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IDENTIFICATION OF COMBUSTION REGULARITIES OF FUEL MIXTURES FROM AZOLLA BIOMASS, GOAT MANURE BIOCHAR AND GOAT MANURE BIO-OIL FOR FCC FURNACE

Fluid catalytic cracking (FCC) is a method of cracking vegetable oils into simpler fractions and green fuel oils. One component of the FCC system is the FCC furnace. The FCC furnace is where the combustion process occurs and provides high heat transfer throughout the FCC system, especially for heating the reactor. The reactor temperature is the catalyst cracking temperature. The cracking temperature of the catalyst depends on the feed oil used in the cracking process, such as crude palm oil at 450–550 °C or crude bio-oil at 300 °C. The fuel for heating an FCC furnace is usually coal. To reduce coal, we use a mixture of Azolla microphylla biomass with biochar and bio-oil from goat manure. The aim of this study was to analyze the mixture of Azolla microphylla biomass with biochar and bio-oil from goat manure to obtain sufficient furnace temperature to heat the FCC reactor, perform analytical calculations to obtain the volume of flue gas formed from the combustion reaction. We conducted two experiments; the first experiment used a mixture of 1 kg of Goat Manure Biochar (GMBC) with 0.5 kg of Azolla microphylla and the second experiment used a mixture of one kg of GMBC with 0.5 kg of Azolla microphylla plus 300 ml of Goat Manure Bio-oil (GMBO). A fuel mixture of one kilogram GMBC with 0.5 kg Azolla is not effective in combustion because the maximum temperature in the furnace is 177 °C but the fuel mixture of one kg GMBC, 0.5 kg Azolla and 300 ml GMBO has a furnace temperature of 472.75 °C, which can heat the stripper up to 313.25 °C so that cracking can occur in the raw bio-oil. Analysis of combustion results showed an increase in total CO_2 volume from experiment one and experiment two of 0.966 ($m^3_{CO_2}$/kg fuel)

Keywords: FCC, biochar, biomass, goat manure, fuel mixture, combustion, Azolla

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1. Introduction

The world is intensively developing renewable energy. In this modern era, renewable energy is needed to maintain energy availability in the future. One of the renewable energy sources is biomass. Biomass is organic material derived from animals, microorganisms, plants, residues, organic matter and waste from agriculture, forests and industry. Indonesia is making a transition from fossil energy to renewable energy. Combustion using a mixture of biomass and coal or co-firing is often used in industry and power plants. The use of coal in combustion causes CO_2 emissions and must be replaced with the use of biomass fuel. The mixed biomass in the industry comes from wood, plantation, or agricultural waste [1–3] and researchers have carried out an analysis of the flue gas produced during the co-combustion of coal and biomass [4]. The burning process of biomass produces CO_2, which will be absorbed by plants, therefore burning biomass will not increase the CO_2 content in the earth. For this reason, biomass is considered a zero-emission fuel [5].

Azolla microphylla can be used as biomass and has many benefits. Azolla is an aquatic plant with small leaves that grows very fast and can live in cold temperatures, namely at 11.5–20 °C so that Azolla can grow even in cold weather. This plant can also grow in polluted waters and reduce the level of pollution in water [6]. Azolla's ability to grow very fast can be used as a method to absorb atmospheric CO_2 and remove carbon from the activated carbon cycle [7]. Most of the research on the utilization of Azolla biomass has carried out the pyrolysis process to obtain biofuel [8, 9] and several researchers have conducted experiments to obtain parameters, bio-oil quality, and environmental benefits from Azolla bio-oil [10–12].

The advantage of biomass from plants is that plants can reduce CO_2 and can be used as fuel, similar to animal waste biomass, which is commonly used as a fertilizer and has the potential as a renewable fuel. Therefore, studies on the combustion of plant and animal waste biomass in a furnace are of scientific relevance.

