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Performance analysis of a 2.4 MW biogas power plant from palm oil mill liquid waste in the Sei Mangkei special economic zone

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ABSTRACT

The Biogas Power Plant (PLTBG), located in the Sei Mangkei Special Economic Zone (KEK), North Sumatra, is an effort to develop environmentally friendly renewable energy and has the potential to reduce greenhouse gas emissions. The PLTBG's performance during its first two years of operation was influenced by several factors, including electricity production, wastewater input capacity, output power, generation efficiency, and its economic value compared to PLN electricity. This study aims to process operational data of the Sei Mangkei SEZ Biogas Plant liquid waste/Palm Oil Mill Effluent (POME) Power Plant that utilizes the existing Sei Mangkei PKS liquid waste related to Performance including the capacity of the input of liquid waste/Palm Oil Mill Effluent (POME), output power. This study uses a performance approach method, stages of work activities that include several stages, namely the survey stage, data compilation stage, analysis stage, and calculation stage, data processing and conclusion. This technical analysis method uses analytical tools in the form of theoretical quantitative and qualitative models, the concept of minimizing Discharge and Waste, and the need for biogas plant environmental studies. The results of this study show that the capacity of the Sei Mangkei POM is 75 tons of FFB per hour or 325,255 tons of FFB per year. Based on fluctuations in FFB production over a 2-year period (2022-2023) in Sei Mangkei, the average production projection is 325,255 tons per year, with POME producing 65% of the average FFB production of 211,416 tons per year using the Covered In Ground Anaerobic Reactor (CIGAR) processing model.

Keywords: Biogas; renewable energy; POME.

1. Introduction

Palm oil is one of the export commodities in the agricultural sector which is still a leading sector in Indonesia with the planting area and harvest increasing from year to year, as seen from the average growth rate of the area of oil palm plantations during 2004-2014 of 7.67%, while palm oil production increased by an average of 11.09% per year [1].

Based on Table 1, the palm oil commodity statistics published by the Directorate General of Plantations, in 2015 the area of palm oil reached 10.9 million hectares with a production of 29.3 million tons of CPO. The area according to its business status is owned by the people (People's Plantations) covering 4.55 million hectares or 41.55% of the total area, state-owned (PTPN) covering 0.75 million hectares or 6.83% of the total area, while privately owned covering 5.66 million hectares or 51.62% where the private sector is divided into 2 (two), namely foreign private sector covering 0.17 million hectares or 1.54% and domestic private sector (local) covering 6.18 hectares or 56.69% [1].

Table 1. Growth of Indonesian oil palm plantation area 2004-2014 [2].

Year	Area (Ha.)				Rate
	PR	PBN	PBS	Total	Growth (%)
2004	2.220.338	605.865	2.458.520	5.284.723	0,00

Year	Area (Ha.)				Rate
	PR	PBN	PBS	Total	Growth (%)
2005	2.356.895	529.854	2.567.068	5.453.817	3,20
2006	2.549.572	687.428	3.357.914	6.594.914	20,92
2007	2.752.172	606.248	3.408.416	6.766.836	2,61
2008	2.881.898	602.963	3.878.986	7.363.847	8,82
2009	3.061.413	630.512	4.181.369	7.873.294	6,92
2010	3.387.257	631.520	4.366.617	8.385.394	6,50
2011	3.752.480	678.378	4.561.966	8.992.824	7,24
2012	4.137.620	683.227	4.751.868	9.572.715	6,45
2013	4.356.087	727.767	5.381.166	10.465.020	9,32
2014*)	4.551.854	748.272	5.656.105	10.956.231	4,69
Average Rate of Increase (%)					7,67

Oil palm is a plantation crop that plays a vital role in the plantation subsector. Palm oil development benefits include increasing farmer and community incomes, production as raw material for the processing industry, creating added value domestically, and CPO exports that generate foreign exchange and provide employment opportunities.

Palm oil production in 2014 reached 29.34 million tons with an average productivity of 3,568 kg/ha/year (directorate general of plantations, 2014). Smallholder-owned oil palm plantations produced 10.68 million tons of CPO, state-owned plantations produced 2.16 million tons, and the private sector contributed 16.5 million tons of CPO production [1].

