WATER WASHING PRETREATMENT ON EMPTY FRUIT BUNCHES OF OIL PALM WASTE

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2011

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by

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Dissertation submitted in fulfillment of the requirements for degree of Master of Science

October 2011

ACKNOWLEDGMENT

In the name of ALLAH, the Most Gracious and the Most Merciful

All praises to Allah for the strengths and His blessing in completing this thesis. Special appreciation goes to my main supervisor, Dr. Nurhayati Abdullah, and co-supervisor, Assoc. Prof. Dr. Fauziah Sulaiman for their supervision and constant support. Their assistance and valuable comments throughout the experimental and thesis works have contributed to the success of this research.

I would like to express my appreciation to the Dean School of Physics, Prof. Zainuriah Hassan for her support towards my postgraduate affairs. My acknowledgment also goes to all technicians and office staffs especially Mr. Ilias Budin from Bioenergy Laboratory, School of Physics, Mr. Muthu and Mrs. Nor Hayati from School of Chemistry and Mr. Azhar from School of Industrial Technology. Their assistance and co-operations have smoothed my research progress.

I would like to acknowledge to Universiti Sains Malaysia for funding this research and also special thank to Malpom Industries Bhd, Nibong Tebal for supplying the empty fruit bunches (EFB) for my research works.

Finally, my deepest gratitude goes to my beloved mother, Mrs. Jamenah Awang and my beloved late father, Mr. Che Khalib Hamid for their endless love, prayers and encouragement. Not to forget to my sisters and brother. Thanks for your love and care. To those who have directly and indirectly helped in this research, your kindness means a lot to me. Thank you very much.

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LIST OF ABRREVIATIONS

ASTM	America Society for Testing and Materials Standard
AAS	Atomic Absorption Spectrophotometer
AES	Atomic Emission Spectrophotometer
Al	Aluminum
boe	barrel of oil equivalent
Ca	Calcium
CHNS	Carbon, Hydrogen, Nitrogen and Sulphur
CO	Carbon monoxide
CO_2	Carbon dioxide
CPO	Crude Palm Oil
DTG	Derivative Thermogravimetric
EFB	Empty Fruit Bunches
FFB	Fresh Fruit Bunches
GHG	Greenhouse Gas
HHV	Higher Heating Value
K	Potassium
LHV	Lower Heating Value
MDF	Medium Density Fiberboard
mf wt%	Moisture free weight percent
Mg	Magnesium
MJ/kg	Mega Joule per kilogram
MPOB	Malaysian Palm Oil Board

N	Nitrogen		
Na	Sodium		
OPF	Oil Palm Fronds		
OPS	Oil Palm Shells		
OPT	Oil Palm Trunks		
P	Phosphorus		
PFF	Pressed Fruit Fibers		
pH	Measure of the acidity of a solution (-log [H^+])		
POME	Palm Oil Mill Effluent		
ppm	Part per million		
TG	Thermogravimetric		
TGA	Thermogravimetric Analysis		
W1SOT	W	=	Washing
	1	=	number of experiment
	SO	=	Soaking
	T	=	Tap water
W47SOD	W	=	Washing
	47	=	number of experiment
	SO	=	Soaking
	D	=	Distilled water
W50STT	W	=	Washing
	57	=	number of experiment
	ST	=	Stirring
	T	=	Tap water

PRARAWATAN BASUHAN AIR TERHADAP TANDAN BUAH KOSONG SISA KELAPA SAWIT

ABSTRAK

Prarawatan basuhan menggunakan air terhadap tandan buah kosong sisa kelapa sawit dikaji dalam penyelidikan ini. Objektif penyelidikan ini adalah bertujuan untuk mengurangkan kandungan abu dari tandan buah kosong kelapa sawit untuk meningkatkan kualiti biojisim tersebut. Penyelidikan ini dijalankan bagi melihat keberkesanan prarawatan basuhan menggunakan air untuk pengurangan abu dengan menukarkan parameter yang sesuai seperti masa basuhan biojisim, isipadu air yang diperlukan, jenis air dan kaedah pembasuhan rendaman dan pengacauan. Air paip dan air suling digunakan dalam penyelidikan ini.

Kandungan abu bagi biojisim yang tidak dibasuh adalah 5.19 mf wt%. Melalui kajian ini, purata kandungan abu bagi biojisim bersaiz 1-3 cm yang direndam di dalam 3 *l* air paip selama 5 min pada suhu ambien adalah 2.95 mf wt%. Ia didapati bahawa kandungan abu kurang daripada atau sama dengan 3 mf wt% telah berjaya dicapai. Menerusi penyelidikan ini, ia menunjukkan air paip berkesan dalam mengurangkan kandungan abu dalam tandan buah kosong sisa kelapa sawit.

Kekonduksian elektrik di dalam sisa air basuhan dengan rendaman biojisim selama 5 min pada suhu ambien di dalam 3 *l* air paip adalah 991 µS / cm dan ia telah meningkat dengan masa rendaman berpanjangan. Kekonduksian elektrik dalam sisa air basuhan meningkat disebabkan oleh resapan mineral dan bahan bukan organik dari tandan buah kosong kelapa sawit.

Abu merupakan proksi bagi kalium dan natrium dan dikenali sebagai pemangkin yang aktif. Oleh itu, kehadiran abu yang tinggi dalam biojisim secara amnya akan menggalakkan tindak balas sekunder kepada produk utama pirolisis cepat. Prarawatan basuhan air adalah berkesan dalam mengurangkan kandungan kalium dan natrium dalam abu. Sebanyak 90% kalium dan 40% natrium mudah diuraikan oleh prarawatan basuhan air.

Ciri-ciri termal untuk biojisim yang dibasuh dan yang tidak dibasuh dianalisis menggunakan Pyris TGA 1. Analisis termal ini dijalankan dengan menggunakan 100 ml /min gas nitrogen dengan kadar pemanasan 10 ºC /min. Puncak lengkung TGA bagi biojisim yang dibasuh berganjak kepada suhu yang lebih tinggi berbanding biojisim yang tidak dibasuh disebabkan oleh kehilangan abu yang membawa kepada kurangnya kesan pemangkin.

WATER WASHING PRETREATMENT ON EMPTY FRUIT BUNCHES OF OIL PALM WASTE

ABSTRACT

The water washing pretreatment on empty fruit bunches (EFB) of oil palm waste has been investigated in this study, with the objective of removing some ash from the EFB to improve the quality of biomass. This study also investigated the effectiveness of water washing to remove ash by changing the appropriate parameters of the water washing pretreatment such as residence time, amount of water, type of water and use of soaking and stirring. Tap water and distilled water were solely used throughout the work.

