Anaerobic co-digestion of tuna factory waste and banana crop residue for biogas production

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Abstract

The objectives of this research are to produce biogas by the co-digestion of tuna factory waste and banana crop residue, then analyze the economic and environmental benefits. In this research the biogas production supports tuna factory waste management system where the tuna factory waste got treated and converted into useful substances, such as biogas and high quality fertilizer. The aim of this work is to find optimal co-digestion substrates to enhance biogas production from fish wastes. The laboratory scale experiments carried out using 5 different ratios showed that the best anaerobic co-digestion of tuna waste and banana crop residue was achieved with the 2:1, where the biogas production was recorded approximately 113.43 l/d, with a methane content of 55.51%, while the startup COD was 54.46 g/l. In the 30 days evolution in the co-digestion the COD reduced up to 56.72%. The investigation provides useful information to determine the most proper ratios of different co-substrates which results in an optimized biodegradation and enhanced methane potential. The final destination of this research is to take this outcome into action at the full-scale.

Keywords: *Biogas, Tuna waste, waste management*

1. Introduction

The seafood processing industry is very important to Thai economy and global economy as well. Tuna industry is one of the most important industries for Thailand's economy, as the industry has reached great transformation and growing export activities. In 2012, Thailand exported approximately 630,000 tons of tuna products, with an export value worth USD $2,896 million which represents about 40 percent of the world's tuna market. Tuna products provide numerous advantages: it is not only considerably cheap when compared to other seafood, it is also high in protein and cholesterol-free seafood. Among the species available in the market, tuna is the most common edible canned seafood product. The seafood industries produces waste whose characteristics depend upon the raw materials processed, which in turn varies throughout the year. The total world tuna catch is about 3 Billion metric tons per annum, tuna industry generates solid wastes that can be as high as 30-40% of the original raw material. Food industry wastes contribute greatly to environmental contamination problems. Banana crop residue is collected from the banana farm after harvesting the banana fruits, its trees/ trunks logs, stem, and leaves becomes the waste for disposal. Banana cultivation in Thailand is approximately 1.7 million tons per annum, while the waste produced is approximately 4.5 time of the banana harvested weight. And normally the waste is just being kept in the banana farm for sometimes without any treatment until it's decayed on the fields before its disposal.

Anaerobic co-digestion has been carried out in order to develop methods to convert these wastes into biogas as a renewable energy. Anaerobic co-digestion considered as an organic recycling technology, as it produces renewable energy from combustion of the biogas obtained. It has a potential to treat biodegradable solid wastes. It could replace fossil fuel and reduce environmental impacts including global warming and acid rain. The main advantages of this technology are improved methane yield because of the supply of additional nutrients from the co-digestion. The most common situation is when a major amount of a main basic substrate (e.g. manure or sewage sludge) is mixed and digested together with minor amounts of a single, or a variety of additional substrates [1]. The use of co-substrates usually improves the biogas yields from anaerobic digester due to positive synergisms established in the digestion medium and the supply of missing nutrients by the co-substrates [2]. However, tuna factory waste contains high contents of biodegradable substances and has low C/N ratios, while banana crop residue contains high C/N ratios thus, making use of these wastes for biogas generation can be quite significant. However, crop wastes cannot be effectively degraded due to an imbalance in nutrients for microorganism and a lack of buffering capacity for the chemical reaction (Babaee et al., 2013) [3].

Due to low carbon and nutrient balances of tuna factory waste (C:N ratio 2.95:1), anaerobic digestion process will not be sufficient to run an effective biogas plant. In the early experiments it was found that tuna factory waste digestion process produces low methane gas with incombustible. In this research tuna factory waste was varied in ratio for disposal purpose and to increase the C/N ratios of the co-digestion, the addition of banana crop residue was used to admixture at fixed ratio. In this research, biogas was produced in the co-digestion process of tuna solid waste with banana crop residue using 5 different ratios and the amounts of biogas production were compared. The biogas produced at the laboratory scale through anaerobic co-digestion batch reactors. The results from the laboratory scale experiments were then analyzed for economic and environmental benefits.

