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Recycling of sewage sludge using microwave pretreatment and elutriated acid fermentation

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ABSTRACT

This work elucidates the effects of pretreatment on primary and secondary sludge using microwave irradiation before the application of elutriated acid fermentation (EAF) systems conducted under different temperature conditions. The EAF used water to elutriate volatile free acids generated in the fermenter which thickened the sludge generated. The results of this study focus on sludge reduction conducted under different temperatures. The SCOD production utilizing a microwave pretreatment method (MW) followed by EAF, with 35˚C after the microwave as pretreatment, and from only the EAF at 35 and 55˚C was 0.33, 0.11, and 0.22 g $SCOD_{prod.}$/g VS_{fed}. Volatile fatty acids (VFAs) production was found to be similar to that of the results of SCOD production. Coliforms and *Escherichia coli* were not detected after pretreatment with microwave irradiation for time over 5 min.

Keywords: Elutriated acid fermentation; Hydrolysis; Microwave; Recycling; Sewage sludge; VFAs

1. Introduction

According to statistics on sewage sludge from the Korean Ministry of Environment, sewage treatment plants can produce 10,130 tonnes of sludge per day. Conventional disposal methods of sewage sludge can be generally grouped into: ocean dumping, incineration, reuse, and landfill. Except in the case of reuse, all of these methods create the problem of secondary pollutants. Dumping into the ocean, incineration, and landfill are the most common methods of sludge disposal, with ocean dumping accounting for more than 70% of the sludge disposal from domestic sewage treatment. In the future, however, ocean dumping will be forbidden by an international convention [1]. As a result, reduction and reuse are essential in the implementation of the London protocol as an international regulation as well as future prohibitions on landfill use by domestic regulation subsequently, the current study regarding sewage sludge reduction and reuse is of great significance.

The concepts of hydrolysis and biodegradation in sludge stabilization are important in order to evaluate the degree of reduction and reuse of sludge. Some pretreatment techniques such as pyrolysis and ultrasonification have been examined [2,3]. Currently, the dehydration [4] and the hydrolysis of sewage sludge demonstrate good efficiencies due to their short heating time compared with convectional thermal treatment [5,6]. The destruction of germs existing in sludge

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by the combined effects of microwave irradiation and electron beams has been reported [7].

Organic sludge treatment by elutriated acid fermentation (EAF), which uses water to wash the fermented sludge for the recovery of acids and to thicken the sludge for reducing volume, is a viable process for sludge treatment. The recovered acid may be used as a carbon source in a biological nutrients removal process resulting in a low influent ratio of carbon to nitrogen concentration for improving denitrification.

This work elucidates the effects of microwave irradiation on the sewage sludge from municipal wastewater treatment plants. Volume reduction, hydrolysis, and the volatile fatty acids (VFAs) production efficiencies of the EAF process with and without prior microwave irradiation were all investigated. The destruction of germs in sewage sludge treated by semi-sequencing EAF systems was compared to the biosolids of EPA's standards for land applications (40 CFR Part 503).

2. Materials and methods

2.1. Laboratory setup

In the batch pretreatment tests, a microwave with a wave length of 12.2 cm, a frequency of 2,450 MHz, and a power capacity of 900 W irradiated three different samples of sewage sludge from a municipal wastewater treatment plant. Microwave at 2,450 MHz, and 600–1,000 Watts sludge reduction was indicated above 90% [8].

The general characteristics of the sludge are indicated in Table 1. "A" and "B" were the primary sludge samples from different wastewater treatment plants of Daegu, Korea. While "C" was secondary sludge sample which was received from C wastewater treatment plants. The semi-sequencing EAF was classified with three modes of the EAF at 35℃ after the microwave pretreatment and the EAF at 35 and 55℃ without any pretreatment, respectively. A schematic diagram of the reactor is shown in Fig. 1. The EAF process was composed of a fermenter with a working volume of 1 L, a settler of 0.5 L, and a temperature control system which is controlled at 35 and 55℃ by heater [9]. Tap water was used for the elutriating water whose flow rate is 0.27–0.29 m/h, HRT is 24 h, controlled at pH 9, and recycled to the fermenter with 0.5 L/d that was proven to enhance the hydrolysis efficiency of sludge in previous research [10].

