COMBUSTION CHARACTERISTICS STUDY OF LOW GRADE PRODUCER GAS FROM CARBONIZED EMPTY FRUIT BUNCH (EFB) BRIQUETTES GASIFICATION

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UNIVERSITI SAINS MALAYSIA

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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LIST OF SYMBOLS

°C	Degree Celcius
H_2	Hydrogen
O_2	Oxygen
N_2	Nitrogen
CO	Carbon monoxide
CH_4	Methane
CO_2	Carbon dioxide

LIST OF ABBREVIATIONS

EFB	Empty Fruit Bunches
GC	Gas Chromatography
TGA	Thermogravimetric analysis
UTM	Universal Testing Machine
HCV	High Calorific Value
HHV	High Heating Value
USM	Universiti Sains Malaysia

ABSTRAK

Malaysia sedang mencari sumber tenaga alternatif yang boleh diperbaharui yang dapat mengurangkan penipisan ini. daripada masalah global kehabisan bahan api fosil, dan briket biojisim merupakan salah satu penyelesaian terbaik untuk mengurangkan kekurangan ini. Di Malaysia, Tandan Buah Kosong (EFB) adalah salah satu sisa pertanian yang paling banyak digunakan, dan briketnya berpotensi untuk digunakan sebagai bahan bakar gas alternatif.. Walau bagaimanapun, EFB mempunyai beberapa kualiti yang tidak diingini yang mengehadkan kualitinya sebagai sumber bahan api yang boleh dipercayai, yang memerlukan proses pra-rawatan untuk menukarnya kepada briket biojisim. Dalam projek tahun akhir ini, ciri-ciri pembakaran gas pengeluar gred rendah daripada briket Tandan Kosong (EFB) berkarbonisasi melalui proses pengegasan akan dikajikan. Pra-rawatan yang dijalankan ialah proses pengeringan sebanyak 40-50^{o}C, proses pengkarbonan sebanyak 350^{o}C dan 4 jam, proses mencampurkan dengan pengikat ubi kayu dengan nisbah 100:110:20 dan proses briket menggunakan mesin briket manual pada 150MPa. Setelah pra-rawatan dijalankan, analisis briket akan dijalankan. Ini akan terdiri daripada analisis proksimat, analisis fizikal, nilai kalori dan ujian kadar pembakaran briket EFB tunggal. Briket EFB akan dibandingkan dengan briket Pemula Kebakaran dan dengan data rujukan pelbagai nisbah briket. Briket kemudiannya akan menjalani proses pengegasan dengan kadar suapan 5 kg/j pada 480^{o}C dalam masa 20 minit untuk keseluruhan proses di mana hasil gas akan diuji di bawah Kromatografi Gas. Menggunakan data yang diberikan, pengiraan kecekapan penukaran karbon dilakukan. Ini akan menentukan sama ada briket yang dibuat boleh menghasilkan gas pengeluar.

ABSTRACT

Malaysia has been searching for affordable, renewable energy alternatives as a result of the global problem of the depletion of fossil fuels, and biomass briquettes are one of the best solutions for reducing this depletion. In Malaysia, Empty Fruit Bunch (EFB) is one of the most widely used agricultural wastes, and its briquettes have the potential to be used as a substitute gaseous fuel. EFB, however, has a number of undesirable qualities that limit its quality as a reliable fuel source, necessitating a pre-treatment process in order to convert it into biomass briquettes. In this final year project, the combustion characteristic of a low-grade producer gas from carbonized Empty Fruit Bunch (EFB) briquettes through gasification process will be studied. The pre-treatment conducted will be are drying process by 40- 50^{o}C, carbonization process by 350^{o}C and 4 hours, mixing process with tapioca binder with 100:110:20 ratio and briquetting process using manual briquette machine at 150MPa. Once the pre-treatment is conducted, briquette analyzation will be conducted. This will consist of proximate analysis, physical analysis, calorific values and burning rate test of a single EFB briquette. The EFB briquettes will be compared to Fire Starter briquettes and with reference data of various ratio of briquettes. The briquettes will then undergo gasification process with 5 kg/h feed rate at 480^{o}C in 20 minutes for the entire process where the gas produce will be tested under the Gas Chromatography. Using the data given, calculation carbon conversion efficiency is done. This will determine whether the briquettes made can produce producer gas.

CHAPTER 1

INTRODUCTION

1.1 Overview

The difficulties of the twenty-first century include the rising need for energy, the limited availability of fuel, and climate change. The primary source of energy consumption in the world in 2016 was crude oil, followed by coal (27%) and natural gas (18%). This implies that fossil fuels accounted for roughly 80% of the energy used. Oil consumption increased by 77 million tonnes of oil equivalent (mtoe) in 2017, followed by natural gas (57 mtoe) and renewable energy (53 mtoe). Petroleum reserves are predicted to run out in less than 50 years. [1]

Researchers are continually exploring for more cost-effective and environmentally friendly alternatives to fossil fuels. Renewable energy resources have long been seen as one of the most viable alternatives to depleting petroleum supplies. Renewable energy supplied 19.2% of net world energy consumption in 2014, according to the Renewable Energy Policy Network for the Twenty-First Century (REN21) 2016 research, with fossil fuels accounting for 78.3% and nuclear power contributing for 2.5%. Renewable energy sources include biomass, hydropower, geothermal, ocean energy, the sun, and wind. Biomass accounts for 14% of net final energy consumption by end-use sector, with 12.6% going to heating and cooling, 0.8% going to transportation, and 0.4% going to power. Bioenergy, or energy obtained from biomass, is the most significant source of renewable energy. [1]

Briquettes are created by mechanically compressing biomass waste into a homogeneous solid fuel. Biomass briquettes have a wide range of applications as a fuel for creating heat and electricity, both in the home and in industry, and the Malaysian briquette industry originated with wood waste. Given the rising global interest in renewable energy sources and the limited supply of sawdust, EFB fibre, on the other hand, is a viable raw material for the production of biomass briquettes. Briquettes are classified as small enough to travel, have a higher density, and have a higher energy content.