2. Literature review and problem statement

A modern FCC system consists of several components, one of which is a furnace. The furnace functions to heat the components in the FCC such as heating the reactor. The reactor serves as a site for the catalytic cracking process to take place. Several studies reported that the temperature required for the catalytic cracking process of crude palm oil is 450–550 °C [13]. The temperature in the furnace must be able to heat the reactor at a temperature of 450–550 °C in the FCC system so that it can carry out the catalytic cracking process of crude palm oil. The type of catalyst can affect the cracking temperature and the results of the cracking process in palm oil [14]. By using a catalyst, the process of cracking palm oil will be easier than not using a catalyst and the cracking process can occur at temperatures lower than 450 °C. The optimum cracking temperature for crude bio-oil is 300 °C [15]. The furnace temperature must be higher than 300°C to heat up the reactor so that the raw bio-oil cracking process occurs. The fuel used greatly affects the temperature in the furnace. Furnace combustion using a mixture of biomass and coal in the furnace has been carried out to present research results with flame temperatures up to 2,000 K [16]. The advantages of using coal in combustion can produce high temperatures, but the problem with using coal is that it produces high carbon emissions and is not a renewable fuel [17]. The solution is to use fuels that have high calorific values to achieve high furnace temperatures and renewable fuels with low emissions. The fuels used are Azolla, and products from goat manure pyrolysis such as GMBC and GMBO. Biogas products can be collected to be used to power generators and GMBO products are used as fuel for vehicles while GMBC can still be used as biomass fuel. Azolla is a fast growing plant and goat manure is developed by pyrolysis into valuable fuels such as GMBC and GMBO. The yield of goat manure pyrolysis at 500 °C is 48.66 % GMBC, 35 % GMBO and 16.34 % biogas [18]. The HHV value of the Azolla plant is 16.13 MJ/kg [19]. GMBC's HHV value is 13.6 MJ/kg [20]. Then the GMBO HHV value is 25.54 MJ/kg [21]. Meanwhile, coal has an HHV value of 26.53 MJ/kg [3]. From the four HHV values, it is shown that the HHV values of Azolla, GMBC and GMBO are still below the HHV values of coal but burning a mixture of Azolla, GMBC and GMBO will produce heat, which is not much different from coal. All of this indicates that it is advisable to conduct a study on furnace combustion with Azolla, GMBC and GMBO mixed fuel.

3. The aim and objectives of the study

The aim of the study is to identify the combustion regularities of two experiments. The first experiment used a mixture of one kilogram of GMBC with 0.5 kg of Azolla microphylla and the second experiment used a mixture of one kilogram of GMBC with 0.5 kg of Azolla microphylla plus 300 ml of GMBO.

To achieve this aim, the following objectives are accomplished:

– to get a high furnace temperature to be able to heat the stripper and carry out the cracking process on palm oil or crude oil;

– to perform analytical calculations to obtain the volume of flue gas formed from the combustion reaction.

4. Materials and methods of research

Referring to our previous research, we have carried out pyrolysis using fish waste, tamanu waste and duck grass to obtain syngas, bio-oil and biochar from their respective pyrolysis raw materials [5]. Then we use goat manure because this waste is widely used as biomass in the pyrolysis process. Goat manure pyrolysis is a process of breaking down complex carbon molecules in goat manure biomass caused by heating at 300–800 °C in the absence of oxygen [20, 21]. The products of the goat manure pyrolysis process are Goat Manure Biochar (GMBC), Goat Manure Bio-Oil (GMBO), and biogas. The product of pyrolysis from goat manure and Azolla can be used as a renewable fuel. So far, there has not been much research on the combustion of Azolla, GMBC and GMBO mixed fuels. Researchers and industry still use coal as a mixed fuel for biomass. Therefore, it is necessary to conduct research on burning Azolla, GMBC and GMBO mixed fuel so that it can replace coal in furnace combustion and that is relevant for the development of renewable energy. Azolla, GMBC and GMBO mixed fuel will be used for combustion in the furnace so it can heat components inside the FCC system and is capable of carrying out the catalytic cracking process.

The materials used in these experiments were Azolla, GMBC and GMBO shown in Table 1 and Fig. 1. Azolla plants were dried in the sun for two days at a temperature of 26–31 °C before being used as fuel as shown in Fig. 1, *a*. Goat manure was dried for three days under the sun at a temperature of 26–31 °C then subjected to pyrolysis process at a temperature of 500 °C for one hour to produce GMBC and GMBO as shown in Fig. 1, *b*, *c*.

a *b* *c*

Fig. 1. Fuel Material: *a* – Azolla; *b* – Goat Manure Biochar (GMBC); *c* – Goat Manure Bio-oil (GMBO)

The Azolla plants used were selected for their dry, wilted, easily crushed and blackened characteristics. If the Azolla plant meets these criteria, it is suitable for use as biomass fuel. Then after the goat manure pyrolysis process was completed, we took GMBC and GMBO from the pyrolysis system. GMBC is left to cool so that it is easy to mix with Azolla biomass and kept away from damp places to keep it dry. GMBO is put into an iron vessel and temperature greatly affects the viscosity of GMBO. At GMBO temperatures of 40–45 °C, it can be used as fuel.

We conducted 2 experiments as shown in Table 1. In the first experiment, we carried out combustion using a fuel mixture of one kilogram of GMBC with 0.5 kg of Azolla. We put one kilogram of GMBC with 0.5 kg of Azolla in a large container and then mix it. Then enter the fuel mixture into the FCC furnace. The combustion process in the first experiment was carried out for 1 hour. The velocity of air entering the furnace is 7.5 m/s and an air valve cross-sectional area is 0.5 inches, so the airflow rate is 13.68 m^3/hour. The second expe iment was carried out using one kilogram of fuel GMBC and 0.5 kg of Azolla, which had been mixed and then put into the FCC furnace. In the next step, 300 ml of GMBO was filled in the container as shown in Fig. 1, *c*. Then on the GMBO inlet valve is installed and the valve opening is adjusted. The running time in the second experiment was 1 hour with an airflow rate of 13.68 m^3/hour. We weigh 300 ml of GMBO equal to 0.325 kg of GMBO. In the second experiment, GMBO entered the crucible then flowed out of the valve and entered a plumb pipe in the furnace. In the plumb line, the GMBO is heated until it vaporizes and exits the nozzle into the furnace. GMBO steam out will burn in the FCC furnace.

