Methane Fermentation of Seaweed Biomass

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Introduction

Recently, problems caused by seaweeds have been recognized in Japanese society, whose land is surrounded by the sea. Seaweeds glow in large quantities and pile up on the seashore (the green tide).[1, 2] **Figure 1** shows an example of such green tide. They spoil the view and release odor as they rot quickly. *Ulva* sp. is the most typical among those seaweeds. In Japan it is often marketed as a material for food. However, such frequently encountered *Ulva* sp. is not of the edible quality. After having been collected by local governments, a massive amount of seaweeds are being incinerated. Recently, seaweeds have been employed for ocean remediation, instead of being consumed as food. It is expected that they may protect fishery fields from waves and reduce nutrient in the sea. Cultivating *Laminaria* sp. has been attempted for such a purpose. Despite its effectiveness, the treatment of harvested seaweeds has arisen as a new problem.

In Japan, such unwanted seaweeds are abundant and, therefore, effective utilization of them is highly desirable. Extracting energy from them is one such example. It contributes as a means of ocean remediation and can serve as a remedy against the green house effect. In the existing literature on the methane fermentation of seaweeds, merely results of laboratory scale experiments[3, 4] have been reported. In the present study, a field test plant was built for the large scale practical processing of biogas from seaweeds. The maximum treating capacity of the plant is one ton-seaweed/day. The present plant is equipped with a gas engine power generator. At the same time, an effective method of converting biogas into energy has also been pursued. The present field test is a collaborative project with the New Energy and Industrial Technology Development Organization (NEDO) of Japan.

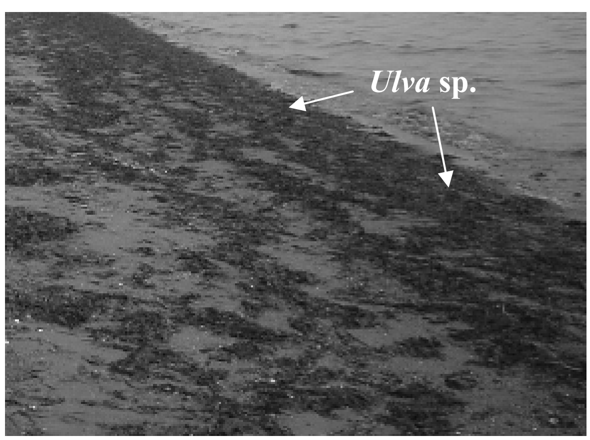

Figure 1 Photograph of the green tide

Source Materials and the Treatment Method

Source Materials

Seaweed samples (*Ulva* sp. and *Laminaria* sp.) were used as source materials for the present field test. Seaweeds collected in the sea and on the beach were a mixture with foreign matters such as sand and shells. Onshore seaweeds were especially rich in sand. Seaweeds used as test materals were first rinsed with fresh water before supplying to the field test plant. **Table 1** shows representative dry compositions of material seaweeds. Typically, seaweeds contain about 90 wt% of water.

Table 1 Representative compositions of seaweeds

		Ulva sp.	*Laminaria* sp.
Composition (wt%)	Lipid	1.6	1.9
	Protein	27.9	15.2
	Carbohydrate	54.3	45.6
	Ash	16.3	37.3
Elements (wt%)	C	35.7	28.8
	H	5.8	4.6
	N	3.9	2.7

The Treatment Method

The methane fermentation process is suitable for converting seaweeds into gaseous fuel in view of a high (about 90 wt%) water concentration. In the present field test pant, therefore, methane fermentation has been selected for energy generation. The plant consists of four processing units; namely, pre-treatment, fermentation, biogas storage, and generation, as shown schematically in **Figure 3**.

In the pre-treatment stage, seaweed test materials are cut after removing foreign objects such as shells. Then, the seaweeds are further cut down to several mm^2 pieces and diluted with water. Finally, they are sent to a receiver tank as the slurry state for ease of handling (**Figure 4**).

The fermentation stage is divided into pre-fermentation and methane fermentation for achieving higher fermentation efficiency. Seaweed slurry is treated by pre-fermentation (acid production) and used in methane fermentation as a substrate. Biogas is produced in the methane fermentation process. Inside the methane fermentation tank, porous matrices are held for immobilizing bacterial cells to minimize washout of bacteria. The two tanks are shown in **Figure 5**.

