



Biogas production from co-digestion *Salvinia molesta* and rice straw and kinetics



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ABSTRACT

The biogas fermentation co-digestion *Salvinia molesta* (SM) and rice straw (RS) was investigated within a wide range of SM:RS of 100:0–0:100 (mass ratio). This study used batch anaerobic digesters in laboratory-scale operated at mesophilic temperature in 30 days. The optimum SM:RS ratio was 60:40 –0:100 (C/N of 29.50–39.17) producing total biogas yield of 103.83–113.92 mL/g VS. The highest biogas yield (113.92 ± 6.90 mL/g VS) was obtained from SM:RS of 40:60 (C/N of 34.80). The biogas produced from SM:RS of 40:60 contained 60.58% CH₄, 38.69% CO₂, 0.73% H₂. Fitting error between measured and predicted total biogas yield for 30 days fermentation by using modified Gompertz, Cone, First Order model was 0.96–6.45%, 0.14–3.52%, and 1.97–15.25% respectively. Furthermore, Cone model was used to design the anaerobic batch digester volume and develop the kinetic model of VS degradability rate. The fit correlation of measured and predicted VS removal was $R^2 = 0.992$.

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1. Introduction

Salvinia molesta (SM) is a free-floating aquatic weed that is one of the fastest growing aquatic plants in the world. The growth rate of this plant is faster than that of water hyacinth [1]. The water hyacinth has doubling time of 7–12 days, whereas the SM has doubling time of 3–10 days [2]. Because of its high growth rate and doubling time, SM can cover the entire surface of water on rice fields in short time in Indonesia. The presence of SM in water bodies of rice fields will reduce the efficiency of irrigation systems and reduce the effectiveness of fertilizer for rice plants, so that the total production of rice plants will decrease. Hence, SM is one of the most problems for Indonesian farmers in growing rice plants.

At the moment in Indonesia, the farmers just drain SM to the rivers, or pile and burn SM, or spray the chemical agent to hamper the SM growth. However, those methods are not effective and efficient, also make the new problems. SM drained into the rivers will grow quickly and cover the river surface, so the rivers are losing their water through evapotranspiration. Besides that, SM will disturb the movement of aquatic organisms including fishes and decrease the amount of oxygen so that the aquatic organisms will be death. Burning SM and using chemical agent is not eco-friendly.

Hence, the new method must be applied to control the SM growth.

The best solution is using anaerobic digestion (AD). With this method, SM will be converted into biogas and fertilizer. The biogas can be used to produce electricity that is useful for rural communities. Also, the biogas can be used in greenhouse farming [3]. By using a greenhouse concept, all plant growth factors can be controlled and maintained, so that it can produce greenhouse products maximally. However, it need a very expensive cost especially heating cost that has almost 60–80% of total production cost. Therefore, the biogas can substitute the heating energy need. Some authors reported that the SM is potential as biogas feedstock [1,2,4]. Indonesian SM contains high carbon to nitrogen ratio (C/N), which is 57.39 (Table 1). One of the most important parameters in AD is C/N ratio. During fermentation, degradation of carbon-rich substrates will generate Volatile Fatty Acids (VFAs) in large amount that causes dropping pH sharply, so that it disturbs the bacterial activities. Meanwhile, degradation of nitrogen-rich substrates will generate ammonium (NH₄⁺-N) or ammonia (NH₃-N) easily. Abundant of these in substrates can hamper the bacterial growth. Anaerobic bacteria need carbon to produce biogas and nitrogen to build their cell structure [5,6]. Anaerobic bacteria especially methanogenic bacteria thrive in the substrates containing C and N in good ratio. Therefore, the nitrogen source must be added to adjust the C/N of SM substrate.

The co-digestion methods is better than addition of synthetic

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Table 1
Characteristics of SM and RS.

Component	SM	RS
Total solid (TS) (%)	86.98	94.48
Ash (%)	36.17	20.75
Volatile solid (VS) (%)	50.81	73.73
Crude fiber (%)	22.09	35.90
Crude carbohydrate (%)	46.93	64.17
Crude protein (%)	3.07	8.68
Crude lipid (%)	0.81	0.87
Lignin (%)	11.73	7.72
Hemicellulose (%)	2.78	6.14
Cellulose (%)	1.83	9.00
NDF (%)	16.34	25.71
ADF (%)	13.56	16.71
Total Organic Carbon (TOC) (%)	28.23	40.96
Total Nitrogen (TN) (%)	0.49	1.39
C/N	57.39	29.50

Remarks: SM, *Salvinia molesta*; RS, Rice straw; VS = TS - Ash; NDF, Neutral detergent fiber; ADF, Acid detergent fiber; C/N, Carbon/Nitrogen ratio; TN = Crude protein/6.25; TOC = VS/1.8; C/N = TOC/TN.

nitrogen source (such as urea), because it can treat two wastes in the same time and it can decrease the operational cost which is buying synthetic nitrogen. In addition, co-digestion methods can enhance the biogas volume [7,8]. Rice straw (RS) is the potential co-digestion partner of SM. RS in Indonesia contains low C/N (below 30) that is obtained from rice field where SM lives. Hence, the transportation cost is cheap. Every single rice plant will produce RS as much as 58% from its total mass.

