

Application of supporting media for improvement of anaerobic digestion performance and biogas production

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Abstract

In this study, the effects of supporting media as attached carriers for microorganisms to improve biogas production were evaluated in a laboratory-scale batch reactor. A batch anaerobic test compared three types of suitable supporting media (bamboo tube, PVC tube and nylon fiber) and the control experiment (without supporting media) with 40 a day retention time. The related parameters were determined, such as pH value, chemical oxygen demand (COD), total solid (TS), volatile solid (VS), alkalinity (Alk.) and carbon and nitrogen (C/N) ratio. It was found that the application of bamboo tube, PVC tube and nylon fiber showed the biogas yields were higher than the control experiment. The results showed that bamboo tube as supporting media had the best methane yield and the highest biogas production (12.19 mLCH₄/g d COD and 22.4 L, respectively). Biogas production and methane yield of the control experiment minimums were set 16.92 L and 7.8 mLCH₄/g d COD, respectively. The removal efficiencies of COD in all experiment sets were bamboo tube 89.54%, nylon fiber 85.24%, PVC tube 70.87% and free-cell digester 69.24%. The study results tended to show that supporting media for attachment of microorganisms can be used to improve and enhance the biogas production and methane yield in anaerobic digestion.

Keywords: *Supporting media, Anaerobic digestion, Methane yield, Biogas production*

1. Introduction

In recent years, intensive animal breeding farms produce large quantities of manure in a restricted area, which poses serious pressure on the environment if not properly managed. Due to the complex characteristics of wastewater, it is causing considerable harmful effects to the environment such as coloring natural water, threat to aquatic life, surface and ground water pollution, changing soil quality/plant growth and causing odors [1]. Therefore, finding effective methods of treatment and application is quite urgent. At present, biogas fermentation in anaerobic system is a widely employed process for the treatment of organic wastewater. Biogas technology has been widely applied to several industrial wastewaters and animal waste to economically produce biogas through anaerobic digestion. Biogas is generally produced from materials that form manure, agricultural waste, sewage, waste products and food waste. Anaerobic digestion has many advantages; for example, it is also considered to be non-polluting. The production of biogas does not require oxygen, decreases greenhouse gas emissions, and eliminates odor problems. In addition, the biogas-slurry from biogas systems are rich in nutrients and can be used as a fertilizer for vegetables and plants. Generally, most digesters have been designed for a 25 - 40 day retention time in order to optimize methane (approximately 60 percent) and gas production. The main components of biogas are methane (CH₄), carbon dioxide (CO₂) and minor impurities, such as H₂S or N₂, depending on the raw materials and the process used [2-3]. There are four key biological and chemical processes in converting organic matter to biogas in the absence oxygen. The processes involve hydrolysis, acidogenesis, acetogenesis and methanogenesis [4] as shown in Fig. 1.

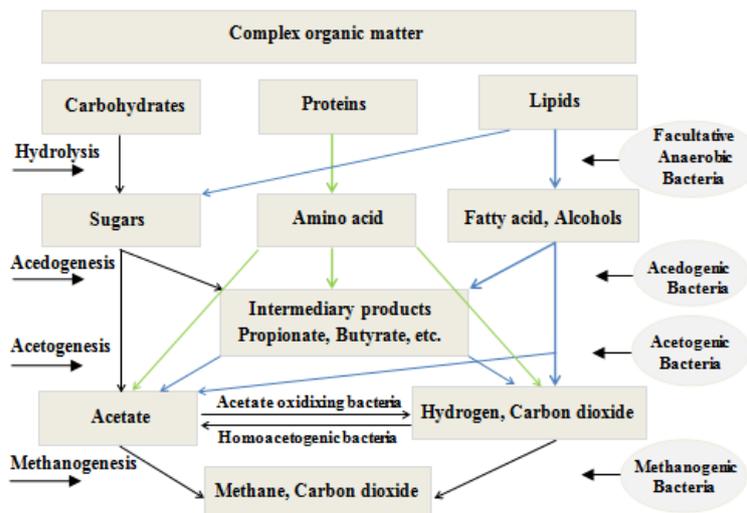


Figure 1 Schematic diagram of anaerobic decomposition in anaerobic digestion process [4, 5, 6, 7].