To replace the demand for fossil fuels, a new fuel source must be discovered. Biomass energy is one of the sources that may be used. What exactly is biomass? Biomass is organic, which means it is made up of material derived from living beings like plants and animals. Plants, wood, and garbage are the most frequent biomass sources utilised for energy. Biomass feedstocks are what they're termed. In order to attain energy independence, biomass has the potential to become a key source of renewable carbon that can be used as a feedstock for biofuel production. Biomass briquettes are extensively utilised as a fuel source in industries such as steam boiler operation, as well as in home uses such as cooking, thermal heating, and other similar applications.

The effect of EFB briquettes utilising the Gas Chromatography (GC) in this research, and the results will vary from one trial to the next will be studied. In comparison to base producer gas, the physicochemical and combustion characteristics of EFB briquettes play a vital role in obtaining the appropriate formulation and efficient burning. Biogas from biomass gasification is difficult to utilise as motor fuel due to its low calorific value (duel fuel engine). Further research is required to improve biogas qualities and combustion characteristics.

1.2 Problem Statement

Fossil fuel burning has negative consequences for human health and the environment, such as climate change and the discharge of pollutants that cause premature mortality, heart attacks, and respiratory problems.[2] Furthermore, the depletion of fossil fuels has contributed to an increase in oil prices, and the negative environmental impact of long-term use of fossil fuels via combustion must be reduced, as would any energy-related commodities. As a result, several academics have looked into the use of alternative and renewable fuels like biomass in power generation.

However, not all of them address the possibility of using biomass producer gas (BPG) as a dual fuel in an internal combustion engine, and few have conducted research on biomass producer gas optimization. Furthermore, the biomass used in this ongoing study is Empty Fruit Bunches (EFB), which is known as the most problematic biomass due to its fibrous structure, and thus producing briquettes from EFB faces several challenges, including poor grind ability, high moisture content, and low energy density, despite the fact that EFB offers high quantity and has great potential as a cost-effective feedstock for briquette production. [3]

The price of oil has risen as a result of the depletion of fossil fuels, and long-term use is harmful to the environment. As a result, numerous researchers have looked into and examined alternate and renewable fuels, such as biomass wastes, in order to reduce the use of fossil fuels. Empty Fruit Bunches (EFB) has a fibrous structure, poor grindability, high moisture content, and a low energy density if not adequately processed. There is an increase of interest among the researchers to perform a parametric study on the quality characteristics improvement of EFB in terms of properties and combustion. In fact, the study is on the combustion characteristics of EFB briquettes as produce producer gas and the properties study of the gas as a potential producer gas are still limited.

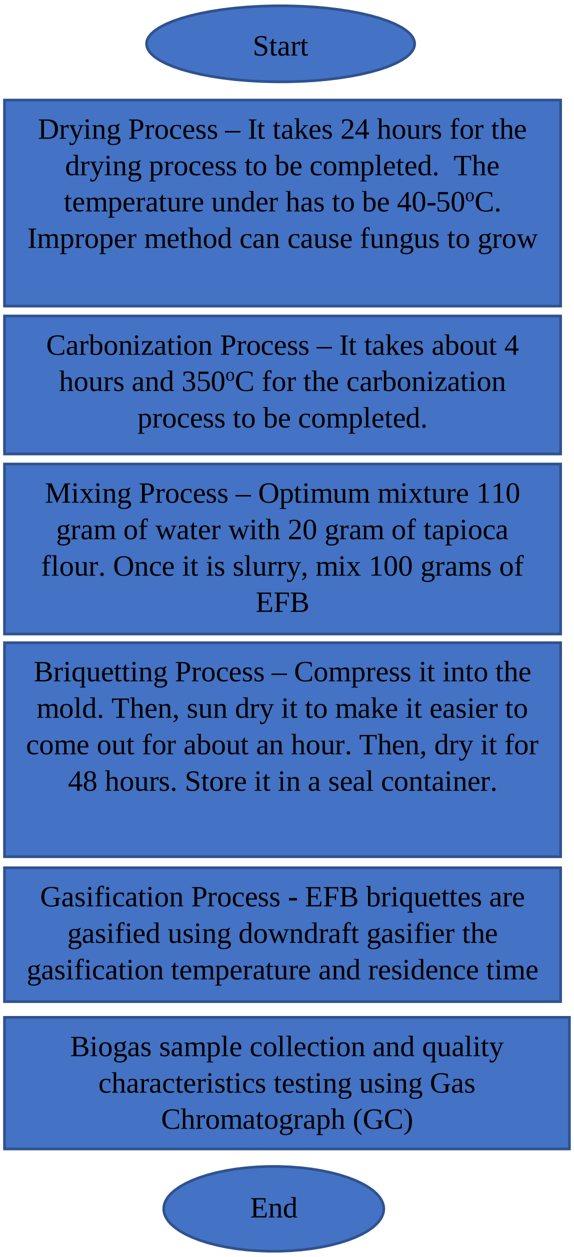
1.3 Objectives

- To determine the compositions of organic binder, water, and EFB samples in order to determine the best mix of EFB briquettes following the pre-treatment procedure.

- To study the combustion performance of EFB briquettes from downdraft gasification process and Burning Rate Test (BRT).

