Torrefaction of Palm Waste Biomass

By

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Regards,

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(NOOR AKMAL MOHAMAD SALEH)

ABSTRACT

Torrefaction of oil palm solid waste mainly empty fruit bunch at atmospheric pressure under nitrogen atmosphere was performed for production of solid biofuel. Due to the problem arising on the gasification of biomass such as high moisture content, production of tar, low energy production and high ash content, this project has been proposed to overcome the problems. This report discusses on the torrefaction of empty fruit bunches. Throughout the experiment, the effect of temperature, particle size and reaction time on the yields of product will be investigated and the results will be analyzed and compared with the previous study. This project is divided into 3 steps which are sample pretreatment step, sample analysis step and experimental procedure by Fix Bed Activation Unit (FBAU). Apart from that, some proximate analysis needs to be carried out to analyze the volatile matter, fixed carbon content and also ash content of the products using Thermal Gravimetric Analyzer (TGA). Based on the results, some observation and justification have been done to explain the difference between the results obtained. Moreover, chemical properties such as elemental analysis, proximate analysis and product analysis are deciding factors for the selection of the biomass as solid fuel.

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Praise to the Almighty God for his mercy and kindness that the author has successfully completed this project within the time frame. Throughout these 2 semesters, it has greatly benefited the author in various aspects especially in engineering knowledge applied. Experiences gained are believed to be very useful to the author in her future career and endeavors. Hopefully all the information gained from this project may benefit others especially UTP students and staff for references. The successful completion of this project has been possible through the help and support of many individuals and organizations.

The author would like to express the highest gratitude to her FYP supervisor, Mr. Mohammad Tazli b Azizan for giving the author an opportunity to acquire knowledgeable experiences throughout this project. The author also would like to extend her deep appreciation to the lab technicians with their guidance and advised has helped the author a great deal in completing this project. Author also appreciates for those their names are not included who either directly or indirectly help this project.

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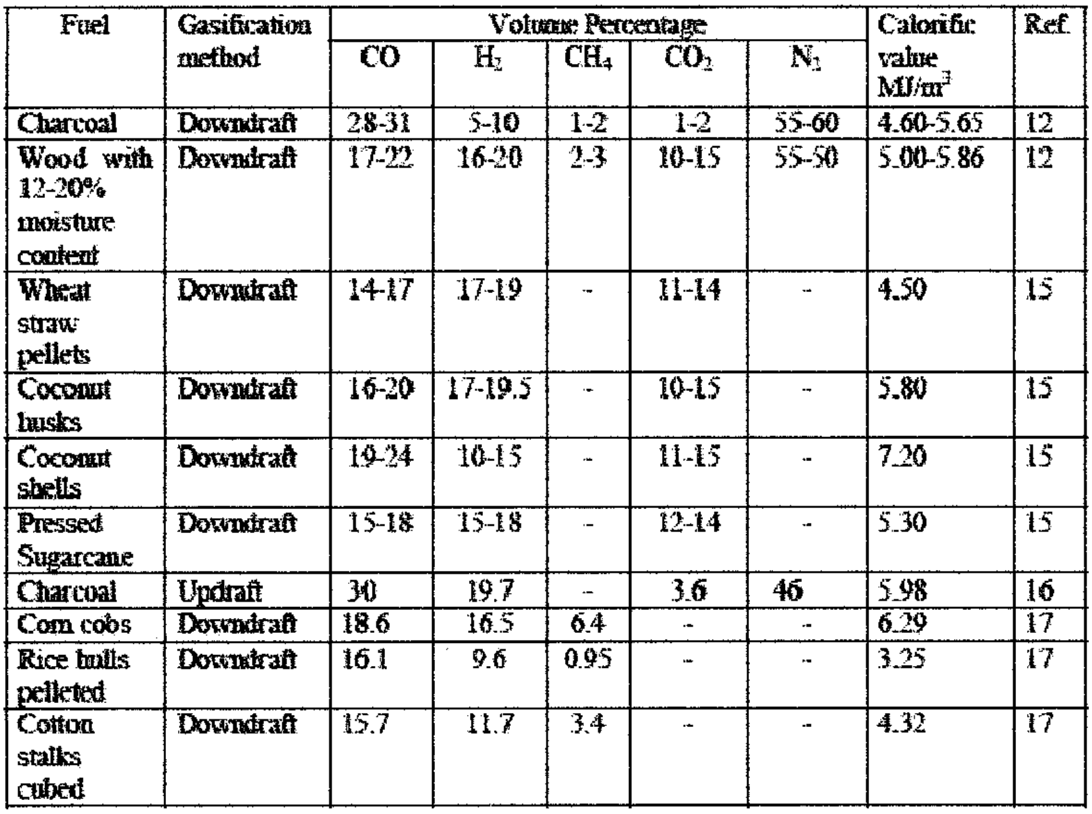
CHAPTER 1

INTRODUCTION

1.0 Problem Statement

Biomass can be exploited to produce energy by different technologies. Gasification is one of the newer technologies that are increasingly being used for waste disposal. The gas composition is also a function of gasifier design and thus, the same fuel may give different calorific value as when used in two different gasifiers. Table 1 therefore shows approximate values of gas from different fuels.



