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Monitoring of Biogas Yield from Livestock Manure at an Anaerobic Digestion Facility

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Abstract This study was conducted to examine the development and implementation of a system equipped with microbial electrochemical technology to reduce environmental impact and methane yield. Daily data produced by a complex gas measuring system installed in the digestion unit were analyzed. In 2019, 44,239 tons of livestock manure and 6,397 tons of food waste were processed, and the amount of biogas produced by anaerobic digestion was 2,471,243 Nm³. In 2020, 37,048 tons of livestock manure and 6,208 tons of food waste were processed, and the amount of biogas produced by anaerobic digestion was 1,930,030 Nm³. Monitoring of biogas in the anaerobic digester showed average CH4 and H2S concentrations were 79.97 % and 2,116 ppm in winters and 62.01 % and 2,309 ppm in summers, respectively. The results of this study would be helpful for researchers exploring ways to improve methane yields efficiency by stabilizing methane yields and applying microbial electrochemical technology to agricultural and livestock waste processing. Monitoring changes in biogas concentrations produced by anaerobic digestion on a seasonal basis could be used to predict the amount of biogas produced.

요 약 본 연구는 생물전기화학전지를 적용하여 농축산부산물의 환경부하 저감 및 메탄 수율 향상 시스템 개발에 활용하기 위하여 혐기소화 공동자원화시설에서 가축분뇨와 음식물 폐기물을 처리한 일별 데이터와 혐기소화조 내 바이오가스를 관찰하기 위하여 복합 가스 측정 시스템을 설치하여 수집한 데이터를 분석하였다. 2019년 가축분뇨 44,239톤 및 음식폐기물 6,397톤을 처리하여 혐기소화로 생산된 바이오가스량은 2,471,243 Nm³이였다. 2020년 가축분뇨 37,048톤과 음식폐기물 6,208톤을 처리하여 생산된 바이오가스량은 1,930,030 Nm³이였다. 혐기소화조 내 바이오가스 중 겨울철에 메탄 79.97 %와 황화수소 2,116 ppm, 여름철에 62.01 %와 2,309 ppm으로 나타났다. 혐기소화조 내 바이오가스의 계절과 주기에 대한 생산량을 예측할 수 있을 것으로 기대된다.

Keywords : Anaerobic Digestion, Biogas, Bio-Gasfication, Livestock Manure, Methane

1. Introduction

In Korea, policies for renewable energy have been established to regulate the amount of biogas extracted from organic waste resources such as food waste, sewage sludge, livestock manure, and so on. Various teleology tools have been developed to improve the efficiency of

