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Energy Production Potential from Co-Digestion between Frozen Seafood Wastewater and Decanter Cake in Thailand

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***Abstract*—**In this paper, a Biochemical Methane Potential (BMP) test provides a measure of the energy production potential from co-digestion between the frozen seafood wastewater and the decanter cake. The experiments were conducted in laboratory-scale. The suitable ratio of the frozen seafood wastewater and the decanter cake was observed in the BMP test. The ratio of the co-digestion between the frozen seafood wastewater and the decanter cake has impacts on the biogas production and energy production potential. The best performance for energy production potential using BMP test observed from the 180ml of the frozen seafood wastewater and 10g of the decanter cake ratio. This ratio provided the maximum methane production at 0.351 l CH_4/g $TCOD_{removal}$. The removal efficiencies are 76.18%, 83.55%, 43.16% and 56.76% at TCOD, SCOD, TS and VS, respectively. The result can be concluded that the decanter cake can improve the energy production potential of the frozen seafood wastewater. The energy provides from co-digestion between frozen seafood wastewater and decanter cake approximately $19x10^9$ MJ/year in Thailand.

***Keywords*—**Frozen seafood wastewater, decanter cake, biogas, methane, BMP test.

I. Introduction

ANAEROBIC digestion is a widely used technology for organic waste treatment in the biogas production. The anaerobic digestion is a biological treatment used for converting organic wastes into biogas under an anaerobic condition. The biogas can be utilized as a renewable energy source [1]-[3]. The biogas is a clean and renewable form of energy. It can be a good substitution of conventional sources of energy (i.e., fossil fuels and oil). Typically, the biogas consists of 55-80% methane gas, 20-45% carbon dioxide, less than 3% hydrogen sulfide with trace amount of ammonia and other impurities [4], [5]. The biogas is the combustible gas produced through an anaerobic digestion at low-temperature and without oxygen. Thus, its application includes cooking, heating and electricity. The biogas production from anaerobic digestion of biomass feedstock and organic waste is widely recognized as a cost-effective process. It is an improving energy production potential. Several researchers found an effort to improve biomass conversion efficiency and biogas yield conducted by improving contact between bacteria and substrate using stirring [6], [7], improving substrate composition by co-digestion with others substrate [8]-[10] and controlling ammonia inhibition [11].

The Energy is one of the most important factors to global prosperity. The recent rise in oil prices may drive the current economy toward alternative energy sources such as biogas. Many countries interest in renewable energy production. In addition, the increasing interests in reduction of the greenhouse gas emissions associated with fossil fuels have made anaerobic digestion of plant organic biomass an attractive option. In Thailand, source of biogas production cover a wide range of feedstock such as municipal solid wastes, animal waste, agricultural waste, agro-industry waste, wastewater, industrial wastewater, sewage sludge and landfill waste [12]. The frozen seafood wastewater treated with the biological treatment, cannot produce the biogas due to its low COD content and its low organic content.

The anaerobic co-digestion of different organic materials may enhance the anaerobic digestion process because the co-digestion adjusts the carbon and nutrient balances [13], [14]. The decanter cake is an agro-industry waste from the palm oil mill industry which is estimated to be 0.27 million tons a year [15]. The decanter cake is used as fertilizers and soil conditioner in palm oil plantation areas. The co-digestion with decanter cake will improve the biogas production and the methane and biogas yields. The co-digestion will improve the energy production potential. Thus, the co-digestion of frozen seafood wastewater with decanter cake offers an interesting alternative way for the biogas production.

Biochemical Methane Potential (BMP) test is a measure of the anaerobic digestibility of substrate. It was established by Owen et al. since 1979 [16]. The BMP test can evaluate the energy production potential of an anaerobic process on the material. The BMP test can be used to determine the amount of organic carbon in the material that can be anaerobically converted to biogas. The BMP test is a simple and inexpensive procedure to monitor relative anaerobic digestibility of substrate.

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In this study, the research evaluated the energy production potential of anaerobic co-digestion at various ratios of frozen seafood wastewater and decanter cake using BMP test. The suitable frozen seafood wastewater and decanter cake ratio was observed in BMP test.