2. Materials and method

2.1 The experimental equipment design and set-up

The anaerobic co-digestion laboratory scale tank was made of modified polyethylene buckets. The total volume capacity of the tank was 200liters while the effective volume of the digester was 150 liters, the bucket was sealed at the top with a gasket and covered by bucket cover. The mixing shaft was designed by using 95 cm length of PVC pipe (one inch in diameter) joined with bucket cover as a horizontal, circular mixing paddle. The waste feeding pipe was made with 2 inch diameter PVC pipe of 65cm length from the cover of the digester tank. The reactor has two outlets located at the bottom of tank one for effluent waste removal and the other installed 20 cm below the tank cover for the effluent over flow output. Gas outlet was installed at the top of the digester tank. Biogas production volumes were measured using the liquid displacement method.

2.2 Waste characterization

To characterize the waste, as well as monitor the effluent from the process, the flowing parameters were determined: temperature and pH are to be recorded every day, while other physical and chemical parameters like chemical oxygen demand (COD), total solids (TS), volatile solids (VS), total kjeldahl nitrogen (TKN), total alkalinity, volatile fatty acids (VFA), ammonium-N were measured every 3 days. These investigations were conducted in accordance with the standardized methods (APHA, AWWA, WEF, 2012) [4].

2.3 Operational conditions

The experiments were carried out with the mixture of five sets of different ratios of tuna waste and banana crop residue (TW:BCR ratios) namely 1:1, 1.5:1, 2:1, 2.5:1 and 3:1 respectively. The batch experiments reactors were operated under mesophilic conditions of temperature between 30-35°C. The experiments were conducted by adding in proportions of 90 liters inoculum, and 60 liters substrate. The inoculum was kept inside the digester for 7 days, at temperature 35°C, until the microorganisms attained a high growth rate of biogas, as indicated on the gas production, then the 5 substrate ratios of co-digestion (the grinded material) were added in the chamber and stirred. The influences of waste ratios were interpreted from the 30 days cumulative methane production records. After the process completion, slurry was drained and analyzed for its quality of fertilization.

Table 1 The Chemical composition of tuna solid waste and banana crop residue

Chemical composition	Tuna solid waste	Banana crop residue
pH	6.2	5.2
COD (g/l)	70.85	18.89
TKN (g/l)	17.80	2.78
TS (g/l)	97.13	28.74
VS(g/l)	88.43	11.47
Ammonium-N (g/l)	9.24	0.09
Total Alkalinity (g/l)	33.21	0.48
VFA (g COD)	25.08	2.70
C:N	1:2.95	1:53

2.4 The economic and environmental analysis

The economic and environmental analysis was performed in this study including the initial investment that consist of the construction of the digester and gas holder, the piping system, the gas utilization system, the operating cost and the maintenance cost which consist of the feeding and the operating of the laboratory, the maintenance and reparation of the laboratory that accounted of 6% of the initial biogas plant cost per annum, the management cost and wages cost consist of the administration cost, gas distribution cost and the utilization cost that includes water supply cost for cleaning the stable, the labor cost and etc. The saving and benefit of the biogas production are based on the consumption of biogas whose price was compared with diesel (fossil energy consumption of the tuna factory) and the sale of fertilizer. The life span of the plants can reach up to 10 years, provided maintenance and repairs are carried out accordingly.

3. Results and discussion

In this section, the results of the evolution of the main variables during the mesophilic anaerobic co-digestion process, such as pH, VFA and alkalinity variation, COD, and biogas production and composition are described in the paragraphs below. The discussions are based on the comparison of the system performance for five different ratios of mixture of tuna waste and banana crop residue, for a 30 days operation.

