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Influence of Hydraulic Retention Time on Biogas Production from Frozen Seafood Wastewater using Decanter Cake as Anaerobic Co-digestion Material

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***Abstract*—**In this research, an anaerobic co-digestion using decanter cake from palm oil mill industry to improve the biogas production from frozen seafood wastewater is studied using Continuously Stirred Tank Reactor (CSTR) process. The experiments were conducted in laboratory-scale. The suitable Hydraulic Retention Time (HRT) was observed in CSTR experiments with 24 hours of mixing time using the mechanical mixer. The HRT of CSTR process impacts on the efficiency of biogas production. The best performance for biogas production using CSTR process was the anaerobic co-digestion for 20 days of HRT with the maximum methane production rate of 1.86 l/d and the average maximum methane production of 64.6%. The result can be concluded that the decanter cake can improve biogas productivity of frozen seafood wastewater.

***Keywords*—**anaerobic co-digestion, frozen seafood wastewater, decanter cake, biogas, hydraulic retention time

I. Introduction

AN anaerobic digestion of biomass feedstock and organic waste from factory is widely recognized as a mature and cost-effective process for producing biogas, which is a valuable renewable primary-energy source. Increasing interest in renewable energy production and in reduction of the greenhouse gas emissions associated with fossil fuels has made anaerobic digestion of plant biomass an attractive option. Source of biogas in Thailand covers a wide range of feedstocks including animal wastes, household wastes, crop residues, sewage sludge, wastewater, industrial waste, agro-industrial waste and waste from landfill [1]. The strategic plan for renewable energy development has been established in Thailand since 2003. The objective is to increase the share of renewable energy to 19,700 ktoe per year, by the year 2022.

Anaerobic digestion is a biological treatment used for converting organic wastes into biogas. The biogas produced can be used as an alternative renewable energy source [2-4].

Biogas can be categorized as an alternative for reduction of greenhouse gas emissions. The efficiency of anaerobic digestion process is controlled by the type of waste being digested, concentration, pH, alkalinity, temperature, hydraulic retention time, solid retention time, food to microorganisms ratio, rate of digester loading and the presence of toxic materials [5].

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Co-digestion of different materials may enhance the anaerobic digestion process due to better carbon and nutrient balances [6-7]. The low organic waste load of frozen seafood wastewater may not be sufficient to produce a cost effective biogas plant. Decanter cake is an agro-industry waste from palm oil mill industry. It was estimated to be 0.27 million tons a year [8]. Anaerobic co-digestion of frozen seafood wastewater with decanter cake offers some interesting alternatives for biogas productions.

In this study, we evaluated the potential of biogas production on anaerobic co-digestion at various HRT of CSTR processes between frozen seafood wastewater and decanter cake. The suitable HRT was observed in CSTR experiments with 24 hours of mixing time using the paddle mechanical mixer.

II. Materials and Methods

A. Experimental Raw Materials

Frozen seafood wastewater was obtained from a frozen seafood industry in Songkhla province, Thailand. Decanter cake is the organic waste remaining after the palm oil extraction which is an agro-industry waste from a palm oil mill industry in Krabi province, Thailand. The decanter cake is currently utilized as fertilizer and soil cover material in palm oil plantation area.

B. Experimental Setup

The schematic diagram of CSTR experimental laboratory set up is depicted in Fig 1. Experimental set-up is shown in Fig 2. The CSTR process was carried out in a 15 l reactor with 10 l working volume for 10 days, 20 days and 30 days of HRT in reactor 1, 2 and 3, respectively. Reactors were built from three PVC cylinders fitted with steel plates at the top and bottom of the experimental set. The top plate supported the paddle mechanical mixer, mixer motor, feed tube and biogas tube. The bottom cylinder supported the sampling port. The temperature was an ambient temperature at 30±2^{o}C. Reactors were stirred 24 hours a day using the paddle mechanical mixers. The experiment was carried out in duplicate. Biogas was sampled in a gas tube every 4 days. All reactors were fed everyday. The feed includes decanter cake and frozen seafood wastewater. The feed was prepared once a week using a kitchen blender. The prepared feed was stored at 4^{o}C. The already prepared feed was fed in all reactors everyday. The biogas production was measured by water displacement systems connected to the headspace of the effluent vessels, logging the gas production automatically at 20 ml intervals (Fig 3).

