Full Scale Anaerobic Digester for Treating Palm Oil Mill Wastewater

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Abstract: This study was conducted to evaluate and improve the performance of the existing full-scale anaerobic digester for treating palm oil mill wastewater at Asian Palm Oil Co., Ltd. Krabi, Thailand. Trials were conducted at hydraulic retention times (HRT) of 14, 10, 7 and 6.5 days which correspond to average organic loading rates (OLR) of 2.43, 5.09, 6.50 and 8.70 kg COD/m^{3}d, respectively. Average BOD_5 and COD removal efficiency was found to be about 93% and 65%, respectively. Wide variations of influent flow and organic loading were carefully monitored to achieve suitable operation criteria. To ensure suitable and stable biological removal efficiency, pH in the digester should not be less than 7.0 at influent temperatures in the range of 35-45 ^oC. At HRT of seven days, corresponding to OLR 6.50 kg COD/m^{3}d, a specific methane gas generation of 0.35 m^3CH_4/kgCOD was achieved, with an average CH_4 content of 67%. The biogas produced from anaerobic digesters is a cheap source of energy which can be used as a gas engine fuel to produce electricity. Up till now, the biogas plant has generated and sold a total of 7.5 Million kWh of alternative electricity to the Provincial Electricity Authority of Thailand.

Keywords: Anaerobic digester; palm oil mill wastewater, biogas, alternative electricity.

1. Introduction

Palm oil mills are one of the most important agro-industries in the South of Thailand. In the process of palm oil milling, effluent is generated through the sterilization of fresh oil palm fruit bunches, clarification of palm oil and from hydro-cyclone operations [1]. Discharge of palm oil mill wastewater without proper treatment will damage the environment by polluting water and causing a foul smell in the neighborhood of a factory. To avoid this proper wastewater treatment methods should be employed. In the past, anaerobic stabilization ponds are used for treating palm oil mill wastewater because of their low capital and operating cost. However, odor from anaerobic ponds disturbs the neighboring community. Another possible efficient treatment system is the closed anaerobic digester that has become more popular in recent times. Continuously stirred tank reactors (CSTR) have also been studied for the treatment of palm oil mill effluent [2]. Furthermore, biogas from the closed treatment system can be utilized as a fuel for electricity generation. This form of utilization of domestic natural resources will not only reduce the dependency on foreign fuel imports for electricity generation but also have a lower environmental impact.

Due to energy demands and environmental concerns being important issues nowadays, the Royal Thai Government policy is to promote and subsidize projects which produce energy from biomass such as biogas from anaerobic digestion in agro-industries, especially anaerobic digestion of high concentrations of organic matter in wastewater. Furthermore, palm oil mills could earn carbon credits as revenue by the utilization of methane gas as a renewable energy from the anaerobic digestion of palm oil mill effluent [3]. The full-scale anaerobic digester of wastewater from production of palm oil in southern Thailand at Asian Palm Oil Co., Ltd. Krabi, is one of these subsidized projects. The digester has been in operation since December 2001. The system not only reduces water pollutants but also produces biogas which the mill utilizes as fuel to produce electricity using an internal combustion engine. Following successful trails, the first biogas engine of 500 kW was procured and installed in September, 2005 for the continuous production of renewable electricity under the original Very Small Power Producer (VSPP) regulation.

2. Materials and methods

The cylindrical anaerobic digester has a diameter of 13.5 m and height of 15.3 m, resulting in an effective volume 2,100 m^3. The reactor comprises of gear motor, torque tube, scrapper set and draft tube for mixing. The system provides good contact between microbes and substrates, reduces resistance to mass transfer, minimizes buildup of inhibitory intermediates and stabilizes environmental conditions [4]. Palm oil mill effluent was pre-treated in an oil recovery tank and primary ponds before being fed to the anaerobic digester by a centrifugal pump. Seed inoculums of 600 m^3 were taken from existing anaerobic ponds and fed to the digester. The total volatile solid concentration of seed was 18,319 mg/L, pH 7.17 and alkalinity 7,500 m/L as $CaCO_3$. The characteristics of palm oil mill wastewater after being pre-treated by oil recovery and primary ponds before feeding to anaerobic digester are shown in Table 1. The main purpose of pre-treatment was to reduce the temperature of wastewater. The pH of influent was in the range of 4.72 - 5.38. The BOD_5/COD ratio for wastewater from palm oil production was in the range of 0.63 – 0.85. This wastewater was considered to be a treated biological process because the BOD_5/COD ratio for untreated wastewater was 0.5 or greater [5]. The pH of wastewater was closely monitored and maintained at 7.0-7.2 and Volatile Fatty Acid (VFA) content was maintained at less than 400 mg/l as CH_3COOH to ensure an efficient anaerobic digestion process.

