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IMPROVEMENT OF ANAEROBIC DIGESTION RATE OF BIOSOLIDS IN WASTE ACTIVATED SLUDGE(WAS) BY ULTRASONIC PRETREATMENT

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Abstract : The ultrasonics is a new technology in waste activated sludge(WAS) treatment. Ultrasonic treatment is well known method for the break up of microbial cells to extract out a variety of intercellular materials inside microorganism cell. This study was done to investigate the effects of the ultrasonic frequency and power on disruption of biosolids in WAS and to examine the effect on methane production of WAS treated by ultrasonics. Biosolids disruption with ultrasound is more effective at ultrasonic frequency of 40 kHz and power of 0.3 watt/mL. In the digestion with WAS pretreated by sonication time for 10 minute at 40 kHz and 0.3 watt/mL, the total quantity of generated methane increased by 75%, as compared with experimental control(non-treatment).

Key Words : Waste activated sludge, Ultrasonic treatment, Anaerobic digestion, Sludge disruption, Biogas

INTRODUCTION

The anaerobic stabilization is a slow process. Therefore, long residence times in the reactors and large reactors volume are required. Anaerobic degradation of particulate material and macromolecules is considered to be hydrolysis, acidogenesis, acetogenesis and methanogenesis. In case of sewage sludge digestion, hydrolysis has been considered to be the rate-limiting stage in the overall anaerobic digestion process.[1]

Therefore, the treatment of sewage sludge such as mechanical, chemical and thermal disruption was well known to improve hydrolysis rates of sewage sludge.[2] These treatment caused breakdown of the cell wall and membrane of bacteria in sewage sludge and resulted in release of organics to the outside of the cell. These organic substances are hydrolyzed easily to biodegradable organic materials through extracellular enzymes of anaerobic bacteria. Therefore, these results are improved anaerobic digestion rates. Treatment methods to increase these hydrolytic rates are ultrasonic lysis, thermal process by autoclave, heat treatment through hot water and freezing process.[3]

Ultrasonic lysis was well known method for the disruption of microbial cells to extract out intercellular materials.[4] The impact of ultrasonic waves on liquid causes the periodical contraction and swelling of the medium, which occurs in the cavitation above a certain intensive strength. When gas bubbles are created, it is gradually grown in size before violently collapsing within a microseconds. Violent collapse forms the very powerful hydromechanical shear forces in the bulk liquid surrounding the bubble. It has been shown that macromolecules with a molar mass more than 40,000 are disrupted by ultrasonic

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cavitation. The mechanical forces are most effective at frequencies less than 100 kHz.[5] When bubbles are collapsed, the temperature and pressure inside bubble rises up to about 5,000 K and several hundreds at atmospheres. These extreme conditions lead to the thermal destruction of compounds in the cavitation bubbles.[6]

This study was performed to investigate the effects of the ultrasonic frequencies and power on disruption of biosolids in WAS. Also the effect on methane generation applying the WAS was examined after ultrasonic pretreatment to anaerobic digestion.

MATERIALS and METHODS

Examination of Biosolids Disruption in WAS

The experiment was done with WAS obtained from the Daejeon municipal sewage treatment plant. WAS was stored to the refrigerator of 4℃ before use for preventing deterioration. Table 1 was shown the composition of WAS used in experiment.

Table 1. The composition of the waste activated sludge used in experiment

Items	Value
Sludge concentration (%)	0.7-0.9
Volatile fatty acids (mg/L)	20-50
Total COD (mg/L)	6,000-9,000
Soluble COD (mg/L)	<100
pH	6-7
Alkalinity (mgCaCO$_3$/L)	100-300

Sonication was done with both ultrasonic reactors equipped with disk transducers operating at 28 and 40 kHz. The disk transducers manufactured at the KoDo Technical Research(located in Daejeon) were placed at the bottom of cylindrical reactor(Figure 1). The dimensions of reactor were internal diameter of 24cm, height of 24cm, and working volume of 10 liters. During sonication, sludge samples were mixed completely by the agitator. The ultrasonic input power was maintained 600 watt.