Biogas is produced from anaerobic microorganisms or anaerobic bacteria in the digestion system. Therefore, the biogas produced depends on anaerobic bacteria in the anaerobic digester for converting organic matter to biogas. Generally, increased stability and performance in anaerobic reactors can be achieved if the microbial consortium is retained and grown in the reactor. Two means of achieving this are to use dense bacterial granula as in reactors or a microbial biofilm attached to inert carriers in supporting media such as rock, ceramic or plastic as shown in Fig. 2 and also providing a larger surface area for faster biofilm development and improved methanogenesis and enhanced biogas production [8].

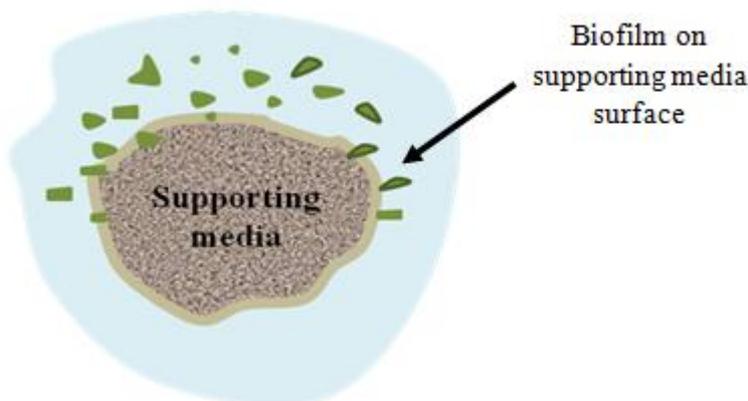


Figure 2 The microbial biofilm attached to supporting media.

In the present study, the effects of various types of supporting media and without supporting media as the control experiment were evaluated for improved biogas yield in a laboratory-scale batch reactor. The experiments were carried out under anaerobic condition and room temperature.

2. Materials and methods

2.1 Swine farming wastewater

In this research, the swine farming wastewater feedstock was kindly provided by the Faculty of Animal Science of Maejo University, Thailand. The wastewater was analyzed and used in the experiment. Chemical oxygen demand (COD), alkalinity (Alk.), total solid (TS), volatiles solid (VS) and carbon to nitrogen (C/N ratio) ratio were measured and analyzed by standard methods [9, 10]. Measurements of every item for each sample were repeated three times and the average value was determined.

2.2 Supporting media preparation

Three types of supporting media were used in the batch system. They were PVC tube (1 inch length), bamboo (1 inch length) and nylon fiber (10 cm length) with 55 cm² per piece of surface area. The supporting media was randomly placed inside the reactor.

2.3 The laboratory-scale experimental set-up

The laboratory-scale reactor was carried out in four sets of experiments and was performed using the supporting media in this study. Anaerobic digestion was tested in plastic tanks with a working volume of 10 L. The schematic of the experiment set up is shown in Fig. 3. The biogas produced was measured by water displacement. During the experiments, biogas was read from the collecting cylinder directly every day. Initially, the reactor removed the air (oxygen) due to anaerobic digestion. The media for microbial attachment was randomly packed at the bottom of reactor (100 pieces) for the best biogas production to compare the three types of suitable media (bamboo tube (A2), PVC tube (A3) and nylon fiber (A4) for microbial adhesion and with no supporting media as the control experiment (A1) to determine the most suitable supporting media for producing biogas and methane. The organic matter was fed into the reactor from the top. All batch experiments were conducted under room temperature (28 ± 3 °C) with the feedstock remaining in the digester typically for 15 - 30 days. The reactors were slowly shaken manually for about 1 min daily for mixing the organic matter. The pH of the reactor was not adjusted in the beginning of the experiments. The effects of various types of supporting media were studied for forty days in order to reach reactor stabilization and the experiments were carried out in duplicate.

