B-16.1.2 Recovery of Methane Gas from Sludge and its Beneficial Use

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Abstract In order to encourage the beneficial use of sewage sludge, most of which is now disposed of as waste material, problems with anaerobic digestion of sludge were surveyed, and the practical utility of gas powered electric generation systems using methane gas produced by the digestion process was studied and the feasibility of using digestion gas as the city gas was also examined. Laboratory experiments were carried out to study the mechanism producing nitrous oxide during composting: another beneficial way to use sludge.

Key Words Methane Gas, Sewage Sludge, Energy Recovery, Beneficial Use, Greenhouse Gas

1. Introduction

Because sludge produced as result of sewage treatment contains large amount of organic matter, sewage treatment processes have long included anaerobic digestion to stabilize the sludge and reduce the quantity produced. Methane gas generated by anaerobic digestion has, up till now, been burned to heat the sludge digestion tank, but we must encourage the beneficial use of this methane gas to cut down on the release of greenhouse effect gasses and to create a new energy source.

And because sludge also contains large amounts of nitrogen and phosphorus, which are typical constituents of fertilizers used to nourish plant life, it is possible to obtain good quality fertilizer by properly controlling the quality of the sludge. The recycling of these resources derived from sludge should be encouraged to maintain the world's supply of raw materials for fertilizer production. Viewing sludge as an energy or fertilizer resource, the apropriate treatment and beneficial use of sludge were studied and assessed in order to contribute to the resolution of global environmental problems.

2. Research Project

The questionnaire survey concerning the anaerobic digestion process and the use of the gas was practiced in medium and small sewage treatment plants to assess the operation and management of the process. The feasibility of practical digestion gas generation system and the possibility of using such gas as city gas were studied. The laboratory experiments were also conducted to clarify the details of the production of nitrous oxide from the compost process.

3. Methods and Results

(1) Survey of the anaerobic digestion process and the use of the gas produced

[1] Questionnaire survey of system operation and management

From among all medium and small sewage treatment plants (Average daily flow : from approximately 5,000 to 50,000 m^3/day) in Japan using the anaerobic digestion process, in the survey their size and location was considered , and 50 plants with high operating rates were selected. Then the opinions of the operators of these selected plants were gathered regarding the operational performance of the anaerobic digestion , the effectiveness of its use, problems to be overcome, and other issues related to the method. Completed questionnaires were returned by 46 treatment plants. A summary of the opinions obtained is shown in Figure 1.

A. Beneficial use of digestion gas

On the subject of the beneficial use of digestion gas, some plant operators stated that they have no plans to generate electricity with gas, others mentioned equipment problems such as the corrosion of the equipment and a lack of sufficient capacity to hold the gas , while other respondents cited maintenance problems including measures to deal with hydrogen sulfide, a shortage of digestion gas, and the need to hire qualified engineers.

B. The anaerobic digestion process

While 14 respondents (30%) reported that it is easy to operate the anaerobic digestion process, 32 (70%) declared it difficult. This result is reflected in the opinions about the maintenance of digestion process shown in Figure 1, and a wide range of negative opinions were expressed. On the effects of sludge treatment, many pointed out that it reduced the quantity of sludge. The numbers who positively and negatively assessed the ability of digestion to dewater sludge were almost equal. When asked about its effect on the water treatment process and the environment, an overwhelming majority listed the reductions of noxious odors as one of its merits, while many more criticized its effects on the water treatment process of supernatant liquor.

[2] Study of the practicality of digestion gas generation systems

Some manufactures were interviewed to find out how much it would cost to install and operate a digestion gas generation system, then the cost of producing electric power with digestion gas (depreciation expenses + operating costs) was compared with its benefits to determine the practicality of installing such a system. The depreciation expenses were assumed to be the cost of machinery, electrical equipment, and civil engineering and building construction work, while operating costs included repairs, electric power to drive the machinery, cooling water, and personnel. The depreciation expenses were found for a case in which the government subsidized the project (assumed to be 3/4 of the costs) and a case in which it did not. Among the benefits gained from power generation on the other hand, there are discrepancies particularly in basic fees, depending on whether or not the power generators are positioned for full time use. And because the penalty charge is levied on a breach of contract, it was assumed that the generator operating rate will be 100%. The equipment costs were computed assuming that the plant would consist of three electric power generators (two running, one on standby). And the benefits of this generator configuration were computed for two cases: a case in which the generators are positioned for full time use and a case in which they are not.

