Production of Biogas and Compost from Fermented OPEFB used for Straw Mushroom Planting

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Abstract: - This research aims to determine the effect of adding various decomposers on making biogas and compost from Oil Palm Empty Fruit Bunches (OPEFB) used for straw mushroom production. Method The treatment comprised the addition of five different decomposers. The decomposers used were (1) Control (addition of water), (2) 1,150 grams of cow dung as manure, (3) Waste activated sludge (WAS) from palm oil mill effluent (POME) 700 grams, (4) Giving EM4 68 ml, (5) 2,720 ml of palm oil mill effluent (POME). The parameters observed include temperature, pH, C/N ratio, biogas volume, biogas composition (CH4, CO2, and N2), and compost composition. The results showed that the highest biogas production occurred with the addition of an f EM4 decomposer, and the methane gas content reached 51.2% at 30°C process conditions, pH 7, and C/N ratio of 26.63. The highest biogas production was obtained with the addition of an EM4 decomposer, followed by manure, POME, WAS, and controls. The compost composition closer to SNI requirements was achieved by adding a manure decomposer that produced a C content of 24.63%, N 1.29 %, P 1.57%, K 0.18%, and C/N ratio 20.

Key-Words: oil, bunches, gas, palm, composition.

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1. Introduction

According to [1], the yield from the conversion of oil palm *Fresh Fruit Bunches* (FFB) into *Crude Palm Oil* (CPO) was approximately 21.5-23.0%, and by-products or waste are generated in the form of liquid, solid, and gas/steam. The solid waste consists of 16-23% OPEFB, 11-26 % fruit juice fiber, 4% palm kernel cake, 4-6% shells, and 16.5% other solid wastes. In 2019, Indonesia was likely to produce 42,869,429 tons of CPO, besides the production of 42,869,429 tons of OPEFB.

Although OPEFB has recently been used as a ground cover (mulch) or natural compost, its application equivalent to CPO has not been maximized. This is because its conversion to natural compost takes 60-90 days [2] or approximately 120 days [3]. Other applications of OPEFB are direct conversion into compost through anaerobic fermentation. However, these methods are uneconomical and also cause greenhouse gas (GHG) pollution, which has always been a barrier to palm oil production globally [4].

Methane gas (biogas) from the anaerobic decomposition of organic matter has a high energy content that can be used as a renewable energy source. [5] stated that OPEFB, with a high organic matter and anaerobic decomposition technology, can produce biogas which can be used as a renewable energy source.

[6] also reported that oil palm empty fruit bunches consist of organic matter 95.64 ± 0.33%, total carbon 41.97 ± 1.42%, total nitrogen 0.664 ± 0.005%, lignin 20.34 ± 0.36%, cellulose 58.42 ± 0.01%, hemicellulose 21.29 ± 2.86%. Based on this composition, it is discovered that OPEFB has a high organic component and lignin content. Generally, lignin takes approximately 6-9 months to degrade and can easily be decomposed by growing white-rot fungi on media containing materials such as oyster mushrooms, ear mushrooms, and straw mushrooms. This fungus uses food derived from oil palm empty fruit bunches [3].

The development of OPEFB by the community as a medium for planting straw mushrooms and compost has been investigated by [7]. Similarly, [8] also showed that the ratio of the biological efficiency of OPEFB to straw mushrooms on an average production scale was 3.93%.

[8] also discovered that OPEFB used as a medium for straw mushrooms, was still unsuitable for composting because the C/N ratio was 42.90 or above 20 [9]. This makes it necessary to accelerate the composting process and biogas production by adding a suitable decomposer. Therefore, this research aims to determine the effect of various decomposers on the production of biogas and compost from OPEFB used for straw mushroom production media.

2. Method

This research used OPEFB raw materials as straw mushroom media. The samples were taken from the mushroom kumbung, stacked for 5-10 days, and dried in the sun until the water content was approximately 10%. Furthermore, the observed parameters included moisture content, pH, temperature, C/N ratio, organic C and N, lignin, cellulose, and hemicellulose.

There were three replications with various types of decomposers. The decomposer treatments were (1) Control (addition of water), (2) 1,150 grams of cow dung as manure, (3) Waste activated sludge (WAS) from palm oil mill effluent (POME) 700 grams, (4) EM4 68 ml, (5) 2,720 ml of palm oil mill effluent (POME). The decomposers were previously diluted with the addition of 26.5 liters of water.

