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Project Report

A Feasibility Study on Effect of Food Waste Leachate Additions in the Full-Scale Waste Leachate Treatment Facility after the African Swine Fever Outbreak in South Korea

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Abstract: Due to the ban on the use of food waste as wet swine feed after the outbreak of African swine fever (ASF), 2900 tons/day of food waste and 1083 tons/day of food waste leachate were additionally generated. As an alternative treatment method for food waste leachate, the input of food waste leachate on weekends (5% of food waste leachate inflow, 100 tons/day) and its increased input (merge ratio 21.7%, 227.01 tons/day → 27.8%, 453.71 tons/day) into the digesters operated in a public sewage treatment plant were investigated. Additionally, the feasibility of the method was evaluated by analyzing the operation parameters, evaluating the operation efficiency, and identifying other environmental effects on the sewage treatment plant. In the case of input on weekends, the organic matter decomposition rate and gas production rate decreased by 8.0% and 9.5%, respectively, although the input on weekends was judged to be feasible, considering that the inflow into the WWTP increased by up to 206% due to the long-term (7 weeks) monsoon. In the case of the increased input of food waste leachate, the organic matter decomposition and gas production rates increased by 2.5% and 4.8%, respectively, compared with before the increased input. The results of this study confirmed that the additional input of food waste leachate into existing biogasification facilities is feasible. When performed in a stable manner, the use of food waste for anaerobic digestion is considered an appropriate alternative treatment method to wet feed. This will lead to technological and industrial development.

Keywords: food waste leachate; sewage sludge; anaerobic digestion; methane production; biogas

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1. Introduction

In South Korea, the amount of food waste varies significantly depending on the season and accounts for approximately 25.8% (14,477 tons/day, 2018) of the total amount of municipal waste [1], exhibiting the highest proportion as a single waste type. Food waste in South Korea has a particularly high water content and causes secondary environmental pollution (e.g., soil pollution and odor) due to leachates [2] without proper treatment. Furthermore, this leads to an increase in the load of wastewater treatment plants. In South Korea, the construction of resource circulation infrastructure was induced through resource facilities that convert food waste into feed and compost. At present, 13,883 tons of food waste are being treated per day through conversion into dry feed (excluding dehydration cakes; 4037 tons/day (29.1%)), composting (excluding dehydration cakes; 2588 tons/day (18.6%)), intermediate processing (3911 tons/day (28.2%)), conversion into biogas (2414 tons/day (17.4%)) and wet feed (e.g., dogs and insect farms; 496 tons/day (3.6%)), incineration (300 tons/day [2.2%]), and landfill (137 tons/day ([1.0%)) [3] (Citizens Environmental Technology Center, 2010).

In the case of conversion into wet feed, approximately 2900 tons/day of food waste [4] (National Institute Environmental Research (NIER), 2020), which was treated as wet swine feed, needs to be urgently treated using an alternative method because feeding pigs with such food waste has been completely banned after the outbreak of African swine fever (ASF) (September 2019) [5] (ME, 2019). As alternative treatment methods to wet swine feed, the conversion of food waste into dry feed and compost, as well as intermediate processing, in which food waste is classified into solid and liquid phases and each phase is consigned, are widely used. However, conversion into dry feed and compost generates food waste leachate in large quantities during the pretreatment process, and intermediate processing also increases the production of food waste leachate as food waste, which is separated into solid and liquid (food waste leachate) phases.

Simultaneously, ME has promoted the expansion of biogasification facilities by establishing "waste resources and biomass energy measures ('08)" [6] (ME, 2007). In South Korea, organic waste biogasification is performed mainly for food waste (including food waste leachate), livestock manure, and sewage sludge. As of 2019, in total, 120 food waste biogasification facilities were in operation, which include 25 single food waste (including food waste leachate) facilities, 43 combined treatment facilities for livestock manure or sewage sludge, 44 sewage sludge gasification facilities that do not treat food waste, and eight livestock manure treatment facilities [7] (ME, 2019). In recent years, a combination of food waste treatment with livestock manure or sewage sludge treatment facilities is commonly used because the treatment of food waste in combination with other input materials (e.g., sewage sludge and livestock waste leachate) can improve treatment efficiency and reduce costs [8,9] (Lee et al., 2013, Lee et al., 2016). This study proposes the stable addition of food waste and food waste leachate into the anaerobic digesters of existing wastewater treatment plants as an alternative method of treatment for those that have not been properly treated in a safe and fast manner following the outbreak of ASF. Furthermore, an attempt was made to examine the appropriateness of the addition and to prepare a treatment method.

2. Material and Methods

2.1. Target Biogasification Facility

The biogasification facility used in this study is a combined sewage digester located in a public wastewater treatment plant in B City, Gyeonggi-do. The facility has 12 digesters with a capacity of approximately 80,000 tons. Raw sludge and food waste leachate were mixed and introduced into 6 digesters. For the other 6 digesters, surplus sludge was introduced for the combined treatment. The operation status of the digesters, such as the digestion method and days of stay, were surveyed in advance, and the results are shown in Tables 1 and 2. Figure 1 shows the full-scale plant and the construction design for the installation of a food waste leachate inlet to input additional food waste leachate. In the case of the wastewater treatment plant, a new food waste leachate inlet was installed in front of the screen so that the food waste leachate treated in the resource circulation center in City B could be introduced into the biogasification facility after being stored in the storage tank through the transport piping and screen. Additionally, a flow meter was installed to examine the flow rate of the additionally introduced food waste leachate.

Table 1. Anaerobic digester capacity of the wastewater treatment plant.

Digestion Method	Treatment Target	Digester Capacity	Gas Production	Days of Stay	Days of Operation
Mesophilic digestion	Raw sludge, surplus sludge, food waste leachate	82,776 m^3 (12 digesters)	27,600 m^3/day (based on 770,000 tons)	33	365

Table 2. The operation status of the wastewater treatment plant (2018).