The biosolids disruption rates were determined at the ultrasonic reactors of 28 and 40 kHz with energy of 600 watt. Generally, ultrasonic disruption rates were determined to depend on quantity of added organic compounds and size of reactor. Also the disruption of biosolids according to ultrasonic energy was assessed. The WAS added each sample 2 and 5 liters into ultrasonic reactors. The sonication pretreatment time proceeded during 60 min. At this time, ultrasonic energy (watt/mL) was 0.12 and 0.3, respectively, at sample of 5 and 2 liters.

The degree of sludge disruption was assessed by determining the chemical oxygen demand (COD) in the sludge supernatant for sonication. A reference was defined as the aqueous phase COD obtained after sedimentation of original WAS in the cylinder beaker for 2hrs. The rate of biosolids disruption was defined as soluble organic substances concentration in the supernatant after ultrasonic pretreatment divided by the total organic substances concentration of WAS before ultrasonic pretreatment.

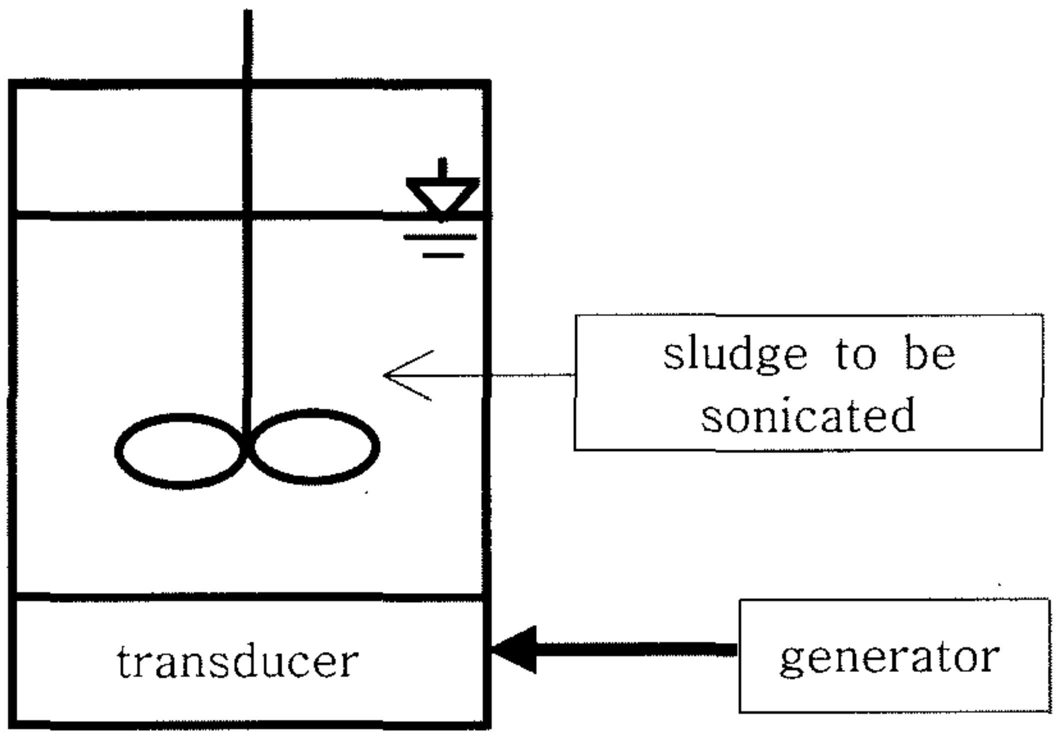

Figure 1. Schematic diagram of the ultrasound reactor.

Examination of Anaerobic Sludge Solubilization

This study was performed at the sonication pretreatment time of 10 minutes with 40 kHz and 0.3 watt/mL to assess biodegradability of biosolids in WAS for anaerobic treatment.

The anaerobic digestion of WAS was studied in laboratory scale reactor with 35℃. The reactor had the total volume of 1 liter with working volume of 0.8 liters. Seed materials were an appropriate mixture of the granular sludge(60%)

from the UASB reactor treating brewery wastewater and digested sewage sludge(40%) from the municipal sewage treatment plant.

The reactor was filled with 0.4 liters of the seed sludge and 0.4 liters of WAS pretreated by sonication. The reactor was operated for 24 days. The biogas generation was collected in calibrated glass cylinders. The cylinders were filled with acidified water with HCl to pH 0 to prevent loss of CO_2 by the formation of carbonate. During experiments, the concentration of volatile solids, biogas generation were measured each one time at the second day.