3.1 The relationship of the pH

The pH is a control parameter during the anaerobic digestion of biogas production. All the 5 reactors were running without adjustment of pH and it was found that the pH recorded (5.7 to 8.4) was relatively higher than the optimal value. The pH profiles at various digestion stages presented in figure 1 showed that the pH value during the 30 days of operation were on average remained 7.51, 7.51,7.50,7.60 and 7.56 respectively, while according to Banes & Bliss [5] the performance of co-digestion process in pH range between 6.5 to 7.5 is found to be the best and the most optimum. The value indicated that the digester is working at optimum rate for methane formation when it was not under inhibitory conditions. Methane production usually terminates when the digester pH drops below 6.0. When the pH was normal, this could be the result of inhibitors generated with the digestion going on, thus affecting the growth of methanogens during the AD process Chen et al., 2008; Madsen et al, 2011)[6-7].

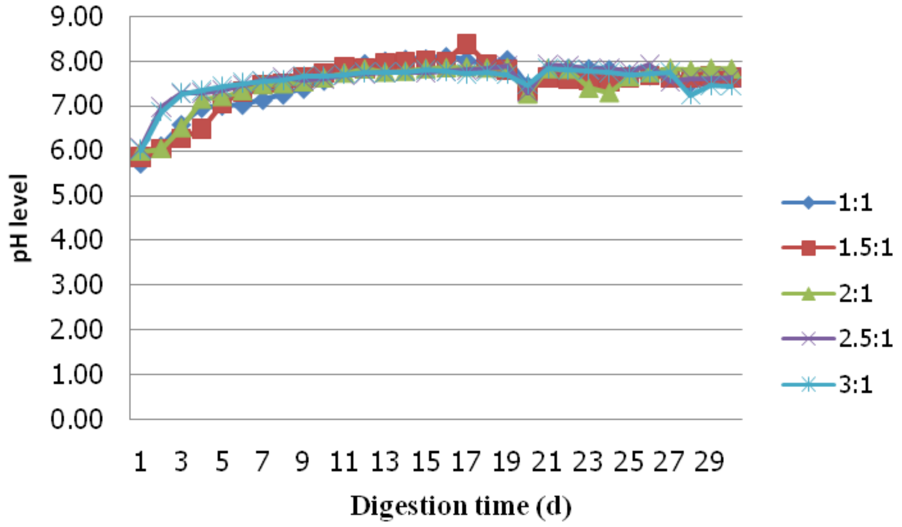

Figure 1 The pH profiles at various digestions

3.2 Chemical Oxygen Demand (COD)

The figure 2 shows the COD evolution, at the startup of process it was 45.2, 49.19, 64.64, 58.24 and 60.14 g/l respectively. During the 30 days process, the effluent of COD removal efficiency of 5 ratios were 41.39%, 45.77%, 56.72%, 50.82% and 34.30% respectively. The most efficient ratio was 2:1 in which the COD at start up process was 54.46 g/l that after the 30 days process was reduced to 23.57g/l.

3.3 VFA and alkalinity variation during the anaerobic co-digestion

As one of the processing performance indicator, the VFA concentration is probably the most sensitive parameter to monitor. When the VFA is under an inhibitory condition, the co-digestion process may lead to a system failure. VFA is required in a small amount as an intermediary step for the metabolic pathway of methane production by the methanogens [8]. The result in figure 2 shows the alkalinity and VFA ratio during the co-digestion in the reactors for the 5 different ratios. The VFA/ alkalinity ratios at effluent value were found in the range of 0.42, 0.38, 0.42, 0.52 and 0.51 respectively, thus indicating that the process operated favorably without the risk of acidification [9].

