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ORIGINAL ARTICLE

# Development of combined plant of biogas and bio solid-refuse-fuel from swine manure slurry

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**Abstract** An environment-friendly treatment of organic waste like swine manure and food waste is considered to be big challenge, because the residue of organic wastes after anaerobic digestion contains still high amount of undigested organics and is not allowed to dump to ocean by international regulation. The residue from anaerobic digestion of organic wastes, on the other side, has high energy potential because of its leftover organics. In this study a new and integrated treatment process plant of 40 ton swine manure with 20 ton food waste a day has been developed to achieve environment-friendly disposal of swine manure and to produce renewable solid fuel, which has combined two processes of biogas plant and bio solid-refuse-fuel plant. The residue of anaerobic digestion from biogas plant was conveyed to the bio solid-refuse-fuel plant and dried in dryer using the biogas produced in biogas plant as a burner fuel and finally pelletized for a renewable solid fuel. About 30% of total biogas was supplied for 8 h operation of dryer and the leftover 70% was used for generating electricity in the 250 kW gas engine power generator. The produced pellet was analyzed to have good fuel property that meets the Korea Bio Solid-Refuse-Fuel Quality Standard.

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**Keywords** Swine manure slurry · Biogas · Bio solid-refuse-fuel · Combined plant · Drying

## Introduction

Anaerobic digestion technology has been commercialized to treat various kinds of organic wastes such as sewage sludge, food waste, dairy, and swine manure during over several decades. However, those who are engaged in these field industries are recently facing a serious challenge with the final disposal of anaerobic digestion residue. Ocean dumping has been the most general disposal method of anaerobic digestion residue because of its cheap process cost and convenience till now. But the offshore dumping disposal of organic wastes such as anaerobic digestion residue is not allowed any more globally by London Convention and Protocol which prohibits all organic waste dumping, except for possibly acceptable wastes on the so-called "reverse list" and it entered into force on 24 March 2006 [1].

Many researchers have tried to reduce the organic compounds in the residue through the improvement of biogas production yield, which investigated the relation between biogas yield and digestion temperature, C/N ratio, C/P ratio, pH to find optimum condition [2–7]. In spite of those efforts and technical advances approximately 15–30% of organic compounds still remains in the final anaerobic digestion residue slurry and an environment-friendly and economical onshore disposal method is urgently required from the related industries like livestock farm, municipal sewage plant, and food factory, etc [8]. There are several commercialized onshore methods for organic wastes disposal such as landfilling, incineration, and composting, etc. Some of the fresh food waste is occasionally processed to be a recycled animal fodder after sanitary treatment. First of all, landfilling disposal is the easiest choice among several options, but that way is not allowed in the EU countries by regulation because biodegradable materials usually produce the $CH_4$ gas during anaerobic digestion in soil that has the global warming potential 21 times stronger than $CO_2$ [9, 10]. When, secondly, incineration method is adopted for organic waste disposal, it generally consumes a lot of fossil fuel such as petroleum oil, natural gas to dry its high water content. Finally, composting method is told that the produced fertilizer is sold only in spring season for seed planting and so full time operation of composting facility all year round is almost impossible.

In the present study, a newly designed disposal plant of 40 ton swine manure with 20 ton food waste a day has been developed to achieve environment-friendly and economical disposal of swine manure mixed with food waste, which has combined two separated plant into one: two plants were biogas production plant and bio solid-refuse-fuel (bio-SRF) production plant, both products are renewable energy source. When the anaerobic digestion residue is disposed by the bio-SRF production method, its high water content is supposed to be the main barrier because of high drying cost. Above two separated plant was combined to overcome this cost barrier and so biogas from the biogas production plant was supplied to bio-SRF production plant to dry the water of anaerobic digestion residue. The leftover biogas after being supplied to bio-SRF production plant was used for generating electricity in the gas engine power generator. Through this new organic wastes disposal plant in a commercial scale, it has been tried to solve the challenging swine manure and food waste treatment problem without ocean dumping and to comply with the international regulation with an environment-friendly and economic effect.

