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Biogas production from oil palm empty fruit bunches of post mushroom cultivation media

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Abstract. The Empty fruit bunches are one of the palm oil industry wastes, which can be used for mushroom cultivation. Post-cultivation of mushroom from former EFB-mushroom media (EFBMM) has the potential to be processed into biogas. The purpose of this research was to examine optimum co-digestion conditions for biogas production of EFBMM.The research was carried out in an anaerobic digester with three different conditions - dry fermentation (Water content (WC)/Total Solid (TS) ratio 1.5 - 3.5), semi-wet fermentation (WC/TS ratio = 4.0 - 5.7) and wet fermentation (WC/TS ratio> 9.0) conditions. Digester of capacity 50L was used. Fermentation was done using 20% cow feces as inoculum which then added with circulation system for 70 days. The results showed that optimum biogas production were produced in semi-wet fermentation conditions (WC/TS ratio = 4). It was produced 37.462 liters (2.420 liters CH_4/Kg Volatile Solid (VS)) of biogas with methane contain about 26.231%. Total volume of inoculum during process was 19.6 liters (1: 4 w/v) with absorbed TS inoculum ratio, TS/I = 0.4 (1:2.5 w/v). The result of research also showed that biogas which was produced from control about2.865 liters (0.041 liters CH_4/KgVS) , with TS absorbed inoculum ratio, TS/I = 0.5 (1: 5w/v).

Keywords: *Biogas,EFBMM, fermentation, WC/TS ratio, anaerobic digester*

1. Introduction

Several efforts to manage the solid waste of palm oil (EFB) have been investigated by utilizing them as raw materials for bioethanol production [1], raw material for composting mixed with mud from Palm Oil Mill biogas production [2], raw material of Biomass power plant [3], and materials for Raw production of biogas [4-7].Biogas is one type of energy that can be generated from the anaerobic fermentation process of organic waste such as EFB, produced every day by the palm oil industry in a very abundant amount. Currently EFB waste is generally used as mulch and compost fertilizer for oil palm plantations. EFB utilization process is less profitable because the decomposition process runs very slow if its used as mulch or compost.

EFB has a high potential for organic material, which is carbon as much as 480-490 kg/ton dry weight of EFB and nitrogen 7.4-9.8 kg/ton dry weight of EFB. The value of C/N ratio ofEFB is 50-65, causing the decomposition process to run slowly when used as mulch. The high content of organic materials in EFB has the potential to be used as biogas raw materials. Currently EFB has begun to be utilized as biogas raw material. The formation of biogas takes place through the decomposition process of the organic compounds in the anaerobic atmosphere by anaerobic bacteria by adding activators such as palm oil mill effluent (POME) and livestock manure (dissolved cow manure).EFB dried at 95°C for 48 hours can be used as biogas feedstock using POME activator. The results showed that the mixture of EFB and POME (F/I) ratio (2:1) incubated at 37°C for 45 days resulted in the highest methane gas with production of 55 m^3 CH_4 / ton [4]. EFB treated with NaOH and drying first then mixed with POME (F/I) ratio (6.8: 1) can produce maximum methane gas as much as 82.7 m^3 CH_4/ton [8].

Sawdust and sawdust fungus media (Baglog) can also be used as raw material for making biogas with cow dung activator. It turned out that the volume of biogas produced from baglog raw material (C/N ratio = 57.79) was 28% higher than the volume of biogas from sawdust raw material (C/N ratio = 88.30). The fermentation process lasts for 32 days [9].In the dry anaerobic digester process, the parameters of; inoculum concentration, pH, moisture, temperature, total solids and C/N ratio are the main parameters affecting biogas production. In addition to the C/N ratio, the choice of raw materials used affects the volume of biogas produced [10].

Currently EFB has also begun to be utilized as a medium of planting mushroom with 2 monthly cycles. Post-utilization of EFB as baglog mushroom (EFBMM) has been used as a material of organic fertilizer (compost) but need to be left first for ± 2 months. Based on some of the previous reference, this research was done with utilization of raw materials as follows, 20% cow dung inoculum using dry anaerobic digestion.

