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The Performance of an Anaerobic Digester Treating Bio-Sludge Generated from a Municipal Wastewater Treatment Plant in a Pilot Scale

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This study aimed to investigate the anaerobic digestion process of bio-sludge generated from a municipal wastewater treatment plant. The experiment was carried out in a pilot-scale reactor with the working volume of 0.3 m^3 at ambient temperature. The reactor was operated at organic loading rate as 4 kg VS/m^3.d in the duration of 35 d. The result showed that this reactor was weakly performed during the start-up time and improved to be stable in the later phase. The maximum biogas yield achieved as 304.8 L biogas/kg VS with the accumulation of biogas as 5 m^3 at the end of the experiment. The COD removal efficiency was gradually increased during the operational time and achieved about 50 % at the steady stage. It was observed that this process was not good at removal of nitrogen and phosphorus matters. The effluent was still contained a high concentration of COD; TN and TP. This investigation recommends that bi-solid waste of wastewater treatment land has a high potential for producing biogas which is considered as one kind of renewable energy sources to replace fossil energy in the near future. In addition, the digested sludge from the anaerobic reactor could be further reused for composting and land enrichment to enhance the use of organic and nutrient elements containing in bio-sludge waste.

1. Introduction

Vietnam is a developing country. In recent years, the economical-social development has been going together with population boom, industrialization, and urbanization. Therefore, the water supply-demand has increased sharply resulting in a huge amount of municipal wastewater has generated. To prevent aquatic pollution by wastewater, the government had established more than 25 plants in the main cities to treat about 600,000 m^3/d of domestic wastewate. In addition, many wastewater treatment plants are approved by the government with a total capacity of 2 Mm^3/d by 2030. It was estimated that the sludge that produced from traditional technologies in wastewater treatment is about 0.15 kg/m^3 from primary settling tank and 0.08 kg/m^3 from secondary sedimentation (Tchobanoglous et al., 2003). As the treatment capacity increases, the sludge production will also increase. The treatment and disposal of sewage sludge is one of the major concerns about environmental issue and operation cost in wastewater treatment plant (Yuan et al., 2019). This bio-sludge contains many kinds of organic contaminants, pathogens, and heavy metals. Therefore, the discharge of the un-treated sludge can cause environmental pollution and effect on human health. Thus, it is a requirement to stabilize and decontaminate the waste to comply with the existing regulations. The common routes for sludge disposal including dewatering, thickening, burning, landfilling, soil enrichment, and anaerobic treatment (Choi et al., 2018). Landfilling is the most common method for treatment of dewatering sludge in Viet Nam. This route is no longer suitable solution due to the land scarcity and sustainable development policies (Farhat et al., 2018). In another hand, the bio-sludge waste contains high concentrations of organic materials, and nutrient elements (N, P) that can be recovered for useful purposes in agriculture and renewable energy production.

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Anaerobic digestion (AD) is an appropriated method for stabilizing the bio-sludge (Gil et al., 2018). This process takes place in the absence of oxygen (Camacho and Ruggeri, 2018); microorganisms utilize organic compounds and produce methane and carbon dioxide gases (Abudi et al., 2006). As a result, it can be achieved two targets in one work which are of sludge treatment and energy generation (Bong et al., 2018).
The advantages of using anaerobic treatment are excellent organic matter removal, less production of sludge, low energy requirement, execution of higher loading rates, less nutrients requirement, and simultaneous production of renewable energy (Abudi et al., 2006). The previous studies have been paid more attention on the lab-scales research. Therefore, it is necessary to carry out the experiment at large scale in order to make fully conclusion about anaerobic digestion process and further application in full-scales. In this study, a pilot-scale of anaerobic was operated to investigate the treatment of bio-sludge generated from domestic wastewater treatment plant.