The weight of OPEFB used for straw mushroom growing media in each experimental unit was kept the same (3,500 grams). Subsequently, the fermentation was carried out for 75 days, and observations were recorded at fortnightly intervals while biogas production was monitored at five days' intervals. The parameters observed include biogas volume, temperature, pH, C: N ratio, and biogas composition (CH_4, CO_2, and N_2). The compost quality in terms of C, N, P, K contents and C: N ratio was carried out after the C/N ratio reached below 20. The data obtained were averaged and presented using descriptive methods in graphs and tables. The research scheme is depicted in the flow chart (Figure 1).

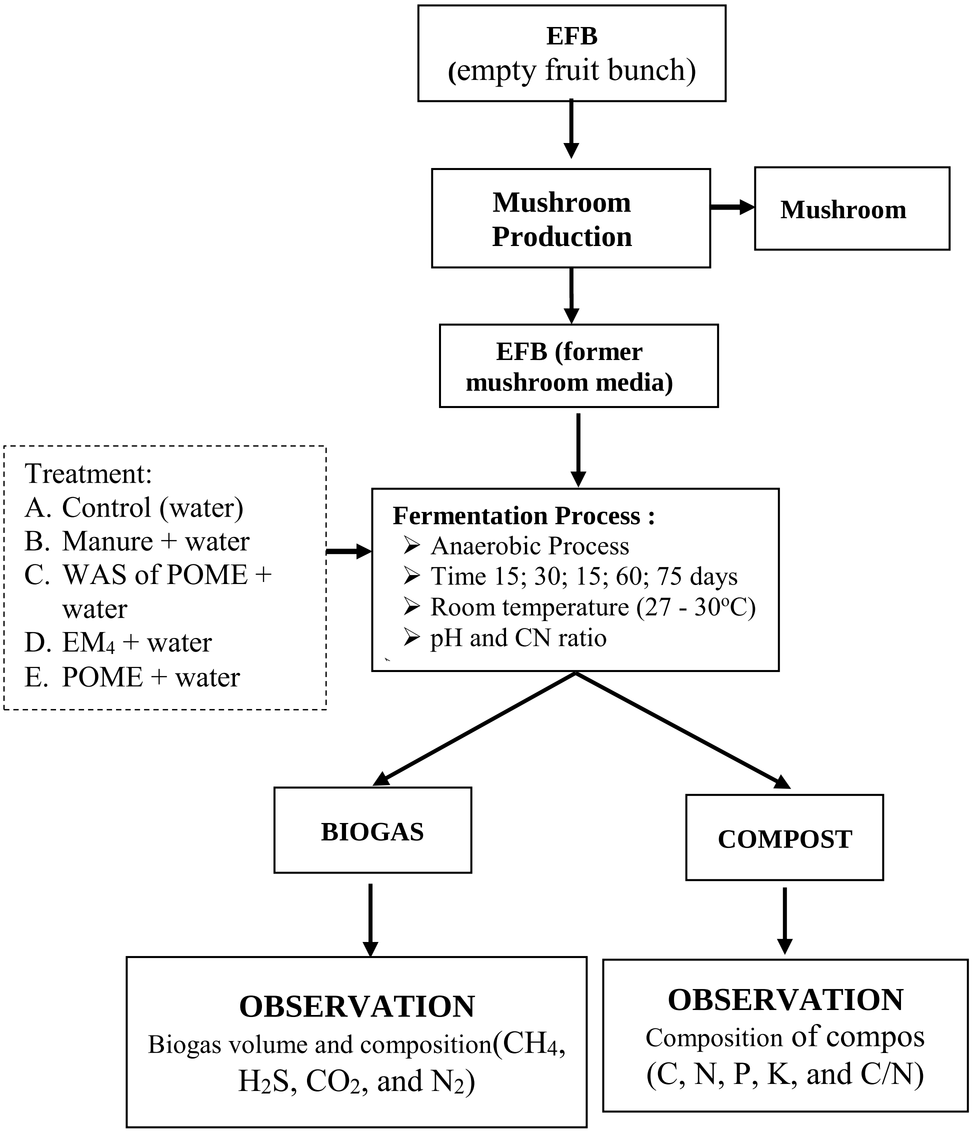

Figure 1. Schematic of Research

3. Result and Discussion

3.1. OPEFB Characterization of Used Straw Mushroom Media.

The physical appearance of OPEFB from straw mushroom growing media is shown in Figure 2. The bunches were intact with softer tissues containing 80-90% moisture and were very fragile after drying. Moreover, the fresh OPEFB was 35-40°C, while after drying, the temperature ranged from 32-34°C. The decrease in organic matter during the straw mushroom production was evidenced by a reduction in the C/N ratio from 63.21 to 42.90. According to [6], methane results showed a decrease in the C/N ratio of 30, 35, 40, 50, and 55, respectively by 13.9%, 17.4%, 4.2%, 73%, and 90.6%.

