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Effect of Agitator Type on Co-digestion of Pig Manure and Vegetable Waste for Biogas Production

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Abstract

The purpose of this research is to investigate the effect of impeller geometry on the anaerobic digestion of vegetable waste and pig manure. Anaerobic digestion is carried out in a 60L semi-continuous digester with a built-in water displacement tank to measure biogas production rate. Three types of impellers were investigated including 6-stright blade (SB-6), 6-marine blade (MP-6) and 4-pitch blade (PB-4). Biogas production, methane content and pH level at four different organic loading rates were monitored over 90 days of anaerobic digestion. Addition of agitators were found to have a positive effect on the biogas production rate and methane content. Impeller with an axial flow pattern gave a more stable biogas production rate even at high OLR. The average methane content increased from approximately 50% to 63% and biogas production from 0.2 to 0.6 m^3/kg_{vs} as the impeller was changed from SB-6 to MB-6.

Keyword: Anaerobic digestion, biogas, impeller, power number.

INTRODUCTION

Implementation of the biogas production process through anaerobic digestion as a source of renewable energy has increased dramatically over the past decade. Anaerobic digestion is the biological process in which micro-organism consumed biodegradable waste or volatile solid (VS) and converted them to methane (CH_4) gas [1]. It is estimated that the combustion of 1 m^3 of methane-rich gas can generated 2.5 kWh of electricity, which is a promising source of clean energy to prepare for electric vehicle in the future [2]. In central Europe most biogas power plants now operate on lignocellulosic energy crops such as cereals, sugar beet, grass, corn-stover and maize [3]. Biogas production is a promising source of energy for Thailand due to high agricultural capabilities. The ministry of energy planned to overcome the energy crisis by installation of biogas power plant to generate as much as 300 MW of electricity by 2036 [4]. Additionally, biogas usage for transportation also help lighten the awareness regarding the climate change [5, 6]

Anaerobic digestion of vegetable waste have been found to be a difficult endeavor due to high content of lignocellulosic content [7]. Various pretreatment technique was employed to loosen the lignin gripped, which make it easier for micro-organism to have access to cellulose and hemicellulose content [8, 9]. Ultrasonic technology for pretreatment have been employed for pretreatment of vegetable and fruit waste before digestion. Although the energy output obtained from biogas production after ultrasonic-assisted pretreatment of vegetable waste is twice the energy input, the cavitation technology is still relatively expensive [10-12]. Sitorus et al. reported an anaerobic digestion of fruit and vegetable waste to offer production of biogas with as high as 65% methane content [13]. Organic loading rate (OLR) was found to have major impact on the stability of biogas production process. An increase in OLR higher than 1.5 g VS/(L d) was observed to have a negative impact on long term production of biogas, which is usually indicated by a decline in pH level [14, 15].

Micro-organism and substrate suspension inside anaerobic digester is an important condition that need to be maintain in order to achieve a stabled high methane production rate [16]. Additionally, an effective mixing strategy can reduce the mixing time required per hour, which will significantly reduce energy consumption of the anaerobic digestion process60 [17]. The impeller's geometry was found to have a significant effect on mixing intensity and torque. Olmos et al. documented a significant increase in both torque and mixing intensity when a double helical impeller was used instead of Rushton blade impeller [18]. An increase in the number of blade was found to enhance the torque and shearing force of the agitation motion, which resulted in a homogeneity improvement in co-precipitation process [19]. Impellers that initiate an axial or mixed flow pattern (including hydrofoil and pitched blades) consumed less energy compared with impellers (radial turbine) that offered only radial flow pattern. An increase in the angle of pitched blade up to 45º was observed to reduce energy consumption as well [20, 21].

The research's goal is to study the influence of agitator type and organic loading rate on the stability of anaerobic co-digestion for biogas production from vegetable waste and pig manure. Four types of agitator were employed including 6-blade marine impeller, 6-straight blade impeller, and 4-pitched blade impeller. The organic loading rate were controlled at 1, 1.5, 2, and 2.5 g VS/(L d). Results from this work suggest that the agitator type play an important role in methane generation. Knowledge obtained from this research was successfully implemented at Rachaburi Municipality.

