The utilization of mushroom growing media waste as raw material for biogas production: energy productivity ratio (EPR) study

Irvan1*, B Trisakti1 and Y Nabilah2

1 Department of Chemical Engineering, Faculty of Engineering, Universitas Sumatera Utara, Medan, Indonesia
2 Department of Chemical Engineering, Diponegoro University, Semarang, Indonesia

*E-mail: irvan@usu.ac.id

Abstract. Indonesia is one of the countries with the largest crude palm oil (CPO) production. Besides CPO production the mills also produce various type of wastes in large quantity. Oil palm empty fruit bunches (OPEFB) are the largest solid waste produced during the process. One of the OPEFB utilizations that has been done by the community around the mills area is to make mushroom as growing media. However, the rest OPEFB from mushroom media which cannot be degraded becomes a new problem for the community. The technology that can be used to overcome this waste is the anaerobic composting process. This paper describes the utilizing OPEFB waste from the rest of the mushroom growth media into energy through the anaerobic composting process. The energy productivity ratio (EPR) was also calculated and reviewed during the process and utilizing by products in the output. The result revealed that the design of OPEFB waste treatment into biogas and its purification are expected to be applied to the concept of clean production (zero waste) and the productivity ratio of energy values obtained from calculations was > 1. This shows that the needs of energy output in the pilot plant are greater than the input.

1. Introduction

Energy requirements is increasing along with the current development and population growth, but the reduction in oil reserves and the elimination of subsidies causes oil prices to rise and environmental quality to decrease due to excessive use of fossil fuels. The government expects other alternative energy that can be utilized, such as biomass.

Currently, Indonesia is one of the countries with the largest crude palm oil (CPO) production [1]. Indonesia's CPO production in 2015 was 33 million tons and the total area of oil palm plantations was 8.56 million hectares approximately [2]. Oil palm empty fruit bunches (OPEFB) are the largest solid waste produced during the process of around 27.6%.

One of the OPEFB utilizations that has been done by the community is to make it as mushroom growing media. The fungus that grows are generally edible mushrooms. Residual waste of OPEFB from mushroom media becomes a new problem for the community, where the waste accumulates more and more because it is a difficult material to degenerate. The technology that can be used to overcome this waste is the anaerobic composting process.

Anaerobic composting is a biological modification in the chemical and biology structure of organic matter without oxygen. The process is a cold process and there are no temperature fluctuations as
occurs in the aerobic composting process. OPEFB composting process generally takes a long time. It because OPEFB contains lignin which is quite large, that is 15.70% dry weight [3]. Lignin is the most difficult component to degenerate, so the process of degrading lignin is one of the factors that determine the speed of the composting process. OPEFB fungi that have been overgrown will benefit the anaerobic composting process. The composting process occurs more efficiently and quickly if using OPEFB that has been overgrown with mushrooms [4]. The use of organic activators in the form of cow dung has also been carried out in the composting process of OPEFB. The provision of livestock manure as an activator in composting is an effort to speed up time and at the same time improve the quality of compost [5].

Anaerobic composting will produce methane gas ($CH_4$), carbon dioxide ($CO_2$) and organic acids which have low molecular weight such as acetic acid, propionate acid, butyric acid, lactic acid and succinic acid. Methane gas can be used as an alternative fuel (biogas). Energy in the form of biogas produced from anaerobic composting of OPEFB waste from the rest of the mushroom media can be utilized and improved in quality as an alternative to premium fuel, while the compost produced can be utilized by people as organic fertilizer. Organic fertilizer from OPEFB can be applied to a variety of plants, both single or combined with chemical fertilizers, in order to reduce costs [6].

Seeing the existing conditions as described above, this paper explains the making of biogas from OPEFB waste. The purpose of the utilization of OPEFB waste biomass residual media mushrooms for the production of biogas as an alternative energy to substituting premium fuel. This paper also provides a plan for the management of OPEFB waste from mushroom growing media that is technically adequate, a plan for managing OPEFB waste into biogas, a design for biogas purification, information and detailed picture of the technology obtaining energy and compost with a good quality using OPEFB utilization technology through the production of mushrooms and biogas (anaerobic) and obtaining data on performance analysis and processing productivity by calculating the energy productivity ratio (EPR) by reviewing the use of electrical energy as an input during the process and utilizing byproducts in the output.