Digestion Input Sludge (m^3/Day)				Digestion Gas Volume (m^3/Day)	Days of Digestion (Days)
Total	**Raw Sludge**	**Surplus Sludge**	**Food Waste Leachate**		
+1907	771	953	183	29,731	44

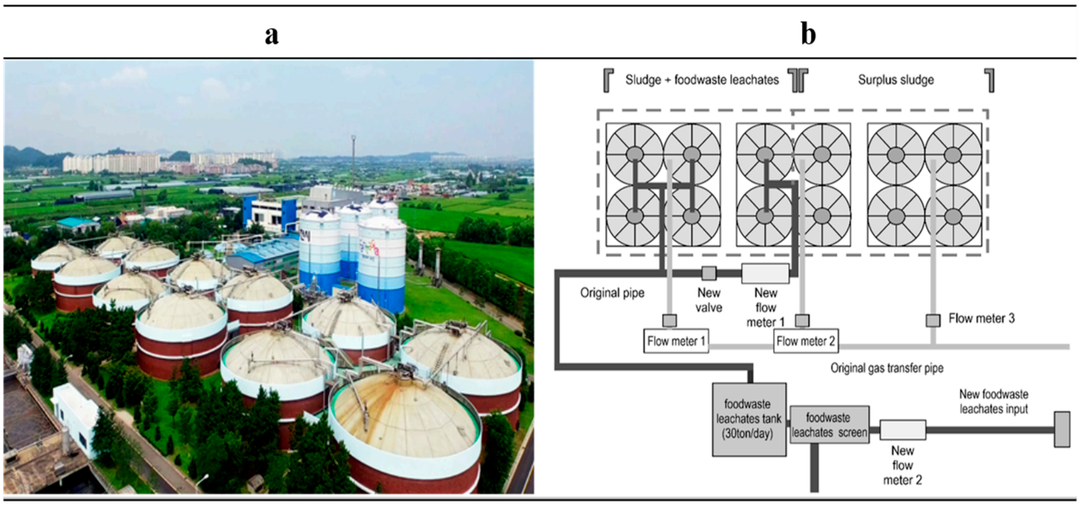

Figure 1. Schematic of the B wastewater treatment plant: full-scale plant (**a**); construction design (**b**).

2.2. Increased Digester Operation for the Additional Input of Food Waste Leachate

Since food waste leachate and sewage were introduced into biogasification facility for treatment only on weekdays (Monday to Saturday), experiments were performed on the input on weekends (Id) and the increased input for the additional input of food waste leachate. First, for approximately 4 weeks, i.e., from 1 to 29 June, the digesters' operation status, inflow, and outflow status, and the operation parameter characteristics of the existing biogasification facility were identified (control: 21.7%, 227.01 tons/day). Id was performed for approximately 8 weeks from 6 July to 3 September. On weekends (Sundays) when neither food waste leachate nor sewage was introduced, approximately 5% (100 tons/day) of the existing food waste leachate input was additionally introduced, and the digesters' operation status was identified.

Finally, the experiment on the increased input was performed for approximately 6 weeks from 4 September to 19 October. The rate of increase was set to 3 stages, considering microbial changes and loads in the digesters due to the rapid increase. The increased food waste leachate rates compared with the amount of inflow were set to Add 1 (23.1%, 197 tons/day), Add 2 (25.7%, 225 tons/day), and Add 3 (27.8%, 237 tons/day) in the experiment.

2.3. Basic Analysis

For basic analysis, sampling was performed for the input food waste leachate and sewage sludge into the anaerobic digesters of the target facility, and the output sludge from the digesters, dehydrated sludge cakes, and leachate. Three components were analyzed: moisture, volatile solid (VS), and fixed solid (FS) contents, along with elemental analysis (C, H, N, and S), chemical oxygen demand (CODcr), total nitrogen (TN, NH^3-N), and total phosphorus (TP). Additionally, alkalinity and volatile fatty acids (VFAs), which are used as inspection indicators for the operation status of anaerobic digesters, were analyzed. The three components were expressed as moisture and solid contents (based on weight %), based on the moisture and solidified substance weight method (ES 06303.1) of the waste process test standard, and VS was calculated by applying the obtained moisture and total solid (TS) content to the following calculation formula that utilized the ignition loss and the organic matter content weight method (ES 06301.1b) [10] (ME, 2017). FS was calculated by subtracting the VS from the TS.

$$\text{Water content}(\%) = \left\{\frac{\text{weight of the sample before dry}-\text{weight of the sample after dry}}{\text{weight of the sample before dry}}\right\} \times 100\text{TS}(\%)$$

$$= 100$$

$$-\text{water content}(\%)\text{VS}(\%) = \text{TS}(\%)\times$$

$$\left\{\frac{\text{weight of the sample before ignition}-\text{weight of the sample after ignition}}{\text{weight of the sample before ignition}}\right\} \times 100$$

CODcr was analyzed using the COD titration method and the potassium dichromate method (ES 04315.3), and TN was analyzed using the ultraviolet spectrometry oxidation method (ES 04363.1). Ammonium nitrogen (NH^3-N) was analyzed using ultraviolet spectrometry (ES 04355.1), and TP was analyzed using ultraviolet spectrometry (ES 04362.1). All of these were analyzed using the water pollution process test method [11] (ME, 2018). VFAs were analyzed using high-performance liquid chromatography (HPLC) [12] (Sa et al., 2011). The supernatant of the centrifuged sample was diluted and pretreated by filtration using a 0.45-µm syringe filter. An HPLC device (HPLC-DAD, Agilent 1200, USA) was used. The amount of biogas generated was measured in a collection facility at the rear end of the digester that generated biogas.

2.4. Energy Balance Analysis

The energy balance in the biogasification facility due to the additional and increased inputs of food waste leachate was analyzed. The biogas production per ton of waste (m^3/ton waste) was calculated using the amount of input waste into the anaerobic digesters of the sewage treatment facility and the biogas production (0 °C, 1 atm) obtained from the facility operation data. Additionally, the biogas production per unit of weight (t_{biogas}/day) of the biogasification facility was calculated by applying the methane and carbon dioxide contents of biogas, which were then applied to the mass balance. The volume of biogas production was calculated in weight units using the following equation:

$$\begin{aligned}
&\text{Biogas production in the weight unit}\left(T_{biogas}/\text{day}\right) \\
&= [\{(\frac{\text{amount of biogas generated}\left(Nm^3/\text{day}\right)}{\text{amount of input waste}(T_{waste}/\text{day})}) \times \text{ methane content } \times 16\ \text{g/mol} \\
&\div 22.4\ \text{L/mol}\} \\
&+\{(\frac{\text{amount of biogas generated}\left(Nm^3/\text{day}\right)}{\text{amount of input waste}(T_{waste}/\text{day})}) \times \text{ carbon dioxide content} \times 44\ \text{g/mol} \\
&\div 22.4\ \text{L/mol}\}] \times \text{ amount of waste generated}(T_{waste}/\text{day}) \div 1000
\end{aligned}$$

The energy balance of the anaerobic digester was calculated using facility operation data, as shown in Figure 2 [13] (ME, 2019). The input included the materials fed into the digester (raw sludge and food waste leachate) and the electrical energy needed for facility operations. The energy of the input materials was used for the energy balance calculation by measuring the heating values of the raw sludge and food waste leachate. The outputs included biogas, dehydration cakes, and effluents. For biogas, the heating value calculated according to the methane and carbon dioxide contents was used. For dehydration cakes and effluent, the output energy was calculated by measuring the heating values of each of them. Therefore, as with the mass balance analysis, the energy balance before and after the increased input of food waste leachate into the digester was compared and evaluated. Table 3 lists the higher heating values for each item of the input and output.

