Pretreatment of Primary Sludge Prior to Anaerobic Digestion

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ABSTRACT

The efficacy of ultrasonication as a pretreatment process for wastewater sludge prior to anaerobic digestion is evaluated with respect to the extent of sludge solubilization, particle size distribution, biogas production, and protein degradation. Primary sludge from municipal wastewater was treated with different ultrasonic intensities varying sonication time. Results show that SCOD/TCOD ratio, volatile fatty acids, ammonia, soluble protein, and gas production increased with sonication time at a constant frequency, while lipid, total protein and particle size of the sludge decrease with sonication time.

Key Words: Anaerobic digestion, ultrasonication, particle size distribution, sludge pretreatment, gas production.

INTRODUCTION

Anaerobic digestion, which is the most widely used sludge stabilization process worldwide, utilizes anaerobic bacteria to break down about 40-50% of the organic matter of the sludge to form valuable biogas (methane) and to reduce pathogen content of the sludge prior to disposal. Anaerobic degradation of particulate material and macromolecules is considered to follow a sequence of four steps: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. In the case of sewage sludge digestion, the biological hydrolysis has been identified as the rate-limiting step (Eastman and Ferguson, 1981; Shimizu et al., 1993), causing large residence times in the fermenters. Pretreatment of sewage sludge by mechanical, chemical, or thermal disintegration methods can improve the subsequent anaerobic digestion (Chiu et al., 1997; Doha´nyos et al., 1997; Hiraoka et al., 1984; Mueller et al., 1998). However, there is a lack of information as to

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how different types of sludge disintegration can impact the sludge parameters and subsequent changes in the digestion process, since most work has only focused on the solubilization aspect of pretreatment techniques.

Ultrasonication, an advanced oxidation process is a well-known method for the break-up of microbial cells to extract intracellular material (Harrison, 1991). When the ultrasound wave (>20 kHz) propagates in a medium such as sludge, it generates a repeating pattern of compressions and rarefactions in the medium. The rarefactions are regions of low pressure (excessively large negative pressure) in which liquid or slurry is torn apart. Micro-bubbles or cavitation bubbles are formed in the rarefaction regions. As the wave fronts propagate, micro-bubbles oscillate under the influence of positive pressure, thereby growing to an unstable size before they violently collapse. The collapsing of the bubbles often results in localized temperatures up to 5000 K and pressures up to 180 MPa (Suslick, 1990; Flint and Suslick, 1991). The sudden and violent collapse of huge numbers of micro-bubbles generates powerful hydro-mechanical shear forces in the bulk liquid surrounding the bubbles (Kuttruff, 1991). The collapsing bubbles disrupt adjacent bacterial cells by extreme shear forces, rupturing the cell wall and membranes. The localized high temperature and pressure could also assist in sludge disintegration. At high temperatures, lipids in the cytoplasmic membrane are decomposed, resulting in ruptures within the cell membrane, through which intracellular materials are released in to the aqueous phase (Wang et al., 2005). The objective of this study was to determine the effect of ultrasonication on various parameters of the sludge, examine the digestion efficiency and to the effect of different types of sludge disintegration on the anaerobic sludge stabilization process, mainly the extent of gas production.

MATERIALS AND METHOD

Experimental set-up

A lab scale ultrasonic probe was used to treat primary sludge from a municipal wastewater plant. The ultrasonic probe was supplied by Sonic and Materials (model VC-500, 500 W, and 20 kHz). The primary sludge was obtained from Adelaide municipal WWTP in London, Ontario. Figure 1 illustrates the ultrasonic process. Primary sludge was sonicated for 1, 3, 6, 15, 30, 45, 60 minutes, and for all the experiments reported in this work, the amplitude was set to 100% and the sonication pulse was set to 2 seconds on and 2 seconds off to control the temperature rise of the sludge.