Based on that, this study investigated the anaerobic co-digestion of SM and RS. The utilization of RS as nitrogen source to SM has not been reported by other authors yet. Previous studies just investigate the mono-digestion SM. Mathew et al. [2] studied biogas production from SM at mesophilic temperature and cow dung was used as inoculum. Total biogas formed was 221 L/kg VS. That value was less than total biogas from water hyacinth (552 L/kg VS). O'Sullivan et al. [4] reported that mono-digestion of SM at mesophilic temperature produced less total biogas (155 L/kg VS) than water hyacinth (267 L/kg VS) and cabomba (221 L/kg VS). Abbasi and Nipanay [1] produced biogas from SM (total biogas of 6.7 L/kg) with ratio of SM:water of 1:7 (w/w).

The aim of this study was to investigate the effect of SM:RS in mass ratio of 100:0, 80:20, 60:40, 40:60, 20:80, 0:100 to biogas production on anaerobic digestion performance in batch test. The SM:RS ratio affected the C/N ratio in substrates. In this study, the author used laboratory-scale batch anaerobic digesters (polyethylene bottles, volume 600 mL) operated at mesophilic temperature (~30 °C) and at pressure of 1 atm in 30 days. The experimental data was used to make kinetic model of biogas production using some models. We compared the modified Gompertz model, first order kinetic model and cone model in predicting biogas yield and find which the model is the best of these models. Furthermore, the best model was used to develop the kinetic model of degradability

of volatile solid (VS). This model could predict the degradation rate of VS during fermentation and calculate the VS removal in the end of fermentation. This model was original and has not been found by other authors yet.

2. Methods

2.1. Wastewater and inoculums

SM and RS were obtained from rice fields in Bayah Regency, Banten Province, Indonesia. Then, these biomasses were analyzed through proximate and van soest methods to obtain the data of their chemical compositions (Table 1). Meanwhile, the total organic carbon (TOC) and total nitrogen (TN) were calculated using relation, $TOC = VS/1.8$ [9] and $TN = \text{protein}/6.25$ [10]. The C/N value was obtained from TOC/TN . The rumen fluid was used as inoculums. In this study, rumen fluid in fresh condition was obtained from cow slaughterhouse in Serang City, Banten Province, Indonesia. Rumen fluid contained *Clostridium* sp., *Clostridium sporogenes*, *Clostridium butyricum* and rich methanogenic bacteria.

2.2. Experimental set up

Anaerobic digesters were made from polyethylene bottles having volume of 600 mL. The bottles were plugged with rubber plug and equipped with valve for biogas measurement. Biogas formed was measured by liquid displacement method as also has been used by the other authors [11–15]. In this method, each digester was connected to gas collector that was reserved cylindrical glass. The connection was done using connecting tube. Each gas collector was immersed in through of water to ensure complete sealing. Biogas formed from digesters was collected by the downward displacement of water.

2.3. Experimental design

Anaerobic digesters of experimental laboratory using 600-mL volumes were operated in batch system. Total mass of SM and RS mixing of 10 gr was put into the digesters. Water was added with substrate:water ratio of 1:7 %w/w. This ratio was adapted from study of Abbasi and Nipanay [1]. Rumen fluid as methanogenic bacteria provider was added into the digester as much as 25 mL [13]. Substrates were varied at SM:RS of 100:0, 80:20, 60:40, 40:60, 20:80, 0:100. Furthermore, initial pH for all variables was adjusted 7.0 ± 0.1 by using NaOH solution 1 N. The variable in this work can be seen in Table 2.

2.4. Experimental procedures

Fermentation was done for 30 days at mesophilic temperature (~30 °C) and at pressure of 1 atm. Hence, the obtained experimental data can be used to make kinetic model of biogas production well.

Table 2
Variation of SM:RS ratios.

VW:TW	Substrate (gram)		Water (mL)	Rumen fluid (mL)	VS (gr)	Total Organic Carbon (gr)	Total Nitrogen (gr)	C/N	Fiber contents			
	SW (gr)	RS (gr)							Hemicellulose (%VS)	Cellulose (%VS)	Lignin (%VS)	NDS (%VS)
100:0	10	0	70	25	5.08	2.82	0.05	57.39	5.47	3.60	23.09	67.84
80:20	8	2	70	25	5.54	3.08	0.07	45.85	6.23	5.89	19.73	67.12
60:40	6	4	70	25	6.00	3.33	0.09	39.17	6.87	7.83	16.88	66.50
40:60	4	6	70	25	6.46	3.59	0.10	34.83	7.42	9.50	14.40	66.00
20:80	2	8	70	25	6.91	3.84	0.12	31.77	7.90	10.94	12.32	65.52
0:100	0	10	70	25	7.37	4.10	0.14	29.50	8.32	12.20	10.47	65.13

Remarks: SW, *Salvinia molesta*; RS, Rice straw; VS, Volatile solid; C/N, Carbon/nitrogen ratio.

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