The original ash content for the unwashed EFB is 5.19 mf wt%. From this study, the average ash content of the washed EFB by soaking the feedstock of size 1-3 cm in 3 *l* of tap water for 5 min residence time at ambient temperature is found to be 2.95 mf wt%. It is found that the ash content less than about 3 mf wt% was successfully achieved. It also showed that tap water is as effective as distilled water in reducing ash in EFB. The electrical conductivity in waste liquor by soaking the feedstock for 5 min at ambient temperature in 3 *l* of tap water was 991 µS/cm and it was increased with the prolonged soaking time. The electrical conductivity in waste liquor was found to increase due to the diffusion of mineral and inorganic materials from biomass.

Ash is a proxy of potassium and sodium, and are known to be catalytically active. Therefore, high ash in biomass generally promotes secondary reactions of primary pyrolysis products. Water washing pretreatment is effective in reducing the potassium and sodium in ash. Almost 90% of potassium and 40% of sodium were dissolved by water washing pretreatment.

The thermal characteristics of unwashed and washed EFB are analyzed with Pyris 1 TGA. A thermogravimetric analysis was performed under 100 ml /min nitrogen with a heating rate 10 ºC /min. The peak of TGA curves of the washed feedstock shifted to higher temperature compared to the unwashed due to loss of ash that leads to less catalytic effect.

CHAPTER 1

INTRODUCTION

Renewable energy is an alternative energy that seeks to replace the depletion in the supply of fossil fuel. Renewable energy, especially from biomass offers an advantage over fossil fuel by reducing the carbon emissions which are necessarily needed in order to mitigate the effect of global warming. Biomass is one of the greatly emphasized sources of renewable energy in Malaysia apart from solar, hydro, geothermal and wind energy. Thermochemical conversion processes such as pyrolysis, combustion, gasification and liquefaction are needed to generate energy from biomass.

1.1 WATER WASHING PRETREATMENT

The water washing pretreatment applied on empty fruit bunches (EFB) of oil palm waste is investigated in this study. Water washing pretreatment is one of the methods adopted to reduce the quantity of ash in the biomass, where it can be carried out using either cold or hot water [1]. The water washing pretreatment is important in producing good quality biomass and to generate better quality of fuel in any thermal conversion process as well as producing homogenous bio-oil for fuel applications. In general, the existence of ash in biomass, primarily potassium and sodium, influences the organic yield, therefore, removing some ash can enhance the organic yield of a fast pyrolysis process [2, 3]. The high ash content in biomass will promote the second reaction of primary fast pyrolysis product and produce non-homogenous liquids [2]. Non-homogenous liquid is produced from original biomass, through two phases, a heavy organic phase and a lighter aqueous phase. The phases exist in different forms, one is in a sticky and viscous form and another is a very watery form [4]. It is found that biomass with the ash content of less than about 3 mf wt% is required to produce homogenous bio-oil via fast pyrolysis technology [5]. According to Fahmi et al. [6], the pyrolysis liquids quality can be improved via washing the highly ashed feedstock. Thus, the effectiveness of water washing pretreatment in removing the ash by using variable parameters is investigated in this study.

1.2 RENEWABLE ENERGY

Malaysia is an agricultural country and hence, has higher potential in generating renewable energy sources which can significantly contribute towards the aims of reducing the greenhouse gases emissions and to the problems related to climate change. Therefore, the protection of environment has to be taken seriously in order to reduce carbon dioxide (CO_2) emissions. The non-renewable energy, fossil fuel consists of coal, oil and natural gas. These types of energy are generated from animals and plants that died millions of years ago and then decomposed to create a useable source of energy for humans [7]. However, the sources of the non-renewable energy especially fossil fuels are getting depleted. Therefore, the exploitation of biomass as the renewable energy resources by conversion to green fuel could potentially place Malaysia as a producer of renewable energy of biomass.

However, the renewable energy industry in Malaysia presently is still at an early stage. It is still generated on a small-scale basis. Apart from biomass, solar, hydro, geothermal, and wind energy are available in Malaysia as the main renewable energy resources. The descriptions of renewable energy resources in Malaysia are highlighted as follow:

a) Biomass

The term *biomass* refers to any derived organic matter either from plants or animals. A few examples of biomass which are available for energy are crops, agricultural food and feed crop, agricultural crops' wastes and residues, wood wastes and residues, aquatic plants and other waste materials including municipal wastes [8-10]. Most of the biomass residues are obtained by harvesting and milling agricultural produce which can later be utilized as fuel for energy generation. There are five major sectors that contribute wastes for generating biomass energy in Malaysia such as forestry, rubber cultivation, cocoa cultivation, sugar cane cultivation and oil palm cultivation [11, 12]. However, oil palm cultivation seems to yield most of the biomass supply of value added by-products since Malaysia is one of the world's exporters of palm oil [13].

b) Solar energy

Malaysia is a tropical country and is blessed with adequate sunshine. Thus, the solar energy can be easily manipulated as a potential energy source. Solar energy is usually used in the drying process of agricultural produce. Open sun drying is a traditional method of drying agricultural products and crops since solar energy is free and sustainable [7]. Solar energy is also produced with the least maintenance, no pollution and no depletion of resource due to the abundant sunshine throughout the year [14].

c) Hydro energy

Hydro energy is generated from the flowing water due to hydro power and then converted to another form of energy called electricity. The hydroelectric dam is the common method used to convert water to electricity. Water rotates the turbines and the energy is captured to run the generator. Hydro energy is used as it is cheaper to convert energy from water to electricity and it is also a clean energy source that does not emit any toxins [14].

d) Geothermal energy

Geothermal energy is the heat generated from the earth's core. The water from underground is replenished by rainfall and the heat is continuously produced deep within the earth. People around the world use geothermal energy to heat their homes as well as to produce electricity. Geothermal energy produces almost no emissions as it does not burn fuel to generate electricity [15].

e) Wind energy

Wind energy is another form of energy in generating electricity. The availability of the wind sources varies depending on the location. Wind energy produces green energy with no air pollutions and greenhouse gases [12]. However, wind energy is still under study in Malaysia.

