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INCREASING ANAEROBIC DIGESTION PERFORMANCE OF WASTEWATER WITH CO-DIGESTION USING DECANTER CAKE

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ABSTRACT

Low biogas production in the frozen seafood wastewater anaerobic digestion is observed due to the low organic and Total Solids (TS) contents in the wastewater. In this research the decanter cake will be used in the anaerobic co-digestion process to improve the biogas production rate. The effect of co-digestion and Hydraulic Retention Time (HRT) will be investigated using the continuously stirred tank reactors under anaerobic conditions. Moreover, the study determines the biogas production potential of different HRTs and that of wastewater digestion alone. The anaerobic co-digestion is operated in continuous with continuously stirred reactors at HRT of 10, 20 and 30 days. The mechanical stirring units of all reactors are operated automatically. The stirring action occurred continuously during the experiments. The anaerobic co-digestion results show that the anaerobic co-digestion provides higher biogas production rate and higher methane yield than that of the wastewater digestion alone. The optimum HRT of the anaerobic co-digestion is 20 days. This reactor produces 2.88 L day^{-1}, with 64.5% of methane and the maximum methane production rate of 1.87 L day^{-1} and the methane yield of 0.321 l CH_4/g $COD_{removed}$. The anaerobic co-digestion of wastewater with decanter cake provides the higher methane yield potential production than that provided by the wastewater digestion alone at the ambient temperature. The best HRT is 20 days for anaerobic co-digestion between the wastewater and decanter cake. The experimental results reveal that HRT and co-digestion are the parameters that can affect the biogas production and methane yield.

Keywords: HRT, Decanter Cake, Wastewater, Biogas, Methane

1. INTRODUCTION

The biogas production source includes agricultural wastes, animal wastes, agro-industrial wastes, solid wastes, industrial wastes and wastewater (Pipatmanomai *et al*., 2009; Roati *et al*., 2012). Thailand has many sources for biogas productions. In Thailand, the strategic plan for renewable energy development has been established since 2003 and the purposed plan is to increase the renewable energy share to 19,700 ktoe per year in 2022 (Paepatung *et al*., 2009). Biogas is a product of anaerobic digestion of organic substrates. The anaerobic digestion is a process where microorganisms break down organic substrates in the absence of oxygen. The typical biogas consists of 55-80% of methane, 20-45% of carbon dioxide, less than 3% of hydrogen sulfide and trace amounts of other gases (Koblitsch *et al*., 2008; Truong and Abatzoglou, 2005). Thus, the biogas can use for electricity generation, heating, cooking and pipeline injection. It is a valuable renewable energy source while it can reduce the greenhouse gas emissions from fossil fuels. Therefore, interest in renewable energy production from organic waste and wastewater is increasing.

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The anaerobic digestion is a slow process. The HRT is 30-50 days for conventional biogas plant. The long HRT leads to a large volume of the anaerobic digester and hence high investment cost. Many options can improve the biogas yields (Shabee *et al*., 2010). One interesting option is anaerobic co-digestion. Anaerobic co-digestion refers to the simultaneous anaerobic digestion of multiple organic wastes or wastewaters in one digester (Keanoi *et al*., 2013; Rahmat *et al*., 2014; Keanoi *et al*., 2014; Saitawee *et al*., 2014). It is used to increase the biogas production of the low-yielding or difficult to digest wastes. The anaerobic co-digestion benefits include improving the nutrient balance, increasing load of biodegradable organic matter, dilution of potential toxic compounds, increasing digestion rate and producing better biogas yield (Sosnowski *et al*., 2002). The anaerobic co-digestion of different organic materials may improve the anaerobic digestion process due to better carbon, nitrogen and nutrient balance (Parawira *et al*., 2007; Yen and Brune, 2007).

The low COD of the frozen seafood wastewater may not sufficient to make a biogas production cost-effective. Thus, anaerobic co-digestion of the frozen seafood wastewater with decanter cake offers some interesting way. The decanter cake is one of the organic wastes from the palm oil mills production (Er *et al*., 2011). It contains the high COD and organic substrates (Kaosol and Sohgrathok, 2012). The decanter cake was estimated to be 0.27 million tons/year in Thailand (Chavalparit *et al*., 2006). Currently, the decanter cake is used as fertilizers and soil cover materials in the palm oil plantation areas which can reduce the waste management problems and improve the environmental quality in nearby community (Yahya *et al*., 2010).

In this study, the different HRTs are investigated using anaerobic co-digestion. The optimum HRT is observed in the continuously stirred tank reactors using the automatic mechanical mixer. The potential of biogas production is evaluated on anaerobic digestion at various HRT of the continuously stirred tank reactors between the wastewater alone and the wastewater with the decanter cake. The biogas is analyzed daily to determine the effect of HRT on anaerobic co-digestion.

