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To cite this article: J R Amelia *et al* 2017 *IOP Conf. Ser.: Earth Environ. Sci.* **65** 012036

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Performance evaluation of integrated solid-liquid wastes treatment technology in palm oil industry

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Abstract. The oil palm industry significantly contributes to environmental degradation if without waste management properly. The newest alternative waste management that might be developed is by utilizing the effluent of POME anaerobic digestion with EFB through integrated anaerobic decomposition process. The aim of this research was to examine and evaluate the integrated solid-liquid waste treatment technology in the view point of greenhouse gasses emission, compost, and biogas production. POME was treated in anaerobic digester with loading rate about 1.65 gCOD/L/day. Treated POME with dosis of 15 and 20 L/day was sprayed to the anaerobic digester that was filled of 25 kg of EFB. The results of research showed that after 60 days, the C/N ratio of EFB decreased to 12.67 and 10.96 for dosis of treated POME 15 and 20 L/day, respectively. In case of 60 day decomposition, the integrated waste treatment technology could produce 51.01 and 34.34 m³/Ton FFB which was equivalent with 636,44 and 466,58 kgCO₂e/ton FFB for dosis of treated POME 15 and 20 L/day, respectively. The results of research also showed that integrated solid-liquid wastes treatment technology could reduce GHG emission about 421.20 and 251.34 kgCO₂e/ton FFB for dosis of treated POME 15 and 20 L/day, respectively.

1. Introduction

Indonesia is currently the largest producer and exporter of palm oil in the world. The oil palm plantation and palm oil processing sectors have become a key part of Indonesia's economy, but oil palm mill also significantly contributes to environmental degradation if without waste management properly. Manufacturing processes generate large quantities of empty fruit bunch (EFB) and palm oil mill effluent (POME) on the output side. Recycling EFB and POME by conversion into usable by products has been done. Nowadays, EFB is used as mulch in agricultural lands and POME will be treated with the pond system. The ponding system is the most conventional method for treating POME. More than 85% of palm oil mills use ponding systems. Ponding systems are easy operating systems but they have some disadvantages such as methane production which results harmful effect on the environment [1]. The anaerobic ponds emit a huge amount of the strong green house gasses and the treated POME of the ponds (effluent) contains nutrients responsible for pollution of surface and ground water. The major concern about the ponding systems is the uncontrollable release of large



amounts of CH₄ and CO₂ into the atmosphere from open ponds, which may worsen the effect of global warming [2]. The large amount of greenhouse gases emission can threaten the palm oil industry sustainability.

Total CH₄ emission per open digesting tank was 518.9 kg/day [3] and total methane emission per anaerobic pond was 1043.1 kg/day [4]. Those data calculated from the two equations derived from relationships between methane emission and total carbon removal. The results showed that the production of 1 ton of FFB produced 119 kgCO₂eq using a yield of 20.7 ton oil palm fresh fruit bunches (FFB)/ha [5]. The production of 1 ton of CPO in a mill without and with biogas capture emitted 971 and 506 kg CO₂eq, respectively. For the production of 1 ton of refined palm oil in a refinery which sourced the CPO from a mill without biogas capture and with biogas capture, the GHG emitted was 1,113 kg and 626 kg CO₂eq, respectively.

Palm oil industry in Indonesia with 19324 million of CPO production, was predicted causing about 15.61 x 10⁶ ton of greenhouse gasses emission equals to CO_{2n} [6]. The anaerobic ponds emit a huge amount of the strong greenhouse gas methane with the biogas and the treated POME of the ponds contains nutrients responsible for pollution of surface and ground water. Each ton of produced crude palm oil is responsible for the emission of 46 m³ (32.9 kg) of methane, corresponding 384 m³ (756 kg) CO₂ equivalent [7]. Emission loose total of 1 ton CPO was 1472.24 kgCO₂eq. The sequence of emission resource per 1 ton CPO production was 1026.4 kgCO₂eq from Palm Oil Mill Treated POME (POME); 179.35 kg CO₂ eq from Empty Fruit Bunch (EFB); 144.18 kg CO₂eq from NPK fertilizer; 44.73 kg CO₂eq fiber 32.25 kg CO₂eq from gas waste; 15.92 kgCO₂eq; from solar and 13.37 kgCO₂ eq from ash waste [8]. The research showed that POME, EFB, and the utilization of chemical fertilizer were the biggest greenhouse gases emission contributor in palm oil plantation industry. The large amount of greenhouse gases emission can threaten the palm oil industry sustainability. The newest alternative waste utilization that might be developed is by utilizing the outcome of wastewater treatment from anaerobic digestion with empty fruit bunch (EFB) through anaerobic integrated composting process. The technology hopefully can reduce or resolve carbon emission and greenhouse gasses loose from palm oil plantation industry. The aim of this research was to examine and evaluate the integrated solid-liquid waste treatment technology in the view point of greenhouse gasses emission, compost, and biogas production.