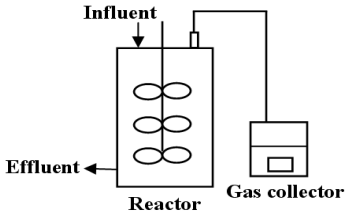

Fig. 1 Flow diagram of the CSTR process

Fig. 2 the anaerobic reactors

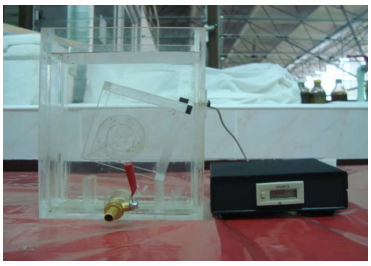

Fig. 3 The gas collector

C. Monitoring parameters

Biogas production was measured by the liquid displacement system similar to that used by Yetilmezsoy and Sakar [9]. The methane gas content of biogas was analyzed by Gas Chromatography (GC) analyzer with flame ionization detection. The monitored performance includes pH, temperature, TS, TVS, COD, TKN, NH_3-N, VFA, alkalinity and biogas [10].

III. Results and Discussions

A. Waste Characteristics

The characteristics of raw materials, including decanter cake and frozen seafood wastewater, are shown in Table I. The wastewater from the seafood industries is generated during the washing process. The frozen seafood wastewater contains high amount of COD (Table I) which is the main cause of deterioration of quality of receiving water bodies as rivers, reservoirs and lakes. Therefore, it should be treated by wastewater treatment plant prior to discharge to any receiving water body. The typical wastewater treatment plant is an aerobic biological treatment. The COD is not enough for a biogas production. However, by adding the decanter cake to the wastewater can increase the COD for biogas productions.

The COD of frozen seafood wastewater increases from 4,000 mg/l to 13,387 mg/l for reactor 1, 14,217 mg/l for reactor 2 and 14,235 mg/l for reactor 3.

These conditions are suitable for anaerobic digestion.

TABLE I
Characteristics of Raw Materials

Characteristics	Unit	Decanter Cake	Frozen Seafood Wastewater
1. pH	-	7.9	5.3
2. TS	%	23.96	0.27
3. TVS	%	20.71	0.20
4. COD	-	1,335 g/kg dry	4,000 mg/l
5. Alkalinity	mg/l as $CaCO_3$	25	598
6. VFA	mg/l as $CaCO_3$	40	355
7. Moisture content	%	76.27	-

TABLE II
Characteristics of Co-Digestion Reactors

Properties	Units	HRT (days)		
		10	20	30
1. pH	-	7.3	7.2	7.3
2. Temperature	^oC	28.5	28.5	28.5
3. COD	mg/l	13,837	14,217	14,325
4. TS	mg/l	14,235	14,355	14,392
5. TVS	mg/l	10,765	10,987	10,950
6. Alkalinity	mg/l as $CaCO_3$	538	494	344
7. VFA	mg/l as $CaCO_3$	328	283	245
8. NH_3-N	mg/l	36	42	42
9. TKN	mg/l	337	351	301

Table II shows the organic matter contains in the three reactors of various HRT at 10, 20 and 30 days. All reactors show the suitable pH before starting CSTR process.

B. CSTR operation

Experiments were performed for a period of 65 days. The temperature has a pronounced effect on the rate of gas production. In this research, the experiments were operated at the ambient temperature. The ambient temperature is range between 28 and 30^{o}C around mesophilic condition (25-40^{o}C).

The relationship of the pH and time was shown in Fig. 4. The pH is a control parameter during the anaerobic co-digestion. In all reactors, there is a decrease of pH value during starting period of the anaerobic digestion, where the pH value varies from 6.6-7.3 while after the steady-state the pH value varies from 6.8-7.3. The pH profiles showed that the pH value during the first 35 days of operation was slightly below 7 in all reactors. The pH value of the anaerobic co-digestion dropped during the initial period of digesting. After this period, the pH value tends to move towards neutral again (Fig 4). Non-methanogenic microorganisms responsible for hydrolysis and digestion can be adapted to low pH while the methanogenic microorganisms will lose activity at the low pH. During hydrolysis and digestion, the particulate materials are converted to soluble compounds and further degraded to acetate, hydrogen, carbon dioxide, propionate and butyrate.