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environmental loads. An anaerobic digestion system is one of the most widely used methods to process organic waste resources and recovering useful components from them. This system satisfies the treatment and the reuse of organic waste resources as methane gas can be recovered in the process and reused for energy. However, it has been reported that the actual methane yield processed by the general anaerobic digestion system is significantly different from the theoretical maximum methane yield [1]. The anaerobic digestion technology that uses a biochemical cell becomes an attractive solution as it increases methane yields. In order to stabilize organic waste and produce methane gas, the anaerobic digestion system is divided into low-temperature, medium-temperature, and high-temperature digestion according to the operating temperature. In general, it is known that the high-temperature anaerobic digestion has a higher rate of the anaerobic degradation in the organic matter than the medium-temperature digestion has [2-4]. Several studies applied bioelectrochemical technology to an anaerobic digester and showed that performance of the digester could be greatly improved, and the methane content of biogas could be increased [5-9]. The bioelectrochemical anaerobic digester is known to have a stable digestion state during operation, and a higher anaerobic decomposition rate for organic matter, resulting in high methane production [8,9]. Microbial electrolysis cell (MEC), which combines the bioelectrochemical technology with the anaerobic digestion, is known as a technology with high field applicability [10,11]. The anaerobic digestion technology is a treatment technology that has recently attracted attention because it can effectively reduce, reuse, and stabilize organic waste resources while recovering methane gas that, is a useful energy source [12]. Livestock manure is discharged at 136,000 m^3 per day, about 10 times more than food waste, and about 87.5 % is composted or absorbed, and 12.5 % of livestock wastewater is treated in public wastewater treatment facilities. Compost produced from livestock manure is commercialized and sold, but its use is limited due to its domestic characteristics. In addition, the composting and liquefying process is not cost effective as it consumes a lot of power and results in, excessive use of compost that leads to water and groundwater pollution problems such as an eutrophication. A general anaerobic digestion process can be divided into a wet digestion process with a total solid content of less than 10 % and a dry digestion process with a solids content of less than 15-35 % [13]. Livestock manure and sewage sludge can be applied to the wet digestion process, and food waste and agricultural by-productions seem to be advantageously applied to the dry digestion process [13]. In 2011, there were 55 organic waste biogasficition facilities in Korea, including food and food wastewater (11), livestock manure (7), sewage sludge (20), and integrated (17)(Table 1). In 2021, the number increased to 110, including food and food wastewater (26), livestock manure (3), sewage sludge (28), and integrated (53)(Table 1). In particular, the integrated anaerobic digestion are continuously increasing from 17 to 53 in the past 10 years [14]. Anaerobic digestion can reduce the volume of sludge while producing energy in the form of methane gas, and had the advantage of using the digested sludge as fertilizer. However, long digestion time due to the slow process of hydrolysis and methane production formation causes an imbalance pH in the progress of the steps. Performance with high fluctuation and low digestion efficiency are dependent on the substrate used for digestion [15]. MEC was developed to overcome the disadvantages of anaerobic digestion and increase the composition of methane gas [16]. In addition, MEC is one of the bioelectrochemical technologies. When an oxidizing electrode and a reducing electrode are inserted into a digester and a small amount of voltage sufficient to overcome the thermodynamic barrier is applied, electrochemically active bacteria on the surface of the electrode undergo an electrochemical oxidation-reduction reaction. It was reported that anaerobic digestion performance could be improved [8,9]. Several studies have examined ways to develop and improve anaerobic digestion facilities, but limited research has been done to predict biogas yield in the field. Biogas is produced through anaerobic digestion, but it is difficult to maintain stable production over time. Therefore, this study was conducted to manage biogas yield from livestock manure by monitoring changes in the biogas production of an anaerobic digestion facility. Data were analyzed to predict the amount of biogas yield in livestock manure and food waste.

Table 1. Number of the organic waste biogasfication facilities in Korea [14].

Year	Food and food wastewater	Livestock manure	Sewage sludge	Integrated	Total
2010	8	7	20	15	50
2011	11	7	20	17	55
2012	11	7	20	19	57
2013	16	7	20	18	61
2014	20	6	21	24	71
2015	20	6	32	30	88
2016	20	7	33	30	90
2017	21	7	35	35	98
2018	21	4	32	43	100
2019	21	4	32	44	101
2020	26	5	33	46	110
2021	25	3	28	53	110

*Include 1 other type in 2021.

2. Materials and Methods

2.1 Analyzing daily data of livestock manure and food waste

By applying the bioelectrochemical cell, basic data were collected to evaluate its efficiency in reducing the environmental load of agricultural and livestock by-products and developing a system to improve methane yields. Among domestic common recycling facilities (integrated anaerobic digestion), the resource recycling center located in Chungcheongnam-do region analyzed the daily data of livestock manure and food waste treated from 2019 to 2020 and recycled into resources. The facility area is 5,892 m^2, and the daily treatment capacity is 100 tons of livestock manure, 36 tons of food waste, and 10 tons of agricultural and livestock by-products. The facility can process a total of 150 tons of environmental load per day. The processing method consists of preprocessing, main processing, and resource utilization (Fig. 1). The daily biogas production is 5,400 Nm^3. The measurement items are the input amount of livestock manure and food waste, the pH of the anaerobic digester, total solid (TS), volatile solid (VS), temperature etc. The pH and temperature were measured daily with a benchtop pH meter (Thermo scientific orion 3-star benchtop pH meter, Thermo Fisher Scientific Inc., USA). CH_4, CO_2, H_2S, etc were measured daily using a portable biogas analyzer (Biogas 5000, Geotechnical Instruments Ltd, England). Then, data collected daily was analyzed by year. At this study, only CH_4 data in biogas was used for analysis.