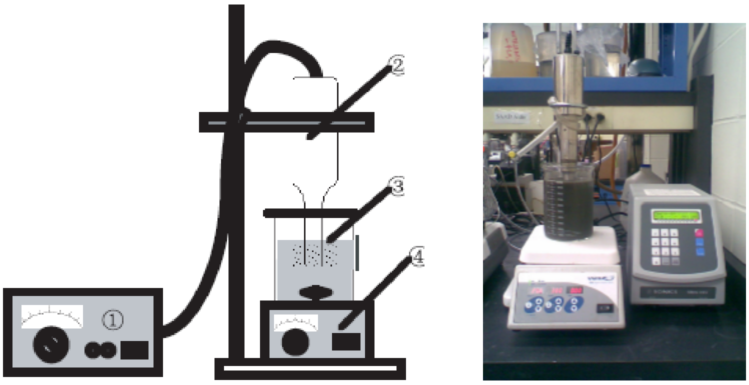

Figure 1 Schematic representation of the lab-scale ultrasonic set-up.

(1) Ultrasonic generator, (2) Ultrasonic probe, (3) 500mL Beaker with primary sludge, (4) Magnetic stirrer

Sludge parameters such as COD, TSS, VSS, volatile fatty acids (VFA), particle size distribution (PSD), lipid, ammonia and total, soluble and bound protein were monitored. The gas production was measured using batch specific methanogenic activity (SMA) to determine the efficacy of the pretreatment process. Except for soluble, bound and total protein, all other parameters were analyzed according to the Standard Methods (, Lowry's method however was used to analyze protein.

RESULTS AND DISCUSSION

Sonication Energy/Power Input:

The economy of an ultrasound system is primarily governed by the power (W or kW) or energy (J or kJ) input needed to achieve effective sludge disintegration. Thus, quantification of energy/power input to obtain a desired degree of disintegration is critical to evaluate the relative efficiency of ultrasound systems. In this study, all results are reported based on sonication time. Figure 2 displays the linear relationship between sonication energy and sonication time.

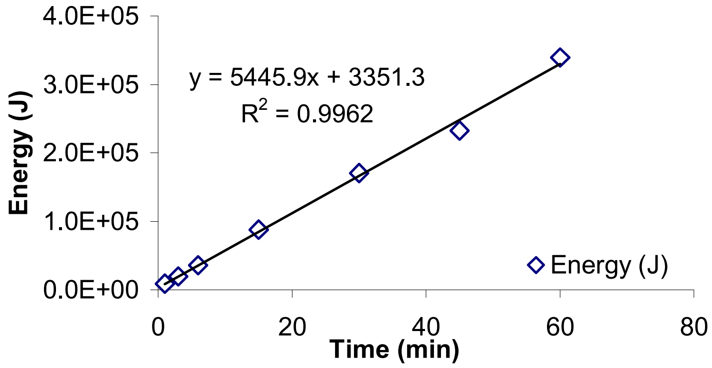

Figure 2: Sonication energy (J) as a function of time.

Chemical Oxygen Demand (COD):

The soluble chemical oxygen demand (SCOD) and total chemical oxygen demand (TCOD) as a function of sonication time are presented below. Results show that TCOD increased initially with sonication time and remained stable thereafter. SCOD, however, drastically increases due to the sonication of the organic matters. Figures 3 a, b, c illustrate the effects of sonication on TCOD, SCOD and SCOD/TCOD ratio, respectively.

