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A BIOMASS ENERGY SYSTEM BY DRY ANAEROBIC DIGESTION FOR URBAN AREAS IN JAPAN

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1. ABSTRACT

In urban areas of Japan, recycling of garbage and paper waste from offices and restaurants is still insufficient. Currently, a significant amount of biomass resources are treated by incineration without recovering energy from them. As a means of energy conversion in treating this class of waste suitable for dry anaerobic digestion, we have developed an anaerobic digestion system for such urban biomass. In developing such a system, we have attempted to achieve 1) stable dry anaerobic digestion for realistic urban biomass comprising garbage and paper waste, 2) simple treatment of residue, 3) optimal control of co-firing city gas and biogas, thereby rendering a biogas-holder unnecessary, and 4) energy balance forecast.

A demonstration plant was completed in March 2009 and soon put in operation. Biomass feed was garbage and paper waste collected from commercial premises in Tokyo. The capacity of feed was 300 kg per day. Generated biogas was used as fuel for co-firing tests. For minimizing the role of a biogas-holder, the proper control of city gas-biogas co-firing has been devised and tested. The residue of demonstration plant was used for the laboratory test to confirm the simple residue treatment and assess the energy consumption. Based on the above data, the energy balance forecast was conducted.

The demonstration plant has successfully confirmed stable and highly efficient dry anaerobic digestion. Although biogas and methane generation as well as methane concentration underwent periodic cycles on a weekly basis, the total output of methane over a week remained almost constant and stable. The decomposition rate of Volatile Solid reached up to 78–84%. The result suggests that the decomposition rate of urban food and paper waste can surpass that obtainable by other classes of waste.

It was confirmed that simple control system for co-firing worked well. The result suggests that unless the operation is unsteady, the biogas-holder may be eliminated entirely.

Analysis based on the energy balance forecast of the new biomass energy system indicates significantly lower energy consumption and carbon dioxide emission than those of the existing incineration systems.

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2.1. Introduction

The recycling rate for garbage and paper waste, to be classified as 'mixed paper', is still low in urban areas of Japan. Currently, a significant amount of biomass resources are treated by incineration without recovering energy from them.

Mixtures of garbage and paper waste are amenable to dry anaerobic digestion (Six and De Baere, 1992)(Hartmann and Ahring, 2006). Since this class of system usually does not call for effluent treatment facilities, it is thought appropriate for a biomass energy system in urban areas (De Baere, 2000) (De Baere, 2006). In developing such a system, we have attempted to achieve 1) stable dry anaerobic digestion for realistic urban biomass comprising garbage and paper waste, 2) simple treatment of residue, 3) optimal control of co-firing city gas and biogas, thereby rendering a biogas-holder unnecessary, and 4) energy balance forecast.

The present paper reports the result of verification tests for a developed urban biomass energy system by dry anaerobic digestion.

2.2. Experimental method

2.2.1. Specifications of the demonstration plant

A demonstration plant, shown schematically in Figure 1, was completed in March 2009 and soon put in operation with the following specifications.

- Biomass feed (55% water content): garbage and paper waste collected from commercial premises in Tokyo
- Capacity of feed: 300kg/day (120-180kg/day of garbage *vs.* 180-120kg/day of paper waste)
- Biogas property: output of ca. 62m^3/day with 48-62% methane content
- Capacity of the digester: 20 m^3
- Capacity of the biogas-holder: 20 m^3

