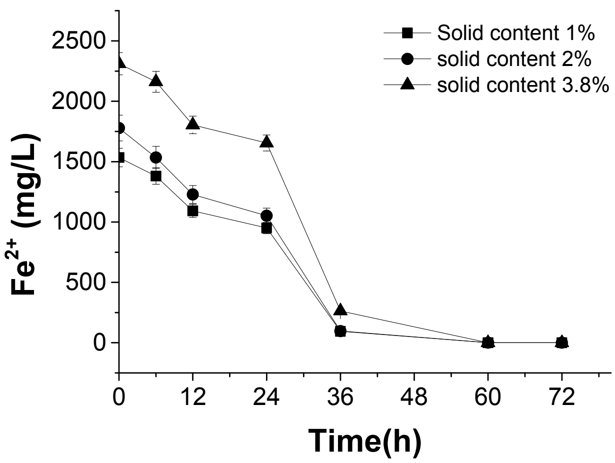

Fig. 2 Bio-oxidation of Fe^{2+} in sludge with different solids content with time during the treatment with *A. ferrooxidans* and *A. thiooxidans* (AF+AT)

solids content respectively. The Fe^{2+} content in the medium during bioleaching process was measured to investigate the bio-oxidation rate of Fe^{2+} (Fig. 2). During the initial 24, the bio-oxidation rates of Fe^{2+} for sludge with 1 and 2% solids were 13 and 11%, respectively which were higher than that with 3.8% solids (6%), but as the bioleaching process progressed, no significant difference in the rate of bio-oxidation was noted among all the treatments. Within 60 h of bioleaching, irrespective of the sludge solids content, almost all of the Fe^{2+} was bio-oxidized in all the treatments. The reduction of Fe^{2+} concentration was attributed to the generation of Fe^{3+} (Gu and Wong 2004). Total Fe^{2+} concentration gradually decreased with the increase of reaction time owing to the formation of ferric precipitates such as iron oxyhydroxysulfate mineral (Gu and Wong 2004, Daoud and Karamanev 2006). In addition, the sludge was supplemented with S^0 and hence, the bio-oxidation of S^0 might lead to a decrease in pH. The acidic conditions are more favorable for the growth and activity of *A. ferrooxidans*. The increased growth and activity of *A. ferrooxidans* in turn accelerates further decrease of pH through the bio-oxidation of Fe^{2+} and S^0 (Chan *et al*. 2003, Wong *et al*. 2004, Chen *et al*. 2005).

3.3 Effect of sludge solids content on dewaterability of anaerobically digested sludge

Specific resistance to filtration (SRF) has been the widely used parameter to evaluate sludge dewatering. If centrifugation or filter press is employed for dewatering process, filtration is a major feature of the sludge dewatering. The resistance to filtration originates from the hydraulic resistance of water flowing in the pores of the filter cake. It is based on the assumption that the average cake resistance is constant over time. Based on this principle, specific resistance to filtration (SRF) is used as a parameter to characterize the dewaterability of sludge. Higher SRF values are always associated with the poor sludge dewaterability (Wakeman 2007). The SRF values for untreated sludge were higher. The increased hydraulic resistance of water flowing from pores of untreated sludge or increased binding is the major reason of higher SRF values (Neyens and Baeyens 2003). The suspended solids present in the activated sludge contribute to the higher resistance to filtration (Sun and Liu 2013). The initial SRF values of the sludge increased with an

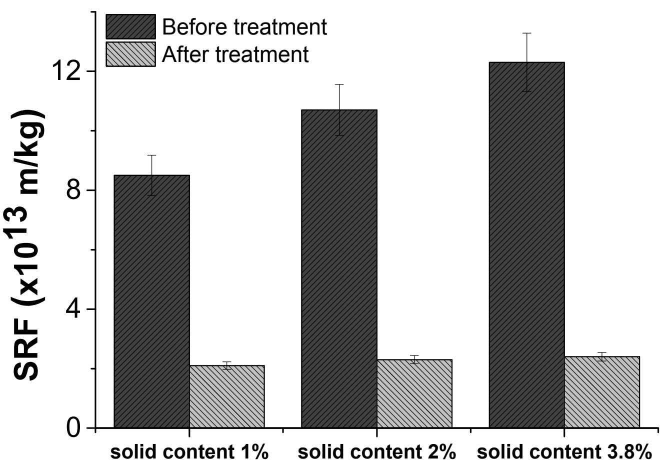

Fig. 3 Effect of different sludge solids content on the SRF of the sludge after treatment with *A. ferrooxidans* and *A. thiooxidans* (AF+AT)