2. Materials and methods

2.1. Oil Palm Empty Fruit Bunches (OPEFB)

Biomass is an important renewable source in contributing to the world economy, sustainability and energy security. In developing countries, the use of biomass has high potential because most of the country's economy is based on agriculture and forestry. Biomass is non-fossil material and biodegradable organic material derived from plants, animals and microorganisms. Biomass originating from agriculture, organic waste, food and the forestry industry can be used for energy production.

The use of biomass offers benefits from a variety of benefits, for example biomass is available in each country in various forms. Thus, biomass can guarantee a safe supply of raw materials for energy systems. The use of biomass as a significant contributor to national energy supply for many countries is the best way to ensure cheap energy for industry. From an environmental perspective, the use of biomass for alternative energy can reduce current environmental problems such as increasing $CO_2$ in the atmosphere caused by the use of fossil fuels. In addition, biomass energy contains little sulfur, thus avoiding $SO_2$ emissions.

OPEFB is a potential pollutant source that can have a serious impact on the environment, so palm oil mills are required to handle this waste through improved processing technology (end of pipe). The increase in consumer demand for palm oil is directly proportional to the production of palm oil mills so that it results in OPEFB increasing which contains biodegradable constituents or can be biologically decomposed with a BOD/COD ratio of 0.5.

Biogas or biomethane is an efficient choice for preventing and reducing pollution as well as providing high quality energy for vehicle fuel, electricity generation and heating. The composition of biogas varies greatly depending on the organic material and biological processes used. Table 1 shows general biogas characteristics.
Table 1. Biogas characteristics

| Parameter                        | Composition |
|---------------------------------|-------------|
| Methane (CH\(_4\))              | 50 – 75%    |
| Carbon dioxide (CO\(_2\))       | 30 – 40%    |
| Nitrogen (N\(_2\))              | 0.4 – 1.2%  |
| Oxygen (O\(_2\))                | 0 – 0.4%    |
| Hydrogen sulfide (H\(_2\)S)     | 0.02 – 0.4% |
| Energy content                  | 6.0 – 6.5 kWh/m\(^3\) |
| Fuel equality                   | 0.60 – 0.65 liter oil/m\(^3\) air |
| Explosion limit                 | 6 – 12% biogas in air |
| Temperature on                  | 650 - 750°C |
| Critical pressure               | 75 – 89 bars |
| Critical temperature            | -82.5°C     |
| Normal density                  | 1.2 kg/m\(^3\) |
| Molar mass                      | 16.043 kg/kmol\(^{-1}\) |

One of the main advantages of biogas production is the ability to convert waste into valuable resources, by using it as a substrate for anaerobic digestion processes. In general, the substrate raw material for making biogas must contain three types of macromolecules, namely carbohydrates, proteins and lipids. The high content of cellulose, hemicellulose, lignin and carbon elements in OPEFB make it as a good substrate for bioconversion through various biotechnological processes. If the substrate for the anaerobic digestion process consists of a homogeneous mixture of two or more types of raw materials (for example animal sludge and organic waste from the food industry), this process is called co-digestion and is commonly used in making biogas. Table 2 shows the biogas potential produced by several substrates.

Table 2. Potential of biogas produced by several substrates

| Component | Biogas (m\(^3\)/kg VS) | Biogas Composition (CH\(_4\) : CO\(_2\)) |
|-----------|------------------------|----------------------------------------|
| Carbohydrate | 0.38                   | 50 : 50                                 |
| Fat             | 1.00                   | 70 : 30                                 |
| Protein         | 0.53                   | 60 : 40                                 |

2.2. Anaerobic digestion process

Some microbial species have been known for their ability to break down organic matter present in waste by producing a value-added product. Biogas is a gas product from anaerobic digestion process, which is a biochemical process in which complex organic matter decomposes in the absence of oxygen by utilizing the activity of various types of microorganisms. During the process, organic matter is converted mainly to methane (CH\(_4\)), carbon dioxide (CO\(_2\)) and biomass. Nitrogen is released from organic compounds and converted to ammonia. Anaerobic processes are used to treat wastewater with a high organic content (BOD > 500 mg/l), aimed at further treatment of primary and secondary sludge from conventional wastewater treatment.

