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COMPOSITION OF EMPTY FRUIT BUNCH, BIOGAS, AND MESOCARP AS RENEWABLE ENERGY TO REPLACE PALM KERNEL SHELL WITH THE OPTIMUM GAS EMISSION (SO_2, NO_2 AND CO_2) IN INDUSTRY

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ABSTRACT

Indonesia is the largest palm oil-producing country in the world, with a share of 59%. In 2013 to 2023, palm oil production in Indonesia increased by an average of 4.7%. The emergence of waste also increases along with the increase in production. Palm oil mill waste consists of palm oil mill liquid waste (POME), mesocarp fiber, palm kernel shells, and empty oil palm bunches. In this study, waste from palm oil, such as mesocarp fiber and empty fruit bunches, can be used to replace the palm kernel shells. Moreover, the addition of biogas to mesocarp fiber and empty fruit bunches will be used as an addition to replace fuel in boiler. Gas emission (SO_2, NO_2 and CO_2) is key parameter for process combustion in boiler Boiler gas emission is regulated by Ministry of Environment regulation. **Aim:** This study was aimed to analyze and determine the optimum composition that can be used in boiler fuel where gas emissions are the main parameters, especially $N0_2$, SO_2 & CO_2. **Methodology and results:** The method in this study are a literature review, analyzing materials for proximate and ultimate, then analyzing the results. The results of this study are the optimum composition of 85% mesocarp fiber, 10% biogas, and 5% empty bunch fiber where composition SO_2 and NO_2 do not exceed the threshold and the lowest CO_2 gas production. **Conclusion, significance and impact study:** This study can be impacted to decrease waste from palm oil industry and used the waste palm as new alternative energy that can replace fuel in boiler.

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1. INTRODUCTION

Indonesia is the world's largest palm oil producer with 59% of total world production (United States Department of Agriculture Foreign Agricultural Service, 2023). Palm oil production in Indonesia will continue to grow annually. Palm oil is useful for a variety of applications, such as industrial oil, cooking oil (Bhikuning *et al*., 2018), and fuel (biodiesel) (Bhikuning *et al*., 2018; Bhikuning *et al*., 2020; Setiawan *et al*., 2022), due to its high coating power, resistance to oxidation under high pressure, and capacity to dissolve substances that are insoluble in conventional solvents. Recently, Indonesia has blended 30% palm oil into 70% fossil fuel. The percentages of palm oil with fossil fuel is still under 50%, this because the fatty fat in palm oil is reached and has a potential in damaging the engine. Moreover, next future with new technology in reducing fatty fat in biodiesel (Maharani *et al*., 2022), the ratio of percentages between palm oil biodiesel will be improved and the needed of palm oil will be increased. As shown in Figure 1, palm oil production will increase at an average rate of 4.7 percent from 2013-2023 (IndexMundi, 2023).

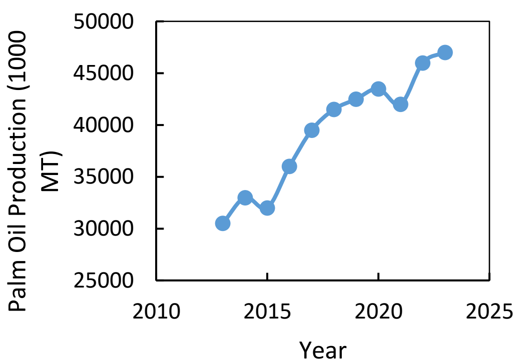

Figure 1 Indonesia palm oil production period 2013-2023 (IndexMundi, 2023)

The increase in production has resulted in an increase in the amount of waste produced. The amount of waste must be properly managed to reduce the negative impact on the environment (Noerrizki *et al.,* 2019). Waste generated from the processing of palm oil mills includes palm oil mill effluent (POME), mesocarp fibers, palm kernel shells and empty fruit bunches (Hambali & Rivai, 2017). All palm oil mill wastes have been utilized as both energy source and organic manure (Noerrizki *et al.,* 2019). Several countries have identified palm kernels as a renewable energy

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resource. This is illustrated by the $138.2 million palm kernel shell trade contract between Indonesia and Japan (Hubungan Masyarakat, n.d.). The contract increases the price of palm kernel shell, which is no longer a solid waste but a by-product with a high selling value.

Boiler fuels used in the palm oil industry are generally palm kernel shell and mesocrap fiber. The composition used consists of palm kernel shell 30% and mesocarp fiber 70%. The combustion process will result in the emission of gas that will be discharged into the environment. This emission gas parameter becomes a control parameter to reduce the greenhouse gas (GHG) effect on the environment. The palm oil mill is equipped with a cogeneration plant, which generates electricity and heat for use in the manufacturing process. The schematic diagram for this cogeneration system is presented in Figure 2.

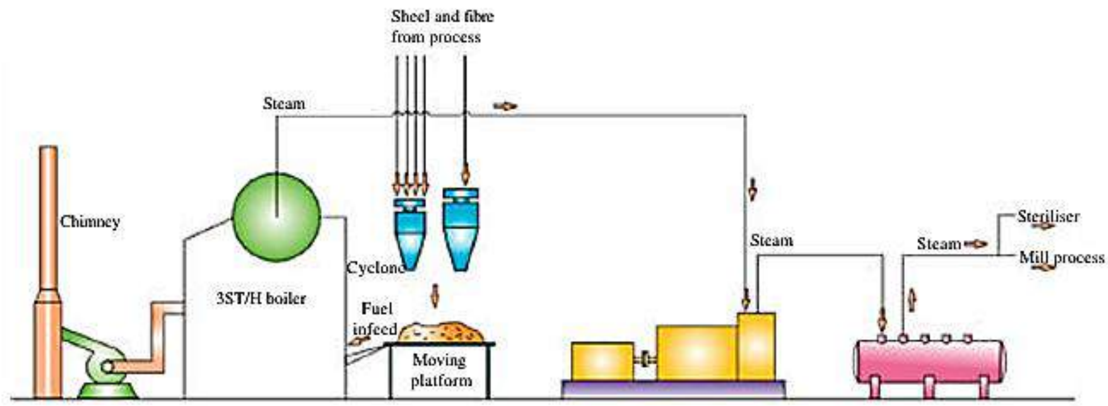

Figure 2 Schematic diagram cogeneration plant (Amin Abd Majid *et al.,* n.d.)

Generally, some waste solids from palm oil mill processing are used as boiler fuel, namely palm kernel shell and mesocrap fiber. However, other wastes can also be used as an alternative source of bioenergy, namely empty fruit bunch (Noerrizki et al., 2019). Boiler flue gas is one of the operating parameters controlled to meet the requirements from the governance regulations. In Indonesia, the Ministry of Environment already has a threshold or a standard value for boiler flue gas. The threshold value is outlined in the Ministry of Environment regulation no. 7 of 2007 where the threshold value can be seen in Table 1.