Table 1

Experimental conditions

Condition Variables	First Experiment	Second Experiment
Azolla	0.5 kg	0.5 kg
GMBC	1 kg	1 kg
GMBO	–	0.325 kg
Air flow rate	13.68 m^3/h	13.68 m^3/h
Running Time	1 hour	1 hour

The flow of this research starts with making the furnace and FCC components completely as shown in Fig. 2. Furnace of a Fluid Catalytic Cracking system

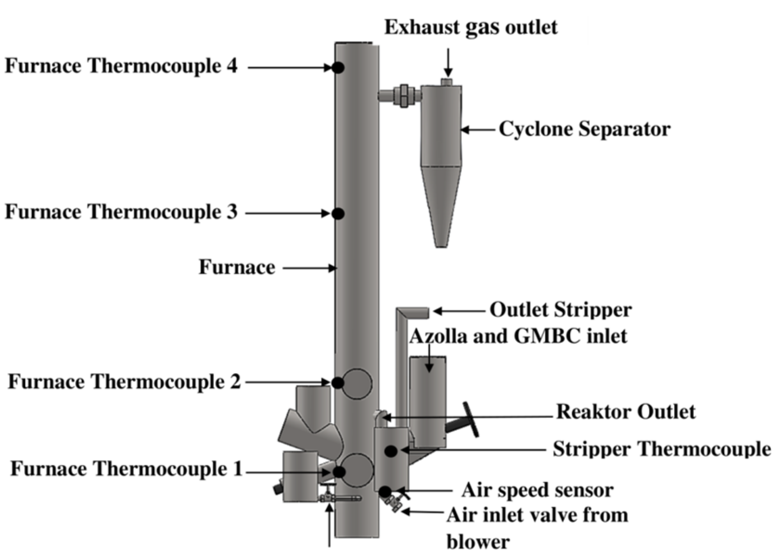

Fig. 2. Furnace of a Fluid Catalytic Cracking system

Fig. 2 shows the FCC furnace has a diameter of 13 cm and a height of 147 cm. This test uses one air inlet and two fuel inlets that will enter the furnace, namely the GMBO inlet valve and the place to enter the mixture of Azolla and GMBC. The air inlet serves as primary air for the combustion process in the furnace and is given an airspeed sensor to measure the speed of air entering the furnace. The air velocity value will be converted into air flow rate. There are 4 thermocouples to measure furnace temperature, namely furnace thermocouple 1 (FT1), furnace thermocouple 2 (FT2), furnace thermocouple 3 (FT3), furnace thermocouple 4 (FT4) and one stripper thermocouple (ST) to measure the temperature of the steam of the cracking product out of the reactor into the stripper. The stripper is used to separate the catalyst from the product vapor. FT1 is 20 cm from the bottom edge of the furnace, FT2 is 25 cm from FT1, FT3 is 52 cm from FT2, and FT4 is 45 cm from FT3. Then all parts of the FCC are covered with five centimeters thick ceramic wool fiber. Measuring tools and components of measuring tools used in these experiments are type K thermocouples, MAX6675 module, Arduino Mega 2560, Hoki digital scales, and the Benetech G-816 Anemometer, and MPXV7002DP. Type-K thermocouple calibration can measure temperatures from –270 to 1,260 °C with a thermocouple accuracy level of 0.25± °C [22]. The MAX6675 module is an Arduino module that functions as an amplifier because the potential difference received by the thermocouple is quite small [23]. The measurement accuracy of the MAX6675 sensor can be converted by hot coupling from 0 to 1024 °C. MAX6675 has a variable systematic error from each other, the temperature after calibration is ±0.3 °C. The calibration method for the thermocouple and MAX6675 sensors uses a DS18B20 thermistor, which has previously been calibrated with an ASTM-117C thermometer [23]. Arduino has a Baudrate data processing feature. Baud rate is the term used for the speed at which data flows. The baud rate unit is bps (bits per second). The baud rate used in this study is 9,600 bps. Baudrate corresponds to Arduino CPU frequency with a limit of 0.5 %. Hoki digital scales are used to weigh Azolla, GMBC, and GMBO fuel. The accuracy level of this scale is 0.001 kilograms. The Benetech G-816 Anemometer is used to measure airflow used in this study to calibrate the MPXV7002DP sensor. The Benetech G-816 Anemometer sensor can measure flow with a reading range of 0–30 m/s with a maximum western flow rate from –10 to 45 °C. While the error or measurement error using this tool ranges from 0.008 % to 0.3 %. The velocity of air entering the furnace is measured using a pitot tube and MPXV7002DP module. The MPXV7002DP is a monolithic silicon pressure sensor designed for various applications, especially microcontrollers or microprocessors with digital analog inputs and processing to compare two pressures for signal accuracy and is intended to read positive and negative pressures. With a 2.5 V to 0 V offset to measure pressure up to 7,000 Pa and calculate an air speed of 5.25 V, the power supply up to 4.75 V.