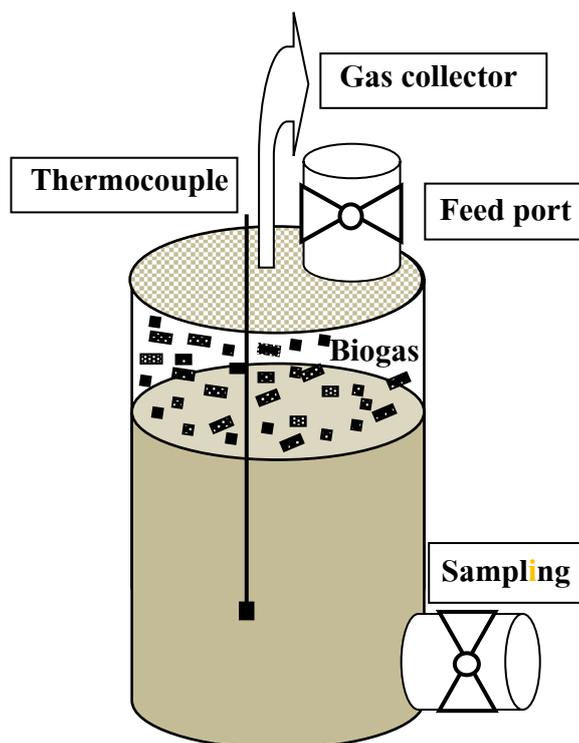


Figure 3 Schematic diagram of the anaerobic reactor.

2.4 Data analyses

In anaerobic batch reactors, biogas composition was continuously measured using a gas detector to detect methane (CH₄) content, carbon dioxide (CO₂) and hydrogen sulfide (H₂S). During the experiments, biogas was daily collected by water displacement. In all experiments the following data determined the volume of biogas produced. The related parameters for biogas and methane production were analyzed for carbon and nitrogen (C/N ratio), chemical oxygen demand (COD), total solid (TS) and alkalinity (Alk). pH measurements were taken with a pH meter (ORION SA 520 pH meter). Each

analytical result was the mean of at least three measurements. In order to study the morphology and surface of the supporting media for microbial adhesion, a scanning electron microscope (SEM) was used to observe surface morphology. After digestion, the surface of each the supporting medias was measured and the amount of attached microorganisms on the supporting medias surface was obtained using the colony forming units (CFU) method to estimate of the number of cells present.

3. Results and discussion

3.1 Feedstock characteristics

The main characteristics of the swine farming wastewater feedstock in this study are shown in Table 1. It was found that the COD concentration of the feedstock was high and has a value of 35000 mg/L. The total solid (TS) was 119842 mg/L of which 84090 mg/L was volatile solids (VS). The initial pH was 6.82 which is suitable for the methanogenic process in anaerobic digestion. Alkalinity in the range 1500 – 5000 mg/L would retain a self-buffering capacity [11].

Table 1 Characteristics of the swine farming wastewater used in the experiments

Parameter	The swine farming wastewater
pH	6.82 ± 0.04
COD (mg L ⁻¹)	35000 ± 9.23
Alk (mg CaCO ₃ L ⁻¹)	3350 ± 5.39
TS (mg L ⁻¹)	119842 ± 9.31
VS (mg L ⁻¹)	84090 ± 7.24
C/N ratio	11.23 ± 1.46

3.2 Digestion performances

The daily biogas production of free-cell reactor (without supporting media) (A1) and adding supporting media (bamboo tube (A2), PVC tube (A3), nylon fiber (A4)) is shown in Fig. 4. Similar trends of daily biogas production were observed for A1 – A4. The main differences between with and without supporting media was the peak values of daily biogas production. To compare adding bamboo tube (A2) started earlier and lasted longer, while the control experiment (A1) started later and lasted a shorter time. In addition, the daily biogas production of A2 was also higher than A1 as the control experiment. As can be seen, biogas production increased and an initial lag phase of about 5 days was observed. Following the lag phase, biogas production increased, which indicated an increase in the activity of the microorganisms. Biogas production gradually decreased after 35 days of digestion and the whole duration of biogas production lasted 40 days. The cumulative biogas production from the anaerobic digestion of feedstock fermentation measured during 8 days represents the total amount of biogas in each of the ranges as a function of time under different types of supporting media is shown in Fig. 5. (A2) produced the highest concentrations of methane at 68.1% while the control experiment (A1) was 50.5% as shown in Fig. 6. The highest biogas productions after 40 days for A1 – A4 were 16.9 L, 22.4 L, 17.2 L and 20.1 L, respectively. The methane yield of A2 was 12.2 mL.CH₄./g.d.COD which is higher than (A1) without supporting media as the control experiment (7.8 mL.CH₄./g.d.COD) as shown in Fig. 7. Data indicated that the anaerobic digestion with supporting media resulted in positive synergism by increasing biogas production and methane yield compared to the control experiment. This may mainly be due to the proper structure and physical characteristic of bamboo tube, nylon fiber and PVC tube for microbial adhesion. The bamboo tube as a supporting media for microbial adhesion had better performance than the other supporting media's and produced the highest volume of biogas whereas, PVC tube produced the lowest of biogas yields.