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Tabel 1 Threshold value of boiler flue gas (Permen LH Nomor 07 Tahun 2007)

No	Parameter	Threshold Value
1	Particle	300 mg/m^3
2	Sulfur Dioxide	600 mg/m^3
3	Nitrogen Dioxide	800 mg/m^3
4	Hydrogen Chloride	5 mg/m^3
5	Chlorine	5 mg/m^3
6	Ammonia	1 mg/m^3
7	Hydrogen Floride	8 mg/m^3
8	Opacity	30.00%

The chemical composition of the fuel material is a significant factor influencing the outcome of the combustion reaction. The flue gas from biomass combustion reactions contains CO_2, NO_2, and SO_2 compounds. Research on palm kernel shell has been done from several study (Novita *et al*., 2023 and Baffour *et al*., 2021). As the outermost portion of the seed, the palm kernel shell serves as protection for the seed. Before the edible portion is revealed, the shell must be shattered. It is thought that the oil palm evolved in the tropical rain forests of West Africa. The shell is a by-product of the process used to extract palm kernel oil and palm oil from palm tree seeds. Its structure is thick and resembles dark or black wood. Physical and chemical analysis from Palm Kernel Shell has been studied by several studies (Fono *et al*., 2014. and Okoroigwe *et al*., 2014). Moreover, ultimate and proximate analysis also have been carried out from many researchers (Fuadi *et al*., 2012 and Osita *et al*., 2011).

Study on Empty fruit bunch fibre has been conducted by previous researchers (Sekar *et al*., 2021 and Ibrahim *et al*., 2019). Empty fruit bunch has also been applied for alternative fuel in boiler. Many studies have been discussed for replacing fossil fuel to Empty fruit bunch. Research on Empty fruit bunch has been conducted in analysing and optimizing the utilization of fibre, shell, and Empty fruit bunch fibre by adjusting the content of the material and evaluating gas emission (NO_2, SO_2 and CO_2) production. The results of the analysis show that the best composition to minimize gas emission (NO_2, SO_2 and CO_2) in biomass power plants is to use 70% fibre, 0% shell, and 30% Empty fruit bunch fibre (Harahap *et al*., 2023). Study on the efficiency analysis of water tube boilers fuelled by fibre and shells in a palm oil mill with a capacity of 60 tons TBS/hour has been conducted. The fuel used were 75% fibre and 25% shells. The results obtained are a calorific value of 21078.48 kJ/kg, and the highest boiler efficiency value was 54.7% (Maulana *et al*., 2016).

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Moreover, Analysis of Empty fruit bunch characteristics for co-firing use has been carried out and the results are biopellets from Empty fruit bunch or empty fruit bunches contain 48.53% C, 6.05% H, 0.32% N, 36.8% O, and 0.08% sulphur. While the calorific value of Empty fruit bunch biopellets is 4.583 kcal/kg (Rusdianasari *et al*., 2023). In addition, research on the efficiency analysis of water tube boilers using fibre and shell fuel has been carried out with a composition of 70% fibre and 30% shell. The results obtained are the calorific value of 70% fibre and 30% shell is 4604.7 Cal/ g. The boiler efficiency obtained for 100% shell is 53.9% and 100% fibre is 51% (Siswanto *et al.,* 2022). Moreover, study on the composition of 100% Fibre, 75% Fibre 25% Shell, 50% Fibre 50% Shell, 25% Fibre 75% Shell 100% Shell has been conducted. The results obtained are the calorific value with variations in fibre and shell composition ranging from 14978.053 kJ/kg to 15463.083 kJ/kg with the calorific value at 100% fibre composition (15463.083 kJ/kg) (Siswanto, 2020). Furthermore, the majority of boilers in palm oil mills utilize biomass as a fuel source. Previous research indicates that biogas generated from POME processing can serve as an alternative fuel option. Combustion of mixed fuels, comprising biogas and biomass (particularly mesocarp fiber), has produced low particulate emission levels(Nasrin *et al*., 2019; Adewumi *et al* (2020).

The purpose of this research is to determine the optimal composition of mesocarp fiber, empty fruit bunch fiber, and biogas that will produce optimum composition gas emission (SO_2, NO_2 and CO_2) that meet the requirement and it does not exceed the threshold.

2. RESEARCH METHODOLOGY

The research framework describes the stage carried out during this research. Figure 3. Shows the research frameworks.

The initial stage of this research begins by looking for literature that are related to the research. Furthermore, secondary data collection is in the form mass balance palm mill 60 TPH, proximate use LECO TGA701 Thermogravimetric Analyzer & ultimate analysis use “ Thermo Scientific™ FlashSmart™ Elemental Analyzer from Thermo Fisher Scientific”(palm kernel shell, mesocarp fiber and empty fruit bunch fiber) gas analyzer use portable biogas analyzer MT 540 (biogas) and boiler specification.

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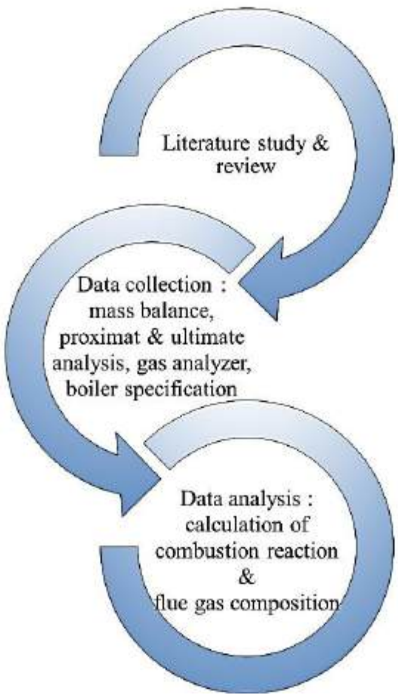

Figure 3 Research frameworks

The research method used in this study is the evaluating of flue gas composition (gas emission) following Indonesia Regulation of the Minister of Environment No. 7/2007 Concerning Emission Standards for Stationary Sources of Steam Boiler.