1.3 BIOMASS CONVERSION AND TECHNOLOGY

Biomass has become more attractive to the industry as a potential renewable source of energy. The most common and convenient route for conversion into energy is the thermochemical conversion of the biomass demonstrated in processes like pyrolysis, combustion, gasification and liquefaction.

1.3.1 Pyrolysis

Pyrolysis is the process that converts biomass into charcoal, liquid and gaseous by heat in the absence of oxygen [10, 16-18]. This thermochemical process is the most suitable process for the conversion of biomass into the liquid fuels. The pyrolysis process is started by heating up biomass at 350-550 ºC and then it increases up to 700 ºC [19]. There are two types of pyrolysis, slow pyrolysis and fast pyrolysis. The slow pyrolysis is the conventional pyrolysis process that produces more charcoal or solid fuel, while, the fast pyrolysis generates higher yield of liquid fuels and obtained yields of up to 80% wt on dry feed, with less charcoal and gas [20].

Slow pyrolysis has been applied in the last thousand years to produce chars and tars. Slow pyrolysis is less energy-intensive in comparison with the fast pyrolysis as low temperatures and heating rates are used, to promote secondary reactions and produce high levels of char and gas. Biomass is typically heated to ~ 500 ºC and the vapor residence time varies from 5 min to 30 min [21]. Vapors do not escape as rapidly as in the fast pyrolysis. Thus, the components in the vapor phase continue to react with each other, as the solid char and any liquid are being formed. The heating rate in the slow pyrolysis is typically much slower than the heating rate in the fast pyrolysis. Biomass can be held at constant temperature or slowly heated. A slow pyrolysis process typically produce 18-30 wt% of liquid bio-oil, 20-35 wt% of solid char, and 30-40 wt% of gases, depending on the feedstock used [22].

Fast pyrolysis is a thermal decomposition process that occurs at moderate temperatures in which the biomass is rapidly heated in the absence of oxygen or air to produce the mixture of condensable liquids, gases and char [23]. It is an advanced process that carefully monitors the controlled pyrolysis reaction temperature of around 500 ºC and vapor phase temperature of 400-450 ºC, and the short vapor residence times of typically 2 s, giving high yields of liquid with minimal gas and char [24]. The fast pyrolysis process, on the other hand produces 75% of liquid bio-oil, 12% of solid char, and 13% of gases, depending on the feedstock used [17] . This liquid can substitute the liquid fossil fuels in some applications [20]. Bio-oil and solid char can be used as a fuel, as the gas can be recycled back into the process and hence, no waste is generated. The fast pyrolysis process has naturally faster heating rates in contrast to the slow pyrolysis process.

1.3.2 Combustion

Combustion is the burning process of biomass in the air. The chemical energy stored in biomass is converted into heat, where the mechanical power or electricity via combustion processes uses equipment such as stoves, furnace, steam turbine, boiler and turbo-generator. Combustion process produces hot gases at the temperature ranging from 800ºC up to 1000 ºC [25]. Combustion can simply be represented by the equation [26]:

$$Biomass + O_2 \rightarrow CO_2 + H_2O + Heat \qquad (1.1)$$

The combustion process is commercialized for the heat production. There are several factors affecting the efficiency of a combustion process such as the moisture content of biomass, the content of excess air needed, and the extent of the complete combustion [26]. Normally, the biomass with a moisture content <50% is used in the combustion process. High moisture content biomass is more suitable to biological conversion processes [25].

1.3.3 Gasification

Gasification is the process converting biomass into a combustible gas mixture by partial oxidation of biomass at high temperature within the range of 800-900 ºC [19, 27, 28]. Biomass is converted into a gaseous product of hydrogen and carbon monoxide and is controlled by oxygen. The reaction of the gasification process is provided below [19]:

$$C + O_2 \rightarrow CO_2 \tag{1.2}$$

$$C + \frac{1}{2}O_2 \rightarrow CO \tag{1.3}$$

$$CO + \frac{1}{2}O_2 \rightarrow CO_2 \tag{1.4}$$

$$CO_2 + C \Leftrightarrow 2CO_2 \tag{1.5}$$

The gasification process usually produces 5% of liquid yield, 10% of solid char and 85% of gases [17]. This is the process where fuel gases are generated as the primary product such as hydrogen, carbon monoxide and carbon dioxide. These gases are very useful for heat and power generation.

1.3.4 Liquefaction

Liquefaction is the process where biomass is converted into the liquid via a thermochemical processes, heated under pressure at the temperature of 350 ºC and high pressure using catalyst, and in the presence of hydrogen [19, 29] . In liquefaction, catalyst is employed to accelerate the breakdown of high molecular weight compounds to the smaller products. This process is very difficult to handle and the cost is quite high [19].

1.4 OIL PALM INDUSTRY IN MALAYSIA

Malaysia is the world's largest producer and exporter of the palm oil. Currently, the oil palm plantations is around 4.16 million hectares which generate an average of 81.5 million tonnes of fresh fruit bunches (FFB). The oil palm industry produces wastes in large quantities; comprising mainly of empty fruit bunches (EFB), fiber, shell and palm oil mill effluent (POME). It is estimated that there are around 17.9 million tonnes of EFB, 11 million tonnes of fiber, 4.5 million tonnes of shell and 50.0 million tonnes of POME [30]. High ash contained in biomass generally promotes secondary reactions of primary pyrolysis products including some ash components, primarily potassium and sodium, which are known to be catalytically active [2, 3].

1.5 OBJECTIVES AND SCOPE OF RESEARCH

1.5.1 Objectives of Research

The objectives of this research are as follow:

i. To remove ash content from EFB in order to improve the quality of biomass.

ii. To find the effectiveness of water washing treatment in removing ash using variable parameters such as residence time, amount of water, types of water and use of soaking and stirring methods in water washing pretreatment.

iii. To determine the effectiveness of tap water as compared to distilled water.

The main research objective is to remove ash from the EFB in order to improve the quality of biomass. It is found that the biomass with ash content less than about 3 mf wt% is required in order to produce homogenous bio-oil and increase bio-oil yield via fast pyrolysis technology [5]. Therefore, this study attempts to investigate the effectiveness of water washing treatment in removing some ash by using variable parameters such as residence time, amount of water, types of water and use of soaking and stirring of water washing pretreatment. Tap water and distilled water are used throughout this current work.