Fuel	Gasification method	Volume Percentage					Calorific value MJ/m^3	Ref.
		CO	H_2	CH_4	CO_2	N_2		
Charcoal	Downdraft	28-31	5-10	1-2	1-2	55-60	4.60-5.65	12
Wood with 12-20% moisture content	Downdraft	17-22	16-20	2-3	10-15	55-50	5.00-5.86	12
Wheat straw pellets	Downdraft	14-17	17-19	-	11-14	-	4.50	15
Coconut husks	Downdraft	16-20	17-19.5	-	10-15	-	5.80	15
Coconut shells	Downdraft	19-24	10-15	-	11-15	-	7.20	15
Pressed Sugarcane	Downdraft	15-18	15-18	-	12-14	-	5.30	15
Charcoal	Updraft	30	19.7	-	3.6	46	5.98	16
Corn cobs	Downdraft	18.6	16.5	6.4	-	-	6.29	17
Rice hulls pelleted	Downdraft	16.1	9.6	0.95	-	-	3.25	17
Cotton stalks cubed	Downdraft	15.7	11.7	3.4	-	-	4.32	17

Table 1: Composition of Producer Gas from various fuels

(Source: Alternative Energy in Agriculture, Vol. II, 1986, Ed D. Yogi Goswam)

The average energy conversion efficiency of wood gasifiers is about 60-70% and is defined as

$$\eta_{Gas} = \frac{\text{Calorific value of gas/kg of fuel}}{\text{Avg. calorific value of 1 kg of fuel}}$$

Thus a gasifier fuel can be classified as good or bad according to the following parameters:

1) Energy content of the fuel
2) Bulk density
3) Moisture content
4) Dust content
5) Tar content
6) Ash and slagging characteristics.

In most fuels there is very little choice in moisture content since it is determined by the type of fuel, its origin and treatment. It is desirable to use fuel with low moisture content because heat loss due to its evaporation before gasification is considerable and the heat budget of the gasification reaction is impaired. Besides impairing the gasifier heat budget, high moisture content also puts load on cooling and filtering equipment by increasing the pressure drop across these units because of condensing liquid. Thus in order to reduce the moisture content of fuel some pretreatment of fuel is required. Generally desirable moisture content for fuel should be less than 20%.

Tar is one of the most unpleasant constituents of the gas as it tends to deposit in the carburetor and intake valves causing sticking and troublesome operations. It is a product of highly irreversible process taking place in the pyrolysis zone. The physical property of tar depends upon temperature and heat rate and the appearance ranges from brown and watery (60% water) to black and highly viscous (7% water). There are approximately 200 chemical constituents that have been identified in tar so far. Very little research work has been done in the area of removing or burning tar in the gasifier so that relatively tar free gas comes out. Thus the major effort has been devoted to cleaning this tar by filters and coolers. A well-designed gasifier should put out less than 1 g/m3 of tar. More research effort is therefore needed in exploring the mechanism of tar breakdown in downdraft gasifiers.

The mineral content in the fuel that remains in oxidized form after complete combustion is usually called ash. The ash content of a fuel and the ash composition has a major impact on trouble free operation of gasifier. Ash and tar removal are the two most important processes in gasification system for its smooth running. Various systems have been devised for ash removal. In fact some fuels with high ash content can be easily gasified if elaborate ash removal system is installed in the gasifier.

Due to the problems arising above, this project has been proposed to improve the properties of biomass as a fuel by reducing the moisture content, removing ash and tar production and increasing product yield and energy content of the solid biofuel (charcoal).

1.2 Objective

In order to solve the stated problem above, this project has come out with two objectives which are:

i. To characterize the potential aspect of biomass product from oil palm source, mainly empty fruit bunches as an energy source.
ii. To produce solid biofuel mainly charcoal from empty fruit bunches via torrefaction instead of gasification to replace fossil fuel.
iii. To analyze and compare both biomass energy conversion which is torrefaction and gasification in terms of quality of biofuel (product).

1.3 Scope of Study

The scope of the study will cover the following:

i) Research and literature review on theories and information from various sources related to project topic.
ii) Perform experiment based on the different particle size of EFB, reaction time and temperature range.
iii) Carry out proximate analysis on the product in terms of fixed carbon, ash content, product yield, moisture content, calorific value etc.
iv) Finalize by selecting the parameters (particle size of EFB, reaction time and temperature range) which produce highest product yield, lowest moisture content, lowest fixed carbon content and lowest ash content as a solid biofuel.

CHAPTER 2

LITERATURE VIEW

2.1 Biofuel

Biofuels is defined as organic primary and/or secondary fuels derived from biomass which can be used for the generation of thermal energy by combustion or by using other technology. It comprises purpose-grown energy crops, as well as multipurpose plantations and by-products (residues and wastes). The term "by-products" includes the improperly called solid, liquid and gaseous residues and wastes derived from biomass processing activities.

Biofuel is a renewable energy resource, it safeguards the environment, it provides net zero CO_2 emission, it can contribute to carbon credits, it provides energy security from an over dependence on fossil fuels in the future and it can probably stabilize the price of palm oil. It will create a whole new industry with tremendous potential with trickle down benefits to further provide new industries in nutraceuticals (vitamin supplements), detergents, glycerine and fine oleochemcials. In the Malaysian scenario, the main constraint is the fuel subsidy, but with rising petroleum prices, new strategies will have to emerge which will have possible social consequences. There may have to be practical and economic solutions, with inevitable use of biofuels through a joint effort involving the government, industry and consumers.

2.1.1 Biofuel Demand and Production

Demand for biofuels will expand almost 20 percent per year through 2011 to 92 million metric tons, despite recent concerns about the impact of biofuels on the environment and world food supplies. Market expansion will be led by a more than doubling of the global market for bioethanol, with the biodiesel market achieving even more rapid growth. Other biofuels will also achieve double digit gains, though from a much smaller base.

In developing countries, charcoal is an important fuel and in some cases as an export product. Charcoal is produced through thermochemical transformation of biomass with oxygen deficiency (pyrolysis). More than half of the energy in the wood is lost in this process, but charcoal has advantages for the user as more even and cleaner combustion than fuel wood. On an industrial scale, charcoal is used among other things as a reducing agent in the metallurgical industry.