The analysis of flue gases from combustion reactions in boilers can be conducted using numerical analysis techniques. The combustion reaction is defined as the chemical reaction between oxygen and fuel, which results in the production of heat. The reaction that occurs in boilers can be generally classified into the following categories (Booneimsri *et al.,* 2018).

$$C + O2 \rightarrow CO2 + Heat \quad (1)$$

$$H2 + \frac{1}{2}O2 \rightarrow H2O + Heat \quad (2)$$

$$S + O2 \rightarrow SO2 + Heat \quad (3)$$

$$N + O2 \rightarrow NO2 + Heat \quad (4)$$

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$$CH4 + 2O2 \rightarrow CO2 + 2H2O + Heat \quad (5)$$

$$H2S + \frac{3}{2} O2 \rightarrow H2O + SO2 \quad (6)$$

The combustion reaction can be expressed as a linear equation. The solution to the equation will indicate the composition of the flue gas resulting from variations in fuel composition. The fuel composition will be selected based on the heat energy required to operate the boiler in accordance with specifications. The energy requirements can be calculated according to the Rankine cycle, whereby the heat energy can be calculated using Equation 7.

$$Q = m\,x\,Cp\,x\,(\Delta T) = m\,x\,(h2 - h1) \quad (7)$$

3. RESULTS AND DISCUSSION

3.1 Material Characteristics

The characteristics of the boiler fuel material are tested using proximate and ultimate analysis for solid materials, whereas gas materials are analyzed using a gas analyzer. The results of the material characteristics test are presented in Table 2 and 3.

Table 2 Material characteristics for solid material

Component (%-mass)	Mesocrap Fiber	Empty Fruit Bunch Fiber	Palm Kernel Shell
Moisture	9.59%	8.56%	8.54%
Ash	4.73%	10.13%	1.73%
Sulphur	0.16%	0.05%	0.07%
Hydrogen	5.57%	6.32%	5.81%
Carbon	47.39%	44.21%	51.22%
Oxygen	32.15%	26.93%	32.16%
Nitrogen	0.41%	3.80%	0.47%
Total	100.00%	100.00%	100.00%

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Table 3 Material characteristic for gas material

Component (%-vol)	BIOGAS
Methane	58.90%
Carbon dioxide	38.70%
Hydrogen sulfide	2.40%
Total	100.00%

As can be seen in Table 2 palm kernel shell has higher carbon than mesocarp fiber and empty fruit bunch fiber. So, it can be seen that Palm kernel shell has the potential to produce high carbon gas emissions compared to others. Moreover, palm kernel shell has the lowest moisture content value compared to empty fruit bunch fibre and mesocarp fibre. This will cause the HHV value of palm kernel shell to be higher than the others. The smaller the moisture content value in the material, the drier and more flammable the material will be (Baffour *et al*., 2021). The oxygen content for all materials has nearly the same as others, this can be explained that biomass contents of oxygen that can help increase the combustion process. Furthermore, the combustion would be perfected if the composition of air is fulfilled in the chamber, resulting the emissions will be reduced (Bhikuning *et al*., 2021).

As illustrated in Table 3, the composition of biogas and the one types only of materials utilized in the study are presented. As can be seen that biogas has many components such as methane, carbon dioxide, and hydrogen sulfide that can improve the combustion in boiler.

The utilization of empty fruit bunch fiber as a substitute for palm kernel shell is a possibility, given that the water content of the two is analogous, as confirmed by result of proximate and ultimate tests.

As can be seen in Tables 2 and 3, the composition between solid materials (mesocarp fibers, empty fruit bunches, palm kernel shells) and gas (biogas) has an impact on gas emissions, especially biogas with the largest CO_2 composition of 38.7% and empty fruit bunches with the largest Nitrogen composition of 3.8%. Therefore, it is important to be concerned about the composition of biogas and empty fruit bunches.

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3.2 Boiler Fuel Required

The calculation of fuel requirements for the boiler will be based on the specifications of the boiler, as detailed in Table 4.

Table 4 Boiler specification

Description	Specification	Unit
Boiler Type	Water Tube Boiler	-
Boiler Capacity	40	Ton/hour
Working Pressure	21	Barg (saturated steam)
Boiler Efficiency	74.6	%
Feed Water Temperature	70	°C
ID Fan Capacity	107.500	CFM
FD fan Capacity	34.600	CFM
Fuel Feeder Capacity	3500	CFM

The availability of materials will be determined through the calculation of mass balance with palm oil mill capacity 60 Fresh Fruit Bunch (FFB) ton per hours, as detailed in Table 5.

Table 5 Availability material (Bambang Sucahyo *et al.,* 2023; Prayitno Susanto, *et al*., 2017)

Description	Material Balance	Unit
Empty Fruit Bunch	21 %	12.6 Ton/hour
Palm Kernel Shell	6.5%	3.9 Ton/hour
Mesocrap Fiber	13%	7.8 Ton/hour
POME	60%	36 Ton/hour
Biogas	28 m^3 / 1 m^3 POME	0.828 Ton/hour

The availability of empty fruit bunch fiber makes it a preferable substitute material, as it is the most readily available. Furthermore, the use of biogas as a substitute material helps to mitigate the greenhouse gas emissions produced by palm oil mills.

The heat energy requirements for boiler operation, as specified, are employed as a reference for determining the composition to be utilized. Subsequent to the acquisition of energy requirements, the fuel composition is determined on the basis of the heating value of each material. The outcomes of the calculations pertaining to energy requirements and fuel

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requirements for each material are presented in Table 6.

Table 6 Energy demand and boiler fuel demand

Energy Required (kJ/hour)	Material	*Higher Heating Value* (kJ/kg)	Boiler Fuel Required (kg/hour)
134,423,646	Mesocarp fiber	19,908	6,752
	Palm Kernel Shell	19,121	7,030
	Empty Fruit Bunch Fiber	18,430	7,294
	Biogas	17,280	7,779

3.3 Combustion Process

The combustion reaction is assumed to be a perfect combustion reaction where excess air is added as much as 30% of the theoretical air requirement. There are several combustion reactions that occur in boilers as follows (Permata, 2012).

- Perfect combustion of carbon will form CO_2 with equation:

$$C + O_2 \rightarrow CO_2$$
$$12 g\ C + 32\ kg\ O_2 \rightarrow 44\ kg\ CO_2$$
$$1\ kg\ C + 2.67\ kg\ O_2 \rightarrow 3.67\ kg\ CO_2 \quad (8)$$

- Perfect combustion of hydrogen will form H_2O with equation:

$$4H + O_2 \rightarrow 2H_2O$$
$$4 kg\ H + 32\ kg\ O_2 \rightarrow 36\ kg\ H_2O$$
$$1\ kg\ H + 8\ kg\ O_2 \rightarrow 9\ kg\ H_2O \quad (9)$$

- Perfect combustion of sulfur will form SO_2 with equation:

$$S + O_2 \rightarrow SO_2$$
$$32\ kg\ S + 32\ kg\ O_2 \rightarrow 64\ kg\ SO_2$$
$$1\ kg\ S + 1\ kg\ O_2 \rightarrow 2\ kg\ SO_2 \quad (10)$$

- Perfect combustion of nitrogen will form NO_2 with equation:

$$N + O_2 \rightarrow NO_2$$
$$14\ kg\ N + 32\ kg\ O_2 \rightarrow 46\ kg\ NO_2$$