Ash is a proxy of potassium and sodium. The existence of ash in biomass influences the organic yield where the fundamental formation of the potassium and sodium in ash also influences the quality of the organic yield [2]. The effectiveness of each washing test is quantified by observing both the percentage of ash reduction and the reduction of potassium and sodium in the ash. Therefore, the correlation between the percentage of ash reduction and the reduction of potassium and sodium in ash for the washed EFB is investigated. The reduction of potassium and sodium is measured by the Atomic Absorption Analysis method.

The thermal characteristics of unwashed and washed EFB were analyzed with the Pyris 1 TGA. The thermogravimetric analysis was performed under 100 ml /min nitrogen with the heating rate of 10 ºC /min.

1.5.2 Scope of Research

The scope of research is given in Figure 1.1.

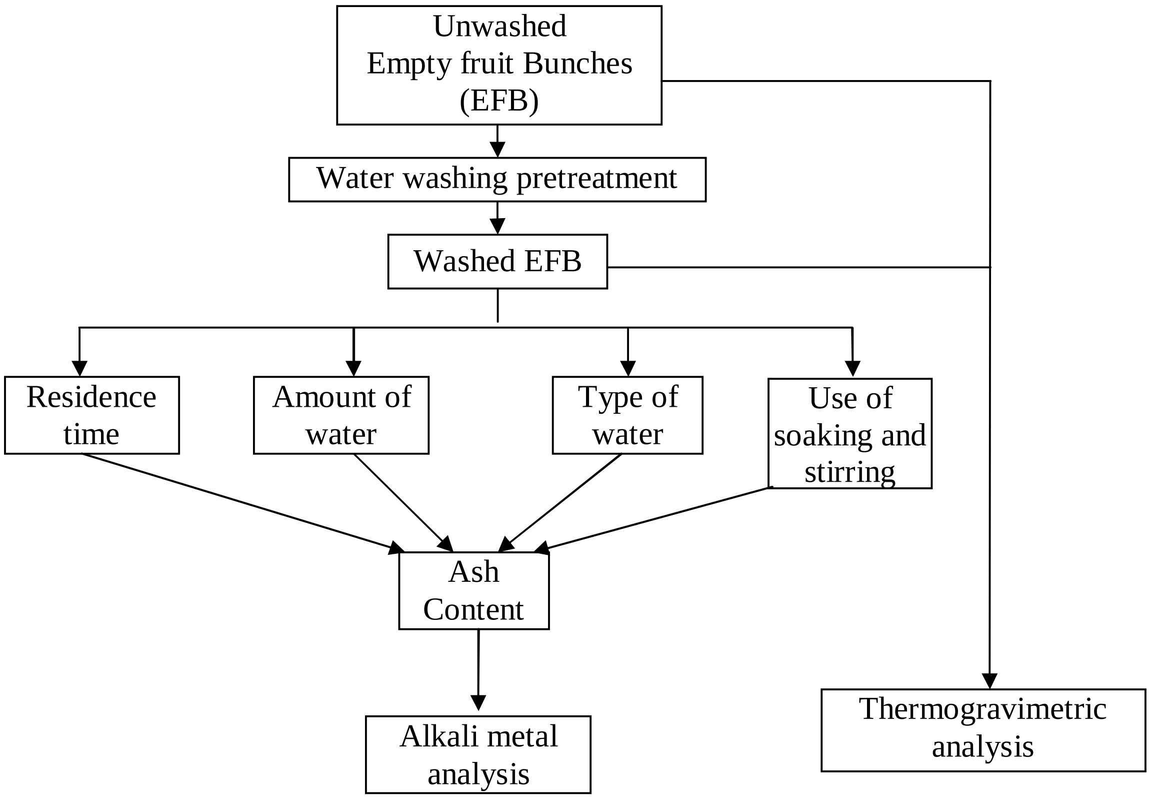

Figure 1.1: The scope of research

Figure 1.1 shows the scopes of the research. In this research, the EFB has been chosen as the biomass source. Water washing pretreatment was used in this study in order to reduce the ash content in the EFB. Variable parameters such as residence time, amount of water, type of water and the use of soaking and stirring have been investigated in order to find out the minimum parameter needed for reducing the ash content to less than about 3 mf wt%. The ash content was analyzed by using the alkali metal analysis. The unwashed and washed EFB were then analyzed through the application of the thermogravimetric analysis. Results of water washing pretreatment and analyses are discussed in detail in Chapter 4.

Although the objectives and scope in this thesis have been thoroughly investigated and studied, there are still some limitations to the research. The washed EFB with the ash content less than about 3 mf wt% was achieved by the water washing pretreatment in this study. It is found that biomass with ash content less than about 3 mf wt% is required to produce homogenous bio-oil via a fast pyrolysis process [5]. However, the fast pyrolysis process necessary in order to obtain the homogenous bio-oil on the washed EFB cannot be performed due to the laboratory does not have fast pyrolysis reactor. In addition, the size of the biomass used in this experiment was fixed in the range 1-3 cm as the size is sufficient to produce biomass with ash content of less than about 3 mf wt% [5].

1.6 STRUCTURES OF THESIS

This thesis is arranged in the following chapters:

Chapter 2 provides information about the oil palm industry processes in Malaysia. This chapter also describes in general the operation of palm oil mill and the wastes generated from the mill. The literature review of the washing pretreatment of biomass is briefly reviewed in this chapter.

Chapter 3 describes briefly the methodology of the water washing pretreatment. Water washing pretreatment is one of the methods to reduce the ash content in biomass using any type of water. Normally, the researchers use the distilled water and de-ionized water. However, in this study, it shows that the tap water is effective in reducing the ash quantity in biomass. The water washing pretreatment is investigated using variable parameters such as residence time, the amount of water, types of water and use of soaking and stirring. The characteristics of the EFB used in the experiments are described in this chapter.

Chapter 4 describes and investigates in detail the experiments of water washing using tap water and distilled water. The EFB is biomass which has high ash content and, thus, promotes secondary reaction of the thermochemical biomass process and produces the non-homogenous liquid (two phases of liquids). Samples were received in wet condition and were dried first to achieve the moisture content less than 10 mf wt%. This chapter describes in detail the water washing experiments and the results which seek to attempt to assess the effectiveness of each experiment.

Chapter 5 concludes all the experiments of water washing presented and draws the conclusion with regards to potassium and sodium in ash. This chapter also gives recommendations for further work and also gives an outline of possible future investigations which may possibly be carried out.