The production of a large amount of volatile fatty acid leads to the decreasing of solution pH value. Between day 35-65, pH value in all reactors was increased until higher than 7.

All reactors reached the steady state. The final pH value ranges between 7.1 and 7.3 which is the result of the high crude protein in decanter cake.

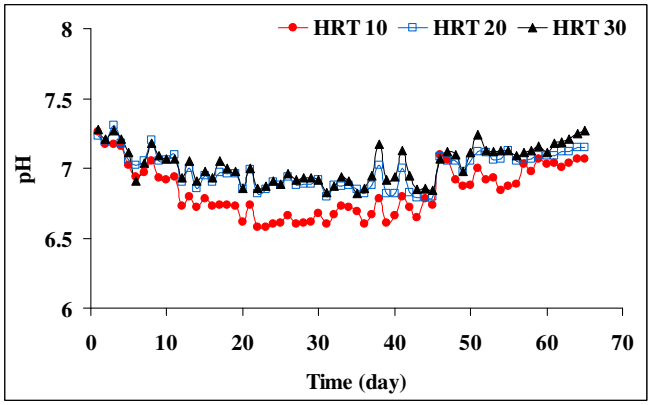

Fig. 4 pH during the CSTR operation

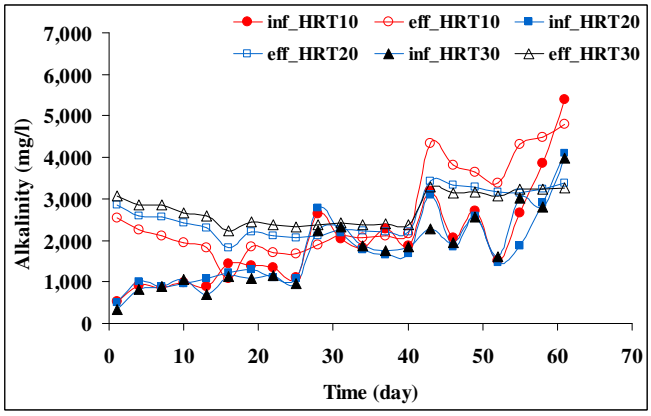

Fig. 5 Alkalinity during the CSTR operation

Alkalinity variation during the CSTR operation shows in Fig 5. The result shows that the alkalinity of all reactors has the same trend. In the first period of CSTR system (i.e., Day 1 to 35), the alkalinity slightly decreased and after the system reached to the steady state, the alkalinity increased.

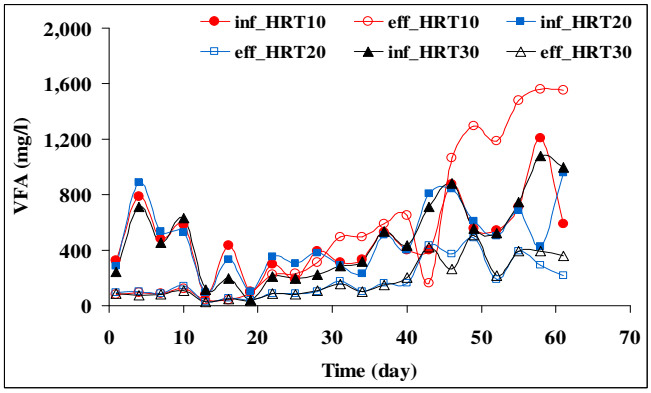

Fig. 6 Volatile fatty acid during the CSTR operation

Fig 6 shows the volatile fatty acid (VFA) variation during the CSTR operation. The influent of VFA has a very high variation. The effluent of VFA tends to slightly increase during the first 20 days. Even though the VFA levels continue to increase later on in all reactors, its values are not increased to the point that can induce the process inhibition.

The highest effluent of VFA of the 10-day HRT reactor results in the decreasing of the biogas production. This event is a result of the shift from methanogenic process to hydrolysis or acidogenic process in this reactor [11].

