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BIOGAS FORMATION FROM RICE STRAW AND MARKET WASTE IN SEMI-DRY FERMENTATION SYSTEM

PEMBENTUKAN BIOGAS DARI JERAMI PADI DAN SAMPAH PASAR DI DALAM SISTEM FERMENTASI SEMI KERING

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ABSTRAK

Penelitian ini bertujuan untuk mengevaluasi potensi penggunaan jerami padi dan fraksi organik limbah pasar untuk menghasilkan biogas dan produk samping lainnya menggunakan sistem fermentasi semi-kering. Satu set digester 1,5 L digunakan untuk menentukan potensi biogas dari berbagai jenis biomassa dalam operasi secara curah, dan satu set digester 10 L digunakan untuk mengevaluasi pengaruh cara pemberian umpan selama pencernaan semi-kontinyu. Dalam kasus jerami padi, produksi biogas maksimal 10 L/kgVS dicapai selama 20 hari degradasi secara curah pada suhu terkendali 32°C. Untuk sampah pasar, produksi biogas maksimal 50 L/kgVS diperoleh selama periode yang sama. Tingkat produksi biogas ini sekitar 60% lebih tinggi dibandingkan dengan produksi biogas pada suhu kamar. Digester dengan umpan 75% jerami segar menghasilkan biogas 42 L/kgVS, tertinggi dibandingkan dengan digester kontrol (100% jerami segar) serta digester dengan umpan 50% jerami segar. Digester dengan umpan 75% sampah pasar segar menghasilkan produksi biogas 40 L/kgVS, lebih tinggi daripada yang dijalankan dengan 50% umpan segar. Namun, keduanya lebih rendah dibandingkan dengan digester kontrol yang menghasilkan biogas 52 L/kgVS. Cara pemberian umpan dengan mengganti hanya 75% volume digester dengan jerami padi segar menyebabkan pH digester lebih stabil. Nilai-nilai parameter kinetika produksi biogas dari jerami padi adalah R_{max}: 1,37-2,07 (l/kgVS.hari), A: 15,82-42,25 (L/kgVS), dan λ: 0,4-2,0 hari, sedangkan sampah pasar R_{max}: 1,58-3,55 (L/kgVS.day), A: 31,09-51,84 (L/kgVS), dan λ: 0,2-1,2 hari.

Kata kunci: jerami padi, sampah pasar, biogas, fermentasi semi- kering, lindi, digesta

ABSTRACT

This research work aims at evaluating the potential use of rice straw and organic fraction of market wastes to generate biogas and other anaerobic by-products using semi-dry fermentation system. A set of 1.5 L digesters were used to determine the biogas potential of the biomass in batch operation and a set of 10 L digesters were used to evaluate the effect of feeding mode during the semi-continuous digestion. In the case of rice straw, a maximum biogas production of 10 L/kgVS was achieved during 20 days of batch digestion at a controlled temperature of 32°C. For market waste, a maximum biogas production of 50 L/kgVS was obtained for the same period of digestion, which was 60% higher than that at ambient temperature. Digester fed on rice straw with 75% fresh feed replacement produced 42 L/kgVS, higher compared to the control digester as well as 50% fresh feed replacement. The digester run at 50% fresh feed addition showed higher rate of biogas generation in the early stage of fermentation and shorter lag phase because of its higher concentration of acclimated sludge. For the case of market waste, digester run with 75% fresh feed resulted in the biogas production of 40 L/kgVS, higher than that run on 50% fresh feed. However, both were lower compared to the control digester that produced 52 L/kgVS. The mode of feeding by replacing 75% digester volume with fresh rice straw led to more stable digester pH. The values of the kinetic parameters of biogas production for rice straw were R_{max}: 1.37-2.07 (L/kg VS.day), A: 15.82-42.25 (L/kgVS), and λ: 0.4-2.0 days, while those for market waste were R_{max}: 1.58-3.55 (L/kgVS.day), A: 31.09-51.84 (L/kgVS), and λ: 0.2-1.2 days.