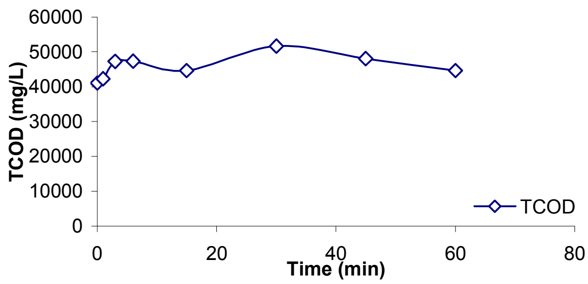

Figure 3a. TCOD as a function of sonication time

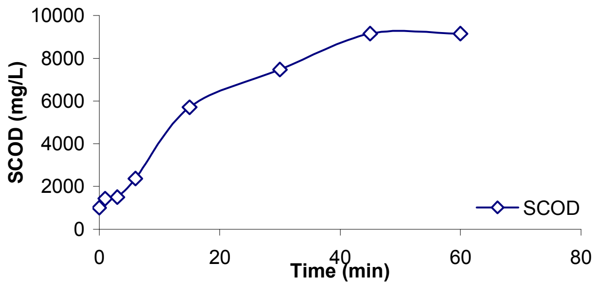

Figure 3b. SCOD as a function of sonication time

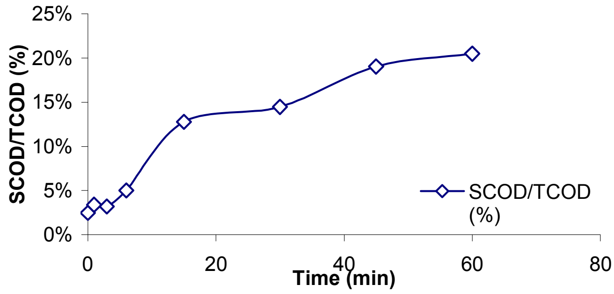

Figure 3c. SCOD/TCOD ration as a function of sonication time

The increase in SCOD/TCOD ratio is due to the release of extracellular polymeric substances (EPS), which consists of polysaccharides, proteins etc. which are embedded in the floc matrix (Drewsa et al., 2006) and disintegrated due to sonication. However, the maximum SCOD/TCOD ratio for treated sludge reached only about 20% after 45 minutes treatment, which indicated that majority of the particle matter did not solubilize with sonication.

Particle Size Distribution:

The sonicated sludge samples were analyzed using a Malvern Mastersizer laser beam diffraction granulometer. The particle size distribution by volume fraction as a function of sonication time is shown in Figure 4. The precision of measurements below 0.5 mm is low and a small number of particles exceeding 1000 mm in diameter would be present in samples, and these were ignored.

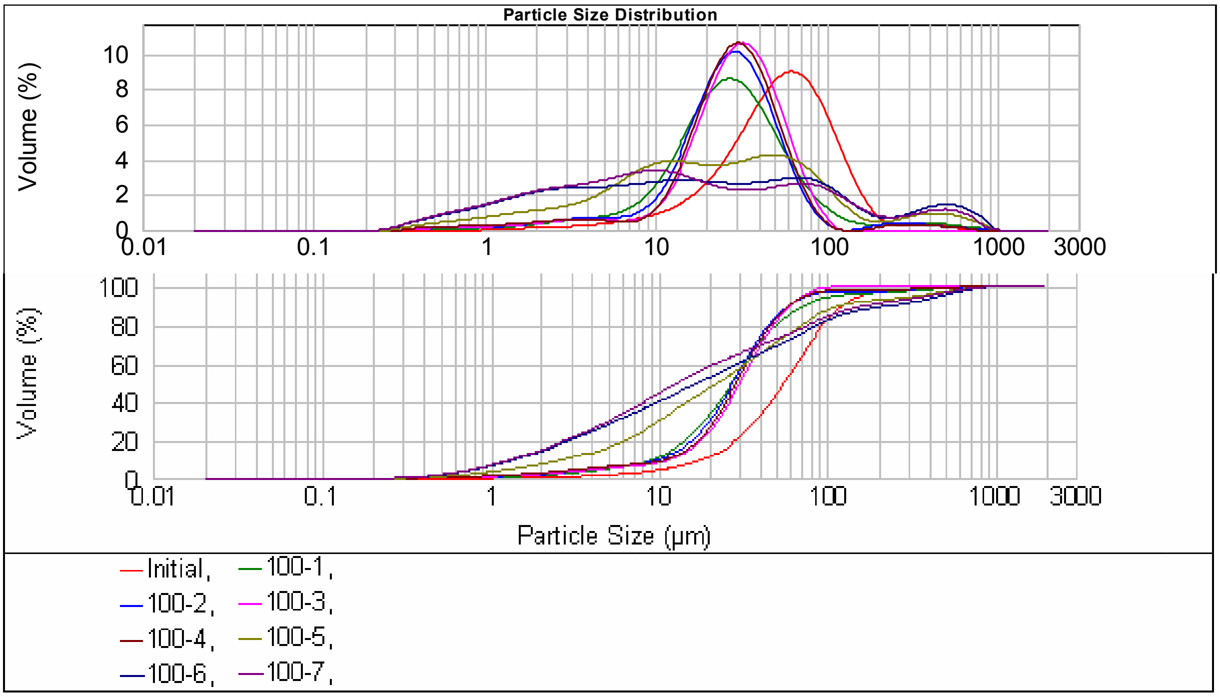

Figure 4. Top panel; particle size distribution for treated and untreated sludge. Bottom panel; the cumulative particle size distribution for treated and untreated sludge.