Table 1. Characteristics of wastewater before being feeding to the anaerobic digester.

Parameter	Range
pH	4.72 – 5.38
Temperature (°C)	37 – 46
Biochemical oxygen demand (BOD_5), mg/l	12,750 – 42,150
Chemical oxygen demand (COD), mg/l	15,000 – 66,000

The start up process is time-dependent; many factors affected it such as characteristics of the feed, source of the seed, and the selected operational and environment conditions [6]. During an acclimatization period the digester was fed with 300 m^3 of wastewater every two days.

The experimental runs were operated at hydraulic retention times (HRT) of 14, 10, 7 and 6.5 days which corresponded to average organic loading rates (OLR) of 2.43, 5.09, 6.50 and 8.70 kgCOD/m^{3}d, respectively. A flow diagram and biogas utilization process of the anaerobic digestion system are shown in Figure 1.

Influent and effluent from the digester were analyzed for BOD_5, COD, pH, Temperature, VFA, and Alkalinity every 3-4 days. The analytical methods used were in accordance with standard methods for the examination of water and wastewater [7]. Gas volume was monitored using an EPI gas flow meter Model: Series 8200 MPNH Insertion style with remote display. Gas composition was determined by gas chromatography.

3. Results and Discussion

3.1 The operating days at different HRT and OLR

The digester was fed with wastewater after pre-treatment in the primary pond. Treatment at HRT of 14, 10, 7 and 6.5 days was conducted. At first experimental runs was operated at hydraulic retention times of 14 days. The digester started up very fast with continuously stable performance because of a high volume of alkalinity and also the effect of good mixing of anaerobic digester. The digester mixing system using biogas recirculation compressor 24 hrs/day for recalculated biogas into digester to make a completely mix. pH is an important indicator to monitor the performance of the anaerobic digestion process and it should be kept in a range of 6.8-7.5 to prevent methanogenesis inhabitation [6]. In operation even the pH of wastewater was in the range of 4.72-5.38, there was not required any chemical adjustment of pH balance because the digester has enough alkalinity in average 7,500 mg/L as $CaCO_3$ together with a large volume of 2,100 m^3 of digester. The pH trends for all mixtures during operation days are show in Figure 2.