Analytical Procedures

The composition of biogas was determined by a gas chromatography(Gow-Mac model 5280) with TCD. A molecular sieve 5A and Porapak Q were connected in parallel to CH_4, N_2, CO_2 at the same time. The temperature of the column, the injector and the detector were 50, 80 and 90 ℃, respectively. Helium was used as a carrier gas at a flow of 30 mL/min.

The particle size distribution of sludge samples was determined by the laser light obscuration method based on the time-of-transition principle. Since repeated measurement of the same sludge sample exhibited significantly different results, five replicate determinations were done. Results are given as median particle size and standard deviation.

For the analysis of aqueous supernatant after sonication, the particulate sludge material was removed by centrifugation(15 min at 10,000 rpm) followed by filtration through 1.0 ㎛ pore size membrane filters.

VS and COD tests were measured according to the Standard Methods.[7]

RESULTS AND DISCUSSION

Effect of Sludge Disruption According to UltraSonic Frequencies

The effect of ultrasonic frequency on sludge disruption was investigated to find out the preferential treatment conditions. Figure 2. indicated the change of pH in WAS on ultrasonic treatment at 28 and 40 kHz. The pH was 6.8 initially but maintained between 6.7 and 6.8 during sonication of both 28 and 40 kHz. As a result, pH has a nearly constant value regardless of change of frequency.

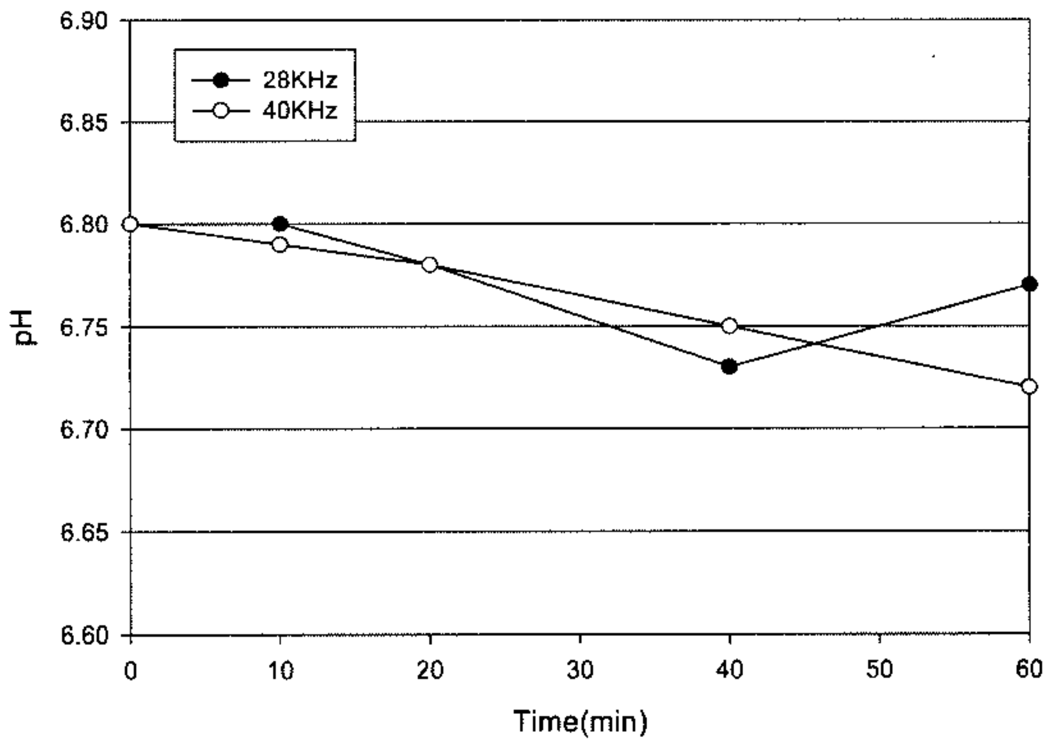

Figure 2. The changes of pH in solution for sonication of WAS.