2. Material and Methode

2.1 Equipment and Material

The equipment were 5000 L anaerobic bioreactor with methane capturer system and H₂S purifier, anaerobic composting digester, gasflow meter, gas sampler bag, pH meter HM-20P, analytic balance, desicator, furnace, DRB200, HACH spektrofotometer DR/4000U, Gas Chromatography, Elementar Analyzer, etc. The materials were Palm Oil Mill Treated POME (POME), sludge, Empty Fruit Bunches (EFB) from palm oil industry in Lampung, etc.

2.2 Method

The research was started by doing POME characterization. Fresh POME was treated by anaerobic treatment process (loading rate was 1.65 gCOD/L/day). Shredded EFB then was added to anaerobic composting digester. The treated POME from anaerobic treatment process was sprayed to EFB everyday. There were two digesters used during the anaerobic composting. The treated POME with dosis of 15 and 20 L/day was sprayed to the anaerobic digester that was filled of 25 kg of EFB. EFB anaerobic composting was run in two months. Detailed scheme on how the research conducted shown in figure 1.

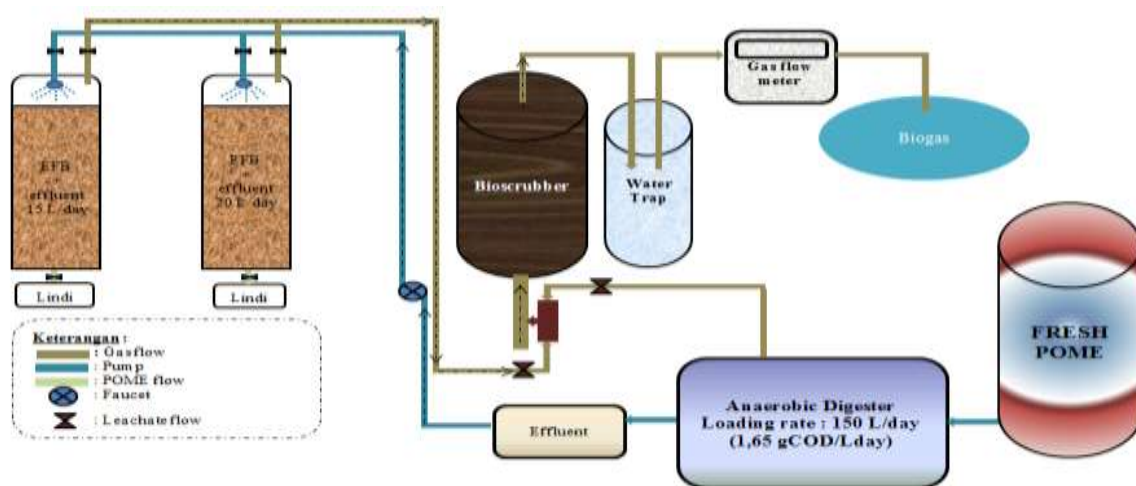


Figure 1. Scheme of research (proposed condition)

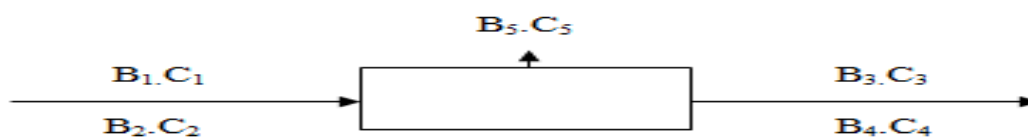
2.3 The Emission Reduction Potential

2.3.1 Existing condition

In Indonesia, almost all palm oil mills use open ponding systems to treat POME. Even though the ponding system is economical, it's land and time intensive, and it releases a large amount of methane gas (one of *GHGs*) into the atmosphere primarily from the organic decomposition that occurs in the anaerobic pond. The emission potential of *GHG* from open ponding systems was calculate based on COD removal.

