A comparison of ultrasound treatment on primary and secondary sludges

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Abstract Ultrasound treatment of primary and secondary sludges was conducted to improve the qualities of sludges for the anaerobic digestion. The impacts of different sonication times, sonication densities and solids concentrations on ultrasonication efficiency were examined. The experimental results indicated that the significant reduction in particle size and increase in soluble organics could be achieved, implying that ultrasonication could offer a feasible treatment method to efficiently disintegrate sludge. The greater decrease in particle size and increase in soluble organics of sludge indicated that the secondary sludge has a more remarkable improvement after sonication over the primary sludge. With respects to the extent of disintegration and energy consumption, higher sonication density performed more effectively in terms of specific energy. There exists an optimal solids concentration range for both the sludges for optimum sonication. Within the optimal solids concentration range, efficient sonication can be effected and sludge would be disintegrated efficiently. The ultrasound would be attenuated by scattering and absorption if the solids concentration exceeds the optimal range. It appeared from the study that the mechanical shear forces caused by ultrasonic cavitation could be a key factor for sludge disintegration and collapse of cavitation bubbles could significantly alter the sludge characteristics.

Keywords Anaerobic digestion; cavitation; disintegration; primary and secondary sludge; ultrasound

Introduction

Anaerobic digestion is the most commonly applied process for stabilization of sewage sludge. The process is more beneficial among several sludge stabilization methods, because it has the ability to produce a net energy gain in the form of methane gas leading to cost-effectiveness. Due to the rate limiting step of hydrolysis, however, anaerobic digestion is a very slow process and large fermenters are necessary. The rate-limiting process of hydrolysis is the first step of anaerobic digestion (Neis *et al*., 2000). Enhanced performance of the anaerobic process could be achieved by finding a pretreatment to accelerate the slow and rate-determining hydrolysis (Eastman and Ferguson, 1981). Comparing with other pretreatment methods, ultrasonication exhibits a great potential of not being hazardous to the environment and economically competitive (Tiehm *et al*., 1997). Ultrasonic disintegration is a well known method for the break-up of microbial cells to release intracellular materials

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(Harrison, 1991). In the sonication stage, some portion of the insoluble particulate organic matter could be transformed into a soluble state (Jorand *et al*., 1995; Chiu *et al*., 1997). The subsequent anaerobic digestion of the ultrasonically disrupted sludge could be improved that is vital to the plant (Onyeche, 2002).

Ultrasonication is an energy intensive process, the cost-effectiveness of this technique is of a concern to the wastewater treatment industry. Two kinds of sludges are produced tremendously everyday in biological wastewater treatment worldwide. The primary sludge generally comes from the settling of easily settleable solids and the secondary sludge comes from the biomass after biological treatment. Secondary sludge is particularly troublesome to stabilize, for its difficulty in dewatering and digestion. This study was done (i) to compare the sonication efficiencies of primary sludge and secondary sludge; (ii) to investigate the optimal sonication density for both sludges with respect to disintegration and energy consumption; (iii) to study the optimal solids concentration of both sludges for sonication.

Methods

Sludge samples were collected from a Water Reclamation Plant in Singapore treating municipal wastewater. The primary sludge, consisting predominantly readily settleable solids of the raw wastewater, was collected from the primary clarifier. The secondary sludge was obtained from a sampling point after the activated sludge treatment and thickening. Sonication treatment was conducted with an ultrasound reactor equipped with a probe transducer (Autotune Series, Sigma Chemical Co. USA). The frequency was 20 kHz and the maximum power output was 200 W. In the pretreatment of ultrasonication, 50 ml of sludge sample was placed in a beaker with the probe placed in at the middle of the batch sample, which was at about 2 cm above the beaker bottom (Figure 1). Particle size and soluble chemical oxygen demand (SCOD) were measured as marker analysis for both sludges. The effects of sonication at different sonication times ranging from 0.5 min to 20 min were investigated. The ultrasound densities of 2 W/ml, 3 W/ml and 4 W/ml were examined to both sludges and the different solids concentrations, ranging from 0.98% to 3.75% total solids (TS) were also evaluated.