Keywords: rice straw, market waste, biogas, semi-dry fermentation, leachate, digestate

INTRODUCTION

Abundant quantity of residual agriculture biomass is currently underexploited. In most cases, it even becomes burden to environment when treated improperly by burning or being left decomposed without control. The application of anaerobic digestion technology that simultaneously converts the organics of biomass into valuable products such as energy in the form of biogas and soil improver in the forms of liquid fertilizer and digestate is considered as a strategic approach. On the other side, increasing crop yields remains a big challenge in agriculture development. Recycling a proportion

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of nutrients and carbon back to land in the forms of organic fertilizer and soil improver can expectedly maintain high crop yields. Carbon recovery in the form of methane will give another important benefit as an alternative energy to fossil fuel.

Rice straw and organic fraction of market solid wastes (mainly consists of residual fruit and vegetable wastes) are potential biomass to undergo anaerobic treatment process. As an illustration, according to BPS (2014) paddy field area in Indonesia is 13.8 million hectares and produces 138 million tons of rice straw (production of rice straw is 10-15 tonnes/hectare). Indonesia also generates 200,000 tons/day of organic solid wastes. These types of biomass are able to be digested anaerobically.

The value of rice straw C/N ratio of 70 has been reported by Haryati (2006). Chemical composition of rice straw is influenced by several factors, such as paddy variety, growing location, and type of fertilizer applied. In Indonesia rice straw usually contains 40-43% carbon, 0.4% nitrogen, 0.02 % phosphor, 1.4% potassium, and 5.6% silica (Makarim, 2007).

This research work evaluates the potential of rice straw and organic fraction of fruit and vegetable wastes to generate biogas and other anaerobic by-products, using semi-dry fermentation system. Semi-dry fermentation system is digester operation at high initial total solid content between 10-20%. In particular, the effect of varying the mode of feeding during semi-continuous fermentation process was investigated. The biogas formation at various conditions was characterized using kinetic parameters of lag phase period, maximum biogas production rate and specific gas production.

MATERIALS AND METHOD

Materials

The model of biomass used in the experiment was rice straw obtained from Cikarawang paddy field, Dramaga, Bogor and the organic fraction of market solid waste collected from traditional market in Bogor (Gunung Batu and Laladon). The market solid wastes composed of (w/w) 7% of banana peel, 24% of cornhusk, 15% bitter cucumber, 20% cabbage, 22% water spinach and 12% carrot. The materials were chopped to about 2 cm in size. Fresh cattle manure obtained from campus farm was used as seeding of the anaerobic bacteria.

Equipment

Digesters with the capacity of 1.5 L and 10 L were used in the experiments. A set of 1.5 L Erlenmeyer flasks was used as the smaller digester. The Erlenmeyer flask was connected with tubing to a measuring cylinder for measuring gas production by liquid displacement method. The 10-L digester made of perplex was consisted of three compartments, namely gas collector (A), digester (B) and leachate collector (C) as shown in Figure 1. The digester was equipped with heating element and thermostat to allow digester operation at mesophilic temperature (35^{o}C). Gas was collected and measured in compartment A. Leachate was collected in compartment C to be recycled back to the digester. Some other lab apparatus, such as chemical oxygen demand (COD) analyzer, total solid (TS) and volatile solid (VS) apparatus, pH meter, and spectrophotometer were used for analytical purposes.

Experiments

The biomass was characterized for its total solid (TS) and volatile solid (VS). The biogas production potential for both types of biomass was determined in a series of 1.5-L digesters operated at high solid fermentation. The amount of biomass used was 500 g of rice straw and 600 g of market solid waste, both were fermented at initial moisture content of around 80% (semi-dry fermentation) at room temperature and controlled temperature of 32^{o}C. Biogas formed was measured by a liquid displacement method (Alvarez *et al.*, 2008). Gas collection from the reactor was made via a flexi glass tube to a separate water displacement flexi glass filled with water.

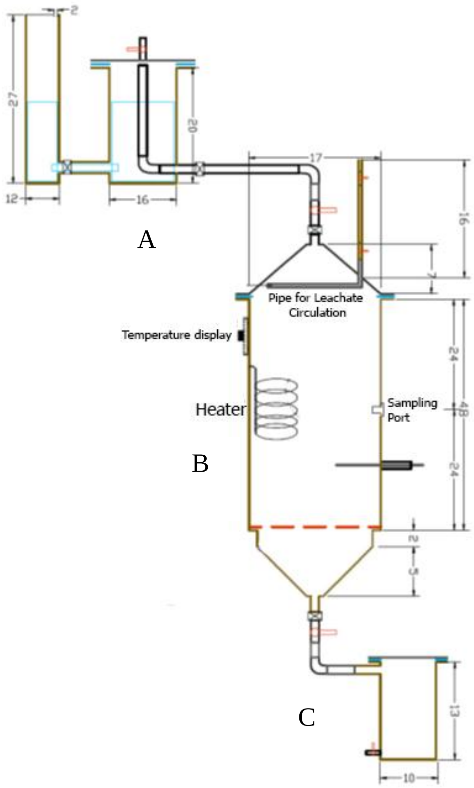


Figure 1. Schematic diagrams of 10-L digester (Modified of Kusch *et al*., 2008)