Figure 2. Physical Condition of Used OPEFB Straw Mushroom Growing Media

The characteristics of OPEFB used for straw mushrooms are shown in Table 1. The results of the chemical characterization showed that the lignin content decreased from approximately 20.34% to a range of 15.07-17.52% after its application. This indicated that straw mushrooms, a group of white-rot fungi, reduce the lignin content of OPEFB. According to [6], OPEFB composition is primarily organic material reaching 95.64, comprising 20.34% lignin content, 58.42% cellulose, and 21.29% hemicellulose. Moreover, OPEFB has a high lignin content, which is the most challenging component for degradation. [3] stated that the white-rot fungi group could secrete lignocellulolytic enzymes that can reduce lignin content.

The white-rot fungus is a microorganism from Phanerochaete sp. that can extensively degrade lignin to CO_2 and H_2O. These microorganisms can also break down all significant polymers, such as cellulose and hemicellulose, in solid organic waste, namely wood, straw, cardboard, and OPEFB [10].

Table 1 shows that the OPEFB used for straw mushroom growing media contained high lignin, cellulose, hemicellulose, and C/N ratios; therefore, it can not be used directly as compost. This is because compost should ideally have a C/N ratio between 10 and 20 [9].

Table 1. Characteristics of Used OPEFB Straw Mushroom Growing Media

No	Characteristics	Unit	Value Range	Average Value
1	Water content	%	9.25 - 11.08	10.27
2	pH	-	4.84 - 5.21	4.86
3	Temperature	ºC	30.50 - 32.50	31.27
4	C/N Ratio	-	40.00 - 44.50	42.90
5	organic C	%	45.86 - 48.02	47.18
6	organic N	%	1.04 – 1.20	1.10
7	Lignin	%	15.07 - 17.52	16.31
8	Cellulose	%	36.07 - 38.62	37.58
9	Hemicellulose	%	23.56 - 27.99	25.57

3.2.Fermentation Temperature Change

The results showed a change in temperature during the fermentation process of the OPEFB due to the addition of different decomposers (Figure 3). In general, the pattern of temperature changes was almost the same between treatments as it started increasing from the 15th day of observation, and the peak was recorded on the 30th day. This showed that both the thermophilic and mesophilic microorganisms were likely to be involved in the anaerobic decomposition process. According to [11], the anaerobic decomposition of organic matter is dominated by mesophilic bacteria, although there are also a small number of thermophilic microbes.

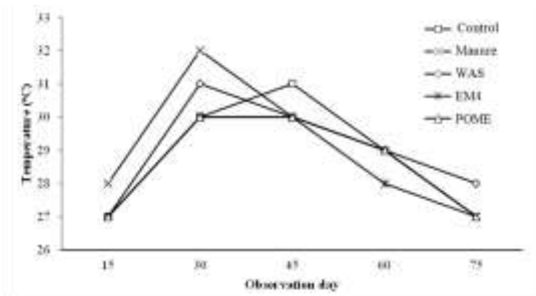

Figure 3. Changes in Temperature during the Fermentation Process in Various Treatments

The increase in temperature, which occurred on the 30th day of observation, ranged from 27-28°C to 30-32°C. This was due to the activity of microorganisms in the aerobic decomposition of organic matter, which will produce by-products in the form of heat energy and methane gas. This implies that the faster the microorganism's cell metabolism, the greater the amount of heat energy produced [12].

The decrease in temperature began to occur from the 60th to 75th day of observation due to the microbial activity's slowdown due to the reduced nutrient content in organic matter. According to [13], a decrease in temperature indicates a reduction in organic matter that microorganisms can decompose.