Results and discussion

The properties of primary sludge and secondary sludge are listed in Table 1. The results showed that both sludge samples were of low SCOD/TCOD before sonication, indicating large proportion of COD originated from solids. High VS/TS range of 75%–79% indicated

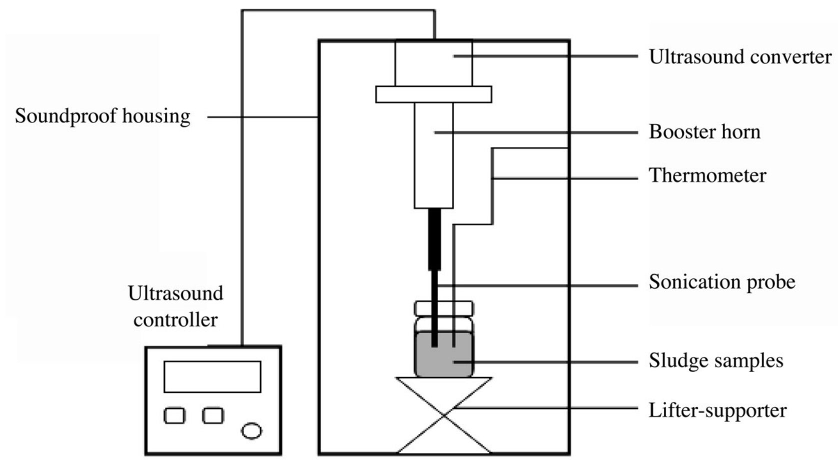


Figure 1 Schematic diagram of ultrasound pretreatment

Table 1 Properties of sludge

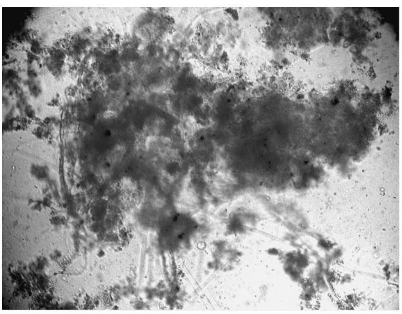
Properties	Primary sludge	Secondary sludge
SCOD (mg/L)	1,000–1,500	500–700
TCOD (mg/L)	14,000–17,500	12,500–18,000
SCOD/TCOD	0.05–0.09	0.03–0.06
ORP (mV)	(–264)–(–288)	(–274)–(–297)
pH	6.1–6.5	6.2–6.6
VS/TS (%)	76.4–78.6	77.3–82.6
Mean particle size (μm)	47.17–53.35	45.59–50.44

a high amount of organic matter present in the sludge. All sludge samples were found to have a low average oxidation-reduction potential of less than –206 mV, indicating a low ability to sanitize. The sludge had an average pH ranging from 6.1 to 6.6. It should be noted that secondary sludge had a lower soluble COD concentration and a higher VS/TS than the primary sludge. The mean particle size of primary sludge was slightly larger than the secondary sludge. Under microscopic examination (Figure 2), larger amounts of filamentous bacteria flocs were observed in secondary sludge.

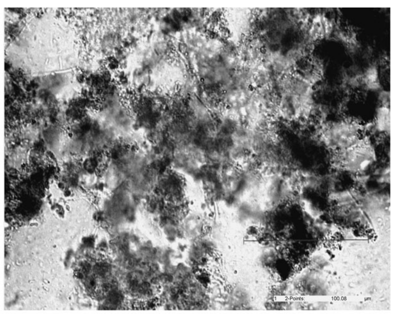
Effects of sonication time

Particle size. Particle size reduction was one of the most significant effects of sludge after sonication. The particle size decreased sharply as soon as the sonication was employed (Figure 3). The reduction of particle size reflected that sludge cells were broken up and free substances were released, which offers better conditions for the subsequent digestion. The secondary sludge decreased by as much as 85% after 20 min of sonication, while the primary sludge decreased by a lower 71% at particle size. Hence, ultrasonication offered better disintegration on the secondary sludge than the primary sludge in terms of particle size reduction. Figure 2 also shows that ultrasonication could reduce the particle size most effectively within the first 5 minutes. After these initial sonication periods, further sonication has little contribution to particle size reduction.

