Development and On-site Verification Test for Improving Oil Treatment Performance with Biogas Generation System "Metafarm"

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Summary

We developed the on-site biogas generation system "Metafarm" and implemented at large-scale commercial building (Abeno Harukas) in Osaka. The system treats the solid recovered from kitchen wastewater, and kitchen waste by anaerobic digestion. The stable operation has been continued from the introduction in 2013 to the present. To keep stable operation, the present system needs to remove oil by grease trap. One of the future issues is to make it possible to reduce the oil processing cost. In this research, to establish an efficient treatment method for the oil, we tried to solve it by adding organic materials and adjusting the oil ratio in the processing raw material. We report that stable operation was confirmed in a demonstration experiment using a 400L fermenter.

Keywords: kitchen drainage, food waste, anaerobic digestion

1 Introduction

The food service industry's recycling rate of food waste has plateaued at around 40% since 2013, instead of the government target of 50% [1-3]. Converting food to feed for livestock and fertilizer for agricultural products is often done to recycle food waste. One of the reasons for less progress in the recycling of food waste generated in the food service industry is the lesser demand for feed and fertilizer in urban areas having many food service industries. Furthermore, urban areas have a significant demand for energy such as heat and electricity. Thus, food waste can be recovered as biogas by methane fermentation treatment. However, treating organic waste generated from a building with methane fermentation requires additional treatment of digestion sludge residue, and the scale of the equipment is smaller than that of existing outdoor methane fermentation equipment. Hence, there has not been much progress in introducing the biogas system as a building facility due to low profitability. To address these issues, we have combined methane fermentation and kitchen detoxification equipment to develop the on-site biogas system "Metafarm" that reduces the cost required for digestion sludge treatment while conducting digestion sludge treatment in a stable manner [4]. This equipment is being used to ensure economic efficiency even with a kitchen waste processing amount of 3 tons/day (Photo 1). Furthermore, we repeated studies on a system that could achieve functionality and economic efficiency even on a smaller scale. We confirmed that this system is feasible even with a kitchen waste generation amount of 1 ton/day. Thus, it may be used in large shopping centers, complex facilities, etc. The practical application system involves a grease trap installed in the biogas system to remove oil from kitchen wastewater and maintain the oil ratio in the methane fermentation raw material below a certain level to avoid fermentation inhibition due to oil (Fig. 1).

Photo 1 Commercialized biogas system

Currently, oil separated by the grease trap (hereinafter referred to as "oil residue") is transported and disposed of off-site. If methane fermentation could be conducted without removing the oil residue, then the amount of methane gas generated would

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increase. The cost of disposing of the oil will decrease, and we can expect an improvement in economic efficiency.

In this study, we devised a biogas system that can treat the oil residue by adding proper organic materials and controlling the oil ratio in the raw materials. We verified the performance with a test device equipped with a 400-L methane fermenter.