Airspeed calibration uses a Benetech G-816 digital Anemometer to provide precise readings as shown in Fig. 3.

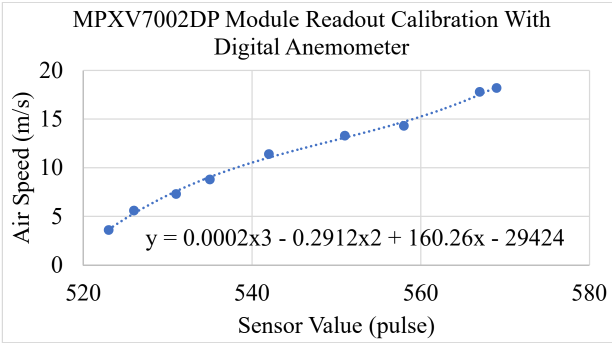

Fig. 3. Air speed calibration

Fig. 3 shows the pulse given by MPXV7002DP is then equated with reading the air velocity from a Benetech G-816 digital anemometer. The equation y=0.0002x^3–0.2912x^2+ +160.26x–29,424. Then the sensor readings are converted into air flowrate with units of m^3/h.

All sensors and actuators are connected to the Arduino Mega 2560 and run using the application as shown in Fig. 4.

Fig. 4 shows the MRPP application aims to display acquisition data in real-time. The MRPP application can monitor sensors on the FCC system such as thermocouples, air velocity sensors and air valve control on the FCC system. The experiment runs for one hour and the MRPP application monitors the conditions in the FCC furnace and then saves the experimental data in a csv file.

Ultimate analysis aims to determine the percentage of constituent elements of Azolla, GMBC and GMBO as shown in Table 2. We use several sources for the ultimate analysis to calculate combustion reactions.

In a combustion reaction, the total mass of the products must equal the total mass of the reactants and the total mass of each chemical element is maintained throughout the process. The composition of the air is estimated to be 21 % O_2 and 79 % N_2. A simple dry air stoichiometric reaction for the combustion of one kilogram carbon, one kilogram hydrogen and one kilogram sulfur to form carbon dioxide and nitrogen is given by the following equation [24].

Table 2

Ultimate analysis of materials

Materials	Ultimate Analysis					HHV (MJ/kg)
	C	H	N	O	S	
Azolla [19]	42.5	7.12	3.15	47.11	0.12	16.13
GMBC 500[a] [10]	42.3	1.5	1.9	23.4	ND[b]	13.6
GMBO 500[a] [9]	51.75	1.5	1.45	23.15	ND[b]	25.54

Note: [a] *– produced at 500 °C;* [b] *– not detected.*

$$1\ \text{kg}\,\text{C}+\frac{22.41}{12}\,\text{m}^3\text{O}_2+\left(\frac{22.41}{12}\times 3.76\right)\text{m}^3\text{N}_2\rightarrow$$
$$\rightarrow\frac{22.41}{12}\,\text{m}^3\text{CO}_2+\left(\frac{22.41}{12}\times 3.76\right)\text{m}^3\text{N}_2, \qquad (1)$$

$$1\ \text{kg}\,\text{H}_2+\frac{22.41}{4}\,\text{m}^3\text{O}_2+\left(\frac{22.41}{4}\times 3.76\right)\text{m}^3\text{N}_2\rightarrow$$
$$\rightarrow\frac{22.41}{2}\,\text{m}^3\text{H}_2\text{O}+\left(\frac{22.41}{4}\times 3.76\right)\text{m}^3\text{N}_2, \qquad (2)$$

$$1\ \text{kg}\,\text{S}+\left(\frac{22.41}{32}\,\text{m}^3\times 2\text{O}_2\right)+\left(\frac{22.41}{32}\times 3.76\right)\text{m}^3\text{N}_2\rightarrow$$
$$\rightarrow\frac{22.41}{32}\,\text{m}^3\text{SO}_2+\left(\frac{22.41}{4}\times 3.76\right)\text{m}^3\text{N}_2. \qquad (3)$$