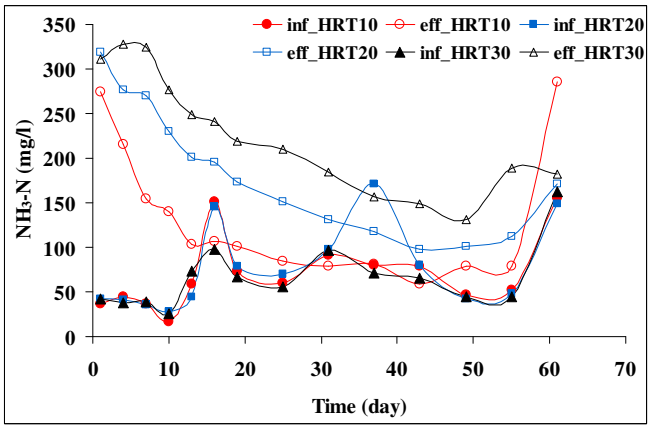

Fig. 7 Ammonia-nitrogen during the CSTR operation

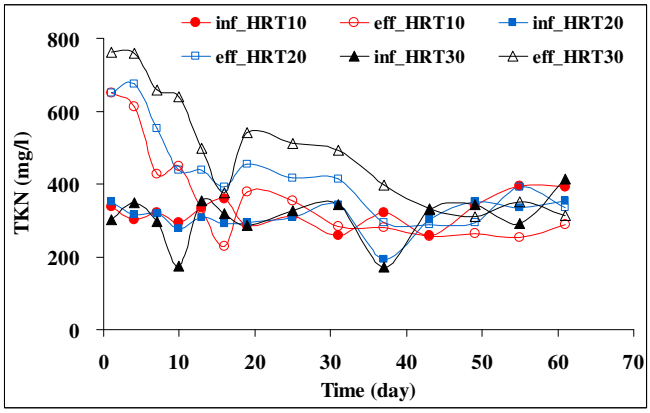

Fig. 8 TKN during the CSTR operation

Ammonia-nitrogen (NH_3-N) and Total Kjeldahl Nitrogen (TKN) variations during the CSTR operation are shown in Fig 7 and 8. The value of NH_3-N and TKN are similar in all three reactors. During the start period, NH_3-N and TKN values slightly decrease.

C. CSTR performance

Experiments were performed for a period of 65 days. Fig 9 shows the COD removal during the CSTR operation. At the starting of the CSTR operation, all reactors well adapt to the situation and produce good performances. As can be seen from Fig 9, the anaerobic co-digestion in all three reactors can remove COD close to 95%. The results during the whole process show that the 20-day and 30-day HRT reactors can remove COD in the range of 92.28%-94.54% while the 10-day HRT reactor show the lowest removal performance (i.e., 71.21%). The COD removal performances of the 20-day HRT and the 30-day HRT reactors show no significant difference.