2.3. Biogas application

Biogas is one of alternative energy that has the potential to replace fossil fuels. The physical and chemical properties of biogas are similar to natural gas, so biogas can replace natural gas for all applications, especially for vehicle fuels that its demand has increased in recent years. The content in biogas can affect the nature and quality of biogas as fuel. Biogas which has methane content of more than 45% is flammable and is a good fuel because it has a high heating value. Whereas H\(_2\)S content in biogas can cause corrosion in equipment and piping. Table 3 shows some components in biogas that can affect the nature of biogas itself.
Table 3. Disturber Component in Biogas

| Component | Total Effect on Biogas                                                                 |
|-----------|--------------------------------------------------------------------------------------|
| CO₂       | Decreases the heat value of the burn, Increases methane number, Causes corrosion, Causes damage to alkaline fuel cells |
| H₂S       | Causes corrosion in equipment and piping systems, Causes SO₂ emissions when burned   |
| NH₃       | Damaging the catalyst used in the reaction, Causes NO₂ emissions after combustion, Can damage fuel cells |
| Water vapor | Corrodes equipment, The condensate can cause damage to equipment and generators, There is a freezing risk in the piping system |
| N₂        | Decreases the heat value of the burn, Improves the anti-knocking properties of the engine |
| Siloxane  | Causes damage to the engine                                                          |

2.4. *Energy productivity ratio (EPR)*

Technically, productivity is a comparison between output and input. The productivity formula can be stated as follows:

\[
\text{Productivity} = \frac{\text{Output}}{\text{Input}} = \frac{\text{0}}{\text{1}} = \text{Effectiveness produces output} \]

\[
= \text{Effective use of inputs}
\]

A measure of productivity is not the same as efficiency. Efficiency is a measure in comparing the planned use of inputs with the realization of input use. If the actual input is used and the greater is the savings, the higher is the level of efficiency. However, the smaller is the input that can be saved, the lower is the level of efficiency. The notion of efficiency is more oriented to input while the problem of output is less of a special concern.

It is often also called single factor productivity, which shows the productivity of certain factors used to produce outputs. These factors are only in the form of the following:

a. Raw material productivity = based on the ratio of output to input for raw material
b. Labor productivity = based on the ratio of output to input for labor
c. Material productivity = based on the ratio of output to input for material
d. Energy productivity = based on the ratio of output to input for energy
e. Capital productivity = based on the ratio of output to input for capital

3. Results and discussions

3.1. Process description

3.1.1. The main process

The schematic of processing OPEFB waste from mushroom media to biogas is shown in figure 1.
Figure 1. Schematic diagram of processing OPEFB waste from mushroom media to biogas

The purposes of this main process are to produce biogas from bioreactor main unit (TK-A-001 and TK-A-002) and from secondary unit (TK-B-001). Biomass feedstock in the form of OPEFB (the remaining mushroom from mushroom house) are put into the bioreactor main unit. In these bioreactors, fermentation process occurred and produced biogas (CH$_4$, CO$_2$, H$_2$S, etc.). Biogas produced is then flown into biogas storage (BS-001). Coarse aggregate (RA-1) in the main bioreactor will be formed and needs to be removed during maintenance, and can be used as compost. At the bottom of main bioreactors, there is an effluent bioreactor fluid which will be flown to make up tank (MT-A-001). Effluent bioreactors in MT-A-001 are mixed with market waste (MW) and dung, then flown into the bioreactor secondary unit (TK-B-001). Biogas will be produced by the bioreactor secondary unit. Biogas produced from TK-B-001 is sent to biogas storage. Crude aggregate (RA-2) and EB-2 effluent are generated in TK-B-001. RA-2 and EB-2 from TK-B-001 are then pumped into makeup tanks (MT-B-001). RA-2 is taken then dried into compost. EB-2 which has been separated from RA-2 is pumped back to bioreactor main unit.