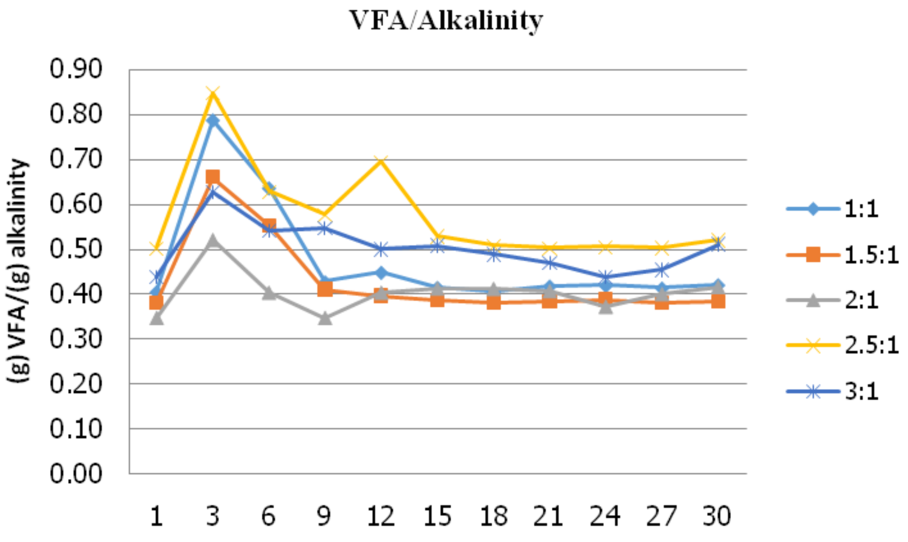

Figure 2 Total Alkalinity and VFA profiles at various digestions

3.4 Organic solid degradation

In order to determine the amount of co-digestion that has been digested in the co-digestion experiments, VS and TS analysis of all the ratios were carried out at the end of the digestion. The calculated reductions for each ratio are reported in table 2. The result indicated that just as the VS reduction for different ratios, the population means of TS reduction for different ratios of the co-digestion were significantly different, ranging from 34.49 to 51.00 %. For the VS reduction of ratio 2:1 performed best in the organic solids destruction, and rather than those different ratio of 1:1, 1.5:1, 2.5:1 and 3:1 led to different substrate reduction results.

Table 2 The Biogas production performance data in co-digestion of 5 ratios

	Laboratory 1:1	Laboratory 1.5:1	Laboratory 2:1	Laboratory 2.5:1	Laboratory 3:1
TS reduction (%)	34.49	37.87	51.00	39.67	37.07
VS reduction (%)	43.61	43.00	54.17	48.00	47.99
COD reduction (%)	41.39	45.77	56.72	50.82	34.30
Volumetric biogas production (l^{-1} d^{-1})	86.03	79.23	113.43	89.83	87.93
Volumetric CH_4 production (l^{-1} d^{-1})	44.05	41.48	62.97	48.67	46.98
CH_4 content (%)	51.20	52.35	55.51	52.18	53.43

3.5 Productivity

The biogas production is probably the most important parameter to monitor the anaerobic digestion. Biogas is composed of methane gas, carbon dioxide gas and a few other gases. The 30 days biogas production yield of each ratio were 2581, 2377, 3403, 2695, and 2638 liter respectively. The daily biogas production from different ratio is shown in figure 4. The highest biogas production was in the ratio of 2:1 at 3403 liters, whereas the production start from day 2 with 42 liter produced, and the highest daily production was 149 liter on day 17. If the biogas production dropped below the average daily values, it is most likely that the other indicators, as discussed above, may have changed as well, and it is a strong indication that the digester process was upset.