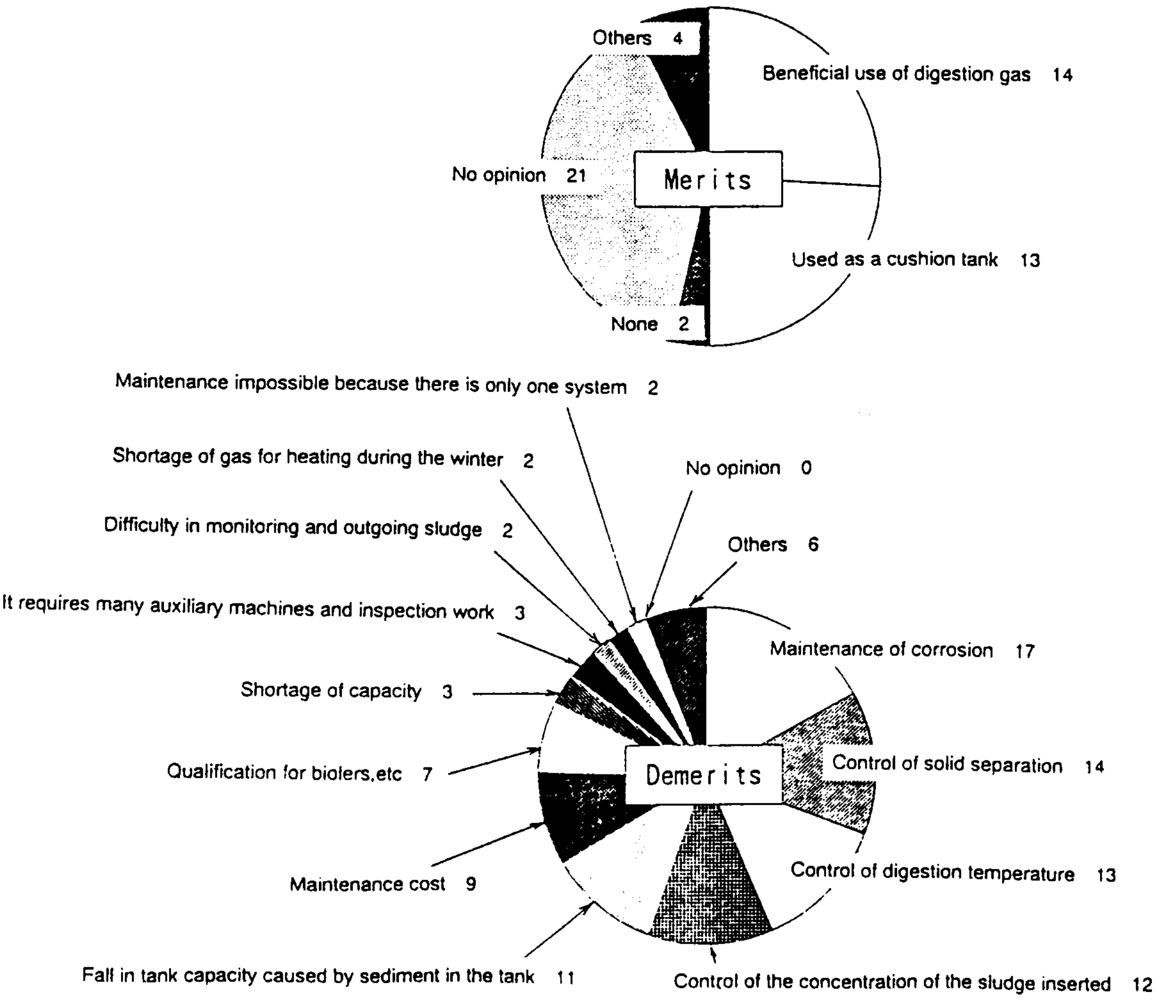
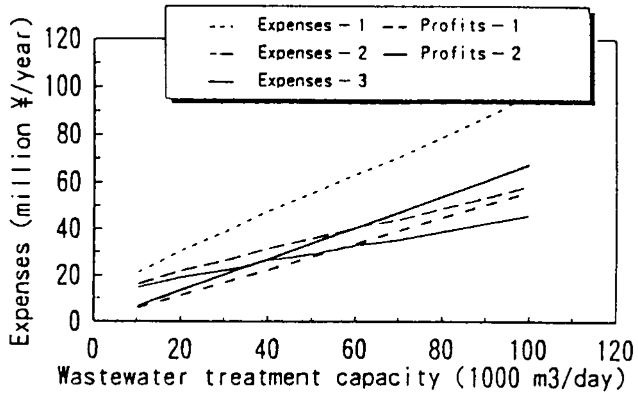