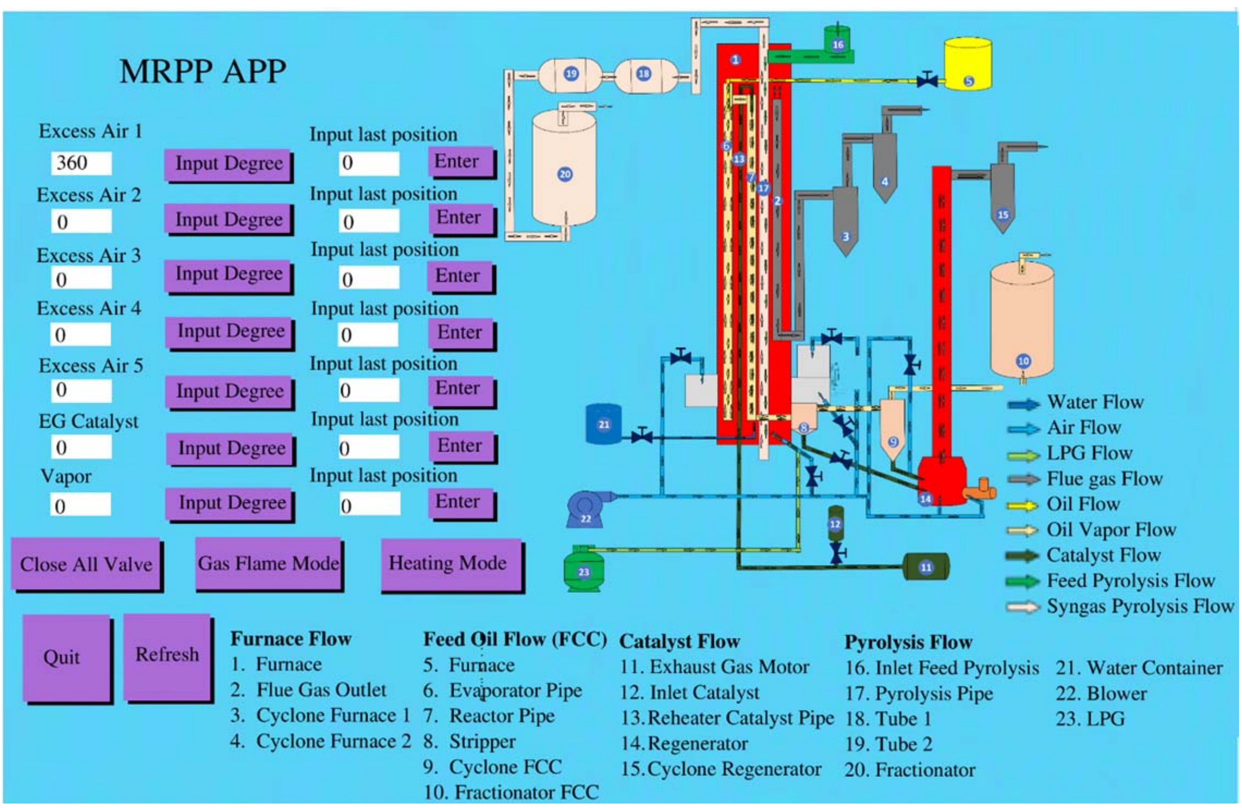

Fig. 4. Mobile Refinery and Power Plant App

However, the furnace uses atmospheric air rather than oxygen. Oxygen has a volume participation in the air of 21 %. The stoichiometric volume of dry air required to burn one kilogram of fuel will be in these conditi-ons [24]:

$$V_a = \frac{\frac{22.41}{100}\left(\frac{C}{12}+\frac{H}{4}+\frac{(S-O)}{32}\right)}{0.21}\left[\frac{m^3_{air}}{\text{kg fuel}}\right], \quad (4)$$

And for the air flow rate [24]:

$$V_a = B \times V_a \left[\frac{m^3_{O_2}}{h}\right], \quad (5)$$

where B is the fuel flow rate, [kg/h] and the volume stoichiometry of the combustion products is given in the following equation [1].

Volume of carbon dioxide:

$$V_{CO_2} = \frac{22.41}{12} \times \frac{C}{100}\left[\frac{m^3_{CO_2}}{\text{kg fuel}}\right]. \quad (6)$$

Volume of water vapor from flue gas:

$$V_{H_2O} = \frac{22.41}{12} \times \left(\frac{H}{2}+\frac{W}{18}\right) + 1{,}61 \times X \times V_a \left[\frac{m^3_{H_2O}}{\text{kg fuel}}\right], \quad (7)$$

where x is absolute humidity and W is fuel moisture.

Volume of sulfur dioxide:

$$V_{SO_2} = \frac{22.41}{12} \times \frac{S}{100}\left[\frac{m^3_{SO_2}}{\text{kg fuel}}\right]. \quad (8)$$

Volume of nitrogen:

$$V_{N_2} = \frac{22.41}{28} \times \frac{N}{100} + 0.79\left[\frac{m^3_{N_2}}{\text{kg fuel}}\right]. \quad (9)$$

The variables C, H, O, N, S are elements of the material used as fuel shown in Table 2. Ultimate analysis of materials from the data in Tables 1, 2 allows calculating the air flow rate, carbon dioxide volume, water vapor volume from the exhaust gas, sulfur dioxide volume and nitrogen volume using equations (1)–(9).