Since biogas contains trace amounts of hydrogen sulfide, it is refined using a de-sulfur agent. Purified biogas is stored in a gasholder (**Figure 6**), which is made of rubber. A residue of methane fermentation is dehydrated and used as fertilizer.

Biogas is employed as fuel for a co-generation system (**Figure 7**), which generates both electricity and heat. The present co-generation system is powered by a gas engine generator. Heat is recovered from exhaust gas and cooling water for the engine casing. In the present plant, biogas is mixed with city gas (natural gas-base) before being fed to the gas engine. A gas mixer of the engine is of an improved type enabling to handle biogas and city gas mixtures. Electricity generated by the gas engine is supplied to the electric equipment of the plant. Heat discharged from the engine is utilized as heating energy for fermentation tanks.

Figure 8 shows a layout of the plant facilities. Deodorization equipment using microorganisms has been installed. Capacities of the facilities are specified below.

- Pre-fermentation tank; 5 kl
- Methane fermentation tank; 30 kl
- Gas holder; 30 kl
- Co-generation system; electricity 9.8 kW, heat 22.7 kW

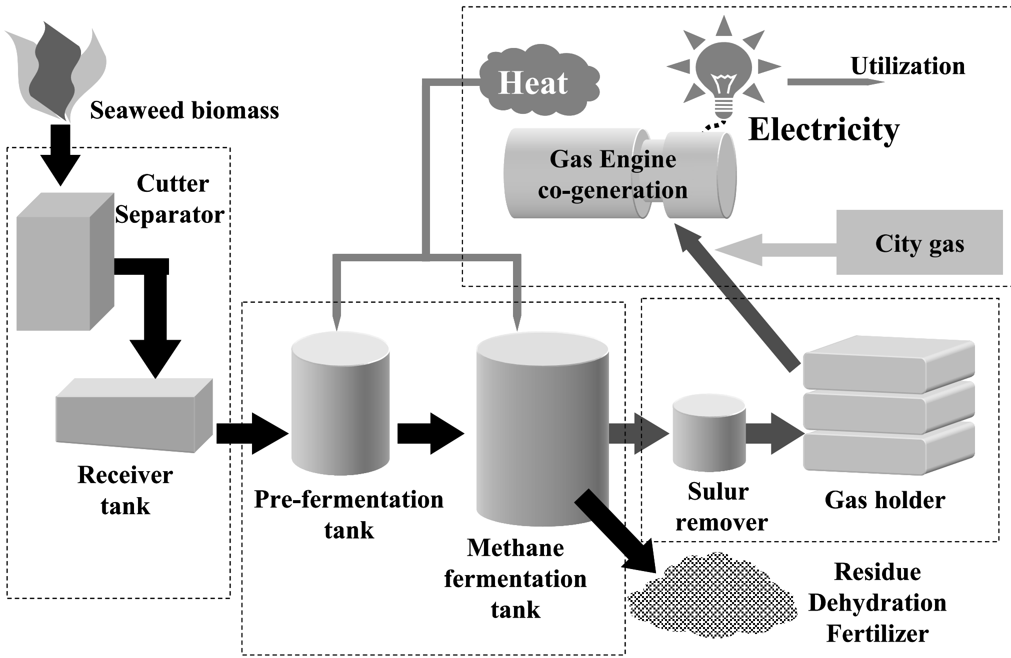

Figure 3 Schematic diagram of the plant

Figure 4 The receiver tank

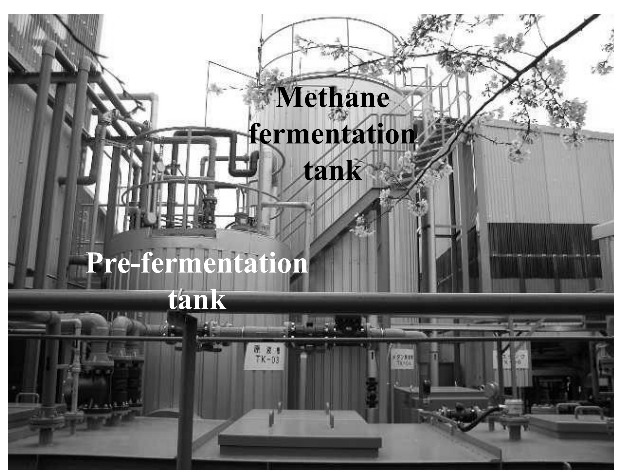

Figure 5 The fermentation tanks

Figure 6 The gasholder

Figure 5 The co-generation system

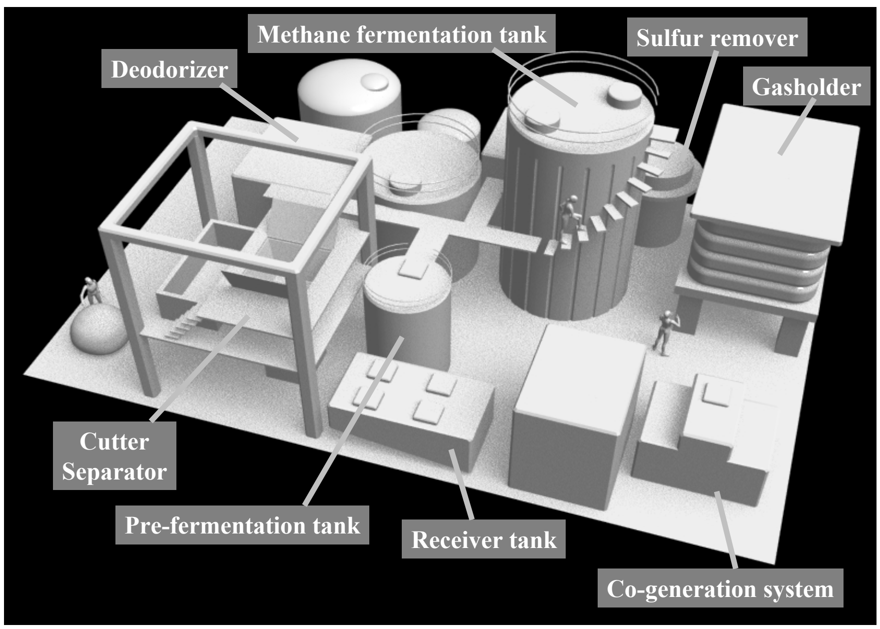

Figure 7 Layout of the plant

Results and Discussion

Methane fermentation of seaweeds