The purpose of this study was to obtain an exact inoculum ratio, according to Brummeler and Koster (1989) the addition of an appropriate inoculum ratio would be advantageous during the start-up process [11]. In this study the exact inoculum determination was done by calculating the volume of inoculum that will be circulated in the fermentation process based on the total ratio of EFBMM + inoculum mixed water content (WC) with total solid (TS) of EFBMM + inoculum mixture (WC/TS ratio). To obtain the optimum condition, the fermentation was done with 3 variations on treatment, dry fermentation with the content of TS 22-40% and water content with 60-78% (WC/TS ratio 1.5 – 3.5), semi wet fermentation With TS content of 15-20% and water content 80-85% (ratio WC/TS = 4.0 - 5.7) and wet fermentation with TS <10% and moisture content> 90% (WC/TS ratio> 9.0). This research also conducts fermentation with the same condition for fresh EFB as control.

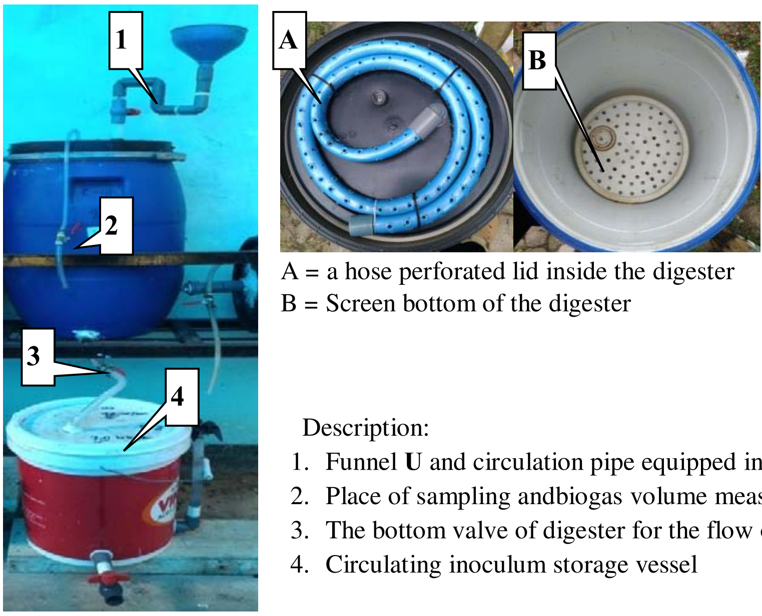
2. Materials and Methods

2.1. Materials Research

The materials used in this research are: Bunches of Blended Palm Oil former media of mushroom (EFBMM) as substrate obtained from strawmushroom farmers and cow dung which then added with water proportions of 1 kg: 5 liters as inoculum.

2.2 Research Utilities

The production of biogas was conducted using a digester. The fermented material (EFBMM) was stored in each tank of digester with a capacity of 50 liters. On the inside of the digester there was a screen that serves as a support for the raw materials to be fermented and to prevent clogging on the bottom of the faucet. The inside/top of the digester was equipped with a hose that was perforated and forms a spiral so that the addition/circulation of the inoculum can spread evenly on the EFBMM. While on the outer lid of the digester was equipped with 2 systems, namely (1) a hose with a flange connected with a gas flowmeter serves to measure the volume of biogas produced and (2) circulation pipe system used to circulate the inoculum. At the bottom of the digester was equipped with a stop faucet and gallon that serve to accommodate stock and inoculum to be circulated. In detail the digester images used in the study are presented in Figure 1.