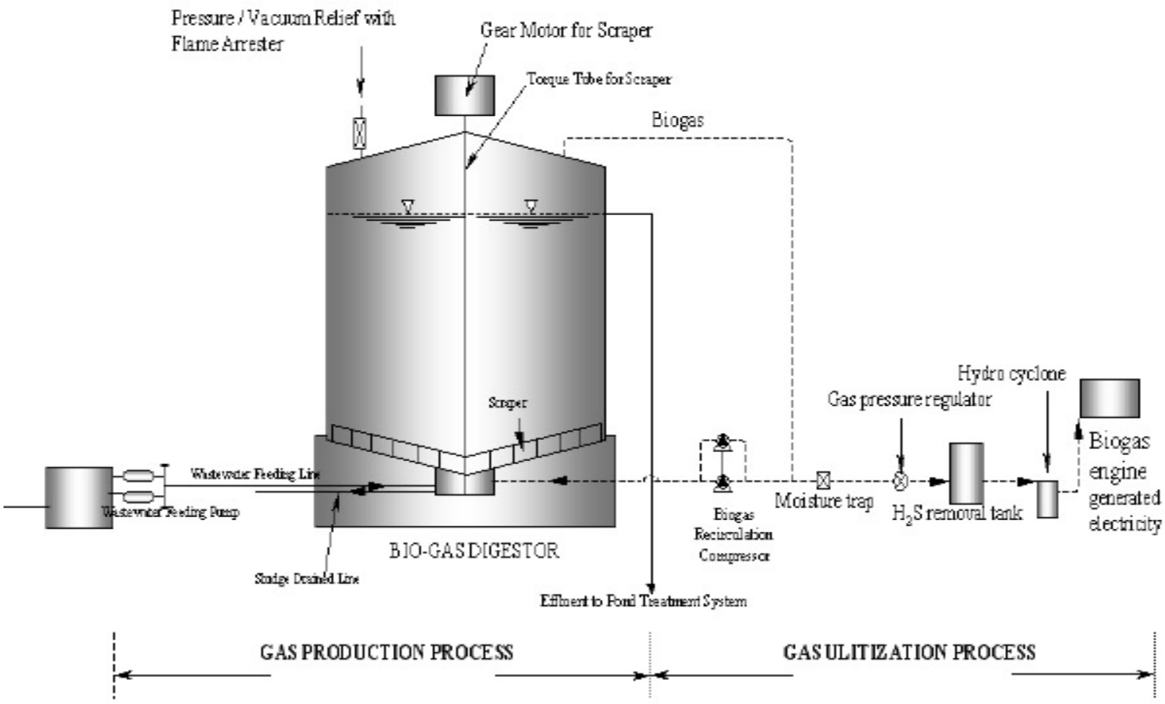

Figure 1. Anaerobic digester at Asian palm oil mill, Krabi, Thailand.

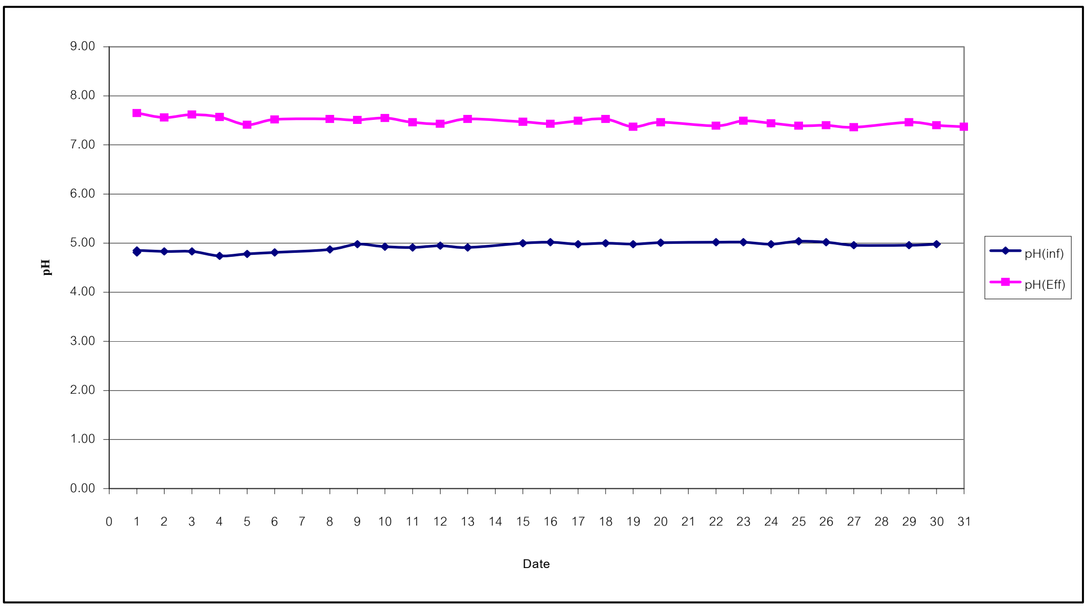

Figure 2. Trend of pH in the influent and effluent of the digester.

Table 2. Performance of anaerobic digester treating palm oil mill wastewater.

HRT (d)	OLR (kgCOD/m^3 d)	COD Removal (%)	BOD_5 Removal (%)	CH_4 in biogas (%)
14	2.43	70	95	70.03
10	5.09	68	95	69.29
7	6.50	65	96	66.83
6.5	8.70	65	93	66.41

The performance of a full-scale anaerobic digester was evaluated by the COD and BOD_5 removal efficiency and methane production. The overall anaerobic digester performance for treating wastewater from palm oil production is shown in Table 2.

An increase in OLR corresponding to a decrease in HRT down to 6.5 days did not significantly affect COD and BOD_5 removal efficiency. Methane formation increased with an increase in the COD removal which can be explained by the fact that the methanogenic consortium acclimatized very well and consequently lead to the digestion of organic matter under anaerobic conditions producing end products such as water, carbon dioxide and the methane [8]. Experimental results indicated that about 96% BOD_5 and 65% COD removal efficiency were achieved at 7 days HRT and OLR 6.50 kgCOD/m^3·d. This result was similar to another report which used the lab-scale high rates at an anaerobic treatment of palm oil mill wastewater at 7 days HRT with 62.5% COD removal efficiency [9]. However, gas production will increase with OLR until a stage when methanogens cannot work quick enough to convert acetic acid to methane [3]. Methane conversion at this experimental run was about 0.35 m^3CH_4/kgCOD. The theoretical amount of CH_4 produced per unit of COD converted under anaerobic conditions at 35°C is equal to 0.40 m^3 CH_4/kg COD [5]. Nevertheless, methane emission may differ depending on treatment practices. Methane emission rates lies between 0.15-0.42 L/g COD removed with COD removal efficiency of 70-97% [10].