Figure 3 indicated the changes of temperature in solution for sonication in both 28 and 40 kHz. The temperature was increased up from 17℃ at the beginning to 48℃ in 28 kHz and 71℃ in 40 kHz for 60 min. This result was explained as follows: The ultrasonic treatment occurred both reactions in liquid at the same time. Strong agitation produced explosion of small bubbles and concomitant increase of temperature in liquid. Therefore It was reported that ultrasonic treatment increased temperature and production of bubble in liquid, which greatly affected the cell' disruption of bacteria.[2]

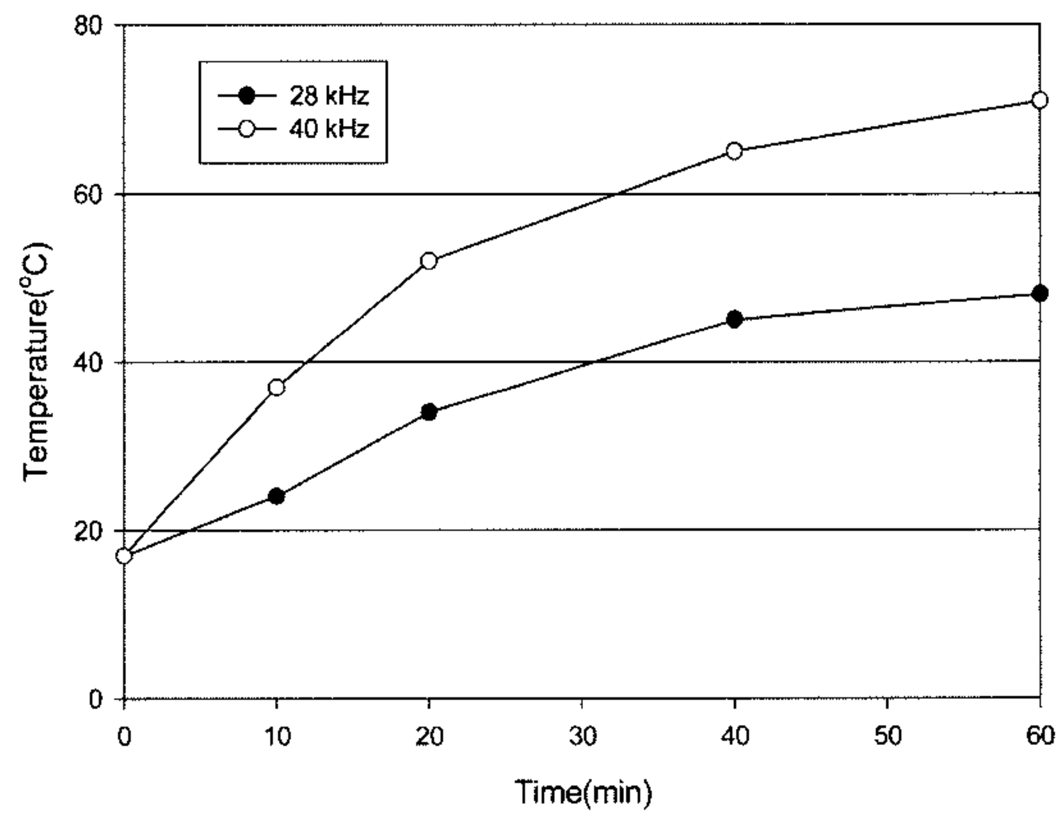

Figure 3. The change of temperature in solution for sonication.

Figure 4 shows the change of SCOD /TCOD ratio of biosolids in WAS in both frequencies. SCOD/TCOD ratio were 0.02 at the beginning. This indicates that most biosolids in WAS is composed of the particulate flocs. SCOD/TCOD ratio in 28 and 40 kHz were 0.35 and 0.67, respectively, at the end period of experiment. This phenomenon indicates that particulate biosolids in WAS are broken down into smaller pieces by increase of frequency intensity.

However, A. Tiehm[8] reported that disruption of biosolids was most effective in 41 kHz within the range of a variety of frequencies between 41 and 3,217 kHz. Generally, the cell' disruption of bacteria occurred in two cavitation phenomena as follows: powerful hydromechanical shear force and sonochemical reaction. Theoretically, hydromechanical shear forces produced by sonication are more important for sewage sludge disruption than sonochemical processes. Mark *et al*[9] reported that sonochemical process producing the radical matters was the most important at frequencies between 200 and 1000 kHz. On the other hand, it was reported that the best disruption of biosolids occurred with the lower ultrasonic frequency like 20 kHz. However, this study is shown that disruption of biosolids in WAS indicates more excellent result at frequency of 40 kHz than 28 kHz.