In the subsequent experiment, the effect of feeding mode was investigated using digesters with a working volume of 10 L. The digesters were fed on both types of biomass in batch mode with leachate recirculation every second day. Semi-dry fermentation was carried out at about 20% TS. After a maximum cumulative gas production was attained, fresh biomass was added into the digester replacing the old digested biomass at the levels of 50% and 75% (of volume). Digester performance was evaluated by measuring the gas production and chemical oxygen demand (COD; APHA 5220 C), total solid (TS; APHA 2540 B), volatile solid (VS; APHA 2540), pH (APHA 4500-H+ B), and total kjeldahl nitrogen (TKN; APHA 4500-Norg C) of the leachate and the digestate every second day. All analysis was conducted according to "*Standards Methods for the Examination of Water and Wastewater*" (APHA, 2005).

Kinetic parameters were derived from the experimental work for describing the biogas formation characteristics, covering the period of lag phase, maximum specific biogas production rate and specific gas production. Flowchart of the study is presented schematically in Figure 2.

RESULTS AND DISCUSSION

Biomass Characteristics

Table 1 presents the characteristics of several types of biomass in terms of its total and volatile solids. The rice straw used in this experiment was not fresh straw, but a few days old (after harvested) straw, therefore contained far less moisture than fresh rice straw.