It is useful with an overview of main reasons for introduction of biofuels:

i. Reduced CO_2 emissions. Biofuels are principally CO_2 neutral, depending on the conversion route from biomass to fuel, and which additives that are being used.
ii. Decreasing vehicle contributions to local air pollution. Most biofuels have a cleaner burning than common fossil petrol and diesel. But expected development of engines and stricter emissions regime will probably decrease this difference
iii. Higher reliability of energy supply. With more sources of fuel, the prices become more stable and shortage is less probable.
iv. Industrial and commercial development of a new industry, with increased employment and possibilities of development of intellectual capital. With introduction of biofuels follows employment in the whole chain from harvesting, processing and distribution.
v. A developed R&D programme on biofuels points out different solution to the way out of fossil oil dependenc

2.2 Kyoto Protocol

The Kyoto Protocol is a protocol to the international Framework Convention on Climate Change with the objective of reducing Greenhouse gases that cause climate change. It was agreed on 11 December 1997 at the 3rd Conference of the Parties to the treaty when they met in Kyoto, and entered into force on 16 February 2005 (Wikipedia, 2008).

The Kyoto Protocol is an agreement made under the United Nations Framework Convention on Climate Change (UNFCCC). Countries that ratify this protocol commit to reduce their emissions of carbon dioxide and five other greenhouse gases, or engage in emissions trading if they maintain or increase emissions of these gases. The objective is to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system (Wikipedia, 2008).

2.3 Biomass

Nowadays, the global electricity consumption is growing rapidly and the exploitation of fossil carbon reserves will someday in the future reach its limits. Furthermore, combustion of fossil fuels causes several environmental problems; for example the emission of greenhouse gases, like carbon dioxide. A possible way to deal with these problems is the development of cleaner and renewable energy sources. Biomass is a promising source of renewable energy with regard to a variety of criteria such as availability, conversion efficiency and usability.

Biomass is living matter derived from plants and animals; energy sources from biomass are often divided into two main categories: biomass wastes (or residues) and energy crops. Biomass wastes or residues refer to the remaining biomass after harvesting and/or after processing. Biomass residues can be categorised into three main groups

1. primary biomass residues - available at the farm
2. secondary biomass residues - released in the agro-food industry
3. tertiary biomass which is remaining after use of products.

The advantage of biomass, in the long-term, is that the energy from it can be produced and consumed on a practically carbon dioxide neutral basis. The carbon dioxide that the plant needs for its growth is released when the plant is burned for energy production. After this, a new plant can take this carbon dioxide up during its growth, so the circle is closed. Therefore the use of biomass is almost carbon dioxide neutral if one considers a complete and continuous cycle. Disadvantages are the current higher costs of bio energy compared to energy from fossil fuels and the land areas that are required for the production of biomass

2.2.1 Biomass Composition

The characteristics that impact availability and suitability as feedstock include whether the items are of a perishable nature, how much moisture content they have, the density, and the seasonality of supply. Based on chemical compositions of common Norwegian wood types, biomass contains the elements; carbon (45-55 weight %), hydrogen (5-7 weight %), oxygen (40-50 weight%) and small amounts of sulphur (0-0.05 weight %) and nitrogen (0-1.0 weight %). The carbon and the hydrogen are the combustible components of the wood.

Biomass consists of 10 – 25 % lignin, which is no sugar, and therefore impossible to convert into sugars. Lignin is therefore a residue in ethanol production, and often used for power generation. Though it is possible to upgrade lignin to valuable fuel additives, and thereby improve competitiveness of ethanol technology. Lignins act like the bounds in the cells, and gives rigidity to the cell wall. They are complex three dimension polymers of phenylpropane.

Lignocellulose comes from woody plant biomass; it is the most widespread source of carbon in nature. However, current lignocellulose-to-bio-ethanol processes are not deemed economical. Lignocellulosic material comprises cellulose, hemicellulose and lignin.

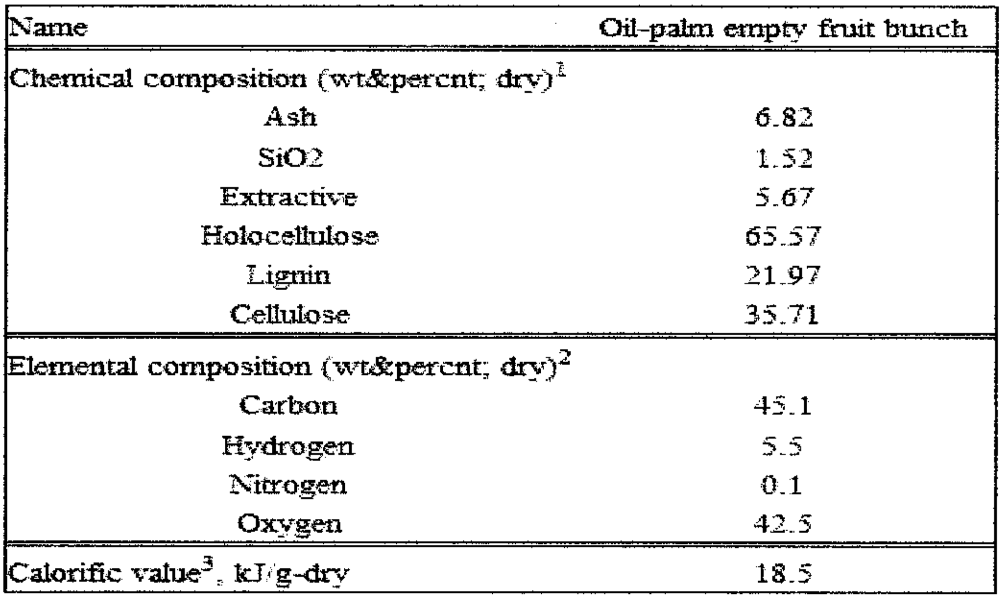
Cellulose and hemicellulose are polymers of fermentable sugars. They are put through a process of hydrolysis to convert them into sugars, which can ultimately be refined into bioethanol. They can also be treated thermochemically through gasification, combustion or pyrolysis to create high-value energy or chemical products. Cellulose is the main part of the cell wall, with the elementary formula $(C_6H_{10}O_5)_{n.}$ It is a highly linear polysaccharide and similar to hemicellulose, but the latter has a more branched structure and is more susceptible to chemical degradation than cellulose.