Boiler capacity: 120kg/hour of steam generation from city gas and biogas fuel

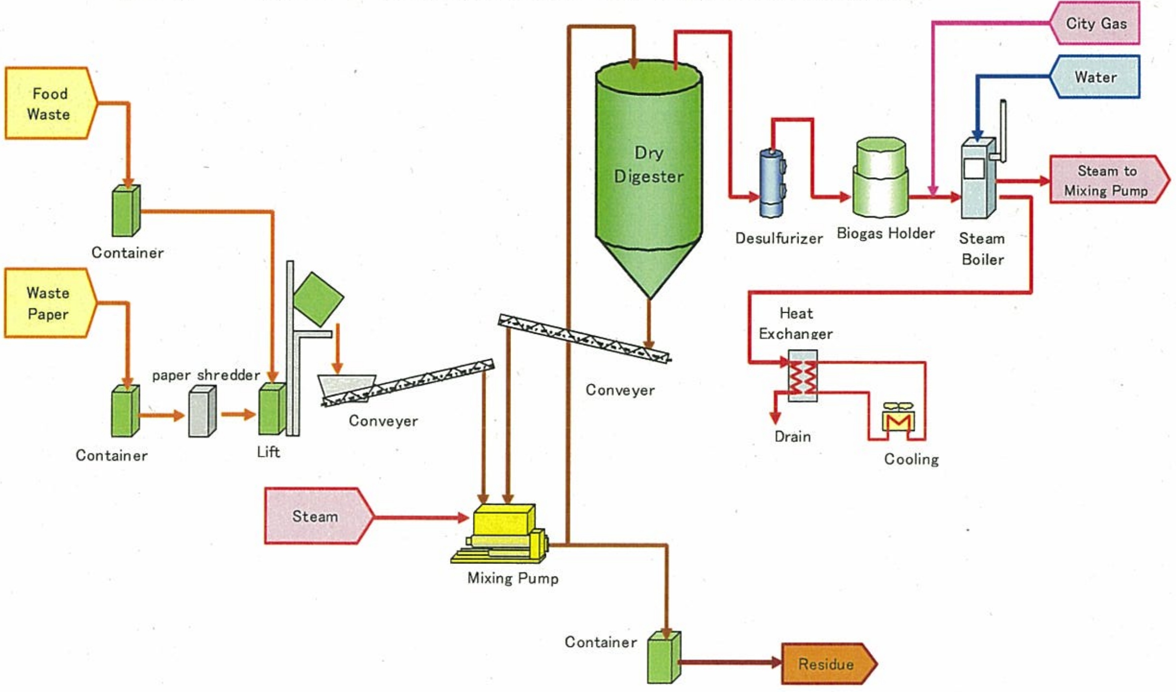

Figure 1. Schematic flow diagram of the urban biomass energy system demonstration plant

2.2.2. Operation of the Urban Biomass Energy System

Referring to a flow diagram shown in Figure 1, plant operations consist of

- Crushing and blending: Garbage and paper waste were collected separately from large commercial premises. After paper was crushed to around 10mm diameter in size, it was blended with garbage at a specified ratio to form feed.
- Mixing and heating: Digester residue (from a previous run) was added to feed, and mixture was heated to 55°C by injecting steam.
- Anaerobic digestion: Mixture was fed to the digester for anaerobic digestion to proceed. Feed left a certain amount of residue.
- Biogas utilization: After removing sulfur in the desulfurizer, biogas was sent to the biogas-holder equipped with a bypass. Biogas was mixed with city gas for co-firing in the boiler in which steam, to be used as heating feed, was generated. Unused surplus steam was condensed to rewater the boiler.

2.2.3. Stability of dry anaerobic digestion

Feeding the digester with collected waste lasted on weekdays (Mondays through Fridays) but not over the weekend (Saturday and Sunday). The various raw materials shown in Table 1 were chosen as feed for verifying stable biogas generation rate for practical use. Steady operation started on June 15, 2009 and lasted over a nineteen-month period.

