CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDIES

The call for the use of alternative energy has rapidly increased in this modern day. Thus, several techniques being created in the progress of extracting energy form the alternative sources. The one of the main targets is biomass. However, nature has created a large diversity of biomass. In addition, modification men makes to biomass to use it in industrial or domestic applications. Therefore, the composition and properties of biomass is subjected to many natural and human factors. Some of these needs to be improved before biomass can be seriously considered as sustainable fuel in highly efficient biomass-to-energy chains.

In Malaysia, the large extend of the biomass bulk, with oil palm based sources lead the way which approximately 14.8 million tones of biomass per year (Wahid, 2007). With Salsuwanda Selamat and Che Zulzikrami Aziz(2007) prediction from their researched discover them to realize that gas reserves estimated to last for another 33 years and oil reserves another 19 years, it only a matter of time before biomass replaced the fossil fuels as a main source of energy.

1.2 PROBLEM STATEMENT

Gasification is one of the newer technologies that that converts carbonaceous material into a mixture of gas that called synthesis gas or syngas that itself is called fuel. However, result of gasification process can be improved and the amount of energy extracted from biomass can increased if certain properties of the biomass can be improved. Therefore, biomass needs to go through pre-treatment process to enable its application as a main source of alternative energy.

Biomass has some disadvantages as fuel such as low calorific value, high moisture content, hygroscopic nature and smoking during combustion. These characteristic affected the gasification process when biomass is feed in the gasifier. Meng Ni et al (2004) strengthen the statement by claiming that gasification application is only applicable for biomass having moisture content less than 35 %. Thus, it is certainly essential for the biomass to undergo pre-treatment before the gasification process.

This project will focus on upgrading palm waste biomass which in this case is palm fiber/ palm shell/ palm frond. The methodology that is going to be use in this project is torrefaction with the hope that better quality biofuel is produced.

1.3 OBJECTIVES

The main objective in this project is to obtain prepare biomass that has an improved properties for gasification applications. In this case, palm waste biomass is use as a biomass material. Apart from that, the project aims to study the characteristic palm waste biomass which for this project will specify on Palm fiber, palm kernel shell and palm frond which are to be used in the torrefaction process.

To justify torrefaction improve biomass characteristic, therefore, a comparison will be make for the biomass properties before and after the torrefaction process. The parameters that will be measure during this project are:

1. Moisture content
2. Calorific value
3. Volatile matters
4. Ash content
5. Fixed carbon content.

1.4 SCOPE OF PROJECT

The scope of the project will cover the following:

i) Research and literature review on theories and information from various sources related to project.
ii) Perform experiment based on target parameters and the availability of the equipment in the Laboratory.
iii) Analyses the properties of the biomass.
iv) Reasoning and justifying the result that being obtained throughout the project.

1.5 THE RELEVANCY OF THE PROJECT

Currently, present energy use is largely dependent on fossil fuel, which are estimated could not sustain the increasing needs in the near future. Therefore, the search for the alternative energy is largely dependent on the other natural sources. Furthermore, the increasing awareness of the global warming and green house affect means the search and development of new energy sources and the technologies behind it is majorly supported and accepted by the government and the people.

There are large quantities oil palm based sources which generates 14.8 million tones of biomass per year (Wahid, 2007). Unlike fossil fuels, which are limited in availability, this biomass is not only abundantly available, but also renewable.

Therefore, the study on the properties and the best way to improve the biomass properties is needed to maximize the efficiency of any technology that being used to extract the energy.

1.6 FEASIBILTY OF THE PROJECT WITHIN THE SCOPE AND TIME FRAME

The Project is accomplished within 2 semesters (11 months) which comprises of literature review study and experimental work. The project begins with detail research on the current situation of energy sources and then move on to the study of torrefaction technology that is believed can improve the biomass properties. Experimental work began in second semester which justified the concept created earlier in the literature review. Experimental is basically divided into three phase where analysis of the palm wastes before being torrefied, the torrefaction process, and the analysis of the torrefied biomass. Overall, the project has managed to be completed in the specified time.

CHAPTER 2

LITERATURE REVIEW

2.1 WORLD ENERGY VIEW

2.1.1 Energy Demand

Oil and Gas have been the main sources in the whole world and Malaysia itself (Refer Figure 2.1). In the survey made by International Energy Agency in 2004, Oil and Gas are the leading supplier of the world energy supply, contributing more than 50% of primary energy. This is followed by coal (25 %) , renewable(13.1 %) and Nuclear(6.5 %). Salsuwanda Selamat and Che Zulzikrami Aziz(2007) researched discover them to realize that gas reserves estimated to last for another 33 years and oil reserves another 19 years.

As a result, the Malaysian government is trying to strengthening the role of renewable energy (RE) as the fifth cornerstone of energy generation. In addition, manufacturing companies also try to reduce their cost in the energy costs to strengthen the call for the use of alternative energy.

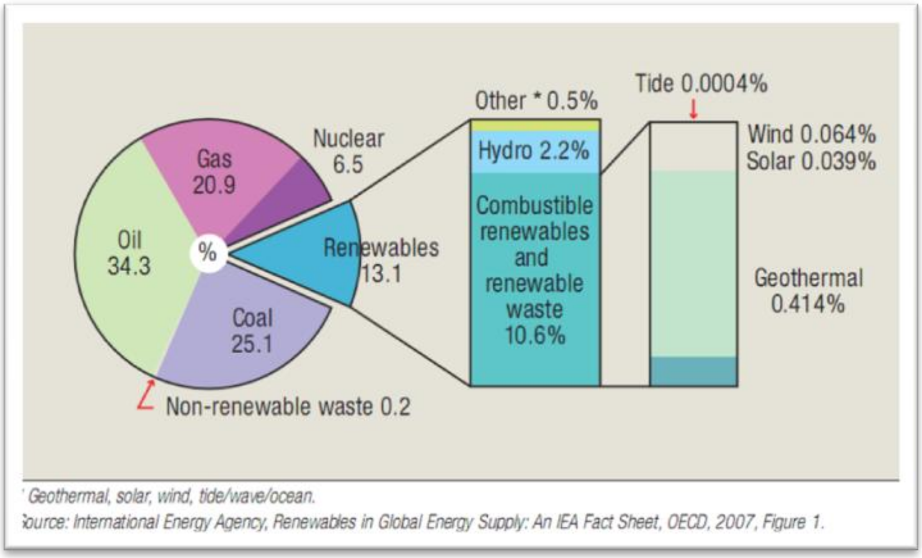

Figure 2.1: Fuel Share of world total primary energy supply, 2004
(Source: International Energy Agency, Renewable in Global Energy Supply: An iEA Fact Sheet, OECD, 2007)

Malaysia as a party of UNFCCC (United Nations Framework Convention on Climate Change) is committed to formulate, implement, publish, and regularly update national and where appropriate, regional programmes containing measures to mitigate climate change by addressing anthropogenic emissions by sources and removals by sinks of all greenhouse gases. Indirectly, Malaysia has the responsibility to implement the things that stated in Kyoto Protocol which purposely to stabilize greenhouse gas concentrations in atmosphere.

In the seventies, the oil crisis forced many to look for alternative renewable energy sources and in the nineties, the global environmental concerns created the awareness to use clean energy. Moreover, the increasing awareness of people in understanding the side effect of using fossil fuels catapulted the search for clean renewable energy and to reduce the conventional energy sources. Their combustion products pollute the environment as such it leads to acid rain and global warming.

This all lead to one conclusion, which to search for new alternative energy that is renewable and the same did little wrong in harming the environment. The coming chapter will discuss more about one of alternative energy sources that suit the characteristic mentioned before and in addition have a big market in Malaysia.

2.1.2 Kyoto Protocol

The Kyoto Protocol is an international linked to the United Nations Framework Convention on Climate Change. The major feature of the Kyoto Protocol is that it sets binding targets for 37 industrialized countries and the European community for reducing greenhouse gas (GHG) emissions.

Under the Protocol, countries' actual emissions have to be monitored and the records have to be kept. Reporting is done by Parties by way of submitting annual emission inventories and national reports under the Protocol at regular intervals. A compliance system ensures that Parties are meeting their commitments and help them to meet their commitments if they have problems doing so.

2.1.3 Carbon Cycle

The carbon cycle is a complex Earth system whereby carbon dioxide (CO2) is exchanged among four main regions of the planet. In the carbon cycle, CO2 is recycled through the atmosphere, biosphere, geosphere and oceans and other waterways in what are called "sinks" or reservoirs.

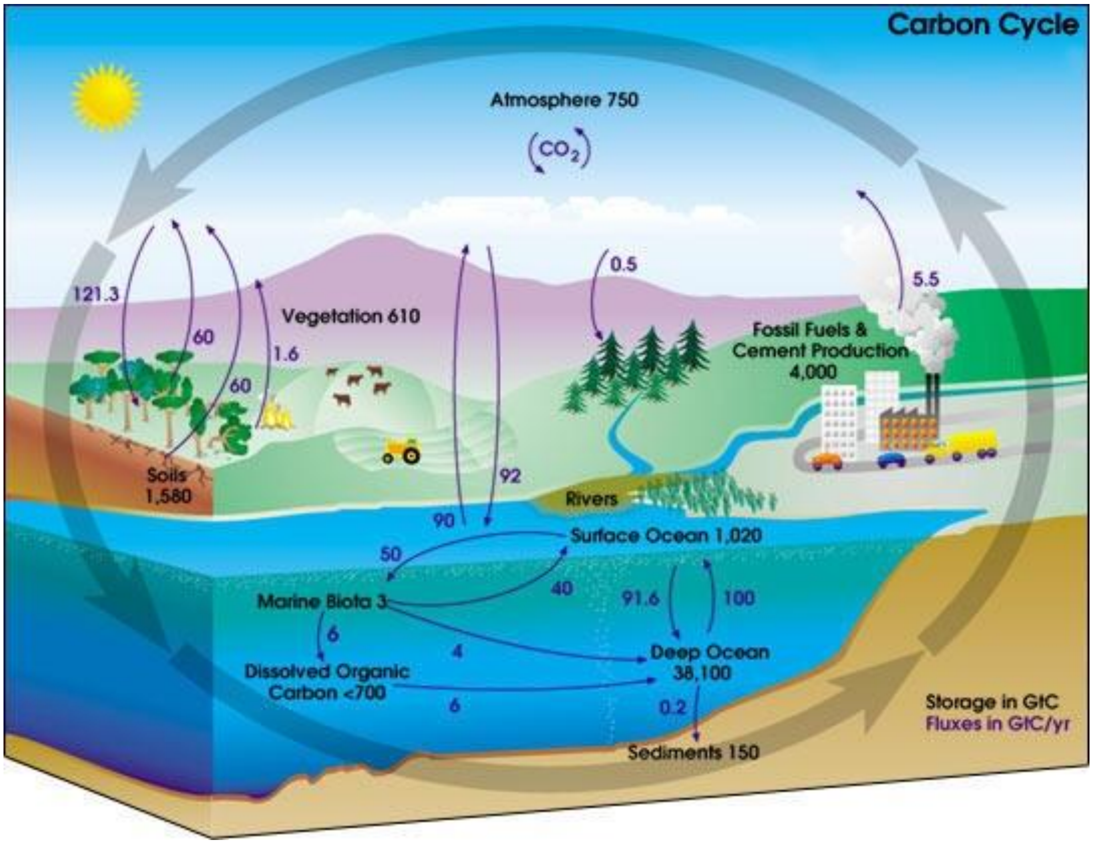

Figure 2.2 Carbon Cylce

Source: www.CO2.climatecleanup.com

In the carbon cycle, carbon dioxide is taken from the atmosphere in several various methods besides the plant life. As illustrate in figure 2.2, Carbon dioxide are release form the fossil-fuel burning activities, plant respiration, land use, decay of residues and etc. However, the carbon dioxide is then reuse for photosynthesis process to produce oxygen to stabilize the flow of carbon cycle.

In another part of the cycle, oceanic plant and animal life absorb carbon in hard and soft tissue of the organism. The weathering of carbon-containing rocks on land that runoff into the streams and oceans also add to the carbon cycle.

However, the threatening part of the cycle, are the parts that are not natural at all. The burning of fossil fuels in the transportation industry and electrical generation in coal fired and natural gas fired power plant create an imbalance in the carbon cycle. Thus, the best solution is to promote the usage of alternative fuels and particularly those created with renewable energy such as solar, wind and other sources that will help the carbon cycle to get back in sync. Without these efforts, however, the natural carbon cycle will continue to erode causing serious climate change and geographical disruption.

2.2 BIO-ENERGY

Vijayalakshmi et al in her book book title *Fuels and Biofuels* defines Biofuel is any fuel with an 80% minimum contact by volume of material derived from living organisms harvested within the ten years preceding its manufacture. Biofuel also known as agro fuel are mainly derived from biomass or bio waste. This type of fuel can be in various sectors, but mainly brought in transportation sector. This is because the facts that, most of vehicles require fuels which provide high power and are dense so that storage is easier. In addition, these engines require fuels that are clean and are in the liquid form.

2.2.1 First Generation Biofuel

First generation biofuel is any fuel made from the products of living of their wastes. For example, starch, animal fats and vegetable oil. The oil is obtained using the conventional techniques of production. Compared to fossil fuel, biofuels are renewable energy source that potentially do not emit net CO_2.

Below, are some of the most popular types of first generation biofuels:

1. Biodiesel – This is the most common type of biofuel commonly used in the European countries. This oil is produced after mixing the biomass with methanol and sodium hydroxide. The chemical reaction there of produces biodiesel.

2. Vegetable oil – These kinds of oil can be either used for cooking purpose or even as fuel. The main fact that determines the usage of this oil is the quality. The oil with good quality is generally used for cooking purpose. Vegetable oil can even be used in most of the old diesel engines, but only in warm atmosphere.