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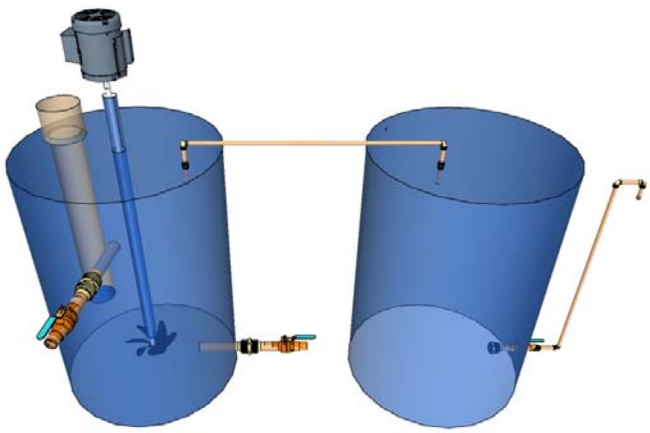


Figure 1: Anaerobic digestion system for methane production from organic waste.

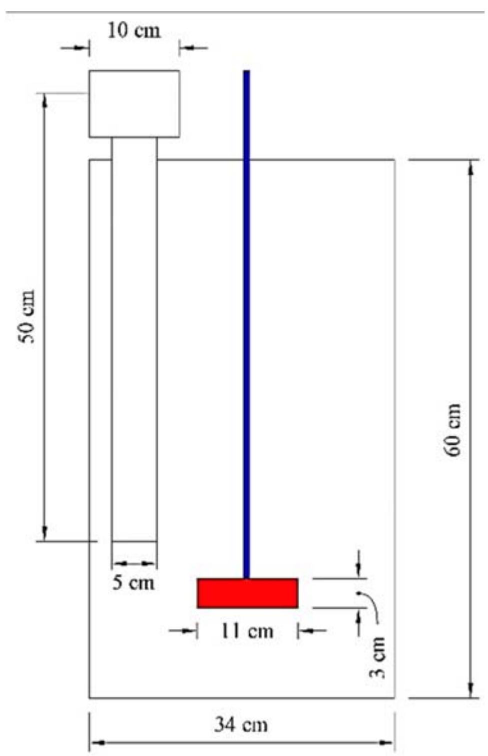
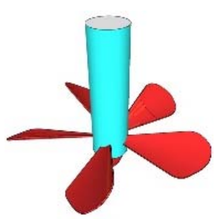
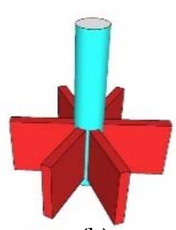


Figure 2: Diagram of the dimension of anaerobic digester and impeller position.



(a)



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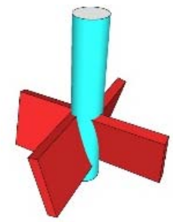

(c)

Figure 3: Different configuration impellers: 6-blade marine a), 6-straight-blade b), and 4-pitched-blade 30^{o}.

EXPERIMENTAL SETUP

I. Origin of material

Pig maure for anaerobic inoculum was obtained from a pig farm in Rachaburi province. The COD content of pig magure collected from the pig farm is 42.3 g/L. Rachaburi province has a relatively large population, therefore waste disposal management is a critical problem. the vegetable residual at community market. The vegetable residual was dried and mechanically chopped into smaller pieces (<1 cm^2).

II. Reactor set-up and operation

A 3-D model and simplied drawing of the anaerobic digester can be seen in Figure 1. The 60 L digester reactor with 34 cm diameter consists of two valves for controlling water level and releasing anaerobic sludge after digestion. A 5 cm diameter pipe installed through the tank was used as an inlet for waste organic loading. The inlet pipe is also designed to be submerge under anaerobic sludge inorder to prevent biogas generated to leak out of the digester. Additionally, smaller pipe (2 cm diameter) is also inserted in the middle of the tank in order to locate the shaft which is attached to a motor (Panasonic 90 W, gear ratio 1:3). The dimension and location of the impeller relative to the thank is designed according to the geometric proportion principles, which state that the blade need to have a diameter of 1/3 of tank's diameter and the length of the impeller from the bottom of the tank need to be equal to the diameter of the impeller [22].