2.3.2 Proposed condition

The emission potential of *GHG* from integrated waste treatment system was estimated for each treatment by using carbon mass balance method. Carbon mass balance that was used is showed on figure 2.



$$B_1.C_1 + (B_2.C_2)n_a = B_3.C_3 + (B_4.C_4)n_b + B_5.C_5 \quad (1)$$

Figure 2. Carbon mass balance

Information:

- | | |
|--|--|
| B_1 = Amount of EFB that is used in composting (kg) | C_1 = Concentration of EFB carbon |
| B_2 = Amount of treated POME (kg) | C_2 = Concentration of treated POME carbon |
| B_3 = Amount of compost produced (kg) | C_3 = Concentration of compost carbon |
| B_4 = Amount of leachate produced (kg) | C_4 = Concentration of leachate carbon |
| B_5 = Amount of evaporated compound | C_5 = Concentration of evaporated biogas |
| n_a = Amount of treated POME sprayer times during one composting cycle | |
| n_b = Amount of leachate retrieval | |

$$\text{Emission potential} = B_5.C_5 \times \frac{\%CH_4}{\%CH_4 + \%CO_2} \times \frac{16}{12} \times 25 \quad (2)$$

$$\text{ERP} = \text{Proposed condition (kgCO}_2\text{e/Ton FFB)} - \text{Existing condition (kgCO}_2\text{e/Ton FFB)} \quad (3)$$

Note : ERP = Emission Reduction Potential

3. Result and Discussion

3.1 Characteristics of Palm Oil Waste

Main materials which were used in this research were empty fruit bunches (EFB) and the treated POME of anaerobic digester process. EFB used in the research had 58.52% of moisture content, 41.48% of total solid (TS) , 42.59% of total carbon, 0.93% of total nitrogen, and 45.79 of C/N ratio. The characteristics of treated POME are shown on table 1.

Table 1. Treated POME characteristics

Treated POME	Value
pH	7.36-7.65
Chemical Oxygen Demand (mg/L)	22815
Total Solid (mg/L)	19577
Total Suspended Solid (mg/L)	14231.60
Volatile Solid (mg/L)	13780
Volatile Suspended Solid (mg/L)	9153.78
Total Carbon (%)	33.63
Total Nitrogen (%)	4.41
C/N Ratio	8.07

3.2 Biogas Productivity

The anaerobic integrated digestion system with anaerobic composting system can produce biogas as the new energy resource compared to the other palm oil waste treatments. Each anaerobic digestion and anaerobic composting process can produce methane gas (CH₄) as energy resource that is caused by decomposition process of organic compounds. Biogas measurement of anaerobic composting process was done by calculating accumulation of carbon total. Biogas productivity from this research is shown in figure 3. Figure 3 also show that biogas productivity accumulation of each treatment is fluctuated, however the constantly increase occurred until last day treatment.