2. MATERIALS AND METHODS

2.1. Raw Materials

Frozen seafood wastewater is obtained from a frozen seafood factory in Songkhla city (Southern of Thailand). Decanter cake is obtained from a palm oil mill factory in Krabi province (Southern of Thailand) (**Fig. 1**). The characteristics of raw materials are determined in accordance with Standard Methods (APHA, 1988). The feedstock was stored at 4°C. The prepared feedstock was fed in all reactors every day. The co-digestion feedstock includes the frozen seafood wastewater and decanter cake. The co-digestion feedstock between the frozen seafood wastewater 180 mL and the decanter cake 10 g at the ambient temperature is the ratio in these experiments.

2.2. Experimental Setup

The schematic diagram of anaerobic digestion reactors was set up in **Fig. 2**. Type of anaerobic digestion in these experiments was a continuously stirred tank reactor. The reactor was enclosed with a mechanical mixing system. The anaerobic digestion in these experiments consists of three reactors. The continuously stirred tank reactor was carried out in a 15 L of reactor with 10 L of working volume for 10, 20 and 30 days of HRT in reactor 1, 2 and 3, respectively. The reactors were stirred automatically using the paddle mechanical mixers. Two sets of experiments were carried out in this research. In the first set, the wastewater alone was operated at varying HRT. The second set of experiments was under co-digestion conditions. The effluent was collected at the bottom section of reactors.

2.3. Gas Production

The biogas is collected daily by the displacement of water to gas counter. The biogas was measured using the gas counter every day. The gas counter used the water displacement system connected to the headspace of the vessel, logging the biogas production automatically at 20 mL of interval (**Fig. 2**). The biogas was collected in a gas tube every 4 days for analyzing the biogas composition. The biogas is analyzed for methane using a Gas Chromatography (GC) analyzer (GC7890A, Agilent technology, USA) with Thermal Conductivity Detector (TCD).

2.4. Monitoring Parameters

During the anaerobic digestion period, the amount of biogas in each reactor is monitored to evaluate the methane yield. The pH and temperature are monitored daily.

2.5. Analysis

In all experiments, the following data are analyzed: pH, temperature, COD, TS, VS, Alkalinity, VFA, NH_3-N and TKN. All analytical procedures are performed in accordance with Standard Methods (APHA, 1988).