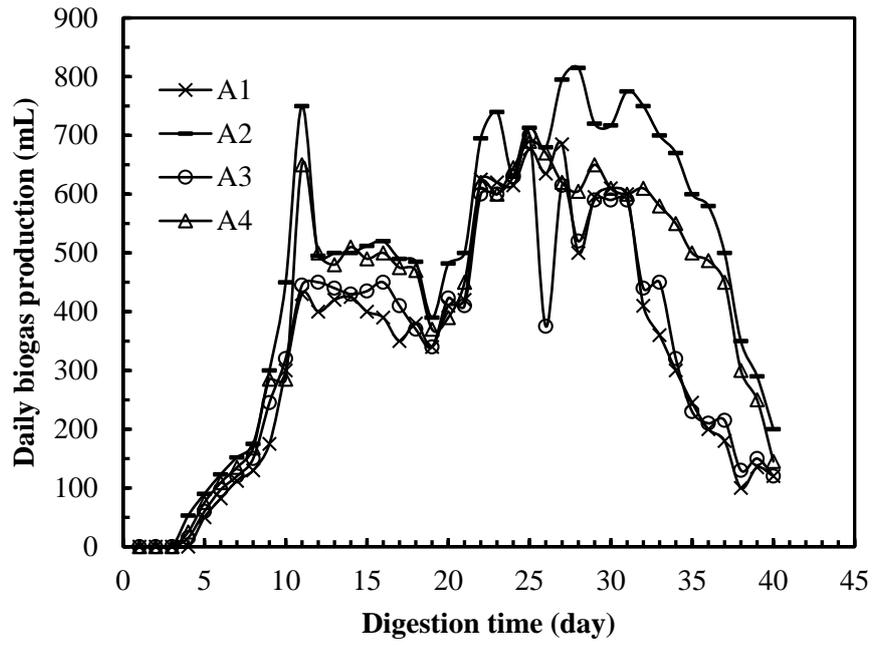


Figure 4 Daily biogas production of A1 – A4 versus digestion time during anaerobic digestion.

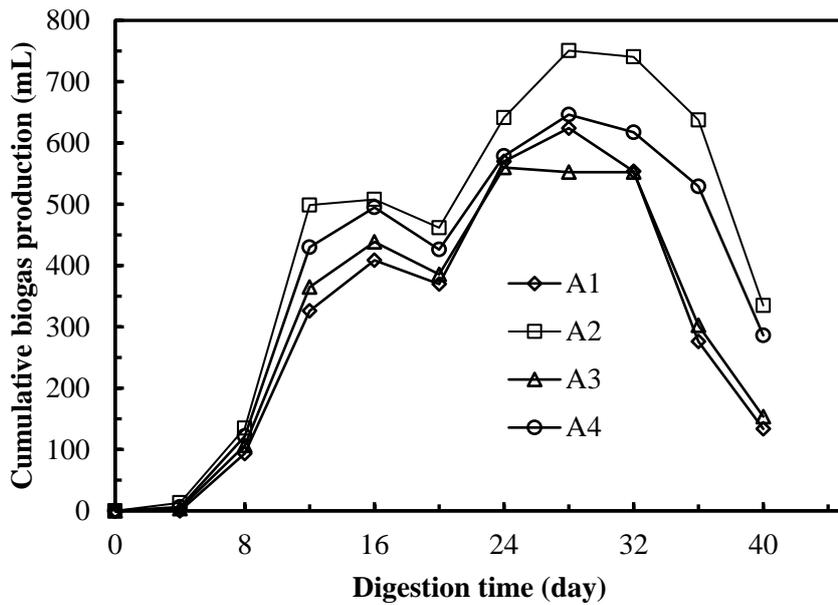


Figure 5 Variation of the cumulative curve biogas production of A1 – A4 versus digestion time during anaerobic digestion.