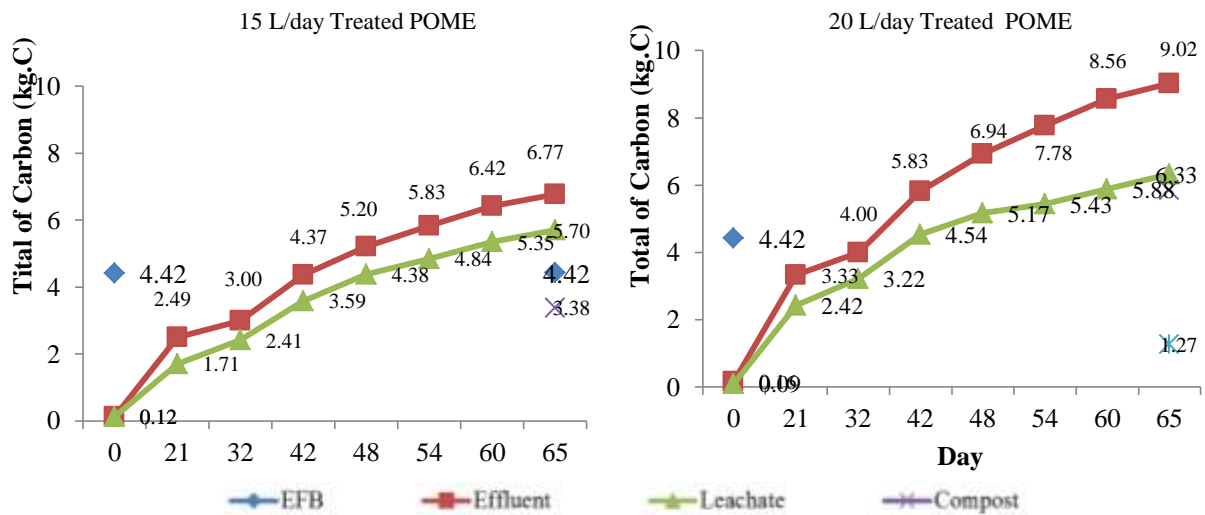


Figure 3. Biogas potential production of various treated POME treatment

Figure 4 shows total carbon in each treatment from the research. Biogas that was produced generally consists of methane gas (CH₄), carbon dioxide (CO₂), and the other gasses. CH₄ and CO₂ content in each biogas treatment were different. Biogas characteristics produced in each treatment show on table 2. The result of research showed that biogas which was produced in 15 and 20L/day treated POME treatment about 38.89 m³/ton FFB and 22.22 m³/ton FFB with methane contain about 19.12 m³/ton FFB and 11.85 m³/ton FFB. The result of research also shows that biogas which was produced in 15 and 20 L/day of treated POME treatments contained methane gas more than 45% (table 2). If the containing of methane gas in biogas is more than 45%, the biogas will be easy to be burnt and able to use as fuel because the biogas has enough high of heat. It showed that biogas that was produced from 15 and 20 L/day treated POME treatment has good burning level because it contained methane gas more than 45%. The containing of methane gas in this research was higher compared to another same kind research [9]. The concentration of methane gas (CH₄) from EFB anaerobic composting (16 kg) with treated POME was only 40,1% [9]. It shows that the amount of material added in composting process will influence contain of methane gas in produced biogas.

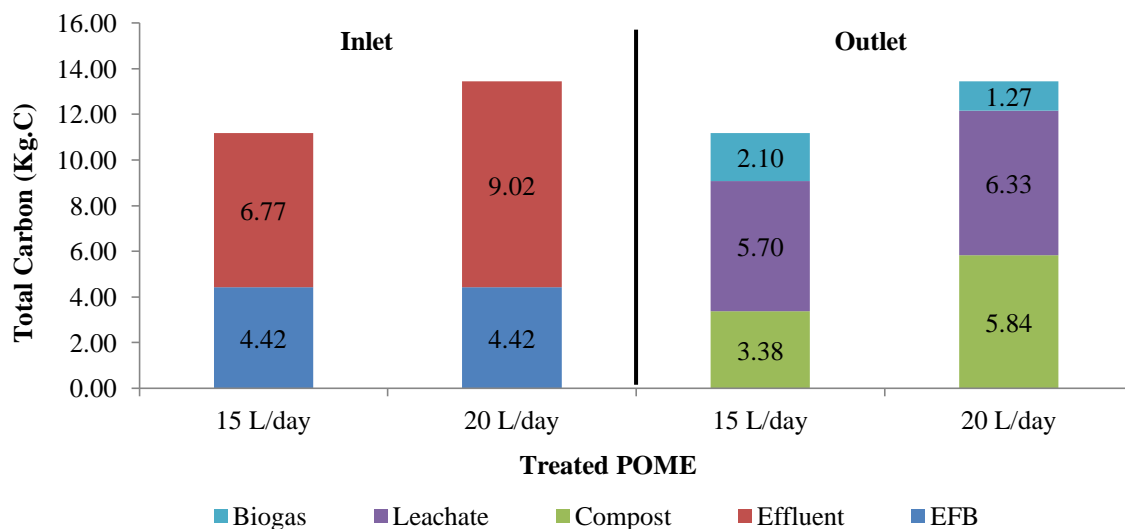


Figure 4. Total carbon from anaerobic composting

Table 2. Characteristic of biogas

Parameter	Unit	Teated POME	
		15 L/day	20 L/day
CH ₄	%	49.17	51.08
CO ₂	%	39.51	38.89