Properties	Rice husk	Rice husk [6]	Rice straw	Rice straw [3]	Maize stalk	Sugar cane	Palm stem	Palm branch	Palm fibre [6]	Palm tree [6]	Wood pellets [7]
Moisture (%)	6.65	8.20	6.71	8.11	8.42	7.94	nd	nd	31.84	48.4	7.7
Ash (%)	19.11	13.20	23.55	15.25	5.25	7.69	nd	nd	6.35	1.2	0.51
Volatile matter (%)	60.90	58.90	58.64	61.10	70.31	71.24	nd	nd	48.61	38.7	nd
Fixed carbon (%)	13.34	19.70	11.09	15.54	16.03	13.14	nd	nd	13.2	11.7	nd
Higher heating value (kJ/kg)	13,233	15,400	11,535	14,660	14,557	14,844	16,404	16,550	13,548	9,354	nd
Lower heating value (kJ/kg)	12,054	14,204	10,297	13,144	12,905	13,382	nd	nd	11,800	7,540	nd

Figure1: Proximate Analysis of Thai Agricultural Residues

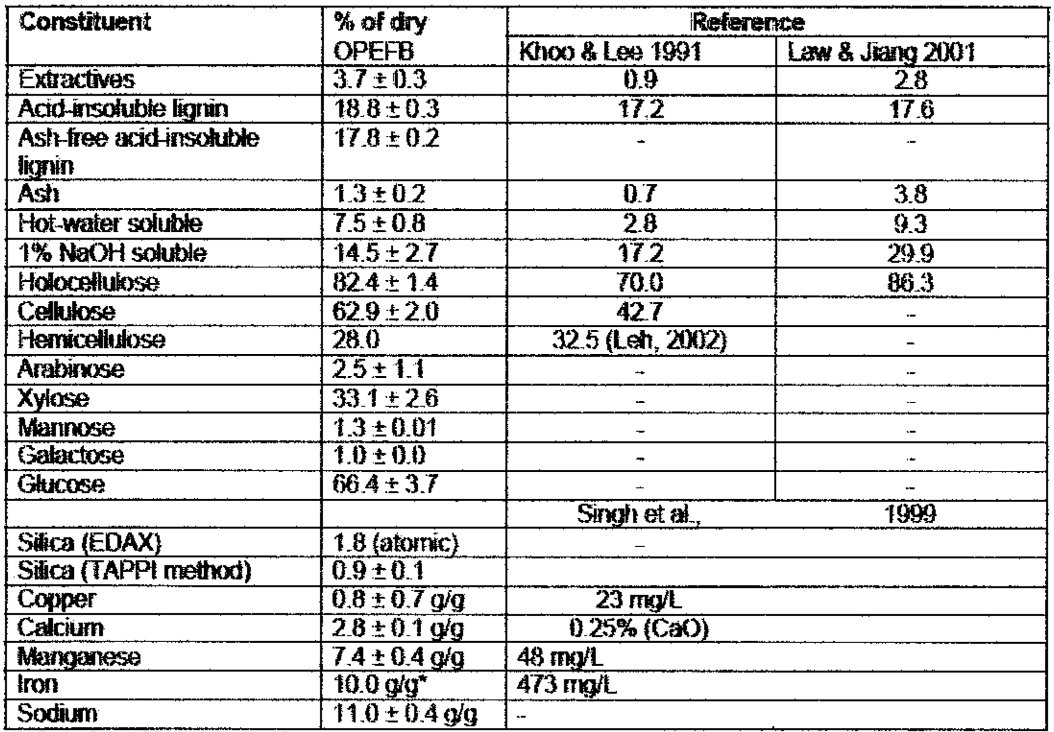
(Source: "Sustainable Energy and Environment, 2006")

From Table 3, oil palm residues contain low volatile probably due to their high moisture content. Taking into account both ash and volatile matter contents, maize and sugarcane materials seem to be the best candidates for pyrolysis and gasification. Rice husk and straw should be used with well adjusted operational conditions considering their high ash contents, in order to prevent problems previously mentioned. Lower Heating Values indicate energy effectively released by the biomass fuels, and so the necessary quantity to feed in the energy conversion unit. Our results showed that among all analyzed samples, sugarcane has the highest calorific value, followed by maize stalk, rice husk and rice straw. Data related to oil palm residues are of low range in the literature, probably due to their high moisture contents.



Name	Oil-palm empty fruit bunch
Chemical composition (wt% dry)[1]	
Ash	6.82
SiO2	1.52
Extractive	5.67
Holocellulose	65.57
Lignin	21.97
Cellulose	35.71
Elemental composition (wt% dry)[2]	
Carbon	45.1
Hydrogen	5.5
Nitrogen	0.1
Oxygen	42.5
Calorific value[3], kJ/g-dry	18.5

Figure 2: Table of Chemical Composition of EFB (2001-2008)
(Source: "AIST – Advanced Industrial Science & Technology, 2008")



Constituent	% of dry OPEFB	Reference	
		Khoo & Lee 1991	Law & Jiang 2001
Extractives	3.7 ± 0.3	0.9	2.8
Acid-insoluble lignin	18.8 ± 0.3	17.2	17.6
Ash-free acid-insoluble lignin	17.8 ± 0.2	-	-
Ash	1.3 ± 0.2	0.7	3.8
Hot-water soluble	7.5 ± 0.8	2.8	9.3
1% NaOH soluble	14.5 ± 2.7	17.2	29.9
Holocellulose	82.4 ± 1.4	70.0	86.3
Cellulose	62.9 ± 2.0	42.7	-
Hemicellulose	28.0	32.5 (Leh, 2002)	-
Arabinose	2.5 ± 1.1	-	-
Xylose	33.1 ± 2.6	-	-
Mannose	1.3 ± 0.01	-	-
Galactose	1.0 ± 0.0	-	-
Glucose	66.4 ± 3.7	-	-
		Singh et al.,	1999
Silica (EDAX)	1.8 (atomic)	-	
Silica (TAPPI method)	0.9 ± 0.1		
Copper	0.8 ± 0.7 g/g	23 mg/L	
Calcium	2.8 ± 0.1 g/g	0.25% (CaO)	
Manganese	7.4 ± 0.4 g/g	48 mg/L	
Iron	10.0 g/g*	473 mg/L	
Sodium	11.0 ± 0.4 g/g	-	