2.5. Economic Analysis

Economic efficiency was analyzed for the construction of new facilities for the input of food waste leachate, waste treatment, utilization of the produced biogas, and electricity consumption, with a focus on the raw sludge anaerobic digester to which the food waste leachate was introduced. There was no increased labor needed for the additional input of food waste leachate (Id and increased input), and the cost of chemicals was also excluded, as there was no significant increase in chemicals. The items for the economic analysis were set as shown in Table 4, and the field survey and facility operation data were utilized. The depreciation cost of the new facility for the input of food waste leachate was calculated by setting the residual value of the facility cost to 10% and using the straight-line depreciation method based on a service life of 10 years. The economic analysis was conducted by reflecting the values surveyed for other cost and revenue items [8,14] (Fachgentur Nachwachsende Rohstoffe (FNR), 2017; Lee et al., 2013).

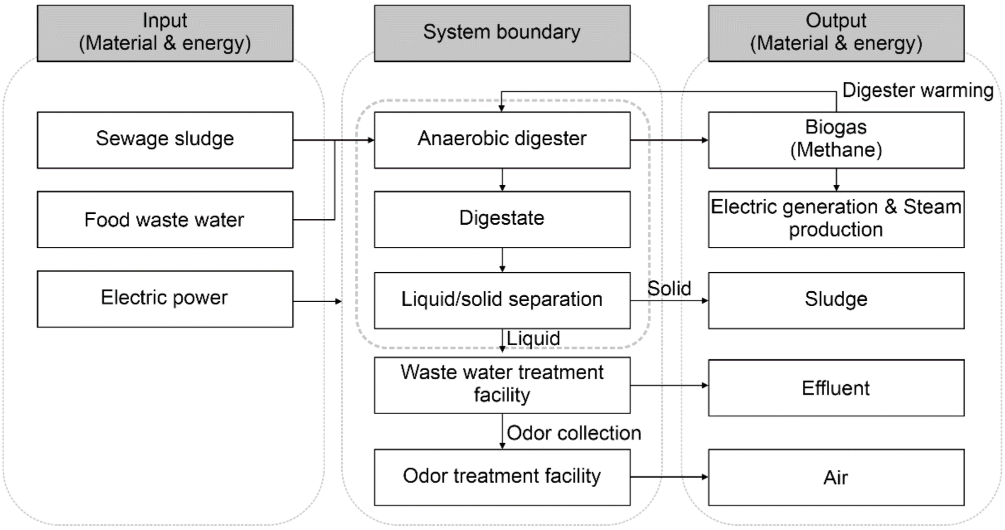

Figure 2. Flow chart of the energy balance analysis model.

Table 3. Outline of the energy balance analysis calculation.

Category		Item	Higher Heating Value (Dried)	Unit
Before the increased input (food waste leachate merge ratio: 21.7%)	Input	Raw sludge	4127	kcal/kg
		Food waste leachate	4556	kcal/kg
		Digester input material	4221	kcal/kg
	Output	Biogas	5875	kcal/m^3
		Dehydration cake	2999	kcal/kg
		Effluent	1294	kcal/kg
After the increased input (food waste leachate merge ratio: 29.3%)	Input	Raw sludge	4463	kcal/kg
		Food waste leachate	5372	kcal/kg
		Digester input material	4727	kcal/kg
	Output	Biogas	5961	kcal/m^3
		Dehydration cake	3030	kcal/kg
		Effluent	1423	kcal/kg

Table 4. Outline of the economic analysis calculation.

Items for Economic Analysis *		
Cost	New facility (depreciation cost **)	Mechanical construction Electrical construction
	Operating cost ***	Dehydration cake treatment cost Electricity cost
Benefit		Carry-in fee income for waste treatment *** Energy sales revenue ****

* The scope of analysis was limited to anaerobic digestion in the facilities in the wastewater treatment plant. In this study, fixed costs (labor costs, management cost, etc.) were excluded from the analysis because there was no additional cost because the increased amount of food wastewater was added to the existing facility. ** Calculated using the straight-line depreciation method based on a service life of 10 years (based on the residual value of 10%); *** Facility operation data were utilized(maintenance costs); **** Biogas production based on city gas use(Nm^3) × biogas calorie (MJ) × average city gas cost (KRW/MJ, refer to the average city gas cost of Gyeonggi-do in 2019).

3. Results and Discussion

3.1. Production and Treatment Status of Food Waste after the ASF Outbreak

The average food waste leachate production in South Korea after the ASF outbreak was 6970 tons/day. The average production was found to be 6821 tons/day in spring, 7959 tons/day in summer, 5974 tons/day in autumn, and 7125 tons/day in winter, exhibiting significant seasonal differences [4] (NIER, 2020) (Figure 3).

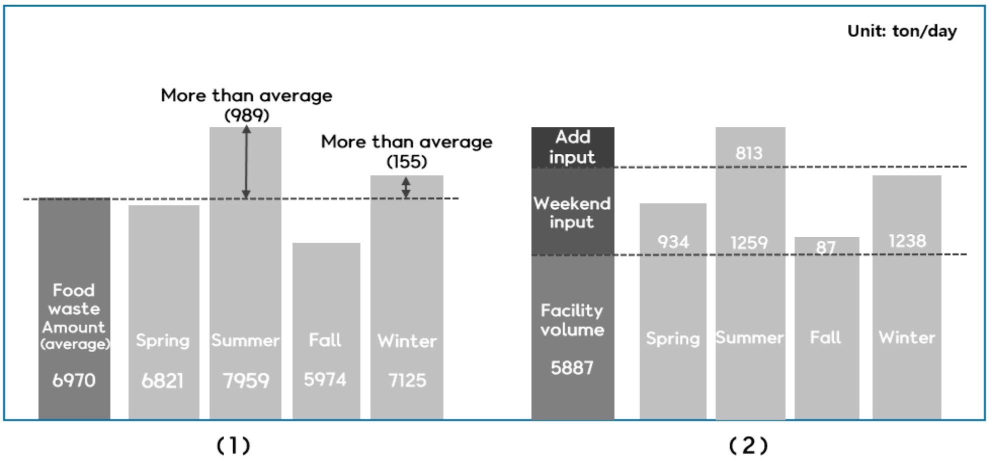

Figure 3. Bar graph depicting the amount of food wastewater (**1**) and treatment estimation, including alternative treatment methods (**2**).