Figure 1. Opinions expressed concerning the operation and management of the digestion process

The results of this analysis are shown in Figure 2. This figure shows that the system becomes beneficial at the stage that profits from the power generation begin to exceed the costs. Based on this, if the government does not subsidize the cost of generating system as in Expenses - 1, the digestion gas generation system will not yield profits for treatment plants of any size. If the government does contribute to the costs as in Expenses - 2, in the Benefits - 2 case which assumes that the basic fees will fall, profits will be earned by treatment plants with a capacity of 60,000m^3/day or more. And at plants this size or larger, profits will be earned from the relationship between Expenses - 3 which forecast only operating expenses and Profits -1 which did not anticipate a decline in the basic fees. In a situation combining Profits - 2 which anticipates a decline in basic rate with Expenses -3 which includes only operating expenses under the most generous conditions, profits will be earned by treatment plants with a capacity of approximately 40,000m^3/day or more. Based on this study method, treatment plants of approximately this size are the smallest where a digestion gas generation system is feasible from the cost-benefit point of view.

Expenses-1: Depreciation expenses (no government subsidies) + operating costs
Expenses-2: Depreciation expenses (government subsidies) + operating costs
Expenses-3: Operating expenses
Profits - 1: Reduction of basic fee not anticipated
Profits - 2: Reduction of basic fee anticipated.



[3] Study of the feasibility of using digestion gas as city gas

Its use as city gas must conform to the Gas Enterprises Act. Based on the provisions in the Gas Enterprises Act, the combustibility, safety, supply method, etc. for digestion gas were studied in order to develop technology to handle gas of this type.

A. Combustibility of digestion gas

The Gas Enterprises Act establishes 15 categories of City Gas aside from LPG based on the relationship between its Wobbe index (WI) and combustion speed index (Cp).

For this study, the Wobbe index and combustion speed index were found assuming that ordinary digestion gas has the following properties: methane content 65%, carbon dioxide 35%, total calorific value 6,200kcal/Nm^3, and specific gravity 0.896. The result was WI of 6,550 and Cp of 20.6. This means that digestion gas does not belong to any city gas category and can not be supplied or used independently. The calorific value of digestion gas is relatively small, the only combustible constituent of the gas is methane, and its combustion speed index is somewhat low. To find a solution to these problems, the use of a mixture of LPG and digestion gas was studied, and reducing of the carbon dioxide content of the digestion gas from 35% to 5% was also considered.

This study indicated that while pure digestion gas did not correspond to any city gas category, digestion gas containing LPG could be used, and the range of its use would be broadened by removing its carbon dioxide. The calorific value of city gas will be raised in the future, and when digestion gas is used, it must have properties permitting its inclusion in the high calory groups: 11A, 12A, 13A, and so on.

B. Safety of digestion gas

The Gas Enterprises Act prescribes standards governing the content of toxic constituents and requires inspections. The principal problem preventing digestion gas from meeting these standards is its hydrogen sulfide. Digestion gas contains between 2,000ppm and 3,000ppm; it must be reduced to 13 ppm or less, which corresponds to 0.2g/Nm^3. Because the hydrogen sulfide concentration in digestion gas after desulfurization now ranges from 10ppm to 300ppm, desulfurization equipment with improved capabilities and more stable performance must be provided if digestion gas is to be used as city gas.

(2) Experimental testing of nitrous oxide generation during composting

[1] Method

The experiments were done using four insulated fermenters with internal diameters of 10 cm and heights of 60 cm in a 30℃ thermostatic chamber under the conditions presented on Table 1. The N_2O is assumed to be produced by the denitrification and nitrification processes. Compost with a high content of oxidized nitrogen was used as the seed compost as a stocking condition for clarifying these phenomena. It was known that the nitrification action during the composting of sewage sludge is brisk in a case where secondary materials are added. For this reason, the study included a case in which rice hulls were added as secondary material. And because a temperature of 60℃ or higher deactivates the nitrification bacteria, the test was also done for a case in which the fermentation was done in a thermostatic chamber set at 60℃ for the first three days of fermentation.