Table 1. Feedstock conditions and the objectives of the demonstration

Feedstock		G-50	G-55	G-60	I-50	I-40	I-30	I-50(2)	I-50(HC)	I-55
Place		large commercial premises			a grocery supermarket					
Ratio of paper waste(%)		50	55	60	50	40	30	50	50	55
Composition of garbage	vegetable	–	–	–	79	79	54	78	1	36
	meat/fish				16	16	16	22	20	27
	bread/noodle				5	5	30	0	79	37
Feeding period		15Jun09 ~22Nov09	23Nov09 ~21Feb10	22Feb10 ~14Mar10	12Jul10 ~15Aug10	16Aug10 ~19Sep10	20Sep10 ~10Oct10	18Oct10 ~7Nov10	15Nov10 ~12Dec10	27Dec10 ~23Jan11
VS feed (kg/d)		103.8	102.2	–	101.4	68.5	116.9	88.3	116.0	89.0
Objective		Verify the applicability for MSW from large premises			Verify the applicability for MSW from general public				Verify the difference depending on the composition of garbage	

2.2.4. Validation of co-firing control

Figure 2 represents the variation of biogas generation over the period of a typical week. Figure 3 shows a schematic flow diagram of the co-firing control system. Biogas generated by the demonstration plant was used as fuel for co-firing tests. Four controlling procedures for co-firing city gas and biogas were examined with aim toward minimizing the role of the biogas-holder.

Two controlling procedures, namely, the regulation of the biogas flow rate and the biogas heat value control, each taking place under a constant city gas flow, relied on the biogas-holder.

While the biogas-holder did not involve the remaining two controlling procedures, which underwent without the biogas flow rate control, as explained below. In one, by taking measurement of the methane concentration and flow rate of biogas, the heat value of biogas was calculated. In the other controlling procedure, the oxygen concentration of exhaust gas was measured. In both cases, the proper amount of city gas was added to sustain boiler input to an assigned constant heat value. Note that, because the combustible component of both biogas and city gas was methane, it was possible to keep the mixed gas heat value constant by controlling exhaust gas oxygen concentration. Only an oxygen sensor and one flow controller were all that were necessary for such very simple controlling procedures.