2. Materials and methods

2.1 Sludge source

Activated sludge waste from the secondary sedimentation tank of Binh Hung municipal wastewater treatment plant (Hochiminh City) was dewatered to increase the organic portion and used as substrate in the anaerobic reactor. The influent sludge had range of COD concentration as 26,716 – 28,624 mg/L and volatile solid (VS) concentration as 13,875 – 15,385 mg/L,. The sludge was collected daily from the wastewater treatment plant and stored in a Polypropylene tank. Before feeding to the reactor, the bio-sludge was adjusted to obtain pH at 7.5-8 and alkalinity at 2,000 – 3,000 mg/L by NaOH and $NaHCO_3$ to provide a suitable condition for anaerobic microorganisms in the reactor.

2.2 Reactor conjugation and operation

The anaerobic digestion experiment was conducted in a pilot-scale reactor that made of non-corrosive steel (Figure 1). The AD digester had 1.2 m in height and 0.3 m in diameter with the working volume is 0.3 m^3. The head of the reactor was equipped with a mechanical stirring system and worked at 60 rounds/min during reaction time. The reactor was connected to a pump, gas meter, and an electrical control box. Before starting up the experiment, the reactor was tested for airtight. At the first day of start-up, sludge was injected to reached working volume; the reactor was covered and connected to stir and other parts. Nitrogen was flushed to release oxygen before conducting the experiment.
The reactor was operated at semi-continuous working mode at organic loading rate as 4 kg VS/m^3/d. Every day, the digested substrate was pumped out and replaced by the new substrate with the flow rate as 3.5 L/min. The duration for substrate injection was calculated based on the designed organic loading rate and COD concentration of the sludge source. The stirring process was stopped during the substrate changing. After feeding, the reactor was stirred continuously and operated for biogas production. The new cycle was repeated in the next day. Experiments ended after an operational time of 35d when the biogas production reached a steady state.

Figure 1: Anaerobic digestion reactor

2.3 Sampling and analytical methods

To evaluate the performance of the reactor, samples of were taken daily and analyzed. Chemical parameters such as such parameter pH, TSS, COD, TN, TP, were analyzed in the laboratory according to APHA (APHA, 2005). Volatile fatty acid (VFA) concentration was measured by high-performance liquid chromatography (HPLC) (LC-2000 plus HPLC system). The biogas volume was measured daily using a gas meter. Biogas composition was analyzed using gas chromatography-mass spectrometry (GC-MS) (Dinh et al., 2014).

3. Results and discussion

3.1 Biogas production

In the AD process, microorganisms convert organic compounds to biogas through a series of reactions, and the efficiency of this work indicates in biogas production rate (BPR) and biogas yield (BY). The BPR and BY were monitored during the time course. Figure 2 shows the biogas yield and biogas accumulation during the time course. It is clear to see that BY was low at the start of the experiment and getting increase sharply after until day 13th of the experimental duration, at this day the BY was achieved 230 L biogas/kg VS. After the start-up stage, the reactor performed stably until the end of the experiment. The average BY during steady stage was 274 L biogas/kg VS. In the previous study, the co-anaerobic digestion between municipal sewage sludge and olive processing wastewater with ratio 7:3 in mass was investigated and achieved the BY as 623 L biogas/kg VS inlet (Farhat et al., 2018). Gil and colleagues operated anaerobic reactor for treating sewage sludge 186 mLCH_4/kg VS (Gil et al., 2019). The biogas accumulation was calculated thought out the duration time. At the end of the operational period, the biogas accumulation was 4,943.4 L in which the methane portion was about 58-67 % (data is not shown). This achievement suggests a good potential for conversion from sludge waste to biogas and further use as renewable energy. Therefore, it is necessary to design and establish an anaerobic digestion plant to collect the bio-sludge from the wastewater treatment plant for producing biogas and electric generation.