A = a hose perforated lid inside the digester
B = Screen bottom of the digester

Description:
1. Funnel **U** and circulation pipe equipped inoculum stop the tap
2. Place of sampling andbiogas volume measurement
3. The bottom valve of digester for the flow of inoculum
4. Circulating inoculum storage vessel

Figure 1. A series of biogas making tools with circulation system

2.3 Implementation of Research

The parameters studied were to determine the optimum condition of biogas production (fermentation process). EFBMM with inoculum of cow dung on each digester with 3 treatments, i.e. wet fermentation (TS material <10%), semi-wet fermentation (TS material 15-20%) and dry fermentation (TS material 22-40%). The fermentation conditions on each digester can be determined by adjusting the volume of inoculum which is added/circulated by using the comparison equation between water content (WC) (Substrate + Inoculum) with total solid (TS) content (Substrate + Inoculum) using the following equation :

$$Ratio\,\frac{WC}{TS} = \frac{(WC\ EFBMMx\,Weight) + (WC\ InoculumxVolume)}{(TS\ EFBMMx\,Weight) + (TSInoculumxVolume)}$$

From the above equation, the volume of inoculum that was circulated daily on each digester is presented in Table 1.

Table 1. Characteristic material and volume of inoculum that is circulated daily at each digester

Code	WC (%)	TS (%)	VS (%)	VI (L/day)	Ratio (WC/TS)	Fermentation
R-1	27.2	72.8	65.4	**6**	2.3	dry
R-2	30.7	69.3	60.8	**10.0**	3.0	dry
R-3	32.7	67.3	59.0	**13.0**	4.0	semi-wet
R-4	45.7	54.3	45.1	**14.5**	5.7	semi-wet
R-5	50.4	49.6	42.6	**22.0**	9.0	wet
R-6	58.0	42.0	33.7	**23.5**	11.5	wet
control-R7	48.3	51.7	48.3	**8.7**	4.0	semi-wet
control-R8	38.0	62.0	59.1	**5.7**	2.3	dry
control-R9	73.1	26.9	24.6	**9.4**	9.0	wet

Description : WC = water content; TS = total solid, VI = volume of inoculum that is circulated daily
VS = Volatile Solid; Weight EFBMM each digester = 5 Kg
Water content of inoculum = 90.3% and TS inoculum = 9.7%

The experiment was carried out by inserting the 5 kg EFBMM into each digester with screened plaster on the bottom, then on the inside of the lid silicone glue was added and then closed tightly and ensured to be

airtight/no leakage. Each EFBMM-filled digester was added inoculum via a circulation pipe with volumes as presented in Table-1 and anaerobic fermentation process was then started. Process of fermentation takes place every day, during the process the measurement of biogas volume was calculated, also measured was the volume of inoculum which was channeled to the containment gallon. The volume-measured inoculum was then recycled into the same volume as the initial circulation volume. If there is a reduction/volume depreciation, then conduct the addition of inoculum onthe stock gallon and if there was an excess volume, the excess volume of inoculum was returned to the stock gallon. Measurement of biogas volume and circulation process was carried out continuously during the anaerobic fermentation process on the digester.
Biogas composition of each digester was measured once every week (7 days) . The biogas samples were taken directly on the biogas flow line of the digester using gas syringes and directly analyzed for the biogas composition (CH_4 , CO_2 and N_2) using Gas Chromatography (Shimadzu GC 2014) with thermal conductivity detectors at 200 ^oC and 100 ^oC injection temperature. GC analysis used a Shincarbon column of 4.0 ms longs and 3 mm inner diameter with Helium gas as a gas carrier with a flow rate of 40 ml/min .

3. Results and Discussions

3.1. Material Characteristics In Digester

The raw materials used in the dry anaerobic digestion process are EFBMM which has been described, fresh EFB which had already pressed from the factory, then chopped as raw material for control and 20% cow feces as inoculum. The result showed that EFBMM used in research had average water content 41.10%, TS content 59.90%, C content 25.44%, N rate equal to 1.20%, and Ratio C/N amounted to 16.639. The presence of C and N content shows that EFBMM still has high organic and mineral element content, while low C/N ratio and high TS at EFBMM show that the raw material are susceptible to degradation, thus has the potential to be used as raw material for biogas production by dry Anaerobic digestions. Various parameters such as inoculum concentration, pH, moisture, temperature, total solids and C/N ratios are the main parameters affecting biogas production. In addition to the C/N ratio, the choice of raw materials used affects the volume of biogas produced [10]. The characteristics of EFBMM and inoculum in each digester are presented in Table 1. Raw materials (EFB-Fresh, EFBMM, and Cow dung) characteristics used in dry anaerobic digestions are presented in Table 2.