3. Biogas – Biogas is mainly produced after the anaerobic digestion of the organic materials. Biogas can also be produced with the biodegradation of waste materials which are fed into anaerobic digesters which yield biogas. The biogas produced is very rich in methane which can be easily recovered through the use of mechanical biological treatments systems.

4. Bioalcohols – These are alcohols produced by the use if enzymes and micro organisms through the process of fermentation of starches and sugar. Ethanol is the most common type of bioalcohol whereas butanol and propanol are some of the lesser known ones.

5. Syngas – This is a gas that is produce after the combined process of gasification, combustion and pyrolisis. Biofuel used in this process is converted into carbon monoxide and then into energy by pyrolisis. During the process, very little oxygen is supplied to keep combustion under control. In the last step known as gasification the organic materials are converted into gases like carbon monoxide and hydrogen. The resulting syngas can be used for various purposes.

2.2.3 Second Generation Biofuel

Helena Paul and Almuth Ernsting (2006) defined second generation biofuels as meaning biomass-to-liquid technologies, namely cellulosic ethanol and Fischer-Tropsch gasification are intended to use lignocelluloses biomass. The technologies are not yet commercially available but in actively seeking ways of using genetic modification to simplify and streamline industrial processes to break down cellulose, hemicelluloses, so as to produce biofuels more easily, cheaply and efficiently from plant biomass. The industry is looking at ways of modifying plants to:

- Produce less lignin
- Engineer the lignin and cellulose so that they break down easily or in different ways
- Speed up the growth and yield of plants

The general aim is to reduce the cost of ethanol production and increase the volume so that it can compete with fossil fuels on price.

2.2.4 Third Generation Biofuel

The third generation of biofuels comes in the form of the water-based plants known as algae (refer figure 3.1). The ability to transform algae into a biofuel is a burgeoning science, and could hold the future of the biofuel industry. Justin Smith (2009) write about The DOE division of Energy Efficiency and Renewable Energy (EERE) explains, “Microalgae are single-cell, photosynthetic organism known for their rapid growth and high energy content. Some algal strains are capable of doubling their mass several times per day. In some cases, more than half of that mass consists of lipids or triacylglycerides-the same material found in vegetables oils. These bio-oils can be used to produce such advanced biofuels as biodiesel, green diesel, green gasoline and green jet fuel.”

lgae have a number of upsides over other biofuels. Microalgae can potentially produce 100 times more oil per acre of land than soybeans or beans or any other oil-producing crop. In addition, algae do not have to compete for land with food crops as it can be cultivated in large open ponds or closed photobioreactors, which mostly sited in deserts and other non-arable areas.

Figure 2.3: Water Based Plant known as Algae

2.3 HYDROGEN PRODUCTION

The declining of fossil fuels reserved has created such awareness for a need of an alternative energy source. One of it is Hydrogen that derived from renewable resources such as biomass. Currently, Hydrogen is derived from nonrenewable energy sources such as natural gas and petroleum. Ning Gao et. Al (2008) in his article stated that hydrogen has good properties as a fuel for internal combustion engines in automobiles. Furthermore, hydrogen could be advantageous as a clean energy carrier for heat supply and transportation purposes.

In Introduction to Hydrogen Technology, Roman J.Press et al describe hydrogen-based technology offers attractive options for use in an economically and socially viable world with negligible environmental effects. Hydrogen is everywhere on the earth in the form of water and hydrocarbons. In other words, hydrogen as fuel produces water as the by-product, and water is the source for hydrogen. It is an ideal energy carrier and hence could play a major role in a new decentralized infrastructure that would provide power to vehicles, homes, and industries.

Currently, fossil fuels such as oil and gas are being currently used to harvest hydrogen. This is not ideal, as it does not solve environmental issues that arise with the usage of fossil fuels.

Researchers are developing a wide range of technologies to produce hydrogen economically from a variety of resources in environmentally friendly ways. There are:

1. Natural Gas Reforming

   Hydrogen can be produced from methane in natural gas using high-temperature steam. This process called steam methane reforming, accounts for about 95 percent of the hydrogen used in the United States (2008). Another form of technique that is being used called partial oxidation, which produces hydrogen by burning methane in air. Both ways will produce a “synthesis gas”, which is reacted with water to produce more hydrogen.

2. Renewable Electrolysis

   Electrolysis uses an electric current to split water into hydrogen and oxygen. The electricity required can be generated using renewable energy technologies, such as wind, solar, geothermal, and hydroelelectric power.

3. Gasification

   Process in which biomass is converted into gaseous components by applying heat under pressure and in the presence of steam. A subsequent series of chemical reactions produces a synthesis gas, which is reacted with steam to produce more hydrogen that then can be separated and purified.

4. Renewable Liquid Reforming

   Biomass can also be processed to make renewable liquid fuels, such as ethanol or bio-oil, that are relatively convenient to transport and can be reacted with high-temperature steam to produce hydrogen or at near the point of end-use.

5. High-Temperature Thermochemical Water-Splitting

   Another water-splitting method uses high temperatures generated by solar concentrators (special lenses that focus and intensify sunlight) or nuclear reactors to drive a series of chemical reactions that split water. All of the chemicals used are recycled within the process.

6. Photobiological and Photoelectrochemical

   When certain microbes, such as green algae and cyanobacteria, consume water in the presence of sunlight, they produce hydrogen as a byproduct of their natural metabolic processes. Similarly, photoelectrochemical systems produce hydrogen from water using special semiconductors and energy from sunlight.

In this paper, the gasification technology will be discussed further in the next chapter. It It is a well-known technology that can be classified depending on the gasifying agent: air, steam, steam-oxygen, air-steam, oxygen-enriched air, etc.This facts support the call for the utilization of biomass as sustainable energy. However, there are some drawbacks that leads to the decrease of the efficiency of biomass gasification that will be discuss later in the next chapter.

2.4 GASIFICATION

Paul Grabowski recognize gasification process as a thermal conversion of organic materials at elevated temperature and reducing conditions to produce primarily permanent gases (CO, H2, CH4, etc.) with char, water, and condensable as minor products. Anil K.Rajvanshi in his theory stated that, the production of generator gas (producer gas) called gasification is partial combustion of solid fuel (biomass) and takes place at temperature of about 1000 °C. The reactor is called gasifier.

A.Azali et al(2005) explain in his article that gasification demonstrates as one of the cleanest, most efficient method to produce synthesis gas from low or negative value carbon based feedstock such as coal, petroleum coke and high sulfur fuel oil that would otherwise be disposed as waste. It is estimated that gasification of biomass at around 1073-1223 K to syngas can potentially be used either as a gaseous fuel for power generation or as a feedstock for the synthesis of clean transportation fuels or many other chemicals. Below, is the flow of complete Gasification process taken from Chanrakant Turare, ARTES Institute from article Biomass Gasification (2004) that illustrates the technology package consists of a fuel and ash handling system, gasification system - reactor, gas cooling and cleaning system. There are also auxiliary system namely, the water treatment plant to meet the requirement of industry and pollution control board.

S.Dasappa et al describe the biomass technology package consist of a fuel and ash handling system, gasification system- reactor, gas cooling and cleaning system. Besides that, there are also auxiliary system namely, the water-treatment plant to meet the requirements of industry and pollution control board. Typical gasifier is shown in Figure 5.1

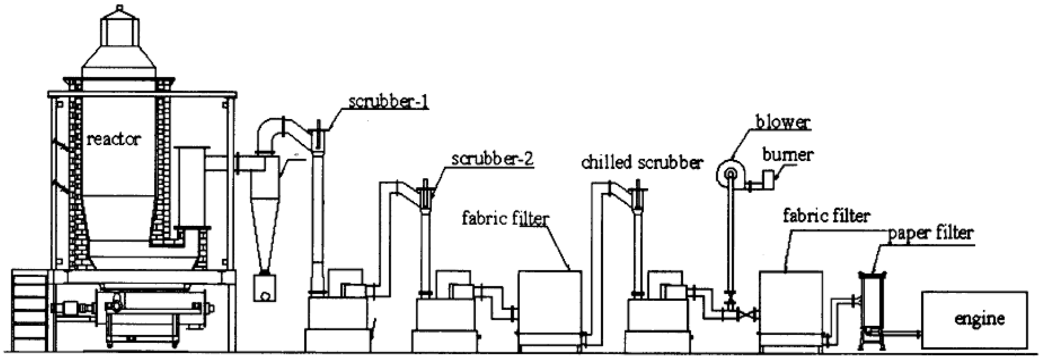

Figure 1. Typical configuration of the gasifier.

CURRENT SCIENCE, VOL. 87, NO. 7, 10 OCTOBER 2004

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Figure 2.4 Typical Configuration of Gasifier

Source: Current Science, Department of Aerospace Engineering (2004)

There are several types of gasifiers that currently used in the industry which are:

Updraught or Counter Current Gasifier

The air intake is at the bottom and the gas leaves at the top. In the upper part of the gasifier, heating and pyrolysis of the feedstock occur as a result of heat transfer by forced convection and radiation from the lower zones. The ashes are removed from the bottom of the gasifier.

The major advantages of this type of gasifier are its simplicity, high charcoal burn-out and internal heat exchange leading to low gas exit temperatures and high equipment efficiency and a possibilities of operating with several feedstock.

However, there also some drawbacks result from the possibility of “channeling” in the equipment, which can lead to oxygen break-through and dangerous, explosive situations and the importance to install automatic moving grates, as well as from the problem associated with disposal of the tar-containing condensates that result from the gas cleaning operations.

Downdraught or co-current Gasifier

A solution to the problem of tar entrainment in the gas stream has been found by designing co-current or downdraught gasifiers, in which primary gasification air is introduced at or above the oxidation zone in the gasifier.

The major advantage of this type of gasifier lies in the possibility of producing a tar-free gas suitable for engine applications. The opposite effects of the equipment its that the inability to operate on a number of unprocessed fuels. It will also suffer from the problems associated with high ash content fuels (slagging) to a larger extent than updraught gasifier.

Cross-draught gasifier

Cross-draught is an adaption for the use of charcoal. It operates at high temperatures (1500 °C and higher) in the oxidation zone which can lead to material problems. The insulation for gasifier will be provided by the fuel (charcoal) itself.

Advantages of the system lie in the very small scale at which it can be operated. Installations below 10 kW (shaft power) can under certain conditions be economically feasible. This is because the very simple gas-cleaning train (only a cyclone and a hot filter) which can be employed when using this type of gasifier in conjunction with small engines.

The system disadvantages of this type system are their minimal tar-converting capabilities and the consequent need for the high quality charcoal.

Fluidized bed gasifier

The operation of fluidized bed gasifier is design to aiming the removal of problems that encountered by previous gasifier which lack of bunker flow, slagging and extreme pressure drop over the gasifier.

Vabder Aarsen (1986) reported that the gasifier of this kind have major advantage in the feedstock flexibility resulting from easy control of temperature, which can be kept below the melting or fusion point of the ash. Furthermore, it has the ability to deal with fluffy and fine grained materials (e.g. sawdust) without the need of pre-processing. Problems with feeding, instability of the bed and fly-ash sintering in the gas channels can occur with some biomass fuels.

Some drawbacks that can be expected from the equipment lie in the rather high tar content of the product gas (up to 500 mg/m3 gas), the incomplete carbon burn-out, and poor response to load changes. Meng Ni et al (2004) also indicate that gasification can only applicable for biomasses that have moisture content less than 35 %. Furthermore, a gasifier requires (sub-) millimeter size feedstock particle to prevent a blockage at the inlet of the gasifier.

Other Types of Gasifier

A number of other biomass gasifier systems which are partly spin-offs from coal gasification technology, are currently under development. In some cases these systems incorporate unnecessary refinements and complications. In others both the size and sophistication of the equipment make near term application in developing countries unlikely. For these reasons, they are neglected from this account.

The essence of gasification is the conversion of the solid fuel to gaseous fuel by thermo chemical reactions of a fuel with oxidizer under sub- stoichiometric conditions, the energy in biomass being realized in the form of combustibles gases (CO, CH4, and H2). The generation of gas occurs in two significant steps. The first step involves exothermic reactions of oxygen in air with pyrolysis gas under fuel-rich conditions. The second step involves the endothermic reaction of these gases largely CO_2 and H_2O with hot char leading to product gases (CO, H_2, and CH_4).

Nevertheless, the disadvantages of raw materials such as variability of quality and calorific value, difficulty in mechanizing continuous feeding) decrease the efficiency of biomass gasification. Several of these disadvantages may be attributed to the adverse effect of heterogeneity and low bulk density of raw materials. Thus, a proper biomass pre-treatment method used to increase its uniform is essential which will be discussed in the next chapter.

2.5 TORREFACTION

2.5.1 Introduction

Motivated by transition to a more sustainable energy, it are expected that the renewable energy such as biofuel to replace nonrenewable energy sources such as fossil fuels. However, as stated in Patrick et al article ‘Torrefaction for Biomass Upgrading’, nature has created a large diversity of biomass that caused composition and properties of biomass is subjected to many natural and human factors. Thus, to enable biomass as a serious and major application as sustainable fuel, some pre-treatment need to be used and one of it is called torrefaction.

Originally developed in the 1930s in France, torrefaction of biomass has been derived from a process traditionally used to dry and roast coffee beans, which makes them brittle and gives them their distinctive flavor. The process involves gently roasting the beans up to the temperatures of 280 °C. In its new and bioenergy-related form, biomass is ‘cooked’ in an oxygen-free environment of anywhere between 200 and 300 °C.

Synonyms for the process are ‘mild pyrolysis’, ‘wood cooking’, high T drying’, ‘wood browning’ or simply ‘roasting’.