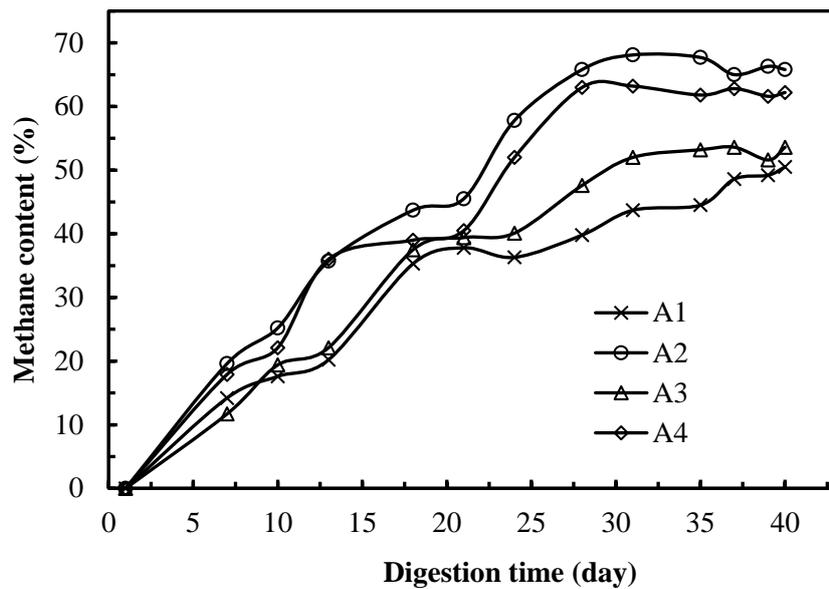


Figure 6 Methane content curve of A1 – A4 versus digestion time during anaerobic digestion.

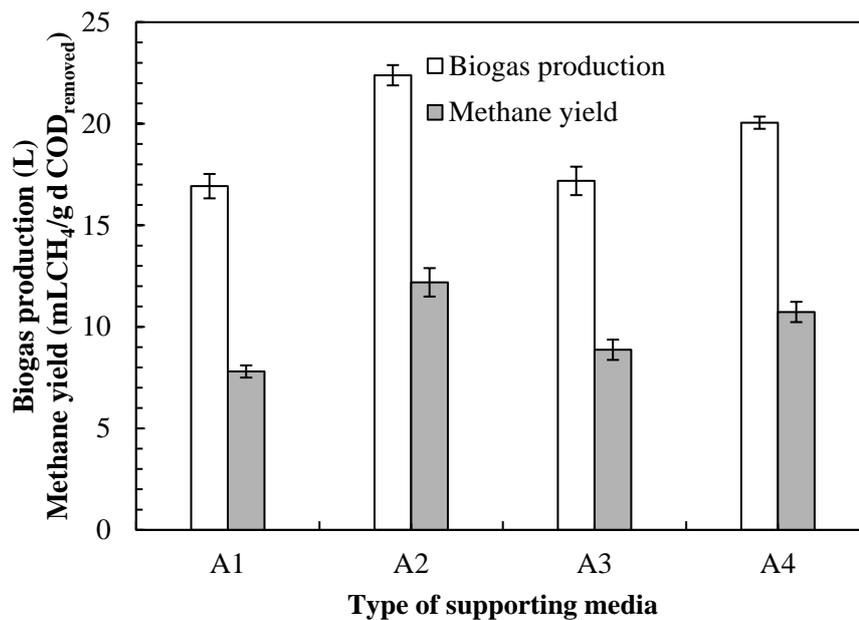


Figure 7 Comparisons of biogas production and methane yield of A1 – A4. The error bars show the standard deviation.

