Wat. Sci. Tech. Vol. 25, No. 7, pp. 135–141, 1992.

0273–1223/92 $15·00

FIELD TEST OF A COMPOSITE METHANE GAS PRODUCTION SYSTEM INCORPORATING A MEMBRANE MODULE FOR MUNICIPAL SEWAGE

K. Kiriyama, Y. Tanaka and I. Mori

Ebara Corp. R&D Division, 2-1, Hon Fujisawa 4-chome, Fujisawa-shi, Kanagawa 251, Japan

ABSTRACT

We examined a field test plant based on anaerobic sewage treatment to elucidate the process of methane fermentation with a UASB in municipal sewage and domestic waste water.
The process consists of a pretreatment system for sparating suspended solids, a hydrolyzation reactor with a membrane module for organic solids, and a UASB reactor. The membrane module increases the sludge residence time in the hydrolyzation reactor. This field test plant is a commercial size system which combines these processes to verify the feasibility of the system.
The aim of this practical test is to produce gas with a conversion rate of over 60% when the volumetric organic loading rate is more than 2 kg BOD/reactor $m^3 \cdot d$, and to construct a methane gas generation system which generates the gas from raw sewage. This practical test demonstrated gas conversion rates from 57% to 60.0%. Volumetric organic loading rate was 1.4 - 2.0 kg BOD/$m^3 \cdot d$; BOD removal was 70 - 80% at ambient temperature, and excess sludge did not exceed 0.04 kg per sewage$\cdot m^3$.

KEYWORDS

Methane; municipal sewage; ambient temperature; UASB; hydrolyzation; membrane module; excess sludge.

INTRODUCTION

Our New Wastewater Treatment System has been under development since 1985 as a part of the Aqua Renaissance Project. It combines bioreactors with high-performance separation membranes to produce methane gas and to reclaim wastewater.

A two-phase bioreactor can be combined with the membrane module, as in the process flow diagram in Fig. 1. This process separates the methane phase from the hydrolyzation acidification phase.

Process flow

The effluent from a grit chamber in the existing treatment plant is transferred from the existing pump discharge pit to the pretreatment unit to remove bulky waste with a fine screen. The raw water is then stored in a raw water tank. The raw water is transferred from the raw water tank to a filter to separate suspended sludge from water, and the separated suspended sludge is pumped out and sent to a hydrolyzation reactor.

In the hydrolyzation reactor, the suspended sludge and the thickened return liquid from the membrane module are mixed, agitated, and heated to degrade the organic matter by hydrolyzation and thereby generate biogas.
The membrane module suppresses the efflux of methane fermentation bacteria, thickens the undegraded suspended sludge, and returns the thickened liquid to the hydrolyzation reactor to keep the methane fermentation bacteria in the reactor at a high concentration. The permeate liquid from the membrane module is mixed with the separated water from the filter of the pretreatment unit, then the mixed liquid enters the upflow anaerobic sludge blanket bioreactor (UASB). The anaerobic bioreactor degrades organic components with anaerobic bacteria to produce separated liquid, gas, and inorganic sludge. The excess sludge in the system is drained from the hydrolyzation reactor and the anaerobic bioreactor as needed. Permeate liquid backwashing and nitrogen gas washing stabilize the membrane module's production of permeate liquid.

After the removal of sulfide, the generated gas is stored in a gas tank. The gas is used as a fuel for the boiler which generates steam to heat the hydrolyzation reactor or burned for release into the atmosphere.

The separated liquid from the anaerobic bioreactor enters an aerobic reactor to undergo biological degradation and filtration under aerobic conditions, bringing the liquid up to reusable quality.