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$$1\ kg\ N\ +\ 2.29\ kg\ O_2 \rightarrow 3.29\ kg\ NO_2 \quad (11)$$

- Perfect combustion of methane will form CO_2 and H_2O with equation:

$$CH_4\ +\ 2O_2\ \rightarrow CO_2\ +\ 2\ H_2O$$
$$16\ kg\ CH_4 +\ 2\ (32\ kg)\ O_2 \rightarrow 44\ kg\ CO_2\ +\ 2\ (18\ kg)\ H_2O$$
$$16\ kg\ CH_4\ +\ 64\ kg\ O_2\ \rightarrow 44\ kg\ CO_2 +\ 36\ kg\ H_2O$$
$$1\ kg\ CH_4\ +\ 4\ kg\ O_2\ \rightarrow 2.75\ kg\ CO_2\ +\ 2.25\ kg\ H_2O \quad (12)$$

- Perfect combustion of hydrogen sulfide will form SO_2 and H_2O with equation:

$$H_2S\ +\ \frac{3}{2}\ O_2 \rightarrow H_2O\ +\ SO_2$$
$$34\ kg\ H_2S + \frac{3}{2}\ (32\ kg)\ O_2 \rightarrow 18\ kg\ H_2O\ \ +\ 64\ kg\ SO_2$$
$$34\ kg\ H_2S\ +\ 48\ kg\ O_2 \rightarrow 18\ kg\ H_2O\ \ +\ 64\ kg\ SO_2$$
$$1\ kg\ H_2S +\ 1.41\ kg\ O_2 \rightarrow 0.529\ kg\ H_2O\ \ +\ 1.882\ kg\ SO_2 \quad (13)$$

The outcomes of the calculations pertaining to theoretical air perfect combustion process for each material are presented in Table 7.

Table 7 Theoretical and excess air for perfect combustion

Material	Theoretical Air (kg Air/ kg fuel)	Theoretical Air + Excess Air 30% (kg air/ kg fuel)
Mesocarp fiber	6.088	7.915
Palm Kernel Shell	6.618	8.604
Empty Fruit Bunch Fiber	6.54	8.502
Biogas	2.913	3.787

3.4 Flue Gas Analysis

In order to achieve the optimal fuel composition with a flue gas composition that falls below the threshold, it is necessary to implement a series of composition variations. The composition variations undertaken in this study are presented in Tables 8.

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Table 8 Composition variation and boiler fuel required

Material	1st Composition		2nd Composition		3rd Composition		4th Composition	
	Comp (%)	Fuel (kg/hour)	Comp (%)	Fuel (kg/hour)	Comp (%)	Fuel (kg/hour)	Comp (%)	Fuel (kg/hour)
Palm kernel shell	0.3	2025.65	0	0.00	0	0.00	0	0.00
Mesocarp fiber	0.7	4726.51	0.85	5739.34	0.825	5570.53	0.8	5401.73
EFB Fiber	0	0	0.05	364.68	0.075	547.02	0.1	729.36
Biogas	0	0	0.1	777.90	0.1	777.90	0.1	777.90
Total	1	6752.16	1	6881.92	1	6895.456371	1	6908.99

Based on the fuel mass flow rate, the calculation of emission gases produced by the combustion reaction can be performed. The composition flue gas production can be seen in Table 9 and Table 10 for comparison against the government regulation threshold.

Tabel 9 Flue gas composition

Composition	Mass Flow Rate (kg/jam)		
	CO_2	SO_2	NO_2
1	12028.177	18.024	95.079
2	11312.961	62.549	123.010
3	11315.223	62.192	143.530
4	11317.486	61.834	164.049

Tabel 10 Comparison between flue gas composition and threshold

Composition	Component			
	SO_2 (mg/m^3)	Threshold	NO_2 (mg/m^3)	Threshold
1	94.60	600	499.00	800
2	329.39		647.78	
3	327.47		755.75	
4	325.54		863.69	

Based on tables 9 and 10, the emission gas produced by composition no. 1 has the highest CO_2 while the lowest SO_2 and NO_2 values where this composition is the composition of fuel commonly used in palm oil mills. Compositions 2, 3 and 4 are compositions using *palm kernel shell* replacement material which uses biogas and empty fruit bunch fiber. The use of empty fruit bunch fiber as fuel has a tendency that the less

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fruit bunch fiber will increase NO_2 and SO_2. This can be seen in Figures 5, 6 and 7.