* Only found in one sample

Figure 3:Chemical Constituent of OPEFB
(Source: "Khoo & Lee, 1991, Law & Jiang, 2001, Leh, 2002, Singh et. Al, 1999")

2.3 Oil Palm Plantation

Nowadays, the increasing demands on fossil fuel have awakened the oil and gas industry due to the limiting resources of its reserved. Therefore, Malaysia can no longer remain idle and complacent in its position as the top grower and supplier of palm oil. In view of the escalating challenge posed by the other oil producing countries, Malaysia has to change its objective of being a world producer of palm oil to amongst others a leader in converting biomass waste into value-added products. Therefore, converting palm biomass into a solid biofuel via torrefaction process appears to be an attractive solution in upgrading its properties and add value. In this project, raw material will be used is empty fruit bunch (EFB) of oil palm waste.

The oil palm industry in Malaysia started 80 years ago in a modest way. Today it is the largest in agricultural plantation sector, exceeding rubber plantation by more than double in area planted. The oil palm tree produces fibrous biomass in the forms of trunks, fronds, and empty fruit bunches. In terms of hectare, the total area under oil palm cultivation is over 2.65 million hectares, producing over 8 million tonnes of oil annually. The oil consists of only 10% of the total biomes produced in the plantation. Although oil from the palm tree is an excellent product for the country, residues from oil palm have not been used sufficiently. One of the abundant lignocellulosic residues consists of empty fruit bunches (EFB), which are left behind after removal of oil palm fruits for the oil refining process at palm oil refineries. The remainder consists of oil palm fronds, trunks. The projection figures of these residues are as follows:

- 7.0 million tonnes of oil palm trunks
- 26.2 million tonnes of oil palm fronds
- 23% of Empty Fruit Bunch (EFB) per tonne of Fresh Fruit Bunch (FFB) processed in oil palm mill

Oil palm is one of the most economical perennial oil crops for its valuable oil-producing fruits in tropical regions such as West Africa (Khozirah and Khoo 1991) and Southeast Asia. In Malaysia alone large amounts of oil palm biomass are generated by the palm oil industry for example 5000 million tones (green) of felled trunk in 2000 (as projected by Husin et al. 1986), 36 million tones (odmt) per year of fronds from pruning and replanting (Wan Zahari et. Al 2004) and 5.2 million tones (odmt) per annum of empty fruit bunches (EFB) in 2002 (Tanaka and Yamamoto, 2004).

MALAYSIA's NATURAL RESOURCE BASE

Region & Status	Area mill Ha				% of Tot Land
	Pen. M'sia	Sabah	Sarawak	**TOTAL**	
NATURAL FORESTS					
Permanent Forests	4.26	3.34	4.62	12.22	*37*
Parks & Wildlife	0.44	0.38	0.23	1.05	*3*
Stateland Forest	1.34	0.6	4.57	6.51	*20*
TOTAL >	**6.04**	**4.41**	**8.7**	**19.15**	***60***
PLANTATIONS					
Wood Plantations				0.08	
Rubber	1.5	0.09	0.21	1.81	
Oil Palm	1.78	0.31	0.07	2.16	
Cocoa	0.14	0.2	0.06	0.39	
TOTAL >				**4.44**	***15***
Total AREA >>				**24.72**	***75***
Total Land Area - M'sia	**13.16**	**7.36**	**12.40**	**32.96**	***100***

Source: Stats on Commodities, Min of Primary Industries - June 1993
(Note 1 sq km = 100 Ha)

Figure 4: Malaysia's Natural Resource Base

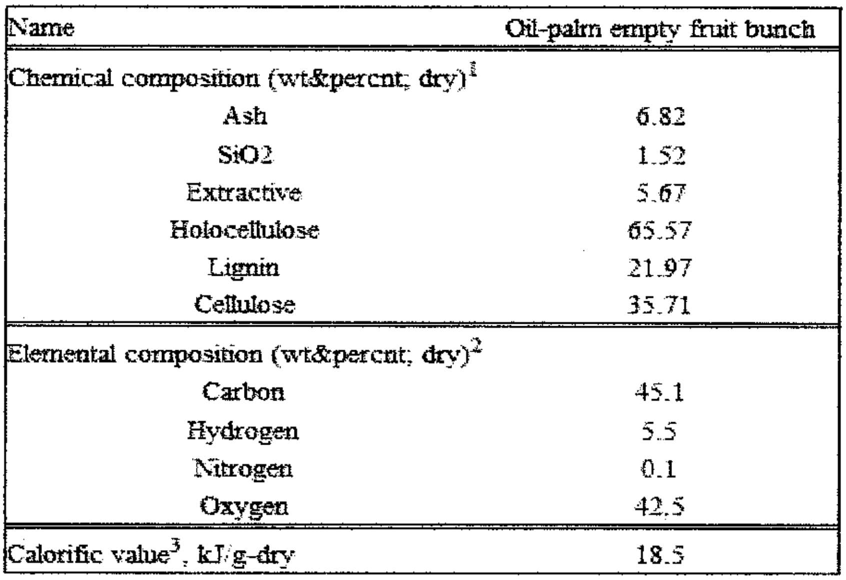
(Source: "Statistics on Commodities- Min of Primary Industries, 1993")

2.4 Empty Fruit Bunch (EFB)

In the oil extraction process, the fruits or nuts are first stripped from fruit bunches leaving behind the empty fruit bunches as waste. The abundance of oil palm empty fruit bunches has created an important environmental issue such as fouling and attraction of pests. Therefore, the substrate used for this project was empty fruit bunches (EFB) because they are cheap source of lignocellulose biomass and readily available.