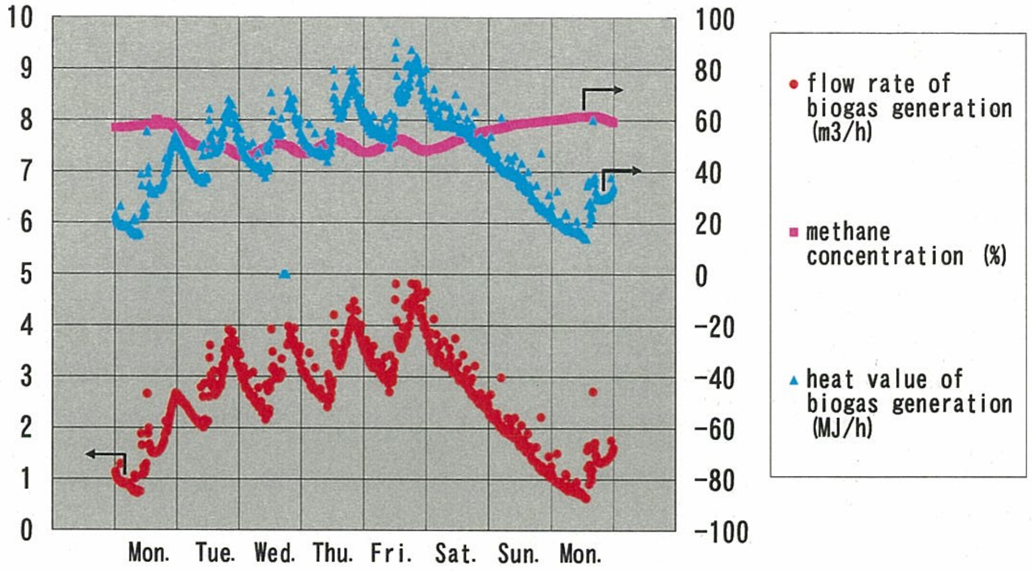

Figure 2. Variation of biogas generation over a typical week period

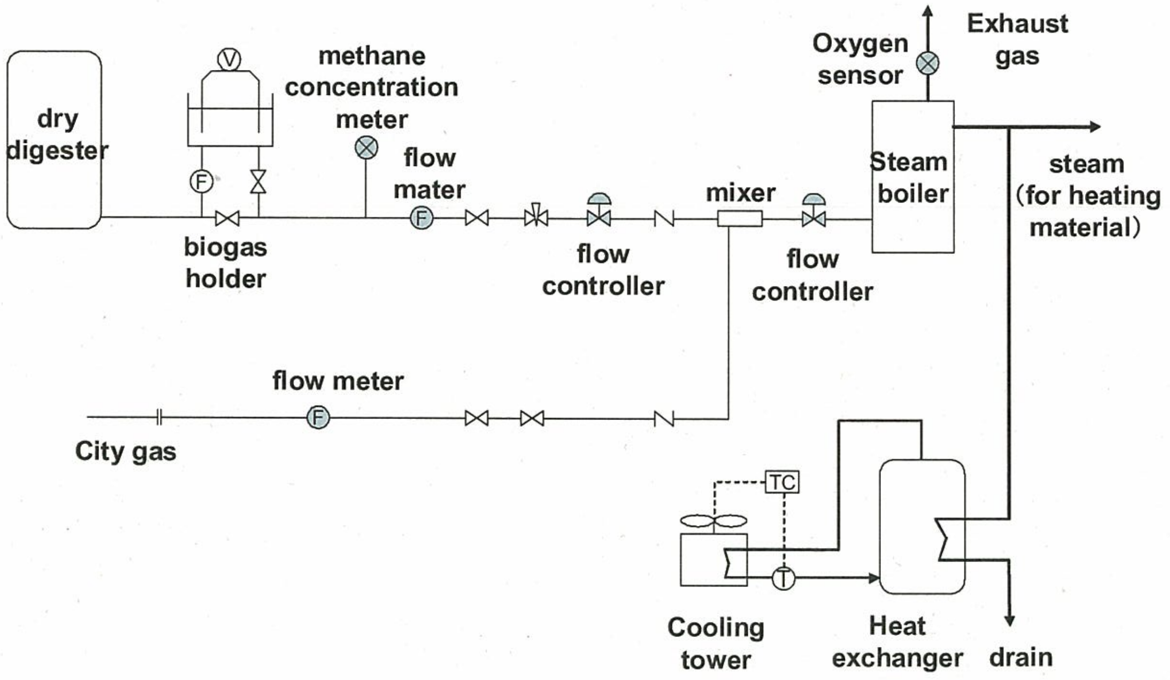

Figure 3. Schematic flow diagram of the co-firing control system

2.2.5. Simple treatment of residue

For a dry anaerobic digestion system, effluent treatment is usually not necessary. However, it still requires handling of wet residue (with a water content at around 80%). To devise a simple residue treatment method, laboratory-scale tests for drying, carbonization and dewatering were conducted using the actual residue from the demonstration plant. As sludge dehydration methods, we have selected direct drying, indirect drying, vacuum drying, carbonization and dewatering, among which the energy consumption rate was compared.

2.3. Results

2.3.1. Stability of dry anaerobic digestion

Figure 4 shows the result of dry anaerobic digestion for product output against the regular feed input mentioned earlier over the entire period of the demonstration run. Although biogas and methane generation as well as methane concentration underwent periodic cycles on a weekly basis, the total output of methane over a week remained almost constant and stable. Comparing I-40 and I-50(2) both of which contained low Volatile Solid feedstock, the output fell as the VS load decreased; however, it recovered by increasing the VS load. Through the demonstration period, no fermentation inhibition was observed.

The actual values of digestion are shown in Table 2. It is seen that the higher the VS feed, the larger the methane output. The decomposition rate of VS reached up to 78–84%. Generally speaking, while the decomposition rate of garbage is high, that of paper depends on its type. In the present demonstration, typical paper waste consisted of shredded OA paper having a sufficiently high decomposition rate. The result suggests that the decomposition rate of urban food and paper waste possibly surpasses that obtainable by other classes of waste.