2.2. Analytical methods

The mixed liquor from reactor was analyzed for CODcr, TS, VS, suspended solids, Volatile suspended solids, Alkalinity, TKN, NH_4^+-N, phosphorus, and analytical procedures were conducted in accordance with Standard Methods [11]. pH was monitored and controlled by using a pH meter. VFAs were analyzed by an HPLC (Shimadzu Model LC-10AD, Japan) equipped with a UV detector and an organic acid analysis column (AQUASIL C18, Thermo Hypersil-keystone, Inc.). Before analysis of VFAs the samples were centrifuged at 4,000 rpm for 15 min by centrifuge (HA-1000-3), and then were filtered through a 0.45 μm of filter paper. Microwave irradiation of primary sludge was conducted in 900 W, 2,450 MHz Q MW Oven (Canada) equipped with rotating platform and microwave intensity control. The dimensions are 297 mm H × 518 mm W × 385 mm D. Biogas production was determined by gas chromatography (Tremetrics Model 9000, USA).

3. Results and discussion

3.1. Hydrolysis with microwave irradiation

Fig. 2 shows the variation in the hydrolysis efficiencies of microwave irradiation with an irradiation time of 1–15 min. The hydrolysis efficiency was calculated as follows:

Table 1
Characteristics of sewage sludge

	Batch test by microwave			Semi-sequencing	
Parameter	A	B	C	Primary sludge	Primary sludge with MW
pH	6.0	7.2	6.7	6.0	6.2
TCODcr (mg/L)	25,300	32,402	7,330	23,650	25,110
SCODcr (mg/L)	1,762	1,080	10.8	2,320	4,140
TS (mg/L)	15,110	30,450	5,720	17,770	19,100
VS (mg/L)	12,010	17,650	4,830	13,200	14,040
VS/TS (%)	0.79	0.58	0.84	0.74	0.74
VFAs (mg/L)	–	–	–	1,204	3,650

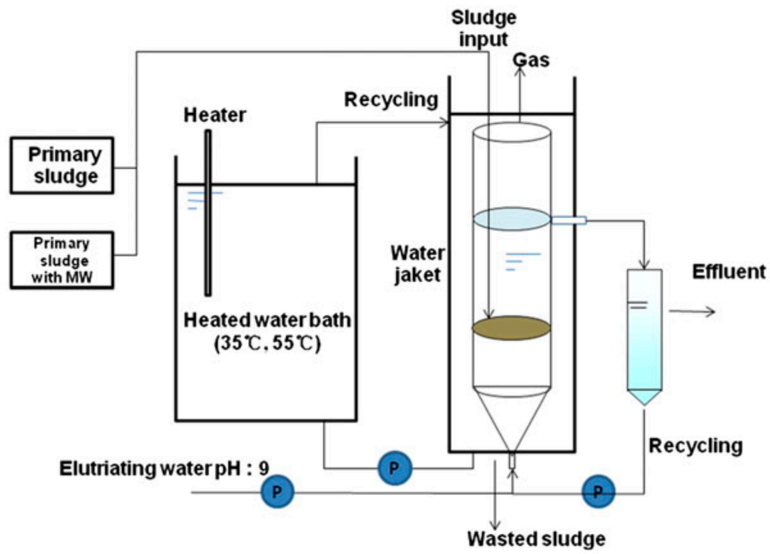

Fig. 1. Schematic diagram of semi-sequencing EAF systems.

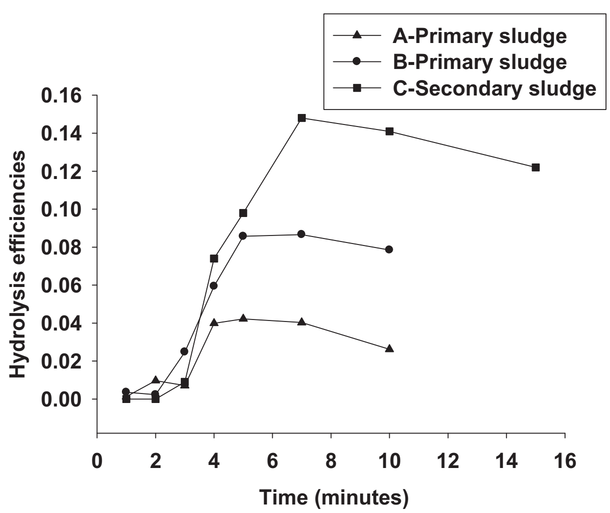

Fig. 2. Hydrolysis efficiency of three kinds of sewage sludge.

$$\text{Hydrolysis efficiency} = \text{g SCOD}_{\text{prod.}}$$
$$(\text{g SCOD}_{\text{out}} - \text{g SCOD}_{\text{in}})/\text{g ICOD}_{\text{in}} \text{ (Insoluble COD)} \quad (1)$$

