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# ANALYSIS OF THE EFFECT OF BIOMASS VARIANTS (FISH WASTE, TAMANU WASTE AND DUCKWEED) ON THE CHARACTERISTICS OF SYNGAS, BIO OIL, AND CARBON CHARCOAL PRODUCED IN THE PYROLYSIS PROCESS

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*Biomass is one of the renewable energy sources that are often found around the Indonesia area. It can be converted into various forms of fuel by pyrolysis. Pyrolysis is a process of chemical decomposition of biomass through a heating process at high temperatures that occurs with no or little oxygen. The purpose of this study was to analyze the effect of the type of biomass on the characteristics of syngas, bio oil and carbon charcoal produced in pyrolysis.*

*Syngas consisting of hydrogen and carbon monoxide can be used as raw materials for the chemical industry in addition to electrical energy, such as methanol, formic acid and ammonia industries. Bio-oil contains a number of chemical compounds that have the potential as raw materials for preservatives, antioxidants, disinfectants, or as biopesticides. Carbon charcoal is useful as an energy source, activated carbon with higher economic value such as catalysts, adsorbents, and supercapacitors.*

*This research used an experimental method. Biomass comes from fish waste, tamanu waste, and duckweed. The parameters observed were temperature of 400–500 °C, for 30 minutes, and 150 grams biomass, in order to determine the duration of the syngas flame and the amount of bio-oil and carbon charcoal. The syngas produced from duckweed has a longer flame test with a time of 126 seconds with a blue flame while the syngas from tamanu waste produces a reddish blue flame for 18 seconds. On the other hand, the results of the bio-oil produced from fish waste, 19.1 grams are weightier than from duckweed, 3.2 grams. Then the most carbon charcoal is produced by tamanu waste weighing 141.9 grams while the least is produced by duckweed weighing 27.7 grams*

*Keywords: renewable energy, biomass, fish waste, tamanu waste, duckweed, pyrolysis, syngas, bio-oil, carbon charcoal, economy value*

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## 1. Introduction

Energy is needed for human activities, especially for economic activities, households, industry, business and transportation. The energy supply in Indonesia mostly comes from fossil fuels, which are non-renewable resources. However, along with the increasing demand for energy, the availability of fossil energy sources in Indonesia has made

Indonesia closer to an energy crisis. The transition from fossil energy to new renewable energy (NRE) is needed to maintain energy availability in the future. Indonesia is noted to have an NRE resource potential of more than 400 gigawatts (GW) including ocean wave energy, geothermal energy, wind energy, solar energy, water energy, biomass and so on. Of these various energy sources, only 2.5 % or 10 have been utilized [1].

Biomass is biodegradable organic material derived from plants, animals, microorganisms, by-products, residues and agricultural, forest and industrial wastes related to non-fossil and biodegradable organic fractions from industry and related wastes. Biomass is produced through the process of photosynthesis by absorbing carbon dioxide ($CO_2$). The process of burning biomass produces $CO_2$, which is spread in the atmosphere and will be absorbed by plants so that burning biomass will not increase the $CO_2$ content in the earth. For this reason, biomass is considered a zero-emission fuel [2].

Biomass requires technology to be converted in order to be utilized. Generally, thermochemical and biochemical conversions are used to convert biomass into alternative fuels. Pyrolysis is a form of thermochemical conversion, which is the process of breaking down complex carbon molecules in biomass caused by heating in the absence of oxygen. The results of the pyrolysis process are charcoal (solid), bio-oil (liquid), and gas products. Generally, the pyrolysis process operates in a temperature range of 280–850 °C with different heating rates and times [3].