3.3 Changes in characteristics feedstock sample

The COD concentration and COD removal curve of A1 – A2 versus digestion time during anaerobic digestion is shown in Fig. 8. The COD concentration started to decrease on day 4 from 35000 mg/L to 27020 mg/L, 20410 mg/L, 26500 mg/L and 25105 mg/L, respectively for the anaerobic digestion of A1 – A4. The efficiencies of the supporting media's process with adding bamboo tube (A2), PVC tube (A3) and nylon fiber (A4) in terms of COD removal was 89.54%, 70.87% and 85.24% on day 40, respectively. During the initial 35 days, COD reduction quickly increased above 70% for A2 and A4. In this state, the microorganisms grew fast and quickly attached to the supporting media to form

biofilms. The results showed that anaerobic digestion is a process which breaks down organic matter in simpler chemicals compounds without oxygen . The minimum removal of COD is 69.2% of A1 as the control experiment in anaerobic digestion. The solid destruction for various types of supporting media led to the reduction of organic matter that measured through TS and VS reduction (%). Fig. 9 shows the results of all experiments for 40 days of batch operation of total solid (TS) and volatile solid (VS) of A1 – A4. The results indicated that there was an increase in the TS and VS removal with the increasing time required.

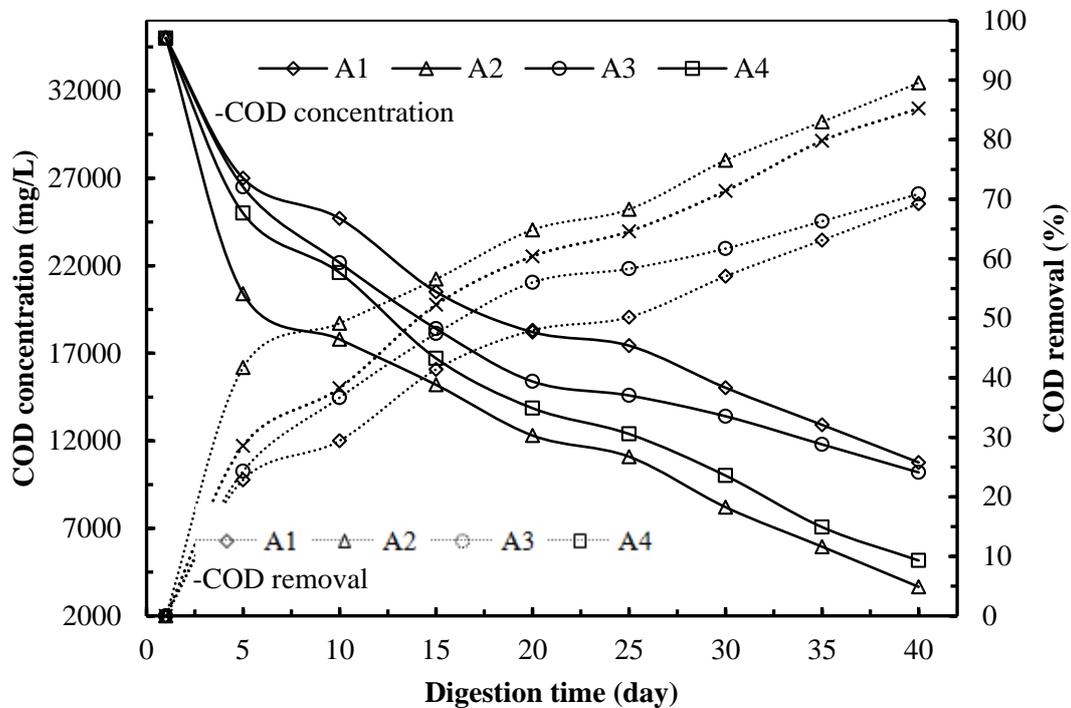


Figure 8 Change of COD concentration and COD removal of A1 – A2 versus digestion time during anaerobic digestion.