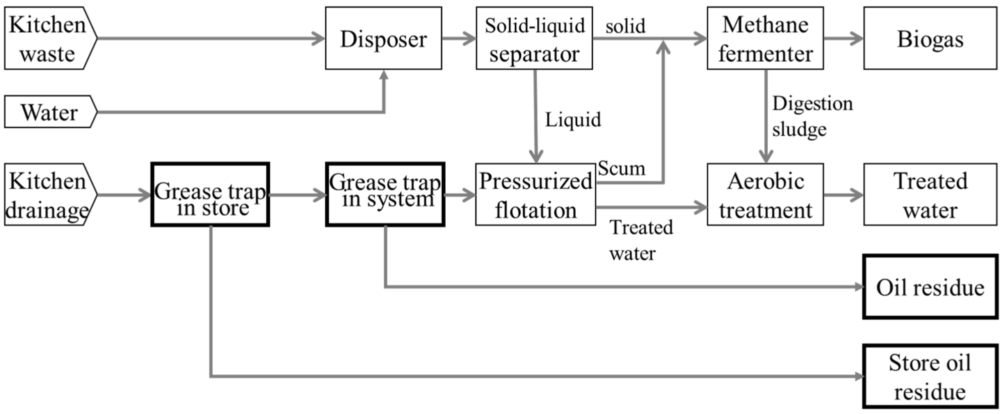

Fig.1 Flow diagram of commercialization biogas system

2 Demonstration test for improving the processing capacity

2.1 Determining the upper limit of the treatable oil ratio and organic matter load [5)]

We experimented on undermining the upper limit of the oil ratio, and organic matter load as these are the main components for stable operating conditions for methane fermentation. The oil ratio is the ratio of the oil content to the organic matter amount; volatile solid (VS) was used as the index of the organic matter amount, and n-hexane extract substance concentration (n-Hex) was used as the index of the oil content. Table 1 shows the test conditions. The test was conducted using methane fermentation test equipment with a 400-L fermentation tank. The fermentation raw materials were prepared by mixing samples (i.e., organic samples derived from kitchen waste and kitchen wastewater), oil residue, and tap water collected from the raw material tank of the methane fermentation facility in the existing commercial facility to meet the test conditions. In Test 1, the upper limit of the oil ratio that enables the stable operation of methane fermentation was confirmed. In Test 2, the upper limit of the VS volume load that allows the stable operation of methane fermentation was confirmed. Previous studies showed that “the VS removal was 76–78% in high-temperature methane fermentation of simulated waste [6)]. Additionally, glucose fermentation was inhibited when the volatile fatty acid concentration (henceforth, VFA concentration) exceeded 4,000 mg/L[7)]”; hence, it was decided to use a VS removal of 75% or more, and a VFA concentration of 3,000 mg/L or less in addition to the stable amount of methane gas was generated as a guideline.

Fig. 2 shows the test results obtained. As the methane production rate was stable in period 1, the average VS removal rate was

Table 1 Conditions for the upper limit confirmation test of oil ratio and organic matter load

		Temperature	HRT	Organic Loading Rate	n-Hex/VS
		(℃)	(day)	(kg-VS/m^3/day)	(—)
Test 1	Period 1	55	25	2	0.30~0.40
	Period 2				0.40~0.50
Test 2	Period 3	55	25	2	0.25~0.30
	Period 4		16	3	
	Period 5		12.5	5.5	
	Period 6		16	4	

78.1%, and Volatile fatty acids (VFA) concentration was less than 1,000 mg/. Thus, a stable operation was possible. Furthermore, the n-Hex removal rate average was 97.3% higher than the VS removal rate average. Therefore, the oil content exhibited more decomposition than other organic substances. Furthermore, the methane production rate in period 2 indicated a decrease in VS removal rate and a VFA concentration that exceeded 3,000 mg/L; as such, methane fermentation was inhibited, and stable operation became challenging to continue. The methane production continued for periods 3 and 4, and the VS removal rate average was more than 75%. No VFA was accumulated, thus enabling a stable operation. However, since the methane production rate decreased at the end of the test period (period 5) and the VFA concentration increased to approximately 3,000 mg/L, it would be challenging to continue a stable operation. The accumulation of VFA was eliminated in period 6, where the organic matter load reduced compared to period 5.

The results show that raw materials are mixed with oil residues with methane when fermenting. The stable operation of methane fermentation can be continued by setting the oil ratio (n-Hex/VS) to 0.3–0.4 or lower and the organic matter load to 3.0–4.0 kg-VS/m^3/day or lower.