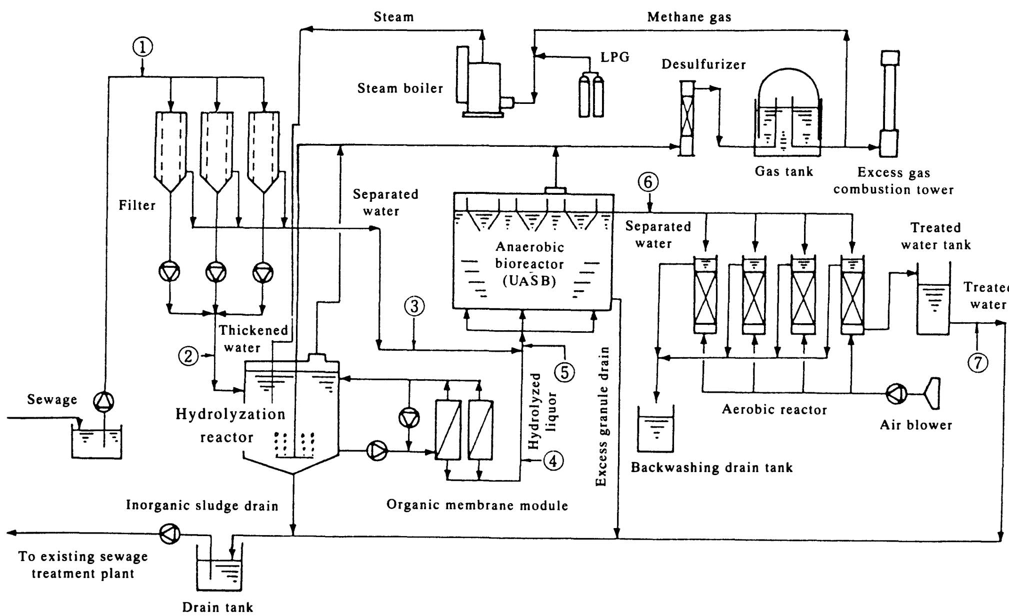

Fig. 1. Process flow

Plant Capacity

The field test plant can treat 240 m^3/d as the mean daily flow rate, or a maximum of 20 m^3/h. Flow rate control of the raw sewage feed pump can create different flow patterns within the hourly maximum flow rate.

In the raw sewage, it is expected that the biochemical oxygen demand (BOD) concentration is about 200 mg/ℓ, suspended solids (SS) is 250 mg/ℓ. The final treated water is expected to have a BOD concentration of 8 mg/ℓ, and SS of 5 mg/ℓ.

Physical characteristics of main components

The field test plant is made up of several components. Their physical characteristics are shown in Table 1.

TABLE 1 Physical Characteristics of Main Equipment

Pretreatment-unit	Hydrolyzation unit	Anaerobic bioreactor	Membrane module	Aerobic bioreactor
Filter oVertical cylindrical screen oPore size; 20 μm oEffective filtration rate 60 $m^3/m^2 \cdot d$	Hydrolyzation reactor oEffective volume; 8.85 m^3 oSteam heating; 25°C oGenerated gas agitation	Anaerobic bioreactor oUASB oVolume; 76.7 m^3 oHydraulic residence time; 1.8 hour (working volume) oAmbient temperature	Membrane module oCapillary organic membrane oExternal pressure one-end fixed oMembrane area; 3.8 m^2 per module o2-stage serial 10 pieces x 2 set	oBiological aerated filter oEffective volume; 13 m^3 oHydraulic residence time; 1.3 hour (working volume)

Method

The anaerobic bioreactor (UASB) and hydrolyzation reactor were fed with seed sludge. The UASB seed sludge was imported from the Netherlands. Its volume was 30.4 m^3, 1778 kg as volatile solids. The seed sludge for the hydrolyzation reactor was digested sludge in the existing treatment plant and had a volume of 6.55 m^3, 67.9 kg as volatile suspended solids (USS). After seeding the sludge in the hydrolyzation reactor, we replaced the air with nitrogen gas and began to agitate the mixture. After investigating the distribution of volatile suspended solids, we began to heat the mixture. The temperature was lowered from 35°C to 25°C, by 2°C every four days. Four days after seeding, the concentrated suspended sludge from the filter began to be changed, and this volume increased gradually in accordance with the volume of raw sewage treated. The UASB started out treating 56 m^3/d and the treatment volume increased in stages judging from the characteristics of the effluent. In three months treatment volume reached 240 m^3/d.

RESULTS

UASB

The results are shown in Table 2.

TABLE 2 Results of Process

		Aug.9 -Aug.27	Sep.12 -Oct.15	Dec.21 -Jan.24
Raw sewage	BOD (mg/ℓ)	166	154	166
	COD_{cr} (mg/ℓ)	394	286	297
	SS (mg/ℓ)	220	191	196
Effluent from UASB	BOD (mg/ℓ)	44.3	32.1	48.9
	COD_{cr} (mg/ℓ)	106	89.6	125
	SS (mg/ℓ)	59.1	31.2	62.0
Reduction(%) (BOD/COD_{cr})		73.3/73.1	79.7/68.7	70.5/57.9
Temperature in UASB (°C)		27.5	23.9	12.4
Treated water	BOD (mg/ℓ)	9.3	4.8	14.7
	COD_{cr} (mg/ℓ)	35.0	31.6	63.0
	SS (mg/ℓ)	9.9	5.0	14.6
Reduction(%) (BOD/COD_{cr})		94.4/91.1	96.9/89.0	91.1/78.8
Organic load	in terms of Empty Volume (kg BOD/m^3·d)	0.58	0.32	0.37
	in terms of Empty Volume (kg COD_{cr}/m^3·d)	0.97	0.73	0.65
	in terms of Working Volume (kg BOD/m^3·d)	2.0	1.4	1.3
Gas conversion rate	in terms of BOD (%)	56.7	60.0	18.2
	in terms of COD_{cr} (%)	29.7	34.9	11.0
	in terms of TOC (%)	41.6	49.9	13.4
Excess sludge (kg/m^3-sewage)		——	0.015	0.03-0.04

