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Acid Fermentation Process for Sewage Sludge as Sludge Recycling Technology†

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Abstract:

JFE Engineering developed "acid fermentation process for sewage sludge" on commission from Japan Science and Technology Agency. This technology aims to decompose sewage sludge and recorver high levels of organic acid from sewage sludge, using anaerobic bacteria, alkalis, and ultrasonic treatment. The authors report here the scheme of this process and the results showing an average solid decomposition rate of 50.8% secured by using a pilot scale plant of 2.5 m^3/d, under the condition of fermentation tank at 30–35°C and retention time in the fermentation tank of 2 days.

1. Introduction

Japan generates approximately 2 million tons of sewage sludge each year (by conversion to dry weight). As the sewerage diffusion rate has increased, the amount of sludge has also tended to increase. Sludge reduction/recycling treatment is performed by anaerobic digestion, incineration, sludge utilization for construction material, etc. However, because the construction cost, operation and maintenance cost, and operational cost of treatment facilities are large and landfill sites for sludge are also inadequate, technologies for reducing the generation of sludge and effective utilization of sludge have been demanded.

The sludge generated by sewage treatment systems comprises raw primary sludge, in which the suspended solids contained in the influent wastewater precipitate, and excess activated sludge, which consists mainly of microorganisms propagated by the aerobic physiochemical reaction of sewage.

The conventional technology for reducing the generation of sludge was a technology in which sludge generation is reduced by physicochemically solubilizing the excess activated sludge and returning it to the wastewater treatment system, and did not consider effective use of the sludge. The physicochemical solubilizing technology was one in which cytoplasm was came out from the cell by destroying the cell membrane of the microorganisms, but when applied to raw primary sludge with a low content of microorganisms, this encountered the problem of a low solubilizing rate per unit of input energy.

On the other hand, as recycling technologies, composting and utilization of sludge incineration ash as construction material faced the problems of (1) limitations on areas where these products can be used and (2) poor economy in case of long transportation routes.

Therefore, based on a proposal by Prof. Naomichi Nishio of Hiroshima Univ., JFE Engineering developed an acid fermentation system for sewage sludge, in which the suspended solids (SS) in sewage sludge are decomposed by combining an acid fermentation process and ultrasonic treatment with alkalis. Acid fermentation system for sewage sludge to aim for efficiently organic acid formation[1)], in which the development of this technology was carried out as a commissioned project for Japan Science and Technology Corporation (now, Japan Science and Technology Agency), and certification of success was received from the organization in May 2004.

This paper outlines the developed acid fermentation system for sewage sludge and reports the operating condition of pilot-scale experimental equipment.

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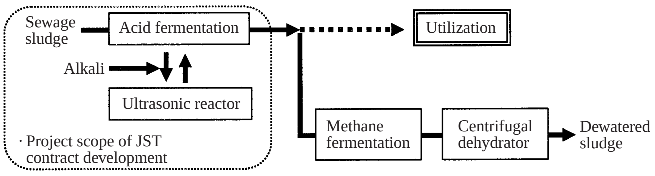


Fig. 1 Schematic diagram of acid fermentation process for sewage sludge

2. Outline of Acid Fermentation System for Sewage Sludge

Figure 1 shows the outline of the system. The area in the figure enclosed by the broken line is the scope of the development project commissioned by Japan Science and Technology Agency. The development targets were decomposition of the solid component of sludge in a short reaction time and production of highly-concentrated organic acid, consisting mainly of short-chain fatty acids such as acetic acid and propionic acid. It is assumed that the sludge containing the formed highly-concentrated organic acid will be used as a reducing agent for denitrification in advanced sewage treatment and as a raw material for anaerobic digestion.