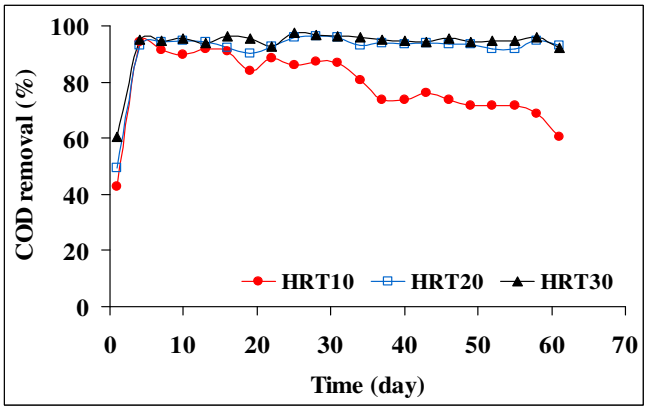

Fig. 9 COD removal at various hydraulic retention times

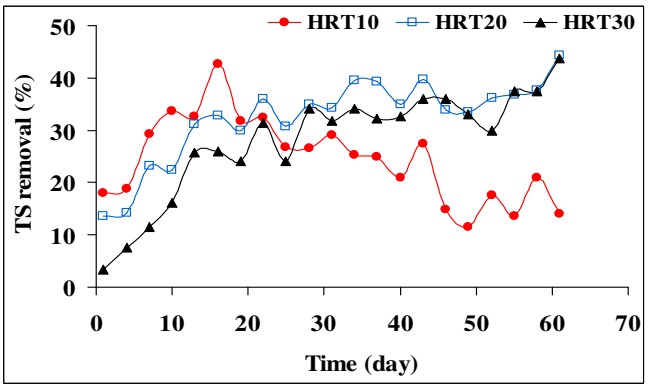

Fig. 10 Total solids removal at various hydraulic retention times

Fig 10 and 11 show the TS and TVS removal. During the starting stage of the operation (i.e., Day 0-20), the 10-day HRT reactor show the maximum TS and TVS removal performances. At the steady-state, however the removal performance of the 10-day HRT reactor decreases. On the other hand, the TS and TVS removal performances of the other two reactors increase continuously. The 20-day HRT reactor produces the slightly higher TS and TVS removal performances among the three reactors.

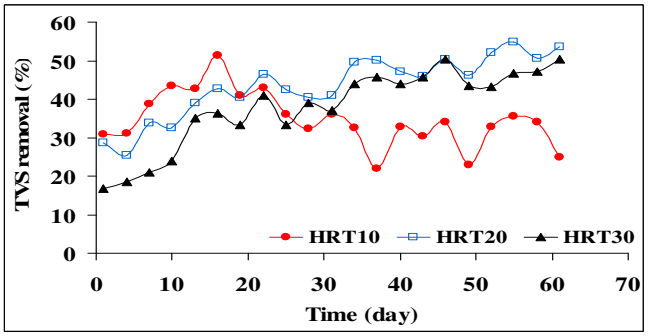

Fig. 11 Total volatile solids removal at various hydraulic retention times

Table III summarizes the steady-state data for the CSTR process. The 20-day HRT reactor provides the maximum COD, TS and TVS removal of 92.28%, 37.41% and 50.09%, respectively.

TABLE III
PROPERTIES OF REMOVAL EFFICIENCY ON CSTR PROCESS IN HRT VARIATION

Properties	Units	HRT (days)		
		10	20	30
1. COD removal	%	71.21	92.28	94.54
2. TS removal	%	16.55	37.41	35.39
3. TVS removal	%	27.33	50.09	46.29

D. Biogas production

Experiments were performed for a period of 65 days. The data on the average biogas production, methane production and percentage of methane are shown in Figs. 12-14 and summarized in Table IV. The stable biogas production is noticed during day 35-65 in all three reactors. At the stable biogas production, the 10-day HRT reactor produces 2.99 l/d; the 20-day HRT reactor produces 2.88 l/d while the 30-day HRT reactor produces 1.83 l/d.

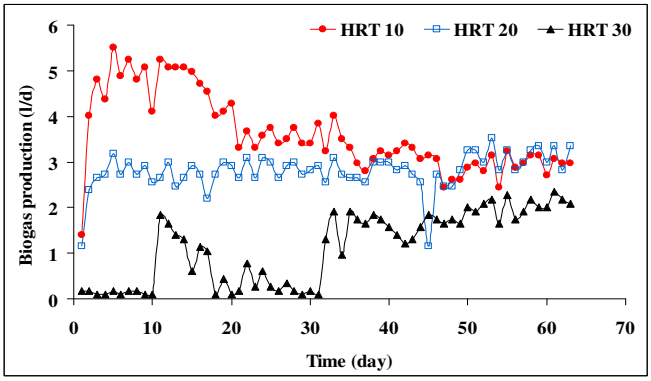

Fig. 12 Daily biogas production at various hydraulic retention times

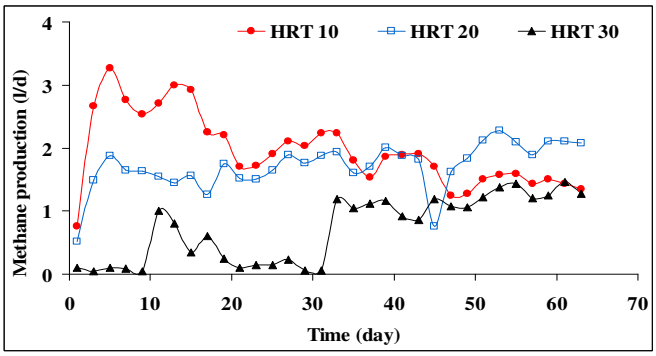

Fig. 13 Daily methane production at various hydraulic retention times

Fig 13 shows the relationship between the methane production and CSTR operation time. The methane production was followed for 65 days. During the first 5 days of the observation, the methane production is either very low or none due to the lag phase of microbial growth. After that, the methane production starts immediately in all reactors and reaches its maximum values after 35 days. The methane production is directly related to the biogas production during the first state of CSTR operation before the steady-state. The result before steady state shows that the reactor 10-day HRT reactor provides the maximum methane production, while the 20-day and 30-day HRT reactors produce the lower performances.