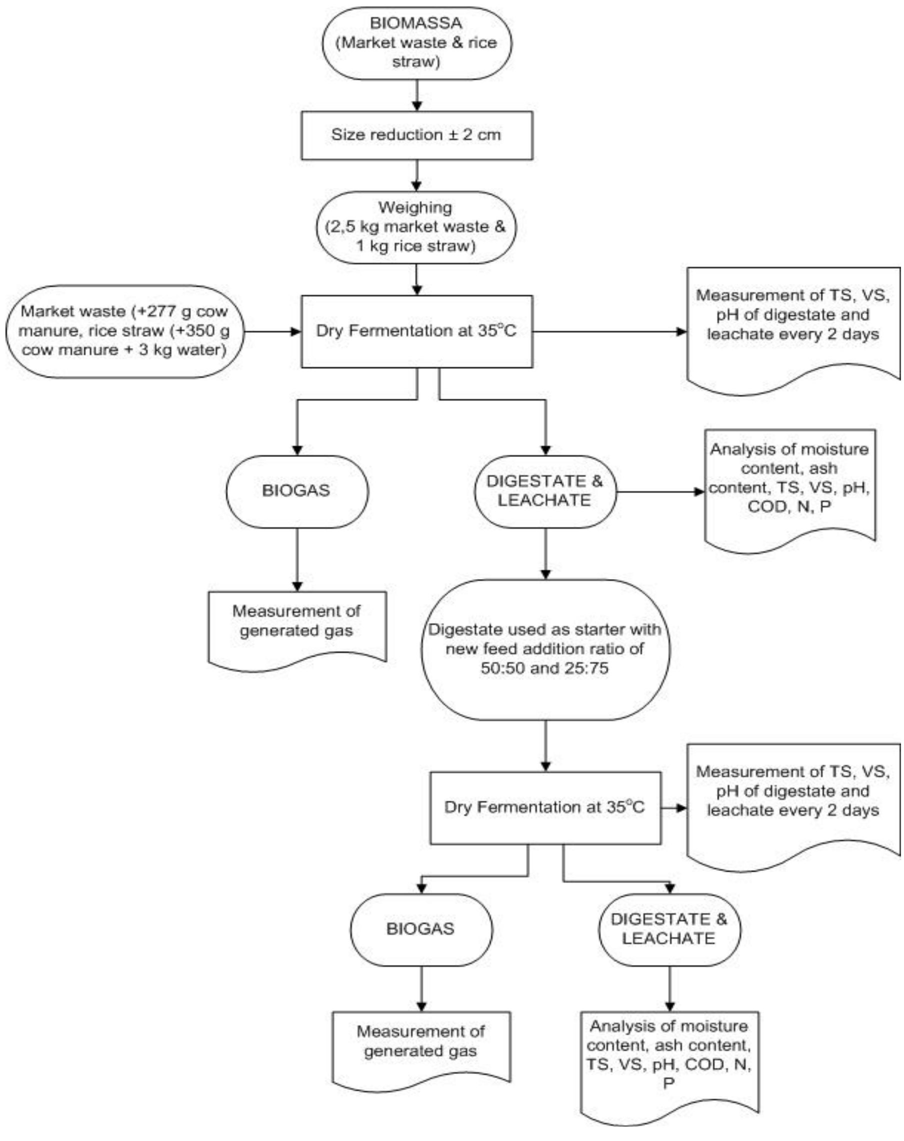


Figure 2. Flowchart of the study

Table 1. Characteristics of various types of biomass

Type of biomass	Moisture Content (%)	Total Solid (%)	Volatile Solids (% wb)	Volatile Solids (% db)
Rice straw	18.70	81.30	53.24	65.47
Market waste of Gunung Batu	82.57	17.43	15.20	87.19
Market waste of Laladon	94.05	5.95	5.12	85.96
Cattle manure	84.23	15.77	12.50	79.27
Banana peel	87.61	12.39	10.50	84.70
Pineapple peel	86.61	13.39	12.73	95.07
Cabbage	93.00	7.00	6.52	93.08

Biogas Production Potential

Small digesters with working volume of 1.5 L were used to determine the biogas production potential of several individual types of biomass. Experiments were run at room temperature for 45 days. The cumulative biogas production profile observed during the experiment was presented in Figure 2. At the initial state of fermentation the gas production rate was higher due to the content of relatively easily degradable organics. Rice straw generated the smallest amount of gas production, about 8 L/kg VS, which was reached after day 40 of fermentation.

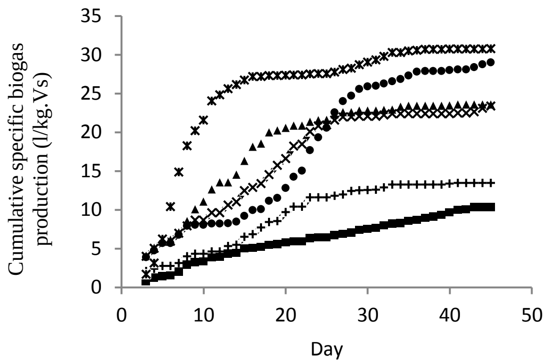


Figure 3. Profile of cumulative specific gas production of several types of biomass (■ rice straw, ▲ banana peel, **x** cabbage, ✱ market waste of Gunung Batu, ● market waste of Laladon, ✚ pineapple peel)

Organic solid waste collected from Gunung Batu market generated the highest production of biogas, about 32 L/kg VS, which was reached after 35 days of fermentation. The market wastes that mainly consisted of rejected (off-spec) vegetables and fruits have shown to be more easily degradable than the rice straw. The individual type of biomass, such as banana and pineapple peel as well as cabbage generated gas at the amount between that of rice straw and the solid wastes mixture. The slower rate of gas generation of rice straw was due to the high content of lignocellulosic materials. This, therefore, indicated the need for rice straw to be pretreated prior to anaerobic digestion in order to improve its rate of hydrolysis. The pretreatment needed could be physical (such as size reduction), chemical (such as alkali addition), or biological treatment (such as bio oxidation and enzyme application).

Effect of Temperature

The similar experiment was also conducted using the same digesters at a controlled temperature of 32^{o}C. As shown in Figure 4 the rates of gas production for both types of biomass were higher than those at ambient temperature. In the case of rice straw, a much shorter fermentation time of only 17 days was required to get the maximum specific gas production of 10 L/kg VS. For market waste, the higher cumulative gas production of 50 L/kg VS was obtained in less than 20 days of fermentation. As shown in Figure 4 specific gas production of market waste was higher than that of rice straw. Consistent with the gas production rate, the specific gas production of the digesters run at controlled temperature of 32^{o}C for both types of biomass was also higher compared to that run at ambient temperature (Figure 3). This confirms that anaerobic mesophilic bacteria operate well at temperature around 35^{o}C (Romli, 2010).