The destribution of volatile suspended solids within the UASB

The UASB in this pilot plant has 15 valves for sampling the interior liquid on each side of the tank. These values are from 300 mm to 3,100 mm above the floor level at intervals of 200 mm. Fig. 2 shows the distribution of volatile suspended solids in the UASB determined by sampling from these valves. The distributions remain in a steady state and there is a zone in which volatile suspended solids are more than 10,000 mg/ℓ near the gas-solid-liquid separator.

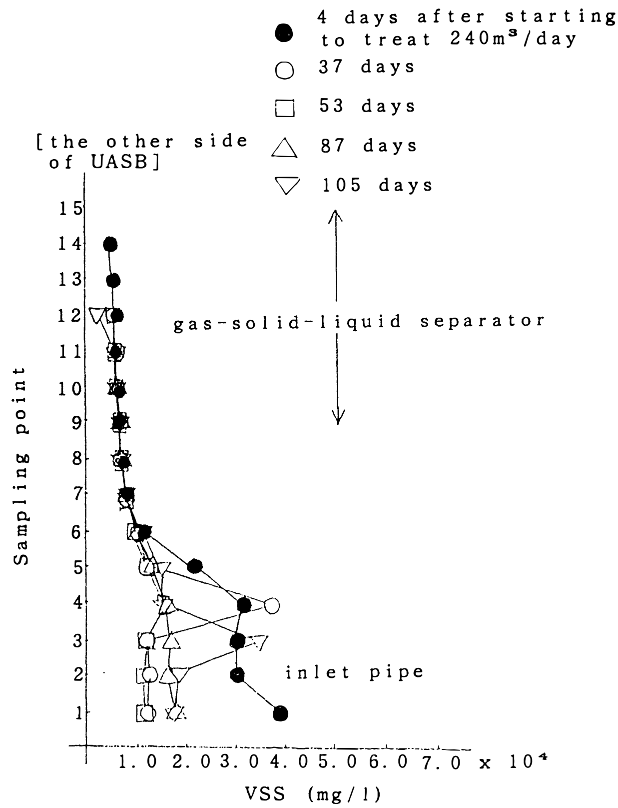

Fig. 2. Distribution of the concentration of VSS in UASB

Organic load

In terms of working volume, the organic loading rate was from 1.3 to 2.0 kg BOD/m³·d. The working volume is defined as the volume at which the concentration of volatile suspended solid is more than 10,000 mg/ℓ as shown in Fig. 2.

Gas conversion rate

The gas conversion rate was from 56.7% to 60.0% in terms of BOD, and from 29.5% to 34.9% in terms of chemical oxygen demand (COD) under the condition that the temperature in the UASB was more than 23°C. The gas conversion rate in terms of BOD (COD) is defined as that amount of oxygen required to completely oxidize the methane produced to total the BOD (COD) load.

Hydrolyzation reactor

The data in Table 3 show the results for the hydrolyzation reactor with the membrane module. The reduction rate for volatile suspended solids charged into the hydrolyzation reactor reached 84.8% under the condition that sludge residence time (SRT) was 445 days and the temperature in the reactor was 25°C. The methane produced by charged volatile suspended solids was 335 ℓ/kg, and methane produced by reduced volatile suspended solids was 441 ℓ/kg. In this case excess sludge from the plant was 0.015 kg per m^3 of sewage. An SRT of 144 days yielded really the same results. Mixing the aerobic sludge produced by backwashing of the aerobic reactor with the separated sludge from the filter shortened the SRT; nevertheless, the rate of reduction in volatile suspended solids reached more than 53%. If the hydrolyzation reactor is not equipped with a membrane module, it cannot reach such a high rate of reduction. It would be no greater than 45% even if the temperature in the hydrolyzation reactor were from 30°C to 35°C with an HRT from 15 to 30 days. When the aerobic sludge is mixed with the separated sludge, excess sludge from this plant was from 0.03 to 0.04 kg per m^3 of sewage. This value is 1/3 to 1/4 of the excess sludge generated from traditional processes, which consist of the standard activated sludge process and sludge digestion.