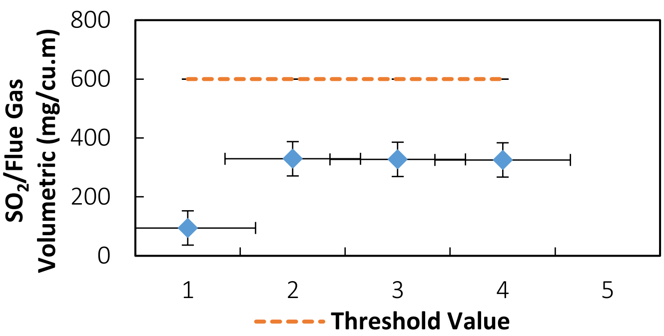

Figure 5 Comparison SO_2 value between calculated flue gas and threshold

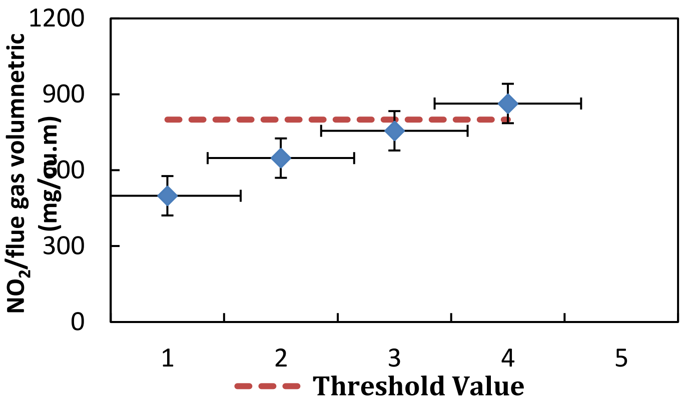

Figure 6 Comparison NO_2 value between calculated flue gas and threshold

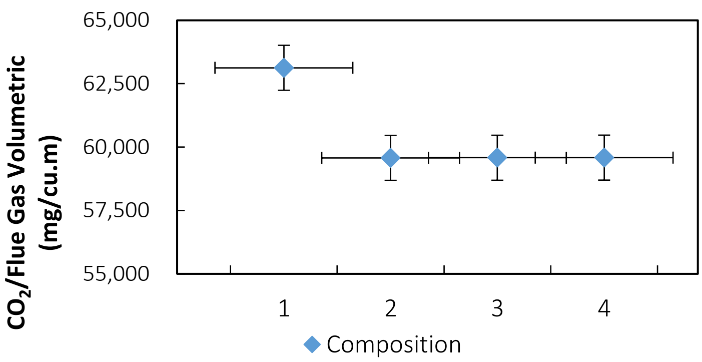

Figure 7 Comparison CO_2 value between calculated flue gas

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As can be seen in Figure 5,6 & 7 the composition that meet the requirements is no.2, with mesocarp fibre 85%, empty fruit bunch fibre 5% and biogas 10%. This composition shows that the analysis of NO_2 emission is smaller than composition no.3 and 4. However, in composition no.2, the results obtained are similar to previous studies where the use of empty fruit bunch fiber will reduce CO_2 production but increase SO_2 and NO_2 production (Harahap *et al*., 2023). The recommended composition in the previous study was 70% mesocrap fiber and 30% empty fruit bunch fiber without biogas (Harahap *et al*., 2023). This has similarities with the results of the study conducted where the palm kernel shell is no longer used as fuel but empty fruit bunch fiber and biogas fuel replacement material.

4. CONCLUSION

The fuel composition is a significant factor influencing the quality of the emission gases produced by boilers in the palm oil industry. Therefore, it is necessary to apply the optimum composition in order to achieve the lowest quality of emission gas, which will in turn reduce the greenhouse effect produced by palm oil mills. The optimum composition is composition no. 2, comprising 85% mesocarp fiber, 10% biogas, and 5% empty fruit bunch fiber. This research presents preliminary data that can be used as a basis for further experiments, either on a laboratory scale or an industrial scale.

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COMPOSITION OF EMPTY FRUIT BUNCH, BIOGAS, AND MESOCARP AS RENEWABLE ENERGY TO REPLACE PALM KERNEL SHELL WITH THE OPTIMUM GAS EMISSION (SO_2, NO_2 AND CO_2) IN INDUSTRY

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ABSTRACT

Indonesia is the largest palm oil-producing country in the world, with a share of 59%. In 2013 to 2023, palm oil production in Indonesia increased by an average of 4.7%. The emergence of waste also increases along with the increase in production. Palm oil mill waste consists of palm oil mill liquid waste (POME), mesocarp fiber, palm kernel shells, and empty oil palm bunches. In this study, waste from palm oil, such as mesocarp fiber and empty fruit bunches, can be used to replace the palm kernel shells. Moreover, the addition of biogas to mesocarp fiber and empty fruit bunches will be used as an addition to replace fuel in boiler. Gas emission (SO_2, NO_2 and CO_2) is key parameter for process combustion in boiler Boiler gas emission is regulated by Ministry of Environment regulation. **Aim:** This study was aimed to analyze and determine the optimum composition that can be used in boiler fuel where gas emissions are the main parameters, especially $N0_2$, SO_2 & CO_2. **Methodology and results:** The method in this study are a literature review, analyzing materials for proximate and ultimate, then analyzing the results. The results of this study are the optimum composition of 85% mesocarp fiber, 10% biogas, and 5% empty bunch fiber where composition SO_2 and NO_2 do not exceed the threshold and the lowest CO_2 gas production. **Conclusion, significance and impact study:** This study can be impacted to decrease waste from palm oil industry and used the waste palm as new alternative energy that can replace fuel in boiler.

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- Biogas
- Boiler
- Empty fruit bunch
- Mesocarp
- Palm kernel shell

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1. INTRODUCTION

Indonesia is the world's largest palm oil producer with 59% of total world production (United States Department of Agriculture Foreign Agricultural Service, 2023). Palm oil production in Indonesia will continue to grow annually. Palm oil is useful for a variety of applications, such as industrial oil, cooking oil (Bhikuning *et al.*, 2018), and fuel (biodiesel) (Bhikuning *et al.*, 2018; Bhikuning *et al.*, 2020; Setiawan *et al.*, 2022), due to its high coating power, resistance to oxidation under high pressure, and capacity to dissolve substances that are insoluble in conventional solvents. Recently, Indonesia has blended 30% palm oil into 70% fossil fuel. The percentages of palm oil with fossil fuel is still under 50%, this because the fatty fat in palm oil is reached and has a potential in damaging the engine. Moreover, next future with new technology in reducing fatty fat in biodiesel (Maharani *et al.*, 2022), the ratio of percentages between palm oil biodiesel will be improved and the needed of palm oil will be increased. As shown in Figure 1, palm oil production will increase at an average rate of 4.7 percent from 2013-2023 (IndexMundi, 2023).

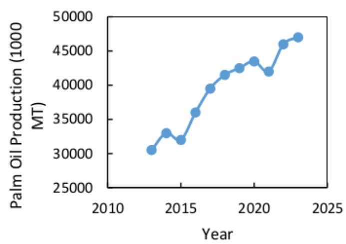

Figure 1 Indonesia palm oil production period 2013-2023 (IndexMundi, 2023)

The increase in production has resulted in an increase in the amount of waste produced. The amount of waste must be properly managed to reduce the negative impact on the environment (Noerrizki *et al.,* 2019). Waste generated from the processing of palm oil mills includes palm oil mill effluent (POME), mesocarp fibers, palm kernel shells and empty fruit bunches (Hambali & Rivai, 2017). All palm oil mill wastes have been utilized as both energy source and organic manure (Noerrizki *et al.,* 2019). Several countries have identified palm kernels as a renewable energy

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resource. This is illustrated by the $138.2 million palm kernel shell trade contract between Indonesia and Japan (Hubungan Masyarakat, n.d.). The contract increases the price of palm kernel shell, which is no longer a solid waste but a by-product with a high selling value.

Boiler fuels used in the palm oil industry are generally palm kernel shell and mesocrap fiber. The composition used consists of palm kernel shell 30% and mesocarp fiber 70%. The combustion process will result in the emission of gas that will be discharged into the environment. This emission gas parameter becomes a control parameter to reduce the greenhouse gas (GHG) effect on the environment. The palm oil mill is equipped with a cogeneration plant, which generates electricity and heat for use in the manufacturing process. The schematic diagram for this cogeneration system is presented in Figure 2.

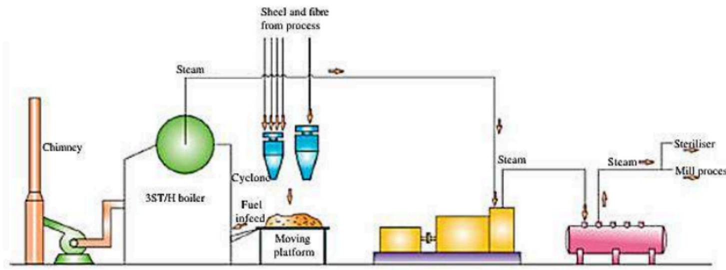

Figure 2 Schematic diagram cogeneration plant (Amin Abd Majid *et al.*, n.d.)