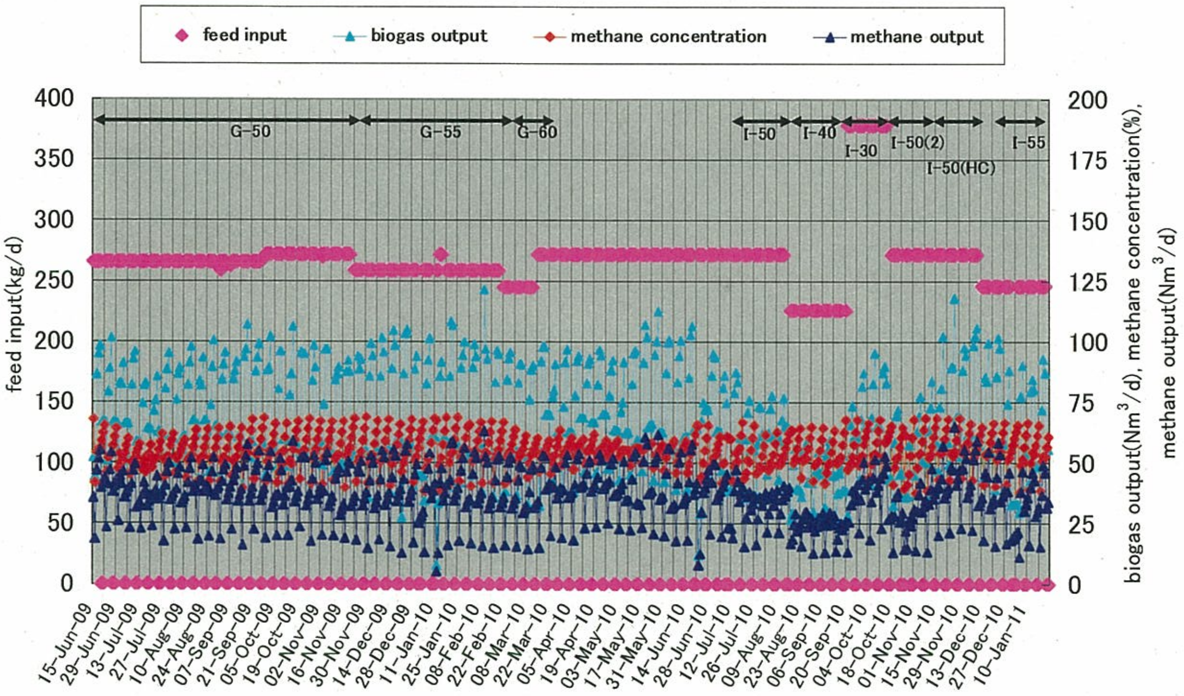

Figure 4 Result of dry anaerobic digestion

Table 2. The actual value of digestion

Feedstock		G-50	G-55	G-60	I-50	I-40	I-30	I-50(2)	I-50(HC)	I-55
Place		large commercial premises			a grocery supermarket					
Ratio of paper waste (%)		50	55	60	50	40	30	50	50	55
Composition of garbage	vegetable	–	–	–	79	79	54	78	1	36
	meat/fish				16	16	16	22	20	27
	bread/noodle				5	5	30	0	79	37
Biogas output (m^3/t)		373.3	391.9	–	314.6	290.7	251.7	278.7	401.1	369.1
Methane output (m^3/t)		201.6	211.6	–	169.9	157.0	135.9	150.5	216.6	199.3
VS feed (kg/d)		103.8	102.2	–	101.4	68.5	116.9	88.3	116.0	89.0
Decomposition rate wt%)		84.1	79.7	–	79.6	78.6	78.1	82.2	82.3	80.1