II. Materials and Methods

A. Experimental Raw Materials

Decanter cake is the agro-industry waste remaining from the palm oil extraction which is the organic waste. The decanter cake is used as fertilizer and soil cover material in the palm oil plantation area. Decanter cake is obtained from a palm oil mill industry in Krabi city, Thailand.

Frozen seafood wastewater is obtained from a frozen seafood industry in Songkhla city, Thailand.

B. Experimental Setup

The BMP tests are conducted in 250ml serum bottles with the rubber stoppers which are filled with the substrate and inoculum (Fig. 1). The nitrogen gas is utilized in flushing over the headspace for 2 min to remove traces of oxygen to insure anaerobic conditions. The frozen seafood industry wastewater (W) and decanter cake (DC) are fed into the six BMP reactors. The BMP batch process is conducted under 38±1°C temperature (Mesophilic phase). The reactors are placed on the orbital shaker at 180rpm. Inoculum is taken from the methane fermentation stage of the UASB, frozen seafood industry in Songkhla city.

The BMP experiment consists of six reactors. Each reactor contains different amount of decanter cake (DC). The detail of each reactor is following below:

180W:0DC = wastewater 180 ml + decanter cake 0 g
180W:2DC = wastewater 180 ml + decanter cake 2 g
180W:5DC = wastewater 180 ml + decanter cake 5 g
180W:8DC = wastewater 180 ml + decanter cake 8 g
180W:10DC = wastewater 180 ml + decanter cake 10 g
180W:20DC = wastewater 180 ml + decanter cake 20 g

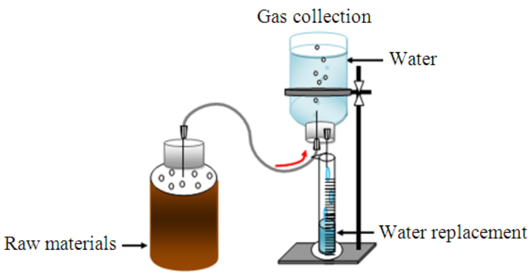

Fig. 1 Flow diagram of the BMP process

C. Monitoring Parameters

The biogas is collected daily. The biogas content is measured by inserting the needle of a gas syringe through the rubber septum and letting the biogas displace the wetted barrel of the syringe. Biogas content was measured by the liquid displacement system similar to that used by Yetilmezsoy and Sakar [17]. The biogas is analyzed for methane gas using a Gas Chromatography (GC) analyzer (GC7890A, Agilent technology, USA). The end of digestion analyses pH, Alkalinity, VFA, NH_3-N, TKN, TCOD, SCOD, TS and VS [18].

D. Calculating the Results

The volume of biogas production is sampling daily. The methane content is analyzed and recorded as percentage of methane. The BMP can calculate by the following equation:

$$BMP = \frac{\text{maximum cumulative methane gas (ml)}}{\text{g COD removed}} \qquad (1)$$

E. Monitoring Parameters

The amount of biogas and methane in each reactor is monitored to evaluate the biogas yield during the experimental period.

F. Analysis

In all experiments, the following data are determined: pH, TCOD, SCOD, Total Solids (TS), Volatile Solids (VS), Alkalinity, VFA, NH_3-N, TKN and biogas content. All analytical procedures are performed in accordance with APHA (1971) [18].

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 decanter cake contains high moisture content. The average of C/N ratio is 34.4:1. The decanter cake contains low nitrogen and high carbon. The C/N ratio of decanter cake is slightly higher than the suitable C/N ratio (20:1 - 30:1) for anaerobic digestion. The microorganism growth decreases when the C/N ratio is higher than the suitable C/N ratio.

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. The frozen seafood wastewater contains low organic content and high nitrogen. The TCOD:TKN ratio is 100:9. The suitable TCOD:TKN ratio is 100:1.1 for anaerobic digestion [19], [20]. The frozen seafood wastewater contains higher nitrogen than the requirement of microorganism on the anaerobic digestion system. The frozen seafood wastewater alone digests for anaerobic digestion. It may result in the inhibition of methanogenic bacteria.