Fig. 1. Decanter cake from palm oil mill factory

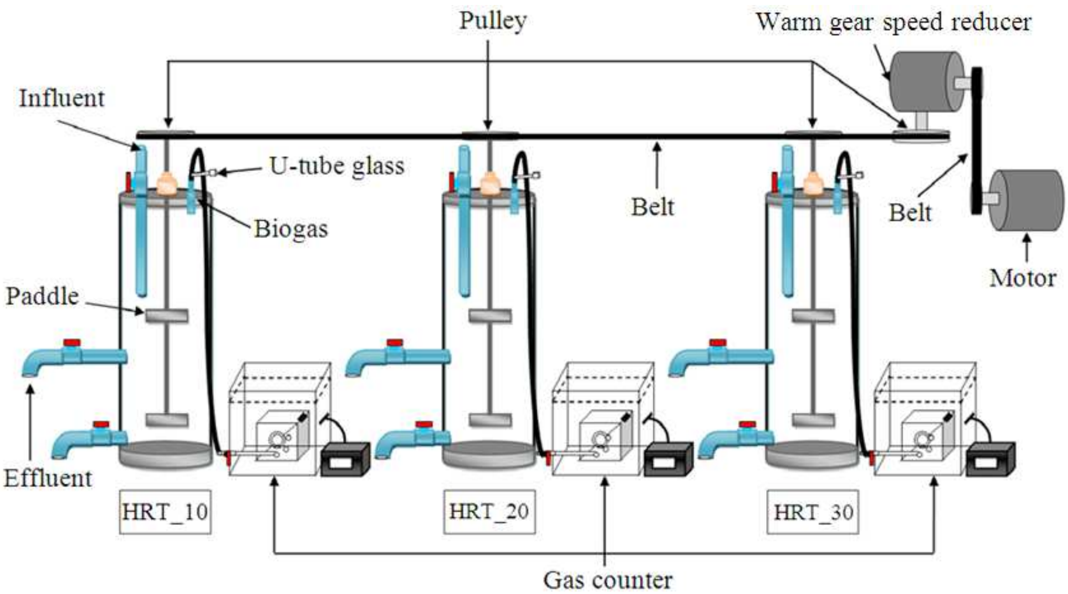

Fig. 2. Anaerobic digestion reactors

3. RESULTS

3.1. Raw Material Characteristics

The main characteristics of decanter cake and frozen seafood wastewater showed in **Table 1**. The frozen seafood wastewater contained 1,643, 1,640 and 955 mg L^{-1} of TCOD, TS and TVS, respectively. The frozen seafood wastewater contained high amount of TCOD which was the main harmful cause of environment, especially the receiving water sources. Therefore, the wastewater should be treated before discharge to any receiving waster source. The decanter cake was a solid waste from the palm oil mill factory which contains high amount of moisture content (76.9%). It had a high biodegradability due to a high amount of TVS and TCOD (Yahya *et al*., 2010; Chavalparit *et al*., 2006). Thus, addition of decanter cake as co-digestion can increase the organic substrates as COD, TS and TVS for biogas production.

3.2. Effects of Anaerobic Co-Digestion on HRT

All three reactors in both sets of experiments used 110-days anaerobic digestion period. All reactors were started with the frozen seafood wastewater alone at different HRTs.

Table 1. Main characteristics of decanter cake and frozen seafood wastewater

Parameters	Decanter cake	Wastewater
pH	4.6	6.5
Moisture content	76.9%	-
TCOD	1,090 g kg^{-1} dry	1,643 mg L^{-1}
SCOD	220 g kg^{-1} dry	721 mg L^{-1}
TS	23.1%	1,640 mg L
TVS	19.6%	955 mg L^{-1}
TKN	37.3 g kg^{-1} dry	147 mg L^{-1}
NH_3-N	0.5 g kg^{-1} dry	140 mg L^{-1}
Alkalinity	11 g kg^{-1} as $CaCO_3$	413 mg L^{-1} as $CaCO_3$
VFA	17 g kg^{-1} as $CaCO_3$	145 mg L^{-1} as $CaCO_3$

After all of reactors led to the steady state, the feedstock of co-digestion is fed in all reactors. The feedstock of co-digestion contains 180 L of wastewater and 10 g of decanter cake ratio. Then, all reactors were continued at different HRTs. The results presented in these experiments are an average value of the two repeated experiments. The results of pH values showed in the **Fig. 3** according to the different HRTs.

The pH value of all reactors was range between 6.5 and 7.7. The pH value of wastewater slightly dropped during the anaerobic digestion period. However, the pH value of all reactors was neutral. The temperature of all reactors was range between 25 and 35°C around the mesophilic phase (Gray, 1989; Castillo *et al*., 1995).

The COD of co-digestion between wastewater and decanter cake rose up to 10 times of that provided by digesting the wastewater alone (**Fig. 4**). Thus, co-digestion with decanter cake could significantly increase the organic substrates for anaerobic digestion.