SCOD. Soluble organics measured as SCOD, which was chosen as the marker analysis, had been used by a number of workers as a measure of the organics availability in sludges. The higher concentration of SCOD is in sludge, the better efficiency of the subsequent anaerobic digestion is expected. The result of the SCOD measurement is presented in Figure 4. The SCOD of primary sludge increased from 1,020 mg/L to 3,980 mg/L, by 4 times after 20 min of sonication at 4 W/ml, while the SCOD of secondary sludge increased from 670 mg/L to 5,260 mg/L, by 7.7 times. The relationship between SCOD and sonication time



(a) Primary sludge



(b) Secondary sludge

Figure 2 Microscopic photographs of sludge at a magnification of 1,000×

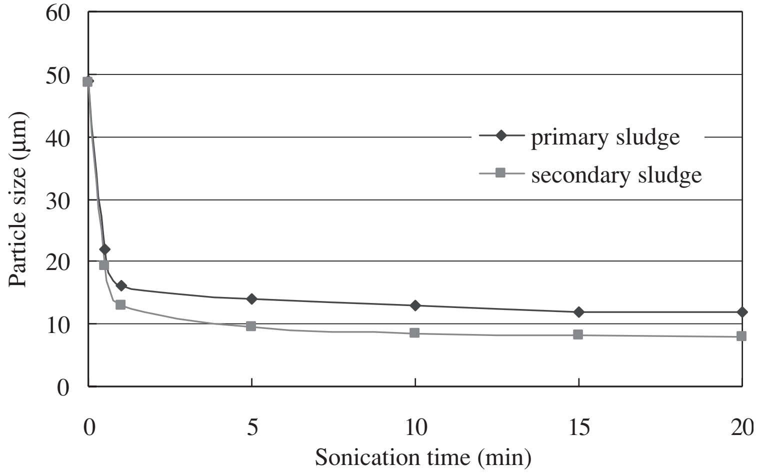


Figure 3 The particle size reduction of primary and secondary sludge (3 W/ml)

was linear with good correlations exceeding 0.97. The results indicated a better performance of sonication treatment on secondary sludge in which sonication could transform more organics into soluble form. The result of greater decrease in particle size of secondary sludge than primary sludge discussed previously could also explain the higher increase in SCOD of the former than the latter, since the SCOD increase was mainly attributed to the break-up of microbial cells leading to the release of intracellular materials.

Effects of ultrasound density

Ultrasound can be applied at a range of densities. In order to express the relationship of disintegration degree and the net energy consumption, specific energy (kWh/kg DS) was employed to compare the efficiency at different densities. The examination of density effects for this was determined by measurements of particle size and soluble COD of the primary and secondary sludges.

Particle size. Figures 5 and 6 show clearly the extent of particle size reduction of the primary and secondary sludges at different sonication times and ultrasound densities. Within the experimental range tested, sonication could result in smaller particle size of both

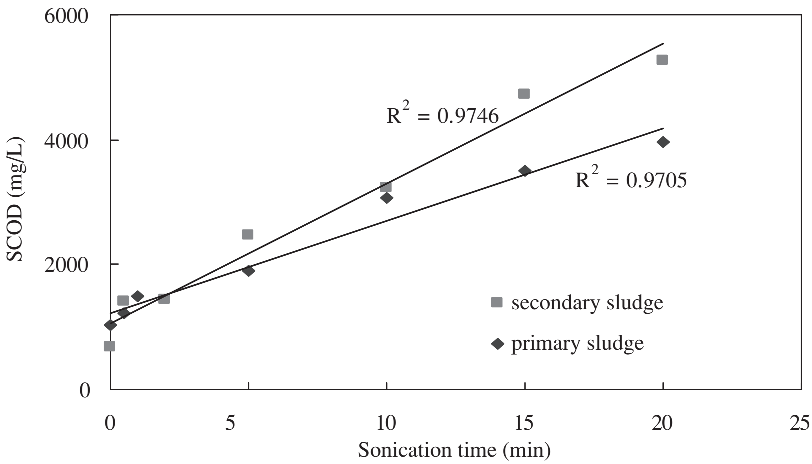
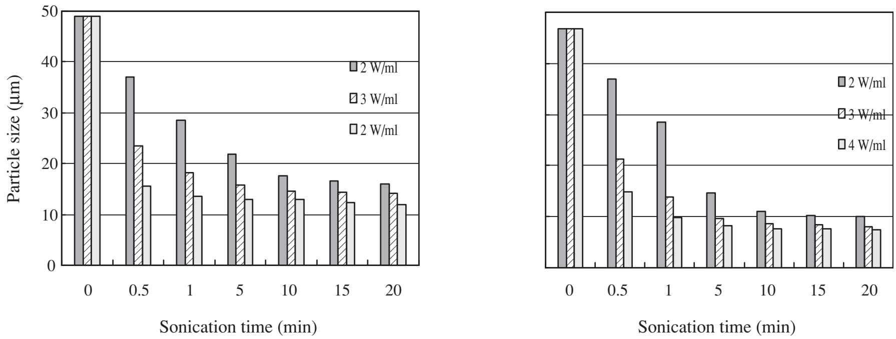