The cumulative distribution (bottom panel, Figure 4) shows clearly the change in particle size as the first curve from the right represents the initial untreated sludge. As sonication time increases the particle size decreases shown by the curves on the left. It is also interesting to note that sonicated time between 1 to 15 minutes seems to have no significant change in particle size; however the effect starts to show after 30 minutes.

Volatile Fatty Acids (VFA)

Volatile fatty acids are important organic substances, which are easily biodegraded by the microorganisms, and are important for the methane production in sludge digestion and helpful to phosphorus release in nutrient removal. VFA assimilation is more efficient than fermentation. Because of that, nitrates and orthophosphates removal is more effective if wastewater contained higher amount of volatile fatty acids.

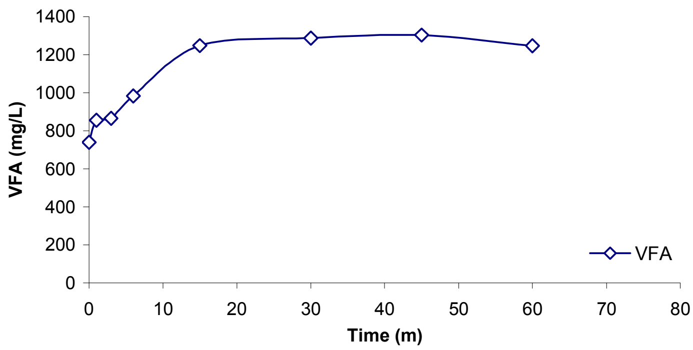

Figure 5, VFA as a function of sonication time

Figure 5 depicts VFA concentration for different sonication time; VFA distinctly increases when the treatment time was less than 20 minutes and reaches plateau after 20 minutes. However, although absolute concentration of VFA increased with sonication time, the ratio of VFA/SCOD decreased from about 0.46 to 0.15 at 20 minutes. Higher VFA/SCOD ratio is generally better for the overall performance of anaerobic digestion.

Lipids:

Figure 6 depicts lipid concentration at different sonication time. It clearly reveals that lipid concentration decreases exponentially with sonication time, and reaches a plateau only about 30 minutes of sonication. This is possible if lipid reacts with the hydroxyl radicals generated in the system due to ultrasonication, and could improve the performance of anaerobic digestion as lipids are difficult to break down in an aerobic digestion.

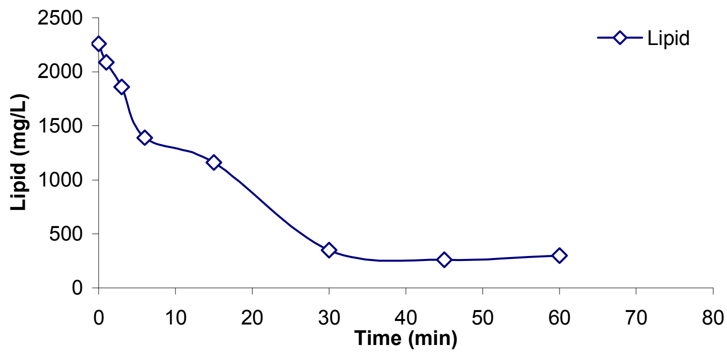

Figure 6. Lipid concentration with sonication time

Total Suspended Solids (TSS) and Volatile Suspended Solids (VSS):

Figure 7 a, b illustrates the TSS and VSS amount as a function of sonication time. A slight decrease in the values of the TSS and VSS can be noticed, this decrease is also possible due to the reaction of the organics in VSS and TSS with the hydroxyl radical reaction and also due to the dissolution of VSS to SCOD.