The experiments was continued during five weeks. The fermentation temperature was

Table 1. Experiment conditions of composting

Case	Material conditions Mixture ratio (dry solids base)			Initial moisture content (w/w %)	Fermentation conditions
	EAS[a]	: Seed compost[b]	: Rice hulls[c]		
30-non	1	: 0.5		50	Fermented in a thermostatic chamber at 30 ℃.
30-RH	1	: 0.5	: 0.25	55	
60-non	1	: 0.5		50	Fermented in thermostatic storage at 60 ℃ for the first 3 days, then in a thermostatic chamber at 30 ℃.
60-RH	1	: 0.5	: 0.25	55	

Notes a. EAS : Excess activated sludge is dewatered in the process of coagulation with polymer, dried and crushed into the particle size of 5㎜ or less.

b. Seed compost : The compost consisting of sewage sludge and crushed rice hulls is fermented for 70 days.

c. Rice hulls : Crushed rice hulls

measured, and changes in the gas discharged by the fermentation and the properties of the fermenting material were studied. And at mixing time, the volume of air supplied was changed and the water content adjusted as necessary.

[2] Results of the experiments

A. Fermentation

Table 2 presents the properties of the raw materials and adjustment materials used for the experiments. During the experiments, the fermentation was done with 500ml/min of air supplied at the beginning of the experiment for the approximately 5 liters stocked in each case. Figure 3 shows changes in the fermentation temperature during the first half of the test. The fermentation temperature was not monitored during this stage for Case 60- and Case 60-RH, two cases where the thermostatic chamber temperature was set at 60℃.. The amount of air supplied in each case was reduced as the fermentation temperature declined, and was fixed at 100ml/min. beginning on the fourteenth day.

B. Changes in oxidized nitrogen in the fermenting material and the nitrous oxide

Figure 4 presents the cumulative totals of the oxidized nitrogen (NOx-N) in the fermenting material and the nitrous oxide (N_2O) in the discharged gas during the fermentation process. It reveals that the release of nitrous oxide responds to changes in oxidized nitrogen. The mutual precipitous changes that occur during early fermentation is believed to be caused by the denitrification process that accompanies vigorous fermentation. But the oxygen concentration in the exhaust gas was maintained at 14 O_2 v/v-% or more, even during the period of vigorous

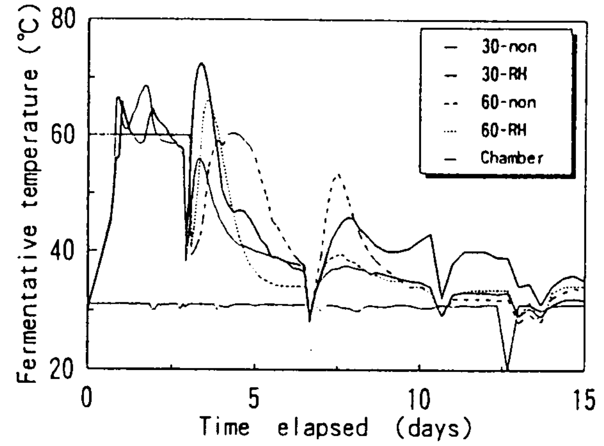


Figure 3. Changes in fermentation temperature

Table 2. Properties of material and adjustment material for feed

Materials		Moisture content (w/w %)	pH (-)	Electric conductivity (mS/cm)	VS/DS[a] (-)	Nitrogen (w/DS %)	C/N[b] (-)	NOx-N[c] (N. mg/DS. kg)
Raw material	Excess activated sludge	8.7	6.16	4.0	0.74	7.7	4.8	32
	Crushed rice hulls	9.2	5.45	0.48	0.78	0.38	104	41
	Seed compost	37.8	7.47	3.7	0.42	2.5	9.1	470
Feed	Case of 30, 60-non	49.3	6.76	3.7	0.63	6.1	5.4	141
	Case of 30, 60-RH	55.2	6.80	3.6	0.67	5.3	6.2	135

Notes
a. VS/DS : Ratio of volatile solids (ignition loss) and dried solids
b. C/N : Ratio of carbon and nitrogen
c. NOx-N : Nitrite and nitrate nitrogen

fermentation. It is assumed that this happens because the microorganisms on the surface and inside the fermenting material, have a strong demand for oxygen, suffer from an oxygen shortage, and nitrate respiration and other denitrification processes occur, regardless of the fact that the interior of the fermentation tank is homogeneously an aerobic atmosphere. During the last half of the fermentation process on the other hand, they both increased sharply only in Case 30-RH, a result of brisk nitrification.