Seaweeds *Laminaria* sp. used as test mateials were supplied continuously with a rate ranging from 0.2 up to 1 ton/day. **Figure 9** shows test results. Material seaweeds were supplied 5 days a week on a regular basis. Total solid concentration (TS) after adding diluting water varied from 1 to 5%. The retention time of pre-fermentation was 2 to 3days. The temperature was controlled over a range of 25-35 °C. Total concentration of produced organic acid (mainly acetic, lactic, and butylic) changed from 1000 to 5000 ppm. In the case of methane fermentation, the retention time ranged from 15 to 25 days and the temperature was regulated at 55 °C. Consumption of organic acid in the methane fermentation tank has been confirmed to occur. Chemical reaction of organic acid and biogas took place in a satisfactory manner. Concentration of ammonium ion remained at a low level (under 150 ppm, not sufficient to prevent methane fermentation). Although a yield of biogas fluctuated due to occasional suspensions of a material feed, biogas generation was continuous. The composition of biogas was about 60 % methane and 40 % carbon dioxide. Several thousands ppm of hydrogen sulfide was also detected. Hydrogen sulfide was removed with iron oxide (de-sulfur agent) in the plant. Results of pH variation tests showed that, from the standpoint of a higher methane gas generation, a pH level larger than 7.5 should be sustained (see **Table 2**). One ton of seaweeds yields 22 kl of methane gas. Throughout the test period exceeding 150 days, biogas had been generated continuously.