Based on previously experiment done by M. Suhaimi and H.K. Ong, EFB is composed of 45-50% cellulose and about equal amounts (25-35%) of hemicelluloses and lignin (Deraman 1993). It is fibrous, and the fibers stick together to form vascular bundles

Table 2 shows the composition of dried empty fruit bunches in terms of chemical, elemental and caloric value by weight percentage.



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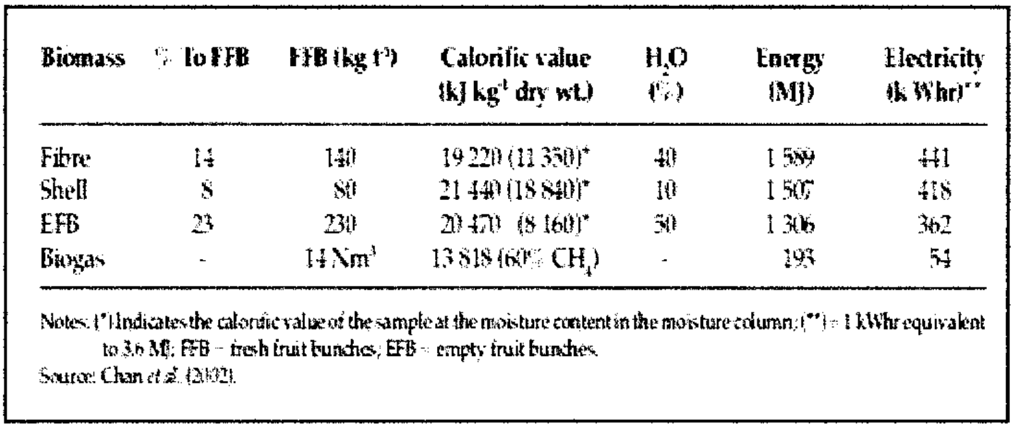
Oxygen	42.5
Calorific value^3, kJ/g-dry	18.5

Table 2: Chemical Composition of EFB (2001-2008)



Biomass	% To FFB	FFB (kg t^{-1})	Calorific value (kJ kg^{-1} dry wt.)	H_2O (%)	Energy (MJ)	Electricity (k Whr)**
Fibre	14	140	19 220 (11 350)*	40	1 589	441
Shell	8	80	21 440 (18 840)*	10	1 507	418
EFB	23	230	20 470 (8 160)*	50	1 306	362
Biogas	-	14 Nm^3	13 818 (60% CH_4)	-	193	54

Notes: (*) Indicates the calorific value of the sample at the moisture content in the moisture column; (**) = 1 kWhr equivalent to 3.6 MJ; FFB = fresh fruit bunches; EFB = empty fruit bunches.
Source: Chan *et al.* (2002).

Table 3: Chemical Composition of Palm Oil Waste
(Source: AIST – Advanced Industrial Science & Technology)

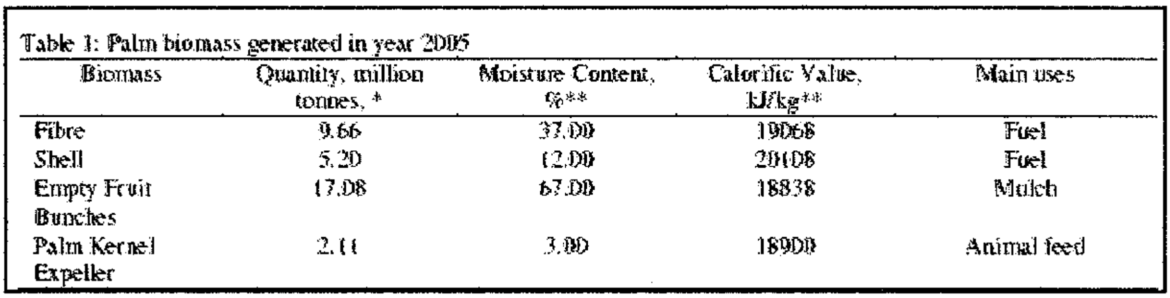


Table 1: Palm biomass generated in year 2005

Biomass	Quantity, million tonnes, *	Moisture Content, %**	Calorific Value, kJ/kg**	Main uses
Fibre	9.66	37.00	19068	Fuel
Shell	5.20	12.00	20108	Fuel
Empty Fruit Bunches	17.08	67.00	18838	Mulch
Palm Kernel Expeller	2.11	3.00	18900	Animal feed

Table 4: Chemical Composition of Palm Biomass Generated in Year 2005

(Source: AIST – Advanced Industrial Science & Technology)

Figure 4: Raw material used in this project- empty fruit bunch

CHAPTER 3

BIOMASS ENERGY CONVERSION

There are many different routes for converting biomass to bio-energy and industrial products, involving various biological, chemical, and thermal processes; the major routes are depicted in Figure 5. The conversion can either result in final products, or may provide building blocks for further processing. The routes are not always mutually exclusive, as there are some combinations of processes that can be considered as well. Furthermore, there are often multiple energy and non-energy products or services from a particular conversion route, some of which may or may not have reached commercial levels of supply and demand.