Generally, some waste solids from palm oil mill processing are used as boiler fuel, namely palm kernel shell and mesocrap fiber. However, other wastes can also be used as an alternative source of bioenergy, namely empty fruit bunch (Noerrizki et al., 2019). Boiler flue gas is one of the operating parameters controlled to meet the requirements from the governance regulations. In Indonesia, the Ministry of Environment already has a threshold or a standard value for boiler flue gas. The threshold value is outlined in the Ministry of Environment regulation no. 7 of 2007 where the threshold value can be seen in Table 1.

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Tabel 1 Threshold value of boiler flue gas (Permen LH Nomor 07 Tahun 2007)

No	Parameter	Threshold Value
1	Particle	300 mg/m^3
2	Sulfur Dioxide	600 mg/m^3
3	Nitrogen Dioxide	800 mg/m^3
4	Hydrogen Chloride	5 mg/m^3
5	Chlorine	5 mg/m^3
6	Ammonia	1 mg/m^3
7	Hydrogen Floride	8 mg/m^3
8	Opacity	30.00%

The chemical composition of the fuel material is a significant factor influencing the outcome of the combustion reaction. The flue gas from biomass combustion reactions contains CO_2, NO_2, and SO_2 compounds. Research on palm kernel shell has been done from several study (Novita *et al.*, 2023 and Baffour *et al.*, 2021). As the outermost portion of the seed, the palm kernel shell serves as protection for the seed. Before the edible portion is revealed, the shell must be shattered. It is thought that the oil palm evolved in the tropical rain forests of West Africa. The shell is a by-product of the process used to extract palm kernel oil and palm oil from palm tree seeds. Its structure is thick and resembles dark or black wood. Physical and chemical analysis from Palm Kernel Shell has been studied by several studies (Fono *et al.*, 2014. and Okoroigwe *et al.*, 2014). Moreover, ultimate and proximate analysis also have been carried out from many researchers (Fuadi *et al.*, 2012 and Osita *et al.*, 2011).

Study on Empty fruit bunch fibre has been conducted by previous researchers (Sekar *et al.*, 2021 and Ibrahim *et al.*, 2019). Empty fruit bunch has also been applied for alternative fuel in boiler. Many studies have been discussed for replacing fossil fuel to Empty fruit bunch. Research on Empty fruit bunch has been conducted in analysing and optimizing the utilization of fibre, shell, and Empty fruit bunch fibre by adjusting the content of the material and evaluating gas emission (NO_2, SO_2 and CO_2) production. The results of the analysis show that the best composition to minimize gas emission (NO_2, SO_2 and CO_2) in biomass power plants is to use 70% fibre, 0% shell, and 30% Empty fruit bunch fibre (Harahap *et al*., 2023). Study on the efficiency analysis of water tube boilers fuelled by fibre and shells in a palm oil mill with a capacity of 60 tons TBS/hour has been conducted. The fuel used were 75% fibre and 25% shells. The results obtained are a calorific value of 21078.48 kJ/kg, and the highest boiler efficiency value was 54.7% (Maulana *et al.*, 2016).

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Moreover, Analysis of Empty fruit bunch characteristics for co-firing use has been carried out and the results are biopellets from Empty fruit bunch or empty fruit bunches contain 48.53% C, 6.05% H, 0.32% N, 36.8% O, and 0.08% sulphur. While the calorific value of Empty fruit bunch biopellets is 4.583 kcal/kg (Rusdianasari *et al*., 2023). In addition, research on the efficiency analysis of water tube boilers using fibre and shell fuel has been carried out with a composition of 70% fibre and 30% shell. The results obtained are the calorific value of 70% fibre and 30% shell is 4604.7 Cal/ g. The boiler efficiency obtained for 100% shell is 53.9% and 100% fibre is 51% (Siswanto *et al.,* 2022). Moreover, study on the composition of 100% Fibre, 75% Fibre 25% Shell, 50% Fibre 50% Shell, 25% Fibre 75% Shell 100% Shell has been conducted. The results obtained are the calorific value with variations in fibre and shell composition ranging from 14978.053 kJ/kg to 15463.083 kJ/kg with the calorific value at 100% fibre composition (15463.083 kJ/kg) (Siswanto, 2020). Furthermore, the majority of boilers in palm oil mills utilize biomass as a fuel source. Previous research indicates that biogas generated from POME processing can serve as an alternative fuel option. Combustion of mixed fuels, comprising biogas and biomass (particularly mesocarp fiber), has produced low particulate emission levels(Nasrin *et al*., 2019; Adewumi *et al* (2020).

The purpose of this research is to determine the optimal composition of mesocarp fiber, empty fruit bunch fiber, and biogas that will produce optimum composition gas emission (SO_2, NO_2 and CO_2) that meet the requirement and it does not exceed the threshold.

2. RESEARCH METHODOLOGY

The research framework describes the stage carried out during this research. Figure 3. Shows the research frameworks.

The initial stage of this research begins by looking for literature that are related to the research. Furthermore, secondary data collection is in the form mass balance palm mill 60 TPH, proximate use LECO TGA701 Thermogravimetric Analyzer & ultimate analysis use " Thermo Scientific™ FlashSmart™ Elemental Analyzer from Thermo Fisher Scientific"(palm kernel shell, mesocarp fiber and empty fruit bunch fiber) gas analyzer use portable biogas analyzer MT 540 (biogas) and boiler specification.

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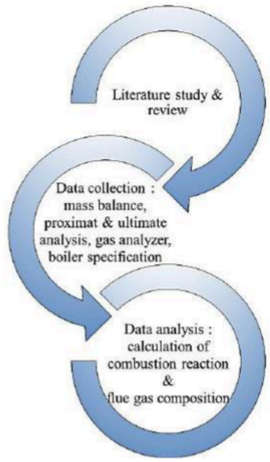

Figure 3 Research frameworks

The research method used in this study is the evaluating of flue gas composition (gas emission) following Indonesia Regulation of the Minister of Environment No. 7/2007 Concerning Emission Standards for Stationary Sources of Steam Boiler.