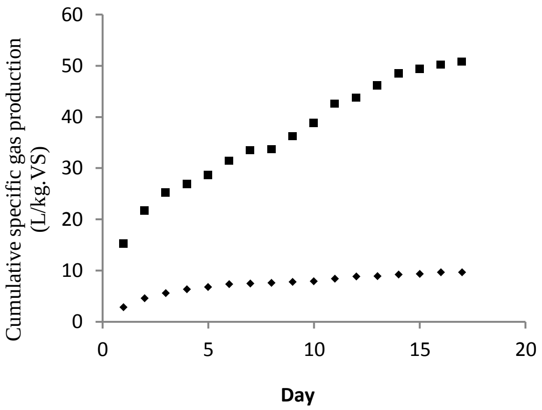


Figure 4. Cumulative specific gas production of the digesters run at 32^{o}C (◆ rice straw and ■ market waste)

Mode of Feeding

Biogas Generation

This experiment was conducted to evaluate the best feeding mode when the digester was run in semi-continuous operation. Digesters were initially run until a maximum gas production was achieved. Three modes of feeding were then applied, namely by replacing 50%, 75% and 100% (control digester) of digester content with new fresh biomass. Figure 5a shows that 75% replacement of the old digester content with fresh rice straw resulted in biogas production of 42 L/kg VS, much higher than 50% replacement, which only generated 16 L/kg VS. Similarly, with market waste, 75% feed replacement also generated higher specific gas production compared to 50% replacement, namely 40 L/kg VS and 31 L/kg VS, respectively (Figure 5b).

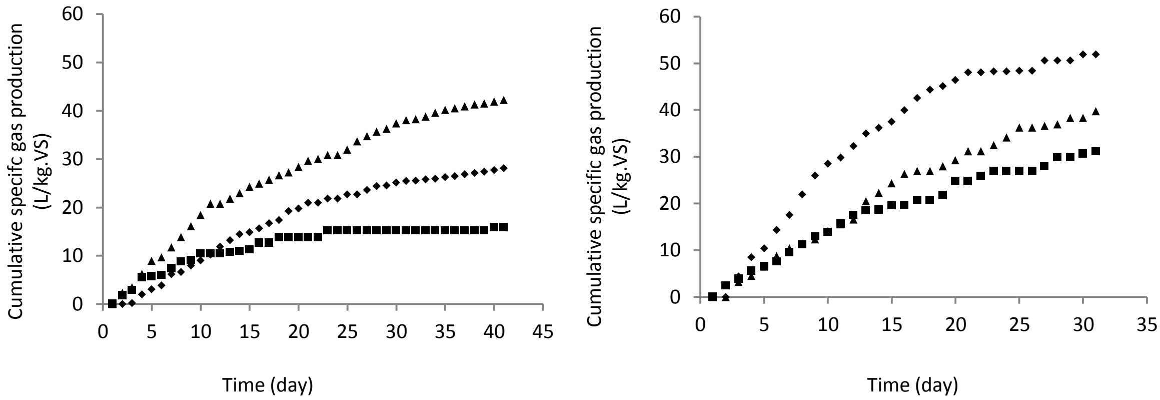
It was noted also for rice straw biomass that both 50% and 75% feed replacement led to higher gas production rate at earlier stage of fermentation (see figure 5). This was a result of higher amount of acclimated seed available in both digesters. At a later stage of fermentation, however, the gas production rate of digester with 50% feed replacement decreased and ended up with the lowest total biogas production compared to control and 75% feed replacement. This could be explained by the fact that digester run at 50% feed replacement contained the lowest organic load. The digester run at 75% feed replacement generated the highest gas production because of the higher organic fraction.

Different response occurred in the digesters fed on market wastes. Values of biogas production rate in control digester, 75% feed replacement and 50% feed replacement were 560 mL/day, 410 mL/day and 360 mL/day. These values were similar to that reported by Alvarez and Liden (2007) using fruit and vegetable wastes, i.e. 316 mL/day. Figure 5b shows that the gas rate and the maximum gas production were a function of organics load. The higher the organic load the higher the gas rate and the cumulative gas production. This result suggested that for easily biodegradable biomass, in this case was market wastes (Figure 5b), the digester performance was not so dependent on the initial seed concentration. On the contrary, the concentration of acclimated inoculum has very important role in improving the performance of digester fed on hardly degradable organics (rice straw).