Figure 4 SCOD increase of primary and secondary sludge (3 W/ml)

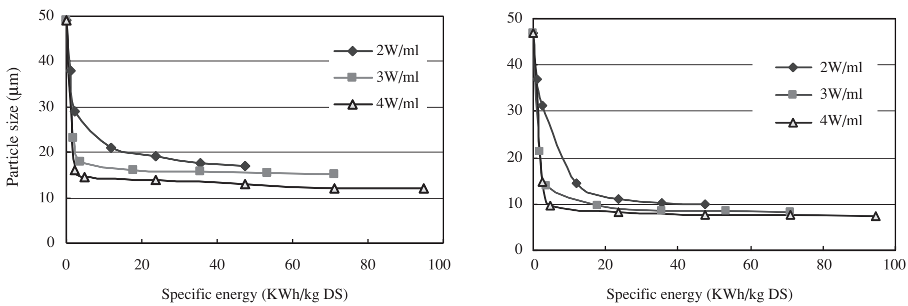


(a) Primary sludge (b) Secondary sludge

Figure 5 Effects of particle size reduction at different ultrasound densities

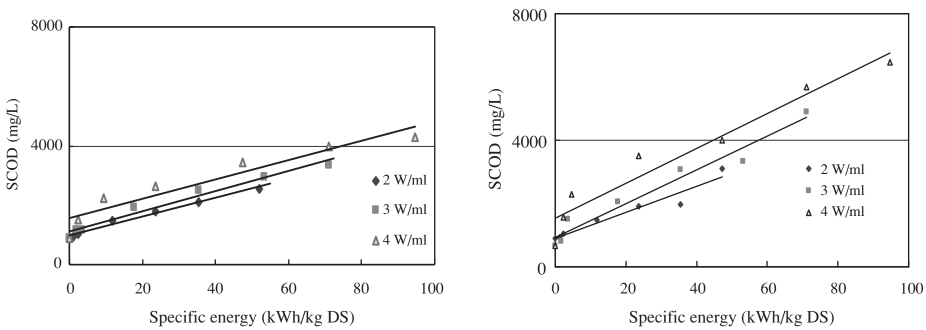
sludges at higher ultrasound density. More complete disintegration can be obtained at higher ultrasound density level. Interestingly, energy input at higher density was found more effective on the treatment of both primary and secondary sludges (Figure 6). For example, when specific energy of 20 kWh/kg was applied, sonication can reduce the particle size of primary sludge by 73% at 4 W/ml, but by a lower 60% at 2 W/ml.

SCOD. The results of the SCOD corresponded well to the results of particle size, which indicated that higher sonication densities had better performance on both sludges. The results were shown in Figure 7. At the same specific energy, for example, of 40 kWh/kg DS, the soluble COD of secondary sludge increased by 1.3 times, 2.3 times and 4.8 times at 2 W/ml, 3 W/ml and 4 W/ml, respectively. It revealed that ultrasonication could transform more COD into the soluble form at higher density condition, with 4W/ml as the most effective within the tested density range.