Additionally, the amount of food waste leachate actually treated through conversion into feed (wet and dry), compost, and biogas was 5887 tons/day on average, and it was found that an average of 1083 tons/day required urgent treatment, and that the largest treatment shortage of 989 tons/day occurred in summer (Figure 3).

Simultaneously, as there is no input of materials such as food waste leachate into biogasification digesters in anaerobic decomposition facilities and wastewater treatment plants across the country on weekends (Saturday and Sunday), it was judged that 1259 tons/day and 1314 tons/day could be additionally treated through Id and the increased input of food waste leachate on weekdays. As such, it was judged that the stable treatment of food waste leachate is feasible through Id and the increased input of food waste leachate on weekdays in summer when the production of food waste leachate increases. Therefore, an empirical study was conducted to evaluate the possibility of additional input (Id and increased input) for food waste leachate that needs to be treated urgently. The digester efficiency according to Id and the increased input are as follows.

3.2. *Analysis of the Digesters' Operation Parameters According to Id and Increased Input*

Table 5 shows the concentrations of the input and output materials in the operation parameters of the digester according to Id (Sunday) and increased input (Add 1: 23.1%, Add 2: 25.7%, Add 3: 27.8%) during the experimental period. During the monsoon from 23 July to 10 September, the average sewage inflow increased approximately 2.1 times from 742,956 to 1,533,680 m^3/day. This caused the TS in the input materials to decrease by approximately 3.5% and VS to decrease by 13.5%.

Table 5. Parameter values for the input and output data.

Date	Sewage Inflow	Rainfall	Input Amount	Additional Input of Food Waste Leachate	Input				Output						
					TS	VS	TCODcr	SCODcr	TS	VS	TCODcr	SCODcr	Alkalinity	VFAs	NH_4^+-N
(day)	(m^3/d)	(mm)	(m^3/d)	(m^3/d)	(%)	(%)	(mg/L)	(mg/L)	(%)	(%)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
6/1	712,140	0.4	805	-	5.22	3.83	-	-	3.13	1.69	-	-	-	-	-
6/4	744,090	2.2	739		5.39	3.97	-	-	3.15	1.74	-	-	-	-	-
6/8	765,780	-	664		5.63	4.19	67,817	13,825	3.15	1.79	21,500	1960	7375	2447	1443
6/11	784,460	6.2	635		5.52	4.08	38,632	1771	3.18	1.75	19,000	2440	7083	-	1458
6/18	673,930	1.1	754		5.15	3.76	73,869	10,695	3.18	1.77	22,000	2560	5167	1291	1643
6/22	719,280	0.1	744		5.73	4.21	49,685	1466	3.20	1.83	20,500	2440	8083	22	1785
6/25	905,460	50.9	616		5.60	4.08	-	-	3.25	1.82	-	-	-	-	-
6/29	712,740	14.0	623		5.67	4.18	55,880	13,358	3.20	1.80	22,500	2280	8167	0	1519
7/6	684,590	66.1	685	35.88	5.22	3.88	79,130	24,606	3.02	1.72	23,000	2520	8000	0	1673
7/13	734,660	55.0	651	34.09	6.01	4.16	68,033	13,244	3.10	1.65	21,000	2520	7875	237	1274
7/16	735,390	9.2	605	31.72	5.24	3.64	64,147	10,119	3.12	1.68	30,000	2520	7833	644	1564
7/23	1,287,670	151.1	671	35.14	5.26	3.77	49,642	11,127	3.20	1.72	25,000	1000	7542	0	132.8
7/30	891,720	26.7	716	37.52	5.13	3.55	79,176	10,867	3.24	1.69	23,000	1840	7542	1219	1505
8/3	1,533,680	110.3	695	36.44	4.81	3.43	59,241	12,306	3.19	1.70	23,000	2440	7000	2301	1300
8/13	972,920	325.2	601	31.47	5.84	3.53	51,659	11,753	3.73	1.82	22,000	880	6833	105	1770
8/17	876,180	27.4	814	42.65	5.90	3.65	39,041	10,288	3.93	1.74	27,000	1280	6625	214	1000
9/3	1,428,900	97.0	841	44.09	5.00	3.08	39,000	1640	3.64	1.53	30,000	1720	6000	0	1060
9/10	1,014,120	68.0	853	197.12	5.17	3.22	52,319	12,688	3.45	1.49	21,000	1760	6125	0	1002
9/14	738,280	6.6	923	237.13	5.50	3.58	53,191	16,168	3.19	1.51	31,000	1560	6125	0	1420
9/24	636,230	19.6	825	211.94	5.13	3.53	51,652	14,467	3.13	1.47	23,000	1280	5580	178	1145
10/8	616,270	-	831	231.11	5.21	3.97	63,178	16,561	3.13	1.78	24,000	1360	5958	0	1263
10/12	611,640	-	885	245.94	5.31	4.10	55,549	16,184	3.06	1.77	20,000	4300	5125	1538	1073
10/19	721,640	-	841	233.71	5.67	4.42	54,923	16,529	3.29	1.91	21,000	2360	5750	754	1225

To identify the direct influence of the monsoon, the alkalinity, VFA, and ammonium nitrogen concentrations of the sludge discharged after Id and increased input were measured. The alkalinity was found to be 7175 mg/L and 7250 mg/L before and after Id, respectively, and it was 6125 mg/L, 5853 mg/L, and 5611 mg/L for Add 1, Add 2, and Add 3, respectively, which showed a tendency to slowly decrease. The VFA concentration was 1253 mg/L and 787 mg/L before and after Id, respectively, and it was 0 mg/L, 89 mg/L, and 1146 mg/L for Add 1, Add 2, and Add 3, respectively. It appears that both the alkalinity and VFA concentration decreased during the monsoon because the microbial activity decreased as the VS concentration decreased compared with the incoming TS.

Additionally, while the direct impact of the monsoon on the TS, VS, and organic matter decomposition rate of the digester was observed for Id and Add 1, the alkalinity and VFA concentration decreased for Add 1 and Add 2, indicating that the recovery was slow due to the influence of the monsoon.

Since ammonium nitrogen is an ion generated by the decomposition of protein and is contained in food waste leachate in large quantities, the additional input of food waste leachate increases ammonium nitrogen [15,16] (Salerno et al., 2006; Choi et al., 2008). However, the experimental results showed that the concentration did not significantly vary or decrease, which indicated that it decreased due to the change in water quality caused by the monsoon.