2.3.2. Examination of co-firing control

Table 3 summarizes the result of verification tests for the co-firing control system. When a biogas-holder served as a buffer for flow rate or total heat control of biogas, firing remained stable. Such advantage would be offset by the fact that the biogas-holder devoured over a third of daily biogas output. Even if no biogas-holder was employed, stable co-firing could be achieved by careful tuning and controlling. In the control procedure sensing the heat value of biogas, even though the heat value generation of biogas varied as shown in Figure 2, heat value of boiler input was controlled to remain fairly constant. Furthermore, in the control procedure sensing the exhaust oxygen concentration, heat value of boiler input was controlled to stay sufficiently constant. The result of the co-firing control test using it is shown in figure 5. For the two biogas-holderless controlling procedures, an extensive run over a period longer than 70 days was accomplished to demonstrate the sustainability of the both methods. The present result suggests that unless the operation is unsteady, not only the biogas-holder may be eliminated entirely but also the control system itself can be much simplified.

Table 3. Result of verification test for co-firing control system

Control system	*With* biogas holder		*Without* biogas holder	
	Biogas flow rate controlled and constant city gas flow added to bring boiler input to constant heat value	City gas flow rate controlled and constant biogas heat value added to bring boiler input to constant heat value	Biogas flow rate NOT controlled and city gas flow rate controlled to bring boiler input to constant heat value	Biogas flow rate NOT controlled and city gas flow rate controlled to bring exhaust gas oxygen to constant concentration
stability	stable	stable	stable	stable
Required biogas holder volume	More than one third of daily biogas output		None (0m^3)	
result	Stability requires a large holder		Stable for long run (> 70 days)	

