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INTEGRATION OF CENTRALIZED BIOGAS PLANT IN COLD-SNOWY REGION IN JAPAN

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Invited paper

Abstract: A centralized biogas plant was built in Shikaoi town,Hokkaido, Japan to treat manure from 1320 cattle heads. The biogas plant was designed to operate at a feeding amount of 85.8 t/day, a hydraulic retention time (HRT) of 37 days and at a digester temperature of 38 °C. In this study, the operational performance of biogas plant, utilization of digested slurry and economic balance were investigated. Since the working conditions of the plant became stable, the biogas production was 2,687 m^3/day, 92% of produced biogas was consumed in power generation. Average methane concentration in produced biogas was 57.7%. The hydrogen sulfide (H_2S) concentration was decreased to below 140 ppm as a result of bio-desulfurization and dry-desulfurization. The average power generation was 3,737 kwh/day and from that 54% of produced biogas was consumed in the facility operation, while 46% was sold to Power Company. About 20,260 t of digested slurry were applied onto 602 ha grassland and agricultural fields. From the results of the operational performance of the plant and the economic balance evidence, it is evident that the centralized biogas plant has a positive effect on the local economy.

Key words: biofuel, biogas, centralized biogas plant, digested slurry, economic balance, electric power selling, snowy cold region

Introduction

Animal waste constitutes of high proportion of biomass and its utilization and recycling is important for economical and environmental aspects. Anaerobic fermentation of animal waste creates combustible methane as a biogas. This biogas can be converted to heat, electricity and fuel, which can subsequently be used as an energy source for local community. Moreover, after anaerobic fermentation, the digested slurry that contains large amount of nutrients, can be used as a liquid fertilizer for crops. The benefits of biogas plant include renewable energy production, reduced greenhouse gas emission, efficient organic waste recycling, and improve utilization of the manure as fertilizer.

In Hokkaido, the first biogas plant was established in 1977 as demonstration plant in Obihiro University. Subsequently, the several demonstration plants were built in 1980s followed by the Kitami city demonstration plant which was built in 1990s *(Takahata et al., 1989, 1990; Umetsu et al., 2000)*. Since the 2000s, construction of practical and demonstration plants has increased due to global concern in environmental degradation and increasing price of fossil fuel *(Aoki et al., 2006)*. So far about 50 units had been constructed. However, currently, except for practical plants in operation, most of the demonstration plants have been shutdown or revoked, because of high cost of maintenance, technical problems such as blockage and freezing of feedstock and low biogas yields.

Base on this background, a centralized biogas plant in Shikaoi, Hokkaido, Japan has been constructed to treat animal wastes from dairy farms of various scales and managing styles. It is characterized by the ability to treat mixture of cow manure and bedding wheat straw, ability to handle other organic wastes and efficiently utilizing of the digested slurry. Further, it is the country's largest practical plant working at snowy cold regions. A centralized biogas plant might benefit from improved technology and economies of scale.

This study was intended to investigate the operational performance, technical and economic viability of the centralized biogas plant. Moreover, the utilization of digested slurry was investigated.

Materials and Methods

Survey study of the centralized biogas plant. The centralized biogas plant built in Shikaoi, Hokkaido, started operation in 2007. Shikaoi town is located in the northwestern part of the Tokachi plain, Hokkaido. This region is a snowy cold region, where annual average temperature is 6.1 °C and the average temperature in winter (November - March) is -3.4 °C. The average winter minimum temperature is -7.7 °C and the maximum snow depth is 61cm.

Based on concept of biomass town, a construction plan of a centralized biogas plant in Shikaoi was formulated in 2006. The implementation of the biogas plant project was to be in four phases: 1. Basic conception; 2. Planning, 3. Construction, 4. Operation. In order to minimize the risk of technical problems and improve the benefits, it was requested to communicate with farmers and local community.

As results of inadequate information to the farmers, insufficient amount of feedstock or failure in maintenance, most of previous biogas plants were aborted. Basic concepts of this plant were to address all the aforementioned problems adequately and to reflect the insights of farmers. Therefore, the key objective of the plant was to reduce the running cost through the scale merit and improved technology such as preventing the blockage or freezing of feedstock during winter in cold snowy region.

Overview of centralized biogas plants. The overview of centralized biogas plant is shown in Figure 1. The plant was designed to a feeding amount of 85.8 t/day, a hydraulic retention time of 37 days and mesophilic fermentation of 38 °C. It is built to treat 1,320 herd cattle manure from 11 dairy farmers. The main feedstock is dairy cattle manure, mixed with little washing water and bedding wheat straw. Sometimes, sewage sludge and kitchen waste are added. Each farmer places a lidded container for storing feedstock and two trucks are used for transporting it to the plant. These vacuum tank trucks can suck liquid manure from the underground storage pit. When the material in the container is frozen in winter, it is thawed by the exhaust heat of truck engine.