2.2 Monitoring the concentration of biogas

In order to monitor the concentration of biogas generated in the anaerobic digestion tank, a complex gas measuring system was installed in the digestion unit (Fig. 2). The configuration of the complex gas measuring system was such that gas introduced from the upper extracting valve of the digester was sucked for 30 seconds, so that the concentration was recorded by the measuring sensor of gas (Fig. 3). Since the gas in the anaerobic digestion tank contains a lot of moisture, it was measuring after removing moisture by allowing into pass through the first and second physical moisture removal devices (Fig. 3). Fig. 3 is the process diagram of the complex gas measurement system. Fig. 4 is on-site photos of the complex gas measurement system. Table 2 shows the specification of the gas sensors such as CH_4, NH_3, H_2S in the system.Fig. 3. Diagram of the complex gas measurement system

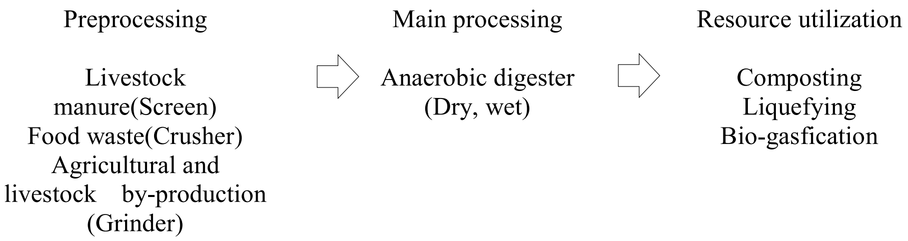

Fig. 1. Biogas production process in the resource recycling center

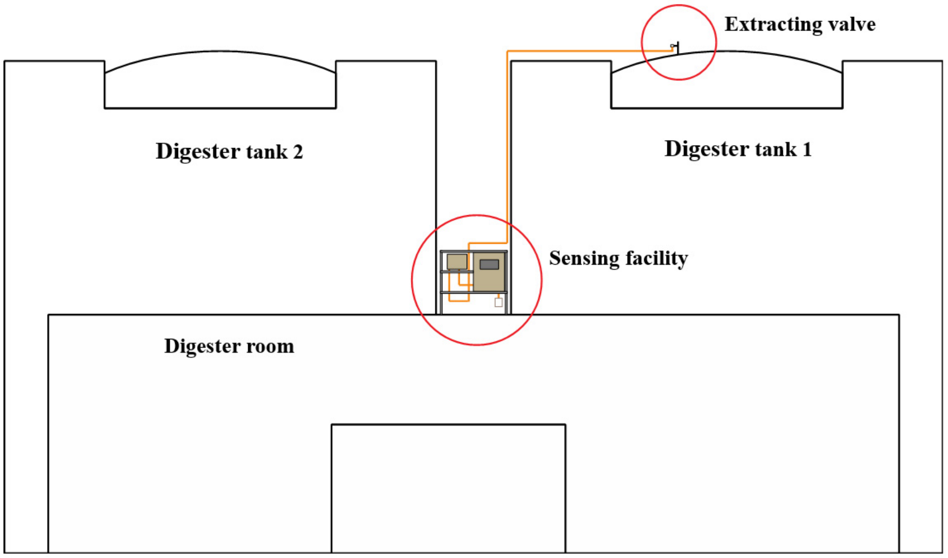

Fig. 2. Structure of the complex gas measurement system

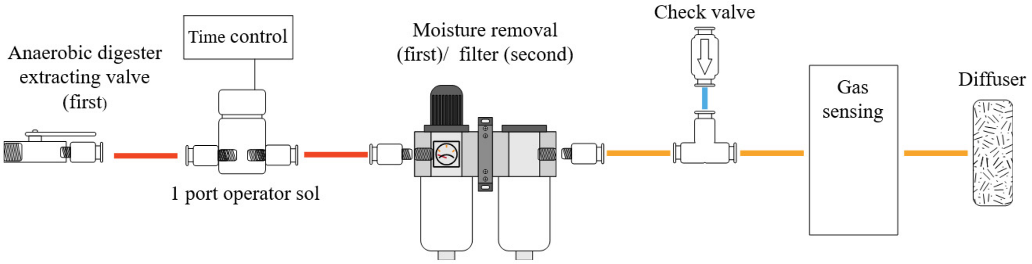

Fig. 3. Diagram of the complex gas measurement system

(a) Extracting valve (b) Plumbing piping (c) Sensor equipment installation

Fig. 4. On-site photos of complex gas measurement system

Table 2. Specification of the gas sensors in the system.