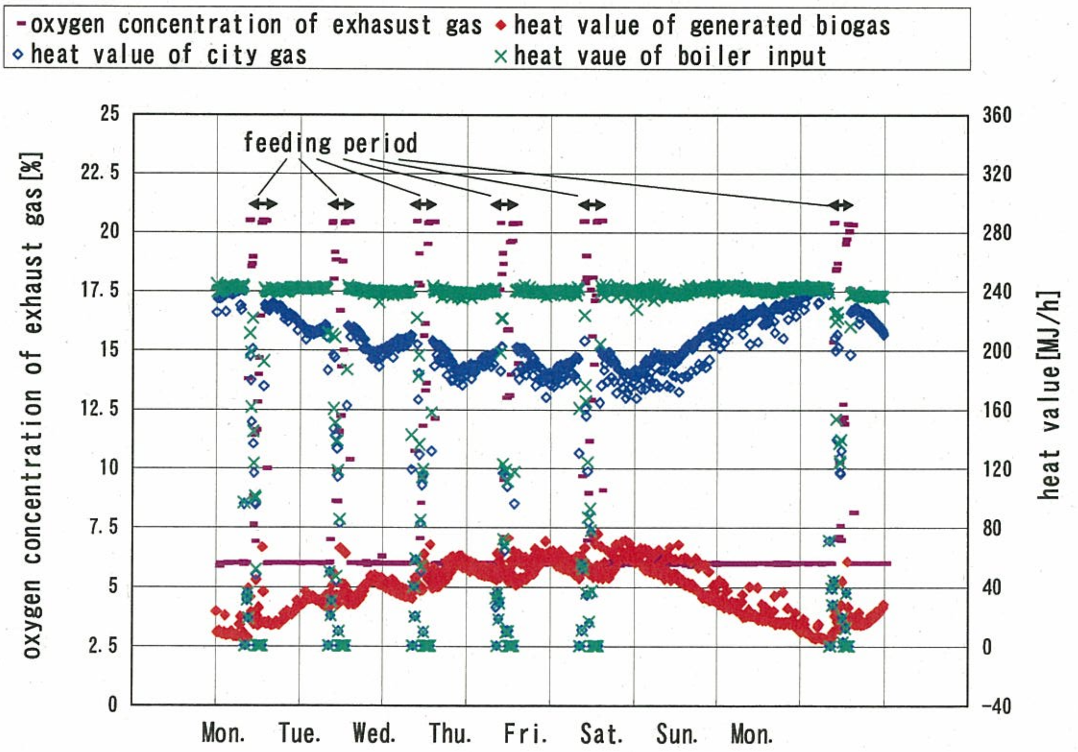

Figure 5. Result of co-firing control test

2.3.3. Simple treatment of residue

Table 4 compares the method-wise energy consumption for residue treatment. Although every system would work well, the high decomposition rate of digestion lowered the heat value of carbonized substance, pushing it down even below, 12500 kJ/kg, a target value for fuel and, hence, unsuitable for fuel use. Dewatering, which consumed the least amount of energy among the methods considered here, would be the most favourable.

Table 4. Result of verification test for residue treatment system

Treatment system	Drying	Drying + Carbonization	Dewatering
Power consumption (kWh / ton–residue)	46.7	85.9	92.4
Biogas consumption (Nm^3 / ton–residue)	133.1	157.5	0
Primary energy consumption (MJ / ton–residue)	2,981	3,794	804

2.4. Discussion

Through demonstration of dry anaerobic digestion using garbage and paper waste collected from urban areas of Japan, stable digestion operations have been accomplished together with high decomposition rate, stable control of biogas and city gas co-firing, and simple treatment of residue. Here we compare the energy consumption and the carbon dioxide emissions of the present system with the conventional incineration cases.

2.4.1.. Assumptions based on the realistic situations

For the energy balance forecast, a system shown in Figure 5 was considered under the following assumptions:

- Feedstock is collected as Municipal Solid Waste.
- The heat value of feed is not accounted for.
- Of an 80 ton/day of MSW, the one half is suitable as feed for the dry anaerobic digestion system and the remaining half is incinerated.
- The entire residue is dried, carbonized, or dewatered. While dried portions are incinerated, carbide serves material for a cement factory.
- Biogas heats biomass feed as auxiliary fuel for drying and carbonization.
- Surplus biogas generates steam as an alternative to city gas.
- Comparison is made with an incineration system with the identical capacity (80 ton/day).

2.4.2. Result of the energy balance forecast

Table 5 presents the energy balance forecast. In all the cases of dry anaerobic digestion, the primary energy consumption and carbon dioxide emission are significantly reduced compared to the baseline data owing to much larger energy recovery which more than offset additional energy required for running the system. Due to the least amount of energy required for dewatering among the residue treatment methods considered here, its primary energy consumption is found to be the lowest.