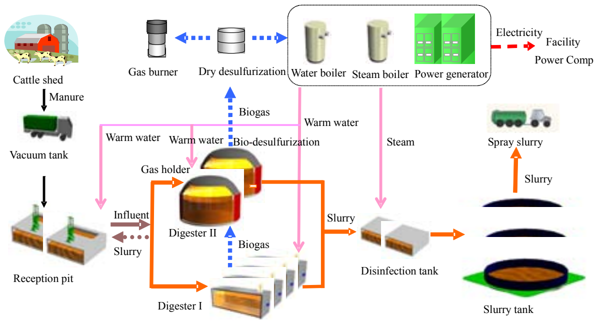

Figure 1. Overview of centralized biogas plant

The feedstock is put into two underground reception tanks and mixed by a large stirrer. Each reception tank is made of concrete and has three units of 15kW agitator. Reception tank was constructed with warm water pipe and slurry return pipe, so it can adjust the feedstock concentration and can thaw partially frozen materials. The adjusted feedstock is transferred to two types of rectangular straight digester I and cylindrical digester II. Transfer system consists of 3.7 kW hydraulic piston pump and 200 mm of large diameter pipes to prevent blockage. The digester I has a spiral horizontal paddle stirrer, suitable for high concentration of feedstock. The digester II has a horizontal paddle stirrer of propeller type and vertical agitator, suitable for processing relatively low concentration of feedstock. Therefore changing concentration of feedstock can be handled by the facility. Effective volumes of each digester were 1600 m^3.

Digested slurry is transferred to the sterilization tank, sterilized by steam boiler for 70 °C, 1 hour. After sterilization, it is stored in 3 slurry tanks. It is then transferred to the truck tank by 7.5 kW pump and applied on to field.

Generated biogas from each digester is collected to a common gas holder. Digester I generated biogas is transferred to gas holder, which has been installed at the top of digester II, mixed with biogas generated from digester II.

The desulfurization of biogas is used a bio-desulfurization and dry desulfurization. Bio-desulfurization equipment has been installed in the gas holder. When injecting air into the biogas holder, the hydrogen sulfide is oxidized by the desulfurization bacteria activity. After biological desulfurization, for most reduced hydrogen sulfide concentration, the biogas was transported to the dry desulfurization unit. Then biogas can be supplied to boilers and power generators as fuel.

Two type generators 108kW and 200kW were installed and used properly according to the biogas production. The generated electricity is used for facility operation and generated heat is heating for reception tank and digester. The excess gas is burning in gas burner, has not been released to atmosphere as methane directly.

Running monitoring. Feedstock amount for each digester is monitored by electromagnetic flow meter and generated biogas was measured by gas flow meter. The methane and hydrogen sulfide concentration were determined by gas analyzer. Power generation and power consumption were measured by the energy meter.

Results and Discussion

Volume of feedstock. Figure 2 shows the change of amount of feedstock for two digesters. In 2008 and 2009 fiscal year, the amounts of feedstock were averaged 61.3 t/day and 81.0 t/day, respectively, which accounted for 71% and 95% of the designed feeding amount of 85.8 t/day. The variation in amount of feedstock was caused by changes in dairy farm management such as feeding or grazing. Among these, digester I accepted 63% and digester II accepted 37%. The HRT of both digesters were longer than the designed HRT. The main reason for extended retention time was because of less feedstock collection compared to initial plan.

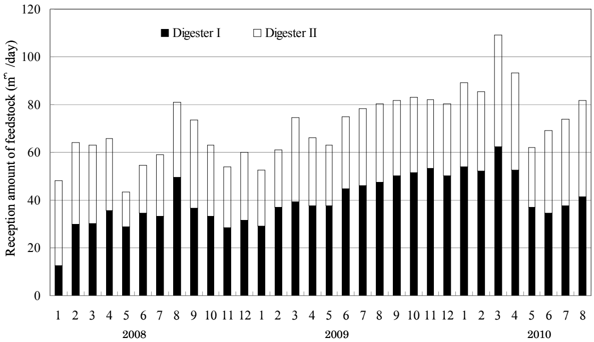

Figure 2. Change of the amount of reception feedstock

Biogas production. Figure 3 shows the changes in biogas production and consumption. In 2008 and 2009 fiscal year, the biogas productions were averaged 2338 m^3/day and 3036 m^3/day, respectively. The significant decline in biogas production was caused by damage of stirrer or faulty computer control and monitoring system. Generally, biogas production increase with longer retention time and when the retention time is more than 50 days average biogas production would be 0.4 m^3/kg-TS. The average influent TS were about 9%. Thus the biogas production can be calculated as 61.3 t/day× 9% × 0.4 m^3/kg-TS = 2207 m^3/day. The results show that the biogas production was nearly the theoretical value. Meanwhile, biogas production of influent 38.1 m^3/t-influent was also calculated. Biogas productions from another 12units biogas plant in Hokkaido were ranged 20 - 27 m^3/t-influent. It is generally agree that biogas production of domestic biogas plant were ranged 20 ~ 25 m^3/t-influent. It is possible that the higher biogas production from this plant was a result of longer retention time.