CHAPTER 2

LITERATURE REVIEW

This chapter discusses briefly about oil palm wastes in Malaysia. This chapter also reports the oil palm industry and the mass balance. The palm oil industry has contributed a huge amount of wastes such as empty fruit bunches, shell and fiber. Usually the wastes are left on the ground and burned. This poses an environmental problem such as the existence of green house gas (GHG). This chapter also describes about the empty fruit bunches and their characteristics. Pretreatment through water washing on biomass is reviewed with particular emphasis placed on the removal of ash.

2.1 INTRODUCTION

Oil palm (*Elaeis guineensis*) originated from West Africa in a belt from Angola to Senegal. Oil palm was introduced to the peninsular of Malaysia in 1870s, and was commercially exploited in the 1900s [31]. Nowadays, oil palm is the most economically attractive crop in Malaysia. With a total planted area of 4.69 million hectares, oil palm has a prominent role to boost the socio-economy in the country [31].

2.2 OIL PALM PLANTATION IN MALAYSIA

Malaysia is blessed with humid tropical climate at the temperature range of 24-32 ºC, with ample sunshine and annual rainfall of almost 2000 mm throughout the year. Such conditions are deemed ideal for the cultivation of oil palm [32].

Malaysia is the world's top producer of palm oil with a planted area of 4.69 million hectares in 2009. It has increased to 4.5% compared to the previous year. Sabah is the largest oil palm state, accounting for 1.36 million hectares or 29% of the total planted area in the country. It is followed by Sarawak which has a planted area with a growth of 12.8%, and 3.3% planted area spread all over the Peninsular Malaysia [31].

An oil palm usually bears fruits from 30 months after field planting. Being a perennial crop, it can be harvested throughout the year, simultaneously projecting its long productive lifespan; usually for about 25-30 years [32-34]. This automatically makes the supply of palm oil uninterrupted. The oil palm plantations in Malaysia are planted with a density of 148 palms per hectare. One stand of oil palm tree occupies 0.0068 ha of land. Each palm yields about 150 kg of fresh fruit bunches (FFB) per year. Therefore, the average total production of the FFB per palm tree for 23 productive years is 3.45 tons. The average planting cycle of a palm tree is about 25 years for efficient productivity [33]. Oil palm fruit is usually harvested after 3 years from planting. Maximum yield is achieved in the following 12-13 years, and then the yield continuously declines until the end of the 25 years [35-37].

2.3 THE OIL PALM INDUSTRY IN MALAYSIA

Malaysia is the world's largest producer and exporter of palm oil. Malaysia is also well known as the producing and marketing country of palm oil, palm kernel oil and their derivative products. In 2008, Malaysia produced about 17.74 million tonnes of palm oil from the 4.49 million hectares of planted area [31]. The production and export of Malaysian palm oil is expected to increase in the future through improved planting materials and better plantation management.

2.3.1 Malaysian Biomass Scenario

Renewable energy sources are abundant in Malaysia and the most important one being biomass sources. Biomass in Malaysia contributes about 14% of the approximately 340 million barrels of oil equivalent (boe) of energy used every year. There are five major sectors that contribute wastes to the biomass energy in Malaysia such as forestry, rubber cultivation, cocoa cultivation, sugarcane cultivation and oil palm cultivation [11, 12]. The biomass production and energy potential in Malaysia are shown in Table 2.1.

Table 2.1: The biomass production and energy potential in Malaysia [11]

Cultivation	Annual Amount of Production(million)		Energy Potential of Utilized Biomass (million boe)	
Oil palms	Fruit shells	23.609	Pruned fronds	77.665
	Fruit fibers	13.63	EFB	11.444
	Effluents	0.022	Effluents	2.928
			Replanting Wastes	12.940
Rubber trees	Wood	4.967	Wood	3.707
			Effluents	0.210
Cocoa trees	na	na	Pruning wastes	16.850
			Pod husks	0.085
			Replanting wastes	0.630
Sugarcane	Bagasse	0.421	Leaves and tops	0.0298
Timber processing	Sawdust and wastes	3.733	Tree bark and sawdust	1.0
Paddy plant	na	na	Rice husks	1.025
			Rice straws	2.541
Coconut trees	Fronds	1.578	Fronds	0.164
	Shells	0.785		

na : not available

At present, the palm oil industry generates a huge amount of oil palm wastes from the mills such as oil palm shells, mesocarp fiber and empty fruit bunches (EFB) and palm oil mill effluent (POME) and also from the field during replanting such as oil palm fronds and oil palm trunks [30]. About 9.9 million tons of palm oil wastes are generated every year in Malaysia, and this keeps increasing at 5% annually [38]. The oil palm wastes can be a raw material for many products such as medium density fibreboard (MDF), particleboard, pulp and paper, plastic composites and bio-compost, as well as for generating bio-energy. Oil palm wastes can also be a good alternative to replace wood in many applications.

2.3.2 The Mass Balance of the Oil Palm Industry in Malaysia

The palm oil mill in Malaysia is sufficient in producing of energy. The wastes that are obtained from the mill are usually burned to generate electricity and power-generation. The amount of biomass generated during normal maintenance operations and during replanting from 1 hectare of oil palm from the field is illustrated in Figure 2.1 [39, 40] and the mass balance of 1 tonne of FFB from the palm oil mill process is shown in Figure 2.2 [4, 41].

The oil palm industry produces wastes in huge quantities such as EFB (17.9 million tonnes), fiber (11 million tonnes), shell (4.5 million tonnes) and palm oil mill effluent (50.6 million tonnes). It is estimated that as a percentage of fresh fruit bunches (FFB), the EFB account for 21%-22%, mesocarp fibre 12%-16% and shells 5%-7% of the wastes generated from the mills. Other wastes such as the decanter solids and effluent treatment sludge, but in relatively smaller quantities are also generated from the mill [30].