1.4 Scope of Work

This project is the study of the characteristics of EFB with water and organic binder. In this project, it will be split in two parts which are pre-treatment and analysis. In the pre-treatment, there are drying, carbonization, mixing, briquetting. Then, the optimization of biomass producer gas from biomass briquettes will be done experimentally using downdraft gasifier. The second part is to test the sample of gas prepared earlier in the GC to determine whatever or not it can be a producer gas.



Drying Process – It takes 24 hours for the drying process to be completed. The temperature under has to be 40-50°C. Improper method can cause fungus to grow

Carbonization Process – It takes about 4 hours and 350°C for the carbonization process to be completed.

Mixing Process – Optimum mixture 110 gram of water with 20 gram of tapioca flour. Once it is slurry, mix 100 grams of EFB

Briquetting Process – Compress it into the mold. Then, sun dry it to make it easier to come out for about an hour. Then, dry it for 48 hours. Store it in a seal container.

Gasification Process - EFB briquettes are gasified using downdraft gasifier the gasification temperature and residence time

Biogas sample collection and quality characteristics testing using Gas Chromatograph (GC)

Figure 1.1 Work Flow

Chapter 2

LITERATURE REVIEW

2.1 Biomass

The most significant biofuel crops include switchgrass, wheat, sunflower, cottonseed oil, soy, jatropha, palm oil, sugarcane, canola, and corn. Table 2.1 shows the raw materials that different countries use to produce biofuels as well as the total cost of production.

Table 2. 1 Feedstock used by countries for the production of biofuels. [1]

Biofuel/Country	**Feedstock**	**Feedstock (Percent of Total)**	**Total Production Costs ($ per Gallon)**
Biodiesel:			
United States	Soybean oil	80-85	2.50
Malaysia	Palm oil	80-85	2.04
EU	Rapeseed	80-85	3.29
India	Jatropha	80-85	1.99
Diesel **United States**	Diesel	75	1.50
Ethanol:			
United States	Corn	39-50	1.50
United States	Cellulosic sources	90	2.69
Brazil	Sugarcane	37	0.98
EU	Wheat	68	2.23
EU	Sugar beets	34	2.88
Gasoline **United**	Gasoline	73	1.29

Indonesia was the world's top producer of palm oil in 2020, with 43.5 million tonnes produced, followed by Malaysia with 19.9 million tonnes. For every tonne of palm oil produced, 1.07 tonnes of empty fruit bunches (EFB) are created. As a result, for every tonne of palm oil produced, the sector produces 1.07 tonnes of EFB. As a result, Malaysia generates around 21.3 million tonnes of EFB yearly. According to reports, EFB production reached over 80 million tonnes in 2018. Comparing it to other biomass products like maize straw (128.02 million tonnes), rice husk (120 million tonnes), sugarcane bagasse (180.7 million tonnes), and wheat straw reveals that this number is significant (354.34 million tons).Due to the enormous amount of biomass produced by Malaysia and Indonesia, it is regarded as an excellent feedstock for the production of bio-oil (85 percent of world palm oil output).

Oil palm biomass is a great source of feedstock for the production of bio-oil since it is readily accessible in Malaysia and Indonesia, which together generate 85% of the world's palm oil. Fresh oil palm fruit bunch (FFB), which generated 81,920 kilo tonnes, produced the largest agricultural production in Malaysia in 2007. A sizable quantity of EFB waste is generated in addition to biomass, as indicated in Table 2.2, and might be utilised as a feedstock for second-generation biofuels. (Figure 2.1 and Table 2.2). Palm oil wastes also contain mesocarp fibre, shell, empty fruit bunches (EFB), fronds, trunks, and palm oil mill effluent (POME). The wastewater created by mills that process palm oil is known as POME (palm oil mill effluent). [1]

Table 2. 2 Components of oil palm residues in Malaysia which have potential of generating energy. [1]

Type of Biomass by	**Quantity per Year (Million Tons)**	**%**
Empty fruit bunch (EFB)	15.8	30.9
Fronds	12.9	25.2
Mesocarp fiber (MF)	9.6	18.8
Trunk	8.2	16.0
Shell	4.7	9.2

There are few studies on the conversion of oil palm EFB to bio-oil, despite the abundance of oil palm EFB in Southeast Asia. It is not frequently used as a feedstock in comparison to other types of biomass. Therefore, technological advancements are necessary in order to utilize this renewable energy source effectively. This study focuses on the oil palm EFB as a source of bio-oil. [1]

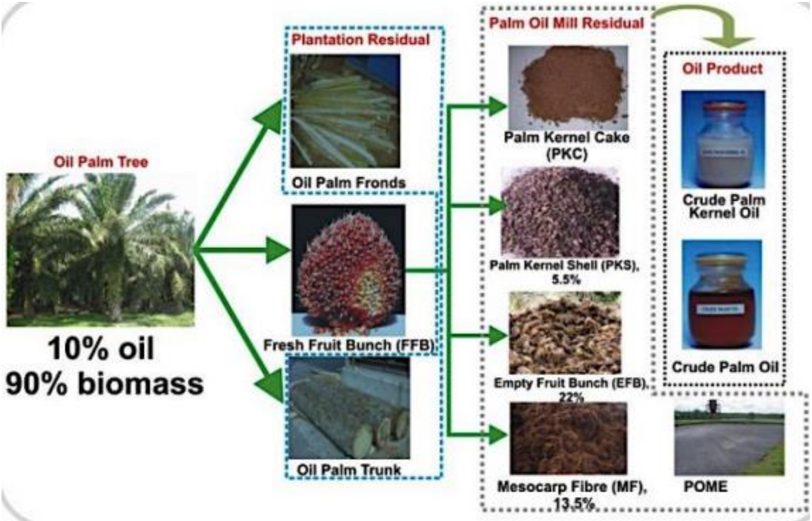


Figure 2.1 Plantation and palm oil mill residual in production of crude palm oil from biomass [1]