Due to the increasing interest in the application of pyrolysis to produce energy, many research efforts have been carried out such as research on the potential of the pyrolysis process in the waste treatment sector. [4], pyrolysis reactor modeling and optimization [5], production of liquid fuel and carbon charcoal from fish waste using the pyrolysis process [6], discusses the characteristics of fast-growing aquatic biomass pyrolysis production – Lemna minor (duckweed) [7], experiments on pyrolysis as clean coal technology [8], and discusses the analytical characteristics of the products obtained from the slow pyrolysis of Calophyllum inophyllum [9]. Each biomass has different characteristics and compositions, so if heated, it will produce different pyrolysis products as well. Therefore, it is necessary to conduct research on the differences in biomass processed by pyrolysis in order to obtain syngas, bio oil, and carbon charcoal.

## 2. Literature review and problem statement

Duckweed (Lemna minor) is one of the fastest-growing aquatic plants and can be easily cultivated from growing media with a simple separation process. This aquatic plant demonstrates outstanding performance in terms of removing nitrogen and phosphorus from the watercourse, furthermore showed good tolerance to the swine wastewater and can perform well in growth [10, 11]. Duckweed is an excellent biomonitoring accumulator of the presence of heavy metals by scoring the number of fronds or by determining the fresh and dry weight and content of chlorophyll and carotenoids [12, 13]. In addition, duckweed also contains high protein and has been used as animal feed [14]. Duckweed proximate analysis (%) is as follows: moisture – 3.7; total volatiles (120–950 °C) – 78.0; fixed carbon – 8.8 and ash – 9.5. Ultimate analysis (%) C – 39.11; H – 6.13; O – 37.74; N – 5.52; S – 0.67; balance mineral matter. Research was conducted by Muradov et al. regarding the pyrolysis experiment with duckweed as raw material at a temperature range of 400–700 °C and holding time of 15 minutes. The main gas products from duckweed pyrolysis are hydrogen ($H_2$), carbon monoxide (CO), $CO_2$, and methane ($CH_4$), with small amounts of ethane ($C_2H_6$) and ethylene ($C_2H_4$). So far $CO_2$ is the main component of the gas mixture, accounting for about 60 %. The gas produced in this experiment increases regularly, which is in line with the increase in temperature that occurs due to the secondary decomposition of charcoal and volatiles at high temperatures. Meanwhile, bio oil and charcoal carbon did not show a significant increase in capacity. Pyrolysis with a low heating rate or low rate pyrolysis (500 °C) can produce a 40 % yield of bio oil.

Tamanu seeds (*Calophyllum inophyllum Linn.*) contain a high enough source of vegetable oil that can be used as fuel. The oil content of tamanu seeds is about 75 % [15]. Meanwhile, according to research conducted by [16], the oil content of tamanu seeds is 40 % to 73 %, respectively [17]. Therefore, tamanu seeds can be processed into alternative biodiesel fuels that meet SNI standards through a dry purification process [18].

Fish waste that is often found polluting the environment can be converted into biodiesel alternative fuels through the transesterification process. De-oiled Fish Waste (DOFW) is a solid fish waste (head, skin, offal, tail), which has been extracted with oil generally used as animal feed. The pyrolysis process made from DOFW at a temperature of 500 °C with a duration of 60 minutes produces bio oil with a yield of 57.13 % and carbon charcoal, which will be processed again to become carbon charcoal [6]. Our goal is to find out how much syngas, bio-oil and carbon charcoal are produced from the pyrolysis process from several biomasses including duckweed, tamanu and fish waste.

## 3. The aim and objectives of the study

This study aims to analyze the effect of the type of biomass on the characteristics of syngas, bio oil and carbon charcoal produced in the pyrolysis process. This will make it possible to observe the pyrolysis results visually.

To achieve this aim, the following objectives are accomplished:

– to analyze pyrolysis products like syngas, bio-oil, and carbon charcoal from fish waste;

– to analyze pyrolysis products like syngas, bio-oil, and carbon charcoal from tamanu waste;

– to analyze pyrolysis products like syngas, bio-oil, and carbon charcoal from duckweed.