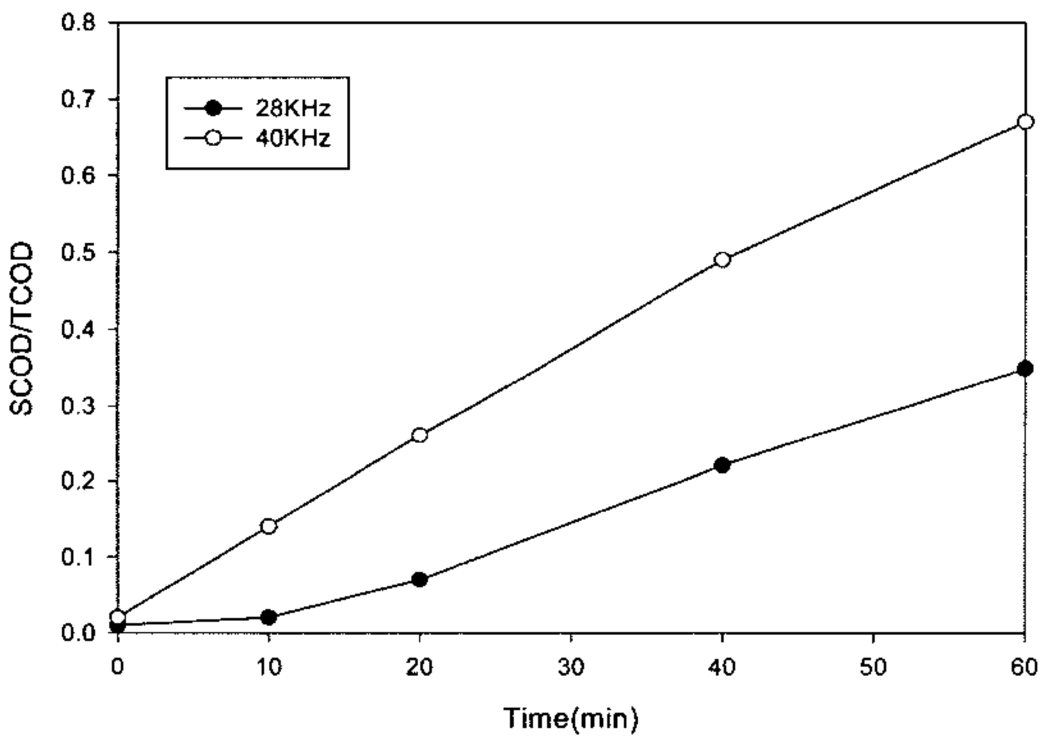

Figure 4. SCOD/TCOD ratio in solution for sonication.

Effect of Biosolids Disruption According to Ultrasonic Power at 40 kHz

Biosolids disruption rates in ultrasonic power of 0.12 and 0.3 watt/mL were 21 and 28%, respectively, at 60 minute and was 3 and 15%, respectively, at 10 minute(Figure 5). This indicates that the disruption of biosolids in WAS is more effective at the higher ultrasonic power. Especially, the disruption rate of biosolids at 0.3watt/mL was rapidly increased at sonication time of 10 minute.

Figure 6 presented the change of the mean floc size for sonication. The average diameter of control floc(non tratment) was 67㎛. The sonication reduced sharply the average diameter of flocs down to 12㎛ at 0.3 watt/mL and to 29㎛ at 0.12 watt/mL for sonication time of 10 minute, and down to 6㎛ at the end period. Taking into consideration the results presented in Figure 5 and Figure 6, Application with sonication time of 10 minute in 40 kHz and 0.3 watt/mL is expected to contribute to a higher disruption efficiency of biosolids in WAS.