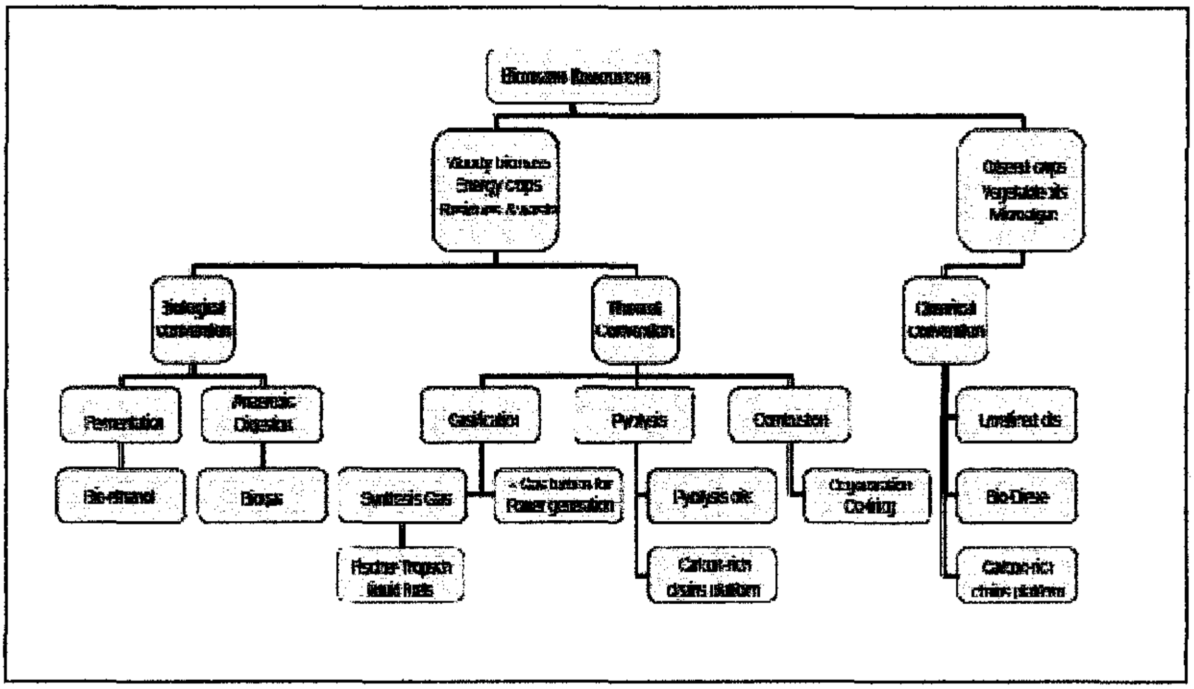


Figure 5: Conversion options for bioenergy and industrial biotechnology

(Source: Bioenergy and the Sustainability Transition, 2007)

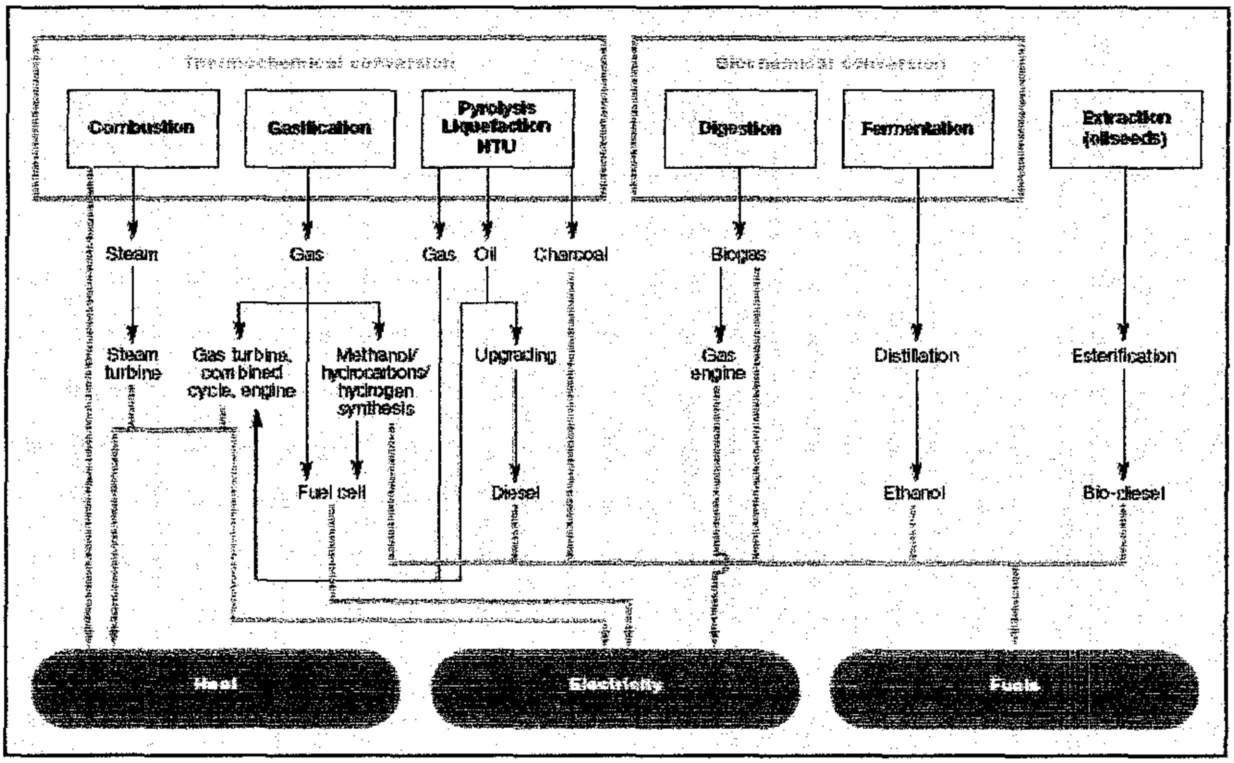


Figure 6: Main biomass energy conversion routes

(Source: Biofuels from lignocellulosic material, 2005)

3.1 Gasification in General

Biomass gasification means incomplete combustion of biomass resulting in production of combustible gases consisting of carbon monoxide (CO), hydrogen (H_2) and traces of methane (CH_4). Gasification is one of the newer technologies that are increasingly being used for waste disposal. It is a thermo-chemical process in which biomass is heated, in an oxygen deficient atmosphere to produce a low-energy gas containing hydrogen, carbon monoxide and methane. The gas can then be used as a fuel in a turbine or combustion engine to generate electricity. Gasifiers fuelled by fossil sources such as coal have been operating successfully for many years, but they are now increasingly being developed to accept more mixed fuels, including wastes. New gas clean-up technology ensures that the resulting gas is suitable to be burnt in a variety of gas engines, with a very favourable emissions profile. Gasifiers operate at a smaller scale than incineration plant, and can also be provided in modular form to suit a range of different scales of operation. A number of British companies are leading in this emerging technology.