Table 2. Characteristics of raw materials

Parameters	Unit	Average levels		
		EFB-Fresh	EFBMM	Cow dung 20%
C content	%	34.97	25.44	24.92
N content	%	0.73	1.20	1.50
C/N Ratio	-	47.83	16.63	16.61
Water Content	%	53.13	41.10	90.30
TS content	%	46.87	59.90	9.70
VS content	%	44.00	52.01	8.29

3.2. Biogas production resulted from fermentation process variations

Production of organic solid waste biogas with cow feces fluid (inoculum) using a circulatory system are a dry anaerobic digestion process. This process is one of the innovations in handling organic biological solids by an anaerobic microbial consortium contained in the inoculum to restore the potential of renewable energy sources and nutrient-rich fertilizers to manage sustainable solid waste. This process generally takes place in solids with concentrations greater than 10% (TS> 10%) and allows for higher loading rates of organic matter, minimal material handling, low energy requirements for heating, limited environmental consequences and effective performance . As for retention time, poor initial performance, poor homogeneous mixing and simple fatty acid accumulation (VFAs) were considered as weaknesses in the dry anaerobic digestion process [11].

Measurement of biogas volume of dry, semi-wet and wet fermentation process were done by using gas flow meter. The biogas production accumulation curve in each digester treatment was presented in Figure 2. Figure 2 shows that the highest biogas production was produced by R-3 with a total volume of 37.47 liters (7.49 liters/kg EFBMM) with solid residence time (SRT) 70 days with WC/TS ratio of raw materials of EFBMM 4.0 . In the same condition the ratio of WC/TS and SRT produced in the control digester (R-7) using fresh raw material EFB is 2.86 liters (0.57 liters/kg EFB). While the result of measurement and calculation of cumulative volumes of biogas compared with the amount of volatile solid (VS) in each digester of the study is presented in drawing 3. Figure 2 shows that the accumulative volume of biogas in dry fermentation group , control digester (R-8) produces biogas Higher than the R-1 and R-2 digesters, but in Fig. 3 it was found that the volume of methane gas (CH_4) produced was still the lowest in the treatment group, ie R-8 0.408 liters/KgVS , R-1 0.571 liters/KgVS and R-2 1.189 liters/KgVS . Physically EFB fiber has a strong fiber, so it takes a long time to be decomposed. The presence of biogas produced in the dry anaerobic digesters process was derived from organic materials such as oil residues from the pressing process of the plant and fibers attached to the EFB [12] .

Figure 2 showed thatthe average of all the digester treatments showed an increase in biogas production after 4 weeks, the same as reported by Lu et al. that during the dry anaerobic process, the pH decreased from the initial conditions of 6.7 to 4.2 under mesophilic conditions and pH 5.8 under thermophilic conditions for the first 2 weeks. Furthermore the pH gradually increased to 7.6 after 4 weeks with a digester temperature of 35ºC and pH 8 after 3 weeks with digester temperature of 55ºC [11].