3.1.2. Biogas purification process

Producing good quality Biogas (where the remaining CO$_2$ content is less than 10% and the remaining H$_2$S content is less than 500 ppm) so that it can improve the quality of the product to be used as an alternative fuel for the engine. Biogas that has been stored in Biogas Storage or gas bag is then distributed to absorption column 1. NaOH solution is pumped into absorption column 1 (to be contacted with biogas so that it absorbs CO$_2$). Underflow adsorption column 1 in the form of effluent liquid (NA$_2$CO$_3$ solution) from the adsorption of CO$_2$ will be flowed to the bioreactor. In the bioreactor microalgae is sought to reduce the content of CO$_2$ and Na in water. While overflow (top flow) in the form of purified gas which still contains H$_2$S and a little CO$_2$ is stored in a gas bag. Biogas that are stored in a gas bag then flow into the adsorption column 2 using a water solvent to remove H$_2$S content. Water solution is pumped into absorption column 2 (to be contacted with biogas so that it absorbs H$_2$S)

Overflow adsorption column 2 in the form of effluent liquid (H$_2$S solution) from H$_2$S adsorption will be flowed into the Aquaculture Tub for further processing by biofixation using Azolla microphylla plants to reduce H$_2$S content in water. In the bioreactor, the Azolla microphylla plant is used to reduce H$_2$S content in water. While overflow (top flow) in the form of gas from purification which still contains a small amount of H$_2$S and CO$_2$ gas (low concentration) is stored in a gas bag. Biogas that is
stored in a gas bag is then flowed into the adsorption column using natural zeolite-based adsorbents to remove the remaining CO\textsubscript{2} content even though it has been reduced in the adsorption column 1. Biogas from the adsorption column output that has been pure then flowed and stored in a gas bag for further application.

3.2. EPR Analysis
Energy input consists of the same energy from the price of oil palm empty fruit bunches, the same electricity processing power requirements and energy from equipment depreciation. For energy output obtained from the selling price of energy, namely biogas and active organic liquid fertilizer (AOLF). The following is the calculation of the same energy input and output at the biogas pilot plant. Table 4 is used to find the same energy input with a 300 work day per year.

### Table 4. Energy information included in pilot scale biogas production and refining

| No. | Input Source                                      | Price or energy used                     |
|-----|---------------------------------------------------|------------------------------------------|
| 1   | Price of OPEFB 300 tons / year and POME           | Rp. 90,000,000.00                        |
| 2   | Electricity usage/year (manufacture and purification unit) | (100800 + 14,400) = 115,200 kWh        |
| 3   | Equipment depreciation                            | Rp. 40,630,000.00                        |

OPEFB as raw materials is fed 300 tons every year, and the investment cost for the pilot plant is Rp. 3,450,000,000. 00
From the data obtained an energy base of 1 liter diesel (42.96 MJ/Kg) [7]

a. The same energy from a biogas pilot plant for a capacity of 300 tons/year:

\[
\text{Energy} = \frac{\text{Rp. 90,000,000.00}}{\text{Rp. 7,000.00}} \times 42.96 \text{ MJ/kg}
\]

\[
\text{Energy} = 552,342.857 \text{ MJ/kg}
\]

b. Electricity usage per year:

\[
115.200 \text{ kWh} \times 3.6 \text{ MJ} = 414.720 \text{ MJ}
\]

c. The same energy from depreciation:

\[
\text{Energy} = \frac{\text{Rp. 40,360,000.00}}{\text{Rp. 7,000.00}} \times 42.96 \text{ MJ/kg}
\]

\[
\text{Energy} = 247,695.086 \text{ MJ/kg}
\]

### Table 5. Energy equality in biogas production and refining

| No. | Input Source                                      | Energy Equality (MJ/year) |
|-----|---------------------------------------------------|----------------------------|
| 1   | Energy of OPEFB and POME                         | 552,342.857               |
| 2   | Electricity usage/year (manufacture and purification unit) | 414,720                  |
| 3   | Equipment depreciation                           | 247,695.086               |
|     | Total                                            | 1,214,757.94               |