3.3. Analysis of the Digesters' Operation Efficiency According to Id and Increased Input

3.3.1. Organic Matter Decomposition Rate

Id was performed through the food waste leachate inlet additionally installed in the anaerobic digester, and the Id and increased input are shown in Figure 4, which depicts the TS, VS, TCOD, and SCOD decomposition rates of food waste leachate according to Id and increased input. The TS and VS decomposition rates before the additional input were found to be 42.0 and 56.0%, respectively. They exhibited a tendency to slightly increase immediately after Id, and decreased by 10% and 5% during the monsoon, as the average decomposition rates were found to be 34.2 and 51.72%. It appears that the decomposition rate of TS rapidly decreased because the amount of high-concentration organic matter increased because of the additional input of food waste leachate and non-biodegradable input materials, such as soil and sand introduced during the monsoon (7 weeks) remain in the sewage. Subsequently, the previous decomposition rates were recovered, as the average TS and VS decomposition rates were 40.5% and 58.1% for Add 2, and 41.5% and 56.3% for Add 3.

In anaerobic fermentation, SCODcr can indirectly determine the amount of organic matter (e.g., carbohydrates) generated in the hydrolysis process of glucose, sucrose, and cellulose [17] (Bahl et al., 1982), and it can be considered as a representative water quality indicator for wastewater treatment plants related to the pollution load of the effluent. As shown in Figure 4, in the case of TCOD and SCOD, the difference in the decomposition rate was slightly larger than TS and VS, and their decomposition rates dropped sharply after the start of the monsoon, as did the decomposition rates of TS and VS; the final TCOD and SCOD decomposition rates (61.8% and 85.7%, respectively); however, they were slightly higher than before the additional input because the organic matter decomposition rate recovered slowly after the monsoon.

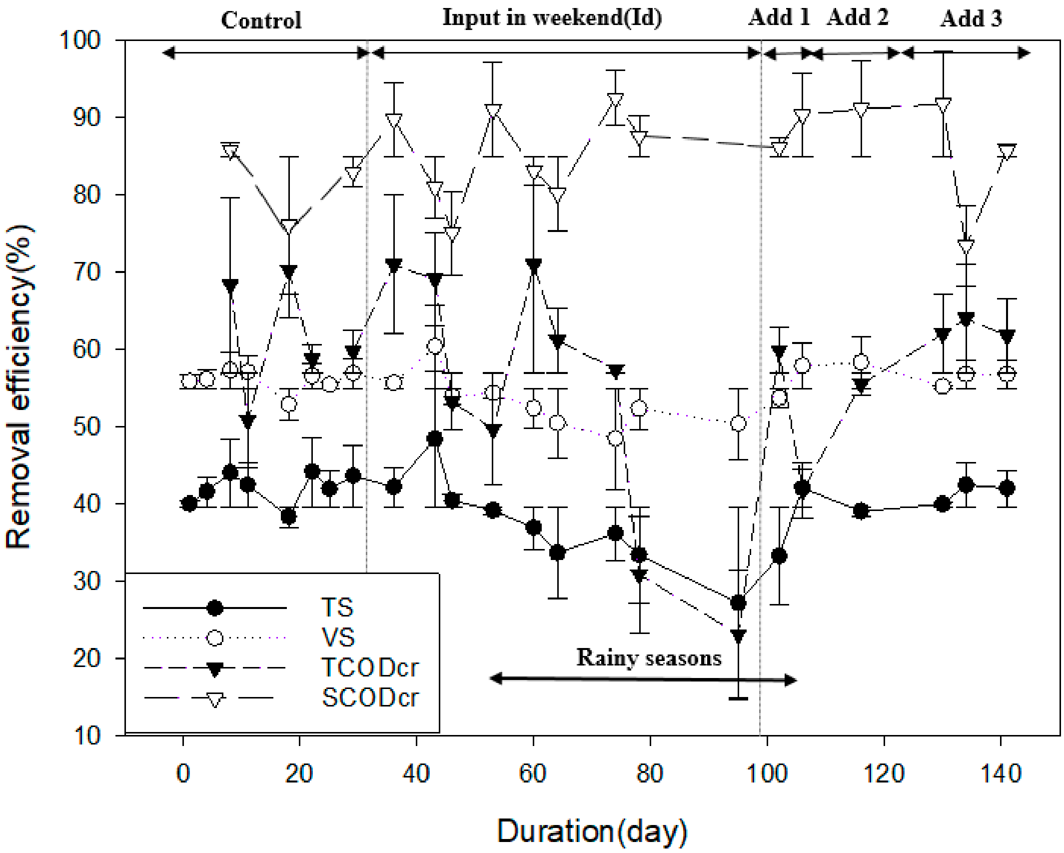

Figure 4. Plot showing the variation in TS and VS efficiency in the experimental period.

3.3.2. Methane Production

The additional input of food waste leachate increased the organic matter load in the digester. Due to the increased organic matter load, increased biogas production can be expected, as the growth of microorganisms occurs [18–21] (Byeon and Ryoo 2019; Heo et al., 2008; Lee et al., 2015) However, it is necessary to provide sufficient stabilization time when additional food waste leachate is introduced, because a sharp increase in organic matter load may inhibit the growth of microorganisms [22] (NIER, 2020). Therefore, biogas and methane production can be used as an indirect indicator of the activity of microorganisms in the digester [23] (Abhay K. and Pratap. P., 2013). Figure 5 shows the methane production and yield before and after Id, and after the increased input (three stages). The average methane production was 12,487 Nm^{3}CH$_4$/day and 10,284 Nm^{3}CH$_4$/day before (control) and after Id, and it was 9230 Nm^{3}CH$_4$/day, 12,125 Nm^{3}CH$_4$/day, and 14,896 Nm^{3}CH$_4$/day for Add 1, Add 2, and Add 3, respectively. Methane production decreased significantly for Id and Add 1 due to the influence of the monsoon, and it increased by 19.3% for Add 3 compared with before Id.

As for the methane yield after the increased input (three stages) before and after Id, the average yield was 0.47 Nm^{3}CH$_4$/kg CODcr and 0.42 Nm^{3}CH$_4$/kg CODcr before (control) and after Id, respectively, and it was found to be 0.38 Nm^{3}CH$_4$/kg CODcr, 0.46 Nm^{3}CH$_4$/kg CODcr, 0.60 Nm^{3}CH$_4$/kg CODcr for Add 1, Add 2, and Add 3, respectively. Further, the methane yield exhibited a tendency similar to that of methane production.