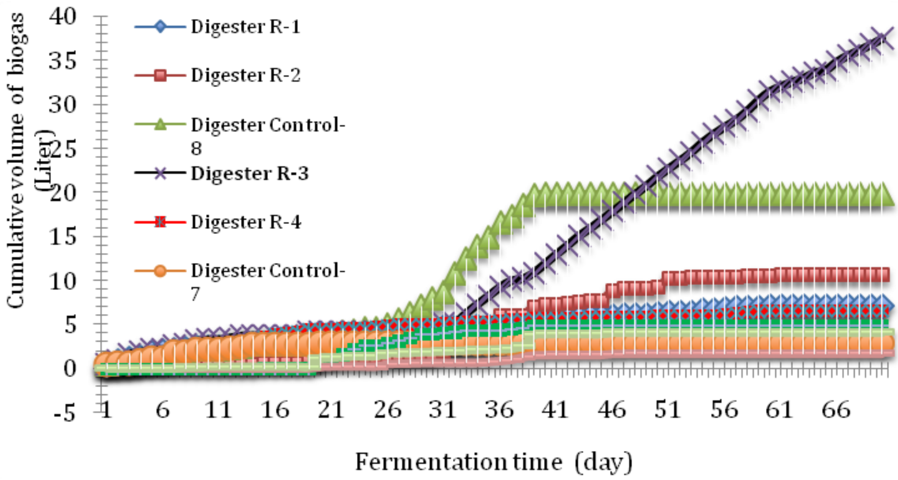


Figure 2. Biogas Production on each digester

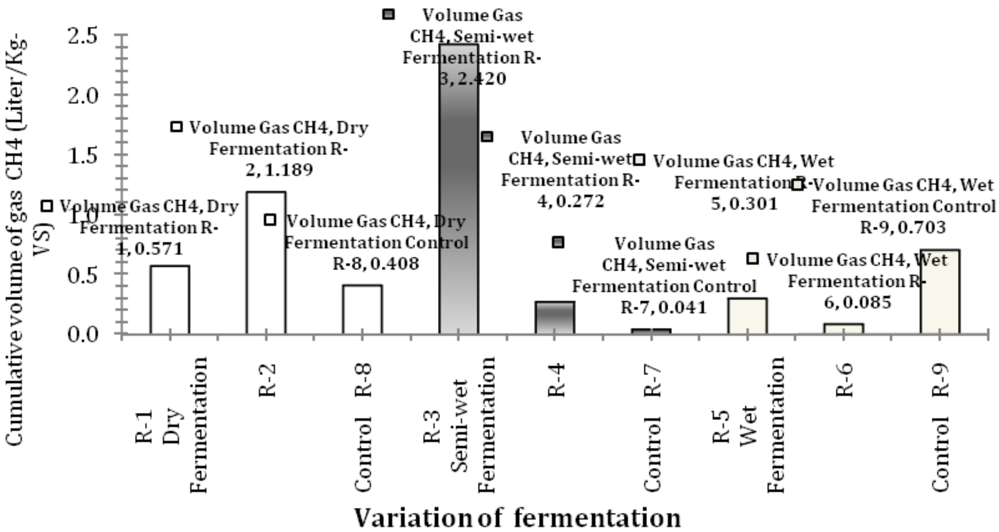


Figure 3. Cumulative volume of gases CH_4based on levels VS

3.3. Optimization of fermentation process

In the determination of fermentation optimization EFBMM uses 20% cow dung inoculum which is circulated with variation on treatment of R-1 (WC/TS 2,3), R-2 (WC/TS 3.0), R-3 (WC/TS 4.0), R-4 (WC/TS 5.7), R-5 (WC/TS 9.0) and R-6 (WC/TS 11.5) results of said biogas produced were 1.42 L/Kg; 2.12 L/kg; 7.49 L/kg; 1.31 L/kg; 0.98 L/kg and 0.34 L/kg EFBMM. From the data, the optimum condition of the fermentation process can be clearly seen in the curve of Figure 4. From Figure 4, it shows that EFBMM fermentation using 20% cows dung inoculum with circulation system in semi-wet condition (ratio of WC/TS = 4) can produce more biogas compared to the conditions of dry fermentation and wet fermentation. The drier or wetter the fermentation condition, can decrease biogas production. If calculated on the basis of the VS content of each EFBMM raw material, the CH_4 gas volume produced under the optimum condition of the semi-wet fermentation process (R-3) was 2.42 L KgVS.When compared with the results reported by Hasanudin et al. 2015, the cumulative volume of biogas generated in this research turned out to be only 10 percent of biogas production from anaerobic composting process of fresh EFB and POME which expected [12].