Seaweeds *Ulva* sp. collected on the seashore were also tested. Samples were contaminated with foreign objects such as sand. Although such mixtures do not affect fermentation directly, they reduce available capacities of tanks. Hence, collected seaweeds were first rinsed with water to wash out contaminants prior to fermentation tests. A 0.6 ton/day (3% TS) of *Ulva* sp. was supplied 5days a week. Conditions of fermentation were identical to those applied to *Laminaria* sp. specimens described above. Organic acid was also generated in the pre-fermentation tank, with an acid concentration ranging from 1000 to 3000 ppm, and consumed in the methane fermentation tank. Concentration of ammonium ion, again remaining at a low level, was about 500 ppm and was thought to have little influence on methane fermentation. The composition of biogas was about 60 % methane and 40 % carbon dioxide, almost the same as in the previous case. **Figure 10** represents a yield of biogas and methane gas. A fluctuating biogas yield was also observed due to the same reason as discussed before. A time history of a weekly averaged gas yield is presented in **Figure 10**. A yield of biogas is seen to increase gradually until the 3rd week and, then, it stays stable. In particular, a yield of methane gas remains almost constant with a value of 15-17 kl per one ton of seaweeds. Overall, an available yield is lower, compared with the case of *Laminaria* sp. A possible cause of the difference may be the fact that *Ulva* sp. specimens were less susceptible to bacterial decomposition. Uninterrupted biogas generation lasted over 70 days. The test results demonstrate practical feasibility of biogas generation using seaweeds such as *Laminaria* sp. and *Ulva* sp.

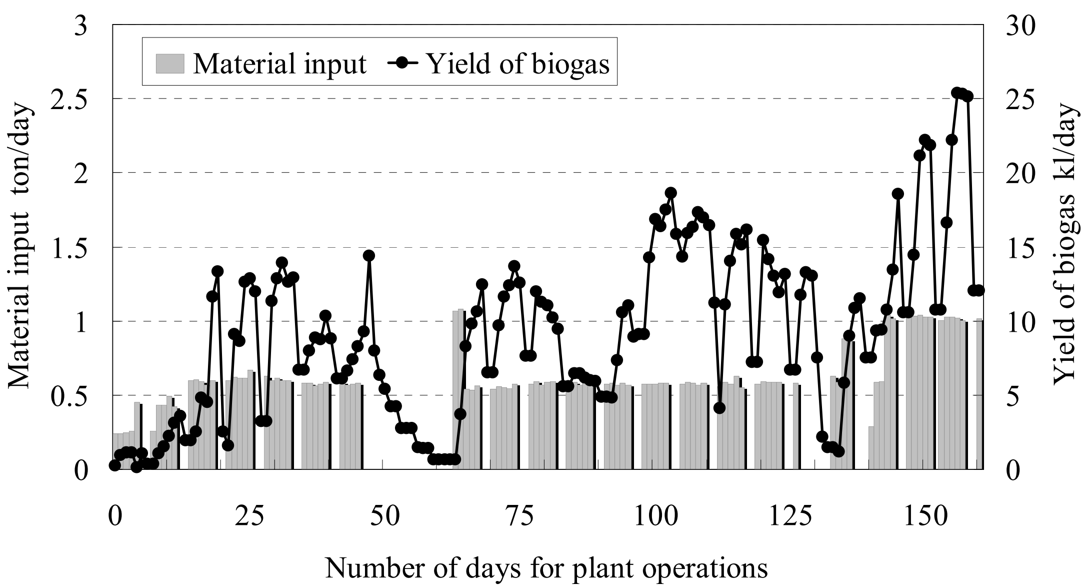

Figure 9 Test results for *Lamnaria* sp.

Table 2 Results of the pH variation test using *Lamnaria* sp.

pH	7.0	7.3	7.5	7.6	7.9
Biogas kl/ton	23.4	13.5	28.9	32.9	25.5
Methane kl/ton	11.2	9.2	18.8	22.0	19.9