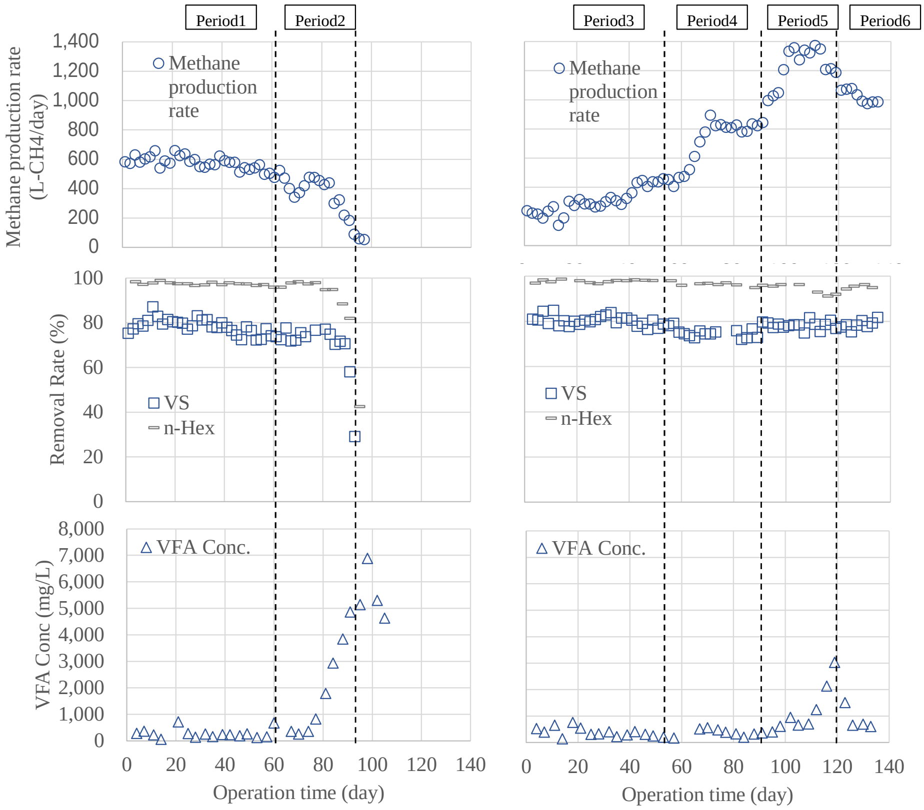

Fig.2 Results of upper limit confirmation test of oil ratio and organic matter load

2.2 Selection of organic materials

We investigated the organic materials used to adjust the oil ratio of the methane fermentation raw material. We selected the following eight types of organic materials that could be procured domestically and are mainly composed of carbohydrates and low in oil: dried kitchen waste (kitchen waste, breadcrumbs, tofu lees, and eco-fed made from them), old rice, corrugated cardboard, seaweed, waste molasses, waste sugar solution, waste sugar, and waste starch. We narrowed the candidates to four types: dried kitchen waste, corrugated cardboard, waste sugar solution, and waste starch by evaluation from the following perspectives: (1) stable procurement throughout the year, (2) raw materials that do not compete with food, (3) possible long-term storage at room temperature, (4) cheap procurement costs, and (5) little progress effective utilization. Table 2 shows the characteristics of selected organic materials. A methane batch fermentation test was conducted using raw material. We mixed each organic material and oil residue to analyze the oil content adjustment effect of the four selected organic materials.

The test involved using a fermenter sludge collected from a methane fermentation facility was put into practical use in a methane fermentation test device with a 3.5-L fermenter as the seed sludge. Then, a mixed raw material of the oil residue was prepared to a VS volume load of 5.0 kg-VS/m^3 and n-Hex/VS = 0.2, and each organic material was added. A 10-L methane fermenter was used to conduct batch tests under a fermentation temperature of 55 °C and a test period of 28 days. Furthermore, the effect of oil ratio adjustments by organic materials was verified by installing a 10-L methane fermentation tank for a system using only oil residue as a raw material (VS volume load 5.0 kg-VS/m^3, n-Hex/VS = 0.76). Batch tests were conducted under the conditions of a fermentation temperature of 55 °C and a test period of 28 days.

Table 3 shows the test results obtained from the fermentation test. The amount of methane gas generated per VS of oil residue was small, and the high oil ratio hindered the methane production. Meanwhile, the methane production rate increased in the mixed raw material of dried kitchen waste, waste starch, and waste sugar solution. The n-Hex removal rate had a value that was equal to or higher than that of the oil residue alone. These results suggested that the dried kitchen waste, waste starch, and waste sugar solution could be used as an organic material for adjusting the oil ratio. Additionally, compared to that of the oil residue alone, the mixed raw material for corrugated cardboard was not suitable as an organic material for adjusting the oil ratio because the methane production rate was approximately the same, and the n-Hex removal rate was approximately the same was lower.