However, by adding the decanter cake to the wastewater can increase the COD for biogas productions. The COD of frozen seafood wastewater increases from 4,000mg/l to

22,500mg/l. 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	-

B. BMP test

The BMP tests were performed for a period of 90 days. After 90 days of observations, the biogas production tends to decrease. This phenomenon is predicable due to the stationary phase of microorganism growth [21]. The result of the anaerobic co-digestion between the frozen seafood wastewater and the decanter cake at various ratios using BMP test showed the average of pH ranges 6.7-7.1 at the end of BMP tests (Fig. 2). The pH is one factor of the anaerobic digestion. The suitable pH for the methanogenic bacteria is between 6.8 and 7.2 [22]-[24]. If the pH is lower than 6.5, the methanogenic bacteria will be inhibited the growth. If the pH is lower than 6.6 and higher than 7.6, the efficiency of VFA digestion decreases.

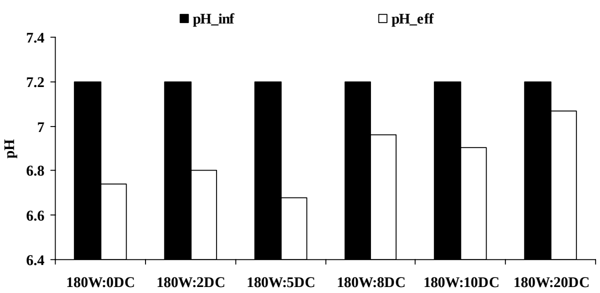

Fig. 2 pH of co-digestion

The alkalinity is the stability index of anaerobic digestion. The optimum alkalinity is between 1,000 and 5,000mg/l as $CaCO_3$ for anaerobic digestion [25]. The average of initial alkalinity is ranged from 1,075 to 2,994mg/l as $CaCO_3$. The average of alkalinity at the end of BMP test is ranged 1,120 to 3,894mg/l as $CaCO_3$. The alkalinity tends to increase in all of ratios. However, the alkalinity of all reactors is suitable for anaerobic digestion.

The average of initial VFA is ranged from 171 to 660mg/l as CH_3COOH. The average of VFA at the end of BMP test is between 46 to 610mg/l as CH_3COOH. The VFA tends to decrease. Because the microorganisms can change the VFA from acid former bacteria to methane gas and the anaerobic digestion is to balance both of microorganisms. The optimum VFA is ranged from 50 to 500 mg/l as CH_3COOH [26].

The average of VFA/Alkalinity is ranged from 0.04 to 0.14. The suitable VFA/Alkalinity ratio is range between 0.4-0.8 for anaerobic digestion. The average of VFA/Alkalinity ratio from the result is less than the suitable VFA/Alkalinity ratio. It shows that the anaerobic digestion system is high buffer capacity. Thus, this result is not effect to the methanogenic bacteria operation.

The average of ammonia-nitrogen is about 123-143mg/l. The optimum ammonia-nitrogen is 100mg/l [27]. The toxicity of anaerobic digestion starts when the ammonia nitrogen is higher than 1,500mg/l [25]. The average of TKN is ranged from 140 to 550mg/l.