## Materials and methods

Figure 1 shows the whole process flow diagram of bio-SRF production plant combined with biogas production plant. The direct photo of the combined plant of biogas and bio-SRF is also shown in Fig. 2. Biogas production process by anaerobic digestion is from Nos. 1 to 6 and bio-SRF production process containing a dryer and a pelletizer is Nos. 7, 9, and 10. In biogas production plant, 40 ton/day swine manure was mixed with 20 ton/day food waste and fed into 3000 ton capacity anaerobic digester to produce biogas that was supplied to both bio-SRF plant dryer and 250 kW electricity generating gas engine. Before supplying biogas to dryer and gas engine, it went through desulfurization unit to remove $H_2S$ that was known to cause serious environment problem with its odor as well as facility corrosion. The unit was consisted of the 1st air desulfurization unit where ambient air was supplied to biogas pipeline and the 2nd microbial desulfurization unit where microorganism capture and destroy $H_2S$ gas. After 50 days HRT (hydraulic retention time) the leftover anaerobic digestion residue was sent to filter press for dewatering and the dewatered solid residue that has still about 80% of water

Fig. 2 The combined plant of biogas and bio solid-refuse-fuel

Fig. 1 Flow diagram of the bio-SRF plant process combined with biogas plant

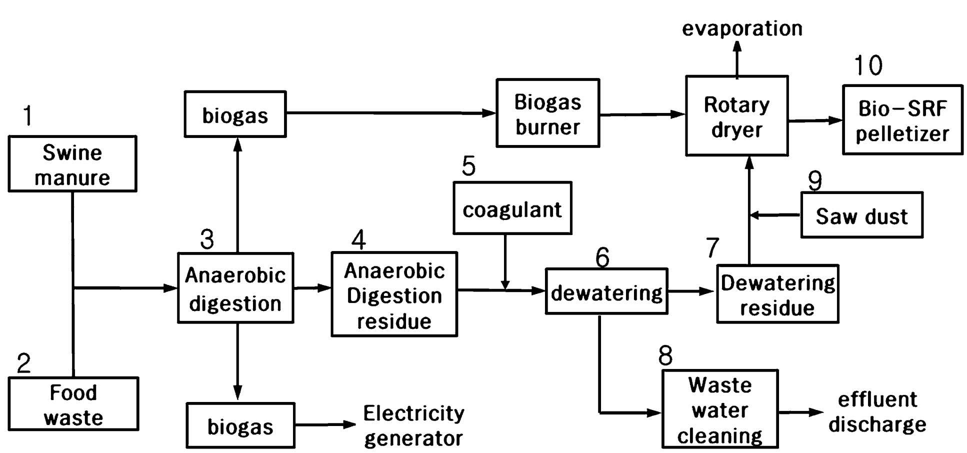

**Table 1** Material balance of each unit in the combined plant

| Process No | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total weight (kg/day) | | 40,000 | 20,000 | 60,000 | 54,767 | 362 | 55,129 | 5213 | 49,916 | 3649 | 4431 |
| Water content | kg/day | 36,812 | 16,028 | 54,840 | 52,840 | 228 | 53,068 | 3962 | 49,106 | 912 | 412 |
| | % | 92.0 | 80.1 | 91.4 | 96.5 | 63.0 | 96.3 | 76.0 | 98.4 | 25.0 | 10.0 |
| Total solids (TS) | kg/day | 3188 | 3972 | 7160 | 1927 | 134 | 2061 | 1251 | 810 | 2737 | 3988 |
| | % | 8.0 | 19.9 | 11.9 | 3.5 | 37.0 | 3.7 | 24.0 | 1.6 | 75.0 | 90.0 |
| Volatile solids (VS) | kg/day | 2445 | 3682 | 6127 | 895 | 23 | 918 | 470 | 448 | 2709 | 3179 |
| | % | 6.1 | 18.4 | 10.2 | 1.6 | 6.4 | 1.7 | 9.0 | 0.9 | 74.2 | 71.7 |

**Table 2** Anaerobic digester operating condition and biogas property

| Digester capacity ($m^3$) | Feeding rate (ton/day) | HRT (days) | Temperature (°C) |
|---|---|---|---|
| 3,000 | 60 | 50 | 35–40 |

content was conveyed to bio-SRF plant dryer to evaporate that water. Waste water (No. 8) from dewatering unit was cleaned through several water treatment processes to meet the effluent water regulation criteria. In bio-SRF production plant, 2 ton/h rotary dryer and 400 kg/h ring-die type pelletizer were designed and built with optimum layout for drying the dewatered solid residue and pelletizing bio-SRF pellet, respectively. Two kinds of additives, Nos. 5 and 9, are shown in the diagram that the former was coagulant, $FeCl_3$ and polyacrylamide, to improve dewatering efficiency through coagulation of suspended solids and the latter was extra sawdust added to the dewatered solid residue to increase bio-SRF heating value. Table 1 shows the material balance of each unit in the above combined plant that disposes swine manure from pig farm and food waste from municipal district. Water content, total solids (TS) and volatile solids (VS) of source feedstock were analyzed to be 91.4, 11.9 and 10.2%, respectively. Table 2 summarizes the anaerobic digester's capacity, feeding rate, HRT and operating temperature. In this plant two-step desulfurization treatment was adopted that the first air desulfurization step was done by blowing 3% air of total biogas volume into anaerobic digester and the second microbial desulfurization step was done in the microbe reactor.