Items	CH_4	NH_3	H_2S
Manufacture	SGX SENSPRTECH	Membrapor	Membrapor
Model	IR12BD	NH_3/CR-5000	H_2S/C-5000
Nominal range	50 ppm – 5 %	0 – 5,000 ppm	0 – 5,000 ppm
Maximum overload	5 %	7,000 ppm	10,000 ppm
Temperature range	-20 to 55 °C	-	-20 to 50 °C
Typical baseline range	-	-70 to 70 ppm	< 40 ppm
Repeatability	-	< 3 % of signal	< 2 % of signal

3. Results and Discussion

3.1 Analyzing daily data of livestock manure and food waste

Analysis of the daily data collected from the anaerobic digestion facilities shows that the average temperature of the anaerobic digestion was 33.2-41.7 ℃, the average pH was 6.0-8.0, and the average methane was 63.6 % in 2019 (Table 3, Fig. 5). In 2019, 44,239 tons of livestock manure and 6,397 tons of food waste were treated, and the amount of biogas produced from the anaerobic digestion was 2,471,243 Nm^3 (Table 5). The average temperature of the anaerobic digestion was 32.1-43.0 ℃, the average pH was 6.8-8.4, and the average methane was 67.2 % in 2020 (Table 4, Fig. 5). In 2020, the amount of biogas produced by treating 37,043 tons of livestock manure and 6,208 tons of food waste was 1,930,030 Nm^3 (Table 5). Generally, the anaerobic digestion process can be divided into a wet digestion with TS of less than 10 % and a dry digestion with TS of less than 15-35 % [13]. Research showed that livestock manure and food waste can be applied to the wet digestion [17]. Moreover, food waste and agricultural and livestock by-product were found to be advantageous for the dry digestion, and the dry digestion was also maintained below 10 %.

Table 3. Measuring results of the anaerobic digestion in 2019.

	pH			TS(%)			VS(%)			Temperature(°C)		
	dry	wet 1	wet 2	dry	wet 1	wet 2	dry	wet 1	wet 2	dry	wet 1	wet 2
Min.	5.67	7.52	7.21	3.33	1.47	1.43	51.2	26.94	31.21	30.60	36.00	38.30
Max.	6.68	8.24	8.14	7.16	3.79	3.68	89.73	80.01	73.63	38.70	41.50	42.90
Aver.	5.97	8.03	8.00	5.71	3.04	2.84	82.49	56.40	52.66	33.17	40.85	41.90
Stdv.	0.61	0.37	0.37	1.01	0.49	15.82	6.71	6.81	268.9	4.06	1.05	1.36
C.V.(%)	10.12	4.60	4.57	17.72	16.25	557.5	8.14	12.08	510.7	12.23	2.56	3.25

Table 4. Measuring results of the anaerobic digestion in 2020.

	pH			TS(%)			VS(%)			Temperature(°C)		
	dry	wet 1	wet 2	dry	wet 1	wet 2	dry	wet 1	wet 2	dry	wet 1	wet 2
Min.	5.46	7.95	6.20	4.88	1.92	2.09	48.00	33.91	35.81	20.10	30.90	34.10
Max.	7.29	8.57	8.61	7.78	3.99	3.44	81.06	79.78	82.53	36.70	43.00	44.60
Aver.	6.83	8.35	8.28	6.81	3.15	2.95	72.90	62.23	66.22	32.09	40.80	43.02
Stdv.	0.42	0.10	0.15	0.61	0.34	0.40	8.60	6.60	7.18	4.33	1.88	2.23
C.V.(%)	6.09	1.24	1.76	8.91	10.71	13.46	11.80	10.60	10.85	13.51	4.61	5.19

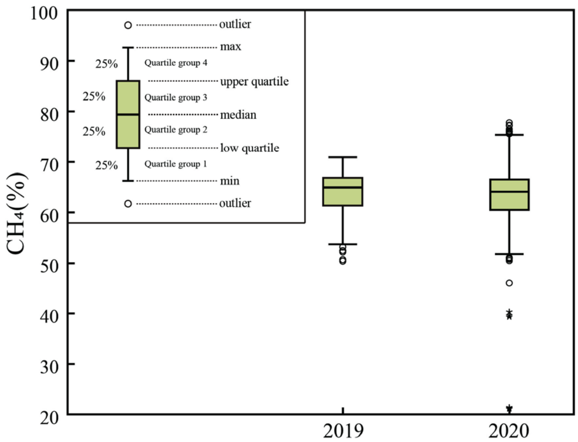

Fig. 5. Measuring results of the methane in 2019 and 2020

Table 5. Amounts of the biogas production at the resource recycling center.