5. Research results of mixed fuel combustion in furnaces

5. 1. Furnace Temperature Results

The results of the first experiment are presented in Fig. 5, for a mixture of one kilogram GMBC with 0.5 kg Azolla.

Fig. 5 shows the combustion temperature from the first experiment. The increase in temperature at the start of combustion from the first experiment tends to slightly indicate that some of the fuel put into the furnace has been burned then the temperature increases exponentially as more fuel is burned. The maximum temperature for TF1 is 177 °C, TF2 – 129.75 °C, TF3 – 78 °C, TF4 – 70 °C and ST – 132.5 °C.

The results of the second experiment are presented in Fig. 6, for a mixture of one kilogram GMBC with 0.5 kg Azolla and 300 ml GMBO.

Fig. 6 shows the combustion temperature from the second experiment. The temperature increase at the beginning of combustion is very significant in the second experiment. The addition of GMBO can increase the heat of combustion and help accelerate the combustion of GMBC and Azolla. The graph of the combustion temperature from initial to maximum temperature is exponential. The maximum temperature for TF1 is 472.75 °C, TF2 – 282.75 °C, TF3 – 146.25 °C, TF4 – 134.5 °C and ST – 313.25 °C.

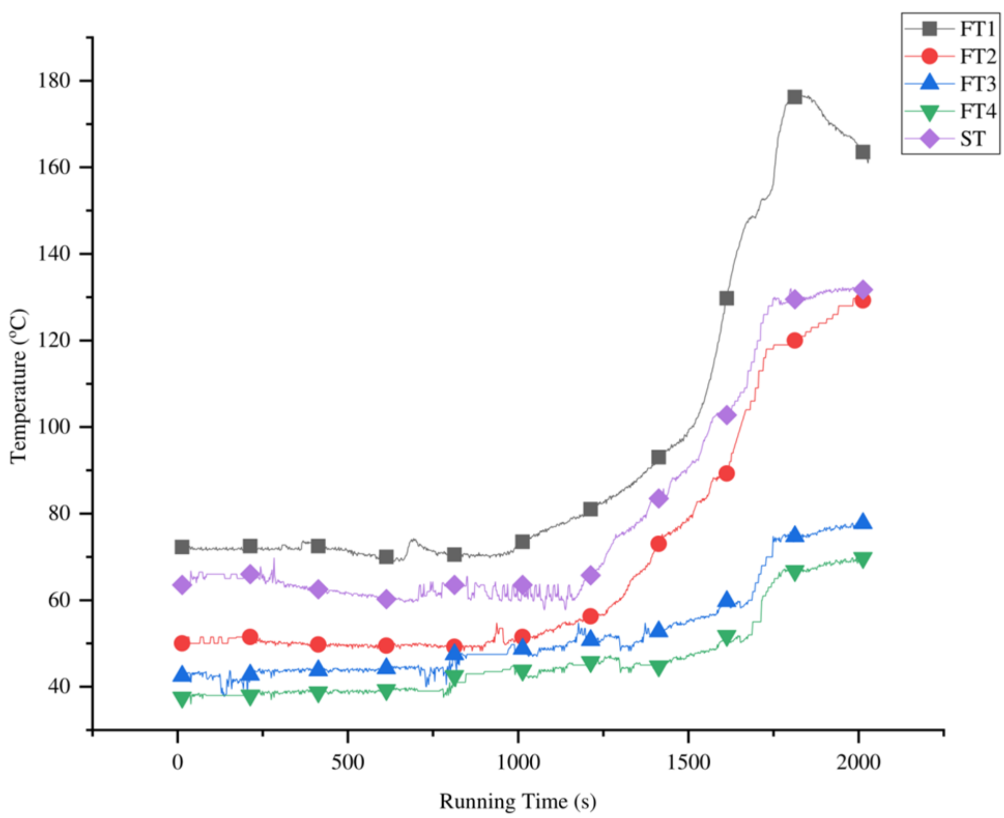

Fig. 5. Combustion temperature from the first experiment

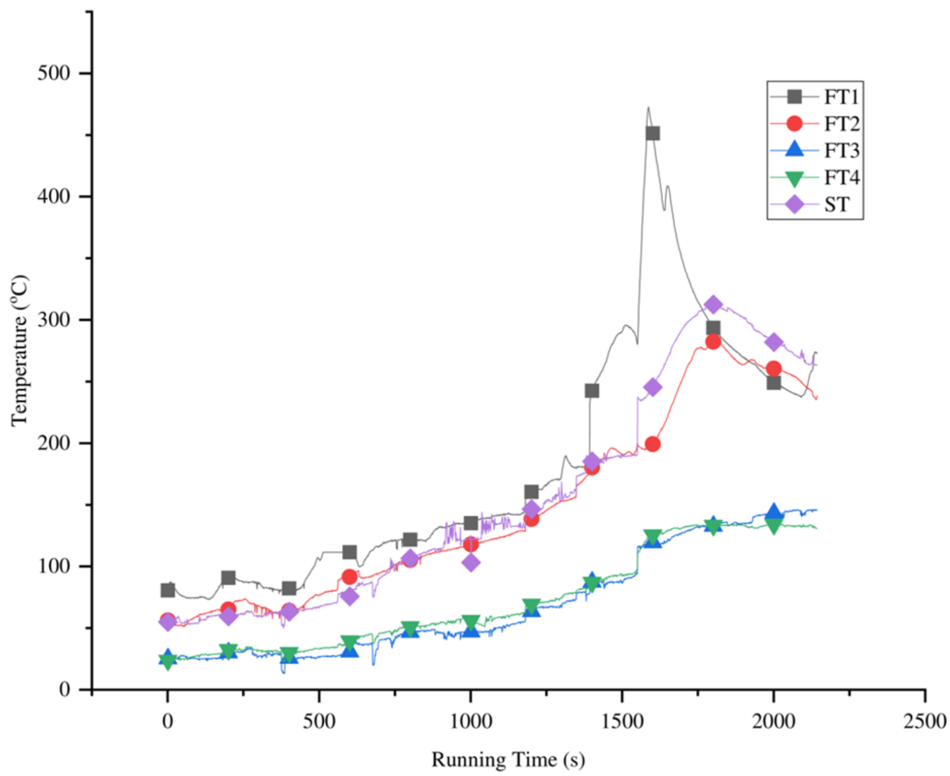

Fig. 6. Combustion temperature from the second experiment

5. 2. Analytical Calculations of Combustion Reactions

Analytical calculations to determine the product of mixed combustion in experiment 1 and experiment 2 are shown in Table 3.

Table 3 shows the results of analytical calculations from the combustion reaction equation. Table 1, 2 were used as input for the calculation and the calculation results were obtained from equations (6)–(9). By the results of the analytical calculation of experiment 1, the total volume of CO_2 is 2.548 $\left(m^3_{CO_2}/\text{kg fuel}\right)$ the total volume of H_2O is 1.133 $\left(m^3_{H_2O}/\text{kg fuel}\right)$, the total volume of N_2 is 9.312 $\left(m^3_{N_2}/\text{kg fuel}\right)$, and the total volume of SO_2 is 0.00084 $\left(m^3_{S_2O}/\text{kg fuel}\right)$. Then from the results of experimental analytical calculations 2, the total volume of CO_2 formed is 1.582 $\left(m^3_{CO_2}/\text{kg fuel}\right)$, the total volume of H_2O is 0.965 $\left(m^3_{H_2O}/\text{kg fuel}\right)$, the total volume of N_2 is 5.959 $\left(m^3_{N_2}/\text{kg fuel}\right)$, and the total volume of SO_2 is 0.00084 $\left(m^3_{S_2O}/\text{kg fuel}\right)$.

6. Discussion of the experimental study of mixed fuel combustion in furnaces

Furnace temperature from the two experiments showed a significant difference in results. In Fig. 5, the combustion temperature from the first experiment shows the maximum temperature for TF1 is 177 °C. The temperature at the top of the FCC furnace, namely TF4, is 70 °C. The low furnace temperature is not effective for heating components in FCC. In the first experiment, it can be seen that the Azolla fuel is burned first but the heat generated by the Azolla fuel is not enough to burn the GMBC, so the GMBC does not burn completely. If the heat generated by burning Azolla is not enough to burn down GMBC. The air entering the FCC furnace will only burn down Azolla and high excess air can cool the FCC furnace so the temperature in the FCC furnace is low.

Table 3

Analytical calculation results

Experiment			Analytical Calculations				
Materials	Fuel Flowrate (kg/h)	Air Flowrate $\left(m^3_{air}/h\right)$	Air Flowrate $\left(m^3_{air}/h\right)$	V_{CO_2} $\left(m^3_{CO_2}/\text{kg fuel}\right)$	V_{H_2O} $\left(m^3_{H_2O}/\text{kg fuel}\right)$	V_{N_2} $\left(m^3_{N_2}/\text{kg fuel}\right)$	V_{SO_2} $\left(m^3_{SO_2}/\text{kg fuel}\right)$
First Experiment							
Azolla	0.5	13.68	2.056	0.793	0.797	3.273	0.00084
GMBC	1		3.3815	0.789	0.168	2.686	0
Total			5.4375	1.582	0.965	5.959	0.00084
Second Experiment							
Azolla	0.5	13.68	2.056	0.793	0.797	3.273	0.00084
GMBC	1		3.3815	0.789	0.168	2.686	0
GMBO	0.325		1.375	0.966	0.168	3.353	0
Total			6.8125	2.548	1.133	9.312	0.00084