The researchers expected the torrefaction process is increasingly seen as a desirable intermediate treatment for biomass because it creates a solid product which is easier to store, transport and mill than raw biomass, which has relatively high moisture content. In more exciting perspective, the torrefaction process made the fuels more friable, making it easier to grind. This might mean that miled biomass could be used in ordinary coal-fired power stations, burned alongside the pulverized coal, greening the fossil fuels act.

2.5.2 Torrefaction Principles

Biomass torrefaction is a pre-treatment method carried out at 200-300 °C in absence of oxygen. The occurring decomposition reactions at this temperature cause the biomass to become completely dried and to lose its tenacious and fibrous structure. The biomass partly decomposes during the process giving off various types of volatiles, which results in a loss of mass and chemical energy the gas phase.

In torrefaction biomass loses relatively more oxygen and hydrogen compared to carbon. Water from dehydration is the best example, but also all organic reaction products (acetic acid, furans, and methanol) and gases (mostly CO2 and CO) contain a considerable amount of oxygen. As a result, the calorific value of the biomass is increased.

Biomass is completely dried during torrefaction and therefore, the existing moisture is very limited. It can be said that it will varies from 1 – 6 % on weight basis depending on the torrefaction. In the torrefaction process, the hygroscopic nature of biomass is at least partly lost, which subsequently result in the destruction of OH groups through dehydration. This prevents the formation of hydrogen bonding.

The volumetric density changes due to the drying and heating causing the biomass to shrink. This process is comparable to drying of biomass. The mass loss during torrefaction causes the biomass to become more porous and as a result, decreased in volumetric density.

2.5.3 Production Technology

The application of torrefaction as a pre-treatment technology yet has not reached a commercial status. The application starts to get attention when it leads to reduce of cost of the overall biomass-to-energy production chain. Figure 6.1 illustrate the example of Torrefaction and Pelletisation (TOP) process that based on direct heating of the biomass during torrefaction by means of hot gas that is recycled. The hot gases that consist of torrefaction gas itself is then re-pressurized and heated after each cycle. The necessary heat for torrefaction and pre-drying is produced by the combustion of the liberated torrefaction gas. If needed, utility fuel will be used if it is found that energy content of torrefaction gas is insufficient to thermally balance the torrefaction process.

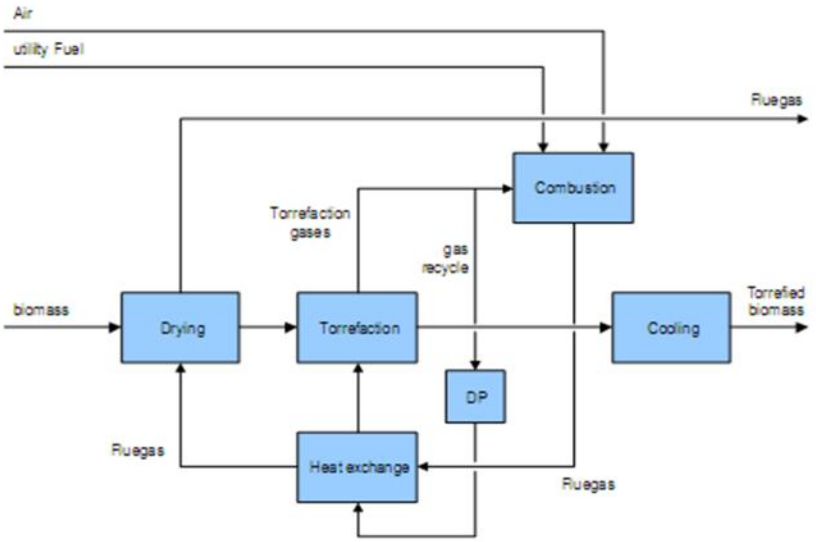


Figure 3: *Plant-layout of the ECN TOP technology [3]. Only the integrated drying-torrefaction part of the process is shown (not size reduction and pelletisation)*

Figure 2.5: Example of torrefaction process

Source: Torrefaction for Biomass Upgrading Article (2005)

Torrefaction can be considered to be a new development for biomass upgrading for biomass-to-energy production chains. During the eighties of the last century a demonstration plant was built and operated by the company Pechiney (France), though this was for a different product application. This plant was dismantled in the beginning of the 1990’s for economic reasons. Since that, the interest in pre-treatment technology such as torrefaction have slightly increased causing new concepts for torrefaction to be proposed but none have been developed to commercial status neither to the stage of technical demonstration.

2.5.4 Application of Torrefied Material

Dewi Soraya et al (2007) researched illustrated that markets for torrified materials are primarily industrial and residential where the torrefied materials have similar application as charcoal. Primarily, for residential use, it usually being used as a cooking tool and for industry, it can be used as a reducer for metallurgical smelting in industry.

The major advantages being found in the torrefied material is its uniformity. Taking as torrefied wood as an example, torrefied wood that has been pelletized after being treated will lower the transportation cost and will increased it heating value (11,000 BTU/lb) nearly the coal heating value(12,000 BTU/lb) in a much lower price. This is justify by Chris Hopkins by explaining that at torrefaction temperatures, the lignin in wood becomes plastic and can actually become a binder for individual wood particles. Thus, as a result, pellets made from torrefied wood withstand 1.5 to 2 times the crushing force of normal wood pellets.

2.6 BIOMASS

2.6.1 Introduction

Ms Fara(2002) and Dewi Soraya(2008), defined biomass energy as renewable resource that is part of the resource occurring naturally and repeatedly in the environment. The energy source that induces the renewability of biomass is the sun in the form of photosynthesis from the photoactive properties of radiation, sustaining the growth of plants with subsequent release in the biosphere. As with all living system, biomass is a highly diverse and complex resource, and has to be studied in a holistic context with a full recognition of the interdependencies in the overall system of land, water, people, nutrients and all the five kingdom of life.

In a report published by the United Nations Development Programme(UNDP), Malaysia(2007), it is expected by 2015, the number of people using biomass for essential domestic purposes is expected to rise to 2.6 billion, and to 2.7 billion by 2030 as population numbers increase. This indicates that almost one-third of the world's population will still be relying on the biomass fuels, a share barely smaller in 2005.

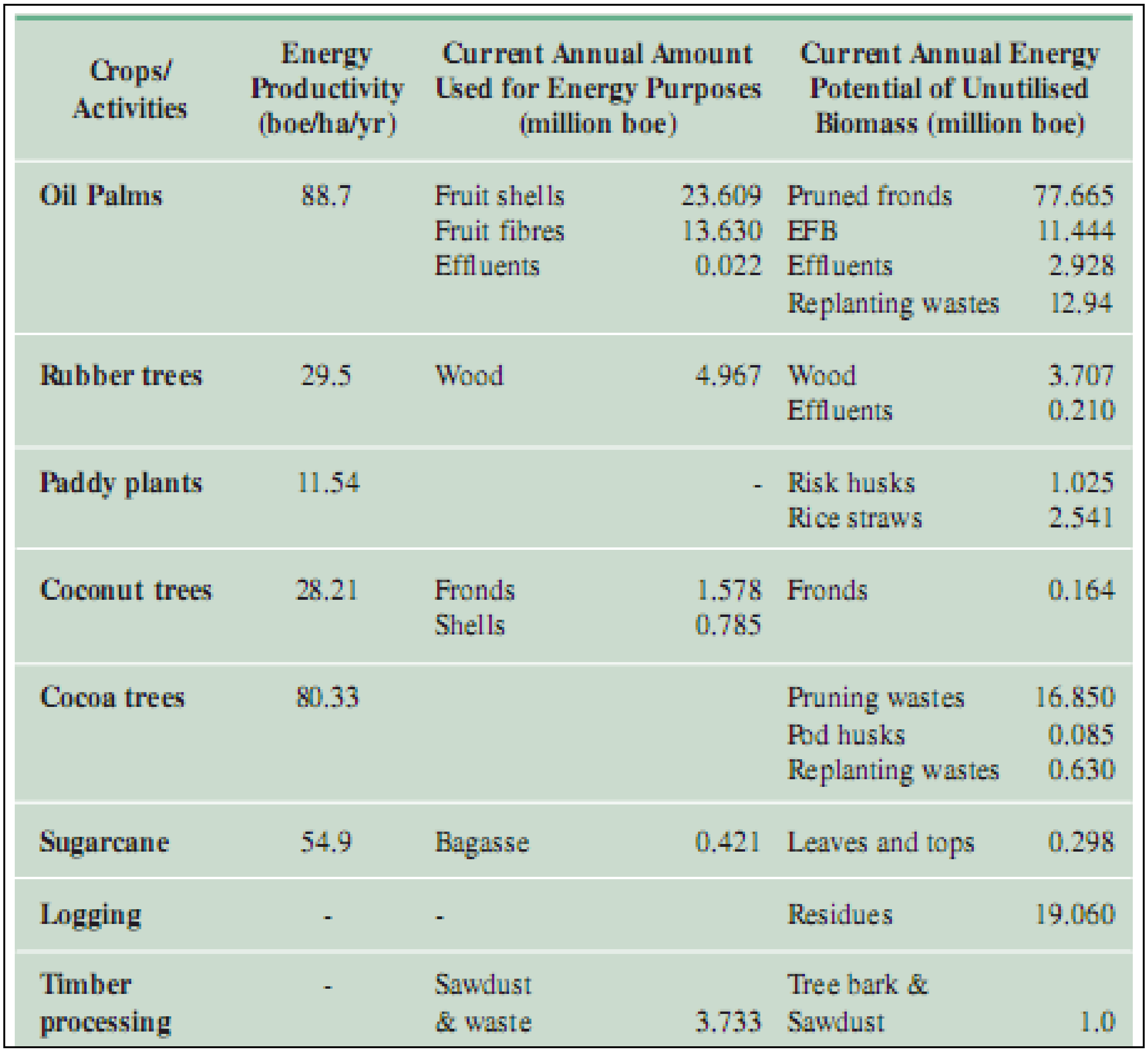
Biomass is attractive for use either as a stand-alone fuel or in fuel blends, such as a stand-alone fuel or in fuel blends, such as co-firing wood with coal, or mixing ethanol or biodiesel with conventional petroleum based fuels. Moreover, it also used in generating electricity and others industry. Figure 7.1 shows the biomass conversion path.

2.6.2 Population Sources

K,sofian & M.Y.Othman (2005) in their observation, found that there are five major sectors that wastes contribute to biomass energy which is Oil palm cultivation, forestry (wood), rubber cultivation, paddy cultivation, animal farming and urban wastes. There are some sectors that still in the phase of studying and researching to produce biofuel which as coconut cultivation, cocoa cultivation and sugarcane cultivation.

Table 7.1 below shows the estimation of the energy productivity and biomass production and utilization. The table shows clearly oil palms material as the main source for energy utilization followed by rubber trees, timber processing, coconut trees, sugarcane , paddy plants, cocoa trees, and logging. However, although oil palms material have already have significant amount of usage for energy utilization, there are still plenty of excess amount of it that have not been used for the same purposes. The same goes to other material where there are big potential in developing the material to be a main source of energy supplier.

Table 2.1 Estimation of the energy productivity and biomass production and utilization



Crops/ Activities	Energy Productivity (boe/ha/yr)	Current Annual Amount Used for Energy Purposes (million boe)		Current Annual Energy Potential of Unutilised Biomass (million boe)	
Oil Palms	88.7	Fruit shells	23.609	Pruned fronds	77.665
		Fruit fibres	13.630	EFB	11.444
		Effluents	0.022	Effluents	2.928
				Replanting wastes	12.94
Rubber trees	29.5	Wood	4.967	Wood	3.707
				Effluents	0.210
Paddy plants	11.54		-	Risk husks	1.025
				Rice straws	2.541
Coconut trees	28.21	Fronds	1.578	Fronds	0.164
		Shells	0.785		
Cocoa trees	80.33			Pruning wastes	16.850
				Pod husks	0.085
				Replanting wastes	0.630
Sugarcane	54.9	Bagasse	0.421	Leaves and tops	0.298
Logging	-	-		Residues	19.060
Timber processing	-	Sawdust & waste	3.733	Tree bark & Sawdust	1.0

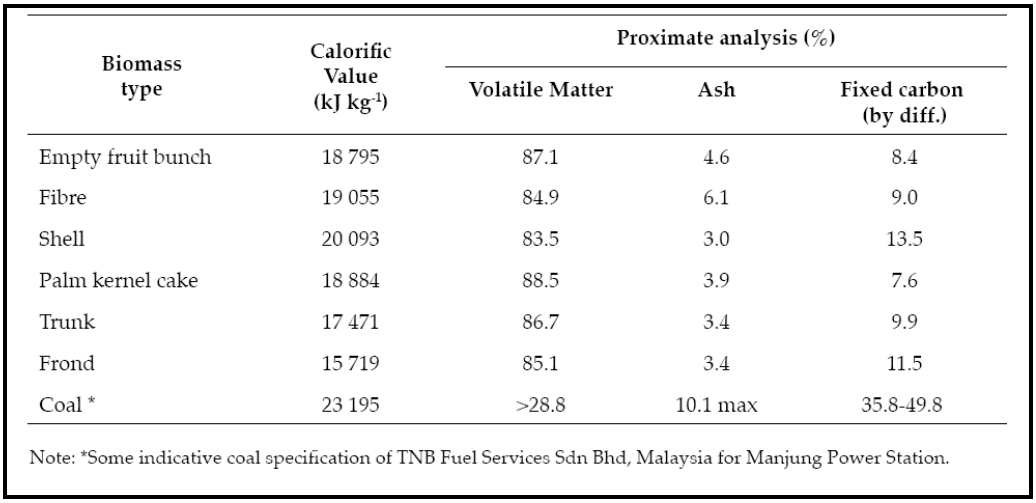
Source: Future Direction In Malaysian Environment Friendly Renewable Energy Technologies Research and Development (2005)

Therefore, based on the data taken from the statistic shown in the table 7.1, this paper will focus on developing oil palms wastes as the most and the biggest potential alternative energy supplier to our nations.