Items		2019	2020
Input	Livestock manure(ton)	44,239	37,048
	Food waste(ton)	6,397	6,208
Output	Biogas(Nm^3)	2,471,243	1,930,030

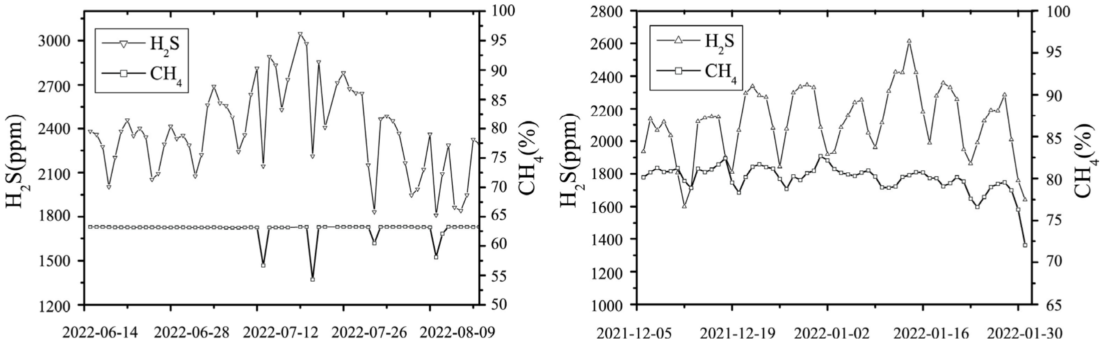

Fig. 6. Variation of H_2S and CH_4 for the anaerobic digestion in the summer (left) and winter (right)

3.2 Monitoring the concentration of biogas

Analysis of biogas monitoring results in the anaerobic digester shows that the average of CH_4 and H_2S were 79.7 % and 2,116 ppm in winter and 62.0 % and 2,309 ppm in summer, respectively (Fig. 6). CH_4 concentration in winter was 17.6% higher than in summer. It is estimated to affect the temperature in the anaerobic digestion depending on the season. H_2S showed a change according to the cycle of an average of ± 209 ppm in winter and an average of ± 390 ppm in summer (Fig. 6). Therefore, it is expected to be able to predict the amount of biogas by monitoring the seasonal and cycle changes of biogas in the anaerobic digestion.

4. Conclusion

This study applied biochemical cells to the treatment of agricultural and livestock by-products to improve methane production efficiency by stabilizing biogas and therefore reducing environmental loads in the through livestock manure and food waste treatment. Daily data collected from the resource recycling center was analyzed to evaluate the efficiency in methane production. In 2019, the amount of biogas produced by treating 44,239 tons of livestock manure and 6,397 tons of food waste was 2,471,243 Nm^3, the average temperature of the anaerobic digestion was 33.2-41.7 ℃, the average pH was 6.0-8.0, and the average methane was 63.6 %. In 2020, the amount of biogas produced by treating 37,048 tons of livestock manure and 6,208 tons of food waste was 1,930,030 Nm^3, the average temperature of the anaerobic digestion was 32.1-43.0 ℃, the average pH was 6.8-8.4, and the average methane was 67.2 %. In addition, in order to monitor biogas in the anaerobic digestion, a complex gas measurement system was installed to monitor biogas, thereby enabling a consistent analysis of biogas production. Among the biogas produced in the anaerobic digestion, methane was 79.7 % in winter and 62.0 % in summer, and H_2S was 2,116 ppm in winter and 2,309 ppm in summer. Additionally, changes in biogas according to seasons and cycles were confirmed, and it is expected that the amount of biogas can be predicted by monitoring the seasonal and cycle changes of biogas in the anaerobic digestion. Further research can be conducted to find ways to stabilize biogas.

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