## 4. Materials and methods of research

The biomass material used in this research was fish waste, duckweed and tamanu waste, shown in Table 1 and Fig. 1.

Table 1

Biomass materials

| Biomass | Mass (Gram) |
|---|---|
| Fish waste | 150 |
| Duckweed | |
| Tamanu waste | |

*a* *b* *c*

Fig. 1. Biomass materials: *a* — fish waste; *b* — duckweed; *c* — tamanu waste

Fish waste consists of head, skin, offal, bones and tail, which have been dried and mashed weighing 150 grams as shown in Fig. 1, *a*. Tamanu waste is obtained from the cold press process of tamanu fruit in a cosmetic production house, which has been mashed as much as 150 grams, and duckweed is obtained from the cultivation of aquatic plants in PT CCIT Group Indonesia, which has been dried weighing 150 grams, as shown in Fig. 1, *b*, *c*, respectively.

This pyrolysis system uses coal as its fuel with 3 biomass variants. This pyrolysis system is equipped with 4 thermocouples to measure the temperature in the combustion chamber and the pyrolysis reactor. This thermocouple is connected to Arduino and read on a laptop using open source software (PLX-DAQ) as shown in Fig. 2.

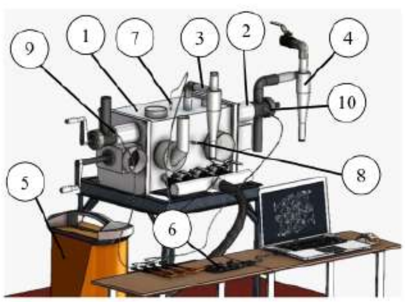



Fig. 2. Pyrolysis System: 1 — Combustion chamber; 2 — Pyrolysis reactor; 3 — Combustion chamber cyclone; 4 — Pyrolysis cyclone; 5 — Blower; 6 — Arduino Mega 2560 module with 0.5 % error; 7 — Thermocouple combustion chamber 1; 8 — Thermocouple combustion chamber 2; 9 — Pyrolysis thermocouple 1; 10 — Pyrolysis thermocouple 2

The pyrolysis system consists of a pyrolysis reactor made of stainless steel pipe with a height of 1.100 mm and a diameter of 2 inches equipped with a screw on the inside, a combustion furnace made of the same material as the pyrolysis reactor with a size of 490×230×230 mm, cyclone separator to separate fly ash particles and combustion smoke, cyclone separator to separate fly ash particles and gases that become pyrolysis products, temperature measuring instrument used is a type K thermocouple placed at 2 points in the furnace and 2 points in the pyrolysis reactor. Blower as an air supply.

This research was carried out in several stages (Fig. 3), preparation of raw materials, fuel preparation, production of syngas, bio-oil and carbon charcoal from raw materials by pyrolysis, fuel testing and retrieval of pyrolysis products.

The discarded fish parts or fish waste (head, skin, offal, bones and tail) are dried and then ground into powder. The same thing is also done on tamanu waste, the dried tamanu waste is crushed into powder. Meanwhile, duckweed is only dried until the water content is reduced. After the three raw materials have dried and are in powder form, each of the raw materials is weighed with a gram digital scale until the weight reaches 150 grams. Then the raw materials are fed into the pyrolysis pipe.

The lumps of coal briquettes are crushed into smaller pieces and weighed on a digital kilo scale until they reach 3500 grams. The coal briquettes are then stacked in the pyrolysis combustion chamber until it is half full. Light a match to test the gas torch.