For this experiment, the anaerobic digestion is carried out in a semi-continuous mode at room temperature, which mean that organic waste (60% vegetable and 40% pig manure) are fed once every day and the exact volume of the anaerobic sludge is withdrawed from the digester through the bottom valve. For the first 20 days of the operation the OLR was contrroled at 1 g VS/(L d). From day 21 to 40 the OLR was increased to 1.5 g VS/(L d), the OLR increased again to 2 g VS/(L d) during a duration of day 41 to 60 and lastly 2.5 g VS/(L d) from day 61 to 90. The impellers were used to mix the anaerobic sludge once a day for 5 hours at 30 rpm.

III. Analytical method

The Volatile Solid (VS) content of both vegetable waste and pig manure was measured by heating the material from room temperature to 550ºC in an oven (rate of heating was 10ºC per min). The VS content is calculated as the difference between the weight of dried material and the weight of ashes that is leftover after the heating. The methane content of biogas in percentage is measured externally by a portable gas analyzer, Vapor Analytical Bio Genious – 02, with an accuracy of ±10%. A water displacement system is employed to mointer the biogas production rate which was found to have an accuracy of ± 0.01 m^3/kg_{vs}. The pH level is measured by a pH meter (Hanna Instrument) with an accuracy of ± 0.1 pH.

RESULTS AND DISCUSSION

I. Characteristic of each impeller

For this research four different types of impeller were investigated including 6-blade marine (MP-6), 6-straight-blade (SB-6), and 4-pitched-blade 30º (PB-6) Each type of impeller have different characteristcs such as the Power Number (N_p) and flow pattern as shown in Table 1. N_p indicated the power required to turn the impeller during agitation, which is related to the energy consumption of each impeller. A higher N_p value mean that more power is required to rotate the impeller which suggest a greater energy consumption [23]. It can be observed that N_p of impeller decrease in this order SB-6 > GA > PB-6 > MP-6. It is also important to observe that SB-6 demonsrated a radial flow pattern which means that the mixing will occur mostly perpendicular to the impeller. On the other hand, the axial type impeller created motion both on top and bottom of the impeller.

Table 1: Summary of characteristic of different type of impeller observed in the research

Type	Code	Flow pattern	N_p
6-straigth blade	SB-6	Radial	5.59
4-pitched blade	PB-4	Mix	0.66
6-blade Marine	MP-6	Axial	0.32

II. Effect of impeller type and OLR

The effect of each type of impeller is mointered for 90 days from anaerobic digestion of vegetable waste and pig manure. The OLR was controled at 1 g VS/(L d) for 20 days, 1.5 g VS/(L d) for another 20 days, 2.0 g VS/(L d) for the next 20 days and 2.5 g VS/(L d) for the last 30 days. According to Figure 4, the anaerobic digestion during the startup phase (first 20 days) without an impeller gave biogas production rate of approximately 0.18 m^3/kg_{vs}. An increase in OLR to 1.5 and 2.0 g VS/ (L d) cause a slight increase in biogas production to 0.22 m^3/kg_{vs}. However, a futher increase in OLR to 2.5 g VS/ (L d) resulted in a reduction in the biogas production rate. This is because of an increase in food per mass ratio which favour the hydrolysis bateria causing the pH to drop to level 5.