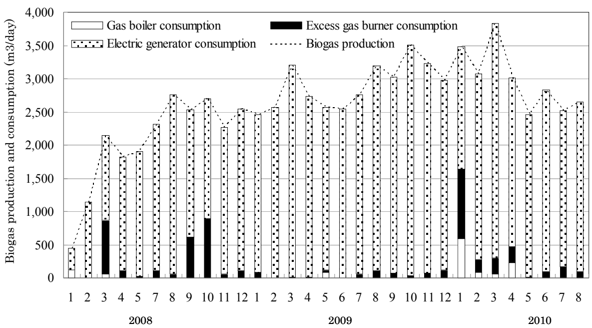

Figure 3. Change in biogas production and consumption

In 2008 year, compared to biogas production of 2338 m^3/day, biogas consumption was as follows: power generator consumed 2157m^3/day, gas boiler consumed 2 m^3/day, waste gas burner consumed 179 m^3/day. In 2009 year, compared to biogas production of 3036 m^3/day, biogas consumption was as follows: power generator consumed 2221 m^3/day, gas boiler consumed 67 m^3/day, waste gas burner consumed 163 m^3/day. Clearly, most of biogas was used for power generators. But 8-9% biogas consumed in waste gas burner then exhaust to atmosphere. The calorific value of biogas is 21.5 MJ/m^3 and equivalent 0.58 L kerosene. When the combusted biogas in waste gas burner is converting to kerosene equivalent, it is equivalent to 38,000 L/year of kerosene. As a result, a large amount of biogas was discarded to atmosphere as unutilized energy.

Methane and hydrogen sulfide concentration of biogas. Figure 4 shows the changes in methane and hydrogen sulfide concentration of generated biogas. The methane concentration remained at 55-65%, averaged 57.7%. Generally, methane concentration of produced biogas is between 50-75%. About 60% methane concentrations were observed from on-farm and centralized biogas plants in Hokkaido (Umetsu et al., 2000; Aoki et al., 2006). In this plant, it can be considered that the methane fermentation was working steadily.

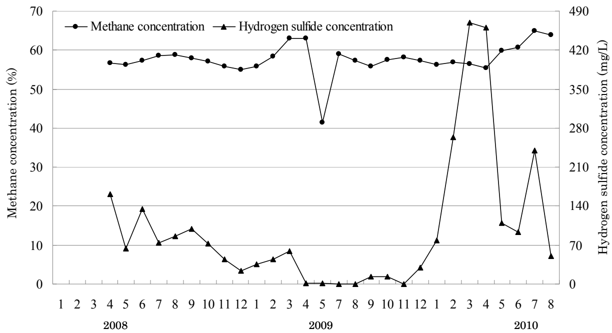

Figure 4. Changes in concentrations of methane and hydrogen sulphide

The hydrogen sulfide concentrations were normally decreased to 160 – 0 ppm. *Ellegaard (2001)* reported that hydrogen sulfide concentration of generated biogas from the methane fermentation was 1000 ~ 3000 ppm, which had led to corrosion of equipment such as boilers and pipeline. Therefore, hydrogen sulfide concentration of biogas often designed to be kept below 200 ppm for animal manure digestion. *Ellegaard (2001)* reported that the efficiency of biological desulfurization was affected by air injection location and amount of air injected, as well as homogenization of biogas and injected air.

Power generation and consumption. Figure 5 shows the changes of power generation, consumption. The power generation was 3737 kWh/day, from that 2026 kWh/day (54%) was consumed for facility, 1716 kWh/day (46%) was sold to Power companies. It is evident from these results that about half of generated electricity has been sold to Power companies.