Table 2 Characteristics of selected organic materials

	Dried kitchen waste	Corrugated cardboard	Waste starch	Waste sugar solution
Stable procurement year-round	No annual fluctuation: ◎	No annual fluctuation: ◎	Limited procurement amount: ○	No annual fluctuation: ◎
Competition with food	No competition: ◎	No competition: ◎	No competition: ◎	No competition: ◎
Long-term storage at room temperature	Long-term storage at room temperature possible: ◎	Long-term storage at room temperature possible: ◎	Long-term storage at room temperature possible: ◎	Spoiling possibility: △
Procurement cost	High procurement cost due to competition with feed: △	Can be cheaply procured: ◎	Relatively cheap since no processing required: ◎	High cost per unit organic material due to high water content: △
Effective use	Competition with feed: △	Recycling established: △	Not used at medium / small scale: ○	Not used due to low concentration: ○

Table 3 Results of mixed methane fermentation test of organic materials and oily residue

	Oil residue alone	Dried kitchen waste	Corrugated cardboard	Waste starch	Waste sugar solution
Methane gas generated per VS (Nml/g-VS)	120	554	161	419	360
n-Hex removal rate (%)	78	78	31	86	76

2.3 Stability confirmation test of adjusted raw material treatment with added organic materials

We confirmed the stable operation of methane fermentation with raw materials whose oil ratio was adjusted with organic materials by conducting a confirmation test with a methane fermentation test device in a 400-L fermenter. Dried kitchen waste and waste sugar solution were selected as organic materials because they could be obtained stably throughout the year. The samples collected from the raw material tank of the methane fermentation facility in the existing commercial facility and the oil residue were mixed based on the amount selected for the fermentation raw material. Organic materials and tap water were mixed to prepare for each test condition (Table 4). Additionally, the oil content adjustment effect of the organic materials was verified by conducting a continuous methane fermentation test on the sample collected from the raw material tank of the methane fermentation facility in the commercial facility. The raw material's oil ratio was adjusted only with oil residue and tap water. Table 5 shows the physical characteristics of dried kitchen waste and waste sugar solutions used in the test. As the Chemical oxygen demand Cr (CODcr) concentration of the waste sugar solution was higher than the VS concentration, there was a risk of overload based on the VS input amount. Therefore, the volumetric load was based on CODcr, and the oil ratio used n-Hex/CODcr instead of n-Hex/VS. The

Table 4 Conditions for continuous methane fermentation test of raw materials adjusted with organic materials

	Temperature (°C)	HRT (day)	Organic loading rate		Oil content ratio		Secondary material (—)
			VS standard (kg-VS/m^3/day)	CODcr standard (kg-CODcr/m^3/day)	n-Hex/VS (—)	n-Hex/CODcr (—)	
Period1	55	20	3.5	9.0	0.30	0.11	-
Period2			3.5	8.0	0.30	0.12	Dried kitchen waste
Period3			-	8.0	-	0.12	Waste sugar solution

volumetric load and oil ratio were found concerning the values of the continuous test using dried kitchen waste. This test's guideline for stable operation is that the methane production rate is stable, as discussed in section 2.1. Furthermore, it was decided that a VS removal rate of 75% or more and a VFA concentration of 3,000 mg/L or less must be used.

Table 5 Properties of organic materials

	CODcr (mg/kg)	VS (mg/kg)	n-Hex Soxhlet extraction (mg/kg)	n-Hex shaking method (mg/kg)
Dried kitchen waste	642, 000	871,000	56,900	-
Waste sugar solution	160, 000	94,300	-	19

Fig. 3 shows the test results. For periods 1, 2, and 3, the methane yield per kilogram of input CODcr was stabilized at around 210–240 m^3. However, the VS removal rate in periods 2 and 3 were 71% and 74%, respectively, which was slightly lower than the standard of stable operation of 75%. However, there was no VFA accumulation for periods 1, 2, and 3, and the methane production was also stable; hence, stable operation was achieved. It is evident from this result that adding dried kitchen waste or waste sugar solution to control the oil ratio enabled the methane fermentation of the entire amount without transporting the oil residue off-site.