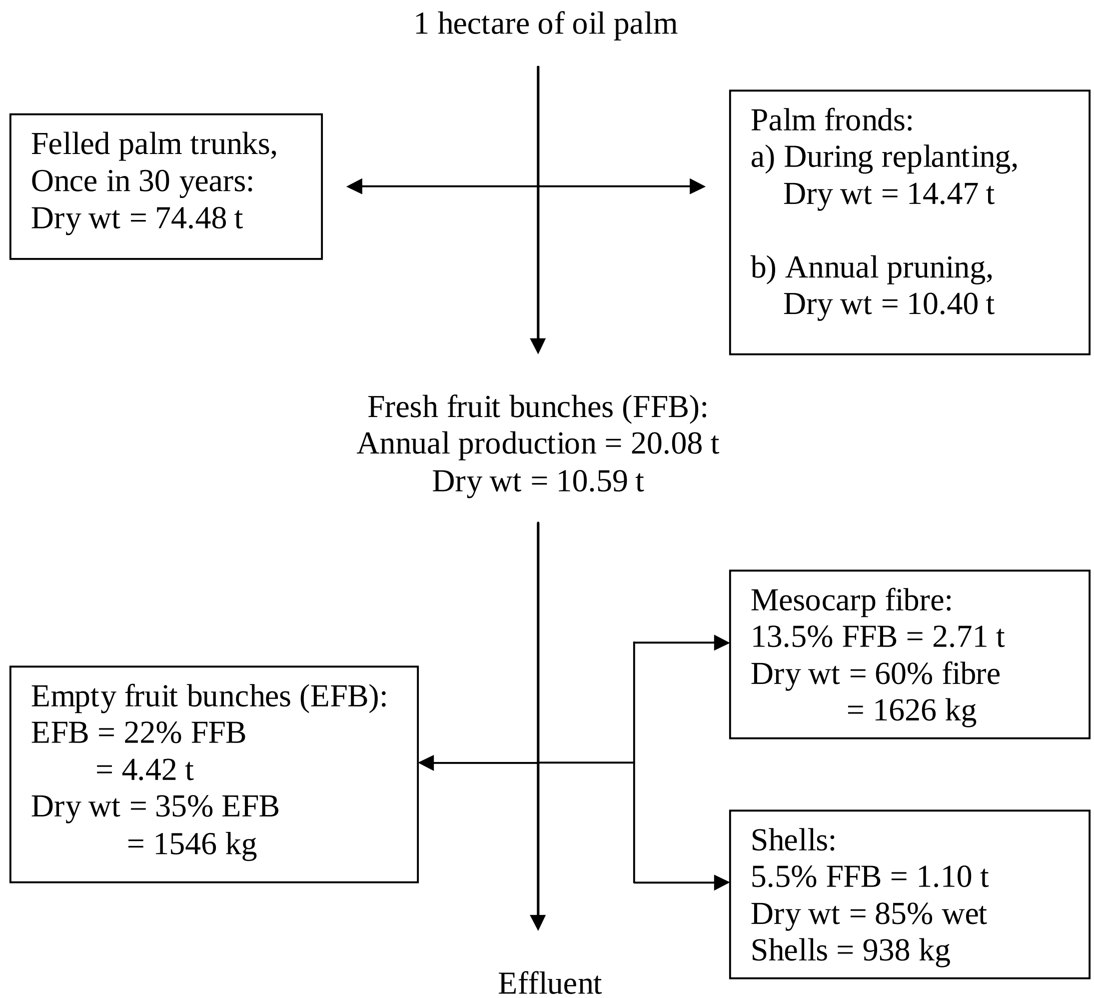

Figure 2.1: Oil palm biomass distribution from oil palm
[39, 40]

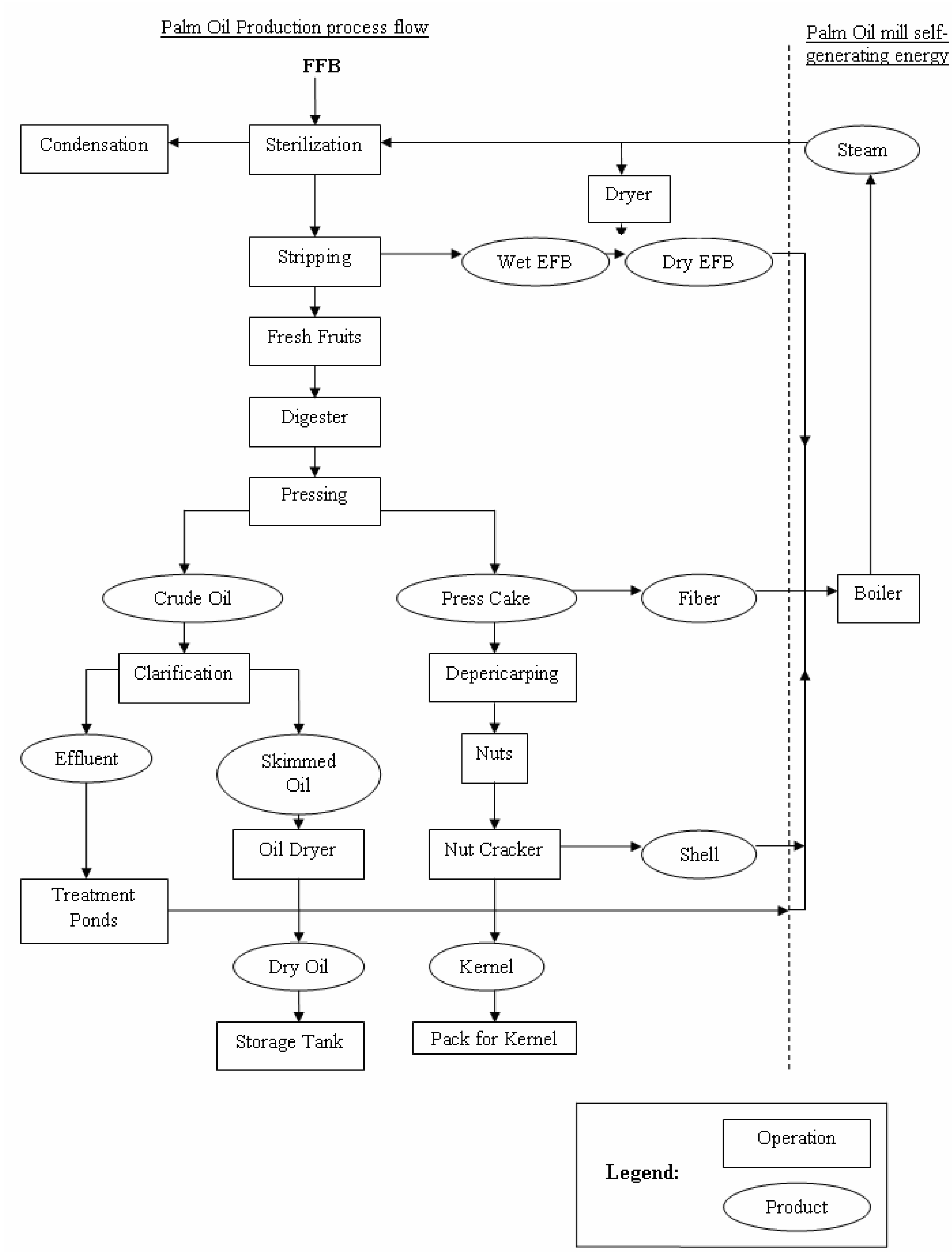

Figure 2.2: The operation of Palm Oil Mill. Adapted from [4, 41].