2.2 Organic binder for briquettes

Organic binders often have strong impact and abrasion resistance as well as excellent water resistance. However, they readily breakdown at high temperatures because to low thermal stability and mechanical strength. Their widespread availability, low cost, great heating value, and low ignition temperature serve as their primary distinguishing features. Biomass (agricultural wastes, forestry wastes, etc.), tar pitch and petroleum bitumen (coal tar pitch, tar leftovers, etc.), lignosulphonate, and polymer binders (resins, polyvinyl chloride, and starch) are the four primary categories of organic binders. Based on how they react with water, organic binders can be further classified as hydrophobic binders (like coal tar and asphalt) and hydrophilic binders (like biomass). The commercial use of organic binders in biomass briquetting has been constrained by their poor thermal stability.

The availability, price, raw material characteristics, mixture moisture content, densification pressure, and required energy content of the briquettes are all important considerations when choosing binders for biomass briquetting. The most crucial aspects considered while choosing binders in the majority of developing societies are the cost and accessibility of the binders. The kind and quantity of binders used in biomass briquetting have been connected to the briquettes' final features, particularly their mechanical and combustion characteristics. Additionally, different binders have different levels of effect on the characteristics of biomass briquettes. [13]

2.3 EFB briquettes and producer gas properties

In this study, for each 100g of carbonized EFB, three different ratios of water to starch were employed in this study: 100:20, 110:20, and 120:20. The two types of binders used were tapioca starch (TS) and maize starch (CS). The carbonized EFB was proportionately mixed with the binder solution before being applied. [11]

Table 2. 3 Effect of binder solution on the maximum compressive load of the carbonized EFB briquette. [11]

Briquette Treatment (carbonized EFB: starch solution)		Label	Maximum Compressive Load (N)
Tapioca starch	100:100/20	TS1	320
	100:110/20	TS2	431
	100:120/20	TS3	550
Corn starch	100:100/20	CS1	243
	100:110/20	CS2	410
	100:120/20	CS3	505

Briquettes that have undergone carbonization treatment and been mixed with starch mixture are stronger than raw EFB briquettes. This is because briquettes adhere better when starch is added and keep their compact shape following the densification process. Additionally, it was found that depending on the kind and solution of the binders, the effect of the binder varied. According to table above, the strength of the briquettes increases as the viscosity of the starch solution increases for both types of binders. This shows that strong briquettes developed more effectively once the right quantity of binder was added. As a result of tapioca's larger proportion of lignin content than corn's, the results also indicated that tapioca starch provided a stronger impact when compared to corn starch. [11]

Table 2. 4 Effect of carbonization and binder on the fixed carbon, volatile matter, ash content and moisture content of the briquette. [11]

Component (%)	Treatment						
	Raw	TS1	TS2	TS3	CS1	CS2	CS3
Fixed carbon	13.05	56.938	54.438	52.113	50.998	50.887	50.023
Volatile matter	80.21	26.42	29.741	32.126	31.721	35.918	35.209
Ash content	6.43	10.927	8.742	7.498	10.6	5.478	7.283
Moisture content	15.8	5.715	7.143	8.263	6.619	7.719	7.458

The effects of the binder content varied depending on the kind of binder solution. The results of this investigation demonstrated that, notwithstanding the little difference, tapioca starch, when used as a binder, generated less volatile matter than maize starch. The variance in cellulosic content, particularly the carbohydrate content, which is easily broken down during thermal processing, as well as the percentage of moisture content, were the reasons for the difference in volatile matter reduction between these two forms of starch. The results in table above also revealed that when the ratio of water to starch increased, fixed carbon content decreased and volatile matter increased dramatically. The moisture level of carbonized EFB briquettes is obviously influenced by the amount of water used in the starch solution, which slows down the breakdown of volatile materials in the briquettes. The greater ash value of carbonized EFB above raw briquettes is also notable because ash is known to impair high heat value. [11]

A gas combination called "producer gas" includes carbon monoxide, hydrogen, carbon dioxide, and nitrogen. Producer gas only has a modest heating value of 5800 KJ/m^3 because the nitrogen in the air remains unaltered and dilutes the gas. It is utilized close to its source once the ash and sulphur compounds have been removed. Gas turbines that can run on low-calorie fuels may be powered by this gas. N_2 makes up 55% of producer gas, CO is 29%, CO_2 is 5.5%, and H_2 is 10.5% of the total volume. [15]

2.4 Bomb Calorimeter

The amount of heat generated during the combustion of a solid or liquid substance is measured by a bomb calorimeter. A bomb calorimeter calculates the amount of calories or joules needed to measure the heat produced or absorbed during a combustion reaction. Units of energy include calories and joules. The reaction occurs in a sealed area known as the calorimeter proper, in constant thermal contact with its surroundings (the jacket). The calorimeter is made up of this set as well as equipment for measuring temperature, heating, cooling, and stirring. The actual calorimeter is typically a metal can with a tight-fitting lid filled with water that is constantly stirred and in which the actual bomb is placed. Following the ignition of the combustible material in an oxygen atmosphere, the reactants are allowed to react under constant volume conditions in a sealed, heavy-walled container. The name comes from the frequent use of gases under high pressure. It is frequently used to calculate a substance's high calorific value. [4]