2.6.3 Palm Waste Characterization

In general, biomass consists of three main polymeric structures: cellulose hemicelluloses and lignin. Together these are called lignocelluloses. For each polymer similar reaction regimes can be defined, but they proceed at different temperature levels. Amongst these three, Hemicelluloses is most reactive and is subjected to limited devolatilisation and carbonization below 250 °C. Above that, Hemicelluloses is subjected to extensive devoltilisation and carbonization. Cellulose is most thermo-stable and is subjected to limited devolatilisation and carbonization only. The reactivity of lignin is in between the Hemicelluloses and Cellulose. Biomass, as a fuel in general, is characterized by high moisture and volatile content, low bulk density, low specific energy and normally low ash content. The proximate and ultimate analysis of oil palm shell (refer Figure 2.6) are shown in table below (Ani, 1992)

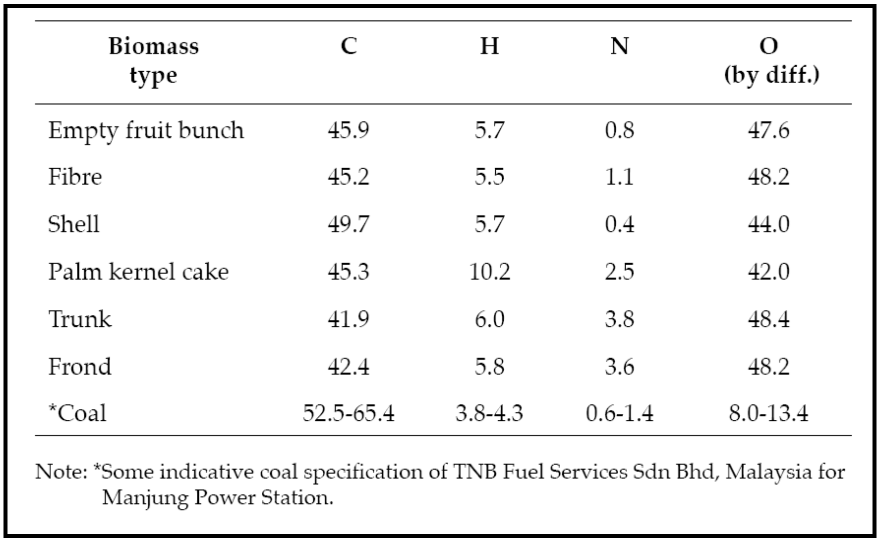
Table 2.2 Proximate Analysis for Palm Wastes



Biomass type	Calorific Value (kJ kg^{-1})	Proximate analysis (%)		
		Volatile Matter	Ash	Fixed carbon (by diff.)
Empty fruit bunch	18 795	87.1	4.6	8.4
Fibre	19 055	84.9	6.1	9.0
Shell	20 093	83.5	3.0	13.5
Palm kernel cake	18 884	88.5	3.9	7.6
Trunk	17 471	86.7	3.4	9.9
Frond	15 719	85.1	3.4	11.5
Coal *	23 195	>28.8	10.1 max	35.8-49.8

Note: *Some indicative coal specification of TNB Fuel Services Sdn Bhd, Malaysia for Manjung Power Station.

Table 2.3 Ultimate Analysis for Palm Wastes



Biomass type	C	H	N	O (by diff.)
Empty fruit bunch	45.9	5.7	0.8	47.6
Fibre	45.2	5.5	1.1	48.2
Shell	49.7	5.7	0.4	44.0
Palm kernel cake	45.3	10.2	2.5	42.0
Trunk	41.9	6.0	3.8	48.4
Frond	42.4	5.8	3.6	48.2
*Coal	52.5-65.4	3.8-4.3	0.6-1.4	8.0-13.4

Note: *Some indicative coal specification of TNB Fuel Services Sdn Bhd, Malaysia for Manjung Power Station.

Md Zahangir Alam et al(2005) estimated oil palm industries in Malaysia are producing a huge amount of exploitation of non-oil palm biomass that are about 90 million tons of lignocelluloses biomass each year of which about 40 million tons are in the form of Empty Fruit Bunches (EFB), oil palm trunks(OPT) and oil palm fronds (OPF).

However, there are some drawbacks of using of biomass. One of it is that material directly combusted in cooking stoves produces pollutants, leading stoves produces pollutants, leading to severe health and environmental consequences, although improved cooking stove programmes are alleviating some of these effects. In addition, burning biomass emits CO_2, even though biomass combustion is generally considered to be ‘carbon-neutral’ because carbon is absorbed by plant material during its growth, thus creating a carbon cycle.

Figure 2.6 Palm Wastes

Source: www.fibre2fashion.com

CHAPTER 3

METHODOLOGY

In achieving the objectives of the project, there are certain steps that need to be followed in achieving the right result. Firstly, palm biomass wastes were obtained from local supply. The biomasses selected are palm frond, palm kernel shell and palm fiber. Then the biomass wastes were dried at 110 ° for approximately 24 hours. The biomasses then were ground into smaller particles and sieved into two mesh sizes which are 250µm and 500µm respectively. After that, the biomasses are being analyzed using several analyzer to measure the target properties. Approximately 2-6 gram of each sample underwent torrefaction process where it was heated for an 90 minutes in a special furnace called Fixed Bed Activation Unit (FBAU) at two different temperatures i.e. 240°C and 280 °C, in the presence of inert nitrogen. The torrefied material was then being cooled and analyzed once again. The simplified methodology is shown in figure 3.1.

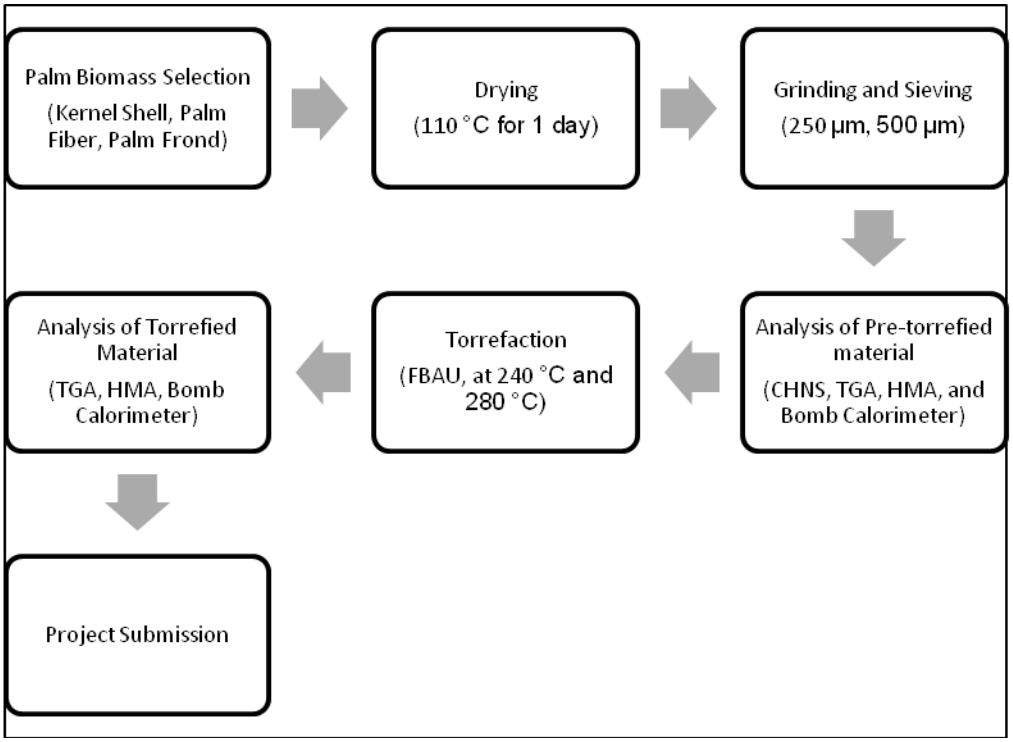


Figure 3.1: Experimental process flow diagram

3.1 **PREPARATION OF RAW MATERIAL**

1. Palm Fronds was collected and stored in the lab.
2. Then, Palm Fronds was washed to separate the sample from physical impurities and volatile component.
3. The sample was heated inside an oven at temperature of 110°C for 12 hour to remove water content inside the sample and weighted every 30 minutes to determine the moisture content of the sample after being heated for few hours.
4. Step 3 was repeated until the weight of the sample is constant. If the weight is not constant after 12 hours, the sample had to continue undergone the drying process. This was done in order to make sure all the moisture content was dried out.
5. Samples were grinded and sieved shaker ranging from 125 µm to 500 µm and screened into three fractions which are 125, 250 and 500 µm.
6. The samples were stored in air tight containers such as desiccators to maintain low moisture content of the samples.
7. Steps 1 to 6 were repeated for Palm Kernel Shell and Palm Fibers.

3.2 **EXPERIMENTAL PROCEDURE**

3.2.1 Torrefaction experiment by using Fixed Bed Activation Unit (FBAU)

1. Three samples palm fronds with different particular size are weighted and put in a crucibles
2. The reactor outlet in untied to locate in the sample from the bottom.
3. The samples are positioned in the middle of the tube where the heated coil is located to ensure a complete burning.
4. The reactor outlet opening is closed tightly to ensure no gas or liquid will be released from the reactor.
5. The FBAU power supply is switch on.
6. Nitrogen gas cylinder is connected to the nitrogen gas inlet of Fixed Bed Activation Unit (FBAU).

7. Valve 1 and valve 5 green buttons were switched on to open the valves. Valve 2, 3 and 4 remain closed.
8. Nitrogen gas flow is controlled by approximately at 0.2 ml/min by using flow meter controller attached to the panels.
9. After the nitrogen flow is stable, the temperature is set to 200°C
10. The reaction will be done at 1.5 hours.
11. Once the reaction has reached the reaction time, the sample will be cooled down to room temperature which takes about 3 to 4 hours.
12. After the temperature has decreased, the reactor outlet tube is untied and the product from the reactor is collected.
13. The product is weighted to determine the weight loss of the sample.
14. Step 1 – 13 is repeated for temperature 280°C.
15. Step 1 – 14 is repeated for Palm Kernel Shell and Palm Fibers.

3.3 ANALYSIS

3.3.1 Ultimate Analysis

The ultimate analysis is done on the torrified and pyrolysed material to know the component content within the biomass sample in term of percentage. The analysis is done using Carbon Hydrogen Nitrogen Sulphur (CHNS) Analyzer. Through this analysis, the composition of the component within the material can be obtained.

<u>Standard Operating Procedure (SOP)</u>

1. Helium, O2 and compressed air were set at 40 psi
2. Checked the ambient monitor for proper values
3. CO2, H2 and sulfur IR Cells were set between ‘7.5-9.2’ volts
4. Oxidation Furnace Temperature was set at 1000oc
5. Reduction Furnace Temperature was set 650oc
6. If necessary, run Leak check
7. “Auto/Manual’ set was switch to Auto when using carousel / to manual when loading samples individually

8. The gas was switch to analyze position
9. Wait until furnace Temperature is stable
10. Blank analysis and standard samples was run.
11. Run the experiment samples.

Samples Preparation

1. CHNS tin capsule was weighted.
2. Approx. 2.0mg of standard sample was been put into the capsule
3. The capsule is closed properly before weighing the weight
4. Repeat the procedure for all other samples
5. Placed those samples into the slot inside the analyzer
6. The weight of the samples is input into the analyzer
7. Each run complete in 3 minutes

3.3.2 Calorific Value Analysis

The heating value of biomass is determined by analyzing through bomb calorimeter. Using this equipment, calorific value of biomass material heated at different parameters can be obtained accurately. Higher calorific value determines better quality of products obtained.

Bomb calorimeter's manual experiment:

1. Turn on oxygen gas regulator (Pressure: 20 – 30 kg/cm2)
2. Turn on bomb calorimeter unit and refrigerator batch switch, wait 20 minutes for waiting stable
3. Prepare sample (weighing below 1.0 gram)
4. Place sample into crucible, secure a cotton thread with a loop in it on the middle of the ignition wire. Place into the decomposition vessel.
5. Open the sample dialog window to key-in weight of sample.
6. Suspending the decomposition vessel into the filling head of the measurement cell cover

7. Activate Start. The measurement cell cover closes the decomposition vessel is the filled with oxygen. Next, the inner vessel is filled with water. As soon as the system begins with the experiment, the display shows a graph (Refer to figure below) of the change over time in temperature of the inner vessel.
8. When the measurement is complete, remove the decomposition vessel, clean and prepare for the next experiment.

3.3.3 Proximate analysis

Proximate analysis is carried out in this study to determine properties of torrefaction. The specified equipment to achieve this purpose is by Thermal Gravitational analyzer (TGA). The outcome of the analysis will be displayed in term of graph part where then further analysis will be done. TGA is used to determine the elements of:

i. Volatile fraction
ii. Fixed carbon content
iii. Ash content

The percentage of moisture in the analysis sample is calculated as follows:

Percentage of moisture = $\frac{\mathrm{A - B}}{\mathrm{B - C}} \times 100$

where;

A: mass of container and wet sample, g

B: mass of container and dry sample, g

C: mass of container, g

Ash is determined by weighing the residue remaining after burning under rigidly controlled conditions of sample weight, temperature, time, atmosphere and equipment specification. The percentage of ash in the analysis sample is calculated as follows:

Percentage of ash = $\frac{\mathrm{A - B}}{\mathrm{C}} \times 100$

where;

A: weight of capsule, cover and ash residue, g

B: weight of empty capsule and cover, g

C: weight of analysis sample used, g

Volatile matter is determined by establishing the loss in weight resulting from heating under rigidly controlled conditions depending on the sample behavior.