Determining the nitrous oxide generation rate during composting from the data obtained from these experiments reveals that it was 0.54 to 0.92 N_2O-w/N-w per unit amount of denitrification and 0.94 N_2O-w/N-w per unit amount of nitrification. Further studies of its generation rate is necessary.

4. Conclusion

1) A questionnaire survey was carried out concerning the operation and management of the anaerobic digestion process and the beneficial use of digestion gas among managers of sewage treatment plants using the anaerobic digestion method. Completed questionnaires were returned by 46 plants. While some reported that anaerobic digestion effectively reduced sludge, others stated that it is difficult to operate and control, the equipment corrodes, hydrogen sulfide measures are necessary, gas holders are not large enough, and it is difficult to get personnel qualified to run the system.

2) The study of the feasibility of digestion gas generation systems revealed that it could only be done at a sewage treatment plant that processes an average of at least 40,000m^3 of wastewater per day, and

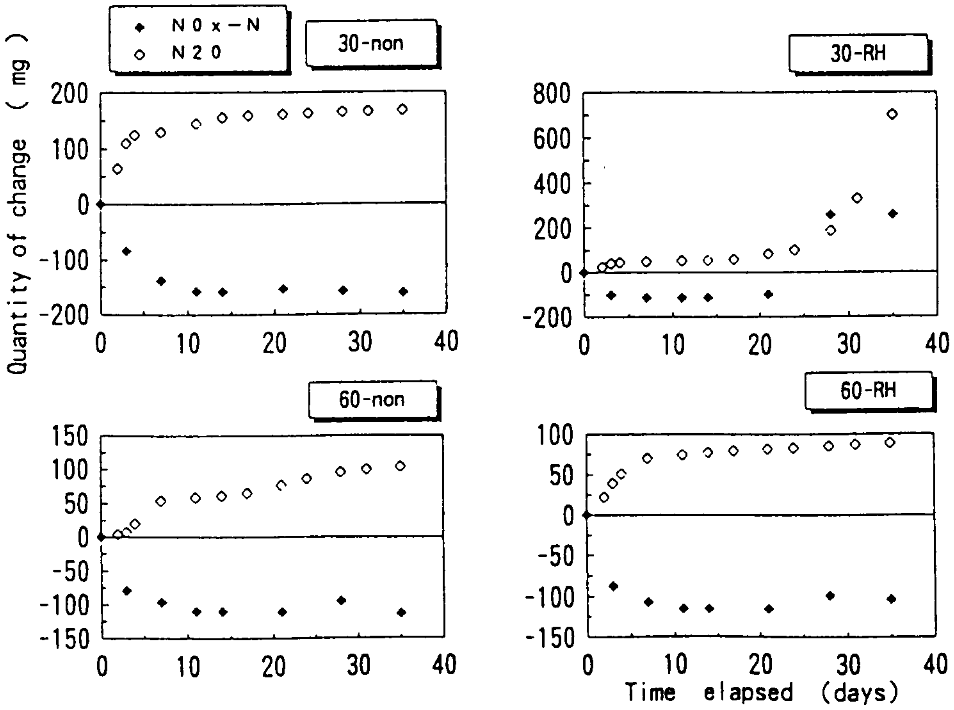


Figure 4. Oxidized nitrogen decline in the fermenting material and accumulation of nitrous oxide in the released gas

that the venture would only provide real profits at plants with a capacity of 60,000m^3/day or more.

3) As a result of a study of the feasibility of using digestion gas as city gas, it was concluded that the digestion gas could not be used by itself. It would have to be mixed with gas with higher calorific value and higher combustion speed. We confirmed that digestion gas mixed with LPG could be used. But to use digestion gas as city gas, its hydrogen sulfide concentration would have to be reduced to 13ppm or less.

4) The testing confirmed that nitrous oxide is released during composting of sewage sludge. The rate of release of nitrous oxide obtained from the testing was 0.54 to 0.92 and 0.94 N_2O-w/N-w per unit of denitrification and unit of nitrification respectively.