The average growth rate of palm oil export volume, especially CPO, during 2003-2014 was 12.94% per year with an average increase in export value of 25.76% per year (Directorate General of Plantations, 2014). The realization of palm oil commodity exports in 2013 had reached a volume of 20.58 million tons (palm oil/CPO and other palm oils) with a value of US $ 15.84 billion (directorate general of plantations, 2014) in the Table 2. The volume of palm oil commodity exports until September 2014 reached 15.96 million tons with a value of US $ 12.75 million. This experienced an increase of 7.59% compared to the export volume until September 2013 of 14.831 million tons. The trade balance for palm oil commodities in 2013 reached US $19.34 billion (directorate general of plantations, 2014).

Table 2. Volume and value of CPO exports 2003-2013

Year	Palm oil			
	Volume (Ton)	Rate Growth (%)	Value (000 US$)	Rate Growth (%)
2003	6.386.409			2.454.626
2004	8.661.647	35,63	3.441.776	40,22
2005	10.375.792	19,79	3.756.557	9,15
2006	10.471.915	0,93	3.522.810	6,22
2007	11.875.418	13,4	7.868.640	123,36
2008	14.290.687	20,34	12.375.571	57,28
2009	16.829.205	17,76	10.367.621	16,23
2010	16.291.856	3,19	13.468.966	29,91
2011	16.436.202	0,89	17.261.247	28,16
2012	18.850.836	14,69	17.602.180	1,98
2013	20.577.976	9,16	15.838.850	10,02
	Rata-rata	12,94	Rata-rata	25,76

The purpose of this study is to process operational data from the Sei Mangkei SEZ Biogas Plant liquid waste/palm oil mill effluent (POME) power plant that utilizes the existing Sei Mangkei PKS liquid waste related to performance including the input capacity of liquid waste/palm oil mill effluent (POME), output power (Output).

2. Method.

Palm oil is one of Indonesia's leading commodities and is experiencing rapid growth. In addition to high palm oil production, palm oil mills also produce significant amounts of byproducts or waste. Generally, palm oil mill waste consists of two types: liquid waste, better known as Palm Oil Mill Effluent (POME), and solid waste. Liquid waste from palm oil mills originates from the steaming (sterilization) process, the clarification process, and hydrocyclone discharge. Generally, palm oil industry wastewater contains high levels of organic matter, potentially polluting groundwater and water bodies. Solid waste from the processing process consists of Empty Fruit Bunches (EFB) discarded from the thresher (rotating drum) after the boiled bunches are separated from the fruit, palm shells, and fiber. Solid waste from liquid waste processing consists of activated sludge carried by the wastewater treatment process. A typical palm oil mill (PKS) requires approximately 14–16 kWh per ton of FFB [3][4][5]. Untuk keperluan penerangan pabrik dan lain-lain dapat dipasang diesel sebagai pembangkit listrik. Diesel juga biasa diinstalasikan sebagai pembangkit cadangan. Pembangkitan energi merupakan salah satu manfaat yang dapat diperoleh dari pengolahan limbah PKS. Pemanfaatan dalam bentuk energi ini berpotensi besar mengingat limbah tersebut masih memiliki nilai kalor yang cukup tinggi.

Essentially, all solid waste from palm oil mills (PKS) can be utilized to meet the energy needs of the PKS, namely as fuel for steam boilers to supply hot steam and generate electricity. Fiber and shell waste can be used directly after leaving the production process as fuel. Depending on the design, steam boilers can operate using 100% shells, 100% fibers, or a combination of the two.

The energy conversion process to produce steam, needed for power generation and other processing purposes, is achieved through direct combustion. Combustion is the rapid oxidation of fuel to produce energy in the form of heat. A palm oil mill with a capacity of 100,000 tons of fresh fruit bunches (FFB) per year will produce approximately 6,000 tons of shells and 12,000 tons of fiber [3][4][5]. Assuming that the generation efficiency is around 25%, electrical energy will be obtained of 7.2–8.4 MW for the shell and 9.2–15.9 MW for the fiber [3][4][5]. Because the electricity requirement for production is 1.4–1.6 MW(e)h, PKS is able to be independent in terms of energy supply for its operational needs.

Considerable energy can be obtained from liquid waste processing. Liquid waste processing is carried out through a multi-stage process utilizing open ponds. For a palm oil mill with a capacity of up to approximately 80 tons of fresh fruit bunches (FFB) per hour, ponds covering tens of hectares are required. The core of this process is the biodegradation of the waste's organic components. Anaerobic decomposition involves the decomposition of compound organic matter into organic acids, which are then further decomposed into gases and water. Methane gas is formed during the liquid waste processing in these open ponds. The methane produced by this process is the largest component of biogas. It can be used as an energy source when processed in an anaerobic digester system. A palm oil mill with a capacity of 0.6-0.7 tons of liquid palm oil waste can produce approximately 20 m^3 of biogas [3].