Digester pH

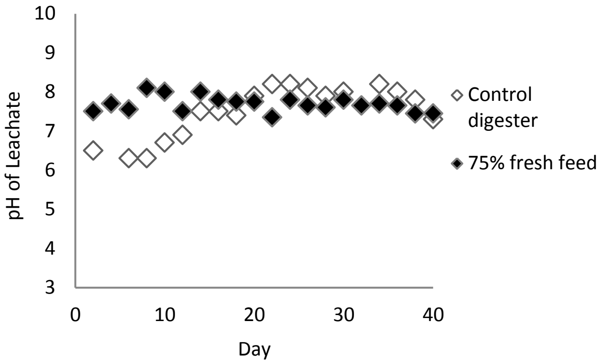
In the early stage of fermentation, the digester pH had a tendency to decrease due to volatile fatty acids (VFA) formation. After this VFA being consumed by the methanogenic bacteria producing neutral products the pH would get increased. Figure 6a showed that pH of the digester fed on rice straw (control digester) decreased during the first week of fermentation, but after that the pH increased to neutral or slightly basic. In digester fed on 75% fresh feed, the digester pH was relatively stable, which indicated that the presence of acclimated seed ensured the fast consumption rate of VFA to neutral products.

In the digester fed on market waste the digester pH tend to be acidic, both for the control digester as well as 75% fresh feed addition. This indicated the need for market waste to be co-digested with other types of biomass that have high pH buffering capacity, such as sludge and slaughterhouse wastes. It should be noted, however, that the low pH of leachate does not necessarily ceased the methanogen's activity. The structure of digestate might create a micro environment with higher pH allowing the methanogens to work. Figure 7b shows the correlation between pH of leachate and digestate, indicating the relatively higher pH environment in the digestate.



(a) (b)

Figure 5. Effect of feeding mode on biogas production (a) rice straw and (b) market waste: control digester (◆), 50% fresh feed (■) and 75% fresh feed (▲)



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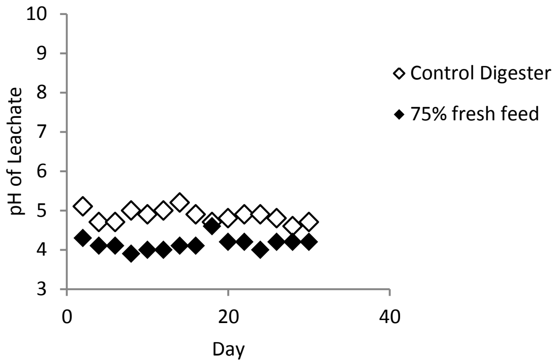
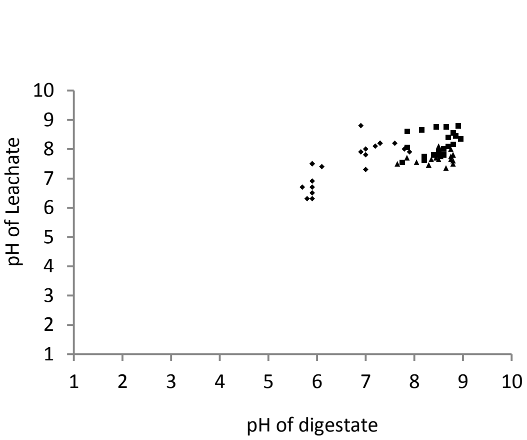
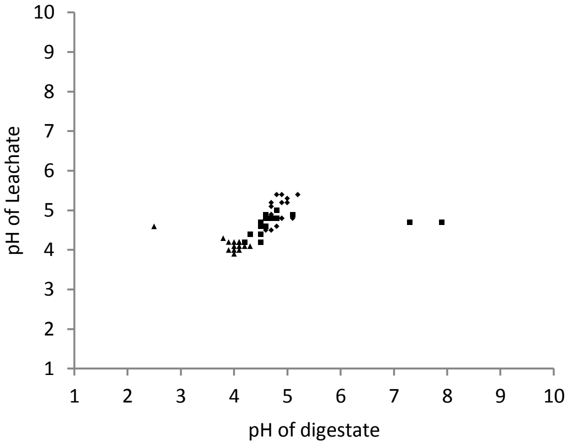


(b)