Percentage of weight loss = $\frac{\text{A - B}}{\text{A}} \times 100$

where;

A: weight of sample used, g

B: weight of sample after heating, g

Percentage of volatile matter = C – D

Where:

C = percentage of weight loss, %

D = percentage of moisture, %

Fixed Carbon is calculated from the summation of percentage of moisture, ash and volatile matter subtracted from 100. All percentages are on the same moisture references base.

Methodology

1. TGA is weighted before the experiment. Weight is denoted as W_1.
2. 10 mg of Palm Frond sample is placed into the sample pan.
3. Sample is heated from 50 °C to 900 °C under sweeping gas rate of 30ml /min.
4. The aqueous and oil phases is separated and weighted and gas yield is calculated from material balances.
5. Percentage of torrefaction yield, char yield, oil yield, gas yield and collected water is determined.
6. Torrefied solid formed is collected on steel wool and were held at torrefaction temperature until number of significant release of gas was observed.

7. After the experiment is done, reactor was weighted again after it has cooled down. Weight denoted as W_2.
8. Char yield is calculated by equation : W_1- W_2
9. Optimum temperature that achieved the highest percentage of oil yield is determined.
10. Step 1 to 10 is repeated with different samples.

3.3.4 Halogen Moisture Analyzer (HMA) Analysis

The main purpose of this analysis is to determine the moisture content in the sample. The best equipment to give the results is by HMA where it analyzes the amount of moisture in the biomass sample. Good product is determined by having low moisture content.

CHAPTER 4

RESULT AND DISCUSSION

4.1 **SAMPLE PRETREATEMENT STEP**

After the raw material been found from the local supply, the first steps that need to be done are drying process. In this step, the raw material was being dried by using laboratory oven at 110 °C. For the purpose of analyzing the drying process, the sample was weighed every 30 minutes until the weight is constant. The outcome of the process is shown in figure 5.1.

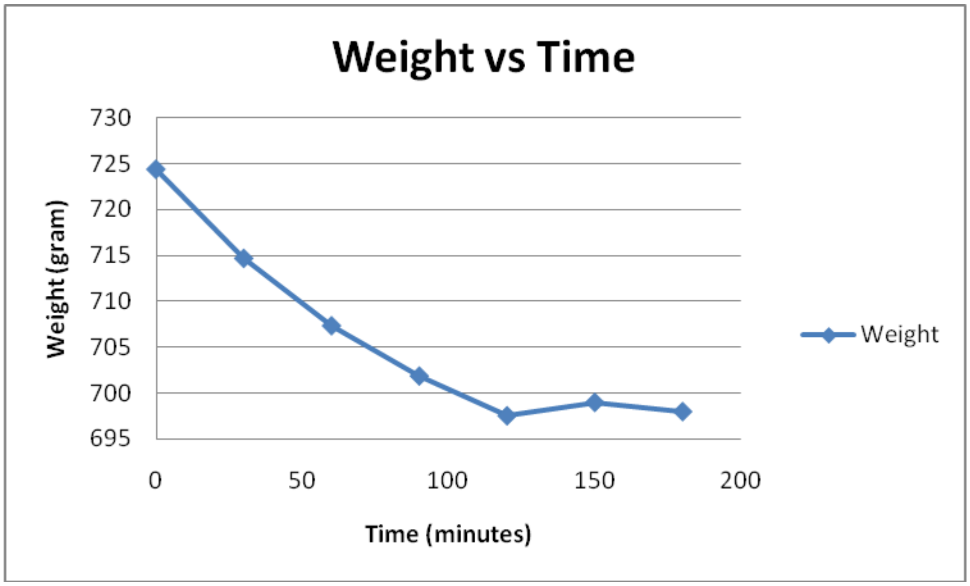


Figure 4.1 Sample (all sample) Pre-treatment Drying

The drying process is important in the pretreatment step for every sample. The purpose was to ensure efficiency and accurateness of the torrefaction process. From the step, water and moisture will be evaporated and the real weight of the sample can be obtained. From the graph, it can be seen that the weight of the samples was decreasing with time until a constant weight was achieved. The decreasing of weight in the samples indicates that significant amount of free water and excess moisture in the sample had been evaporated. The graph shows that after 3 hours, the weight of the sample was stable. It can be assumed that the water and excess moisture content in the samples was fully evaporated within 3 hours of drying in the oven.

4.2 EXPERIMENT

In this analysis, the torrefied product was weighed and characterized. Product yield was obtained by determining the weight loss once the product was collected from Fixed Bed Activation Unit (FBAU). The experiment was being setup to run for 90 minutes for every sample taken into the furnace. The experimental procedure then repeated by changing temperature 240° C to 280°C. Table 4.1 tabulates the data from the outcome of the experiment.

Generally, the sizes that not affected the percentage of weight loss, it only affect the time take to convert the raw materials to the torrefied materials (Azizan, 2008). However, temperature does affect the percentage of weight loss. At 280°C, most of moisture content and volatile matter are released from the biomass and contributed to greater mass losses of the biomass samples. This is due to the fact that at high temperature, water evaporation rate will be higher and thus greater weight losses were observed. Thus in the moisture content analysis it is expected that the torrefied material at 280 °C will be slightly lower than the torrefied material at 240 °C. The results are illustrated as per figure 4.2, 4.3 and 4.4.

Table 4.1: Product Yield of Torrefied Frond, Fiber and Kernel Shell

Sample	Run	Temperature (°C)	Particular Size (μm)	Weight Loss (Mass$_{before}$-Mass$_{after}$/Mass$_{before}$) x 100 %
Frond	1	240	500	5.50
			250	14.80
	2	280	500	24.44
			250	25.64
Fiber	3	240	500	7.00
			250	10.16
	4	280	500	29.80
			250	21.00
Kernel Shell	5	240	500	4.67
			250	8.22
	6	280	500	6.09
			250	23.00

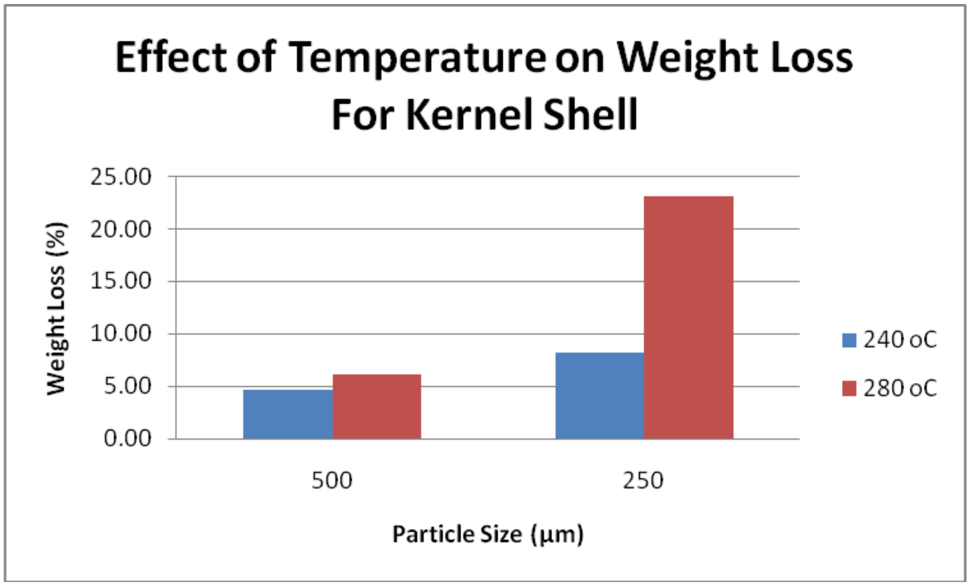


Figure 4.2: Effect of Temperature on Weight Loss for Kernel Shell

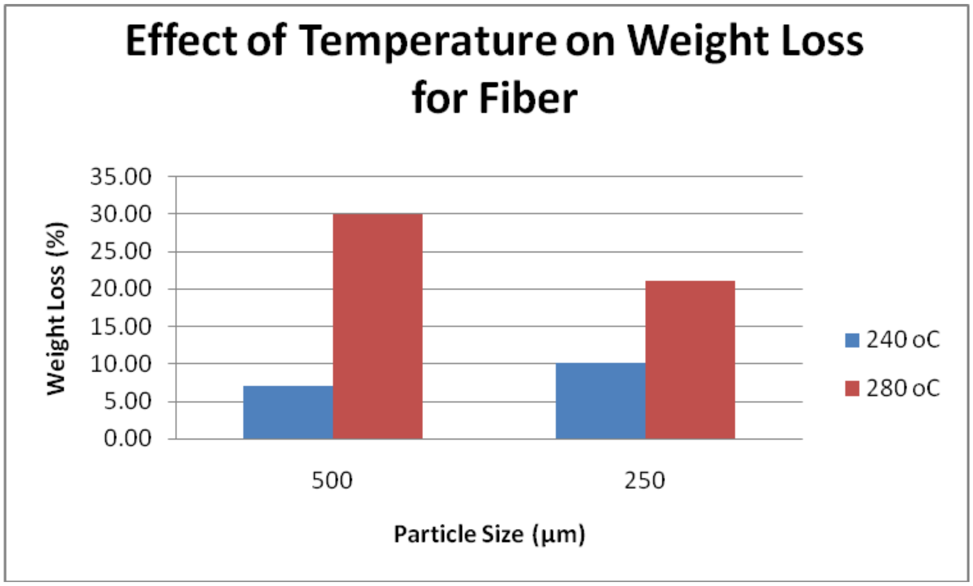


Figure 4.3: Effect of Temperature on Weight Loss for Fiber

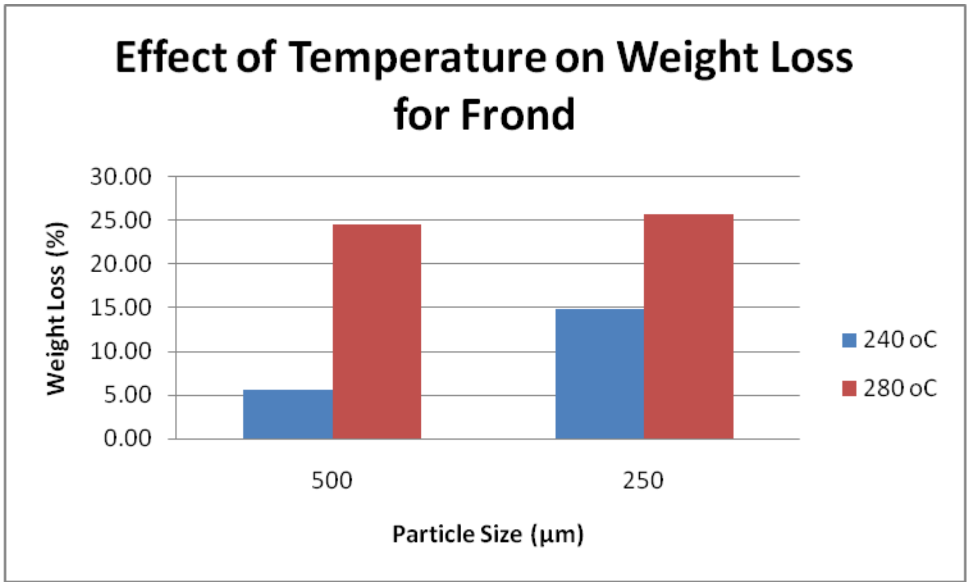


Figure 4.4: Effect of Temperature on Weight Loss for Frond

4.3 ANALYSIS

4.3.1 Moisture Content Analysis

According to Azizan et al(2008), three main criteria should be achieved from the torrefied materials: Low moisture content, low volatile matters and high fixed carbon. Therefore, in this analysis, the analysis was made to investigate the effect of particle size and torrefaction temperature on the moisture content of Palm fibers, Palm Fronds and Kernel Shell. In the table 5.2, the comparison was made to differentiate the moisture content for each sample.