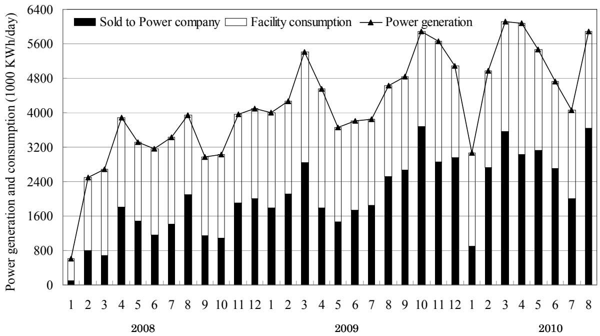

Figure 5. Change of the power generation and consumption

Utilization of digested slurry. Table 1 shows the nutrients composition of digested slurry. The average contents of three nutrient elements were nitrogen 2.59 g/kg, phosphate 1.43 g/kg, potassium 4.79 g/kg. Its calcium and magnesium contents were 1.40 g/kg and 0.63 g/kg, respectively. Digested slurry can improve the balance of soil minerals and provide nutrients for crop growth. The digested slurry can be used as liquid fertilizer, has been sprayed on field. The spreading quantity and method have been decided by crops species and soil diagnosis results that were provided from local agricultural extension centers and agricultural cooperatives. About 20,260 t digested slurry were sprayed on 602 ha field. As a result of this application of digested slurry, it has been confirmed that there were growth in revenue from crop, improvement in crop quality and reduction in cost of chemical fertilizer. Therefore, the demand for digested slurry application will be expected to increase in the future.

Table 1. Fertilizer component of digested slurry (g/kg)

	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
	N	P_2O_5	K_2O	CaO	MgO
2008 fiscal year	2.94	1.31	4.65	1.41	0.61
2009 fiscal year	2.23	1.54	4.92	1.39	0.65
Average	2.59	1.43	4.79	1.40	0.63

Economic balance of centralized biogas plants. Table 2 summarized the economic balance of this plant. Incomes include revenue from plant use, electricity sales, spray of slurry, organic sludge treatment and facility uses. The revenue from plant use is equivalent to the manure treatment fee, is 12,000 yen/head for cattle. Digested slurry spray fee is 500 yen/t. The Power sold was 624 MWh and the electricity selling price were 9.5 yen/kWh at weekday and 4.5 yen/kWh during holiday daytime and overnight time. Expenditures consists mainly personnel expenses, electricity, heat and water expenses, office supplies and maintenance expenses. Plant's incomes were 28,388,000 yen and expenses were 24,451,000 yen, in 2008 fiscal year. In 2009 fiscal year, the income was 43,130,000 yen and expenses were 34,965,000 yen. Eventually, it is possible to operate in a positive economic balance.

Table 2. Economic balance of centralized biogas plant (1000 yen)

Income		
Item	2008 fiscal year	2009 fiscal year
Plant use	8,753	14,454
Spray slurry	9,077	11,337
Sludge treatment	4,566	4,047
Sales of electricity	4,945	6,489
Kitchen waste treatment	0	2,062
Others	1,047	4,740
Total	28,388	43,130
Expenditure		
Item	2008 fiscal year	2009 fiscal year
Services	337	379
Food	8	19
Travel	27	42
Staff salary	9,514	12,555
Demand	12,777	19,944
Insurance	71	81
Tax and dues	357	444
commission	1,500	1,500
Reserve fund	0	0
Total	24,591	34,965
Profit	3,797	8,165

This biogas plant has more benefits than other centralized biogas plants. However, the equipment repairing costs are expected to increase with the aging of equipment and machinery. In future, it is important to investigate acceptance of other organic waste and fertilizer effects of digested slurry *(Matunaka et al., 2002; Umetsu et al, 2002)* and the effect of slurry at soil and soil aggregate formation *(Yasui et al, 2005)*. In order to make the plant economically feasible, it is necessary to investigate that plant's acceptance feedstock amount and type, utilization of digested slurry. Also, it is necessary to investigate introduction of advanced biogas purification technology and sales of purified biogas.

Integracija centralizovanih biogas postrojenja u hladno-snežnim predelima Japana

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Rezime

Centralizovana fabrika biogasa je izgrađena u Shikaoi gradu, Hokaido, u Japanu za obradu stajnjaka od 1320 grla stoke. Postrojenje za biogas je projektovano da radi pri ishrani od 85,8 t/dan, hidrauličkom zadržavanju vremena (HRT) od 37 dana i na temperaturi u digestoru od 38 °C. U ovoj studiji su ispitivane operativne osobine postrojenja za biogas, upotreba digestovanog tečnog stajnjaka i ekonomska ravnoteža. U stabilnim uslovima postrojenja, proizvodnja biogasa je bila 2.687 m^3/dan, 92% proizvedenog biogasa je potrošeno za proizvodnju električne energije. Prosečna koncentracija metana u proizvedenom biogasu je bila 57,7%. Koncentracija vodonik sulfida (H_2S) je smanjena na ispod 140 ppm kao rezultat bio-desulfatizacije i suve desulfatizacije. Prosečna proizvodnja električne energije je 3.737 kwh/dan a od toga 54% proizvedene struje je utrošeno u postrojenju, dok je 46% prodato Elektroprivredi. Oko 20.260 t digestovanog tečnog stajnjaka je primenjeno na 602 hektara pašnjaka i oranica. Rezultati operativnih performansi postrojenja i ekonomska ravnoteža dokazuju da centralizovana postrojenja za proizvodnju biogasa imaju pozitivan uticaj na lokalnu ekonomiju.

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