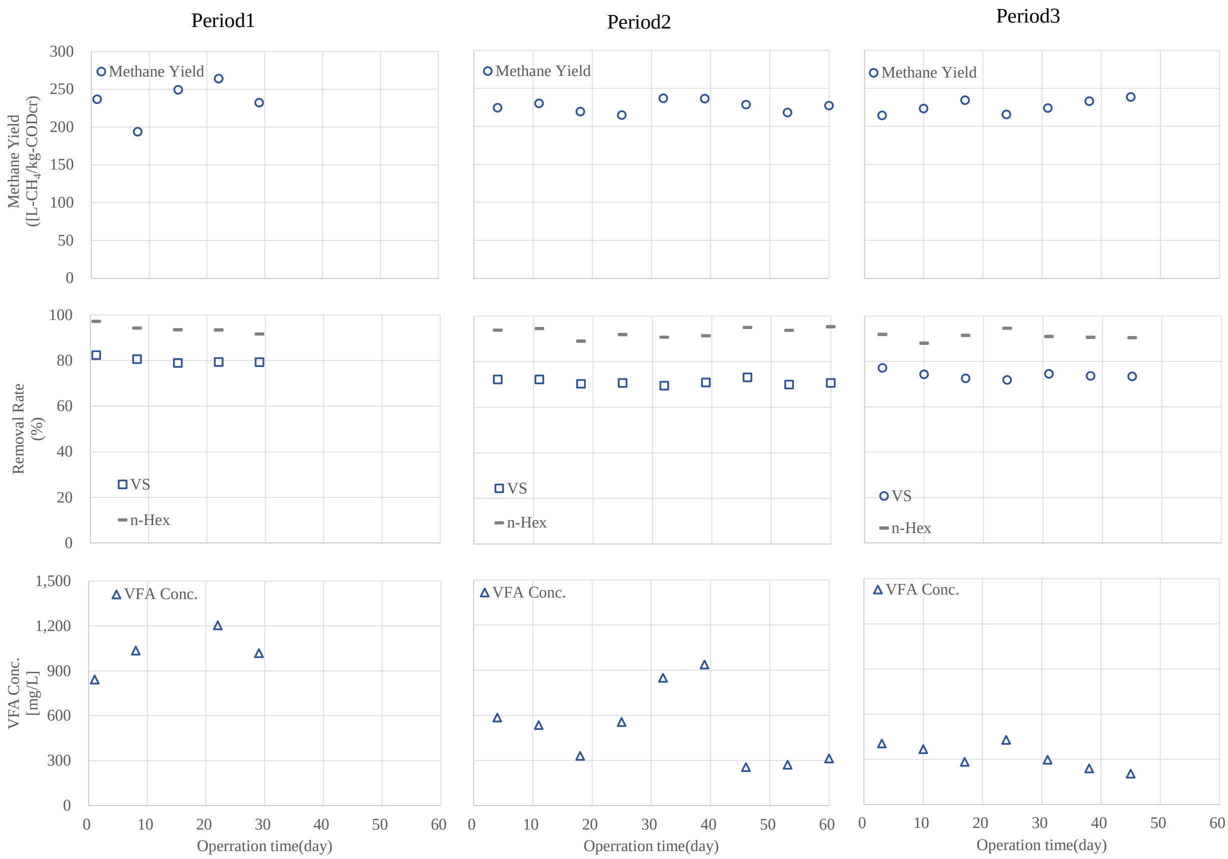

Fig. 3 Results of continuous test of raw materials adjusted with organic materials

3 System evaluation

3.1 Verification of the n-Hex concentration in treated water

Methods for separating the oil from the kitchen wastewater include collecting oil residue with a grease trap installed in each store and floating separation using a pressurized flotation tank in a biogas system (Fig. 4). Since the recovery of oil residue from the grease trap is a manual process that requires regular cleaning to maintain performance, significant effort is required. Furthermore, the cases wherein a grease trap us not used result in a decreased amount of oil that could be recovered from kitchen wastewater and an increased amount of oil flowing into the aerobic treatment in subsequent stages. Hence, even after aerobic treatment, the n-