(a) Primary sludge (b) Secondary sludge

Figure 6 Effects of specific energy on particle size at different ultrasound densities



(a) Primary sludge (b) Secondary sludge

Figure 7 Effects of specific energy on SCOD at different ultrasound densities

Effects of solids concentration

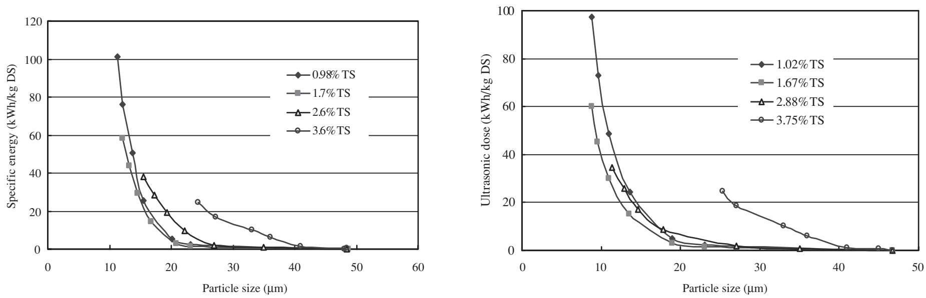
Sludge solids concentration can influence the disintegration efficiency. A suitable concentration range of particles is required for sonication to work well in a liquid-solid system. When the solids concentration is too low, the number of sites available for the formation of cavitation bubbles will be limited. On the other hand, when the solids concentration is too high, the attenuation of the ultrasound energy will limit the treatment performance.

From Figure 8, the ultrasound disintegration performed well at the solids concentrations ranging from 0.98 to 2.88%. When the solids contents increased to 3.6% for the primary sludge and 3.75% for the secondary sludge, ultrasound treatment appeared to be less effective in terms of specific energy.

From the examination of SCOD (Figure 9), the larger SCOD increases for sludge were noted in the TS range of 0.98%–2.6% for the primary sludge, and 1.02%–2.88% for the secondary sludge. It appeared that, at a higher solids content of 3.6% in the primary sludge and 3.75% in the secondary sludge, the growing attenuation effect would weaken the sonication, which caused inferiority in transforming the solids into soluble form.

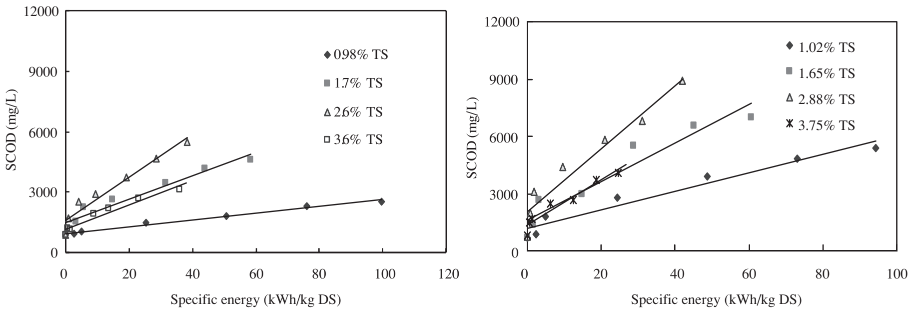
Conclusions

This study examined the effects of ultrasound treatment on the primary and secondary sludges. Experimental results showed that ultrasound treatment could improve the characteristics of sludge by the reduction of particle size and increase of soluble COD. Ultrasonication has a better performance on the secondary sludge than the primary sludge, as more significant disintegration could be effected through the sonication treatment. Ultrasound treatment could be influenced by sonication density and solids concentration. The higher the sonication power employed, the more sludge particles are ruptured and the more completely the structure is deteriorated. A higher ultrasound density required less



(a) Primary sludge (b) Secondary sludge

Figure 8 Specific energy vs particle size reduction at different solids concentrations



(a) Primary sludge (b) Secondary sludge

Figure 9 Specific energy vs SCOD increase at different solids concentrations specific energy to derive a better sonication treatment. There exists an optimal solids concentration range in both the sludges for optimum sonication. Within the optimal solids concentration, efficient sonication can be effected and sludge would be disintegrated efficiently. The ultrasound would be attenuated by scattering and absorption if the solids concentration exceeded the optimal range. It appeared from the study that the mechanical shear forces caused by ultrasonic cavitation may be the dominant factor for the disintegration enhancement. The collapse of cavitation bubbles could significantly modify the characteristics of sludge. Further study is being carried out to verify the hypothesis.

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