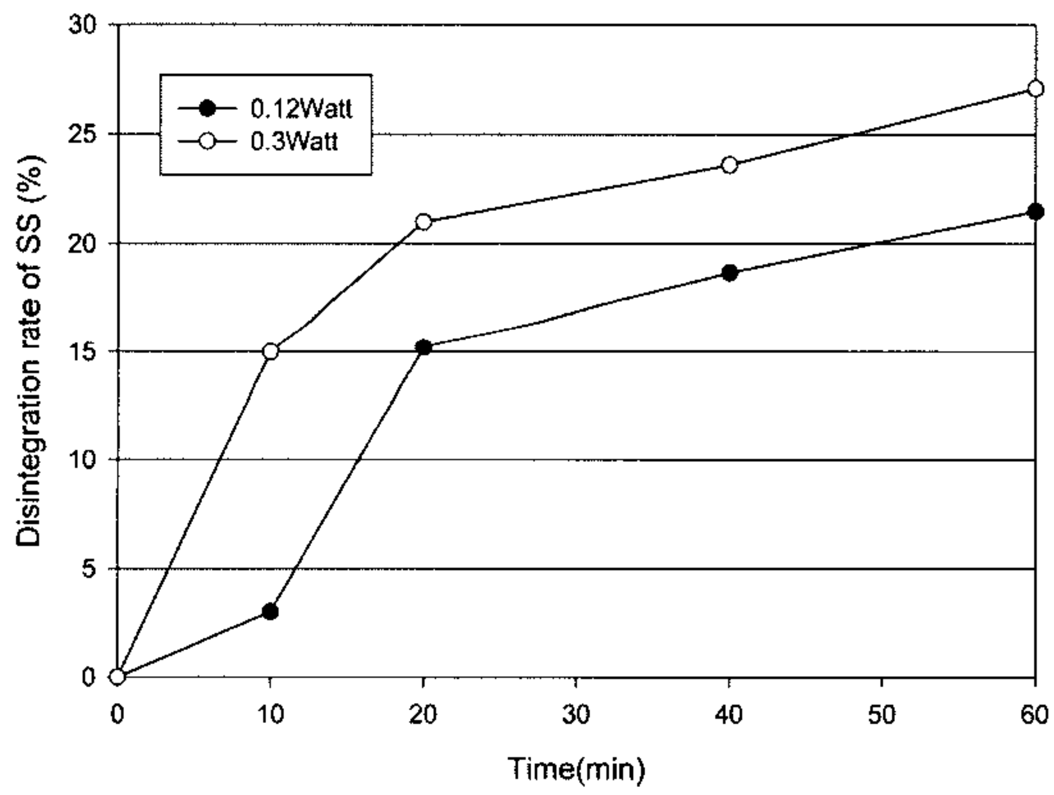

Figure 5. The change of disruption rate of biosolids at 40kHz.