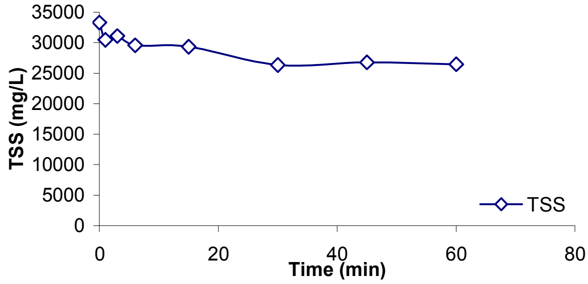

Figure 7a, TSS as a function of sonication time

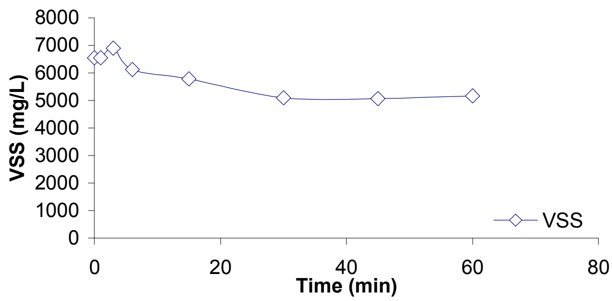

Figure 7b, VSS as a function of sonication time

Ammonia:

Ammonia concentration increases when the treatment time was less than 20 minutes and reaches a plateau after that. Figure 8 shows the ammonia concentration as a function of sonication time.

This might be due to the break down of the biomass, the limit of ammonia was not critical to cause inhibition in the anaerobic digestion.

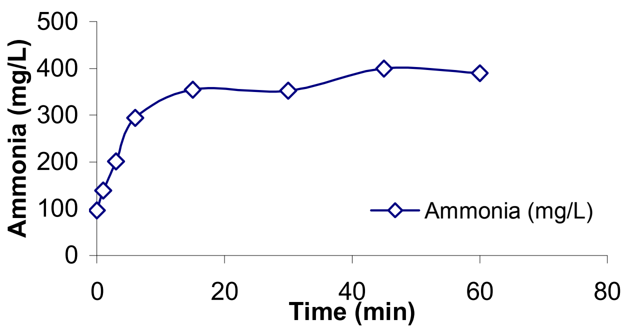

Figure 8. Ammonia as a function of sonication time

Protein:

Proteins in wastewater and sludge are generally divided into there fractions: soluble, bound/labile (loosely attached with the cells) and tightly bound fractions (within the bacterial cells). Labile proteins are thought to become readily bioavailable giving rise to higher odor potential. Total (cell + bound), soluble and bound protein were monitored in this study. The total protein was unlike the soluble protein distinctly decreased with time, while the soluble protein increased with sonication time. Due to cell rupture, total protein, which is the cellular and extracellular protein loosely bound to the cell disintegrated, some were changed into bound protein and loosely attached with the cell, and mostly were dissolved into soluble protein. It is important to say that increased soluble protein concentration increases the performance of anaerobic digestion.

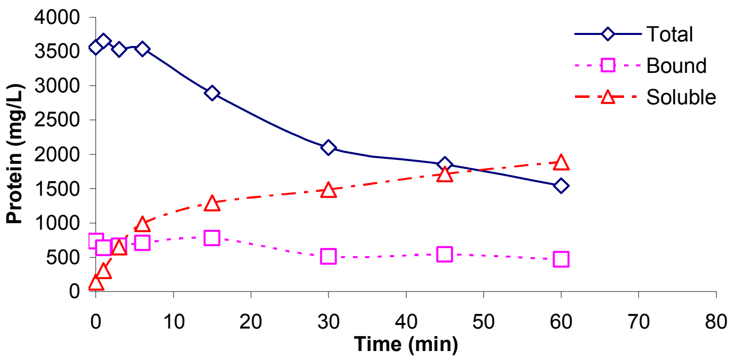

Figure 9. Total, Bound and Soluble protein as a function of sonication time

Specific Methanogenic Activity (SMA):

Anaerobic biodegradability study was conducted to determine the effect of sonication on the anaerobic gas production, specifically methane production. The sonicated sludges for different sonication time were used for SMA at 37°C, using 250 mL bottle capped with Teflon septum. 50 mL anaerobic seed and 50 mL treated primary sludge were added together into the bottles. All the bottles were sealed after purging the headspace with nitrogen to eliminate the present of oxygen/air. The experiment was continued until the bottles stopped producing biogas. Daily biogas was measured by inserting needle attached to a syringe (100 mL and 20 mL). Methane composition was measured by Gas Chromatography (GC) SRI 310C with a packed column.