From the calculation, the total input energy is 1,214,757.94 MJ/year. The following data is used to find the same energy output. OPEFB raw material per year is 300 tons with the percentage of biogas yield of 13,500 m\textsuperscript{3} and the percentage of active organic liquid fertilizer products is 300 tons. Active organic liquid fertilizer is used as fertilizer in the plantations themselves.
The output energy data obtained is continued by calculating the same energy. The basis for determining the same energy is from the price of 1 liter of diesel oil. 

a. Energy is produced from biogas for a capacity of 300 tons/year:

\[
\text{Energy} = \frac{\text{Rp}.23,625,000,000.00}{\text{Rp}.7,000.00} \times 42.96 \text{ MJ/kg}
\]

\[
\text{Energy} = 144,990,000.00 \text{ MJ/kg}
\]

b. Energy produced from AOLF

\[
\text{Energy} = \frac{\text{Rp}.600,000,000.00}{\text{Rp}.7,000.00} \times 42.96 \text{ MJ/kg}
\]

\[
\text{Energy} = 3,682,285.71 \text{ MJ/kg}
\]

Energy = 3,682,285.71 MJ/ton

c. Energy Total

Energy = Energy produced from biogas + energy from AOLF

\[
\text{Energy} = 148,672,285 \text{ MJ/ton}
\]

The total energy output obtained is 314,375,143 MJ/ton, after being able to equalize the energy input and output, then it will calculate the Energy Productivity Ratio (EPR)

\[
\text{Energy} = \frac{\text{Output product}}{(\text{by product} - \text{input})}
\]

\[
\text{Energy} = \frac{148,672,285}{(3,682,285.71 - 1,214,757.94)}
\]

\[
\text{Energy} = \frac{148,672,285}{2,467,527.77} = 60.215 \text{ (EPR > 1)}
\]

4. Conclusion
The design of OPEFB waste treatment into biogas and biogas purification is expected to be applied to the concept of clean production (zero waste). Biogas production from OPEFB waste reaches 13,500 m³ per year and liquid fertilizer production is 300 tons per year. Purification plant produces purified biogas products with CO₂ content of 2% and H₂S of 2.5 ppm. The productivity ratio of energy values obtained from calculations is > 1, this shows that the energy output needs are greater than the input in the pilot plant. In accordance with the theory, EPR shows that this pilot plant provides benefits to the company. From the results of calculations performed, an EPR value of 60 is obtained, the result of this EPR value is included in the high EPR category due to the use of electrical input energy during an efficient processing, which is 414,720 MJ/ton per year.
Acknowledgment
This program was financially supported by NON PNBP Universitas Sumatera Utara, Program Profesor Mengabdi fiscal year 2019, no: 330/UN5.2.3.2.1/PPM/2019, date 20th Mei 2019.

References
[1] Irvan, Trisakti B, Maulina S and Daimon H 2018 *Rasayan J. of Chem*. 11 378.
[2] Trisakti B, Irvan, Adipasah H, Taslim and Turmuzi M 2017 *IOP Conference Series : Materials Science and Engineering* 180 012127.
[3] Hambali E, Mujdalipah S, Tambunan A H, Pattiwiri A W and Roy H 2007 *Teknologi Bioenergi* (Jakarta : Agromedia Pustaka)
[4] Nasrul and Maimun T 2009 *Jurnal Rekayasa Kimia dan Lingkungan*, 7 194.
[5] Hartatik W and Widowati L R 2005 *Pengaruh Kompos Pupuk Organik yang Diperkaya dengan Bahan Mineral dan Pupuk Hayati terhadap Sifat-Sifat Tanah, Serapan Hara, dan Produksi Sayuran Organik* (Bogor: Balai Penelitian Tanah)
[6] Trisakti B, Mhardela P, Husaini T, Irvan, and Daimon H 2018 *IOP Conference Series : Materials Science and Engineering* 309 012093.
[7] Felten D, Froba N, Fries J, Emmerling C 2013 *Renewable Energy* 55 160-174.