Table 3 shows the higher heating value and element composition of C, H, O, N, S, Cl after sawdust addition before drying and it was noticed that the measured higher heating value 3873 kcal/kg was high enough to be an alternative and renewable fuel of coal known to be one of main fossil fuel causing global warming crisis by massive $CO_2$ emission in the electric power generation plant all over the world. Chlorine and sulfur content which are known to be air pollutant source elements were analyzed to be 1.0 and 0.91%, respectively, which was a little lower than normal coal's 0.8–3% [11, 12] and also regarded as an acceptable concentration level for bio-SRF quality. We note that the Bio-SRF produced from swine manure has to meet Korean bio-SRF Quality Standard [13].

In this study, new compact design of rotary dryer was developed and it could save a half of dryer installing area by adopting a double drum design shown in Fig. 3. Table 4 refers to the specification of double drum rotary dryer and operating conditions in which dryer volume was about 43 $m^3$ and hot gas temperature from gas burner was 600 °C with direct heat transfer to feedstock. Material feeding rate was decided to have sufficient capacity so that it could afford increasing demand in the future and all components in the dryer system were also designed with double capacity.

Table 5 shows the designed energy balance in double drum rotary dryer planned to operate 8 h a day and to consume about 1/4 of biogas produced in the anaerobic digester. Its drying efficiency was determined to be 70% through the investigation on commercial rotary dryer's efficiency.

**Table 3** HHV (higher heating value) and element composition of feedstock before drying

| HHV (Dry basis) | Chlorine (Dry basis) | Element analysis (Dry basis) | | | | |
|---|---|---|---|---|---|---|
| 3873 | 1.0 | C | H | O* | N | S |
| | | 45.12 | 6.33 | 40.87 | 6.77 | 0.91 |
| kcal/kg | wt% | wt% | wt% | wt% | wt% | wt% |

* By difference

**Fig. 3** Schematic of double drum dryer

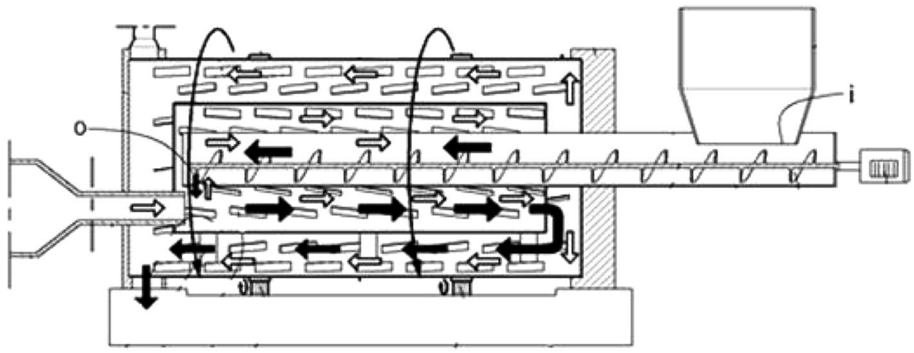


**Table 4** Rotary dryer specification and operating conditions

| Item | | Unit | Specification |
|---|---|---|---|
| Double drum rotary dryer | Diameter × length | m | 3 × 6 |
| Burner | Heat supply | kcal/h | 1,200,000 |
| Material (before drying) | Feeding rate | kg/h | 2000 |
| | Water content | % | 55 |
| | temperature | °C | 20 |
| | Specific heat | kcal/kg °C | 0.3 |
| Product (after drying) | Water content | % | 15 |
| | temperature | °C | 75 |
| Gas temperature | Input gas | °C | 600 |
| | Output gas | °C | 120 |