increase in sludge solids content (Fig. 3). After bioleaching, the SRF of the treatment with solids content of 1, 2 and 3.8% decreased sharply by 75, 78 and 80%, respectively, and the final SRF values of all treatments with different solid contents did not show any significant difference. The moisture contents of the dewatered sludge after bioleaching were 77, 73 and 72% for the sludge having solids content of 1, 2 and 3.8% respectively. The decrease in moisture content suggested the effectiveness of bioleaching. In all the three cases, bio-oxidation of Fe^{2+} is likely the major reason responsible for the improved dewaterability. Ferric iron is well known to play a crucial role in flocculation, sludge settling, and dewaterability as it can strongly adsorb onto sludge EPS (Bezawada *et al*. 2013, Yang and Li 2009). The strong affinity of Fe^{3+} to the EPS could result in charge neutralization and densely aggregated flocs. The decreases in SRF may result from coagulation effects of ferric and ferrous ions in the acidified sludge and also the bio-oxidation of S^0. Ferric ion can absorb onto the negatively charged sludge granules and consequently facilitate aggregation of sludge granules through charge neutralization, adsorption bridging and precipitation.

3.4 Effect of solids content of sludge on supernatant retrieval

In real plant scale at a wastewater treatment plant, the pretreated sludge is subjected to mechanical centrifugation to recover the effluent. In the current study, to investigate the change in volume of supernatant during bioleaching process, the bioleached sludge was centrifuged at 4000 rpm for 3 min and the separated supernatant was measured. The volume of supernatant was increased as the bioleaching process progressed. As solids content of the sludge was increased, the supernatant volume was also increased. There were 3, 8 and 18% increase in the supernatant volume with sludge solids content of 1, 2 and 3.8% respectively as compared to the untreated sludge. The supernatant volume increased with an increase in the time of bioleaching process.

The sludge before and after bioleaching was kept in a measuring cylinder statically and the supernatant volume was monitored for 24 h, to check the settling rate. It is obvious that the sludge with low solids content can release the bound water molecules associated with sludge particles

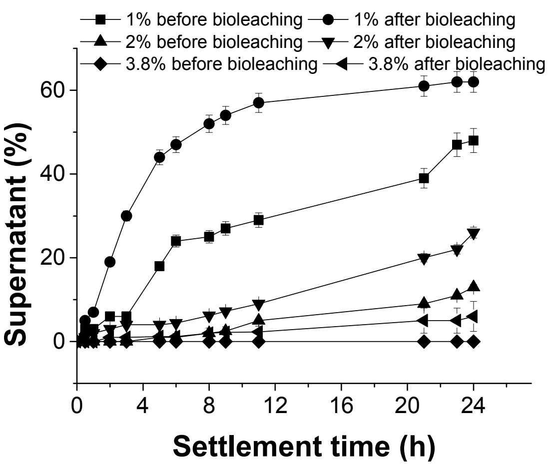

Fig. 4 Effect of different sludge solids content on supernatant removal after treatment with *A. ferrooxidans* and *A. thiooxidans* (AF+AT)

quite easily than the sludge with higher solids content. As shown in Fig. 4, the quantity of the supernatant was higher in case of sludge with low solids content. Bioleaching of the sludge improved the settling rate of the sludge and ultimately improved the effluent retrieval.

4. Conclusions

During the three days of bioleaching, the different solids content of sludge did not show any significant effect on the final bioacidification of sludge or bio-oxidation of Fe^{2+}. As the solids content of the sludge increased, the dewaterability of the sludge was affected, with a lower SRF in sludge with lower solids content indicating a better dewaterability. Due to bound water release, the effluent retrieval and sludge settling rate were increased after bioleaching.

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