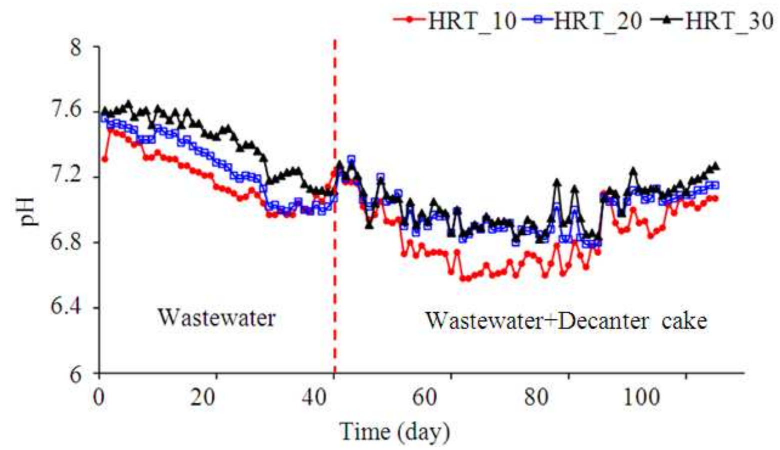

Fig. 3. Variation of pH with the digestion time for the different HRTs

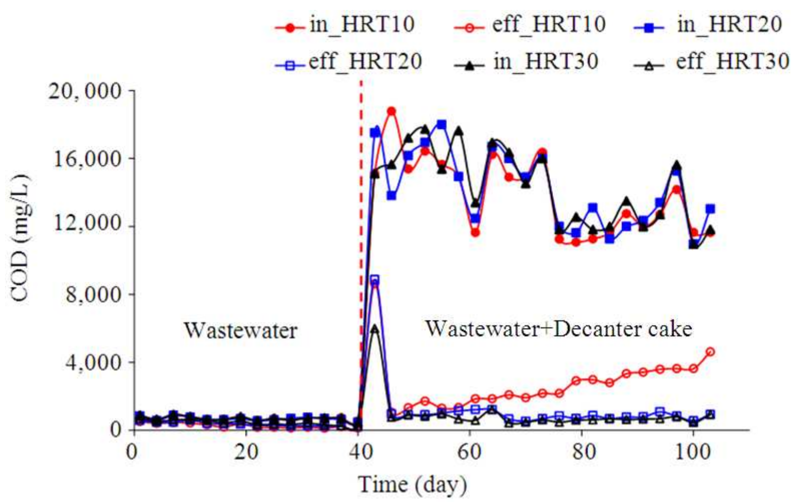

Fig. 4. Variation of COD with the digestion time for the different HRTs

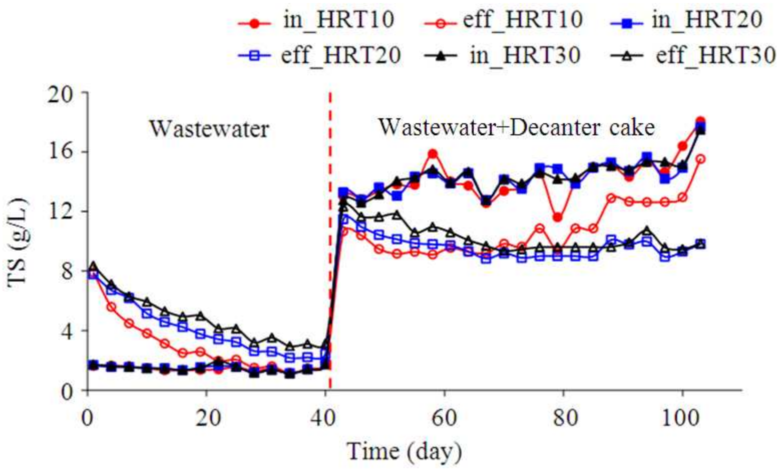

Fig. 5. Variation of TS with the digestion time for the different HRTs

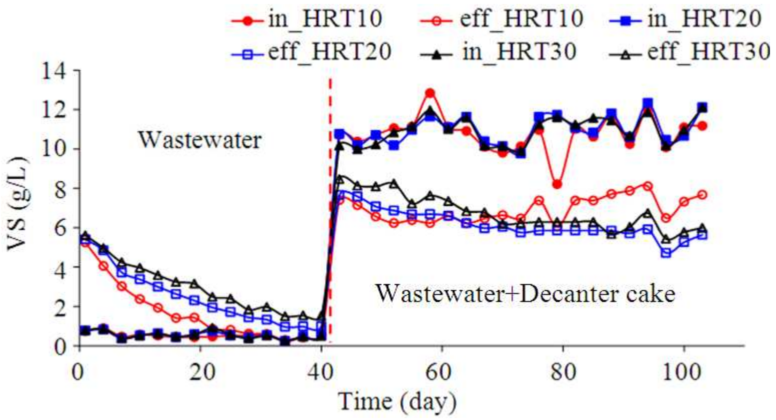

Fig. 6. Variation of VS with the digestion time for the different HRTs

From this result, the COD removal efficiency of wastewater digestion alone was 74.5, 59.1 and 50.2% in the 10, 20 and 30 days HRT reactors, respectively. The COD removal efficiency of co-digestion between wastewater and decanter cake was 71.2, 93.3 and 94.5% in the 10, 20 and 30 days HRT reactors, respectively.

The variations of TS and TVS with anaerobic digestion and co-digestion under different HRTs were studied (**Fig. 5 and 6**). The addition of decanter cake as co-digestion feedstock can significantly increase the total solids, volatile solids and the biodegradability in the anaerobic digestion (Budiyono *et al*., 2010), because the decanter cake form is solid.

The results of alkalinity from effluent showed that the alkalinity of wastewater alone was 1,972, 1,765 and 1,732 mg L^{-1} as $CaCO_3$ in the 10, 20 and 30 days HRT reactors, respectively and the alkalinity of co-digestion between wastewater and decanter cake was 2,670, 2,612 and 2,749 mg L^{-1} as $CaCO_3$ in the 10, 20 and 30 days HRT reactors, respectively (**Fig. 7**). The influent alkalinity was lower than the effluent alkalinity for wastewater digestion alone and wastewater and decanter cake co-digestion. The alkalinity ranges between 1,000 and 5,000 mg L^{-1} as $CaCO_3$ is recommended for anaerobic digestion by Agdag and Sponza (2005). The alkalinity is a measure of its capacity to neutralize acids is due primarily to the salts of weak acids (Qasim and Chiang, 1994). If the VFA exceeds the available alkalinity, the anaerobic digestion will sour. It will be inhibiting the methanogens in anaerobic digestion reactors. The methanogens prefer neutral pH value with a generally accepted optimum range of approximately 6.5-8.2 (Anderson and Yang, 1992).