The process of methane formation can be divided into three stages: hydrolysis, acetogenesis (dehydrogenesis) and methanogenesis [6]. In the hydrolysis stage, complex biomass materials are decomposed into simple glucose using enzymes produced by microorganisms as catalysts. An important result of this first stage is that the biomass becomes soluble in water and has a simpler chemical form that is more suitable for the next stage. In the second stage, dehydrogenation (the removal of hydrogen atoms from the biomass material) occurs, namely the conversion of glucose to acetic acid, carboxylation (the removal of carboxyl groups) of amino acids, the breakdown of long-chain fatty acids into short-chain acids, and the production of acetic acid as the final product. The third stage is the formation of biogas from acetic acid through fermentation by methanogenic bacteria. One popular methanogenic bacteria that is abundant in sludge is Methanobachillus omelianskii. Anaerobic cellulose metabolism involves complex reactions and is more difficult than anaerobic reactions of other organic materials such as carbohydrates, proteins, and fats.

Organic material collected in the digester (reactor) will be decomposed in two stages with the help of two types of bacteria [7]. In the first stage, the organic material will be degraded into weak acids with the help of acid-forming bacteria. These bacteria will decompose the liquid waste/Palm Oil Mill Effluent (POME) through the stages of hydrolysis and acidification. Hydrolysis is the decomposition of complex compounds or long-chain compounds such as fats, proteins, and carbohydrates into simpler compounds. Acidification is the formation of acids from simple compounds. After the organic material is converted into acids, the second stage of the anaerobic process is the formation of methane gas with the help of methane-forming archaebacteria such as Methanococus, Methanosarcina, and Methanobacterium.

Anaerobic cellulose metabolism involves complex reactions and the process is more difficult than anaerobic reactions of other organic materials such as carbohydrates, proteins and fats. In a palm oil mill that processes 40 tons of FFB/hour, liquid waste will be produced as much as 20 m^3/hour (calculation basis: 55% of FFB with a specific gravity of 1.1 g/cm^3 [8]. If the factory operates for 20 hours/day, it will produce 400 m3 of liquid waste per day. Calorific Value of Palm Oil Mill Waste [3][9][5][10].

Shell	: 4.105–4.802 kkal/kg
Fiber	: 2.637–4.554 kkal/kg
TBK	: 4.492 kkal/kg
Stem	: 4.176 kkal/kg
Leaf sheath	: 3.757 kkal/kg
POME	: 4.695–8.569 kkal/m^3

The record, 1 kcal = 4.187 Joule = 1,163 Wh.

Conducting an economic analysis of the development of PLTBg [11]. The PLTBg is designed with a capacity of 700 kW using a continuous stirred tank reactor (CSTR) biodigester. The electricity generated will be sold to PLN at a selling price of 85% of the basic cost of supply (BPP) for the Riau region of 1,249.5 Rp/kWh. The results of economic calculations show that the investment cost reaches 26.3 billion rupiah with a scheme of 70% bank loans and the remaining 30% with equity. Operation and maintenance costs reach 2.3 billion rupiah annually. The construction of the PLTBg is feasible to implement with an IRR value of 11.44%, a payback period of 7 years and 11 months, and an NPV of 1.1 billion rupiah.

Conducting a small renewable energy analysis of biogas liquid waste/palm oil mill effluent (POME) from a palm oil mill using the covered lagoon type, an alternative solution to the electricity deficit in Riau Province [12]. The palm oil plantation agro-industry spread across the Riau region has 147 palm oil mills (PKS) with a total production capacity of 6,584 tons/hour, potential liquid waste of 710,103,744 m^3/year. The electrical energy that can be generated is 434.54 MW, with electrical energy production of 2,476,849,990 kWh/year, potential electricity sales of Rp 2,414,928,740,015.87/year. The electricity deficit is 134.4 MW, while the potential for electrical energy from liquid waste/Palm Oil Mill Effluent (POME) is 434.54 MW, there is still a surplus of 300.14 MW, and if the power capacity is added up, 316.3 MW + 434.54 MW = 750.84 MW, more than enough for the electricity needs of Riau Province until 2016, which was only 701 MW.