**Table 5** Designed energy balance in rotary dryer

| Item | Unit | Value |
|---|---|---|
| Water evaporation energy | kcal/h | 668,632 |
| Solid fraction heating energy | kcal/h | 13,200 |
| Water heating energy in solid fraction | kcal/h | 7766 |
| Net drying energy | kcal/h | 689,598 |
| Supply energy amount ($\eta = 0.7$) | kcal/h | 985,140 |
| Total energy consumption (8 h) | kcal | 7,881,120 |

As for pelletizer for bio-SRF forming, a ring-die type machine has been selected because it was suitable to produce a small diameter pellet with large production capacity and the designed specification is shown in Table 6. The produced bio-SRF from swine manure slurry is also shown in Fig. 4. Bio-SRF pellet size was determined as diameter 8 mm and length 30 mm that was almost similar with the commercial wood pellet.

**Table 6** Pelletizer specification and operating condition

| Item | Specification | Item | Specification |
|---|---|---|---|
| Ring inner diameter | 55 cm | Linear velocity | 2.62 m/s |
| Nozzle diameter | 8 mm | Main motor | 90 kW |
| Pellet length | 30 mm | Capacity | 600 kg/h |

**Fig. 4** Bio solid-refuse-fuel from swine manure slurry

## Results and discussion

The amount of produced biogas in the biogas plant and its properties are shown in Table 7, in which about 4700 $m^3$/day biogas was produced and $CH_4$ concentration was about 65% after stabilization with lower heating value of 5525 kcal/$m^3$. About 26 million kcal energy in a day was produced from biogas plant. Figure 5 shows the $CH_4$ concentration in the biogas measured in the two point of the 1st air desulfurization treatment and the 2nd microbial desulfurization treatment for about 14 months. As shown in Fig. 5, standard deviation of $CH_4$ concentration was found 5% max. between the 1st and the 2nd desulfurization treatment. In the 1st air desulfurization unit 0.1 $m^3$/min of

**Table 7** Biogas production amount and properties

| Biogas production amount ($m^3$/day) | $CH_4$ concentration (%) | Lower Heating Value (kcal/$m^3$) | Total energy (kcal/day) |
|---|---|---|---|
| 4675 | 65 | 5525 | 25,829,375 |

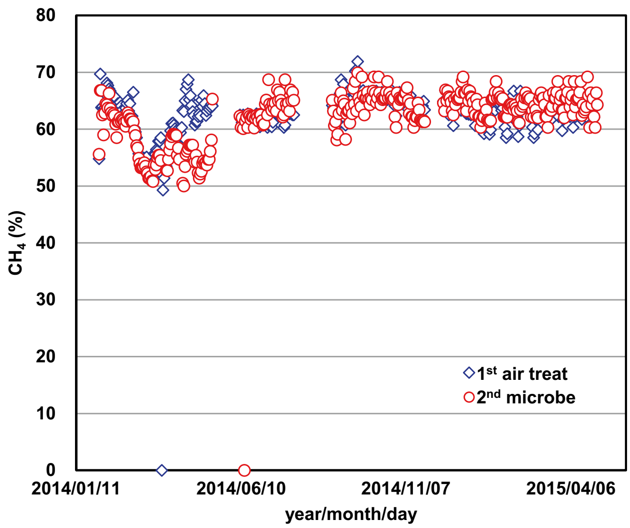


**Fig. 5** $CH_4$ concentration for 4 months

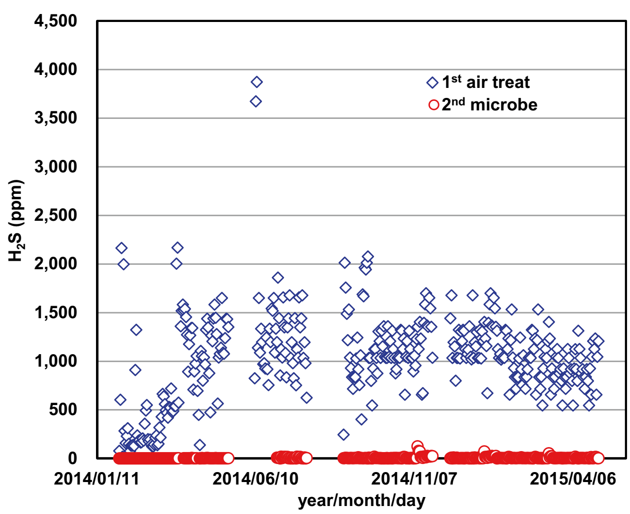


**Fig. 6** $H_2S$ concentration for 4 months

ambient air was supplied to the biogas stored within membrane of anaerobic digester and this biogas went through the 2nd microbial desulfurization unit where the operating temperature was maintained about 35 °C for optimum condition of microorganism's activity. Figure 6 shows $H_2S$ concentration for about 14 months and it was found that almost all of $H_2S$ was removed through two-step treatment. Corrosion in biogas engine was not found and its generation power output was about 230 kW with stable performance for almost 1 year operation.