Measuring tools and measuring aid components used in the pyrolysis process include a Type K Thermocouple, Arduino Mega 2560. Module, MAX6675 4, Taffware Scale, Yisun Digital Scale, and Benetech G-816 Anemometer. All measuring instruments and auxiliary components are known for their accuracy and error specifications. Specification of Type K thermocouple has a reading range in temperature measurement 270 to 1,260 °C and an error of ±0.75 % or equal to ±2.2 °C. Arduino has a data processing level feature on Arduino called Baudrate. This feature relates to the Arduino CPU frequency with an allowable limit of 0.5 %. The measurement accuracy of the MAX6675 sensor can be converted with hot junctions ranging from 0 to 1,024 °C. This sensor has a systematic error that varies from one another, the temperature after calibration is ±0.3 °C. The Taffware scale is used to measure the mass of raw materials in this study and has an error of 13 grams. While the Yisun digital scale is used to measure the mass of coal for pyrolysis combustion, which has an accuracy of 5 grams. To measure the air flow, the Benetech G-816 Anemometer is used in this study, which has a flow behavior reading range of 030 m/s with a maximum west flow rate of –10 to 45 °C. While the error or measurement error using this tool ranges from 0.008 % to 0.3 %.

Raw materials (fish waste, duckweed, tamanu waste) weighing 150 grams are put into the pyrolysis reactor equipped with 2 type K thermocouples at both ends of the pyrolysis tube. Coal briquettes are inserted into the combustion chamber, which is equipped with 2 type K thermocouples in the middle of the combustion chamber to fill half the combustion chamber. 4 thermocouples are installed on the Arduino (Italy), which are connected to a laptop with software open source PLX-DAQ, which functions to monitor the temperature in the pyrolysis and combustion chamber.

Combustion begins by burning coal briquettes using a torch until the coal briquettes ignite then the air source from the blower is installed with the valve fully open. After the fire grew and spread all the valves were opened halfway. When the temperature in the combustion chamber monitored in the Macro Excel PLX-DAQ has reached the range of 400–500 °C, the temperature is maintained for 30 minutes (Table 2) by adjusting the coal briquettes and the air source that enters the combustion chamber.

Table 2

Combustion of pyrolysis system

| Biomass type | Holding time (minutes) | Average temperature in the combustion chamber (°C) |
|---|---|---|
| Fish waste | 30 | 400–500 |
| Duckweed | | |
| Tamanu waste | | |

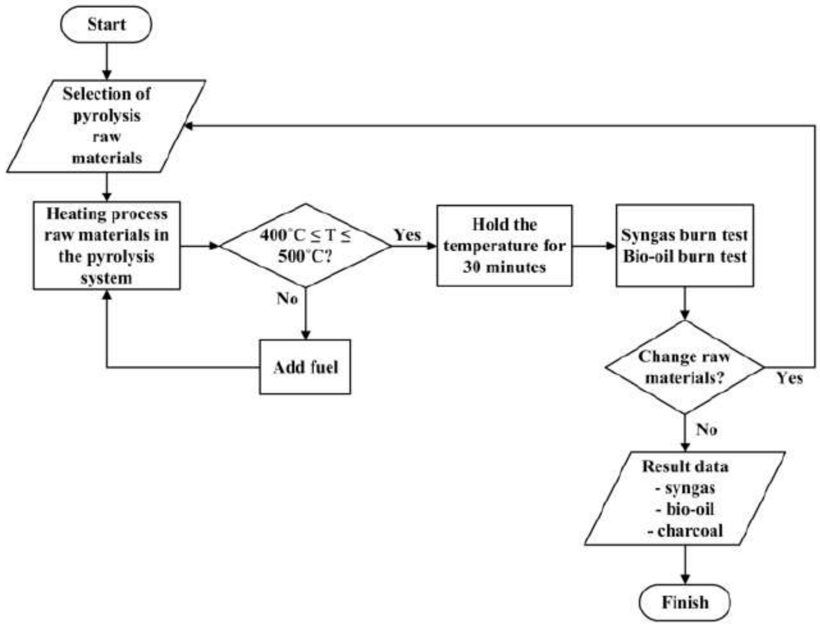



Fig. 3. Flow chart of pyrolysis

The syngas burn test was carried out after the combustion chamber temperature had been maintained for 30 minutes with a temperature range of 400–500 °C. The cyclone pyrolysis valve is opened and then fire is ignited with a match in front of the mouth of the cyclone valve. During the combustion test process, a timer is installed during the syngas combustion process. It is calculated how long the syngas burns using a timer.