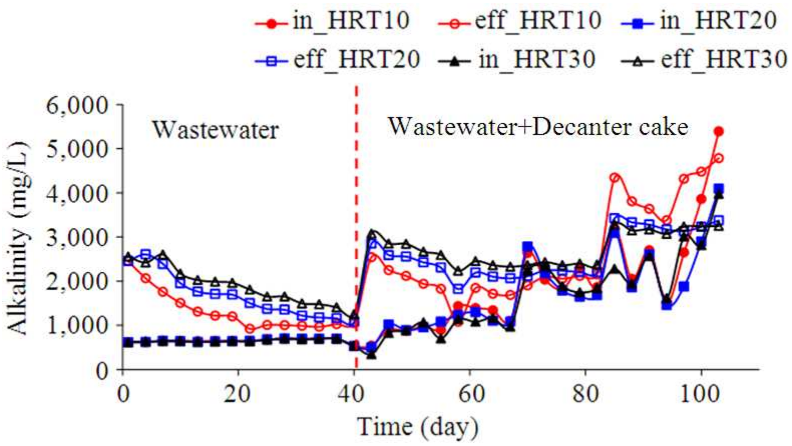

Fig. 7. Variation of alkalinity with the digestion time for the different HRTs

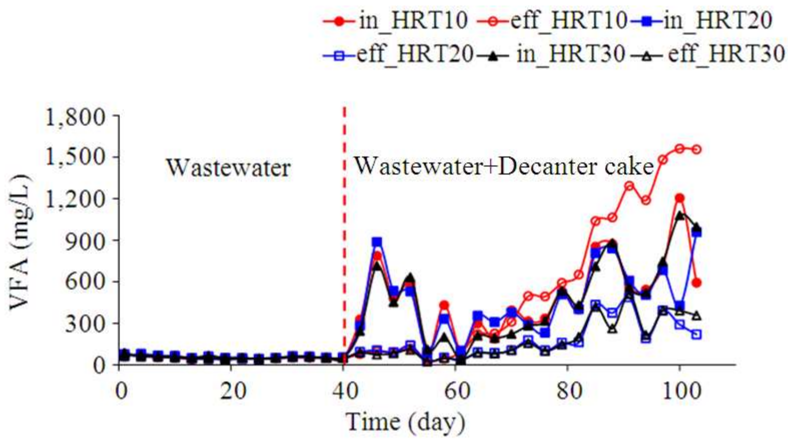

Fig. 8. Variation of VFA with the digestion time for the different HRTs

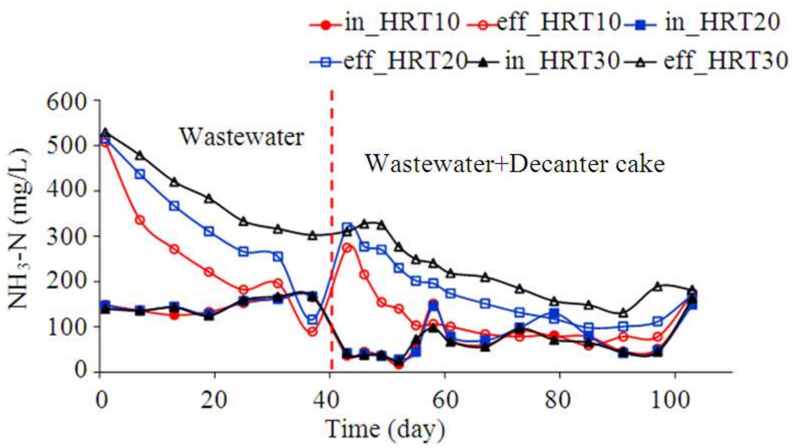

Fig. 9. Variation of ammonia nitrogen with the digestion time for the different HRTs

The influent VFA in wastewater digestion alone samples was approximately 55 mg L^{-1} in all reactors and the influent VFA in co-digestion between wastewater and decanter cake was approximately 500 mg L^{-1} in all reactors (**Fig. 8**). The VFA of co-digestion had a very high variation in the digestion period. Even though the VFA levels continued to increase later on in all reactors, its values were not increased to the point that could lead to the inhibition of anaerobic digestion. The recommended VFA for anaerobic digestion is ranged between 50 and 500 mg L^{-1} (Halber, 1981).