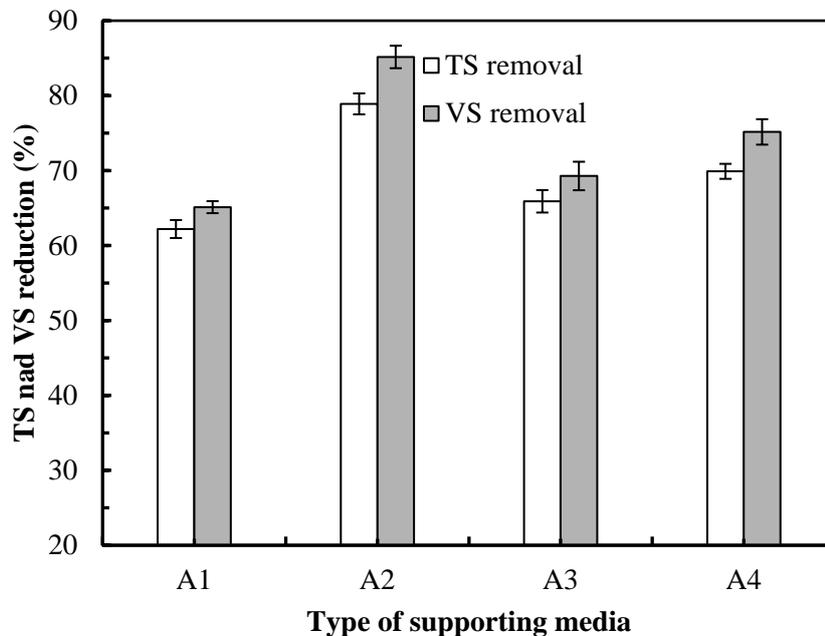


Figure 9 Comparisons of total solid (TS) and volatile solid (VS) of A1 – A4. The error bars show the standard deviation.

The variation of pH values for the period of digestion is shown in Fig. 10. There was an initial decrease in pH in all of experiments because the biodegradable organic matter of the substrate was hydrolyzed and converted to volatile fatty acids. The lowest pH values were obtained on day 4 and increased on day 8 due to the presence of volatile fatty and lactic acids converting to methane and carbon dioxide [12]. The pH value of adding bamboo tube supporting media (A2) decreased from 6.82 on day 0 to 6.12 on day 4 and increased to 6.88 on day 40. At the end of experiments, the pH values of all experiments ranged between 6.0 – 7.0.

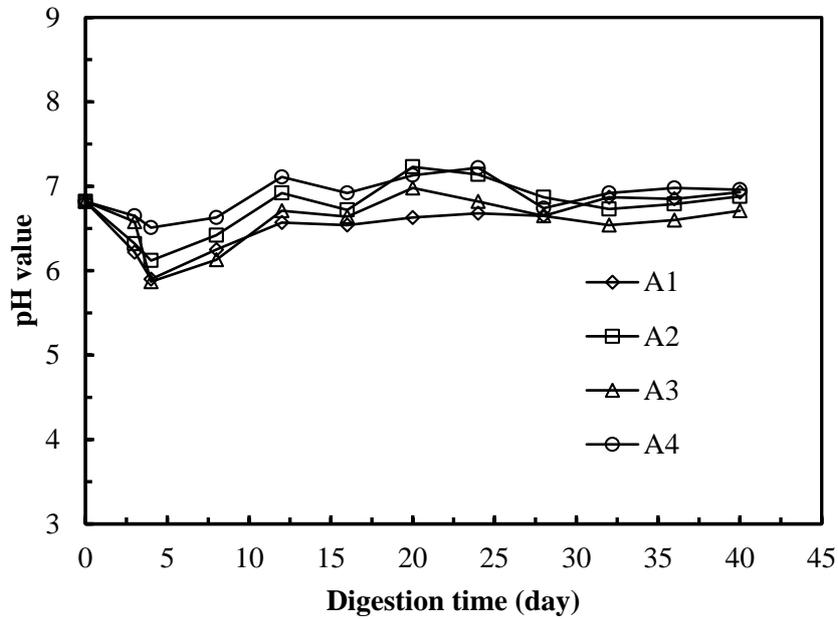


Figure 10 Change of pH value curve during batch digestion of A1 – A4 versus digestion time during anaerobic digestion.

3.4 The morphology surface of supporting media

For a better understanding, the surface structures of the supporting media were observed under SEM. The SEM technique was used to identify morphological changes on the supporting media surfaces. Images obtained of bamboo tubes and nylon fibers before and after undergoing anaerobic digestion on day 40 are shown in Fig. 11. SEM images of the supporting media revealed that, three types of surface media showed the surface roughness from biomass adhesion.