Figure 6. pH profile of digester during fermentation: (a) rice straw and (b) market waste



(a)



(b)

Figure 7. Correlation between digester pH and leachate pH: (a) rice straw (b) market waste: control digester (◆), 50% feed replacement (■) and 75% feed replacement (▲)

Leachate Production

During digestion process organic carbon of the biomass were converted partly into biogas, dissolved as VFA (volatile fatty acids) in leachate and left undigested in the digestate. The leachate contained very rich of nutrients and inorganic materials so that potential to be utilized as liquid fertilizer. The measurement of leachate quantity at the end of fermentation showed that control digester run on market waste produced similar quantity of leachate with 75% fresh feed addition, namely 337 mL and 335 mL, respectively. The digester with 50% fresh feed addition resulted in higher quantity of leachate, i.e. 455 mL. Run on rice straw, control digester, 75% fresh feed digester, and 50% fresh feed digester produced 538 mL, 550 mL, and 769 mL of leachate, respectively. These results indicated that quantity of leachate increased with acclimated seed concentration. Figure 8 indicated that there was a nearly linear correlation between biogas production and leachate volume. For each operating condition, biogas production increased in parallel with the increased leachate volume.

Digestate Characteristics

Analysis of digestate showed that digestion of biomass led to decreased C/N ratio from 72 to 41 in the case of rice straw and from 56 to 39 in the case of market waste. The C/N ratio of rice straw was too high from the ideal value of around 30 in order to ensure complete degradation of organics. High C/N leads to slow degradation due to nutrient limitation for growth, whereas low C/N will cause ammonia release that inhibit degradation process. This suggested the need to co-digest rice straw with high protein containing biomass

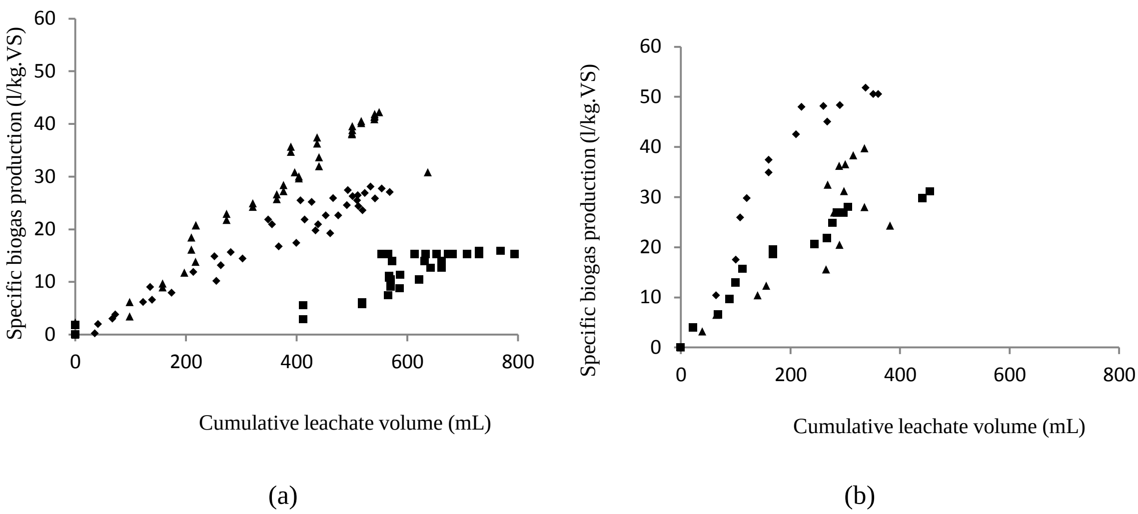


Figure 8. Correlation between biogas production and cumulative volume of leachate (a) rice straw and (b) market waste; control digester (◆), 50% feed replacement (■) and 75% feed replacement (▲)

Analysis of digestate also revealed that the VS removal of all treatment was relatively low, less than 20%. The highest was achieved by the digester fed on rice straw with 50% fresh feed addition, i.e 18%. This result indicated that higher VS removal could only be achieved at longer digestion period.

The digestate is suitable to be used as landfill covering or land bioremediation without any further treatment. The use of digestate as landfill covering is environmentally better than the use of direct organic wastes, because digestate is much more stable due to less content of organics compared to the raw untreated biomass. Landfill leachate volume and pollutant load are, therefore, lower by using digestate. The use of digestate as organic soil improver will need further treatment such as composting in order to get more stable material.