The VFA/Alkalinity of wastewater digestion alone was 0.05, 0.04 and 0.04 in the 10, 20 and 30 days HRT reactors, respectively. The VFA/Alkalinity of co-digestion between wastewater and decanter cake was 0.31, 0.10 and 0.10 in the 10, 20 and 30 days HRT reactors, respectively. The VFA/Alkalinity ranging between 0.4 and 0.8 is recommended for anaerobic digestion (Behling *et al*., 1997).

The influent ammonia nitrogen of wastewater digestion alone and wastewater and decanter cake co-digestion was ranged between 146 and 148 mg L^{-1} and between 66 and 74 mg L^{-1}, respectively (**Fig. 9**). The effluent ammonia nitrogen was ranged between 258 and 395 mg L^{-1} and between 123 and 225 mg L^{-1} for the wastewater digestion alone and wastewater and decanter cake co-digestion, respectively. The amonia nitrogen level that is higher than 1,500 mg L can cause the toxicity for anaerobic digestion (Stering *et al*., 2001).

The influent TKN of wastewater digestion alone and wastewater and decanter cake co-digestion was ranged between 157 and 162 mg L^{-1} and between 307 and 323 mg L^{-1}, respectively (**Fig. 10**). The effluent TKN was ranged between 400 and 524 mg L^{-1} and between 361 and 496 mg L^{-1} for the wastewater digestion alone and wastewater and decanter cake co-digestion, respectively.

3.3. Effects of Biogas Production on HRT

At the steady state of anaerobic digestion, the biogas production rate of wastewater digestion alone was 0.33, 0.17 and 0.14 L d^{-1} in the 10, 20 and 30 days HRT reactors, respectively. The biogas production rate of wastewater and decanter cake co-digestion was 2.99, 2.89 and 1.85 L d^{-1} in the 10, 20 and 30 days HRT reactors, respectively (**Fig. 11**).

At the steady state of anaerobic digestion, the results show that the methane production rate of wastewater digestion alone was 0.04, 0.02 and 0.02 L d^{-1} in the 10, 20 and 30 days HRT reactors, respectively. The methane production rate of co-digestion between wastewater and decanter cake was 1.58, 1.87 and 1.18 L d^{-1} in the reactors of 10, 20 and 30 days HRT reactors, respectively (**Fig. 12**).

The results of methane composition in all reactors showed in **Fig. 13**. At the steady state, the results showed that the average methane composition in biogas of wastewater digestion alone was 9.9, 10.7 and 15.4% in the 10, 20 and 30 days HRT reactors, respectively. The average methane composition in biogas of co-digestion between wastewater and decanter cake was 51.9, 64.5, 63.5% in the 10, 20 and 30 days HRT reactors, respectively. The typical methane composition is 55-75% (Karellas *et al*., 2010). It was observed that the co-digestion between wastewater and decanter cake significantly provided the higher methane composition than that provided by the wastewater digestion alone for anaerobic digestion. The decanter cake is added in the anaerobic digestion reactor, the TS, VS and COD contents were increased because of the increasing in the organic substrate. Thus, the biogas and methane productions were improved during the anaerobic co-digestion.