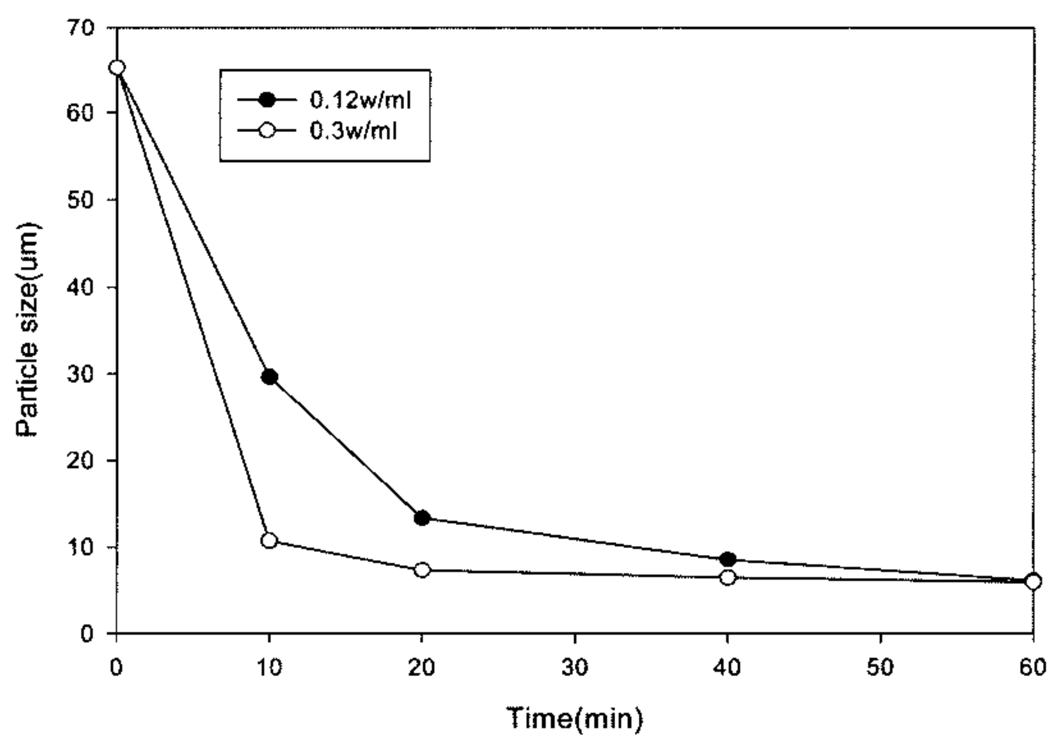

Figure 6. The distribution of particle size in WAS at 40kHz.

Anaerobic Sludge Digestion Following Ultrasonic Disintegration

For assessing biodegradability on anaerobic treatment of WAS pretreated by sonication, this study was performed at the frequency of 40 kHz and power of 0.3 watt/mL and the sonication time of 10 minute.

Figure 7. indicated the accumulated methane production for digestion of WAS. The methane generation rates in case of pretreatment for 10 minute increased with increased digestion time compared with control. A consideration increase in methane was observed for the initial 6 days. Thereafter methane generation rates gradually decreased and dropped to a very low level after the 12th day. The amount of methane production increased up to 150g CH_4/kg-DS on the 6th day and 210 CH_4/kg-DS on the 24th day after ultrasonic pretreatment. Compared with the control, the amount of methane of pretreated WAS by sonication increased 1.14 times on the 6th day and 0.75 times on the 24th day. Accordingly, it is summarized that ultrasonic treatment enhances significantly digestion rates of WAS.

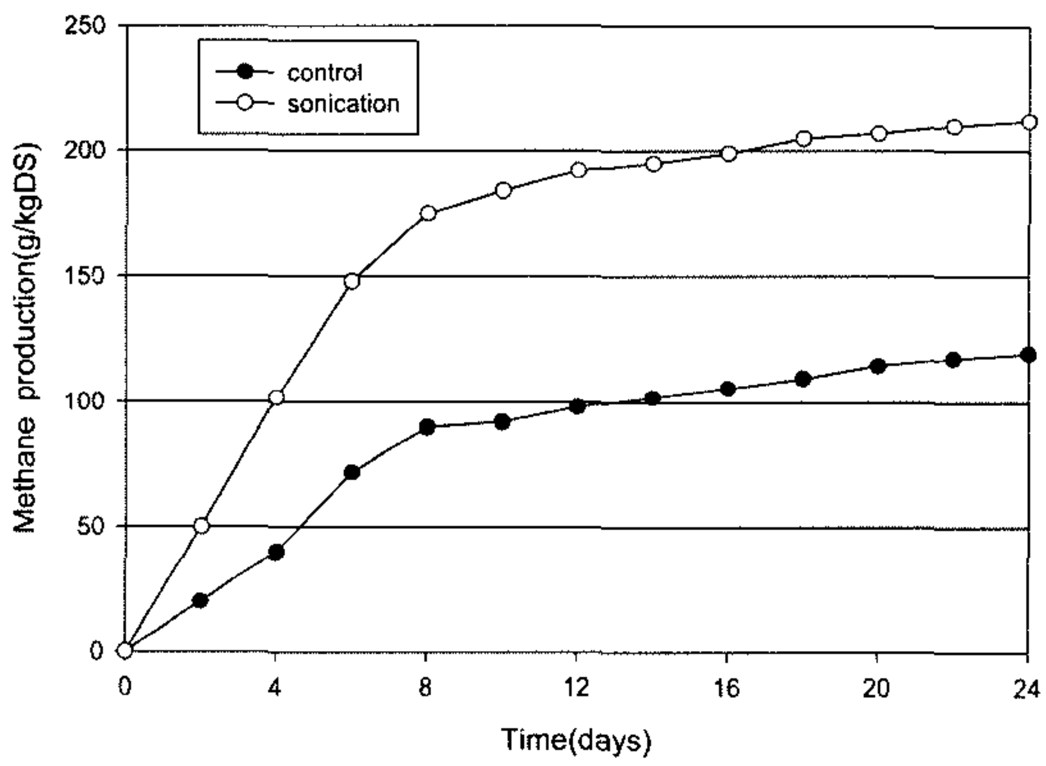

Figure 7. the change of accumulative amount of methane production for digestion.