Based on the government regulation No.28/Permentan/SR.130/5/2009 on organic fertilizer, bio-fertilizer and soil improver, the fertilizer (solid and liquid) must have pH value in the range of 4-8. Another important parameter is the organic C content that must be higher than 12%. The leachate and digestate produced from biomass fermentation meet these requirements. The digestate has organic C content of 22-42% and pH of 7.3-7.5. The organic and inorganic materials contained in digestate are very beneficial in improving soil characteristics physically, chemically and biologically. The materials provide nutrients, minerals, source of energy for most of soil microorganisms, and act as a bonding matrix of the fertilizer. The organics also lower the fluctuation of soil temperature and help the plant roots to penetrate the deeper layer of soil and thus better access to nutrients and moisture (Simanungkalit *et al.*, 2006).

Kinetics of Biogas Formation

The process of biogas formation can be described using kinetic parameters based on the following modified Gompertz equation (Nopharatana *et al.*, 2007 and Budiyono *et al.*, 2010):

$$P = A * exp\left\{-exp\left[\frac{R_{max}e}{A}(\lambda - t) + 1\right]\right\}$$

where P is specific cumulative biogas production (L/kg VS); A is potential biogas production (L/kg VS); R_{max} is maximum rate of biogas production (L/kg VS.day); λ is lag phase (day); and *t* is cumulative time for the biogas production (day).

As shown in Table 2 control digester run on market waste resulted in the highest value of R_{max} (3.55 L/kg VS.day) and A (51.84 L/kg VS). This was likely due to the higher content of easily biodegradable organics. As expected, feeding mode with 50% fresh material addition would result in the smallest values of R_{max} and A. This mode of feeding also resulted in the highest ratio of acclimated seed to fresh feed, which therefore leading to shortest lag phase period.

A different effect of feeding mode was noticed for rice straw biomass. Digester fed on 75% fresh rice straw resulted in the highest value of potential biogas production (A) of 42.25 L/kg VS and the highest value of maximum rate of biogas production (R_{max}) of 2.07 L/kg VS.d. This result indicated that in semi continuous digester operation, the mode of feeding, by replacing only a proportion of old digestate with fresh feed could increase the rate and the yield of biogas production, especially for the relatively hard-to-degrade biomass. This was due to the increased ratio of acclimated sludge to fresh feed, which led to shorter lag phase highest conversion rate. Therefore, the digester run on 50% addition of fresh rice straw, which gave the highest acclimated seed to feed ratio, resulted in the shortest lag phase.

Table 2. Kinetics parameters of biogas formation

Type of Biomass	Treatment	R_{max} (L/kg VS.day)	A (L/kg VS)	λ (day)
Rice Straw	Control (100% Fresh feed)	1.37	28.10	2.0
	50% Fresh Feed	1.86	15.82	0.4
	75% Fresh Feed	2.07	42.25	0.6
Vegetable Waste	Control (100% Fresh feed)	3.55	51.84	1.2
	50% Fresh Feed	1.58	31.09	0.2
	75% Fresh Feed	2.07	39.71	0.8

CONCLUSIONS AND RECOMMENDATION

Conclusions

The results of the experimental works showed that the anaerobic digester performance was strongly influenced by the type of biomass, process temperature and feeding mode. Faster biogas formation was observed in the digester fed on market waste biomass, which contained more proportion of easily biodegradable materials compared to that fed on rice straw, which contained lignocellulosic materials that was relatively difficult to degrade.

The mode of feeding by replacing only 75% digester volume with fresh rice straw led to more stable digester pH. The presence of acclimated seed ensured the fast consumption rate of VFA, and thus avoids its accumulation.

The anaerobic digestion of residual agriculture biomass enabled the recovery of organic carbon and nutrients of the biomass into biogas as source of energy and digestate and leachate as soil improver and fertilizer. Based on its carbon content and pH, the leachate and digestate produced from agriculture biomass digestion meet the government regulation for land application.

Recommendation

The solids removal efficiency, and thus the biogas formation for both types of biomass were still lower compared to its theoretical value (Arati, 2009). Improvement of feed composition, such as through co-digestion of two or more types of biomass, is therefore worth to be evaluated. Co-digestion enables the deficiency in one type of substrate to be compensated with the other co-substrate.

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