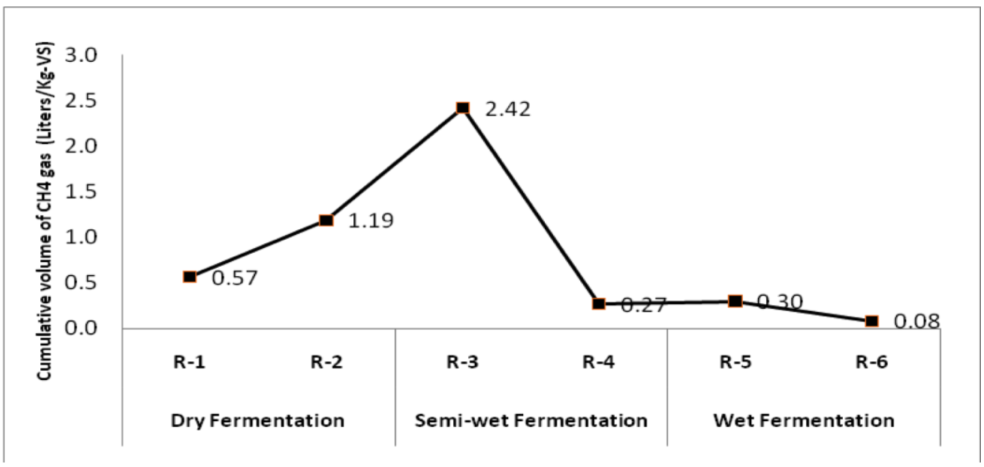


Figure4. Fermentation optimization curve

3.4. The composition of biogas produced on the variety of the fermentation process
In the process of determining the optimum conditions of fermentation in this study, no observations were made on other factors such as temperature and pH digester. In the determination of optimum conditions the researchers only wanted to know the best WC/TS ratio of theusage of inoculum circulation process. Based on the data presented in Table 3, the CH_4 gases content generated from each digester ranged from 3.218% to 24.63%. CH_4 gas content of this research was lower when compared with previous studies. Biogas formed from into co-composting process of EFB and POME can produce biogas with CH_4 gas content of 40.1% [12]. Other research results reported by Amelia JR et al. (2017) stated that CH_4 gases content in the anaerobic process of composting fresh fruit bunch (FFB) with 20 litres of POME per day, can produce 51.08% CH_4. The CH_4 gas content exceeding 45% will be highly flammable and can be a proper fuel because the high calorific fuel value [13]

Table 3. Gas composition CH_4each digester

Parameter	Treatment ratio (WC/TS)								
	R-1	R-2	Control-R8	R-3	R-4	Control-R7	R-5	R-6	Control-R9
CH_4 (%)	17.977	18.236	24.630	16.356	12.498	18.269	11.686	3.218	18.027
CO_2 (%)	31.712	32.668	41.816	30.710	27.505	35.987	25.771	20.587	25.975
N_2 (%)	50.277	48.759	32.515	52.570	59.997	46.752	62.509	76.116	55.982