The analysis of flue gases from combustion reactions in boilers can be conducted using numerical analysis techniques. The combustion reaction is defined as the chemical reaction between oxygen and fuel, which results in the production of heat. The reaction that occurs in boilers can be generally classified into the following categories (Booneimsri *et al.,* 2018).

$$C + O2 \rightarrow CO2 + Heat \quad (1)$$

$$H2 + \frac{1}{2} O2 \rightarrow H2O + Heat \quad (2)$$

$$S + O2 \rightarrow SO2 + Heat \quad (3)$$

$$N + O2 \rightarrow NO2 + Heat \quad (4)$$

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$$CH4 + 2O2 \rightarrow CO2 + 2H2O + Heat \quad (5)$$

$$H2S + \frac{3}{2}O2 \rightarrow H2O + SO2 \quad (6)$$

The combustion reaction can be expressed as a linear equation. The solution to the equation will indicate the composition of the flue gas resulting from variations in fuel composition. The fuel composition will be selected based on the heat energy required to operate the boiler in accordance with specifications. The energy requirements can be calculated according to the Rankine cycle, whereby the heat energy can be calculated using Equation 7.

$$Q = m\,x\,Cp\,x\,(\Delta T) = m\,x\,(h2 - h1) \quad (7)$$

3. RESULTS AND DISCUSSION

3.1 Material Characteristics

The characteristics of the boiler fuel material are tested using proximate and ultimate analysis for solid materials, whereas gas materials are analyzed using a gas analyzer. The results of the material characteristics test are presented in Table 2 and 3.

Table 2 Material characteristics for solid material

Component (%-mass)	Mesocrap Fiber	Empty Fruit Bunch Fiber	Palm Kernel Shell
Moisture	9.59%	8.56%	8.54%
Ash	4.73%	10.13%	1.73%
Sulphur	0.16%	0.05%	0.07%
Hydrogen	5.57%	6.32%	5.81%
Carbon	47.39%	44.21%	51.22%
Oxygen	32.15%	26.93%	32.16%
Nitrogen	0.41%	3.80%	0.47%
Total	100.00%	100.00%	100.00%

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Table 3 Material characteristic for gas material

Component (%-vol)	BIOGAS
Methane	58.90%
Carbon dioxide	38.70%
Hydrogen sulfide	2.40%
Total	100.00%

As can be seen in Table 2 palm kernel shell has higher carbon than mesocarp fiber and empty fruit bunch fiber. So, it can be seen that Palm kernel shell has the potential to produce high carbon gas emissions compared to others. Moreover, palm kernel shell has the lowest moisture content value compared to empty fruit bunch fibre and mesocarp fibre. This will cause the HHV value of palm kernel shell to be higher than the others. The smaller the moisture content value in the material, the drier and more flammable the material will be (Baffour *et al*., 2021). The oxygen content for all materials has nearly the same as others, this can be explained that biomass contents of oxygen that can help increase the combustion process. Furthermore, the combustion would be perfected if the composition of air is fulfilled in the chamber, resulting the emissions will be reduced (Bhikuning *et al*., 2021).

As illustrated in Table 3, the composition of biogas and the one types only of materials utilized in the study are presented. As can be seen that biogas has many components such as methane, carbon dioxide, and hydrogen sulfide that can improve the combustion in boiler.

The utilization of empty fruit bunch fiber as a substitute for palm kernel shell is a possibility, given that the water content of the two is analogous, as confirmed by result of proximate and ultimate tests.

As can be seen in Tables 2 and 3, the composition between solid materials (mesocarp fibers, empty fruit bunches, palm kernel shells) and gas (biogas) has an impact on gas emissions, especially biogas with the largest CO_2 composition of 38.7% and empty fruit bunches with the largest Nitrogen composition of 3.8%. Therefore, it is important to be concerned about the composition of biogas and empty fruit bunches.

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3.2 Boiler Fuel Required

The calculation of fuel requirements for the boiler will be based on the specifications of the boiler, as detailed in Table 4.

Table 4 Boiler specification

Description	Specification	Unit
Boiler Type	Water Tube Boiler	-
Boiler Capacity	40	Ton/hour
Working Pressure	21	Barg (saturated steam)
Boiler Efficiency	74.6	%
Feed Water Temperature	70	ºC
ID Fan Capacity	107.500	CFM
FD fan Capacity	34.600	CFM
Fuel Feeder Capacity	3500	CFM

The availability of materials will be determined through the calculation of mass balance with palm oil mill capacity 60 Fresh Fruit Bunch (FFB) ton per hours, as detailed in Table 5.

Table 5 Availability material (Bambang Sucahyo *et al.,* 2023; Prayitno Susanto, *et al*., 2017)

Description	Material Balance	Unit
Empty Fruit Bunch	21 %	12.6 Ton/hour
Palm Kernel Shell	6.5%	3.9 Ton/hour
Mesocrap Fiber	13%	7.8 Ton/hour
POME	60%	36 Ton/hour
Biogas	28 m^3 / 1 m^3 POME	0.828 Ton/hour

The availability of empty fruit bunch fiber makes it a preferable substitute material, as it is the most readily available. Furthermore, the use of biogas as a substitute material helps to mitigate the greenhouse gas emissions produced by palm oil mills.

The heat energy requirements for boiler operation, as specified, are employed as a reference for determining the composition to be utilized. Subsequent to the acquisition of energy requirements, the fuel composition is determined on the basis of the heating value of each material. The outcomes of the calculations pertaining to energy requirements and fuel

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requirements for each material are presented in Table 6.

Table 6 Energy demand and boiler fuel demand

Energy Required (kJ/hour)	Material	*Higher Heating Value* (kJ/kg)	Boiler Fuel Required (kg/hour)
134,423,646	Mesocarp fiber	19,908	6,752
	Palm Kernel Shell	19,121	7,030
	Empty Fruit Bunch Fiber	18,430	7,294
	Biogas	17,280	7,779

3.3 Combustion Process

The combustion reaction is assumed to be a perfect combustion reaction where excess air is added as much as 30% of the theoretical air requirement. There are several combustion reactions that occur in boilers as follows (Permata, 2012).

- Perfect combustion of carbon will form CO_2 with equation:

$$C + O_2 \rightarrow CO_2$$
$$12g\ C + 32\ kg\ O_2 \rightarrow 44\ kg\ CO_2$$
$$1\ kg\ C + 2.67\ kg\ O_2 \rightarrow 3.67\ kg\ CO_2 \tag{8}$$

- Perfect combustion of hydrogen will form H_2O with equation:

$$4H + O_2 \rightarrow 2H_2O$$
$$4kg\ H + 32\ kg\ O_2 \rightarrow 36\ kg\ H_2O$$
$$1\ kg\ H + 8\ kg\ O_2 \rightarrow 9\ kg\ H_2O \tag{9}$$

- Perfect combustion of sulfur will form SO_2 with equation:

$$S + O_2 \rightarrow SO_2$$
$$32\ kg\ S + 32\ kg\ O_2 \rightarrow 64\ kg\ SO_2$$
$$1\ kg\ S + 1\ kg\ O_2 \rightarrow 2\ kg\ SO_2 \tag{10}$$

- Perfect combustion of nitrogen will form NO_2 with equation:

$$N + O_2 \rightarrow NO_2$$
$$14\ kg\ N + 32\ kg\ O_2 \rightarrow 46\ kg\ NO_2$$