The maximum hydrolysis efficiencies of primary sludge A, B, and secondary sludge C were 0.042, 0.086, and 0.15 g $SCOD_{prod.}$/g $ICOD_{in}$, respectively. The initial temperature was 18.5℃. Insoluble COD was hydrolyzed and converged into soluble COD after more than 4 min of irradiation reaching a temperature over 70℃. After 7 min of irradiation, the temperature reached 92.7℃ at last. The hydrolysis efficiency of primary sludge decreased due to gasification after 5 min, in case of secondary sludge it needs 7 min. Organic carbon in the sludge was converted into CO, CO_2, and CH_4 which was reported by a previous work [12]. Sludge characteristics can be evaluated with VS/TS and water contents that contribute to the different hydrolysis efficiencies of primary and secondary sludge. The energy consumption of hydrolysis with microwave irradiation was 1,080 kJ/L of primary sludge and 1,512 kJ/L of secondary sludge. The optimum irradiating time under the conditions of 2,450 MHz and 900 W was 5 min for the primary sludge and 7 min for the secondary sludge. So that secondary sludge was not considered economically feasible. Primary sludge was adopted by latter research.

3.2. Semi-sequencing EAF system

3.2.1. Reduction of the sludge

Table 2 indicates the reduction in the efficiencies of volumes, TCOD, TS, and VS at each test. The volume was reduced to 55% by the EAF at 35℃ after the microwave pretreatment, the only EAF at 35 and 55℃ were 44 and 51%, respectively. These reductions were influenced by the thickened sludge, water evaporation, and gasification of organic carbon such as CO, CO_2, and CH_4. VS reduction using microwave pretreatment after the EAF at 35℃ was 59%, while the values of the EAF without pretreatment at 35 and 55℃ were 47 and 52%, respectively.

Table 2
Volume, TCOD, TS, and VS reduction* of semi-sequencing EAF

	Volume (%)	TCOD (%)	TS (%)	VS (%)
35°C with microwave	55	32	57	59
35°C without microwave	44	23	46	47
55°C without microwave	51	27	49	52

*Reduction (%) = (1 − wasted sludge/fed sludge) × 100.

The reduction efficiencies of volumes, TCOD, TS, and VS by the microwave pretreatment followed by the EAF were higher than the EAF at 35 and 55°C without microwave pretreatment.

3.2.2. Hydrolysis and acidification

Fig. 3 shows the ratio of SCOD production to VS fed under each condition. The average hydrolysis efficiencies of the microwave pretreatment followed by the EAF and only the EAF at 35 and 55°C were 0.33, 0.11, and 0.22 g $SCOD_{prod}$./g VS_{fed}, respectively. The value from the EAF at 55°C without the pretreatment was about three times higher compared with that at 35°C. The high temperature seemed to be superior to the mesophilic condition in enhancing the activity of micro-organisms. In addition, VFAs production was similar to the result of SCOD production in as shown in Fig. 4. But using high temperature is not an economical process because of the energy consumption. Furthermore, EAF at 35°C after microwave treatment reach more SCOD production and VFAs production than EAF at 55°C. As the result of fermentation, the sludge pretreatment by the microwave irradiation was appropriate to the reduction in volume and VS as well as the acid production with the temperature at 35°C. The effluent from the acidification system includes abundant VFAs such as acetate that may be available for the external carbon source in a biological nutrients removal process with the low ratio of carbon to nitrogen from the domestic wastewater. It is recommended that the gas production in the methanogenesis step may be enhanced by applying the effluent of acid fermentation to an anaerobic digestion process such as up-flow anaerobic sludge blankets (UASB).

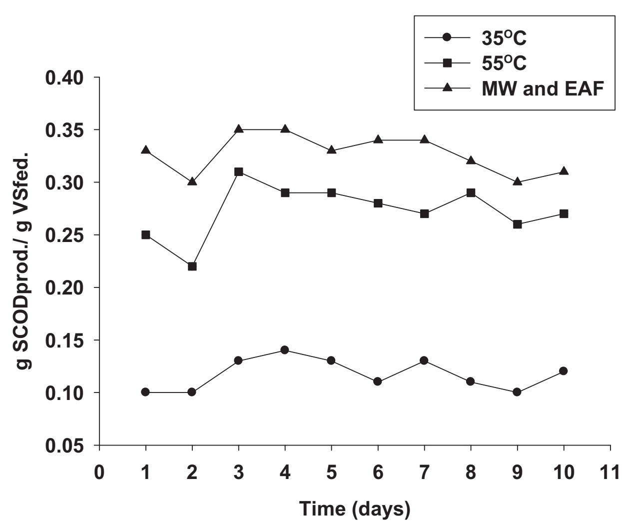

Fig. 3. SCOD production.