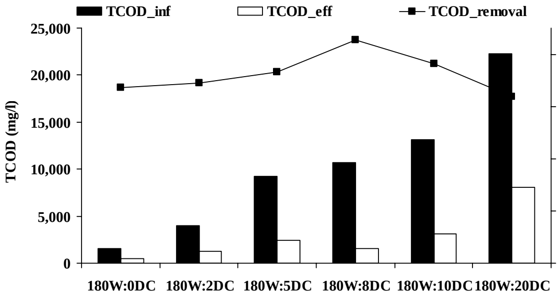

Fig. 3 TCOD and TCOD removal of co-digestion

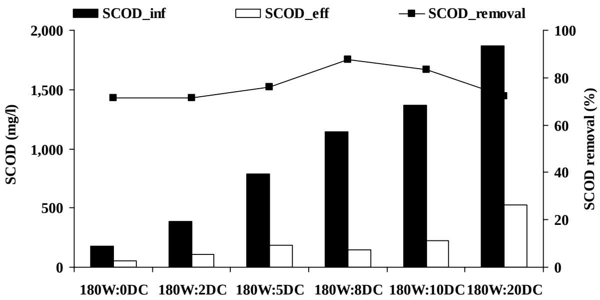

Fig. 4 SCOD and SCOD removal of co-digestion

The removal efficiency at the end of BMP test showed that the efficiency of TCOD and SCOD removal ranges 63.7-85.4% and 71.2-87.5%, respectively (Figs. 3, 4). The TCOD and SCOD removal of co-digestion between frozen seafood wastewater and decanter cake is higher than frozen seafood wastewater digestion alone. The best TCOD and SCOD removal is 85.4% and 87.5% at the 180W:8DC ratio.

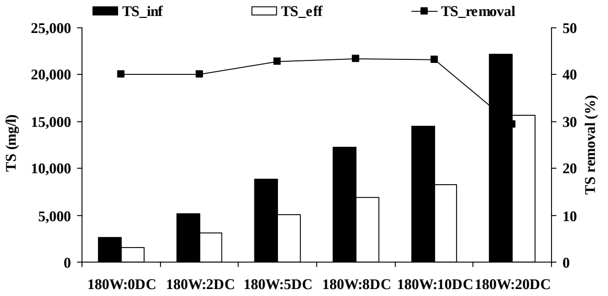

Fig. 5 Total solid and total solid removal of co-digestion

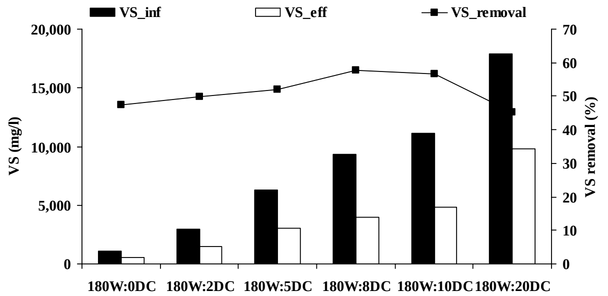

Fig. 6 Volatile solid and volatile solid removal of co-digestion

The efficiency of TS and VS removal is between 29.3 and 43.4% and 45.4-57.8%, respectively (Figs. 5 and 6). The TS and VS removal of co-digestion between frozen seafood wastewater and decanter cake is higher than that of frozen seafood wastewater digestion alone. The best TS and VS removal is 43.4% and 57.8% at the 180W:8DC ratio.

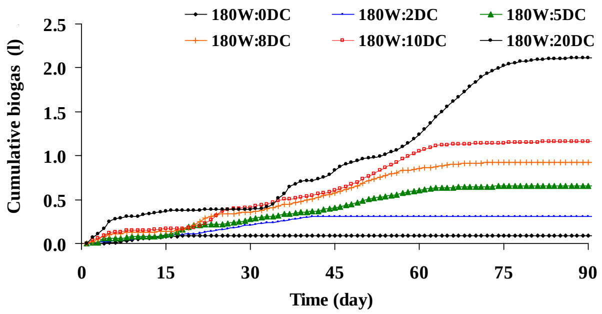

Fig. 7 Cumulative biogas of co-digestion

The biogas production at the end of BMP test shows the cumulative biogas is between 0.09 and 2.12 l (Fig. 7). At the first of anaerobic digestion, the biogas production rate significantly increases because the microorganisms digested the easily organic substances for growth and new cell production. Then, the microorganisms decompose the difficult organic substances later. The cumulative biogas is 0.09, 0.31, 0.65, 0.93, 1.16 and 2.12 l at 180W:0DC, 180W:2DC, 180W:5DC, 180W:8DC, 180W:10DC and 180W:20DC, respectively.