Table 4.2: Moisture Content Analysis

		Before	After (240 oC)	After (280oC)
Type	Size (µm)	Moisture Content %	Moisture content %	Moisture content %
Kernel shell	250	6.17	3.82	3.42
	500	4.83	4.41	3.80
Fiber	250	7.13	4.73	4.22
	500	4.88	4.24	1.68
Fronds	250	8.66	5.13	4.57
	500	7.60	3.34	1.41

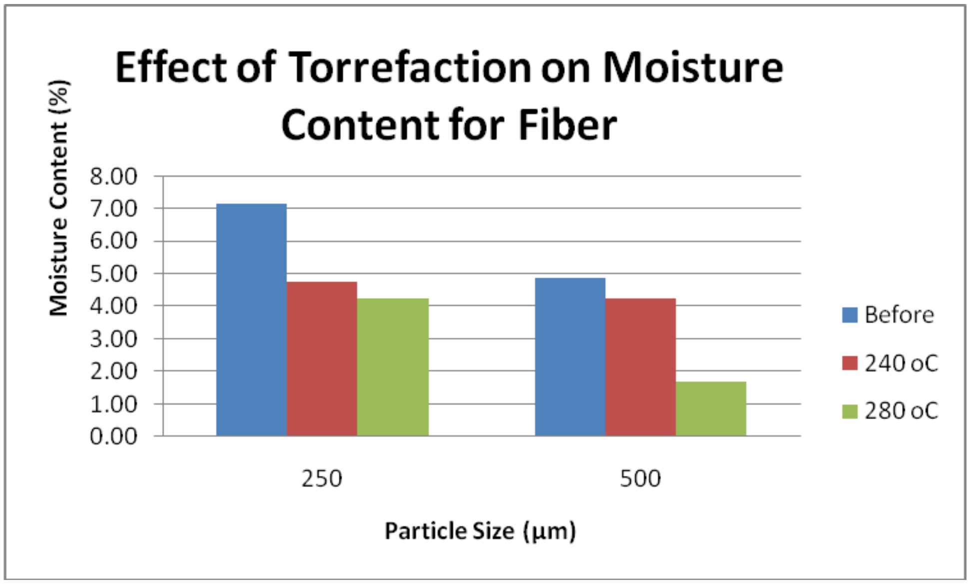


Figure 4.5: Effect of Torrefaction on Moisture Content for Fibers

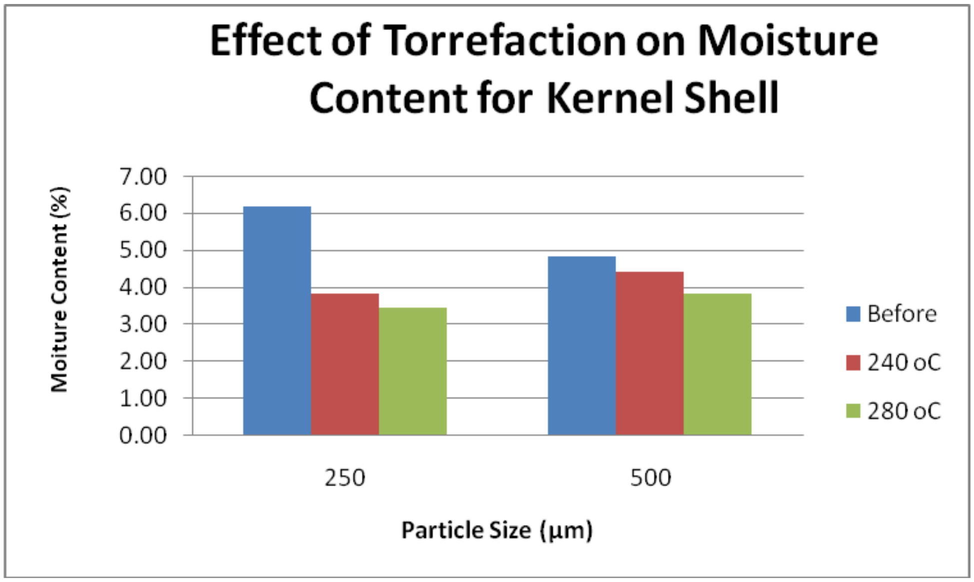


Figure 4.6: Effect of Torrefaction on Moisture Content for Kernel Shell

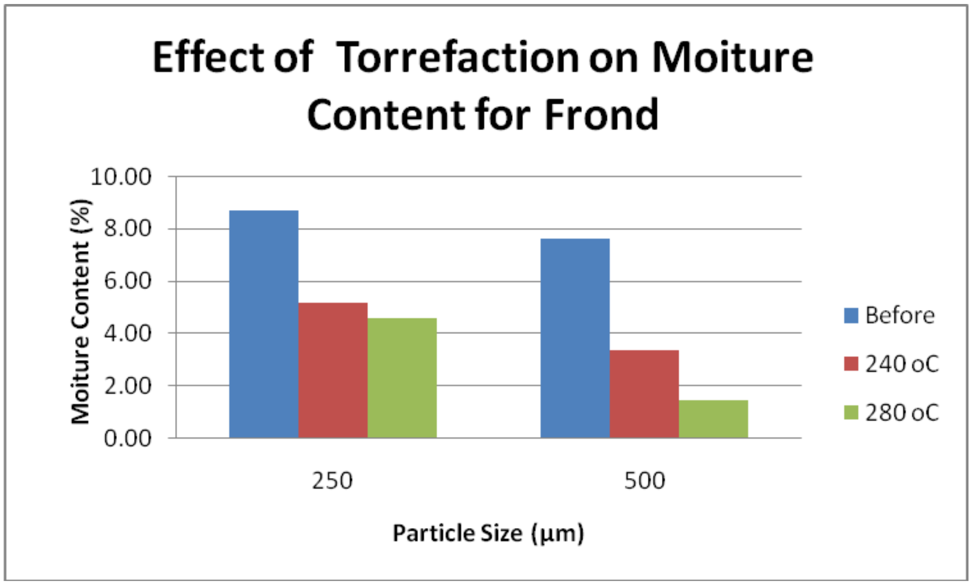


Figure 4.7: Effect of Torrefaction on Moisture Content for Frond

In measuring moisture content of the samples, firstly, sample will be dyt through halogen moisture analyzer (HMA). In the analysis, the samples will be dried for 15 minutes at 110°C to remove the moisture content. Therefore, the smaller particle will be tend to lose more moisture content compare to the bigger on in this analysis. These are due to the fact that the smaller the particle sizes, the bigger the surface area of the samples. Thus, the contact area will be much larger and expose to the heat. It was consistent with the result that been obtain in Azizan et al(2008) that indicates the bigger the sizes, the lesser the weight loss. Thus it is expected the greater the particle sizes, the longer time was required to convert the raw materials to the torrefied materials.

Figure 4.5, 4.6, 4.7 also demonstrated that torrefied material at as high as 280 °C are able to reduce the moisture content as low as possible. Cagnon er al.(2008) demonstrated that pure hemicelluloses decomposed at 295 °C. However, it is believed that torrefied material of 280 °C will decompose hemicelluloses and therefore unable to contain the moisture anymore. Therefore, torrefaction at 280 °C will produce biomass with more resistant to moisture compare to torrefied material of 240 °C.

4.3.2 Calorific Value Analysis

For calorific value analysis, the reading was taken twice from the bomb calorimeter and the average value was recorded for each biomass. Calorific value or heating value resembles the heat release when the biomass sample undergoes combustion process. In other way it represents energy content of the biomass. Therefore, it is favorable that the biomass with higher calorific value is chosen for gasification process. Table 4.3 tabulates the calorific value data that taken before and after the torrefaction according to its sizes and samples. To indicate the comparison for the calorific value, it is illustrated in figure 4.8, 4.9, 4.10 which are for Kernel Shell, Palm Fiber and Palm Frond.

Table 4.3: Calorific Value of Fronds, Kernel Shell and Fibers

		Before	After (240°C)	After (280°C)
Type	Size	Calorific Value(J/g)	Calorific Value(J/g)	Calorific Value(J/g)
Palm Frond	250	16005.0	19817	19852
	500	16781.5	18218	18296
Kernel Shell	250	18495.0	21162	20671
	500	18978	19843	19290
Palm Fiber	250	18624.5	22802	20372
	500	19133.5	20137	19830

Figure 4.8, Figure 4.9 and Figure 4.10 the increment of caloric value after the torrefaction process differ by torrefaction temperature.

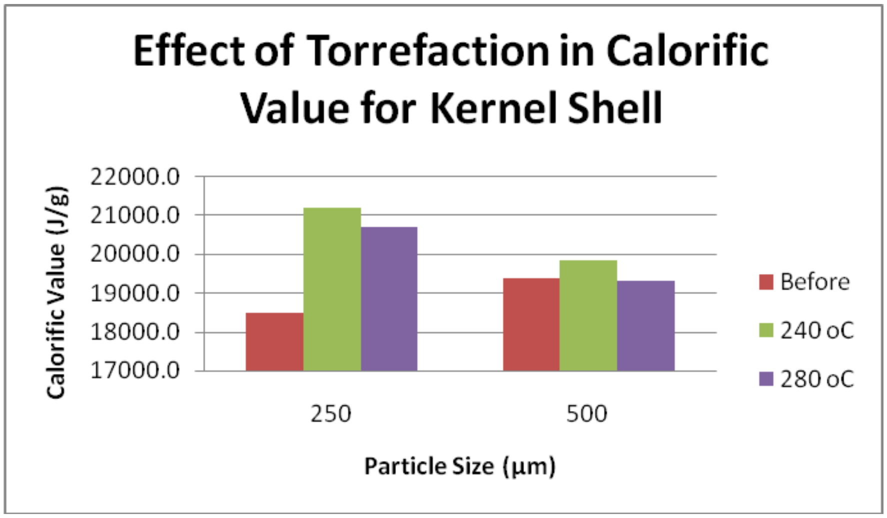


Figure: 4.8: Effect of Torrefaction on Calorific Value for Kernel Shell

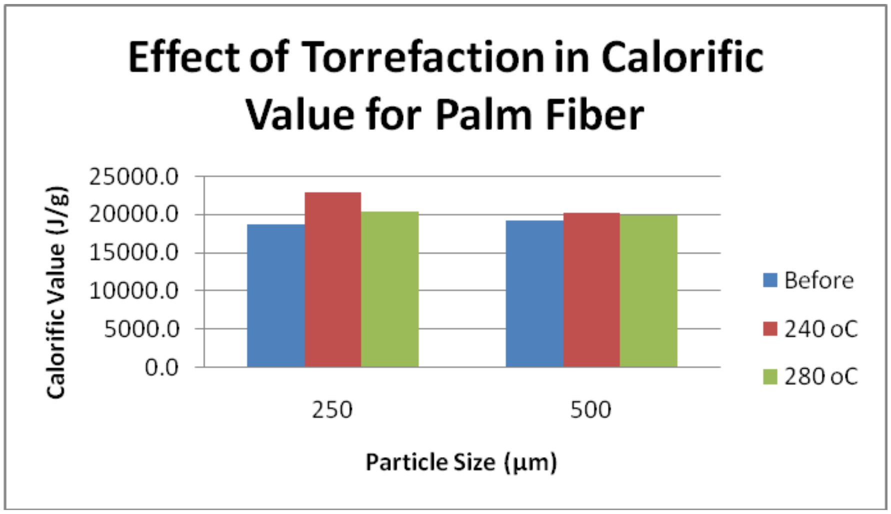


Figure 4.9: Effect of Torrefaction on Calorific Value for Fiber

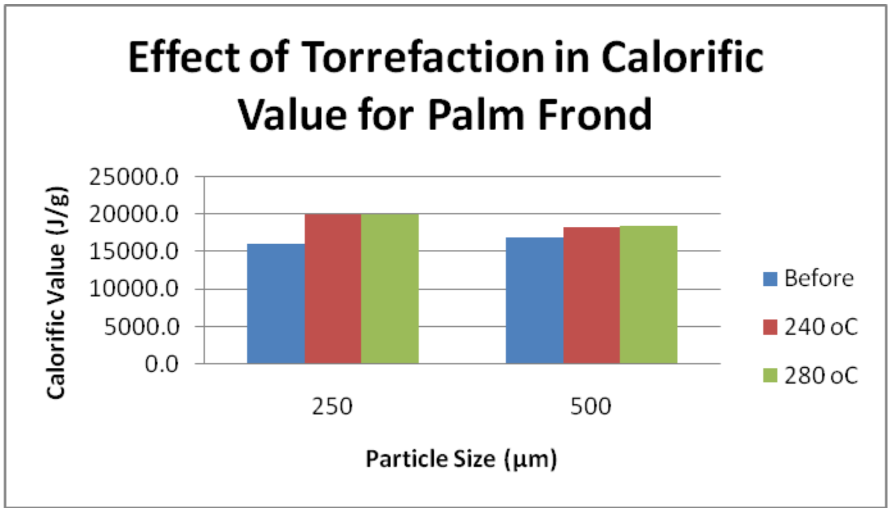


Figure 4.10: Effect of Torrefaction on Calorific Value for Frond

Patrick .C.A.Bergman and Jacob H.A. Kiel stated in his principal that in torrefaction, more mass than energy is lost to the gas phase. This lead to a phenomenon results in energy densification. In each biomass generally, oxygen is the main component which lowers down the heating value. Thus, torrefaction is essential in combusting and releasing oxygen where subsequently increase the calorific value of the biomass.

As shown in the all three figures, there are significant changes to the calorific value after the torrefaction where the value increases. Palm Fiber and Palm kernel Shell have the higher calorifc value compared to Palm Frond. However, if the results are going to compare against the sizes of the material, the material which have the smaller sizes (250 µm) have the greater percentage of increment of calorific value.

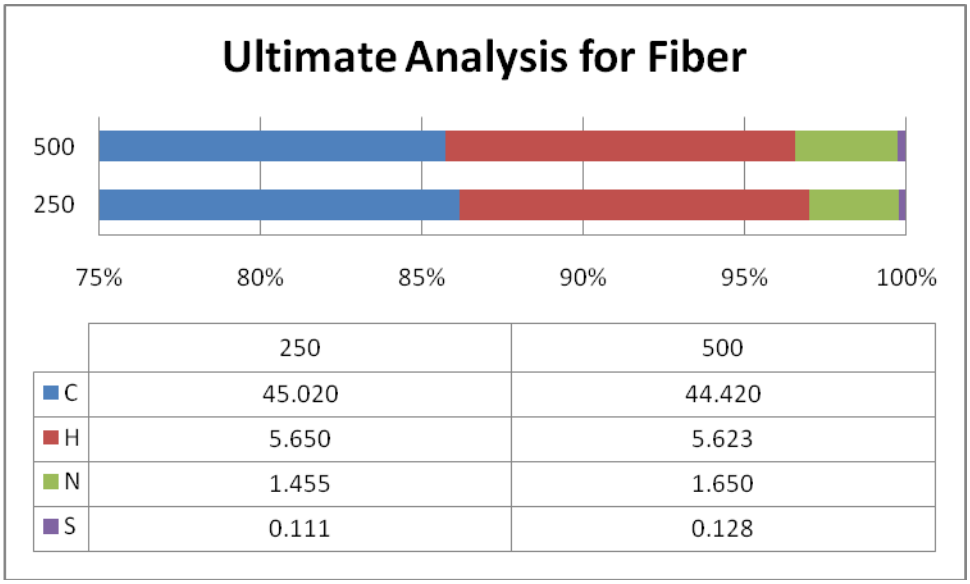
As temperatures increases, palm fiber and kernel shell show a decreasing in the calorific value. It is believed that it is related to the polymeric structure of both samples. TGA result will illustrate both of this sample will yield a lower fixed carbon content and a slightly higher or a slightly similar in volatile content. Therefore, a decrease in fixed carbon content will lead to decrease in calorific value.