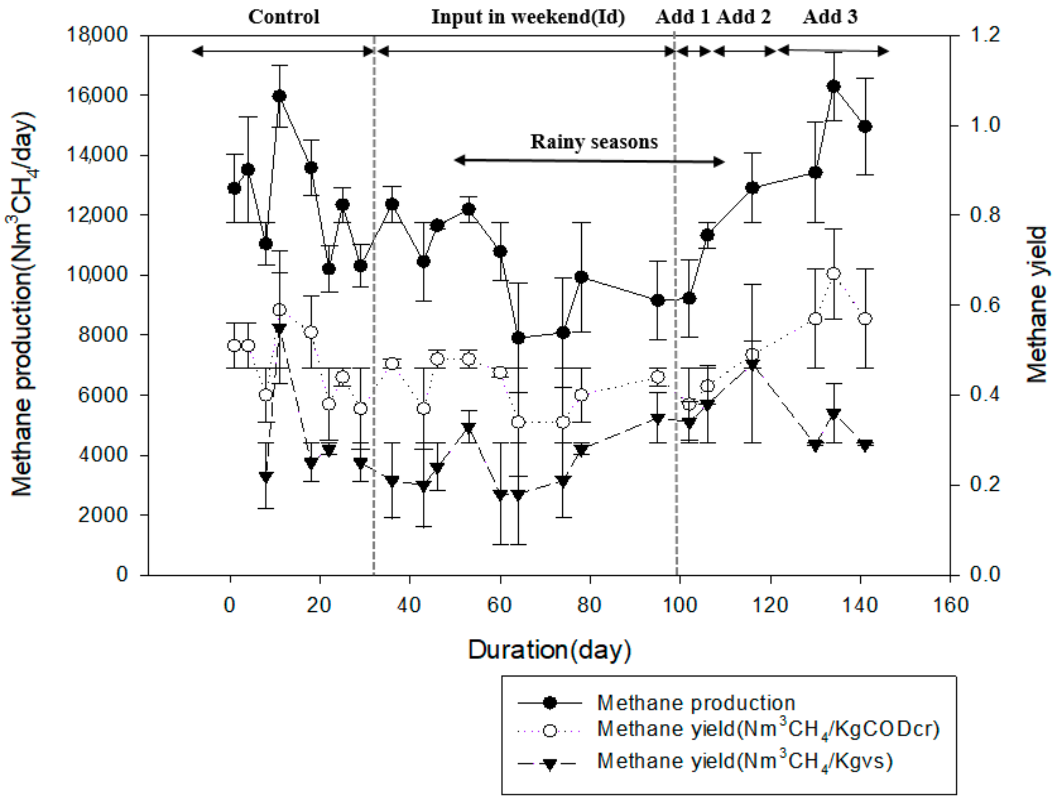

Figure 5. Plot depicting the variation in methane yield and methane production in the experimental period.

3.3.3. Analysis of the Influence of the Monsoon on the Digesters through FS/TS Analysis

Figure 6 shows the FS and FS/TS concentrations in the previous year (the same period in 2019) and during the experimental period, which can be used to examine the direct and indirect influences of the monsoon. During the experimental period, the average FS concentration of 1.62% before the monsoon increased sharply to 2.09% during the monsoon, which indicated an increase in influent water and the increased inflow of foreign substances, such as soil and sand. After the start of the monsoon, the FS/TS ratio increased by up to 58% compared with before the experiment, indicating that the monsoon (7 weeks from 23 July to 10 September) had direct and indirect impacts on digester operation, such as a reduction in the organic matter decomposition rate and methane production of the digester.

Additionally, De Freitas et al. (2020) reported that methane production decreases by up to 20% if the sewage inflow increases by 5% to 9%. In this study, methane production also decreased by approximately 26.1% during the monsoon [24], while the sewage inflow increased by up to 206%. It appears that a sharp increase in sewage inflow had relatively little influence on the internal environment (e.g., alkalinity and pH) and microbial activity of the digester due to the additional input of food waste leachate, which is a high-concentration organic waste. Additionally, there were differences in the FS and FS/TS values even after the monsoon. These appear to be due to foreign substances, such as soil and sand, being introduced during the monsoon, remaining in the digester, and affecting the FS/TS value.

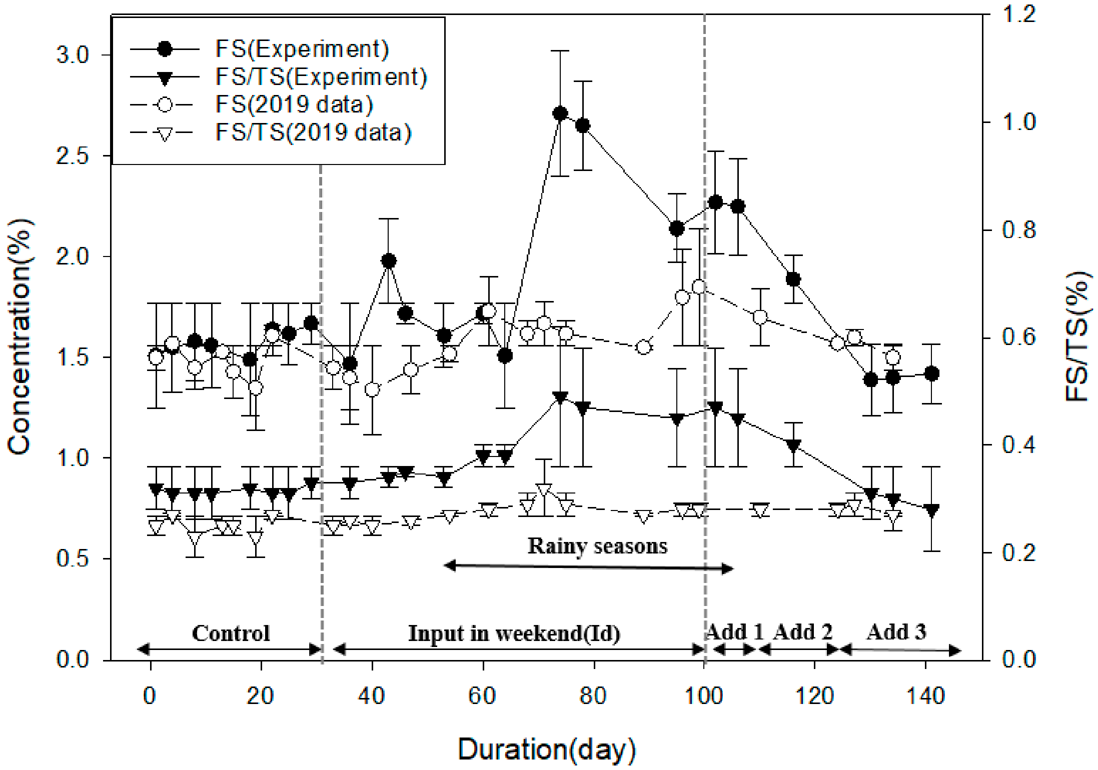

Figure 6. Line graph depicting the variation in FS and FS/TS concentrations in the experimental period.