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$$1\,kg\,N + 2.29\,kg\,O_2 \rightarrow 3.29\,kg\,NO_2 \quad (11)$$

- Perfect combustion of methane will form CO_2 and H_2O with equation:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2\,H_2O$$
$$16\,kg\,CH_4 + 2\,(32\,kg)\,O_2 \rightarrow 44\,kg\,CO_2 + 2\,(18\,kg)\,H_2O$$
$$16\,kg\,CH_4 + 64\,kg\,O_2 \rightarrow 44\,kg\,CO_2 + 36\,kg\,H_2O$$
$$1\,kg\,CH_4 + 4\,kg\,O_2 \rightarrow 2.75\,kg\,CO_2 + 2.25\,kg\,H_2O \quad (12)$$

- Perfect combustion of hydrogen sulfide will form SO_2 and H_2O with equation:

$$H_2S + \frac{3}{2}\,O_2 \rightarrow H_2O + SO_2$$
$$34\,kg\,H_2S + \frac{3}{2}\,(32\,kg)\,O_2 \rightarrow 18\,kg\,H_2O + 64\,kg\,SO_2$$
$$34\,kg\,H_2S + 48\,kg\,O_2 \rightarrow 18\,kg\,H_2O + 64\,kg\,SO_2$$
$$1\,kg\,H_2S + 1.41\,kg\,O_2 \rightarrow 0.529\,kg\,H_2O + 1.882\,kg\,SO_2 \quad (13)$$

The outcomes of the calculations pertaining to theoretical air perfect combustion process for each material are presented in Table 7.

Table 7 Theoretical and excess air for perfect combustion

Material	Theoretical Air (kg Air/ kg fuel)	Theoretical Air + Excess Air 30% (kg air/ kg fuel)
Mesocarp fiber	6.088	7.915
Palm Kernel Shell	6.618	8.604
Empty Fruit Bunch Fiber	6.54	8.502
Biogas	2.913	3.787

3.4 Flue Gas Analysis

In order to achieve the optimal fuel composition with a flue gas composition that falls below the threshold, it is necessary to implement a series of composition variations. The composition variations undertaken in this study are presented in Tables 8.

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Table 8 Composition variation and boiler fuel required

Material	1st Composition		2nd Composition		3rd Composition		4th Composition	
	Comp (%)	Fuel (kg/hour)	Comp (%)	Fuel (kg/hour)	Comp (%)	Fuel (kg/hour)	Comp (%)	Fuel (kg/hour)
Palm kernel shell	0.3	2025.65	0	0.00	0	0.00	0	0.00
Mesocarp fiber	0.7	4726.51	0.85	5739.34	0.825	5570.53	0.8	5401.73
EFB Fiber	0	0	0.05	364.68	0.075	547.02	0.1	729.36
Biogas	0	0	0.1	777.90	0.1	777.90	0.1	777.90
Total	1	6752.16	1	6881.92	1	6895.456371	1	6908.99

Based on the fuel mass flow rate, the calculation of emission gases produced by the combustion reaction can be performed. The composition flue gas production can be seen in Table 9 and Table 10 for comparison against the government regulation threshold.

Tabel 9 Flue gas composition

Composition	Mass Flow Rate (kg/jam)		
	CO_2	SO_2	NO_2
1	12028.177	18.024	95.079
2	11312.961	62.549	123.010
3	11315.223	62.192	143.530
4	11317.486	61.834	164.049

Tabel 10 Comparison between flue gas composition and threshold

Composition	Component			
	SO_2 (mg/m^3)	Threshold	NO_2 (mg/m^3)	Threshold
1	94.60	600	499.00	800
2	329.39		647.78	
3	327.47		755.75	
4	325.54		863.69	

Based on tables 9 and 10, the emission gas produced by composition no. 1 has the highest CO_2 while the lowest SO_2 and NO_2 values where this composition is the composition of fuel commonly used in palm oil mills. Compositions 2, 3 and 4 are compositions using *palm kernel shell* replacement material which uses biogas and empty fruit bunch fiber. The use of empty fruit bunch fiber as fuel has a tendency that the less

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fruit bunch fiber will increase NO_2 and SO_2. This can be seen in Figures 5, 6 and 7.

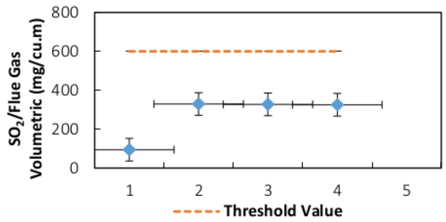

Figure 5 Comparison SO_2 value between calculated flue gas and threshold

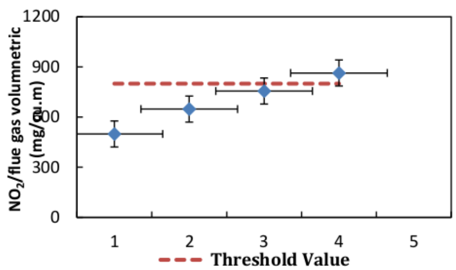

Figure 6 Comparison NO_2 value between calculated flue gas and threshold

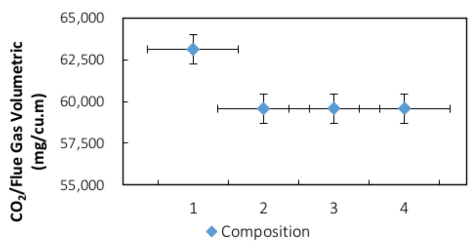

Figure 7 Comparison CO_2 value between calculated flue gas

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As can be seen in Figure 5,6 & 7 the composition that meet the requirements is no.2, with mesocarp fibre 85%, empty fruit bunch fibre 5% and biogas 10%. This composition shows that the analysis of NO_2 emission is smaller than composition no.3 and 4. However, in composition no.2, the results obtained are similar to previous studies where the use of empty fruit bunch fiber will reduce CO_2 production but increase SO_2 and NO_2 production (Harahap *et al*., 2023). The recommended composition in the previous study was 70% mesocrap fiber and 30% empty fruit bunch fiber without biogas (Harahap *et al*., 2023). This has similarities with the results of the study conducted where the palm kernel shell is no longer used as fuel but empty fruit bunch fiber and biogas fuel replacement material.

4. CONCLUSION

The fuel composition is a significant factor influencing the quality of the emission gases produced by boilers in the palm oil industry. Therefore, it is necessary to apply the optimum composition in order to achieve the lowest quality of emission gas, which will in turn reduce the greenhouse effect produced by palm oil mills. The optimum composition is composition no. 2, comprising 85% mesocarp fiber, 10% biogas, and 5% empty fruit bunch fiber. This research presents preliminary data that can be used as a basis for further experiments, either on a laboratory scale or an industrial scale.

5. ACKNOWLEDGEMENT

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