4.3.3 Ultimate Analysis

In this analysis, the samples are analyzed to know the component content within the biomass sample in term of percentage. Table 5.1 indicates the component content of the every sample before the samples undergo torrefaction process.

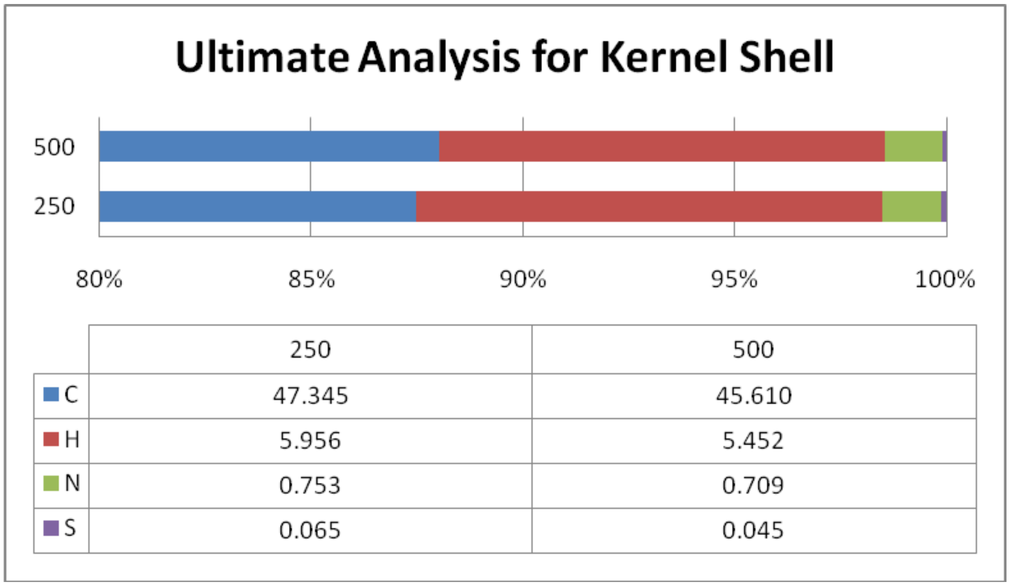
Table 4.4 Carbon, Hydrogen, Nitrogen and Sulphur Content in Oil Palm Wastes

Ultimate Analysis of Oil Palm Wastes						
Sample	Particle Size (µm)	C (%)	H (%)	N (%)	S (%)	O (%)
Frond	250	40.570	5.523	0.404	0.090	53.414
	500	42.040	5.272	0.328	0.029	52.331
Kernel Shell	250	47.345	5.956	0.753	0.065	45.882
	500	45.610	5.452	0.709	0.045	48.186
Fiber	250	45.020	5.650	1.455	0.111	47.764
	500	44.420	5.623	1.650	0.128	48.180



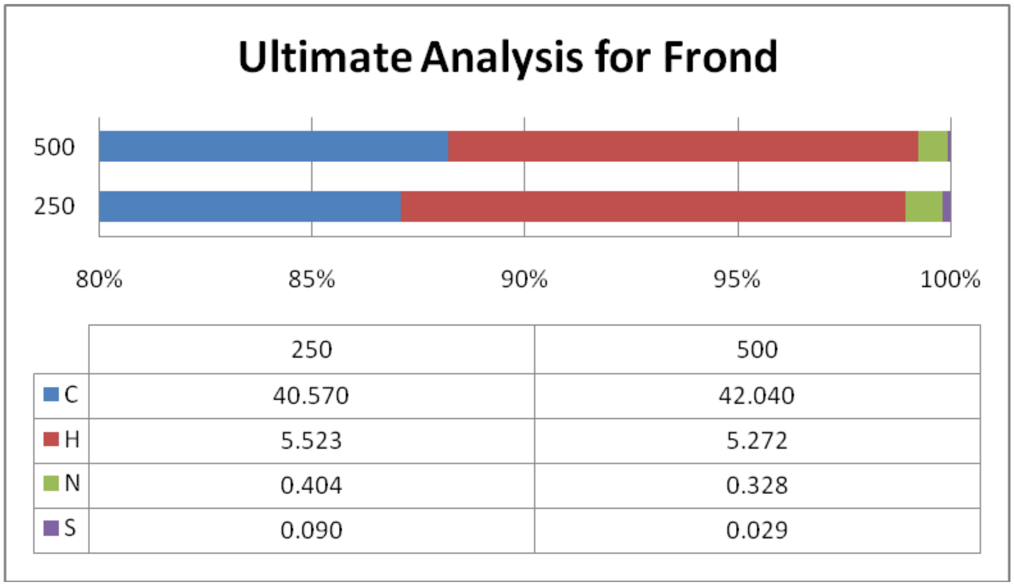
	250	500
🟦 C	45.020	44.420
🟥 H	5.650	5.623
🟩 N	1.455	1.650
🟪 S	0.111	0.128

Figure 4.11: Carbon, Hydrogen, Nitrogen and Sulphur Content in Fiber



	250	500
🟦 C	47.345	45.610
🟥 H	5.956	5.452
🟩 N	0.753	0.709
🟪 S	0.065	0.045

Figure 4.12: Carbon, Hydrogen, Nitrogen and Sulphur Content in Kernel Shell



	250	500
🟦 C	40.570	42.040
🟥 H	5.523	5.272
🟩 N	0.404	0.328
🟪 S	0.090	0.029

Figure 4.13: Carbon, Hydrogen, Nitrogen and Sulphur Content in Frond

In the table 4.1 obtained, it shows Kernel Shell has the highest initial carbon content prior to the torrefaction process. If the material exhibited high amount of fixed carbon content upon completion of the torrefaction process, the torrified material can be considered as a good solid fuel. However, in calculating calorific value or heating value of one sample, following formula are taken into account:

$$\text{Dulong's formula, HHV} = 33.83\ C + 144.25\ (H - O/8) + 9.42\ S$$

From the formula, it can expected that a substances that content higher carbon and hydrogen content will increase its heating value. Oxygen is a composition that will lead to lower heating value, and therefore it is desirable to be combusted during torrefaction process.

Nitrogen and Sulphur is undesirable because after the process the gas tend to form NO_x adn SO_x that are considerd as green gas house.

4.3.4 Proximate Analysis

TGA was used to analyze the decomposition percentage of the torrefied materials in term of the moisture content, volatile matters, fixed carbon and ash content. The experiment was conducted with temperature ranging from 50° to 900°C.

The main aim of this investigation was to convert the chosen raw materials in into solid fuel (ash content), however, there also three main properties that should be achieved from the torrefied material, low moisture content, low volatile matters and high fixed carbon content. (Refer appendix A for TGA analysis graph)

Figure 4.14 demonstrated that even though Palm Fiber, Palm Frond and Kernel Shell have high carbon content in the initial raw as depicted in CHNS analysis earlier, it was found that it were decomposed into volatile matters (refer figure 4.15). Azizan et al(2008) believed in his thesis, that crystalline structure of the cellulose has been fully decomposed into CO and CO2 and the percentage of lignin in the materials are insufficient to retain as fixed carbon.

Since biomass are composed of high amount of cellulose and hemicelluloses, which are easily decomposed at temperature at approximately at 290 °C and 345 °C respectively, it highly believed that torrefied material at higher temperature (at 280 °C) will decompose more of these component which lead to low yield of fixed carbon and high volatile matters.

Figure 4.16 illustrated the non-combustible residue left after the biomass is burnt. The result shows an increment in the ash content for each material. It can be observed that an increase in reaction temperature can crack the solid compound into gaseous component and thus increased the volatile matter decomposition rate.

Mackay and Roberts (1982) assumed that biomass which largely composed of lignin will be the main contributor to the final char weight. Thus it can be assumed that Palm Frond is majorly composed of lignin. It subsequently will contribute to high fixed carbon content.

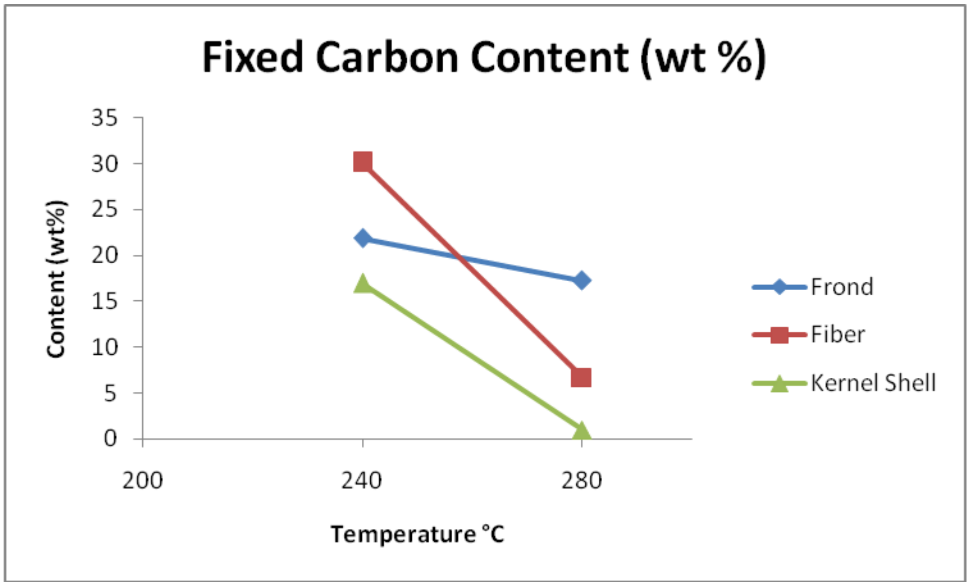


Figure 4.14: Fixed Carbon Content of Torrefied Biomass

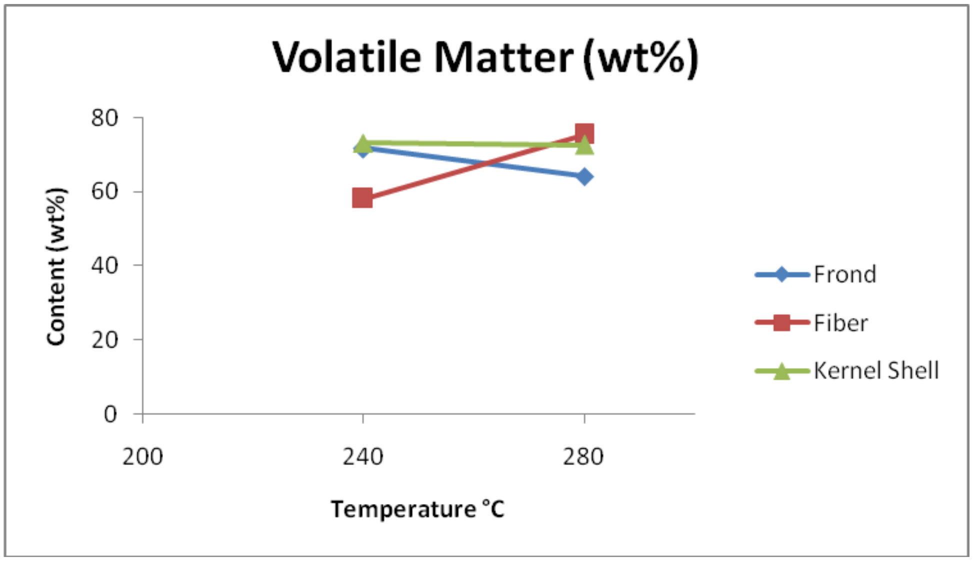


Figure 4.15: Volatile Matters of Torrefied Biomass

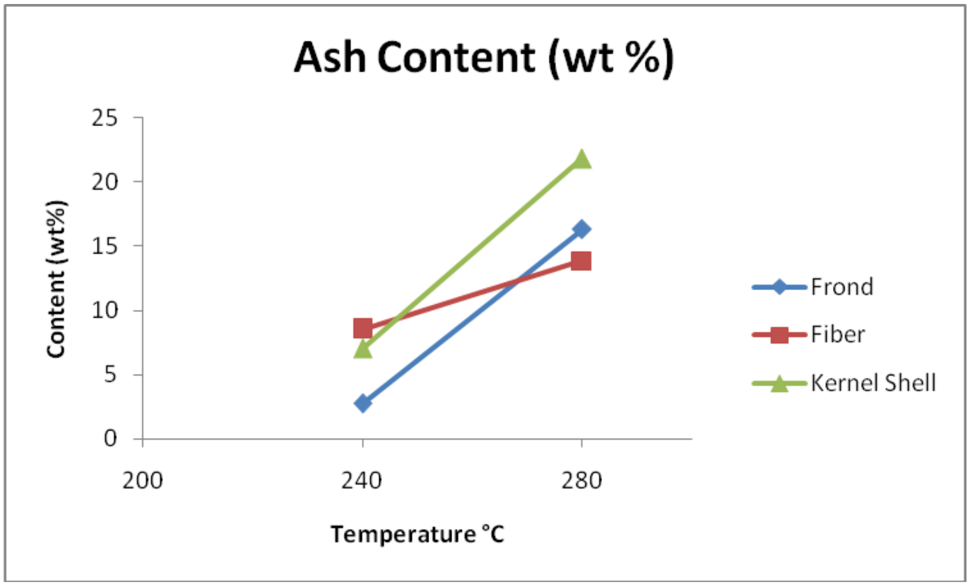


Figure 4.16: Ash Content of Torrefied Biomass

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The study of biomass palm characterization was successfully conducted with several parameters have been measured and compared. The objective was to study five parameters that will be compared between the raw material and torrefied material. From the project, it is concluded, that torrefaction will increase the calorific value of the biomass through the process of energy densification. The process involve by combusting the material and consequently the mass are loss to the gas phase as energy. But due to the ratio that energy that is superior to energy in term of being released as a gas, therefore, the char will have more energy per unit mass. Moreover, it also due to the fact that oxygen is combusted and released, thus rose up the heating value for each material.