3.2 Biogas Utilization

Full biogas utilization was done by the management group of the factory. Biogas can also be used as a source of heat by direct combustion [11]. Asian Palm Oil Co., Ltd. generated electricity from biogas using the first 500 kW Shengli biogas combustion engine Model 500GF-RZ which was procured and installed in September, 2005 for the continuous production of renewable electricity and has been operating for more than 17,500 hrs up to the present time. The second set was commissioned in April 2007. Before utilization of biogas in the internal combustion engine, the gas has to be cleaned in a dry or wet scrubber because digester gas contains hydrogen sulphide, nitrogen, particulates and water vapor [5]. Biogas was taken from the digester and scrubbed to reduce hydrogen sulphide (H_2S) using iron chip to prevent corrosion in any part of the engine. It appears that the selection of lubricating oil with the right total base number (TBN) for the gas engine is sufficient to overcome the H_2S problem; the oil needs to be changed every 500 running hours. The generated electricity from the 500 kW gas engine has been sold to the Provincial Electricity Authority (PEA) under the Very Small Power Producer (VSPP) regulation. The system can produce 20 m^3 of gas from 1 m^3 of wastewater or an electricity generation of 2.5 kWh/m^3 of biogas. The efficiency of the gas engine that used 65% CH_4 of Biogas was calculated to be 35% efficient. The amount of power generation is about 2.2 Million kWh/ a year is sold to PEA creating a total average income of 4.9 Million Baht/ a year.

In addition, the recovery and utilization of methane contributes to significant Greenhouse Gas (GHG) emission reduction. The Clean Development Mechanism (CDM) under the Kyoto Protocol will allow the proven GHG emission reductions to be recognized as credits, and this is a source of substantial revenue to support the project investments [12]. According to baseline methodology, the amount of Carbon Emission Reduction (CERs) can be calculated as:

Annual lagoon baseline emission
= COD Loaded at digester inlet x B_0 (kg CH_4/kg COD)
x $MCF_{baseline}$ x GWP / 1000 kg/t
= (450,000 kg COD/month) x 12 month x 0.21 x 0.623
x 21 / 1000 kg/t
= 14,836 tCO_2 e / year

Where:
$MCF_{baseline}$ = Monthly methane conversion factor
GWP = Global warming potential = 21 times that of CO_2
B_0 = Maximum methane production capacity

This study is optimistic that the environmental and economic benefits of biogas are reinvigorating the market of anaerobic digestion technologies. It offers all mill plantation owners and palm oil companies an opportunity to play a major role in reducing the burden of waste management and helping to tackle the problem of global warming before its effects become catastrophic.

4. Conclusions

Anaerobic digester can be used to treat wastewater from palm oil mill factories. A maximum average BOD_5 removal efficiency of 96% was achieved at hydraulic retention time (HRT) of seven days and an organic loading rate (OLR) of 6.50 kg COD/m^3·d. The specific methane conversion rate was 0.35 m^3 CH_4/kgCOD which was similar to specific biogas generation rates reported elsewhere in the literature. Wide variations of influent flow and organic loading rates have been carefully monitored. To ensure suitable and stable biological removal efficiency, pH in the digester should not be less than 7.0 at influent temperature in the range of 35-45°C. A total of 20 m^3 biogas can be obtained from 1 m^3 of palm oil mill wastewater with average electricity generation of 2.5 kWh/m^3 of biogas. The biogas generation from wastewater from palm oil mill encourages the strategy of Krabi province which visualizes itself as “Being the center of an e-co-tourism city, with a healthy environment and sustainable agricultural industries”. This also follows the National Energy policy of the Ministry which aims at 8% of the total nationwide energy usage coming from renewable energy in 2011. This also coincided with the policy of accelerating the amount oil palm plantations in Thailand to 5 million rai (approx. 2 million acres) for bio-diesel production which is increasing.

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