After testing the syngas and stopping the entire pyrolysis system, other pyrolysis products such as pyrolysis oil, fly ash from the pyrolysis cyclone, fly ash from the combustion chamber cyclone are taken in various places provided. Meanwhile, activated carbon and raw materials that are not processed are taken after the entire pyrolysis system has cooled or has reached room temperature.

## 5. Research results of pyrolysis product

### 5. 1. Pyrolysis product (syngas, bio-oil, carbon charcoal) from fish waste

Fig. 4 shows the pyrolysis test results using fish waste biomass.

*a* *b* *c*

Fig. 4. Fish waste raw materials: *a* – syngas test; *b* – pyrolysis oil; *c* – carbon charcoal

Table 3

Pyrolysis process results from fish waste

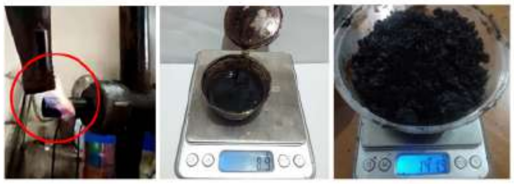
| Biomass type | Results | | | | | |
|---|---|---|---|---|---|---|
| | Syngas | Pyrolysis oil | Carbon charcoal | Fly ash cyclone pyrolysis | Fly ash cyclone combustion chamber | Unprocessed raw materials |
| | Seconds | Grams | Grams | Grams | Grams | Grams |
| Fish waste | 56 | 19.1 | 67.3 | 0 | 0 | 35.5 |

The results of pyrolysis from fish waste biomass are shown in Table 3. It produces syngas with a flame test for 56 seconds. As can be seen in Fig. 4, *a*, the syngas burn test produces a reddish blue flame and tends to come out of the valve surface. This can happen because the gas produced is clean, completely burned. Fig. 4, *b* depicts pyrolysis oil with a weight of 19.1 grams has a high viscosity but the pyrolysis oil produced cannot be burned directly, it must go through a further process in order to burn easily. The carbon charcoal produced weighs 67.3 grams as shown in Fig. 4, *c*.

### 5. 2. Pyrolysis product (syngas, bio-oil, carbon charcoal) from tamanu waste

The pyrolysis test results using tamanu waste biomass are shown in Fig. 5.

The results of pyrolysis from fish waste biomass are shown in Table 4. The main product of the pyrolysis process with tamanu waste as raw material is syngas, which can be burned for 18 seconds with a reddish blue flame as shown in Fig. 5, *a*. This shows that the fire produced from this process has a fairly clean syngas and the temperature is not too high. Fig. 5, *b* shows pyrolysis oil weighs 8.9 grams with a lower viscosity than fish waste pyrolysis oil but greater than duckweed pyrolysis oil. Carbon charcoal from this process weighs 141.9 grams as depicted in Fig. 5, *c*. The by-product of this test is fly ash from a pyrolysis cyclone weighing 0.1 grams and the fly ash coming out of the combustion chamber cyclone weighs 0.4 grams.



*a* *b* *c*

Fig. 5. Tamanu waste raw materials: *a* – syngas test; *b* – pyrolysis oil; *c* – carbon charcoal

Table 4

Pyrolysis process results from tamanu waste

| Biomass type | Results | | | | | |
|---|---|---|---|---|---|---|
| | Syngas | Pyrolysis oil | Carbon charcoal | Fly ash cyclone pyrolysis | Fly ash cyclone combustion chamber | Unprocessed raw materials |
| | Seconds | Grams | Grams | Grams | Grams | Grams |
| Tamanu waste | 18 | 8.9 | 141.9 | 0.1 | 0.4 | 0 |

**5. 3. Pyrolysis product (syngas, bio-oil, carbon charcoal) from duckweed**

The pyrolysis test results using duckweed biomass are shown in Fig. 6.