3.3 The Evaluation of Green House Gas Emission from Waste Integrated Treatment

Waste water treatment in palm oil plantation industry generally is done by using open lagoon. That conventional process will produce carbon dioxide (CO₂) and methane gas (CH₄) that if it dispersed to atmosphere would cause global warming. Green House Gas (GHG) emission that is produced from POME conventional treatment is 215.24 kgCO₂e/Ton FFB with 0,7 m³ ton CPO produced. POME potentially produces GHG emission about 133,95 kgCO₂e/EFB [10]. Those data show that POME conventional treatment is not effective because it can potentially cause global warming.

Treated POME utilization system from anaerobic digestion combined with EFB throughout anaerobic integrated composting process hopefully can be a solution to reduce GHG emission. The CO₂ emission potential from POME anaerobic treatment has been calculated by carbon mass balance of each treatment process. Potential of CO₂e emission from POME anaerobic treatment has been calculated from carbon total measurement, POME as carbon inlet, treated POME as carbon outlet, and biogas carbon total as evaporated carbon, meanwhile anaerobic composting CO₂e emission potential was from carbon total measurement, newest EFB and treated POME as carbon inlet and the carbon outlet was from compost total carbon, leachate and total carbon evaporated. The result of research shows that total emission from POME anaerobic process by using anaerobic digestion lagoon system was 77.26 kgCO₂e/ton FFB. The result of research shows that total emission from POME anaerobic process by using anaerobic digestion lagoon system was 77.26 kgCO₂e/ton FFB. Anaerobic composting process from each treatment could produce total emission differently, as it is presented on figure 5.

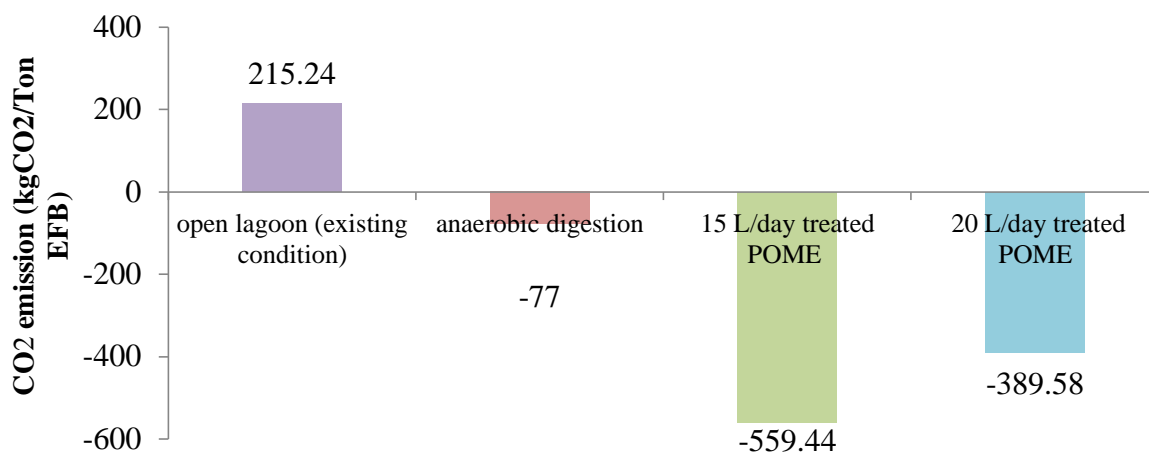


Figure 5. GHG emission potential from each anaerobic composting treatment

The result of research showed that palm oil mill integrated waste treatment technology could reduce GHG emission about 421.20 kgCO₂e/ton FFB (15 L/day treated POME) and 251.34 kgCO₂e/ton FFB (20 L/day treated POME). POME anaerobic treatment with methane capture technology could reduce GHG emission only 109.41-175.35 kgCO₂e/ton FFB [11]. Those data showed that palm oil mill integrated waste treatment could reduce GHG emission higher than other waste treatment in palm oil industry (existing conditions).