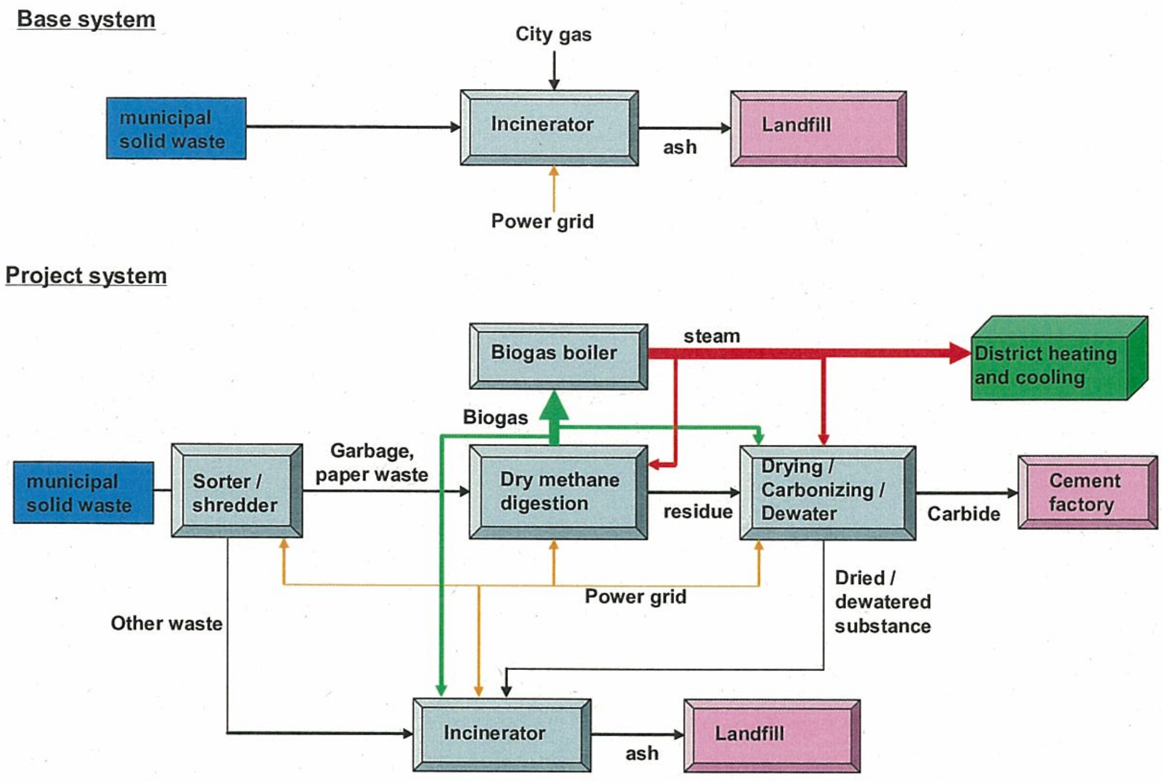

Figure 6. Schematic system flow diagram for energy balance forecasting

Table 5. Result of energy balance forecast

	Base case (Incinera–tion only)	Dry anaerobic digestion + Incineration		
Residue treatment system		Drying	Drying + Carbonization	Dewa–tering
Primary energy consumption (GJ–LHV / year)	49,855	17,588	3,424	–1,562
Carbon dioxide emission (ton–CO_2 / year)	2,169	262	–1,045	–867

2.5. Conclusions

The dry anaerobic digestion demonstration plant for an urban biomass energy system has been constructed. The following findings have been obtained through the system verification tests and the energy balance forecast:

- Using the realistic urban waste, stable operations have been accomplished for the present dry anaerobic digestion system.
- The decomposition rate has reached up to 78-84%.
- Co-firing of city and biogas was possible without using the biogas-holder, allowing much simplified facility design in the future.
- With an 80 ton/day of MSW, one half of which is thought to form feed for the dry anaerobic digestion system, significant energy conservation and carbon dioxide reduction may be realized.

A new biomass energy system such as this one considered in the present investigation would be successfully operated for treating urban waste in Japan.

3. REFERENCES

1. Angelidaki, I., Sanders, W. (2004) Assesment of the anaerobic biodegradability of macropollutans. Re-views in Environmental Science and biotechnology, 3 (2), pp. 117-129
2. De Baere, L. (2000) Anaerobic digestion of solid waste: State-of-the-art. Water Science and Technology, 41 (3), pp. 283-290
3. De Baere, L. (2006) Will anaerobic digestion of solid waste survive in the future? Water Science and Technology, 53 (8), pp. 187-194
4. Hartmann, H., Ahring, B.K. (2006) Strategies for the anaerobic digestion of the organic fraction of municipal solid waste: An overview. Water Science and Technology, 53 (8), pp. 7-22
5. Saint-Joly, C., Desbois, S., Lotti, J.-P. (2000) Determinant impact of waste collection and composition on anaerobic digestion performance: Industrial results. Water Science and Technology, 41 (3), pp. 291-297
6. Six, W., De Baere, L. (1992) Dry anaerobic conversion of municipal solid waste by means of the Dranco process. Water Science and Technology 25 (7), pp. 295-300

4. ACKNOWLEDGEMENT

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