After day 35, all reactors reach to the steady state. The result during the steady state shows that the 20-day HRT reactor provides the maximum methane production. The 10-day HRT reactor produces the second highest methane production. The lowest of methane production is in the 30-day HRT reactor. Fig 14 shows the percentage of methane variation during the CSTR operation. The percentage of methane occurs quite same in all three reactors. But the percentage of methane observed in 10-day HRT reactor is slightly lower than that in 20-day and 30-day HRT reactors. All reactors reach to the steady state at day 35. The percentage of methane in 20-day and 30-day HRT reactors shows the same trend. But 10-day HRT reactor provides significant lower percentage of methane than others.

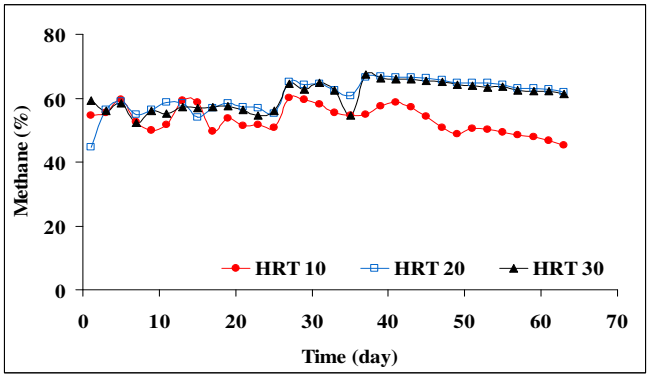

Fig. 14 Methane at various hydraulic retention times

Methane production performance is measured by the average percentage of methane and the maximum percentage of methane. The average percentage of methane observed in the 10-day HRT, 20-day HRT and 30-day HRT reactors is 51.7%, 64.6% and 63.6%, respectively. The maximum percentage of methane observed in the 10-day HRT, 20-day HRT and 30-day HRT reactors is 60.2%, 66.7% and 67.4%, respectively (Table IV). Table IV summarizes the biogas production performance during the steady state which includes the average biogas production, the maximum biogas production, the average methane production and the maximum methane production. The maximum methane production and percentage of average methane in the 20-day HRT reactor are 1.86 l/day and 64.6%, respectively. Finally, the conclusion can be drawn that the variation of HRT significantly affects the digestibility in the biogas production.

TABLE IV
PROPERTIES OF BIOGAS AND METHANE PRODUCTION ON CSTR PROCESS IN HRT VARIATION

Properties	Units	HRT (days)		
		10	20	30
1. Biogas production	l/day	2.99	2.88	1.83
2. Maximum biogas production	l/day	5.50	3.53	2.35
3. Methane production	l/day	1.57	1.86	1.18
4. Maximum methane production	l/day	3.27	2.29	1.46
5. Average methane	%	51.7	64.6	63.6
6. Maximum methane	%	60.2	66.7	67.4

IV. CONCLUSION

The effect of HRT on the biogas production was studied by performing the CSTR experiment using the frozen seafood wastewater and the decanter cake as co-digestion material. The experimental results in this study demonstrated that the suitable HRT for anaerobic co-digestion is 20 days with the maximum methane production rate at 1.86 l/d and the average maximum methane production at 64.6%. The most important finding of this research is that the best performance for biogas production is the anaerobic co-digestion with 20 days of HRT. The HRT of CSTR operation has a significant impact on the efficiency of biogas production. Anaerobic co-digestion of various biomass substrates or organic wastes increases the biogas yield and offers a number of advantages for the management of organic wastes. In conclusion, anaerobic co-digestion of decanter cake from palm oil industry and frozen seafood wastewater from frozen seafood industry is very important for corporate economy of the biogas plant and for the socio-economic reason. It can be concluded that the decanter cake helps increase the biogas productivity of frozen seafood wastewater.

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