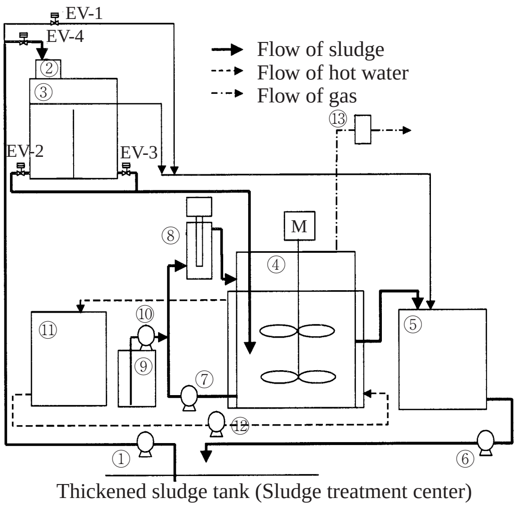
When input sewage sludge undergoes acid fermentation treatment, the component which is easily decomposed by biological treatment is partially converted to an acid producing bacteria. Part of the sludge which has undergone acid fermentation treatment is extracted from the system. After alkali is added, the cell membranes of the acid producing bacteria which were allowed to propagate are destroyed by performing ultrasonic treatment, and the cytoplasm came out form the cell. Because the come out cytoplasm is easily decomposed by biological treatment, it is recycled to the acid fermentation process and converted to organic acid[2)].

3. Experiment to Demonstrate the Process Performance

3.1 Plant for the Demonstration

An experimental plant was installed in the Hokubu Sludge Treatment Center, Sewage Works Bureau, City of Yokohama. A photograph of the experimental plant is shown in **Photo 1**; an outline of the process is shown in **Fig. 2**. Sludge which had been thickened to 4–5% was pumped up from the thickened sludge tank in the center and charged to the acid fermentation tank at a rate of 2.5 m^3 of sludge once/day. An overflow method, in which the sludge in the acid fermentation tank was discharged simultaneously with sludge charging, was adopted for extraction from the acid fermentation tank. Except during this sludge exchange time, the sludge was circulated

Photo 1 Panoramic view of demonstration plant



①Thickened sludge feed pump, ②Screen, ③Scale tank, ④Acid fermentation tank, ⑤Discharged sludge storage tank, ⑥Sludge discharge pump, ⑦Sludge circulating pump, ⑧Ultrasonic reactor, ⑨Alkali tank, ⑩Alkali feed pump, ⑪Hot water storage tank, ⑫Hot water circulating pump, ⑬Gas meter

Fig. 2 Schematic diagram of demonstration plant

by a sludge circulating pump, and ultrasonic irradiation was performed while adding 20% NaOH aqueous solution at the specified rate. A bi-cylindrical structure was adopted for the acid fermentation tank, and the specified temperature was maintained by supplying warm water to the outer side. The operating conditions are summarized

Table 1 Operating conditions of demonstration plant

Acid fermentation tank

Effective volume (m^3)	5
Solid retention time (d)	2
Temperature (°C)	30–35

Solubilization conditions

NaOH addition rate	4 kg/m^3-input sludge (Constant injection during sludge circulation pump working)
Electrical consumption of ultrasonic generator	10 kWh/m^3-input sludge (2 kW ultrasonic generator)

in **Table 1**.

3.2 Analytical Method

During the period of the experiment, the properties of the input sludge and treated sludge were analyzed at set intervals. For comparison purposes, digested sludge from an actual facility was sampled and its properties were analyzed in the same manner. The analysis of the solid component was performed in accordance with standard method[3]; volatile fatty acids were analyzed with an ion chromatograph (model DX-120, manufactured by Dionex Corp.), and analysis of the separation column was performed using an IonPac ICE-AS1 (same company). In this paper, the volatile fatty acids were considered to be organic acids, and the mass sum of formic acid, acetic acid, propionic acid, butyric acid, and valeric acid was defined as VFA (volatile fatty acid).