Hex concentration cannot be reduced below the sewage discharge standard. Therefore, the material balance was calculated using the conditions shown in Table 6 based on the stability confirmation test results and the practical system's operational data. We investigated the upper limits of the number of organic materials required to make the oil ratio of methane fermentation raw materials 0.3, methane production rate, and the n-Hex concentration in kitchen wastewater to achieve an n-Hex concentration of 30 mg/L. This could be discharged after aerobic treatment for the case where the grease trap is installed at the store and for the point where the grease trap is not installed at either the store or in the biogas system. The VS concentration was set to the value obtained by adding 350 mg/L to the n-Hex concentration, and the dried kitchen waste was used as the organic material.

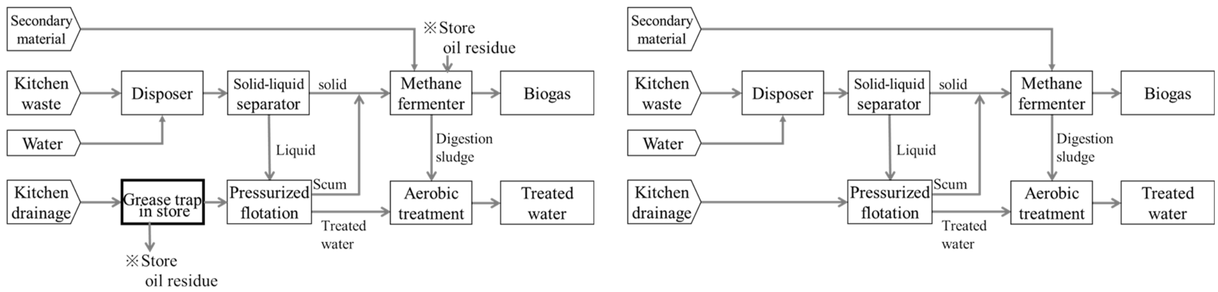

Fig. 4 System diagram for material balance Calculation

Table 6 Calculation condition for material balance

Calculation conditions								
Amount discharged			Solid remover recovery rate			VS removal rate		
Kitchen waste	kg/日	900	VS	%	65	With secondary material	%	73
Kitchen drainage	m^3/日	300	n-Hex	%	55	Without secondary material	%	80
VS concentration			Grease trap recovery rate			n-Hex removal rate		
Kitchen waste	g/L	180	VS	%	35	With secondary material	%	92
Kitchen drainage	g/L	871	n-Hex	%	43	Without secondary material	%	95
n-Hex concentration			Pressurized flotation recovery rate			Methane production rate per removed VS		
Kitchen waste	g/L	15	VS	%	46	Organic matter other than oil	L/kg-removedVS	600
Kitchen drainage	g/L	57	n-Hex	%	71	oil	L/kg-removedVS	1,350