3.3.Changes in the Degree of Acidity (pH)

Based on the observation of raw materials, the pH values obtained were between 4.84 and 5.21. The changes in pH during the composting process are shown in Figure 4. The increase in pH occurred due to the change of protein and organic acids into other compounds such as methane (CH_4), ammonia, and carbon dioxide (CO_2) [14]. The breakdown of protein into ammonia (NH3) and the release of OH- ions affected the increase in pH. Meanwhile, neutral pH balanced between (H+) and (OH-) ion concentration.

The continuous increase in pH led to alkaline conditions in the anaerobic fermentation environment caused by the concentration of hydroxyl ions (OH-). Furthermore, some ammonia was converted to nitrate (NO_3^-), and denitrification occurred, which increased pH to neutral conditions [7]. The formation of nitrogen gas in the denitrification stage starts with the conversion of nitrate to nitrite and back into nitrogen gas [15].

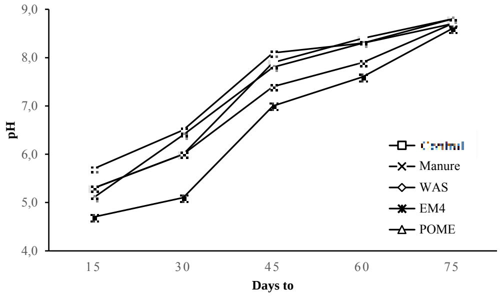

Figure 4. Changes in pH during the Fermentation Process in Various Treatments

3.3.C/N Ratio

The C/N ratio is a critical indicator in observing organic matter's decomposition process. Carbon (C) is a source of energy for microorganisms during decomposition. At the same time, nitrogen (N) functions as a constituent of the cells that make up the body of microorganisms [16]. Figure 5 shows the change in the value of the C/N ratio during the anaerobic decomposition process.

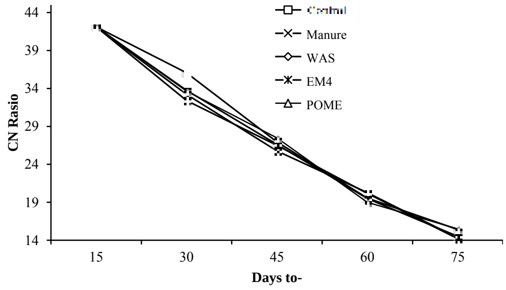

Figure 5. Changes in C/N Ratio during the Fermentation Process at Various Treatments

The raw material used in making biogas was OPEFB, which was used as a mushroom growing medium. According to [11], the C/N ratio of OPEFB was originally 72 but decreased to 42.90 in raw materials because it had been used as a mushroom growing medium. Therefore, there is a need to consider the percentage of the C/N ratio in the anaerobic fermentation process because lower values inhibit the activity of microorganisms. Generally, organic matter in all treatments was decomposed by microorganisms, as indicated in the graph that showed a continuous decrease in the C/N ratio to approximately 14. The decomposition rate in all treatments was influenced by temperature and pH conditions.

3.4. Biogas Volume

The results showed that adding POME and its WAS did not affect the volume of biogas produced or was almost similar to the control (Figure 6). This result occurred due to the absence of organic matter in the WAS. With adding POME, biogas production did not happen substantially because the pH was very acidic, 4-5 [8]. [8] also stated that biogas production in POME occurred at a pH of approximately 7.5 - 8.

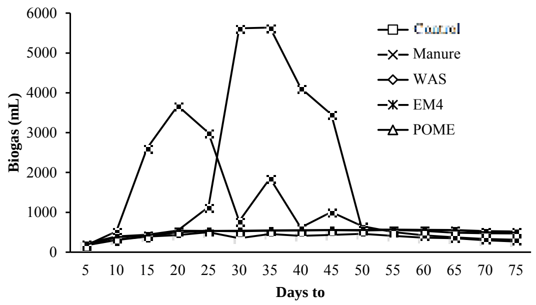

Figure 6. Changes in Biogas Production during the Fermentation Process under Various Treatments

The addition of manure and EM4 decomposer significantly increased biogas production compared to the control. On the 10th day, there was an increase in biogas production under the expansion of EM4, while gas production increased significantly on the 20th day. The increase in gas production was due to EM4 and manure containing methanogenic microbes, which are very active in large numbers. The highest daily gain in biogas volume occurred with the addition of EM4 treatment at 1,127.4 ml/day (Figure 6). Figure 6 shows that the more substrates available, the higher the biogas produced. According to [17], biogas production will be maximum because the use of substrate by microorganisms is also optimal. Meanwhile, EM4 (Effective Microorganisms 4) is a solution that contains various kinds of bacteria and functions to accelerate composting. It is a mixed culture of microorganisms from Indonesia, containing Lactic Acid Bacteria (Lactobacillus sp.), Photosynthetic Bacteria (*Rhodopseudomonas* sp.), Actinomycetes sp., Streptomyces sp., Yeast (yeast), and Cellulose Decomposing Fungi [18].