Conducting an Analysis of a Biogas Power Plant (PLTBG) using Palm Oil Mill Effluent, which aims to determine the potential for electrical energy from liquid waste/Palm Oil Mill Effluent (POME) [13]. With a total production capacity of 45 tons/hour, the potential liquid waste flow is 492.25 m3/day. The results obtained from the biogas production analysis average 7.37 Nm^3/day. The electrical energy that can be generated is 1.2 MW, and the electrical energy production is 8,640,000 kWh/year with a production cost of Rp. 498,231/kWh. The potential excess power that can be sold to PLN is 5,186,426.4 kWh/year with a fed-in tariff of Rp. 1,575. Viewed from an economic perspective, the feasibility of investing in the construction of a biogas power plant is Rp. 43,039,606,156 with annual income from electricity sales of Rp. 6,943,328,343 will receive a down payment for 6.1 years.

Conducting a technical and economic analysis of biogas power plants (PLTBG) from palm oil liquid waste (Case study of Bangka PLTBG), that the liquid waste can provide benefits to the factory from an economic perspective, by analyzing the production of methane gas whose raw material is liquid waste processed anaerobically for PLTBiogas fuel [14]. The results obtained from the analysis of biogas production are methane gas 11,182.07 Nm^3/hour, and for the electrical energy produced an average of 1.62 MW, if converted into kWh, 38,880 kWh is obtained with a feed-in tariff of Rp. 1575/kWh, the income is Rp. 61,236,000/day, in terms of economic feasibility of investment NPV biogas analysis Rp. 40,416,194,104, with an interest rate of 11%, IRR 23%, DPBP 5 years, and from PLN revenue data, NPV Rp. 36,468,500,543, IRR 22%, DPBP 5 years [15].

Conducting analysis of liquid waste/palm oil mill effluent (POME) potential for biogas power plants in West Tanjung Jabung Regency [16]. The potential of liquid waste/palm oil mill effluent (POME) The assessment was conducted in Tanjung Jabung Barat District, which is one of the areas with very large liquid waste/palm oil mill effluent (POME) potential in Jambi Province. The results of measurements and discussions revealed that the flow rate of liquid waste/palm oil mill effluent (POME) is 146,880 m^3/year. With this potential, it can be designed to produce a power plant of 4.5 MWe, and the electricity generated is 42,336.00 kWh/year.

3. Results and Discussion

The palm oil mill (PKS) operating in the Sei Mangkei area has implemented an integrated and highly efficient liquid waste treatment system. The waste produced from the palm oil extraction process, known as palm oil mill effluent (POME), has a high organic content and has the potential to pollute the environment if not managed properly.

In an effort to reduce environmental impact while harnessing the energy potential of organic waste, Pertamina power Indonesia utilizes covered in-ground anaerobic reactor (CIGAR) technology in its POME processing process. This technology enables efficient biological degradation of organic matter in POME through a continuous anaerobic process 24 hours a day.

With the support of adequate processing infrastructure and based on tested technical parameters, this system is expected to not only be able to meet the established environmental standards, but also support the goals of clean production and sustainable waste management.

- PKS Capacity : 30 + 45 tons of fresh fruit bunches (FFB) per hour, or 325,255 tons of FFB per year.
- Based on fluctuations in FFB production over a two-year period (2022-2023) in Sei Mangkei, the projected average production is 325,255 tons per year, of which POME accounts for 65% of the average FFB production of 211,416 tons per year.
- POME Production : 211,416 tons per year.
- Digester tank capacity : 2 x 5.000 m^3
  - Equalization tank : 1 x 1.400 m^3
  - Mud sediment tank : 1 x 500 m^3
  - Processing parameters : BOD = 27.000 mg/L
    COD = 54.500 mg/L[17]
  - Effluent from the digester : BOD (total) < 1,350 mg/L (95% degraded)
    BOD (dissolved) < 650 mg/L
    COD (total) < 11,000 mg/L (80% degraded)
  - Digester operating time : 24 hours a day
  - Processing Model : Covered in ground anaerobic reactor (CIGAR)

Technical description of liquid waste/palm oil mill effluent (pome) processing into biogas

In palm oil mills, traditionally liquid waste or what is called palm oil mill effluent (POME) which is a by-product of FFB processing is processed anaerobically or aerobically in open ponds to reduce BOD and COD content, so that it meets environmental regulations and can then be discharged into waterways or used as fertilizer because it is rich in nutrients.