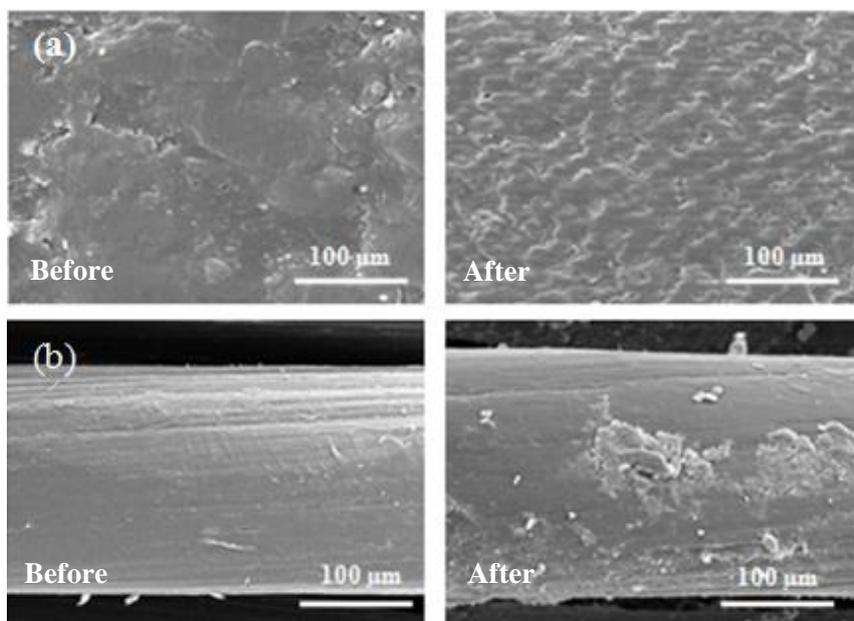


Figure 11 SEM micrographs on supporting media surfaces before and after undergoing in anaerobic digestion (on day 40); (a) bamboo tube and (b) nylon fiber.

3.5 The total amount of microorganisms

The attachment of microorganisms of 3 types supporting media sample after 40 days in anaerobic digestion reactor was observed. The total amount of microorganisms attached to the supporting media's surface was measured. Microorganisms were grown on a suitable medium; the development of growing microorganisms was used to estimate the numbers of microorganisms in the feedstock sample. The total amount of microorganisms was indicated by total plate count based on AOAC official methods that are used to estimate the number of viable cells present in a sample as shown in Fig. 12. The results indicated that the numbers and distribution of attached cells on the bamboo tubes, nylon fibers and PVC tubes showed 1.4×10^8 CFU/mL, 1.2×10^8 CFU/mL and 9.2×10^7 CFU/mL per piece, respectively.

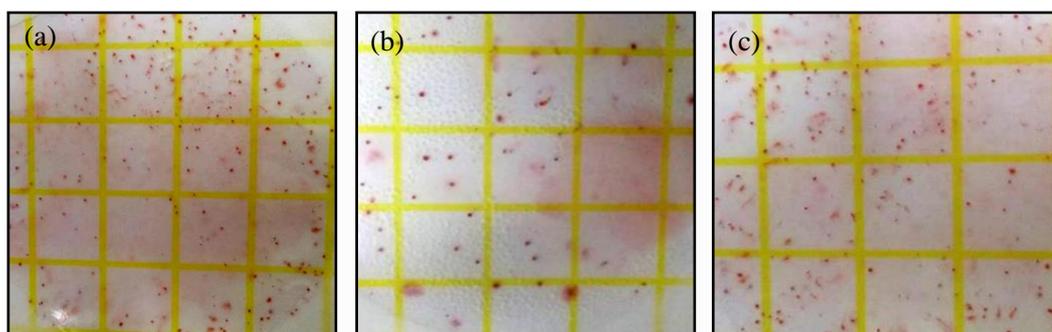


Figure 12 Images of the total amount of microorganisms on surface of bamboo tube (a), PVC tube (b) and nylon fiber (c) as supporting media surface.

4. Conclusions

In this study, significant increases of biogas could be achieved by using bamboo tube and nylon fiber as supporting media the anaerobic digestion of swine farm wastewater feedstock. Bamboo tubes reached maximum biogas production and methane yield of 22.4 L and 12.19 mLCH₄/g d COD, which was higher than the control experiment (16.9 L and 7.8 mLCH₄/g d COD). The results could provide a better support to use bamboos tube as a supporting media for the attachment of microorganisms as an efficient method for improving and enhancing biogas production potential in anaerobic digestion.

Acknowledgments

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