According to the manufacturer, EM4 is designed as an ingredient that accelerates the composting process of organic matter and improves the quality produced. Furthermore, it is used to improve soil structure and texture, provide nutrients needed by plants, and offer relatively higher resistance against pests and diseases. The benefits of EM4 for plants and soil include (1) Inhibits the growth of pests and plant diseases in the soil, (2) Increasing the photosynthetic capacity of plants, (3) Improving the quality of organic matter as fertilizer, and (4) Enhances the quality of vegetative and generative growth of the plant. The number of fermenting microorganisms in EM4 is significantly large, which consists of 80 genera. These microorganisms are divided into five main groups: photosynthetic bacteria, Lactobacillus sp., Streptomyces sp., yeast, and Actinomycetes. In fermenting organic matter, they function correctly in a suitable environment, such as anaerobic conditions, temperatures around 35-40^{o}C, pH 7.0 to 8.0, and water content of 80 to 90%. Biogas production with the addition of EM4 was higher than in other treatments. This is because the microorganisms in EM4, namely anaerobic and aerobic, are selective methane-producing bacteria, while in other manures, they are non-selective. The content of EM4 consists of photosynthetic and lactic acid bacteria, actinomycetes, phosphate solubilizing bacteria, lactobacillus, yeast, and fermented fungi. Moreover, other dissolved materials are amino acids, saccharides, and alcohol.

3.5. Biogas Composition

Based on the biogas composition analysis results, the highest percentage of methane gas was recovered with the addition of EM4, which reached 51.20%, followed by manure treatment of 32.64% (Figure 7). The increase in the volume of methane gas was accompanied by a decrease in carbon dioxide (CO_2) and nitrogen gas (N_2). The importance of biogas produced also depends on the number of bacteria and the nutritional requirements in the raw material during the methanogenesis process. Therefore, more organic matter and nutrients could lead to the proper development of methanogenic bacteria and produce more excellent organic raw materials that can be converted into methane gas [19].

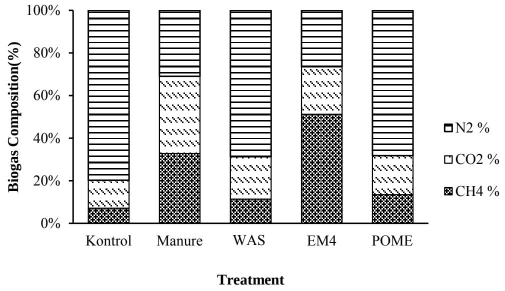

Figure 7. Composition of biogas (CH_4, CO_2, and N_2) in Different Decomposers

The process of biogas formation by fermentation or anaerobic decomposition of organic waste is almost the same. In an anaerobic environment, microorganisms play a role in liberating methane from acetic acid, including Methanosarcina, Methanococcus, Methanobacterium, and Methanobacillus. Figure 8 shows the reshuffle process that occurred in the anaerobic digester [20].