In Fig. 6, the combustion temperature of the second experiment shows that the maximum temperature for TF1 is 472.75 °C, TF4 – 134.5 °C and ST – 313.25 °C. Combustion of GMBO produces a flame in the furnace so that Azolla and GMBC can burn completely. The flame in the furnace can accelerate the burning of Azolla and GMBC resulting in a high temperature on TF1. TF1 high temperature can heat TF4 up to 134.5 °C and ST temperature up to 313.25 °C. Stripper temperature (ST) is the temperature of the product vapor leaving the reactor to the stripper. In the second experiment, if we refer to references regarding the catalytic cracking process of crude palm oil, the cracking process is imperfect if the temperature of the product steam from the reactor entering the stripper is 313.25 °C because it requires a temperature of 450–550 °C. But with a temperature of 313.25 °C, the cracking process of crude bio-oil can be carried out because the optimum cracking of crude bio-oil is at 300 °C. Thus, burning the mixture using one kilogram of GMBC and 0.5 kg of Azolla plus 300 ml of GMBO is enough to heat the furnace without using coal as fuel.

From Table 3, it can be seen that the airflow rate for the two experiments was 13.68 $\left(m^3_{air}/h\right)$ then the results of the analytical calculation of the discharge for complete combustion in the first experiment was 5.4375 $\left(m^3_{air}/h\right)$ and for the second experiment – 6.8125 $\left(m^3_{air}/h\right)$. The combustion in the first experiment contained excess air of 8.2425 $\left(m^3_{air}/h\right)$. The excess air in the first experiment was quite large and was able to cool the furnace so that the temperature of TF1 only reached 177 °C. Combustion in the second experiment contained excess air of 6.8675 $\left(m^3_{air}/h\right)$. The excess air in the second experiment was quite large and could cool the furnace but the temperature of TF1 was able to reach 472.75 °C because the addition of 300 ml GMBO could maintain the flame in the furnace. Of the two experiments, the results of the second experiment were better than those of the first experiment. By adding 300 ml of GMBO in the second experiment, the difference in TF1 of the two experiments reached 295.75 °C. From the calculation of the combustion results analysis, there is an increase in the total volume of CO_2 from the first experiment and the second experiment is 0.966 $\left(m^3_{CO_2}/\text{kg fuel}\right)$, there is an increase in the total volume of H_2O from the first experiment and the second experiment is 0.168 $\left(m^3_{H_2O}/\text{kg fuel}\right)$, and the total volume increase of N_2 from the first experiment and the second experiment is 3.353 $\left(m^3_{N_2}/\text{kg fuel}\right)$. The increase in total flue gas volume in the second experiment was due to the addition of 300 ml GMBO in the furnace. GMBO combustion produces a higher CO_2 volume of 0.966 $\left(m^3_{CO_2}/\text{kg fuel}\right)$, compared to the CO_2 volume of Azolla combustion – 0.793 $\left(m^3_{CO_2}/\text{kg fuel}\right)$, and the CO_2 volume of GMBC combustion is 0.789 $\left(m^3_{CO_2}/\text{kg fuel}\right)$. The volume of CO_2 in GMBO burning is high because the carbon element in GMBO is also high compared to Azolla and GMBC.

The limitation of this study is that we only used two fuel variations in both experiments. The drawback of this study is that there is still energy loss to the environment when opening and entering the fuel mixture of Azolla and GMBC for FCC furnace combustion. The next development in this research is to create an automatic system to supply fuel into the furnace so as not to lose energy to the environment. This study can be further developed using many variations of fuel mass and air flow rate to obtain optimum combustion efficiency and furnace temperature.

7. Conclusions

1. The furnace temperature from experiment one and experiment two showed a significant difference in results. From the first experiment using a fuel mixture of one kilogram GMBC with 0.5 kg Azolla, furnace combustion is not effective because the maximum temperature of TF1 is 177 °C and is not enough to heat the FCC comt ponents. From the second experiment using a mixture of fuel between one kilogram kg of GMBC, 0.5 kg of Azolla and 300 ml of GMBO, the maximum temperature of TF1 is 472.75 °C. The FCC furnace temperature is enough to heat the FCC components. The temperature of product vapor from the reactor entering the stripper is 313.25 °C, we can carry out the cracking process of crude bio-oil due to the optimum cracking process for crude bio-oil at a temperature of 300 °C. The addition of GMBO to the furnace combustion can increase the heat of combustion and help accelerate the combustion of GMBC and Azolla.

2. From the analysis of the combustion results, there was an increase in the total volume of CO_2 from experiment one and experiment two of 0.966 $\left(m^3_{CO_2}/\text{kg fuel}\right)$, there was an increase in the total volume of H_2O from experiment 1 and experiment 2 of 0.168 $\left(m^3_{H_2O}/\text{kg fuel}\right)$, and the total volume gain of N_2 from experiment one and experiment two is 3.353. The volume total flue gas in the second experiment increased due to the addition of 300 ml GMBO in the furnace.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Data cannot be made available for reasons disclosed in the data availability statement.

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