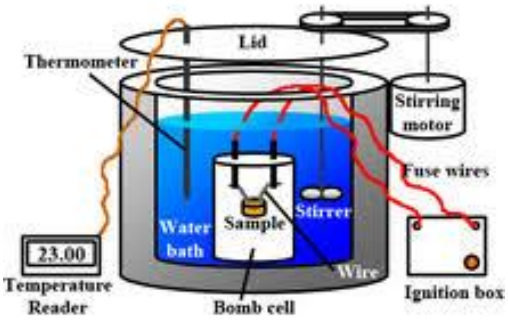


Figure 2.2 Bomb Calorimeter [4]

2.5 Thermogravimetric analysis (TGA)

Thermogravimetric analysis (TGA), which analyses weight changes in a substance as a function of temperature, is carried out in a controlled environment (or time). Some of its key uses include measuring a material's thermal stability, the quantity of fillers in polymers, the quantity of moisture and solvent, and the percentage composition of components in a compound. In order to conduct a TGA analysis, a sample is gradually heated inside of a furnace while being weighed using an analytical balance outside of the furnace. Mass loss is seen in TGA if a heat event leads to the loss of a volatile component. Mass loss occurs during chemical processes like burning, but not during physical changes like melting. To depict thermal transitions in the material, such as the loss of solvent and plasticizers in polymers, water of hydration in inorganic materials, and finally material decomposition, the weight of the sample is plotted against temperature or time. [5]

Figure 2.3 Perkin Elmer Pyris 1 Thermogravimetric Analyzer (TGA)

2.6 Universal Testing Machine (UTM)

To assess a test specimen's mechanical properties, a universal testing machine (UTM) is used on apply tensile, compressive, or transverse loads to it (tension, compression, etc.). The name of the device alludes to the range of tests it is capable of performing on many kinds of materials. Numerous tests, including as the peel, flexural, tension, bend, friction, and spring tests, may be performed with the use of UTM. The two primary parts of a universal testing machine are the loading unit and the control unit.

The loading unit holds the setup of the test specimen and the load's exertion. The control unit provides the variations in load application and the corresponding test result. With the comparison of fire starter briquettes, we will study the compressive load test on EFB briquettes in this test.[6]

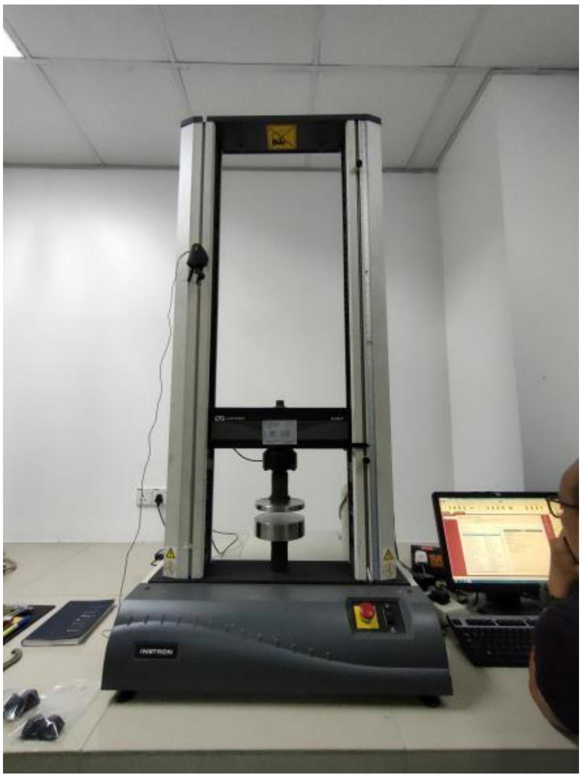


Figure 2.4 Instron Universal Test Machine (Model No 3367)

2.7 Downdraft Gasifier

One approach is to add primary gasification air to the gasifier at or above the oxidation zone. Due to the fact that the created gas is drawn from the bottom, both fuel and gas are delivered in the same direction. The fuel's tarry and acidic distillation by products must travel through a bed of burning charcoal on the way down, where they are converted into stable gases like hydrogen, carbon dioxide, carbon monoxide, and methane. Depending on the hot zone's temperature and how long the tarry vapours remain. To a greater or lesser extent, the tars are broken down.

The main advantage of a downdraft gasifier is its capacity to produce tar-free gas for engine running. In practise, tar-free gas is only occasionally produced, and there is much less tar in the product stream than there would be in an updraft gasifier.

A downdraft gasifier's main drawback is its inability to process a variety of feedstocks. Low density feedstock results in flow problems and a high pressure drop. Compared to updraft gasifiers, this type of gasifier has more issues with coal with a high ash content. Since there is no provision for internal exchange, it is less efficient than an updraft gasifier, which is another disadvantage. The product stream's calorific value is also low. [7]

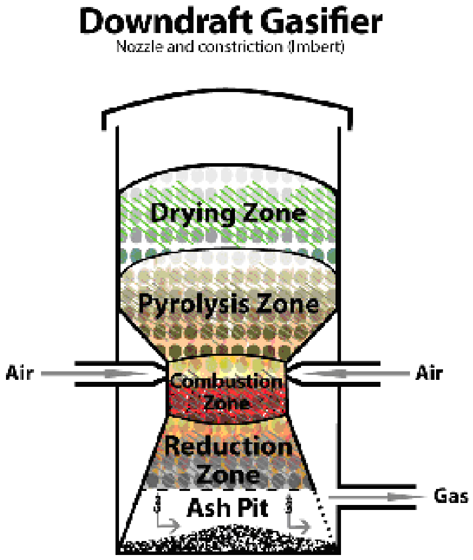


Figure 2.5: Downdraft Gasifier. [7]

2.8 Gas Chromatography (GC)

By using a technique called chromatography, components in a mixture are separated depending on how efficiently the mobile and stationary phases separate. Gas chromatography is one of the popular chromatography techniques for separating volatile molecules or chemicals (GC). The stationary phase is a liquid that is adsorbed on a solid and has a high boiling point, while the mobile phase is a gas, such as helium. Because of its simplicity, high sensitivity, and effectiveness in efficiently separating mixtures, gas chromatography has grown into one of the most important instruments in chemistry.