Generally the most important parameter for industrial dryer is the drying efficiency $\eta$, defined as the ratio of theoretical evaporation energy to real consumption energy, because it is the main parameter to reduce the dryer operation cost. Drying efficiency depends on the effectiveness of heat transfer between hot gas and wet material as well as the heat loss in the dryer surface, which means that the less surface area dryer can gain the higher drying efficiency and it can be a cost effective dryer. *L*/*D* (length/diameter) ratio of the double drum rotary dryer is up to 50% less than general single drum rotary dryer as shown in Fig. 3 and its surface area is up to 30% less than the single drum dryer. For the double drum dryer developed in this research the drying efficiency was found to be 76.5–79.1% as shown in Table 8 through 3 times real scale experiment. Considering that a general efficiency of rotary dryer is 65–75%, this new rotary dryer is regarded to have very competitive performance.

Performance of bio-SRF pelletizer showed a high dependence on the water content of feedstock supplied from the previous dryer unit. In case of feedstock its water content was less than 10%, bio-SRF was well pelletized in the pelletizer continuously, however, feedstock of more than 10% water content was partly agglomerated in the ring inside and not passed through the pelletizer hole smoothly. Table 9 shows the analysis results of bio-SRF pellet's property and element composition and the quality items of Korean bio-SRF standard with limiting criteria. It was well shown that the produced bio-SRF pellet has a good quality and can meet all items of standard criteria for normally dried feedstock. Water and ash content were 10 and 15.4%, respectively, and lower heating value was about 4000 kcal/kg that could be an alternative fuel for general solid fuel consumers.

## Conclusion

This study aimed to develop an environmental and economical swine manure treatment plant, where anaerobic digestion residue of swine manure could be completely treated in land and so offshore dumping problem is clearly solved. A new process, the combination of biogas plant and bio-SRF plant, has been developed and experimented in a commercial scale, that is, 40 ton swine manure and 20 ton food waste in a day. Performance test results showed synergetic benefits of an environment-friendly waste disposal with a renewable solid fuel production. About 4700 $m^3$/day biogas was produced with $CH_4$ concentration of 65%, and

**Table 8** Drying test results of rotary dryer

| Exp.# | Feeding rate (kg/h) | Water content (%) | | Evaporation rate (kg/h) | Heat input to dryer (kcal/h) | Drying efficiency (%) | Drum speed (rpm) |
|---|---|---|---|---|---|---|---|
| | | Wet | Dry | | | | |
| 1 | 1750 | 56.6 | 24.1 | 749 | 636,350 | 76.5 | 2.2 |
| 2 | 1750 | 56.6 | 21.5 | 768 | 636,350 | 78.4 | 1.5 |
| 3 | 1750 | 56.6 | 20.0 | 776 | 636,350 | 79.1 | 0.9 |

**Table 9** Analyzed Bio-SRF properties and Korean bio-SRF Quality Standard

| Items | | Bio-SRF | Korean bio-SRF Standard | Unit |
|---|---|---|---|---|
| water content (wet basis) | | 10.0 | <10 | wt% |
| Ash content (dry base) | | 15.4 | <25 | wt% |
| Lower heating value (dry base) | | 3,954 | >3000 | kcal/kg |
| Chlorine (dry base) | | 0.68 | <2 | wt% |
| Ultimate analysis (dry base) | C | 33.97 | – | wt% |
| | H | 5.16 | – | wt% |
| | N | 2.17 | – | wt% |
| | S | 0.85 | – | wt% |

$H_2S$ was almost removed through two-step desulfurization treatment which contains the 1st air desulfurization and the 2nd microbial desulfurization. The produced biogas could afford both energy consumptions needed for 8 h operation of dryer in bio-SRF plant and the 250 kW electricity generation gas engine. New design dryer with double rotary drum showed good drying efficiency of 78%. Bio-SRF pellet with 8 mm diameter was produced by ring-die pelletizer and its quality was good enough to meet Korean Bio-SRF Quality Standard Criteria.

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