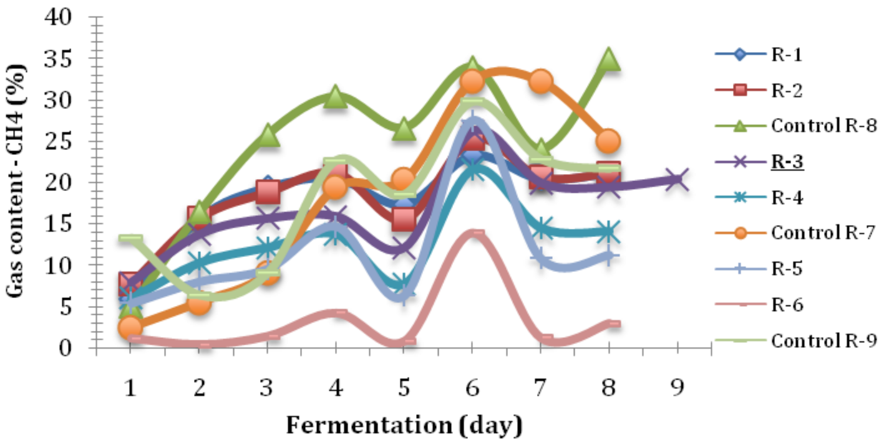


Figure5. CH_4 gas trend curveon fermentation process variation

Figure 5 also showed that during the fermentation process, with increasing time, the CH_4 gas content generated from each of the average digester tends to increase, but fluctuates (up and down). As stated earlier that in this fermentation process, researchers did not observe changes in temperature and pH in the digester. Jha AK et al. 2011 stated that the bacteria in the reactor were very sensitive to changes in temperature and the rise in temperature of about 2°C per day can lead to the termination of the fermentation process. In addition, the more important thing was the pressure in the fermentation reactor. High gas pressure within the reactor was reactive to methane bacteria and slows the methane formation process. When the inoculum circulation was done, the fermentation process just continuously goes again [14]. Kunatsa T et al. 2013 also states that the anaerobic decomposition process occurs in the mesophilic range and has a 15 day retention time. In tropical countries, the unheated digesters tend to be at an average temperature between 20-30°C. In addition to temperature effects, biogas production levels also depends on the pH and the dryness of the feedstock [15].

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3.5. The volume of inoculum that was circulated on the variety of fermentation processes

In the anaerobic fermentation process, the solid organic matter in the digester requires the inoculum to speed up the reaction process. Inoculation can improve digestion efficiency of the digester and may reduce the residence time of solids [11].

Table 4. Volume of inoculum in each digester

Description	R-1	R-2	Control R-8	R-3	R-4	Control R-7	R-5	R-6	Control R-9
Vol. of circulation-Inoculum (L/day	6	10	5.7	13	14.5	8.7	22	23.5	9
Weight TS EFBMM (Kg)	3.64	3.465	3.365	2.715	2.48	2.1	2.585	3.1	1.345
Absorbed Inoculum Vol (L)	3.55	5.35	0.15	6.6	10.15	4.05	10.5	6.35	0.35
The Ratio TS/I adsorbed	1.0	0.6	22.4	0.4	0.2	0.5	0.2	0.5	3.8

Table 4 showed that variations in circulating volume of circulating inoculum based on calculation of WC/TS ratio in each digester being absorbed differently. Overall absorption capacity of EFBMM raw material was greater than absorption of control raw material (EFB). This is because the physical structure of EFBMM was relatively soft/not hard and easily decomposed, so it has larger surface area and pores than the control material that has denser and harder physical texture.The calculation of TS ratio of inoculum (TS/I) absorbed in each digester ranged from 0.2 to 1.0. The highest biogas production of this research was obtained in absorbed inoculum with a TS/I ratio of 0.4. Brummeler et al. (1992) reported that the optimum ratio of ‘solid inoculum form’ to solids at start-up was 0.5 to 0.6 with 30-day solid residue time. The time of solids retention will be longer at a lower inoculum ratio, since the leachate circulation was not optimum. When the inoculum ratio falls to 0.4 or lower, the residence time of solids will increase to 50 days or more, since other conditions were not optimal, such as low pH and high organic acid concentrations [11]