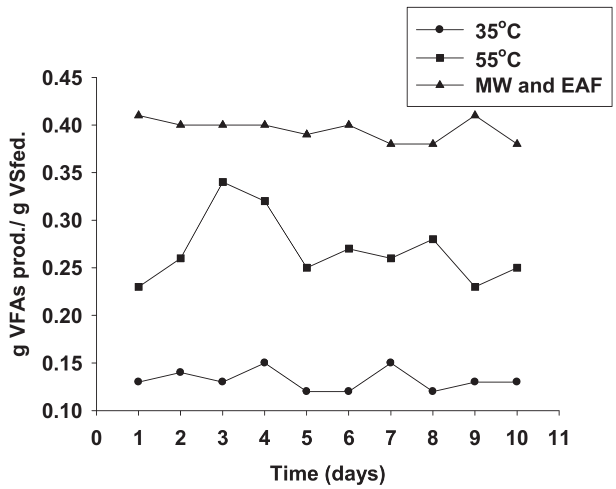

Fig. 4. VFAs production.

3.2.3. Production of VFAs

During anaerobic fermentation, three basic steps (hydrolysis, acidification, and methanogenesis) are usually involved. VFAs are the important intermediate products in the anaerobic digestion. Fig. 5 shows the VFAs production of sewage sludge during the semi-sequencing EAF reactor. The major by products from the fermentation of sewage sludge were acetic acid (HAc), propionic acid (HPr), and butyric acid (HBu). In the EAF with MW, acetic acid was the dominating product of VFAs which was more than 50%. Because

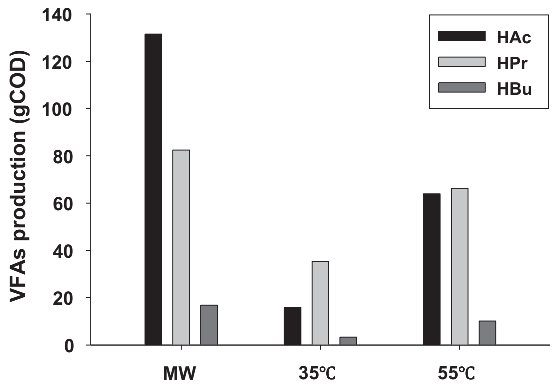

Fig. 5. Composing of VFAs.

the solubilization rate was increased by microwave treatment, and the small chain acetic acid was easy to produce.

3.2.4. Reuse as biosolids

The US Environmental Protection Agency has established laws concerning the reuse and disposal of sewage sludge. Biosolids can be obtained by available organic sludge through processes such as stabilization and compost. The fecal coliforms of biosolids are regulated below 1,000 MPN/g of dry solid which enables the treated sludge to be reused in golf courses and gardens, these are classified as Class A. Coliforms and *Escherichia coli* in the input sludge injected into the semi-sequencing EAF systems were 1.9×10^7 and 2.8×10^5 MPN/g of dry solid. On the other hand, *E. coli* in both the microwave pretreatment followed by EAF at 35℃, and the EAF at 55℃ without the microwave irradiation was not detected. *E. coli* from the EAF at 35℃ without the microwave irradiation was 3.7×10^4 MPN/g of dry solid. In the case of coliforms, 1.8×10 and 1.2×10^6 MPN/g of dry solid were detected at the EAF at 55 and 35℃, respectively. Coliforms and *E. coli* were not detected after the pretreatment of microwave irradiation, especially in radiation over 5 min when the temperature reached 70℃. The mechanisms for the destruction of pathogens such as fecal coliforms by the microwave irradiation seemed to be cell breakage, bacteria damage, or inactivity and transformation of bacteria DNA [13]. The microwave's effects were different than that of a conventional heating system [14].

Sludge can be reused in land applications satisfying the standards for biosolids categorized as grade A by the US EPA because of the death of pathogens caused by microwave pretreatment.

4. Conclusions

Microwave irradiation could enhance the hydrolysis of sewage sludge and produce more VFAs with the sequential process of EAF. Microwave pretreatment seemed to break the solids of the primary sludge and the cells of microbe floc in the excess sludge through the vibration effect and the high temperature. The reduction efficiencies of volume, TCOD, TS, and VS by the EAF at 35℃ after the microwave pretreatment were higher than only the EAF at 35 and 55℃ without the microwave pretreatment.

The hydrolysis efficiency of the EAF at 35℃ after the microwave pretreatment was 0.33 g $SCOD_{prod.}$/g VS_{fed}, and only the EAF at 35 and 55℃ were 0.11 and 0.22 g $SCOD_{prod.}$/g VS_{fed}, respectively. VFAs were produced similar to that of SCOD production.

Coliforms and *E. coli* were not detected after pretreatment with microwave irradiation, which indicates that the treated sludge may be reused in land applications. The energy consumption of the EAF with 35℃ was the lowest. But the use of EAF with high temperatures or a microwave as pretreatment method was preferable in terms of the hydrolysis, sludge reduction, and the destruction of pathogen.

Acknowledgments

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