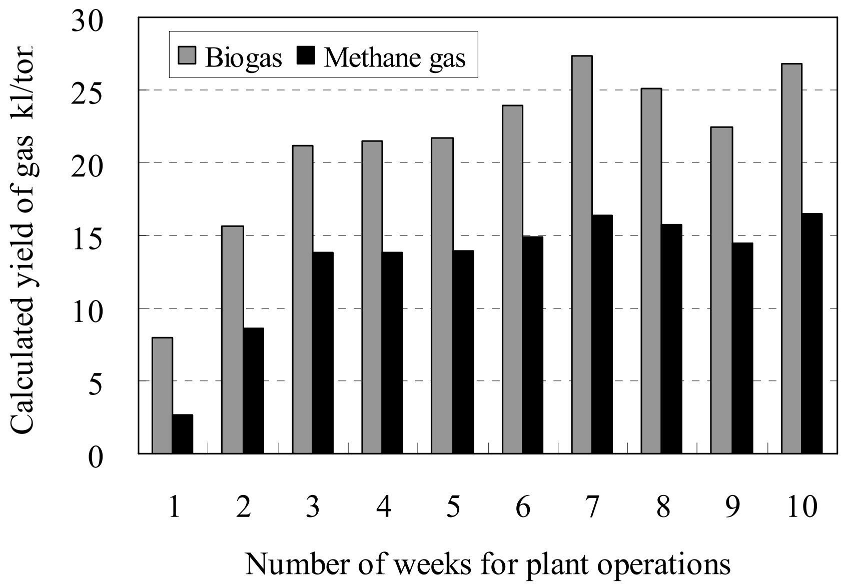

Figure 10 Test results for *Ulva* sp.

Tests of the co-generation system

De-sulfured biogas is used as gas engine fuel, which generates electricity in the present field test plant. The quantity and the composition of collected biogas often varied with an input amount of seaweed materials, which again depended on conditions of, for instance, the sea, weather and fermentation processes. Hence, an effective way of biogas utilization as fuel may be found in mixture form with other fuel sources of stable supply, such as city gas. By properly controlling the ratio of city gas to biogas in gas mixtures, stable engine operation may be possible even under fluctuating of amount of produced biogas. Attempts for adding city gas to biogas were made by regulating heat value of fuel gas. Mixing fuel gases can contribute to lower concentration of carbon dioxide, which acts against combustion, and lead to improve thermal efficiency of the gas engine. Experimental results in **Figure 11** show that higher thermal efficiency may be reached using biogas and city gas mixtures, compared with the case of biogas only as fuel gas. In the tests, the power output of the gas engine was held constant at 9.8kW and the air/fuel ratio was regulated in such a manner that concentration of NOx in exhaust gas was maintained at 150 ppm (O_2=0%). The obtained results illustrate that almost the same level of thermal efficiency as that achievable with city gas alone may be gained by using gas mixture.

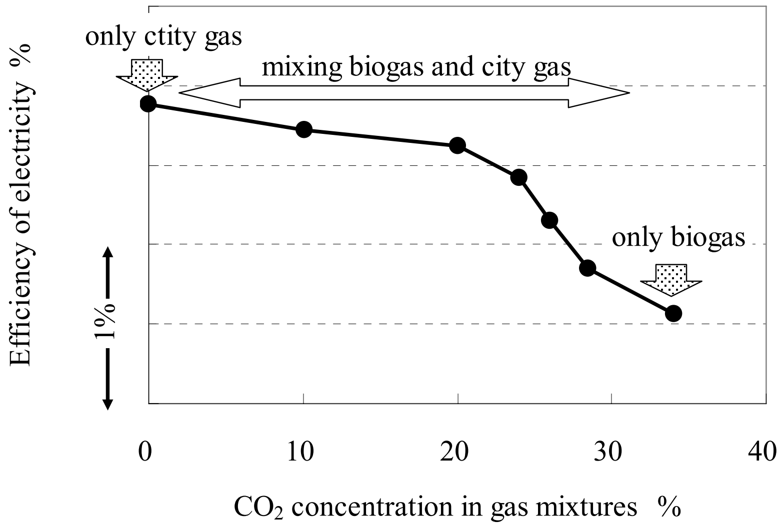

Figure 11 Results of the gas engine test

Conclusion

Continuously generating biogas from seaweeds over a long period of time has been successfully demonstrated. Generated biogas has been effectively used as fuel gas of the gas engine power generator. Encouraged by the present results, wider utilization of seaweed biomass is expected in the future.

References

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