Referring to Figure 2.2, when the fresh fruit bunches reach the processing plant, the sterilization process begins with the steam temperature at 140 ºC, pressure set at 2.5 to 3.2 kg / cm^2 for 50 min. Then, the stripping process will take over. During the stripping process, a rotating divesting machine is used to separate the sterilized oil palm fruit from the sterilized bunch stalks. The EFB will fall on the collector and are brought to the burning place as fuel. After the stripping process, the sterilized fruits are fed into a digester where water at 80 ºC is added. This is performed in steam-heated vessels with stirring arms, known as digesters or kettles. The most common method of extracting oil from the digested palm fruit is by pressing. The type of press used in this palm oil is the screw type press.

The crude oil extracted from the digested palm fruit by pressing contains varying amounts of water, together with impurities consisting of vegetable matter, some of which are dissolved in water. The purifying process of oil uses centrifugal and vacuum driers before pumping it into a storage tank. When the digested fruits are pressed to extract the oil, a cake made up of nuts and fibre is produced. When the fibre is separated from the nuts, the latter then is prepared for cracking. Any uncracked nuts must be removed and recycled for the shell to be separated from the kernels. The waste fibre and shell are transported to the burning place as fuel and the kernels are packed and sold to kernel oil mills.

2.4 BIOMASS

2.4.1 Introduction

Renewable energy from biomass is considered as an eco-friendly way of reducing the mounting wastes problem. Biomass is a very heterogeneous and chemically complex, renewable process. The term *biomass* implies that it is any plant that derives organic matter from plants or animals. Examples of biomass available are energy crops, agricultural food and feed crops, agricultural crops wastes and residues, wood wastes and residues, aquatic plants and other waste materials including municipal wastes [8, 9].

2.4.2 Lignocellulosic Biomass

Biomass also known as lignocellulosic biomass consists mainly of three major components such as cellulose, hemicellulose and lignin together with a trace amount of extractives and minerals [9, 42]. Generally, lignocellulosic biomass materials contain 40-60 wt% of cellulose, 20-40 wt% of hemicellulose and 10-25 wt% of lignin on a dry basis [9, 42, 43]. Biomass is a renewable source of energy and provides energy for great many activities of mankind. The use of renewable energy sources especially biomass is becoming increasingly important since it is considered to alleviate global warming. Biomass generally has less carbon, more oxygen, more silica and potassium, and volatile matter close to 80% [11].

2.4.3 Structure of Biomass

The structure of biomass can be categorized into the biological structure and chemical structure. Biological structure is about the structures of biomass. The location of ash can be known from biological structures. It is important to know the location of ash since this study involves the water washing pretreatment on the EFB in order to remove some ash to improve the quality of EFB for increasing bio-oil yield via fast pyrolysis. However, there is no information provided for the structure of EFB. Therefore, the biological structure in this thesis will discuss the structure of general biomass. The chemical structure of biomass will broach the aspects of cellulose, hemicellulose and lignin in biomass.

2.4.3.1 Biological Structure

The biological structure of biomass is composed of millions of individual cells. These cells consist of cell components such as middle lamella, primary wall, secondary wall (S1-S3) as shown in Figure 2.3. The main cell components within plants are [4, 44]:

- Middle lamella (ML): the layer of intercellular substance between cells. This layer mostly consists of lignin bonds.
- Primary wall (P): mostly consists of lignin on the outside which forms the surface of the cell, however on the inside it consists of cellulose between the lignin.
- Secondary wall (S1): mostly made of cellulose, some Phenolic esters between the wall and the lamella. It is also known as the outer layer.
- Secondary wall (S2): mostly made of cellulose, contains micro fibrils giving hemicellulose strength to the cell and it is known as middle layer of the secondary cell wall.
- Secondary wall (S3): consists of cellulose, lignin, hemicellulose, tertiary lamella and hemicellulose xylans, which give chemical resistance to the cell. This is called the inner layer.

• Lumen: Lumen is a cell cavity. Each cell possesses a limiting wall enclosing a lumen.

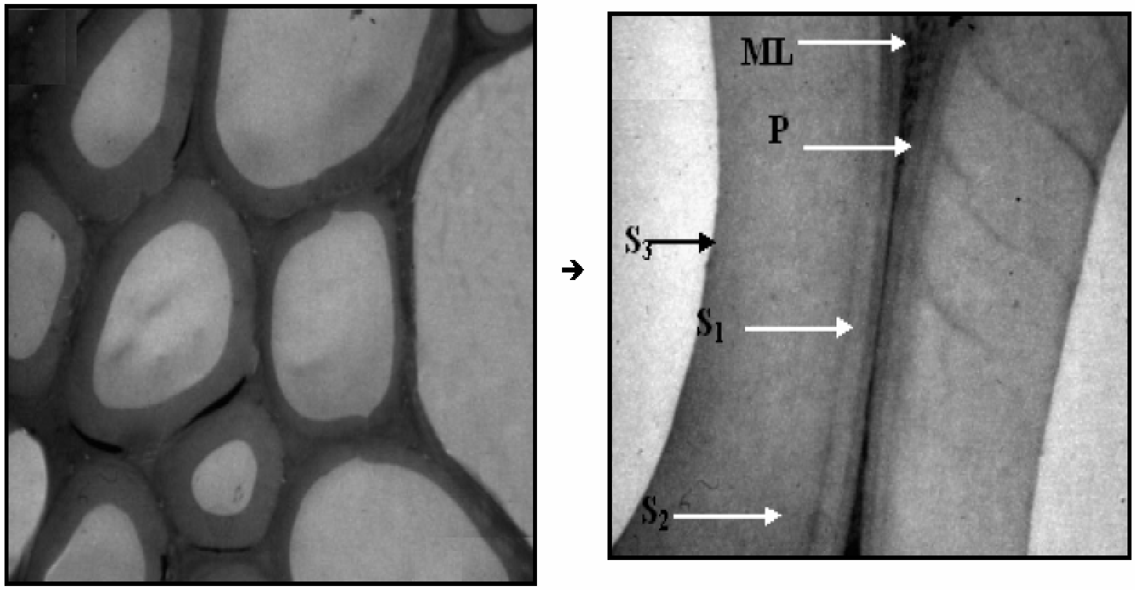

Figure 2.3: Cell wall components in biomass [4]