Installation of a 6-blade straight impeller is also shown in Figure 4. An increase in biogas production rate was observed compared with the anaerobic digestion without impeller. This indicate the impact of the SB-6 impeller. The highest biogas production rate from a SB-6 impeller was approximately 0.42 $m^3/kg_{vs.}$ However, similar to anaerobic digestion without the impeller, an increase in OLR to 2.5 g VS/(L d) also cause the biogas production rate to reduce due to the overwhelming concentration of substrate inside the digester. When the impeller was changed from the SB-6 to PB-4, it was observed that there is a gradual increase after the OLR was adjusted from 1.0 to 2.0 g VS/(L d). Unlike the anaerobic digestion system without an impeller and the one with a SB-6 impeller, an increase in OLR further to 2.5 g VS/(L d) does not cause the biogas production rate to decrease. The biogas production rate remained steady at approximately 0.40 m^3/kg_{vs} even after 60 days of operation. An enchancement in anaerobic digestion is clearly shown in Figure 2 after installation of a MP-6 impeller. It can be observed that an axial flow behavior of the impeller have a positive effect on stability of biogas production. The biogas production rate from a MP-6 impeller increased gradually to as high as 0.6 m^3/kg_{vs} after the OLR was adjusted to 2.5 g VS/(L d).

Figure 5 illustrate the average methane content of biogas production from anaerobic digestion (60 to 90 days of operation)s using the three different impellers. An increase in average methane content was observed as the anaerobic digestion without impeller is compared with the agitated system. As the impeller was changed from radial flow (SB-6) to axial flow (MP-6), averaged methane content included to 63%.

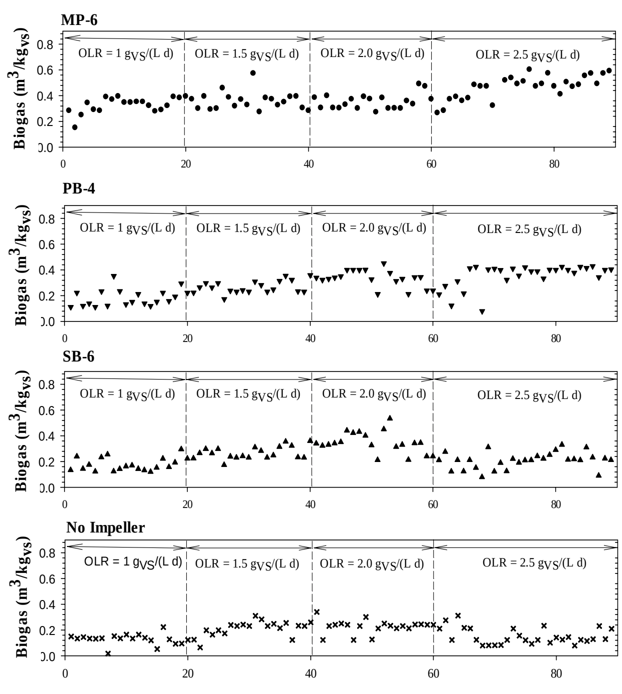

Figure 4: Biogas production rate from anaerobic digestion with no impeller, with 6-striaght blade, 4-pitched blade, and 6-marine blade propeller

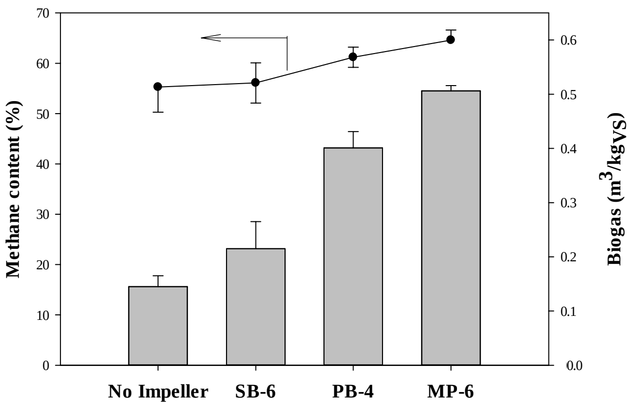

Figure 5. Averaged methane content and biogas production rate mointered from 60 to 90 days of anaerobic digestion.

CONCLUSION

Anaerobic digestion was successfully performed in a semi-continuous pilot-scale digester. Biogas with high methane purity produced can be compressed to CNG for vehicle transportation and combusted to generate electricity. The installation of agitator inside the digester was observed to have a positive effect on the rate of biogas production. Anaerobic digestion with MP-6 propeller was found to give the highest and the most stable production of methane compared with PB-4 and SB-6, which indicate the effectiveness of axial flow pattern compared with mix and radial flow.

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