3.4. Analysis of the Digesters' Operation Effects According to the Additional and Increased Input of Food Waste Leachate

3.4.1. Analysis of Dehydration Cakes and Water Pollution Load

When food waste leachate is additionally introduced into the existing combined sewage treatment facilities, the production of dehydration cakes may increase owing to the change in digester efficiency [25] (Moon et al., 2009). Therefore, the average amounts of dehydration cakes and effluent generated compared with the TS decomposition rate were calculated. Before the Id and increased input (food waste leachate merge percentage: 21.7%), the average amounts of dehydration cakes and effluent generated were found to be 120.3 and 881.3 tons/day, respectively. After the increased input (food waste leachate combined percentage: 29.3%, food waste leachate input: 236.9 tons/day), the average amounts of dehydration cakes and effluent generated increased by 11.0% and 9.8%, respectively, compared with before the increased input, 133.6 and 969.8 tons/day, respectively. In this instance, the average TS decomposition rate of the digester was 42%, which is a relatively low rate during the monsoon. If the TS decomposition rate of the digester increased by 5% to 6% and reached a normal state in a case other than the monsoon, the same amount of dehydration cakes as before the increased input would be generated. This is due to the increased VS decomposition rate in the input material caused by the digestion efficiency being improved by the input of food waste leachate. Finally, the additional input of food waste leachate generated no or an insignificant amount of additional dehydration cakes (Table 6).

The pollution loads of the existing combined sewage treatment facility and in the case of additional inputs were calculated and compared. The food waste leachate merge ratio before the additional input of food waste leachate was 21.7%, and the proportions of BOD, COD, SS, TN, and TP in the design input load were 0.8%, 0.7%, 0.4%, 2.3%, and 2.9%, respectively. When additional input of food waste leachate (merge ratio: 27.8%) was added, the food waste leachate merge ratio was 27.8%, and the proportions of the five main substances were 0.9%, 0.8%, 0.5%, 2.5%, and 3.2%, showing a 0.1% increase for BOD, COD, and SS; a 0.2% increase in TN; and a 0.3% increase in TP. The increase in water pollution load due to the increased input of food waste leachate was also insignificant.

Table 6. Calculation of dehydration cakes and influent of the wastewater treatment plant.

Category	**Total Input (Tons/Day)**	**Output**				**Total Output (Tons/Day)**
		Biogas	**Moisture**	**Dehydration Cake**	**Effluent**	
Control	1021.8	19.5	0.7	120.3	881.3	1021.8
After the increased input	1131.6	28.6	0.9	133.6	968.5	1131.6
Category	**Total Input (%)**	**Output**				**Total Output (%)**
		Biogas	**Moisture**	**Dehydration Cake**	**Effluent**	
Before the increased input	100.0	1.9	0.1	11.8	86.3	100.0
After the increased input	100.0	2.5	0.1	11.8	85.6	100.0

3.4.2. Energy Balance Analysis

For the energy balance analysis, the input into the anaerobic digesters of the wastewater treatment plant and the amount of biogas generated were examined, and the results are shown in Table 7. The biogas conversion efficiency is the efficiency of converting the energy of the input waste into biogas [26] (Lee. D.J. at al., 2016). The conversion efficiency after the additional input of food waste leachate (50.1%) was approximately 4.9% higher than that before the additional input (45.2%). The biogas production efficiency is calculated by adding the energy required for internal facility operation to the input. The biogas production efficiency after the additional input of food waste leachate (49.7%) was 5.4% higher than that before the additional input (44.3%). The biogas plant' efficiency is the biogas utilization efficiency, which excludes the unused gas from the output. The biogas plant efficiency after the additional input of food waste leachate (45.9%) was approximately 6.6% higher than that before the additional input (39.3%). This is because the additional input of food waste leachate could improve biogas production and utilization efficiency by increasing the digesters' efficiency through the inflow of high-concentration organic waste.

Table 7. Energy balance for biogas energy use.

Category	**Input (kcal)**		**Output (kcal)**		**Biogas Conversion Efficiency (%)**	**Biogas Production Efficiency (%)**	**Biogas Plant Efficiency (%)**
	Organic Waste	**Electricity**	**Biogas**	**Unused Biogas**	**Total Output/ Organic Matter Input**	**Total Output/ Total Input**	**(Total Output-Unused)/ Total Input**
	A	**B**	**C**	**D**	**C + D/A**	**(C + D)/(A + B)**	**C/(A + B)**
Before the increased input (merge ratio: 21.7%)	241,525,907	4,949,678	96,978,625	12,219,879	45.2	44.3	39.3
After the increased input (merge ratio: 27.8%)	305,415,215	5,296,156	142,736,145	11,761,709	50.1	49.7	45.9

3.4.3. Economic Analysis

Table 8 shows the economic analysis results for the anaerobic digester due to the increased input of food waste leachate. An economic analysis was conducted on a new facility for the input of food waste leachate, the cost of digester operation and sludge treatment, and the benefit of introducing food waste leachate and using biogas [27] (Philip D.L., 1991).

Table 8. Results from the economic analysis of the anaerobic digester of the wastewater treatment plant.

Category			After the Increased Input
Cost	New facility	Mechanical construction	16,621,000 *
		Electrical construction	15,917,000 *
		Subtotal	32,538,000 *
		Depreciation cost (A)	8023
	Variable cost	Dehydration cake treatment cost	5,344,000
		Electricity consumption	689,731
		Subtotal (B)	6,033,731
		Total (A + B)	6,041,754
Benefit	Revenue	Carry-in fee income for waste treatment (C)	17,569,500
		Biogas production (D)	8,328,422
		Subtotal (C + D)	25,897,922
Carry-in fee and other revenues included		Management balance ((C + D) − (A + B))	19,856,168
		Benefit/cost analysis ((C + D)/(A + B))	4.3
Carry-in fee and other revenues excluded		Management balance (C − (A + B))	11,527,746
		Benefit/cost analysis (C/(A + B))	2.9

* Units are KRW.

The management balance was expressed as the value obtained by subtracting the costs from the benefits, and the economic analysis was expressed as the benefit/cost (B/C) ratio [28] (Gu et al., 2020). The economic analysis results after the additional input of food waste leachate, which included the carry-in fee and other revenues, showed that the management balance was KRW 19,856,168 per day and the B/C ratio was 4.3, which was much higher than 1.0. The economic analysis results after the additional input of food waste leachate, excluding the carry-in fee and other revenues, showed that the management balance was KRW 11,527,746 per day and the B/C ratio was 2.9. The B/C ratio was higher than 1.0, as in the case including the carry-in fee and other revenues. This implies that anaerobic digestion by adding food waste leachate to a sewage treatment facility leads to sufficient management balance and business feasibility.