3.3 Sludge Volume Reduction Effect

Changes over time (day) in the SS concentration and SS reduction rate of the input sludge and treated sludge are shown in **Fig. 3**. The average composition of the input sludge, acid fermentation-treated sludge, and digested sludge from an actual facility are shown in **Table 2**. Here, digested sludge from an actual facility means digested sludge from the Hokubu Sludge Treatment Center. This sludge was generated when anaerobic digestion of input sludge is performed at a planned digestion temperature of 35°C for a planned digestion time of 30 days[4].

Although the SS concentration of the input sludge fluctuates greatly, the SS concentration of the treated sludge was reduced stably. After achieving a steady condition in the tank, changes in the SS concentration similar to fluctuations in the input sludge properties could be seen; however, following the 20th day from the start of the experiment, which was considered to be the steady period, the average SS reduction rate over a 15-day period was 50.8%. As shown in Table 2, the average SS concentration in the acid-fermented sludge during the steady period was 20 500 mg/*l*, which is virtually the same value as the average SS concentration of 21 100 mg/*l* in the digested sludge. The SS reduction rate at the actual facility was 49.8% at this time. This value is on the same order as the SS reduction rates obtained at conventional-type digestion facilities. It may be noted that, at conventional-type digestion facilities, the reduced SS is converted to a biogas with CH_4 as its main component, but with this system, SS is converted to soluble organic matter consisting mainly of VFA.

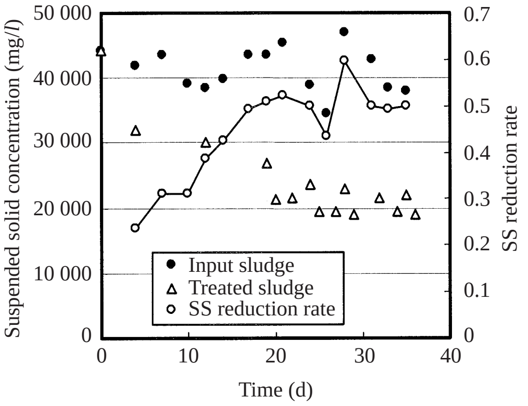


Fig. 3 Changes in suspended solid concentration of sludges and SS reduction rate from start up

Table 2 Sludge composition (average value)

(mg/*l*)

	Input sludge	Effluent sludge (This study)	Digested sludge (Sludge treatment center)
Total solid	43 600	40 900	25 200
Volatile total solid	36 300	29 300	17 300
Suspended solid	41 300	20 500	21 100
Volatile suspended solid	35 200	15 400	14 400
Formic acid	0	0	0
Acetic acid	400	4 300	10
Propionic acid	400	2 800	0
Butyric acid	300	1 100	0
Valeric acid	100	1 000	0

3.4 Condition of VFA Formation

Changes in the VFA concentration and pH of the treated sludge are shown in **Fig. 4**. Based on the data presented in Table 2, the changes in input sludge composition in cases where this system and a conventional digestion process were applied are shown in **Fig. 5**. The biogas in Fig. 5 shows the results of a calculation assuming that 100% of the reduced sludge is converted to biogas.

As can be seen in Fig. 4, the rate of VFA formation did not follow the amount of alkali addition in the initial stage of the experiment, and the pH of the sludge was approximately 8. However, pH decreased as VFA formation increased. In the steady period, alkali addition at a rate of 4 kg/m^3-input sludge was continued, but the pH of the treated sludge was held to within a range of 6–7.

From Fig. 5, the average concentration of soluble organic matter in the treated sludge in the steady period was 13 900 mg/*l*, and the average VFA concentration was 9 200 mg/*l*. Thus, 66% of the soluble component was VFA, and the remainder was estimated to be organic matter which is easily decomposed by biological treatment, such as saccharides, amino acids, etc. Using input sludge as a standard, 38% of input sludge VTS was soluble, and VFA corresponding to 25% of the input sludge VTS was produced.