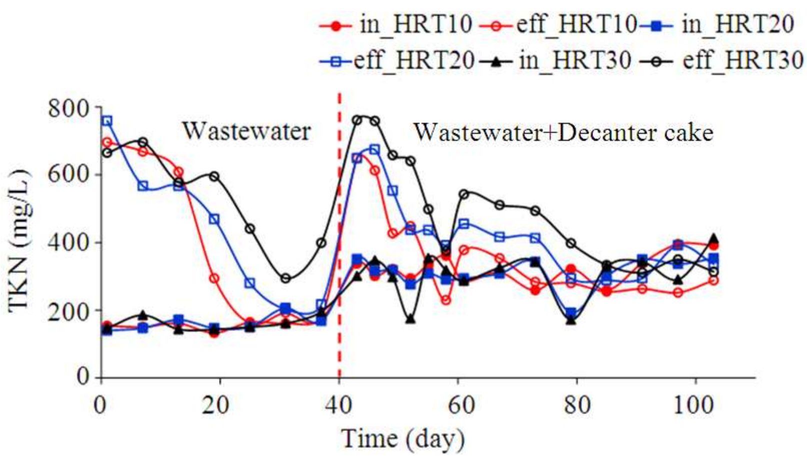

Fig. 10. Variation of TKN with the digestion time for the different HRTs

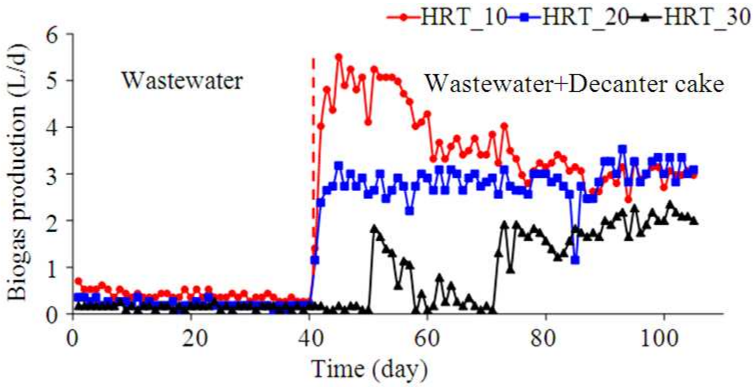

Fig. 11. Variation of biogas production with the digestion time for the different HRTs

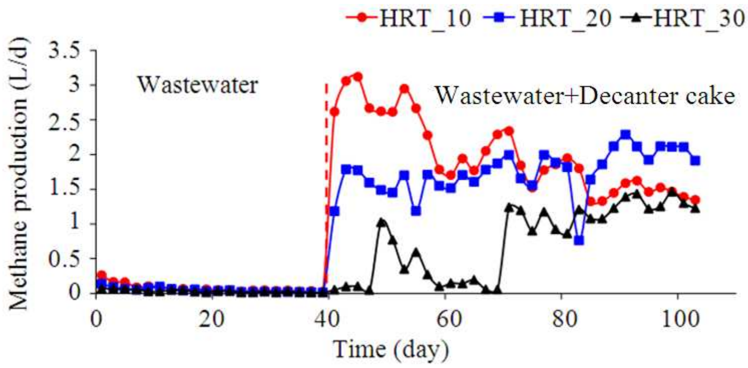

Fig. 12. Variation of methane production with the digestion time for the different HRTs

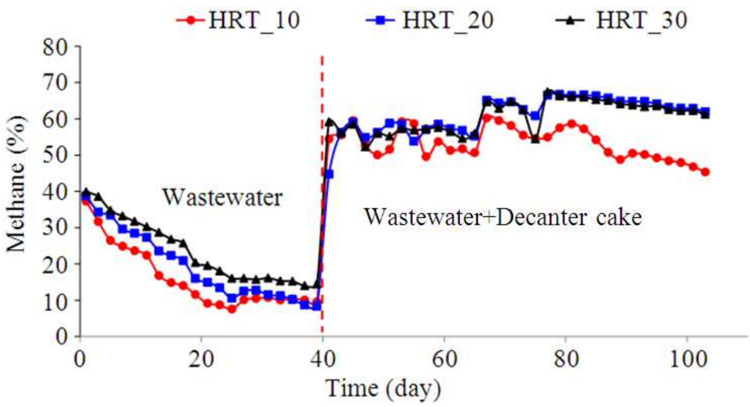

Fig. 13. Variation of methane composition in biogas with the digestion time for the different HRTs

4. DISCUSSION

The waste stabilization is directly related to the amount of methane production and methane composition of the biogas. The methane yield is taken to be an indicator of waste stabilization degree and performance of anaerobic digestion.

4.1. Effects of Co-Digestion on Anaerobic Digestion

In the anaerobic digestion reactors of wastewater alone, the pH of all reactors was within the optimum range but the pH in all reactors slightly declined during the digestion period. The VFA/Alkalinity in all reactors was lower than the recommended VFA/Alkalinity for anaerobic digestion (Behling *et al*., 1997). These results of VFA/Alkalinity showed that the anaerobic digestion reactor had high buffering capacity. The influent TS of 1.6% was added daily. The recommended influent TS of feedstock was 3-8% for continuously stirred tank reactor (Gunaseelan, 1997). Thus, the organic substrate was slightly low in the anaerobic digestion reactor of wastewater alone. It was observed that in the anaerobic digestion reactor of wastewater alone the biogas production was continued at a low rate for a period of 40 days; and the methane composition was fairly low. At the steady state, the results showed that the average methane composition in biogas of wastewater digestion alone was ranged between 9.9 and 15.4%.