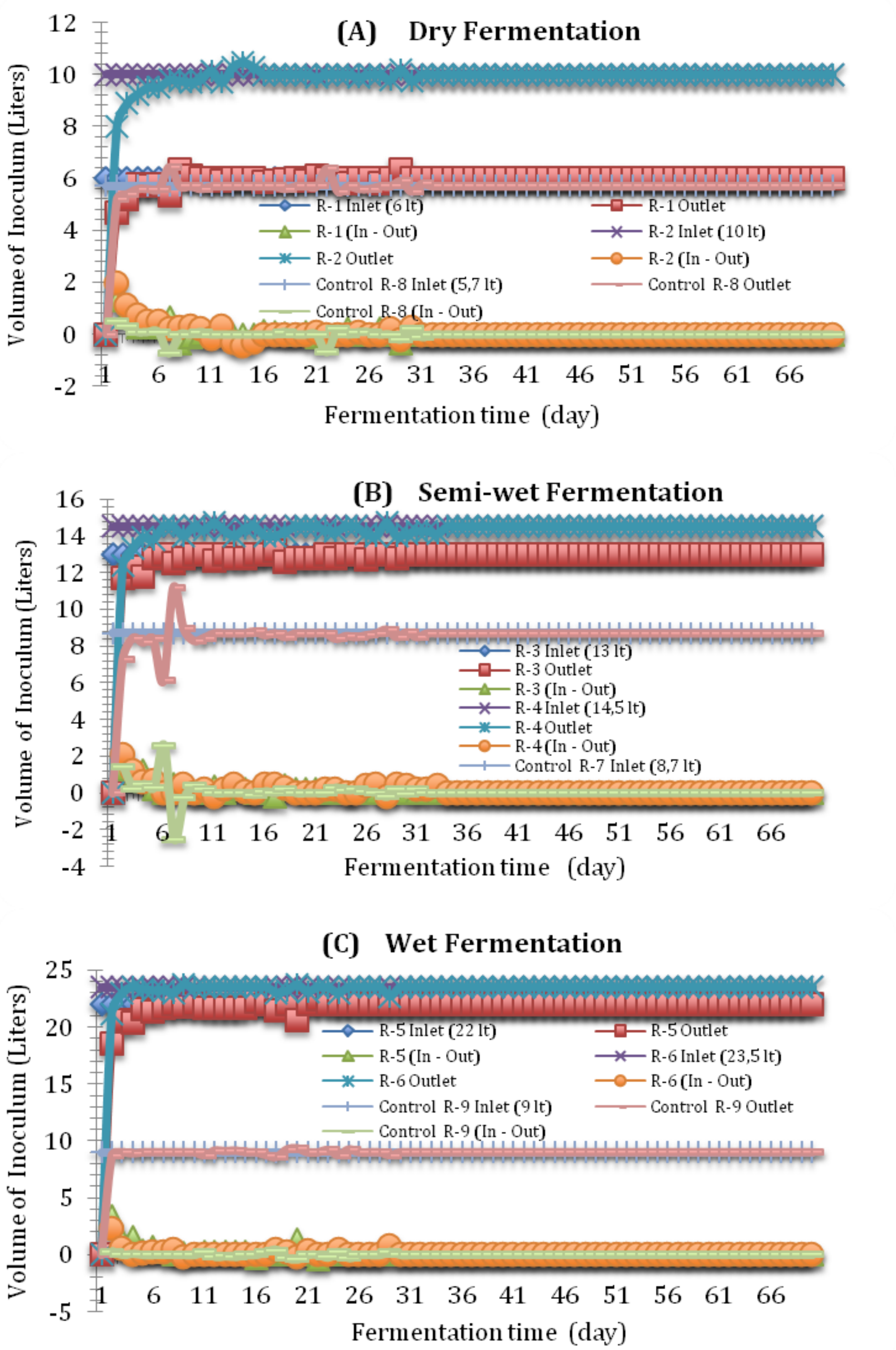

Figure6. The inoculums circulation volume curva in dry (A), semi-wet (B) and wet (C) fermentation

Figure 6 shows that the average daily circulation volume of all new digester treatments was stable after week 4th. Entering the 5th week onwards, the volume of inoculum that was circulated/introduced into the digester equals the volume of inoculum output. This was in line with the biogas production presented in Figure 2 which shows that biogas production begins to increase after 4th weeks.

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4. Conclusions

The optimum condition of biogas production using EFBMM raw material takes place in semi-wet fermentation with WC/TS ratio was 4, with biogas volume produced 37.462 liters (2.420 liters CH_4/KgVS). While control samples biogas yields was 2.865 liters (0.041 liters CH_4/KgVS). Under optimum condition, the average concentration of CH_4 gas produced were 16.356% with the lowest CH_4 concentration being 7.872% at startup and the highest concentration was 26.231% at maximum production. The total volume of inoculum used at optimum conditions during the circulation process were 19.6 liters with a TS/I ratio of 0.4 or (1:2.5 w/v).) and the total volume of inoculum in the control were 12.75 Liters with a ratio of TS/I = 0.5 or (1:5 w/v)

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