3.5 Summary of the Experiment

With the present system, an average SS reduction

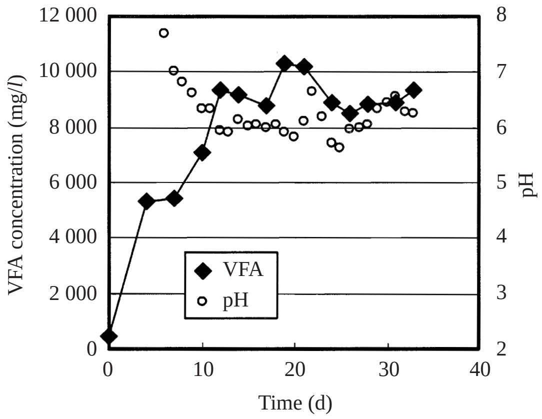


Fig. 4 Changes in VFA concentration and pH of treated sludge from start up

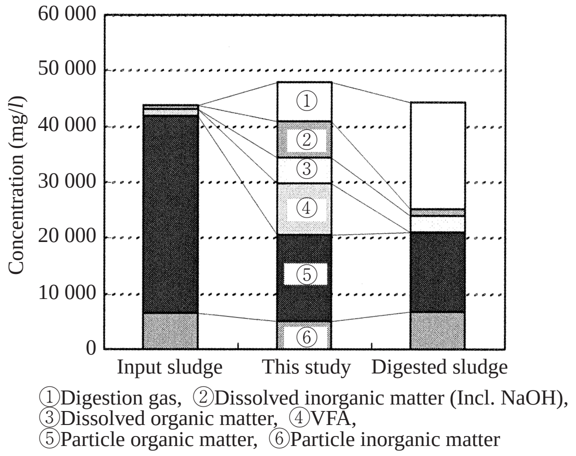


Fig. 5 Changes in input sludge components after acid fermentation and methane fermentation (Digested sludge: Collected from sludge treatment center)

rate of 50.8% was obtained with a retention time of 2 days in the acid fermentation tank. This value is virtually the same as the SS reduction rate obtained at conventional-type digestion facilities. Here, the reduced SS component is organic matter which should essentially be decomposed to CH_4, and with this system, the SS component remains in solution in the form of soluble organic matter with VFA as its main component. Because the formed VFA is an organic matter which is easily decomposed by biological treatment, it can also be used as a reducing agent for denitrification in advanced sewage treatment. Assuming that the capacity of the produced VFA as a reducing agent is equal to that of methanol, it was expected to be possible to form VFA corresponding to 23 kg/d of methanol with the present experimental plant.

4. Conclusion

A new acid fermentation process for sewage sludge was developed. By applying a solubilizing treatment in combination with ultrasonic treatment with alkalis to the sludge after acid fermentation, it was possible to obtain a high suspended solid (SS) reduction rate and high organic acid producing rate with a short retention time.

When considering the future application of this system to actual facilities, it will be possible to construct a sludge volume reduction/organic acid use system for small-scale wastewater treatment facilities by determining the level of performance of the sludge after acid fermentation as a reducing agent for denitrification, and how the operating conditions of the water treatment system and the quality of the treated water change, depending on recycling of sludge containing SS to the wastewater treatment system.

In addition to application as an organic acid producing system, it is also possible to apply this system as pretreatment equipment for anaerobic digestion facilities. Laboratory experiments confirmed that gas generation can be increased by 25% and the amount of sludge can be reduced by approximately 20% in comparison with conventional anaerobic digestion when anaerobic digestion is performed using acid-fermentation sludge, in which solubilizing is accelerated by NaOH addition/ultrasonic treatment[1].

Future plans include study of the applicability of this system as a pretreatment process for anaerobic digestion and expanded use as a sludge recycling system for medium- and large-scale wastewater treatment facilities.

In carrying out this research, the authors received much guidance from Prof. Naomichi Nishio of Hiroshima Univ., and also received cooperation from the management and staff of the Hokubu Sludge Treatment Center, Sewage Works Bureau, City of Yokohama, who provided the site and samples for the experiment. Here, the authors wish to express our deep appreciation to all those concerned.

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