The various wall layers (primary and secondary wall) clearly appear in ultra-thin transverse sections of fibers as shown in Figure 2.3. The primary wall (P) appears as a solid boundary of the cell. The middle lamella (ML), which glues the cells together, shows a clear transition to the adjacent primary wall layers. The dark staining of the ML has indicated that the ML is strongly lignified. The S1 layer of the secondary wall has well defined the brightest layer compared to other layers. The thickness of the S1 layer in agro fibers is found to be in the range of 0.10-0.84 µm. The S2 layer serves to control all the cell wall's thickness. The S2 layer is reinforced by microfibrils that usually lie from 5 to 30 degrees to the axis and it is about forty times thicker than any of the other layers. The S2 layer occupies about 43-78% of the whole wall in thickness [44, 45]. The S3 layers lie at the surface of the double cell wall at the position of maximum compressive and tensile stress in the wall. The average microfibril orientation in the S3 layer lies close to the plane of the cell walls along the tangential direction, while that of the S2 layers lie approximately perpendicular to the tangential direction. Hence, the microfibrils in the S3 layer are comparatively much more effective in stiffening the wall in the transverse plane than those of the S2 layer [45].

2.4.3.2 Chemical Structure

Lignocellulosic biomass is essentially a composite material constructed from oxygen containing organic polymers. The major structural chemical components with high molar masses are carbohydrate polymers and oligomers (65%-75%) and lignin (18%-35%) as shown in Figure 2.4. Minor low molar mass extraneous materials mostly organic extractives and inorganic minerals are also present in wood (usually 4%-10%). The major constituents consist of cellulose (a polymer glucosan), hemicelluloses (which are also called polyose), lignin, organic extractives, and inorganic minerals. In general, lignocellulosic biomass is structured as can be seen in Figure 2.5 [46].

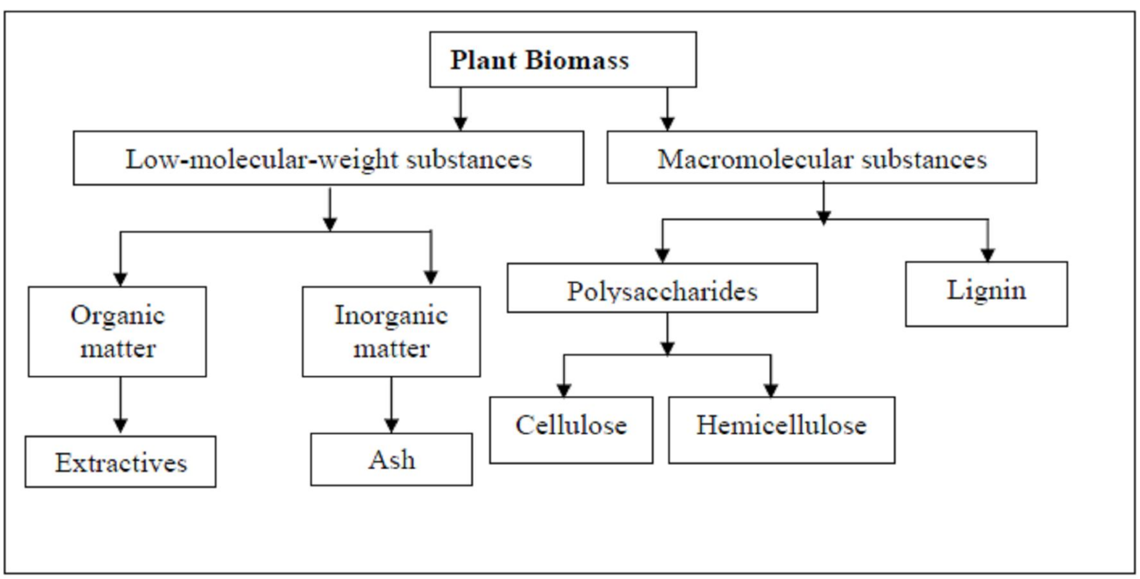

Figure 2.4: General component in biomass. Adapted from [21]

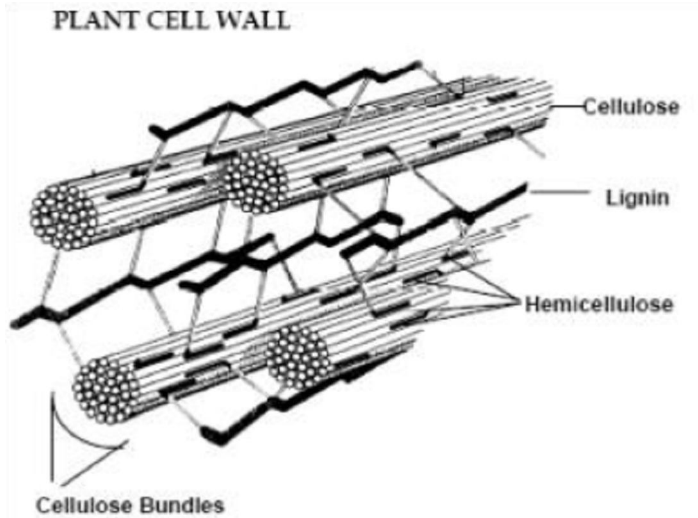

Figure 2.5: Structure of plant cell wall. Adapted from [46, 47]

2.4.3.2.a Cellulose

Lignocellulosic is the largest source for cellulose in the world [44]. Cellulose is one of many polymers which is readily available naturally on earth and is usually known as polysaccharides. Cellulose is a high molecular-weight (10^6 or more) linear polymer of β-(1→4)-D-glucopyranose units in the C_1 and C_4 atoms conformation. The fully equatorial conformation of β-linked glucopyranose residues stabilizes the chair structure, at the same time minimizing flexibility. Glucose anhydride, which is formed via the removal of water from each glucose, is polymerized into long cellulose chains that contain 5000-10000 glucose units. The basic repeating unit of the cellulose polymer consists of two glucose anhydride units, called a cellobiose unit. Cellulose consists of between 2000 and 14000 residues which is crystalline. A chemical structure of cellulose is presented in Figure 2.6.