The results of pH were observed during all digestion time. The pH declined in the first period (anaerobic digestion of wastewater lone), then it recovered with the initiation of methane production during the second period (anaerobic co-digestion of wastewater and decanter cake). The pH value of co-digestion between wastewater and decanter cake also dropped during the initial period of anaerobic digestion. After the initial period of anaerobic digestion, the pH value tended to move towards neutral. When pH falls below 6.2, it can lead to the anaerobic digestion failure (Gray, 1989). In the anaerobic co-digestion reactors of wastewater and decanter cake, the influent TS of 13% was added daily. The organic substrate was enough for the microorganism in the anaerobic co-digestion reactors. The average methane composition in biogas of co-digestion between wastewater and decanter cake was ranged between 51.9 and 63.5%. The co-digestion between wastewater and decanter cake provided the higher average methane composition than that provided by the wastewater digestion alone. The methane composition from co-digestion in the 20 and 30 days of HRT reactors was in the range of the typical methane composition from anaerobic digestion (55-75%) (Karellas *et al*., 2010). The average methane composition from co-digestion was slightly lower in the 10 days HRT reactor. It may be the short of hydraulic retention time then the microorganisms cannot digest all of the organic substance (Gunaseelan, 1997).

Biogas production and methane composition in anaerobic co-digestion reactors showed that the decanter cake addition had a positive effect on biodegradation due to the high biogas productions and the high methane composition.

The results can be investigated that the methane yield of wastewater digestion alone was 0.072, 0.095 and 0.160 l CH_4/g $COD_{removed}$ in the 10, 20 and 30 days of HRT reactors, respectively. The methane yield of co-digestion between wastewater and decanter cake was 0.185, 0.321 and 0.309 l CH_4/g $COD_{removed}$ in the 10, 20 and 30 days of HRT reactors, respectively. For stoichiometric conversion, the methane yield is directly related to organic degradation (0.395 l CH_4/g $COD_{removed}$) (Speece, 1996). According to the experimental results, if the decanter cake is added as co-digestion, the methane yield is estimated to significantly increase. The best results are obtained when the anaerobic digestion system is done with the co-digestion between wastewater and decanter cake. Improved anaerobic digestion performance in terms of waste stabilization is achieved (Sulaiman *et al*., 2009).

4.2. Effects of HRT on Anaerobic Digestion

The different HRTs have been considered as the potential factors for biogas production. The methane yield of wastewater digestion alone showed no significant difference in the various HRTs because the methane yield is more or less similar in all reactors. The results for anaerobic co-digestion showed significant effect of HRT on anaerobic digestion.

For anaerobic co-digestion between wastewater and decanter cake at 10 days of HRT, the methane production rate was 1.58 L d^{-1}. The average methane composition was 51.9%. The methane yield was 0.185 CH_4/g $COD_{removed}$. At 20 days of HRT, the methane production rate was 1.87 L d^{-1}. The average methane composition was 64.5%. The methane yield was 0.321 CH_4/g $COD_{removed}$. At 30 days of HRT, the methane production rate was 1.18 L d^{-1}. The average methane composition was 63.5%. The methane yield was 0.309 CH_4/g $COD_{removed}$. Increasing HRT can improve the biogas potential production (Gunaseelan, 1997). However, too long HRT can cause the biogas potential production to decrease because the organic substrate is not enough for microorganism in the anaerobic digestion (Speece, 1996). Therefore, the 20 days HRT reactor provided the best performance of biogas production for anaerobic co-digestion between wastewater and decanter cake. It enhances methane production rate and improves biogas composition by increasing its methane composition.

Nevertheless, the co-digestion between frozen seafood wastewater and decanter cake should be taken into consideration for scale-up purposes, in operating at industrial scale with continuous system.

5. CONCLUSION

This research presented the optimizing HRT and the best performance for anaerobic co-digestion. The experiments were conducted on frozen seafood wastewater digestion alone and co-digestion between frozen seafood wastewater and decanter cake at different HRTs. The methane production and methane yield was used to determine performance during ambient temperature anaerobic digestion. This research indicated that the decanter cake addition to frozen seafood wastewater has a positive effect on the rate of biological degradation in anaerobic digestion at ambient temperature (mesophilic temperature). These results showed that the co-digestion can improve the anaerobic digestion rate and methane yield. The anaerobic co-digestion between frozen seafood wastewater and decanter cake provided the highest methane yield at 0.321 l CH_4/g COD removed at 20 days of HRT. The methane composition in biogas was 64.5%. The methane production rate was 1.87 L d^{-1}. These results proved that anaerobic co-digestion provided the higher biogas production than that of wastewater digestion alone. It can be concluded that the anaerobic co-digestion of frozen seafood wastewater with decanter cake is a possible process in the waste stabilization and in the improving potential of wastewater to biogas production.

6. ACKNOWLEDGEMENT

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