Figure 8. presented the SCOD/TCOD ratio during digestion. The total COD concentration of control WAS of this experiment was 9,000 mg/L and SCOD/TCOD ratio was 0.04. This value increased up to 0.13 on the 6th day. on the other hand, The SCOD/TCOD ratios of sonication increased up from 0.14 to 0.28 at the same time. Also, the ratio rose rapidly during the subsequent digestion process up to 0.32 on the 8th day. This agreed with the improvement of methane production shown in Figure 7.

Thereafter the ultrasonic treatment is possible for biosolids in WAS to break down biodegradable organics more readily by the hydrolysis enzyme as shown in Figure 7. and Figure 8. Although the short sonication time for 10 minute at the ultrasonic energy with 0.3 watt/mL is insufficient to disrupt the floc interior(Figure 5), the subsequent anaerobic digestion process make a contribution to effective organics destruction.

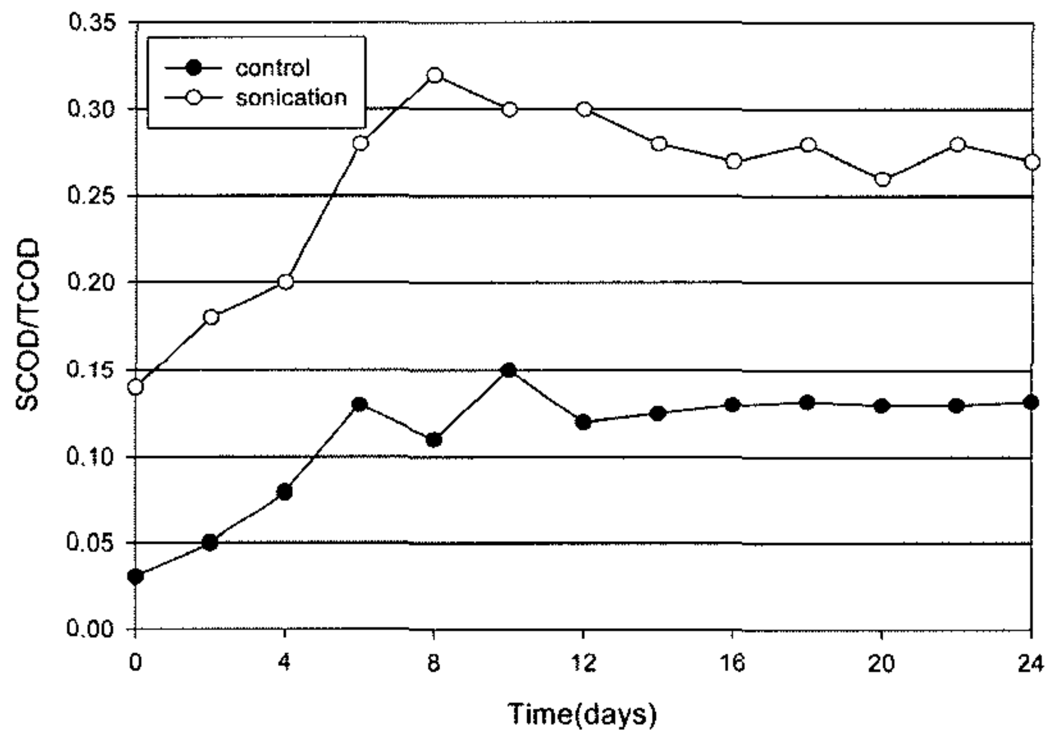

Figure 8. The change of SCOD/TCOD for digestion.

CONCLUSION

This study was performed to investigate the effects of the ultrasonic frequencies and power on disruption of biosolids in WAS. Also the effect on methane generation applying the WAS was examined after ultrasonic pretreatment to anaerobic digestion. The most important results are:

- Biosolids disruption in WAS on ultrasonic treatment is the most effective at ultrasonic frequency of 40 kHz and power of 0.3 watt/mL.
- The ultrasonic exposure of 10 minute at the 40 kHz and 0.3 watt/mL expected to make a contribution to a higher disruption efficiency of biosolids in WAS.
- Ultrasonic treatment enhances the subsequent anaerobic digestion resulting in a better degradation of volatile solids and an increase of biogas generation.

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