Torrefied material also have characteristic that is more resistant to water due to the destruction of hygroscopic nature of biomass and yielding a hydrophobic material. Moreover, torrefaction have managed to yield a solid fuel that high in fixed carbon content and less volatile matters that are being combusted during the process. The characteristic that gain during the process lead to better biomass properties that leads to favorable biomass that are easier to be gasifies and is believe to produce a better fuel quality.

Others parameters that is being evaluated such as particle size does affected some of the parameters. The smaller sizes are a better resistant to moisture content compare to larger one but throughout the other parameters, it is difficult to differentiate between the sizes. Thus, it is concluded small sizes of biomass is favorable to the larger one but not a major issues in improving biomass properties.

5.2 Recommendation

For further improvement of the project, there are some improvement may need to be carried out as an improvisation on the study of torrefaction process. This can lead to better outcome of the project. The following are the recommendation that being suggested for future improvement:

- Study on the polymeric structure of raw material to support the result being obtained throughout the torrefaction process. This can be done by using Scanning Electron Micron (SEM).
- More parameters are suggested to be varied to get an optimum condition of the torrefied biomass before it being feed in the gasifier. Some suggested parameters are reaction time, and type of reactor.
- All analyzer need to be maintain at the highest level.
- The torrefied material being feed into the gasifier and the process are being evaluated to justify the characterization study before.

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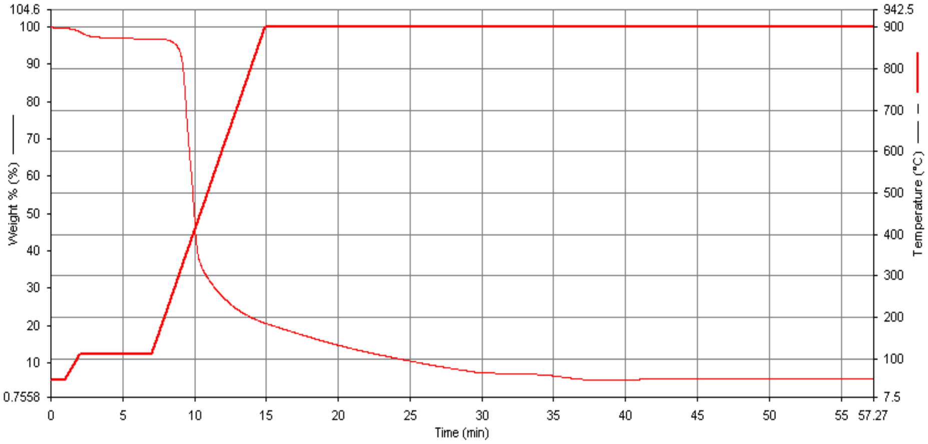
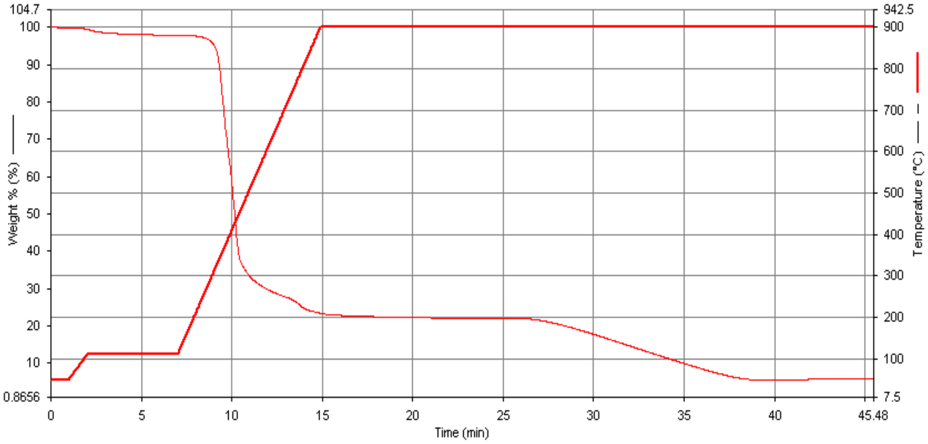
APPENDIX

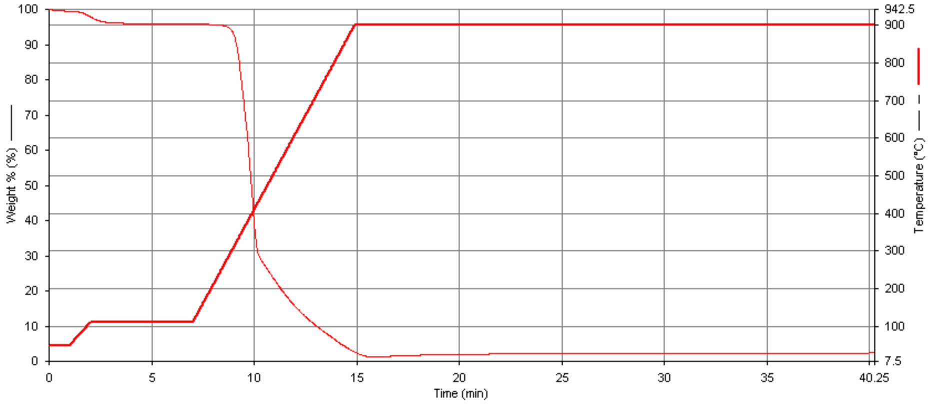
Appendix A: TGA Analysis Graph



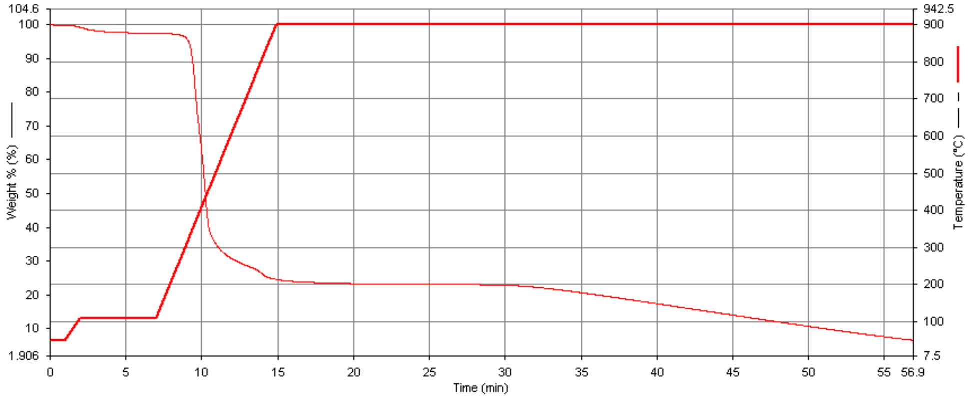
Fiber 500 µm: Before Torrefaction



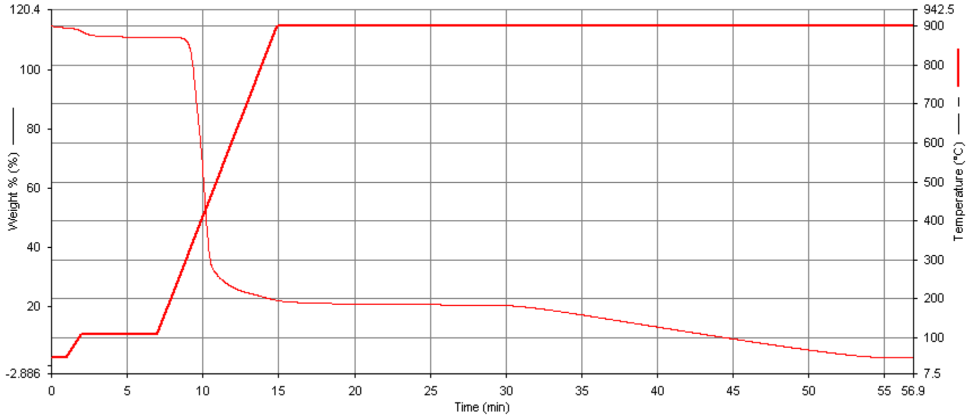
KS 500 µm: Before Torrefaction



Frond 500 µm: Before Torrefaction



KS 500 µm T (240°C)



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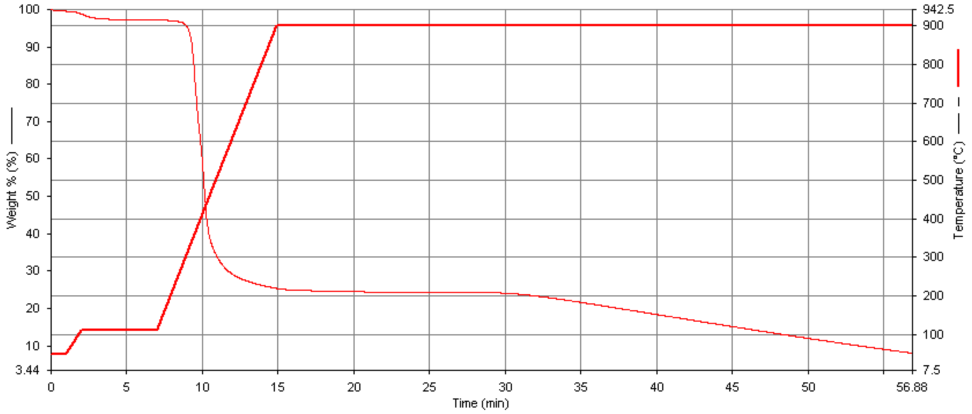

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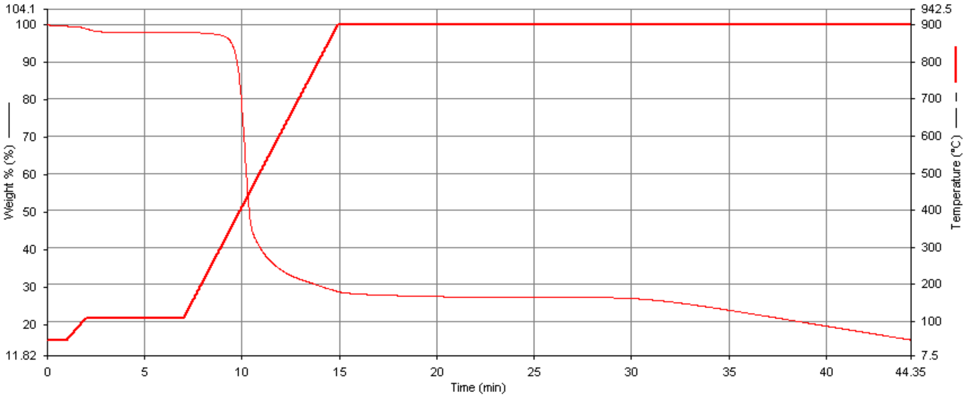

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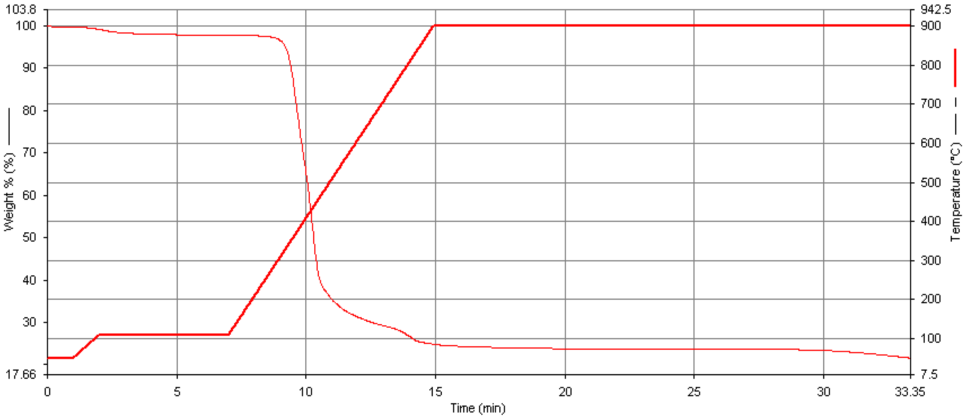

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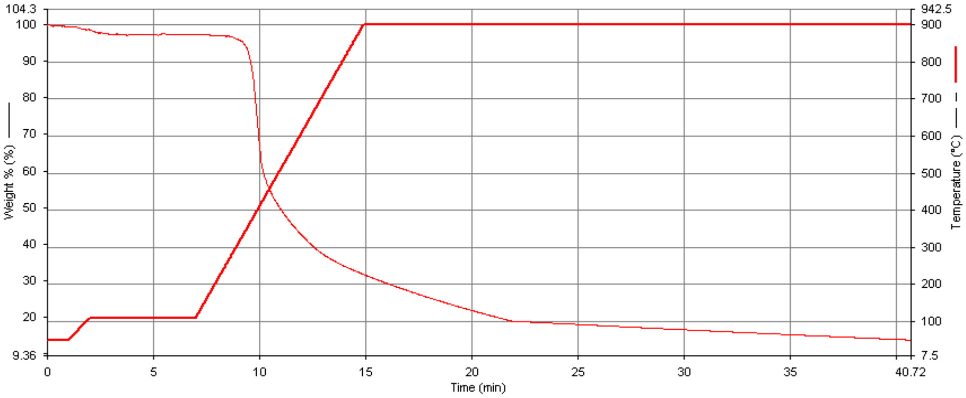

FB 500 µm T (280°C)