*a* *b* *c*

Fig. 6. Duckweed raw material: *a* – syngas test; *b* – pyrolysis oil; *c* – carbon charcoal

Table 5

Pyrolysis process results from duckweed

| Biomass type | Results | | | | | |
|---|---|---|---|---|---|---|
| | Syngas | Pyrolysis oil | Carbon charcoal | Fly ash cyclone pyrolysis | Fly ash cyclone combustion chamber | Unprocessed raw materials |
| | Seconds | Grams | Grams | Grams | Grams | Grams |
| Duckweed | 126 | 3.2 | 27.7 | 1.4 | 0 | 59.3 |

The results of pyrolysis from duckweed biomass are shown in Table 5. Pyrolysis with duckweed as the main product produces syngas, Fig. 6, *a*, which can be burned for 59.3 seconds with a blue flame but is still inside the valve. This shows that the syngas produced is clean and has a high temperature. The resulting pyrolysis oil weighs 3.2 grams with a low viscosity and carbon charcoal from this process weighs 27.7 grams, as shown in Fig. 6, *b*, *c*, respectively. Meanwhile, the by-product of this pyrolysis system is fly ash from the pyrolysis cyclone weighing 1.4 grams and very little fly ash coming out of the combustion chamber cyclone. While the raw material that is not processed weighs 59.3 grams.

## 6. Discussion of experimental study of pyrolysis from several biomasses

The pyrolysis experiments demonstrated significant differences in the results of fish waste, duckweed and tamanu waste towards syngas flame, yield of pyrolysis oil and carbon charcoal. The carbon char produced from each biomass shows different results. Carbon charcoal from duckweed, as shown in Fig. 6, *c*, tends to clump and the color is not so dark, even has the lowest yield. However, the syngas produced, as shown in Fig. 6, *a*, is quite a lot, as evidenced by the long flame time. This can be related to secondary reactions that speed up the decomposition of pyrolysis oil produced into non-condensable gas and low moisture content in raw materials. Visually, the carbon char from fish waste and tamanu waste, as shown in Fig. 4, *c*, 5, *c*, is solid black but not too dry. This is because the water content in the raw materials is still high, so it affects the char results. However, higher bio-oil yields from fish waste, as shown in Fig. 4, *b*, compared to other biomass can be attributed to that fish waste is pyrolyzed as received without removing other components, such as fat or protein.

The pyrolysis process on fish waste, tamanu waste, and duckweed produces syngas, bio-oil, and carbon charcoal with different characters and different amounts at the same average temperature and holding time, and the same number of grams, as shown in the result section, as a result of different types of biomass and variables contained in biomass such as humidity, protein and fat content.

In this study, the material used as raw material for pyrolysis is bio-waste, which has the potential to be an alternative energy source to help manage waste in the environment. There are several obstacles in carrying out this research, namely in the form of tools or components used, which are still not optimal for combustion, so there are materials that are not processed and lead to defective pyrolysis results. It is necessary to improve the design and manufacture of tools or components of the combustion chamber and repair the pyrolysis chamber system. Thus, it can produce optimal results.

## 7. Conclusions

1. Syngas with a flame time test for 65 seconds, bio-oil weight of 19.1 grams, and carbon charcoal as 67.3 grams produced by pyrolysis of fish waste.

2. Syngas with flame time test is the fastest than the other, which is 18 seconds. Bio-oil weight of 8.9 grams, and carbon

charcoal was higher than other raw materials with a weight of 141.9 grams produced by pyrolysis of tamanu waste.

3. Syngas with flame time test is longer than the other, which is 126 seconds, bio-oil and carbon charcoal produced are less than in other experiments with a weight of 3.2 grams and 27.7 grams, respectively produced by pyrolysis of duckweed.

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