The mixture's components are split between two phases: a stationary phase and a mobile phase gas, or carrier gas, which transports the mixture through the stationary phase. As they move through the stationary phase, compounds in the mobile phase interact with it. The size and affinity of each interaction with the stationary phase vary depending on the characteristics and structural differences of each component. Because different components have different retention times in the column under the same driving force, they exit the column in different sequences.[8]

Figure 2.6 Gas Chromatography

Chapter 3

RESEARCH METHODOLOGY

3.1 Overview

The methodology, equipment, materials, and complete experimental setup used for the project are detailed in this chapter. The initial step is to get EFB samples at the palm mill. The sample was delivered to the School of Mechanical Engineering Bio Lab, where it underwent pre-treatment in accordance with its instructions. Then, EFB briquettes are created by the briquetting process.

In order to compare the briquettes with fire starter briquettes, analysis has been done. Studies with a close proximity and HHV were utilized to evaluate the briquettes' physical, chemical, and combustion characteristics. Approximal measurements are made of the briquettes' volatile matter (VM), fixed carbon (FC), moisture content (MC), and ash content. A Perkin Elmer Pyris 1 Thermogravimetric Analyzer was used to measure the analyses in accordance with ASTM standard protocol (TGA). Using the Nenken 1013-B bomb calorimeter, the HCV was estimated. A compressive load test using the Universal Tensile Machine was also performed to determine the maximum compressive load for both briquettes (UTM). Additionally, a single briquette test is carried out. This test will establish the briquettes' ignition duration, combustion rate, and ash content.

After the analysis, gasification process is proceeded by using the downgraft gasifier. Gas sample was then place in a Gas Chromatography (GC) to investigate the presence of combustible gases such as hydrogen (H_2), carbon monoxide (CO), and methane (CH_4), as well as incombustible gases like carbon dioxide (CO_2) and nitrogen (N_2). Using a formula, high heating value can be determined.

3.2 Workflow of the project

The overall activities of this project throughout this process research are **d**epicted in Figure 3.1 flow diagram.