(1) Hydrolysis. This is the earliest stage that occurs in the anaerobic process, where complex compounds such as proteins, carbohydrates, and fats are breakdown into simple ones (monomers). This is carried out through exoenzymes from anaerobic bacteria [21], namely *Clostridium,* which can degrade waste containing cellulose. Protein is hydrolyzed in the presence of protease and peptidase enzymes, while the fat contained in the raw material is hydrolyzed in the presence of lipase enzymes secreted.
(2) Acidogenesis or fermentation is the stage of reshuffling the hydrolyzed material into simpler organic substances such as ketones and alcohol. According to [20], this is a stage of overhauling organic matter from hydrolysis, which was fermented into various final products, including formate, acetate, propionate, butyrate, lactate, succinate, ethanol, carbon dioxide, and hydrogen gas. This organic acid is formed through some bacteria, such as Pseudomonas, Escherichia, Flavobacterium, and Alcaligenes [21].
(3) Acetogenesis is the stage where acetate, carbon dioxide, and hydrogen compounds are formed. According to [22], methanogenic bacteria cannot use fermentation products or the results of the acidogenesis stage with more than two carbon atoms for growth. These bacteria only use simple energy sources such as acetate, methanol, methylamine, CO2, and H2. The products from this step, which include propionic acid, butyrate, and ethanol, need to be converted to acetic acid through Acetobacterium woodii and Clostridium aceticum before the bacteria use them. In the oxidation process, hydrogen and carbon dioxide are produced, and the acetogenic bacteria function in the conversion process. Apart from the oxidation of propionate, butyrate, and ethanol, acetic acid is also produced by homo acetogenic bacteria.
(4) Methanogenesis is an essential process in anaerobic digesters. In this step, carbon dioxide is reduced to methane and water, while acetate is converted to methane and carbon dioxide. Meanwhile, methane-producing bacteria include Methanococcus, Methanobacteria, and Methanosarcina. Most of these bacteria are mesophilic with an optimum temperature range of 20ºC-40ºC, but they can also be found at thermophilic temperatures. The formation of methane gas occurs due to the reaction of acetate decarboxylation and CO_2 reduction (Deublein and Steinhause 2011), as stated below:

$\mathbf{CH_3COOH \rightarrow CH_4 + CO_2}$ (acetate decarboxylation)
$\mathbf{CO_2 + 4\,H_2 \rightarrow CH_4 + 2\,H_2O}$ (CO_2 reduction.)

The two main groups of bacteria responsible for methane formation are acetoclastic and hydrogen-using methanogenic. The acetoclastic converts acetic acid to methane, while hydrogen-using methanogens remove hydrogen to produce methane.

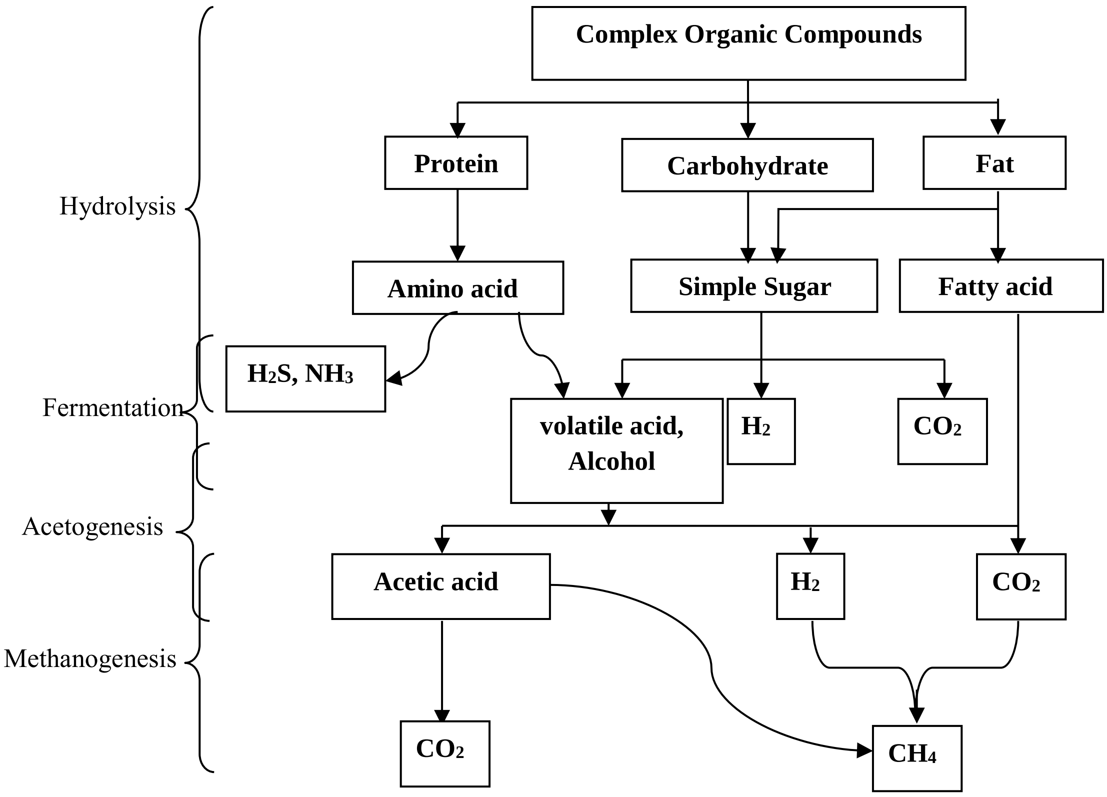

Figure 8. Schematic of Anaerobic Biodegradation of Complex Organic Materials [20]