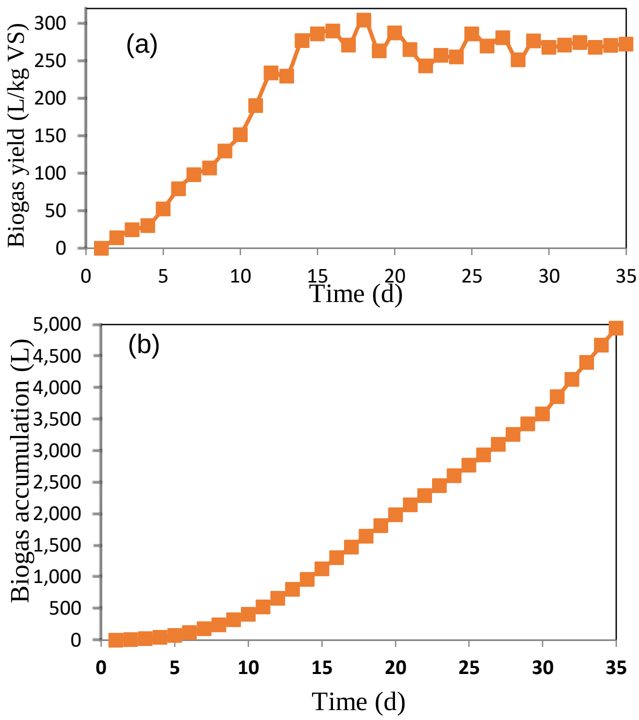

Figure 2: The biogas production during the time course: a) Biogas yield; b) Biogas accumulation

3.2 Chemical oxygen demand (COD) removal

Figure 3 shows the COD concentration in the influent, effluent and removal efficiency during the time course. The COD concentration in the input sludge was stable in the range of 26,716 – 28,624 mg/L. The COD removal efficiency changed in the same trend with biogas production. Thus, it illustrated that the conversion of the carbon element to biogas by anaerobic reactions. The COD removal was low at the start-up stage and increased gradually from 0 % to 41 % at day 17 of the duration time. After that, the removal rate was increased slowly and achieved the values of 50-51 % until the end of the experiment. The anaerobic co-digestion of sewage sludge and glycerol was operated at different OLR, results indicated that the COD removal efficiency as 65 % at OLR 1.03 kg COD/m^3.d and dropped to 15 % at OLR 4.05 kg COD/m^3.d (Zahedi et al., 2018). In this study, the reactor was operated at high OLR as 4 kg COD/m^3.d during the operational time. The result indicated that the reactor could endure high OLR and performed stably. The short solid retention time caused high organic remaining in the effluent. Therefore, the effluent COD concentration in the effluent was about 13,256 – 16,435 mg/L. Hence, it is suggested to continue to dewater the effluent sludge and reuse for agriculture purpose to recover more useful organic matter containing in the digested sludge.