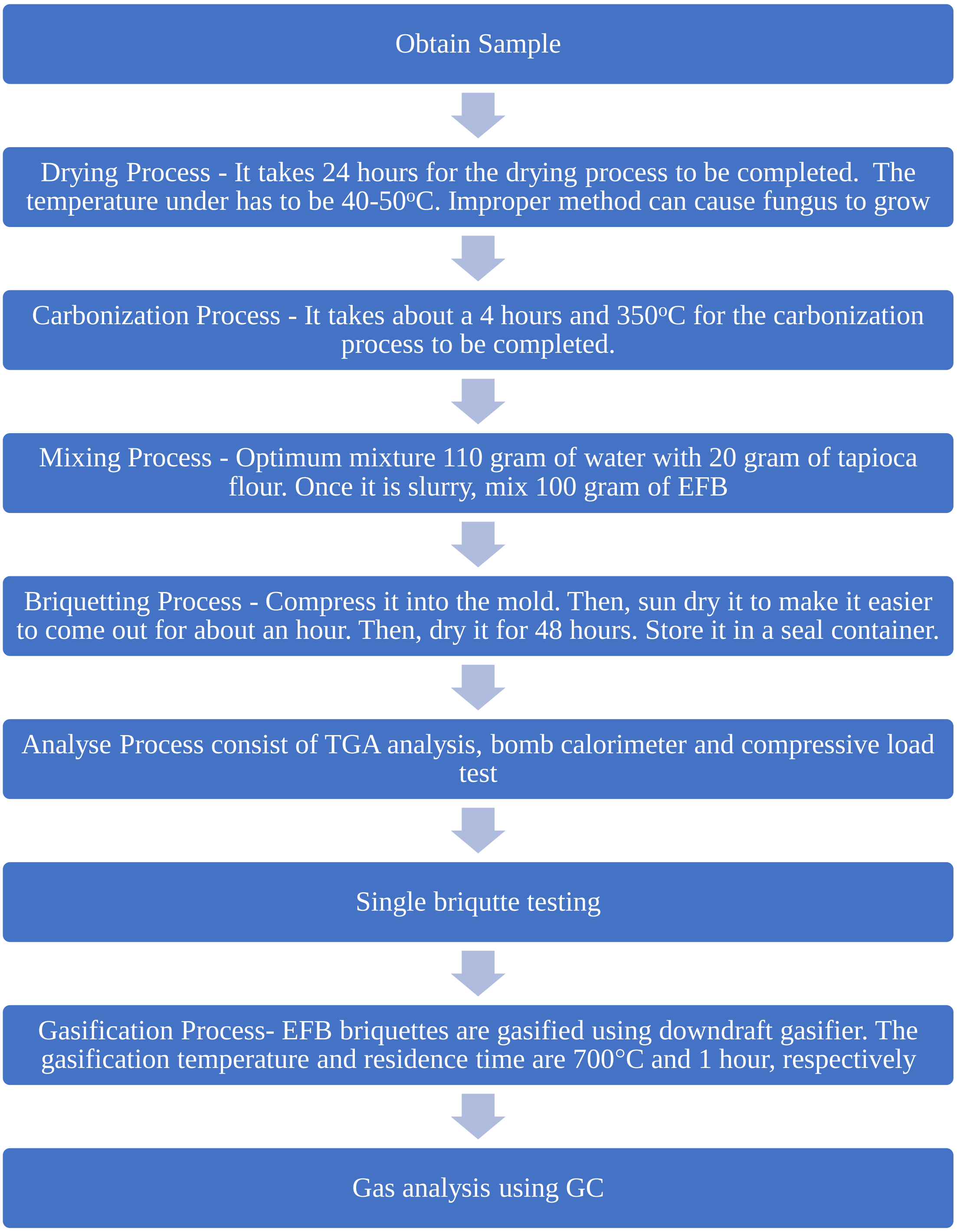


Figure 3.1 Workflow of the project

3.3 Material Selection

3.3.1 Obtaining Empty Fruit Bunches Fibers

With the consent of the business, raw EFB samples were obtained from Hilltop Palm Sdn. Bhd., Bagan Serai. EFB fibre samples were given by the palm mill in the Bagan Serai region. Tali Ayer Palm Oil, Batu 70, Jalan Ipoh/Parit Buntar, 34300 Bagan Serai, Perak is where you can find Hilltop Palm Sdn. Bhd. The initial collection of samples took place on December 27, 2021. The first meeting with Mr Danesh Krishnan, the manager of the palm factory, went off without a hitch. From the plant, about 20 kg of dried EFB were removed. More samples were needed after the pre-treatment. The second set of samples was gathered on April 4, 2022. 20 kg more dried EFB were collected this time. The final storage container for the EFB was a black plastic bag, which was used to retrieve it from the palm mill. The substance is then delivered back to the University Science Malaysia School of Mechanical Engineering's Bio Lab for treatment and laboratory testing.

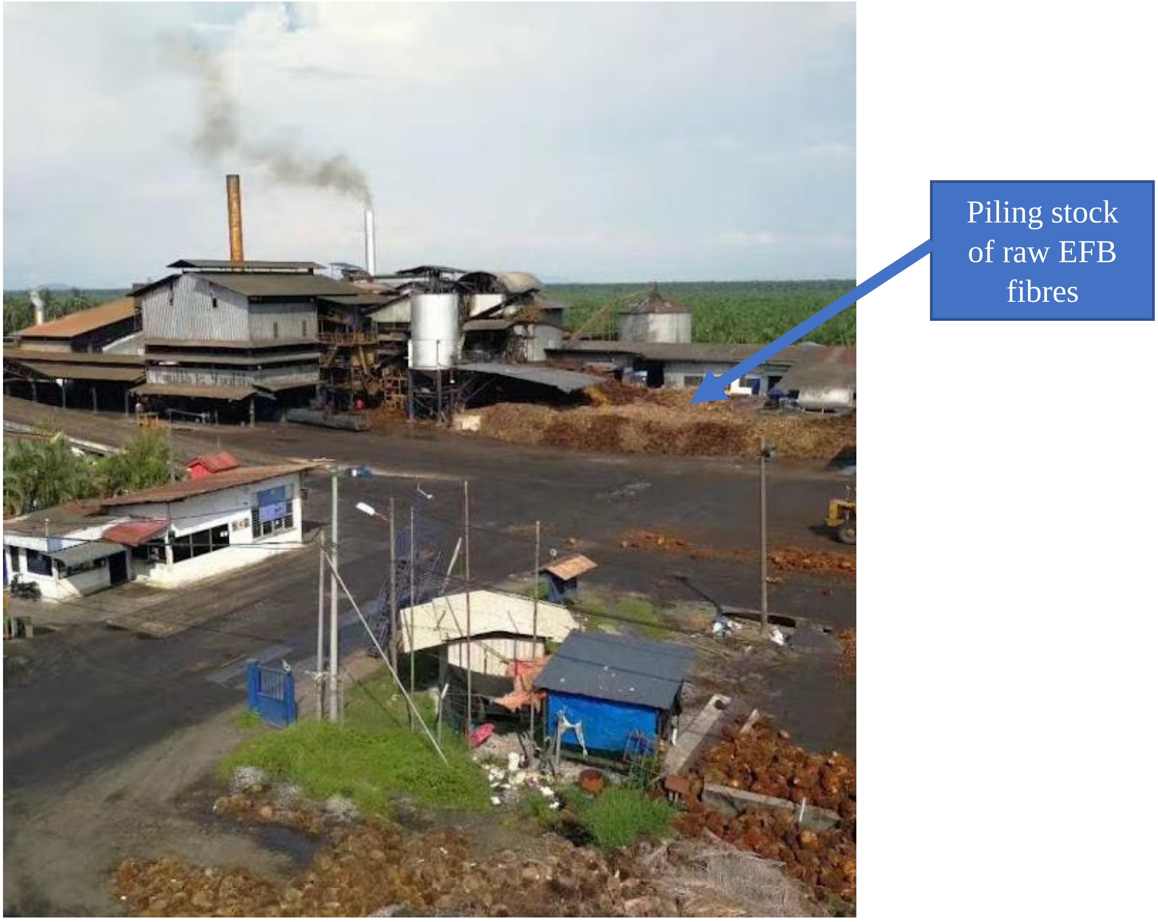


Figure 3.2 Raw EFB procurement from industry

3.3.2 Pre-treatment on Empty Fruit Bunch

The pre-treatment procedure is a series of steps that the briquette must go through before it is prepared to undergo physical and proximate testing. The pre-treatment flow method is depicted in Figure 3.3.