Figure 10, displays the percent gas produced from the untreated batch and the seven treated samples, and Figure 11 exhibits the volume of methane produced from the untreated batch and the seven treated samples. The experiment was stopped after 17 days due to the lack of gas production.

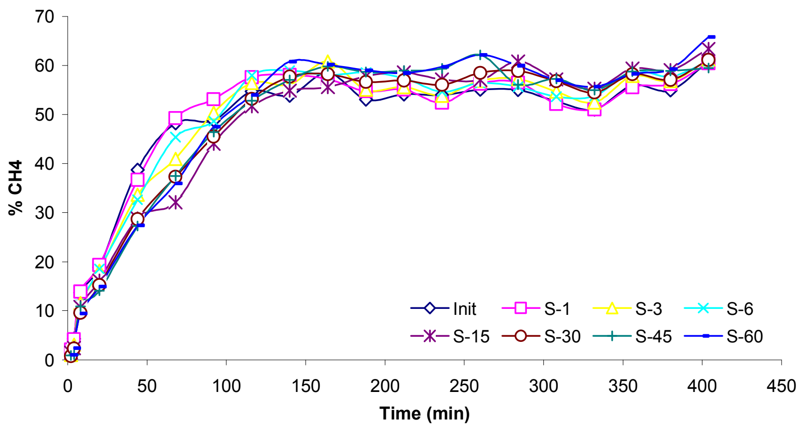

Figure 10. Percentage of methane production for initial and sonicated samples for 17 days

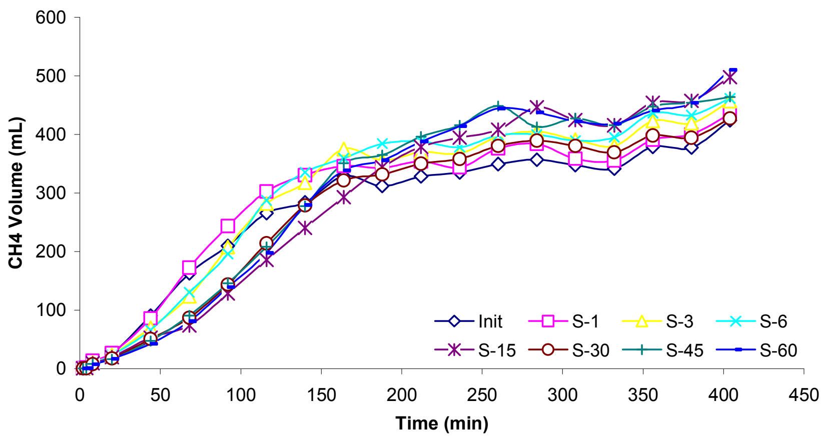

Figure 11. Volume of methane production for initial and sonicated samples for 17 days

Assessing the figures above, percentage methane produced seems to be fluctuating between 54% and 65% for treated and non treated samples after 100 minutes, and there is no clear advantage in sonication in the sludge. However, the volume of gas production seems to have an interesting pattern, the initial rate of gas seems to be high at low sonication time and decreases with sonication time, however, final gas produced seems to higher as sonication time increases, which needs to be further investigated.

CONCLUSIONS

The ultrasonic disintegration was used as pre-treatment for primary sludge obtained from municipal wastewater plant, London Ontario. The important parameters for better performance in anaerobic digestion such as SCOD, VFA and soluble protein increased due to ultrasonication, whereas particle size and lipid concentration decreased with sonication indicating good solubilization of particulates and larger molecules due to sonication. The final gas production also increased with sonication time, although initial rate of gas production was lower for the sonicated sludge.

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