3.4.4. Consideration of Food Waste Emergency Treatment in the Sewage Treatment Plant

Based on the results of this study, Table 9 shows the input amount calculation method and input method when adding food waste and food waste leachate to the existing wastewater digester. In the case of increasing the amount of food wastewater input to the existing digester, it is necessary to consider the characteristics of the food waste or food waste leachate first. Changes in the organic loading rate (OLR) and retention time due to the increased input should be investigated in advance, and then the final rate of increase should be calculated. In addition, the digester operating factors of alkalinity, VFAs, methane production, etc. during digestion are substances generated after the metabolism of microorganisms and cannot be checked immediately after inflow. Therefore, food waste and food waste leachate should be introduced in stages in consideration of the adaptation period of microorganisms. On the other hand, the existing digester is divided into the combined digestion used in this study and single sewage sludge digestion. Since the allowable input amount varies depending on the type of digester, additional inputs should be applied after sufficient prior consideration. In the future, if an increase in the amount of food waste is calculated according to the type of digester and an input plan is prepared, it is judged that it can be used as a solution for the emergency treatment of food waste and food waste leachate in the sewage treatment plant.

Table 9. Checklist and maintenance methods for emergency food waste treatment in the sewage treatment plant.

<table>
<tr><th>Section</th><th>Checklist</th><th>Maintenance Method</th><th colspan="2">Standard Value</th><th>Reference</th></tr>
<tr><td rowspan="11">Precaution</td><td>Input component</td><td>Measuring the component of foodwaste or foodwaste leachate (TS, VS, COD, TN, etc.)</td><td colspan="2">TS: 10 ± 2%
TN: 2000~4500 mg/L</td><td>This study</td></tr>
<tr><td rowspan="8">Retention time</td><td rowspan="8">Check the appropriate residence time according to the operating temperature of the anaerobic digester</td><td>Temperature (°C)</td><td>Retention Time (Day)</td><td rowspan="8">[29]</td></tr>
<tr><td>15</td><td>67.8</td></tr>
<tr><td>20</td><td>46.6</td></tr>
<tr><td>25</td><td>37.5</td></tr>
<tr><td>30</td><td>33.3</td></tr>
<tr><td>35</td><td>23.7</td></tr>
<tr><td>40</td><td>22.7</td></tr>
<tr><td>45</td><td>14.4</td></tr>
<tr><td>Organic loading rate (OLR)</td><td>Calculate the input ratio so that the final OLR is less than 3.0 $kg_{vs}/m^3 \cdot day$</td><td colspan="2"><3.0 $kg_{vs}/m^3 \cdot day$</td><td>[29]</td></tr>
<tr><td></td><td>Expected that the amount of dehydrated cake and the pollutant load will increase
Calculate the increase rate in advance</td><td colspan="2">Pollutant load <10%</td><td>[30]</td></tr>
<tr><td colspan="2">Calculation of food waste input amounts</td><td>Calculate the total input amount that can be inputted according to the digester's capacity
The input amount being processed is subtracted from the total input amount</td><td colspan="2">$Q_t = V/HRT$
$Q_{Foodwaste} = Q_t - Q_{\text{Existing treatment amount}}$</td><td>This study</td></tr>
</table>

Table 9. *Cont.*

Section	Checklist	Maintenance Method	Standard Value		Reference
Input method	Combined sewage digester	Check the storage tank capacity and how to feed input to the digester	Storage capacity for at least 2 days		[31]
		Estimation of optimal combined ratio	$<3.0\ \mathrm{kg_{VS}/m^3 \cdot day}$		
		Adjusting the input speed considering the effective height of the storage tank	-		
	Single sewage digester	Prepare a tempoary tank for the step by step input of food waste and food waste leachate			
	How to increase	A rapid increase in the organic matter load factor should be prevented by changing the number of increases according to the difference between the existing OLR and the final OLR	**Final OLR – Existing OLR**	**Minimum Number (Number)**	[21]
			≤ 1.0	3	
			1.0~2.0	4	
			≥ 2.0	5	
Monitoring	Alkalinity	-	>5000 mg/L		[21]
	VFAs	-	≤ 3000 mg/L		
	Biogas/methane gas production	Gas production is expected to increase to more than existing gas production. Check the existing gas storage tanks' capacity and the facility's capacity	Methane amount ≒ 60%		

4. Conclusions and Recommendations

In this study, the feasibility of introducing food waste leachate into the existing combined sewage treatment or single sewage sludge treatment facilities on weekends and weekdays was evaluated for the urgent treatment of food waste leachate, which is rapidly increasing after the outbreak of ASF. Food waste leachate was added (Id and increased input) to the digesters operating inside the wastewater treatment plant, and its feasibility was evaluated by analyzing the operation parameters, evaluating the operation efficiency, and identifying its impacts and operation effects on the wastewater treatment plant.

The amount of food waste leachate in South Korea that needs to be urgently treated is 1083 tons/day. It was confirmed that such food waste leachate can be treated if Id is performed at the digesters in the anaerobic decomposition facilities operating across the country because 1259 tons/day (approximately 5% of the amount currently treated) can be additionally introduced. In summer, when the production of food waste leachate rapidly increases, it is necessary to increase the food waste leachate merge ratio by approximately 1.3% on weekdays for the digesters in operation, in addition to Id. Based on this, it was confirmed that all food waste leachates could be treated regardless of the season.

Therefore, experiments were performed to evaluate the possibility of Id and the increased input. During the experimental period, the inflow into the wastewater treatment plant increased by up to 206% owing to the long-term monsoon, although the organic matter decomposition rate and methane yield increased by approximately 5% and 21% to 85.7% and 0.57, respectively, which verified the feasibility of Id and increased input. Additionally, after the additional input of food waste leachate, there was no significant increase in the amount of dehydration cakes generated and the effluent load, indicating that anaerobic digestion had no significant environmental impact.

Simultaneously, the economic analysis results according to the additional input of food waste leachate showed that the B/C ratio was 4.3 after the additional input, indicating that performing anaerobic digestion by adding food waste leachate into the existing sewage treatment facility leads to sufficient management balance and business feasibility [32].

Based on the results of this study, it was confirmed that the additional introduction of food waste leachate into existing biogasification facilities and combined sewage treatment facilities on weekends and weekdays makes it feasible to treat food waste leachate in a stable manner. This indicates that the additional input of food waste leachate into existing anaerobic decomposition facilities is appropriate as an alternative treatment method to using food waste leachate as wet feed after an ASF outbreak. If further research is conducted to identify the main influencing factors to be considered for the additional input and to evaluate the specific efficiency of the increased input for each stage, it will lead to the development of the related technology industries and food waste leachate treatment.

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