TABLE 3 Results of Hydrolyzation Reactor

Temperature (°C)	25	25	25	25
HRT (Hydraulic residence time)(days)	3.7	5.0	4.2	4.2
SRT (Sludge residence time) (days)	445	144	33.7	29.1
Reduction rate of VSS (%)	84.8	84.5	69.7	53.4
Methane product by VSS charged(ℓ/kg)	335	343	292	173
Methane product by VSS reduced(ℓ/kg)	441	387	394	333
VSS of aerobic sludge to total VSS led into hydrolyzation reactor (%)	0	0	12.5	30.4

Aerobic Reactor

In Japan, treated water must pass strict standards, so the effluent from the UASB must be polished through biological degradation and filtration under aerobic conditions.

The influent was from 27 to 41 mg/ℓ (average 32.1 mg/ℓ) BOD and from 16 to 54 mg/ℓ (average 31.2 mg/ℓ) SS. The effluent was from 3 to 12 mg/ℓ (average 4.8 mg/ℓ) BOD and from 2 to 14 mg/ℓ (average 5.0 mg/ℓ) SS. The average ambient temperature was 22.3°C; volumetric organic loading was from 0.5 to 0.76 kg BOD/m^3·d ; air consumption was from 3.6 to 4.0 Nm^3 per m^3 of sewage. BOD reduction was 85% and SS reduction was 84%.

Against untreated raw sewage, BOD reduction reached 96.9% and SS reduction reached 97.4%. Sulphate increased 14 mg/ℓ in this reactor, corresponding to a sulphide reduction of 5 mg/ℓ.

COD balance

The COD balance in raw sewage is shown in Fig. 3. Of the COD components taken into the plant, 100% was recovered.

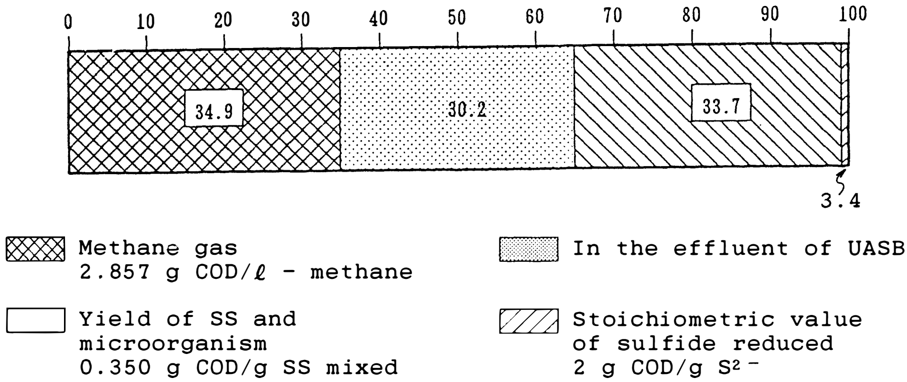

Fig. 3. COD balance

CONCLUSION

Our field test of a composite methane gas production system with membrane module for municipal sewage, which has a capacity of 240 m^3/d, yielded the following results. A two-phase anaerobic bioreactor combined with a membrane module is the effective process for anaerobic treatment of raw sewage at ambient temperature. This system makes it possible to degrade from 70% to 80% of the raw sewage BOD and achieve a gas conversion rate from 57% to 60% in terms of BOD, when the volumetric organic loading rate is from 1.4 to 2.0 kg BOD/m^3·d at ambient temperature.

The hydrolyzation reactor combined with a membrane module is very effective for degrading volatile suspended solids. When the SRT in this combination system is 144 days, 84.5% of the charged volatile suspended solid are degraded. Mixing the aerobic sludge produced by backwashing of the aerobic reactor with the separated sludge from the filter shortens the SRT. Nevertheless, the reduction in volatile suspended solids is still more than 53%. This contributes to the fact that excess sludge production is from 0.03 kg to 0.04 kg per m^3 of sewage and this value is from 1/3 to 1/4 of that using traditional processes.

ACKNOWLEDGEMENT

As a member of the Aqua Renaissance Research Association (ARRA), we are conducting this investigation under the auspices of the New Energy and Industrial Technology Development Organization.
We thank all the people at Kawasaki Heavy Industries, Nitto Electric Company, and Toshiba Corporation who helped to operate the plant used in this study.