3.4 Compost

Composting is an aerobic or anaerobic biological process that uses naturally occurring microorganisms to convert biodegradable organic matter into a humus-like product, can destroy pathogens, converts nitrogen from unstable ammonia to stable organic forms, reduces the volume of waste, and satisfies the needs of fertilizer for agricultural use seasonally [12]. Composting is a biologically based process which is practiced to stabilize the organic matter for soil amendment (producing compost) and to protect the environment from the detrimental effects of these waste products [13]. Composting of the empty fruit bunch (EFB) could simultaneously treat the solid waste from palm oil mill. Composting EFB is a possible way to transform the bulky bunches into a valuable, manageable product for use in the plantation or as market product [14]. C/N ratio is one of the important factors affecting composting process and compost quality. The course of decomposition of organic matter is affected by the presence of carbon and nitrogen. C/N ratio compost from this research is shown in figure 6.

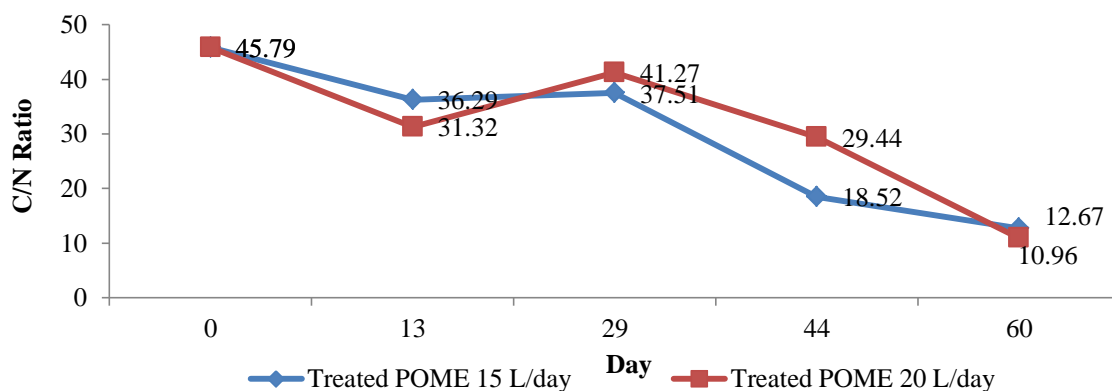


Figure 6. C/N ratio compost from this research

The results of research showed that after 44 days the C/N ratio of EFB decreased rapidly from an initial value (45.79) to 18.52 and 29.44 for dosis of treated POME 15 and 20 L/day, respectively. After 60 days, the C/N ratio of EFB continue decreased to 12.67 and 10.96 for dosis of treated POME 15 and 20 L/day, respectively. The changes in the C/N ratios reflect the organic matter decomposition. The optimum ratio in soil organic matter is about 10 carbons to 1 nitrogen, or a C:N ratio of 10:1, and a C:N ratio of 20, where C and N are the available quantities, is the upper limit at which there is no danger of robbing the soil of nitrogen [15].

4 Conclusion

The conclusion from this research are:

1. Palm oil mill integrated waste treatment technology could reduce greenhouse gasses emission about 421.20 kgCO₂e/ton FFB (15 L/day treated POME) and 251.34 kgCO₂e/ton FFB (20 L/day treated POME).
2. Palm oil mill integrated waste treatment technology could produce biogas about 51.01 m³/ton FFB (15 L/day treated POME) and 34.34 m³/ton FFB (20 L/day treated POME).
3. The best treatment in palm oil mill integrated waste technology is 15 L/day treated POME. It could reduce greenhouse gasses emission higher than other treatment.

Acknowledgements

The authors would like to thank The Directorate General of Higher Education of the Ministry of Education and Culture, Republic of Indonesia, and The Japan Society for The Promosition Of Science (JSPS) for financial support. Thanks also go to all leaders of the Directors and Chairmen of PTPN VII Bekri, AgroIndustrial Technology Department of Fateta IPB, Faculty of Agriculture of UNILA, and

Analytical Laboratories of Department Agro-Industrial Technology UNILA, for the provision of data, information and discussion.

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