Palm oil mill effluent (POME)

Liquid waste from palm oil mills (PKS), known as palm oil mill effluent (POME), is an organic waste product with significant potential for use as a raw material for biogas production. In the context of waste management and renewable energy, POME is no longer viewed solely as an environmental problem, but as an alternative energy source that can be processed through anaerobic fermentation

POME is produced from various stages of the palm oil processing process, particularly from the clarification and sterilization of palm fruit. This waste has a very high organic content, including fats, proteins, and carbohydrates, making it highly suitable as a substrate for biogas production. The chemical and physical characteristics of PKS liquid waste significantly determine the efficiency and effectiveness of the fermentation process, as shown in Table 3.

Table 3. Characteristics of fermented biogas

No	Parameter	Unit	Nilai
1	pH	-	3,3 – 4,6
2	Total Solid	mg/L	16.580 – 94.106
3	Total Suspension Solid	mg/L	1.330 – 15.700
4	BOD	mg/L	8.200 – 35.400
5	COD	mg/L	15.300 – 65.100
6	Ammoniak (NH_4)	mg/L	2,5 – 50
7	Total Nitrogen	mg/L	12 – 126
8	Oil dan Grease	mg/L	190 – 14.720
9	C	%	34,3
10	H	%	4,68
11	N	%	3,53

The following presents the characteristics of liquid waste at the Sei Mangkei PKS:

1. Calculating daily production capacity
   If the initial capacity is 30 tons/hour and then increased to 75 tons/hour, we can calculate the total daily production with the average operating time.
   - New capacity: 75 tons/hour
   - Operating hours: 20 hours/day
   Amount of production per day: Daily production = Capacity × operating time
   Daily production = 75 tons/hour × 20 hours/day = 1,500 tons/day.
   PKS PSMKI currently has a capacity of 30 tons/hour and will be increased to a capacity of 75 tons/hour with an average operating time of 20 hours a day so that the production capacity will be 1,500 tons/day.
2. Calculate the liquid waste (POME) produced
   In this case, it is indicated that for every ton of fresh fruit bunch (FFB) processed, 0.65 m^3 of liquid waste is generated. To calculate the total liquid waste per day, we can use the following formula:
   - Daily production: 1,500 tons/day
   - Liquid waste per ton: 0.65 m^3/ton
   Amount of liquid waste produced per day:
   Liquid waste = Daily Production × Liquid Waste per ton
   Liquid waste = 1,500 tons/day × 0.65 m^3/ton = 975m^3/day.
   The calculation of the liquid waste/palm oil mill effluent (POME) produced is 0.65 m3/ton FFB, which is 975 m^3/day.
   Using the data above:

Increasing production capacity from 30 tons/hour to 75 tons/hour is a strategic step to improve the efficiency and output of the PSMKI palm oil mill (POM). With an average operating time of 20 hours per day, the daily production capacity reaches 1,500 tons of fresh fruit bunches (FFB). This demonstrates process optimization and the use of technology that allows for faster and greater processing in one working day. With a daily production of 1,500 tons of FFB and the assumption that each ton produces 0.65 m^3 of liquid waste (POME), the total liquid waste per day reaches 975 m^3. POME is one of the main wastes produced from the palm oil extraction process, and its management is crucial given its impact on the environment. This study shows that increasing production capacity must be accompanied by improved waste management to ensure the sustainability of the POM operation. High production is indeed promising from an economic perspective, but without good waste management, risks to the environment can increase.

4. Conclusion.

The results of this study are the Sei Mangkei palm oil mill (PKS) with a capacity of 75 tons of FFB per hour or 325,255 tons of FFB per year. Based on fluctuations in FFB production over a period of 2 years (2022-2023) in Sei Mangkei, the average production projection is 325,255 tons per year, of which POME is produced at 65% of the average FFB production of 211,416 tons per year. Processing of liquid waste/palm oil mill effluent (POME) into Biogas as a source of electrical energy is obtained through a fermentation reaction in an anerobic digester, with a covered in ground anaerobic reactor (CIGAR) system. This biogas-powered power plant from palm oil liquid waste has produced with a capacity of 13,137,996 kWh/year and operates for 300 days a year. The factory is located in the Sei Mangkei Special Economic Zone, Simalungun Regency, North Sumatra Province. Operation of the Sei Mangkei SEZ biogas plant power plant that utilizes the existing Sei Mangkei PKS Liquid Waste/palm oil mill effluent (POME) to analyze the liquid waste (POME) input capacity, output power, and PLTBG power plant production in the first and second years of operation (2022–2023).

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