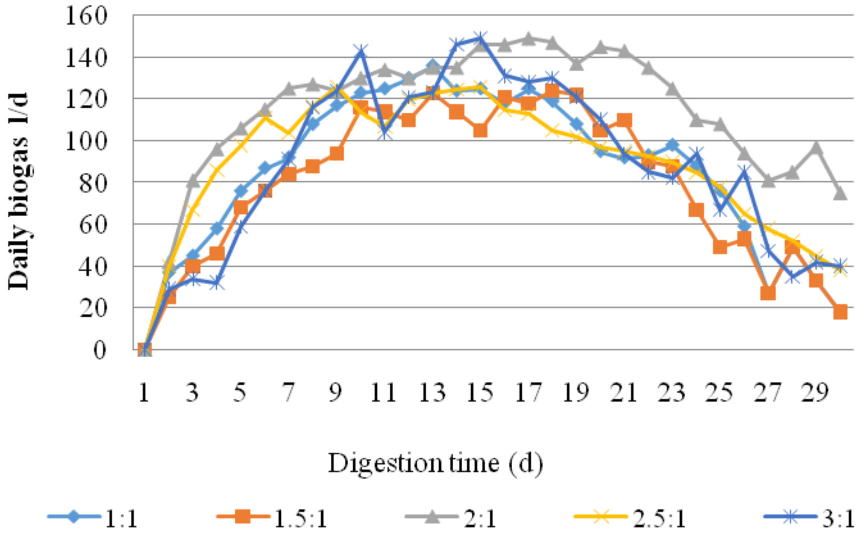

Figure 3 The daily biogas production

The ratio of 2:1 provides most optimal result in the biogas production whereas 113.43 l/d,in which the methane production was 55.51%, volume of 62.97 l/d, that equal to 0.55 liter of diesel, while the startup COD was 54.46 g/l., the 30 day evolution in meshopholic digestion the COD reduced up to 56.72%.

Based on the laboratory experiments, tuna factory can design its waste management by implementing semi-continuous anaerobic co digestion system, by utilizing its solid waste mixed with banana crop residue, to produce biogas to power the factory boiler. The Semi-continuous anaerobic co digestion system can be managed in the different hydroulic retention time (HRT), whereas implementing ratio 2:1, as per analysis of previous laboratory experiments was the most optimal for the biogas production. The biogas production supports the waste treatment of the waste management system, it offers many advantages to the fish industry specifically and to other food industry in general.

3.6 The biogas economic and environmental performance assessment

Based on the batches study experiments, economic and environmental impacts were calculated using the best proved ratio i.e 2:1 in the experiment. The initial investment of the biogas laboratory was 22,280 baht, while 6% operation and maintenance cost comes out to be 1,336.80 baht, the management cost and the wages were 35,706 baht/annum. The annual saving and benefits were 42,672.96 baht/annum. The anaerobic co-digestion of 10 year period at the discount rate of 5%, found out that the NPV was 21,128.53baht/annum, showing that 2:1 ratio provides profitability to the investor. The BCR was equal to 1.07, with IRR 15.90%, and PB period was approximately 3 years and 7 months.

The Biogas production provides substantial economic and environmental benefits to tuna factory by improving the tuna factory waste management system that support tuna factory waste treatment, while reducing its carbon emission and converting factory waste into useful substance, such as biogas and high quality fertilizer.

4. Conclusion

The objectives of this research were to produce biogas by the co-digestion of tuna factory waste and banana crop residue, and analyze the economic and environmental benefits. According to the results, the best operating conditions for the mesophilic anaerobic co-digestion of tuna waste and banana crop residue were achieved with the 2:1 ratio. Moreover, a higher level of biogas production (113.43 l/d) was achieved, while methane production was 62.97 l/d. The economic and environmental analysis shows that the payback period was 3 year and 7 months. Overall, the economic and environmental benefit analysis proven that simultaneous co-digestion of tuna waste and banana crop residue has lower unit cost due to its laboratory unit and its facilities, as well as its operating cost was considered very low, while it provides greater revenue because of its more robust process performance to generate biogas and its byproducts. The results of the experiments will form the basis for the design of a large-scale biogas plant for the anaerobic utilization of tuna factory waste. The biogas can be upgraded into fuel for the Tuna factory and ultimately to achieve sustainable renewable energy.

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