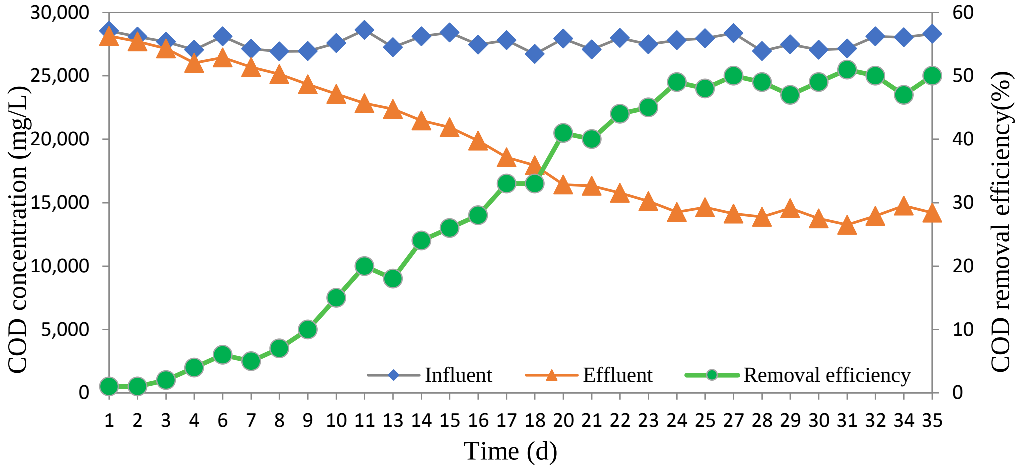

Figure 3: The COD removal during the time course

3.3 Volatile solid (VS) removal

VS concentration is a part of total solids contains in the material. VS indicates the organic fraction containing in the substrate. In bio-sludge waste are mainly microbial biomass and other organic compounds (Feng, 2019). The VS concentration implies the potential biogas production from initial material. Figure 4 illustrates the VS profile during the time course. The data elucidates that VS removal increased gradually during the first day of the experiment and became stable in the later phase. The average removal rate of VS was 27.32 % in the steady stage of the experiment. It was elucidated that the pre-treatments of dewatered sewage sludge by ultrasonication-ozone combination could reach the removal VS as 36.9 % compared to 31.5 % by acid pretreatment (Wenjing et al., 2019). It was showed that the bio-electrochemical anaerobic digestion of sewage sludge and achieved 55.4 % VS removal efficiency with a similar organic loading rate, in which, is higher than this study (Feng, 2019). Maybe the different experimental conditions between two studies resulting in the different efficiency achievement. Especially, the pretreatment and or combination of bio-physical-chemical processes may make the organic compounds become more degradable in anaerobic digestion.

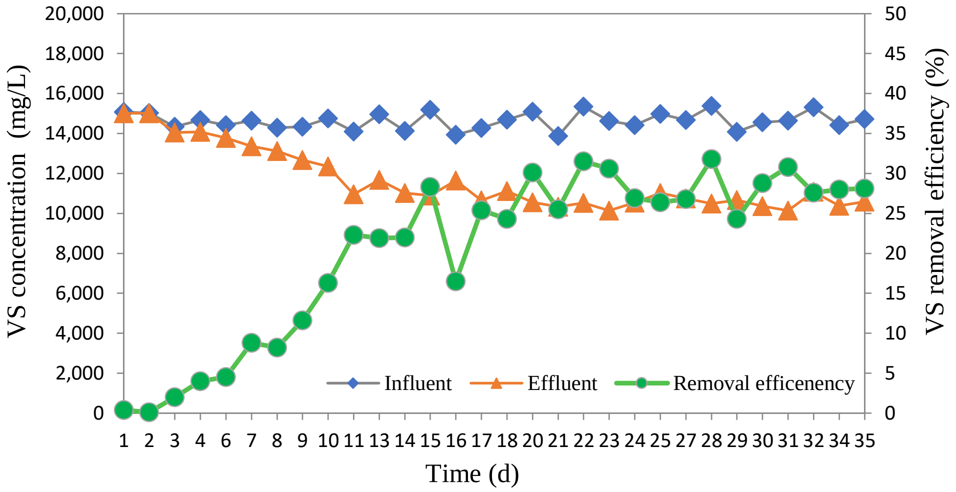

Figure 4: The VS removal during the time course

3.4 Nutrient removal

Besides the organic matters, the nutrient elements such as nitrogen and phosphorus are also presented in domestic wastewater. During the biological wastewater treatment at the plant, those components are consumed by microorganisms throughout the metabolism process and convert them to biomass; nutrient elements are utilized to produce new cells. Therefore, nitrogen and phosphorus are also content with a high concentration in bio-sludge waste. Figure 5 shows the nutrient concentration and removal efficiency during the time course. The influent concentration was 500 – 600 mg/L for TN and 275-330 mg/L for TP. The maximum removal rate was 38 % for TN was and 12.5 % for TP,. This result can be explained that the nitrogen and phosphorus demand is not low in the anaerobic digestion process. At the steady stage, the effluent concentration of nitrogen was 346-428 mg/L and effluent concentration of phosphorus was 248-276 mg/L. Those values indicate that the digested sludge still contained a high concentration of nutrient elements.