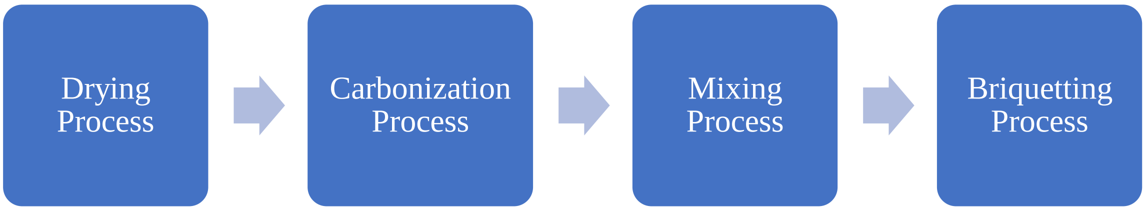


Figure 3.3 Flow process of Pre-Treatment EFB

3.3.3 Drying Process

Once the samples were obtained for the palm mill, the samples were taken to the School of Mechanical Engineering Bio Lab. The samples were then place to be dry under the sunlight. The optimum temperature for drying the samples are in the range of 40^{o}C – 50^{o}C. It requires around 24 hours for the samples to be complete dry so that it can proceeded to the following step. Improper drying or storage can cause fungus growth which can affect the samples.

Figure 3.4 Drying Process

3.3.4 Carbonization Process

In this process. Kitchen Waste Carbonizer can be used. In using Kitchen Waste Carbonizer, more quantity can be place in it at a time comparing to the torrefaction process. While the torrefaction can only hold 90g at a time, the Kitchen Waste Carbonizer can hold up to 5kg. The Kitchen Waste Carbonizer is turned on and the stirrer is switch on as well. The sample is then placed within it. The temperature is then turn on by one by one. The Kitchen Waste Carbonizer is then set 350°C. After 4 hours, the machine is turned off. After a few hours, the carbonized sample is then taken out of the machine.

Figure 3.5 Kitchen Waste Carbonizer

Figure 3.6 Carbonized sample

3.3.5 Mixing Process

An organic binder, tapioca starch, was used in this briquette formulation. The ratio that is use is 110:20 starch binder ratios in each 100g biomass sample. This ratio is obtained by the previous FYP student who conducted the experiment to determine the optimum value. To create the necessary combination composition, weigh out tapioca starch to 20 grams and add in 110 grams of water. The water is then mixed with tapioca starch before being heated. The mixture can then be heated until a slurry condition is reached. 100 g of carbonized EFB are then added and well mixed by hand.

Figure 3.7 End product of the mixing process

3.3.6 Briquetting Process

Densification is the procedure used to create briquettes. All combination samples were manually compressed using this procedure, using ice molds as indicated in Figure 3.8. The briquette must next be dried in the sun with the mold intact in order to make it simpler to remove for about 24 hours. The briquettes were then removed from the molds. The briquettes were then dried in the sun for another 48 hours. In each sample, the exact same process is used. The briquette must be dried before to use since its wet state will result in a high moisture content. Finally, a sealed container is used to store the dried briquettes. The final product is shown in Figure 3.9.

Figure 3.8 Ice mold use for the briquetting process

Figure 3.9 Final Product

3.4 Standard Test Equipment and Procedures

3.4.1 Bomb calorimeter test

The calorific value (energy content) of the sample carbonized EFB briquette and fire starter briquettes is measured using a bomb calorimeter. Figure 3.10 displays the test apparatus.

Figure 3.10 Nenken Adiabatic Bomb Calorimeter

Sample preparation was the first step of the experiment. The mass of tracing paper is taken. The briquette mass was taken and weighed between 0.5g and 0.99g on the scale. The briquette was then carefully wrapped in nichrome wire after being placed in tracing paper. 10 cm lengths of nichrome wire are cut. The bomb head is put on the support stand, and the nichrome wire is fastened to the electrodes. Carefully thread the wire through each eyelet. Be careful not to disturb the sample when charging and closing the bomb. Press the head assembly into the bomb cylinder as far as it will go after sliding it into the cylinder and opening the vent cap to allow air out.

The oxygen tank's valve is opened. Slowly open the regulator valve when the bomb pressure rises to the desired filling pressure of 30 bar while keeping an eye on the pressure gauge. Once this pressure is reached, shut the tank valve first, then the control valve. The quick-release valve is used to instantly detach the oxygen tank in order to stop oxygen from leaking. The inside cylinder of the bomb calorimeter is filled with 2100 mL of water before use. The inner cylinder of the bomb calorimeter is filled with the bomb, which is noticed to be resting on the elevated triangular frame of the bomb calorimeter. The inner cylinder screw is evenly tightened by placing the inner cylinder lid on top of the ignition cap.

To make sure the stirrer runs smoothly, crank it by hand before slipping the driving belt into the pulley. It is turned on. The stirrer should reach equilibrium after 5 minutes. At the end of this time, start the timer, take a minute to read and record the initial temperature on the Beckmann's thermometer. At the beginning of the sixth minute, press and hold the ignition button for 5 seconds to detonate the device (until the light goes out).

The temperature starts to rise 20 seconds after the shot. After 30 seconds, the first temperature reading is collected, and so on for the next 5 minutes. Precise time and temperature data must be recorded in order to calculate the briquette's calorific value. After this five-minute interval, the temperature is measured until there is no change between subsequent readings (or perhaps becomes negative). This work can be finished in around five minutes. After the last temperature reading, cut off all electrical connections, remove the drive belt, and then put the cover on the support ring. The electrode is measured for any remaining unburned nichrome wire. The length of the unburned nichrome wire must be subtracted from the original length of the wire when assessing the results. The process is then repeated for the fire starter for comparison value.

3.4.2 Thermogravimetric Analyzer (TGA)

The proximate analysis of EFB briquettes and fire starter briquettes was examined using a thermogravimetric analyzer. The test apparatus is seen in Figure 3.11.

Figure 3.11 Perkin Elmer Pyris 1 Thermogravimetric Analyzer (TGA)