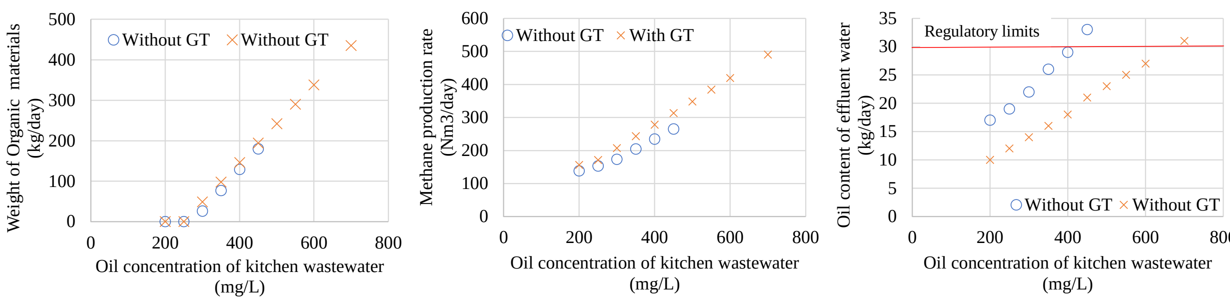

Fig. 5 Calculation results

Fig. 5 shows the results of the trial calculation. In the figure, the case where the grease trap is not installed is described as "Without GT," and that where the grease trap is installed on the store side is described as "With GT." Organic materials were added when the n-Hex concentration in the kitchen wastewater was 300 mg/L or more, with or without a grease trap on the store side, and more oil was recovered when a grease trap was installed on the store side. Therefore, it was confirmed that more organic materials were used and an increased methane production rate with a grease trap on the store side. Additionally, the upper limit of n-Hex concentration in kitchen wastewater that satisfied the sewerage discharge criteria of 30 mg/L or less after aerobic treatment after aerobic treatment was 400 mg/L when a grease trap was not installed on the store side and 600 mg/L when a grease trap was installed on the store side.

3.2 Comparison of the operating costs

It is concluded that the increased methane production rate will positively affect the system's operating cost due to the installation of the grease trap on the store side and the increased amount of organic materials used. In contrast, the maintenance costs of the grease trap will have a negative effect. Therefore, we calculated the operating costs under the conditions shown in Table 7 and verified whether grease traps should be installed on the store side for the three cases where the n-Hex concentration in the kitchen wastewater is 300 mg/L, 350 mg/L, and 400 mg/L.

Table 7 Calculation conditions for operating costs

Calculation conditions		
Unit price		
Secondary material	¥ /kg	40
Methane	¥ /kg	50
Maintenance cost		
GT cleaning cost	¥ /day	3,000
Piping cleaning cost	¥ /year	600,000

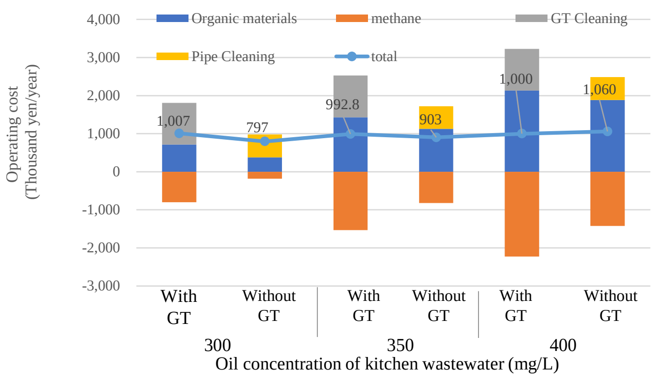

Fig. 6 Calculation result of operating costs

Fig. 6 shows the results of the estimated operating costs. In cases where the n-Hex concentration in kitchen drainage was 300 mg/L and 350 mg/L, it was more helpful not to install a grease trap. In cases where the n-Hex concentration in the kitchen drainage was 400 mg/L, it was more beneficial to install a grease trap. It was suggested that establishing a grease trap should be considered by estimating the n-Next concentration in the kitchen drainage when treating the oil in the drainage on-site without carrying it off-site.

However, the Ministry of Construction Notification No. 1597 (Revised March 29, 2010, Ministry of Land, Infrastructure, Transport and Tourism Notification No. 243) stipulates the installation of a grease trap to maintain the function of piping equipment. Hence, it should be noted that consultation with the government is required when an in-store grease trap is not used.

4 Conclusion

In this study, we focused on the constraints on the amount of oil acceptable in kitchen wastewater, one of the significant issues in operating a "Metafarm." We verified the operational stability of the biogas system under the condition that the oil ratio in the acceptable raw materials was increased by adding organic materials. Dried kitchen waste and waste sugar solution were selected as organic materials based on availability and batch tests. We confirmed stable operation under the operating conditions of n-Hex/VS = 0.3 and VS volumetric load of 3.5 kg-VS/m^3/day, using raw materials whose oil ratio was adjusted with dried kitchen waste and waste sugar solution.

Furthermore, we evaluated the effects of the presence or absence of grease traps on the n-Hex concentration after aerobic treatment. We also analyzed the impact on operating costs based on the results of stable operation tests and the operation data of commercial systems. Results showed that it might be helpful not to install a grease trap depending on the n-Hex concentration in the kitchen wastewater.

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