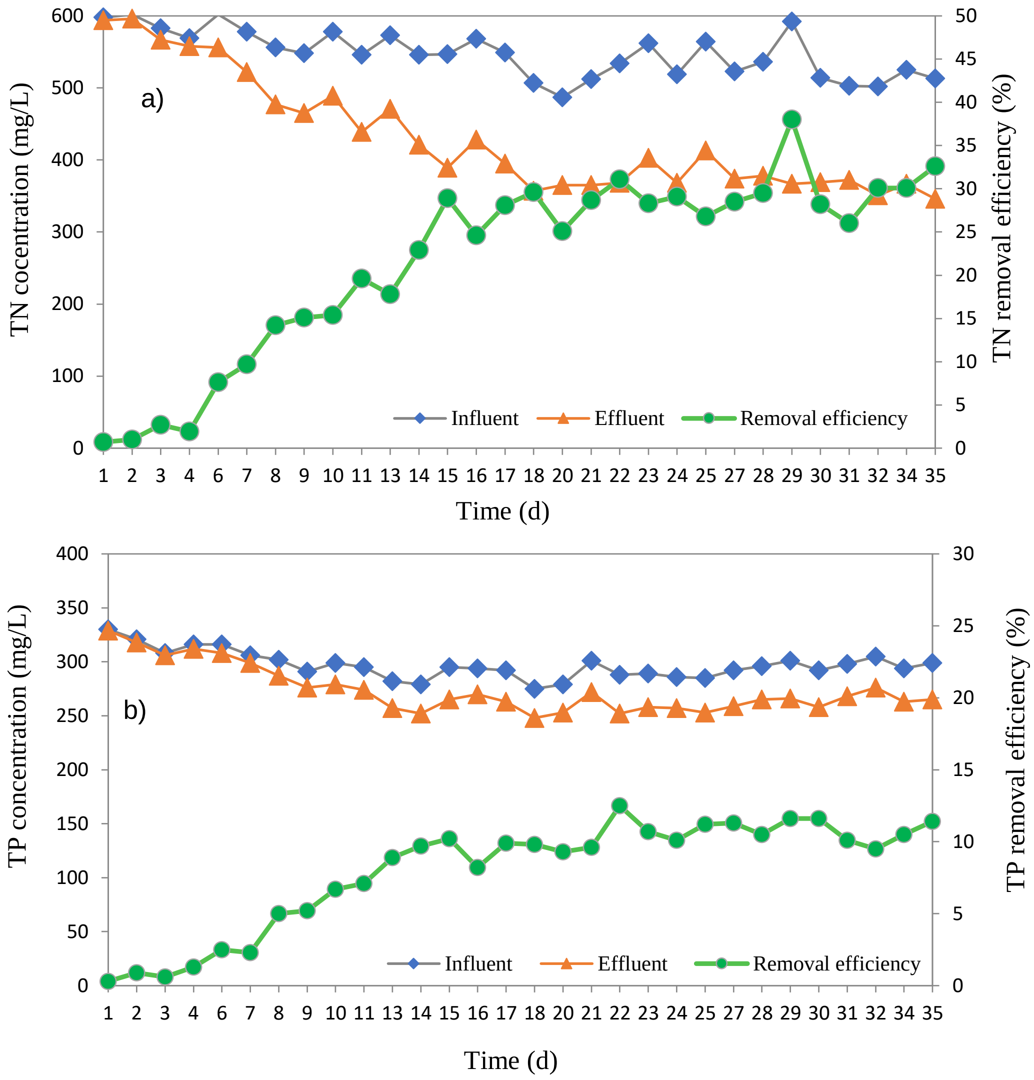

Figure 5: The nutrient profile during time course: (a) TN removal; (b) TP removal

4. Conclusion

The anaerobic digestion of bio-sludge generated from a municipal wastewater treatment plant was investigated. The result elucidated that this sludge provides a high potential for renewable energy generation. The maximum biogas yield achieved as 304.8 L biogas/kgVS. The maximum removal rate of COD; VS; TN; and TP was 50; 32; 35; 38 and 12.5 %. Therefore, it is suggested for further use of the effluent in another useful process such as composting, landing enrichment, or other agriculture applications. In addition, in order to improve the biogas production rate, it is necessary to carry out more investigation the sludge pre-treatments and co-anaerobic digestion between sludge and or organic materials.

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