According to [20], the reaction mechanism in anaerobic fermentation is carried out through four stages, namely:

(1) Acid-forming bacteria breakdown glucose compounds into*:*

a. $C_6H_{12}O_6 + 2\ H_2O \longrightarrow CH_3COOH + 2\ CO_2 + 4\ H_2$ (Acetic acid)

b. $C_6H_{12}O_6 \longrightarrow CH_3CH_2CH_2COOH + 2\ CO_2 + 2\ H_2$ (Butyric acid)

c. $C_6H_{12}O_6 + 2\ H_2 \longrightarrow 2\ CH_3CH_2COOH + 2\ H_2O$ (Propionic acid)

(2) Acetogenic bacteria breakdown propionic acid and butyric acid into:

a. $CH_3CH_2COOH \longrightarrow CH_3COOH + CO_2 + 3\ H_2$ (Acetic acid)

b. $CH_3CH_2CH_2COOH \longrightarrow 2\ CH_3COOH + 2\ H_2$ (Acetic acid)

(3) Acetoclastic methane decomposes acetic acid into:

$CH_3COOH \longrightarrow CH_4 + CO_2$ (methane)

(4) Methane bacteria synthesize hydrogen and carbon dioxide into:

$4\ H_2 + CO_2 \longrightarrow CH_4 + 2\ H_2O$ (methane)

3.6.Compost Composition

The results showed that the compost was formed after 60 days of fermentation (C/N < 20). The data in Table 2 show the effect of adding various decomposers, the treatment yielding results closer to the requirements issued by the [9]. According to the standard specification of compost from domestic organic waste is with the addition of manure. However, other treatments did not meet the requirements mainly because of the low K content, an essential macro element in composting from organic waste.

The elemental potassium (K-total) or K_2O value of cow dung varies depending on the cow breed, feed given, and storage conditions, such as the high and lowlands. According to [23], the potassium content in cow dung ranges from 0.1 to 1.5%; therefore, adding manure to OPEFB could increase the K content.

[23] also stated that the chemical composition of cow dung (manure) includes total organic carbon > 37%, 0.4 – 1.0% nitrogen, 0.2 - 0.5% phosphorus, 0.1 - 1.5% potassium, 85-92%water content. Furthermore, manure contains several other secondary- and micro-nutrients such as Ca, Mg, S, Mn, Fe, Cu, and Zn. Since cow dung has an acidic pH in the

range of 4.0 – 4.5, the microbes that can survive in it are limited [24].

[25] reported that the importance of potassium (K) content in compost plays a significant role in plant growth. This includes (1) Forming and transporting carbohydrates in the plant body, (2) As a catalyst in the process of protein formation in plants, (3) Regulates various types of activity from mineral elements, and (4) Increasing the strength of plant stems; hence, they are not easy to collapse, (5) Increase levels of carbohydrates and sugars in fruit for the fruit to have a sweet taste, (6) Make seeds plants fuller and solid for easy application as superior seeds.

Table 2. Effect of Addition of Decomposers on Compost Composition

Parameter	Added Decomposer					SNI 19-7030-2004*)
	Control	Manure	*WAS*	EM4	POME	
pH	8.35	7.45	8.36	7.63	8.28	6.80 – 7.49
C (%)	24.63	25.93	24.63	26.57	25.28	9.80 – 32.00
N (%)	1.26	1.29	1.23	1.37	1.33	Min. 0.40
P (%)	1.28	1.57	1.56	1.22	1.39	Min. 0.10
K (%)	0.06	0.18	0.07	0.05	0.07	Min. 0.20
C/N	19.48	20.00	20.11	19.44	19.03	10 - 20

Note: *) National Standardization Agency, 2004

4. Conclusion

Based on the research, the highest biogas production was obtained with the addition of an EM4 decomposer, followed by manure, POME, WAS, and controls. The highest methane gas content (51.2%) was found with the addition of EM4 at a temperature of 30°C, pH 7, and a C/N ratio of 26.63. However, the composition of compost close to the SNI value was with the addition of manure which produces manure containing 24.63% C, 1.29% N, 1.57% P, 0.18%K, and 20 C: N ratio.

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Conflict of Interest

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