The cumulative methane ranges from 0.03 to 0.78 l (Fig. 8). The methane gas content is 33.1-47.1%. The methane yield is 0.140-0.351 l CH_4/g $COD_{removal}$ (Fig. 9). The methane yield is 0.140, 0.192, 0.239, 0.314, 0.351 and 0.300 l CH_4/g $COD_{removal}$ at 180W:0DC, 180W:2DC, 180W:5DC, 180W:8DC, 180W:10DC and 180W:20DC, respectively. The maximum methane yield provided 0.351 l CH_4/g $COD_{removal}$ at the ratio of 180 ml frozen seafood wastewater and 10 g decanter cake (180W:10DC).

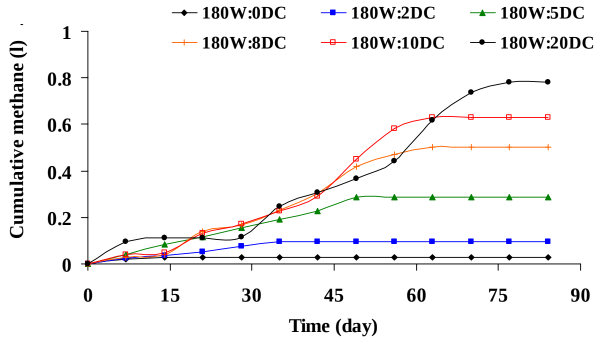

Fig. 8 Cumulative methane of co-digestion

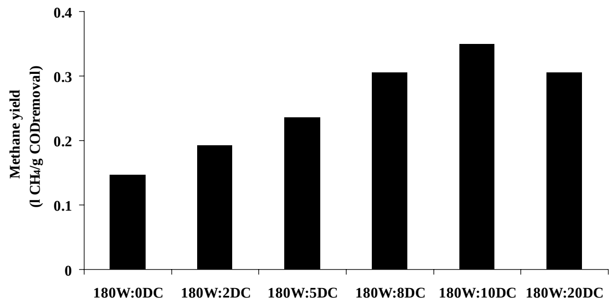

Fig. 9 Methane yield of co-digestion

C. *Economic*

This section shows the energy estimation for co-digestion between frozen seafood wastewater and decanter cake comparing with frozen seafood wastewater digestion alone in Thailand. The frozen seafood production is estimated at 0.5 million tons per year. The frozen seafood wastewater will be produced approximately 31m^3/ton. Then, the frozen seafood wastewater will be produced approximately 15 million m^3/year.

The fresh palm oil bunch is approximately 64 million ton/year to go to the palm oil mill industry (Centre for Agricultural Information and Regional Offices of Agricultural Economics, 2007 [28]). The decanter cake provides 42kg per ton of fresh palm oil bunch [29]. Thus, the decanter cake will be approximately 0.269 million ton/year.

From this research, the suitable ratio of co-digestion is 10g of decanter cake and 180ml of frozen seafood wastewater. Thus, the decanter cake will utilize approximately 0.269 million ton/year while the frozen seafood wastewater will use approximately 4.84 million m^3/year.

The biogas 1m^3 produces 39.4 MJ of energy (Department of Alternative Energy Development and Efficiency, Ministry of Energy, Thailand, 2012 [30]). The co-digestion between frozen seafood wastewater and decanter cake estimates to the biogas production about 28 million m^3/year. Thus, this biogas production can produce energy about 19x10^9 MJ/year.

IV. Conclusions

The anaerobic co-digestion between frozen seafood wastewater and decanter cake at various ratios using BMP tests can be concluded that the co-digestion provided the higher biogas and methane production comparing with the frozen seafood wastewater digestion alone. The suitable ratio is the 180mL of frozen seafood wastewater and 10 g of decanter cake. This ratio provides the methane production potential at 0.351 l CH_4/g $TCOD_{removal}$. The TCOD, SCOD, TS and VS removal efficiency is 76.18%, 83.55%, 43.16% and 56.79%, respectively.

The anaerobic co-digestion of decanter cake and frozen seafood wastewater is a possible profitable way 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 and energy production potential of frozen seafood wastewater. The energy provided from co-digestion between frozen seafood wastewater and decanter cake is estimated at 19x10^9 MJ/year in Thailand.

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