Biomass fuels available for gasification include charcoal, wood and wood waste (branches, twigs, roots, bark, woodshavings and sawdust) as well as a multitude of agricultural residues (maize cobs, coconut shells, coconut husks, cereal straws, rice husks, etc.) and peat. Because those fuels differ greatly in their chemical, physical and morphological properties, they make different demands on the method of gasification and consequently require different reactor designs or even gasification technologies.

Gasification occurs in a number of sequential steps:

- Drying of fuel to evaporate moisture
- Pyrolysis – a process in which tar and other volatiles are driven off
- Gasification or partial oxidation of the solid char, pyrolysis tars and pyrolysis gases

The gasification experiment was successfully conducted using the circulating fluidized-bed (CFB) by Ahmad Hussain, Gas containing H2, CO and CH4 was produced with a heating value of 1000 kcal Nm-3 or more under proper conditions. The tar generation was low which may be due to quick heat decomposition of the EFB on the CFB. On the other hand, the generation of soot and char was high which may also be the cause of the low tar generation. The dependence of the emission quantity on the infurnace temperature and primary air flow was identified and relationships between them derived. By this research, we have examined the gasification/ combustion properties of palm shell waste powder which is found in abundance in Malaysia. Also fundamental data on gasification of palm shell waste has been obtained using a CFB.

3.2 Pyrolysis in General

Pyrolysis transforms hazardous organic materials into gaseous components, small quantities of liquid, and a solid residue (coke) containing fixed carbon and ash. Pyrolysis of organic materials produces combustible gases, including carbon monoxide, hydrogen and methane, and other hydrocarbons. If the off-gases are cooled, liquids condense producing an oil/tar residue and contaminated water. Pyrolysis typically occurs under pressure and at operating temperatures above 430 °C (800 °F).

In order to investigate the effect of pyrolysis temperature, particle size and heating rate on the yield of products with sweep gas flow rate of approximately 20 cm^3/ min, pyrolysis was performed by Farah Dila Mohd Laziz. The result shows that the moisture content (wet basis) of empty fruit bunch are 90.76% in the beginning of the drying (0 hour). On further drying, a gradual decrease in moisture content was observed till the end of the period. A rapid moisture loss during the initial stage of drying was observed for the first 5 hours for samples. Empty fruit bunch loss approximately 1.77% of its moisture during the first few hours. After 5 hours, the rate of moisture loss became slower. Thermo gravimetric analysis of oil palm empty fruit bunches shows significant influence in pyrolysis temperature, particle size and heating rate. The pyrolytic oil was identified and presented as a bio-fuel candidate. The liquid product may be used as a source of low-grade fuel directly, or it may be upgraded to higher quality liquid fuels

3.3 Torrefaction

Torrefaction is a feasible method for improvement the properties of biomass as a fuel . It consists of a slow heating of biomass in an inert atmosphere to a maximum temperature of 300 °C. The treatment yields a solid uniform product with lower moisture content and higher energy content compared to those in the initial biomass. The process may be called mild pyrolysis, with removal of smoke producing compounds and formation of solid product, retaining approximately 70% of the initial weight and 90% of the original energy content.

The torrefied biomass has the following properties:

- Hydrophobic nature: the material does not regain humidity in storage and therefore unlike wood and charcoal, it is stable and with well defined composition.
- Lower moisture content and higher calorific values compared to biomass
- Formation of less smoke when burnt.
- Higher density and similar mechanical strength compared to the initial biomass
- Desired form
- Suitable for various applications as a fuel - in the steel industry, combustion and gasification.

Two of the most important parameters in evaluating torrefaction are the mass and energy yield of the process. When looking at the macro composition of biomass, it can be expressed in terms of loosely bound water, organics and ash. The organic part of the biomass contains all the (reactive) chemical energy and during torrefaction part of this energy is removed in the form of reaction products. Therefore, from a fundamental point of view, it is best to express the mass and energy yield on a dry and ash-free basis.

It is also fan effective method to improve the grindability of biomass to enable more efficient co-firing in existing power stations or entrained-flow gasification for the production of chemicals and transportation fuels. According to Uslu et. al., (2005), it is a thermal pre-treatment technology carried out at atmospheric pressure in the absence of oxygen. It occurs at temperatures between 200-300 degrees C where a solid uniform product is produced. This product has very low moisture content and a high calorific value compared to fresh biomass.

3.3.1 Torrefaction principles

Torrefaction is carried out at temperature ranging from 200-300 C at a near-atmospheric pressure. Its main characteristics are the absence of oxygen and low particle heating rate (<50 degrees C/min). The process will partially decompose the biomass, giving off various volatiles. This will result n loss of mass and chemical energy, especially in the gasesous phase (Bergman & Kiel, 2005).

The thermochemical process of torrefaction is actually an interaction of a drying process and an incomplete pyrolysis process, and is characterized by the following parameters.

- ✓ Reaction temperature 200-300°C
- ✓ Heating rate < 50°C/min
- ✓ Absence of oxygen (to avoid oxidation and ignition)
- ✓ Residence time < 30min at T > 200°C
- ✓ Ambient pressure
- ✓ Flexible feedstock

Bergman et.al (2005) discussed the importance of the definition of reaction time Since biomass needs to be heated through several stages before the real torrefaction region is reached, the residence time of solids is never equal to the time that the biomass particles are exposed to torrefaction. The definitions provided by Bergman et.al (2005) have been used as a basis to further define the temperature-time stages in torrefaction. This takes into account the changes in moisture content, mass loss and required heat duties of these stages. Figure 7 illustrates these temperature-time stages for torrefaction process. Five main stages have been defined:

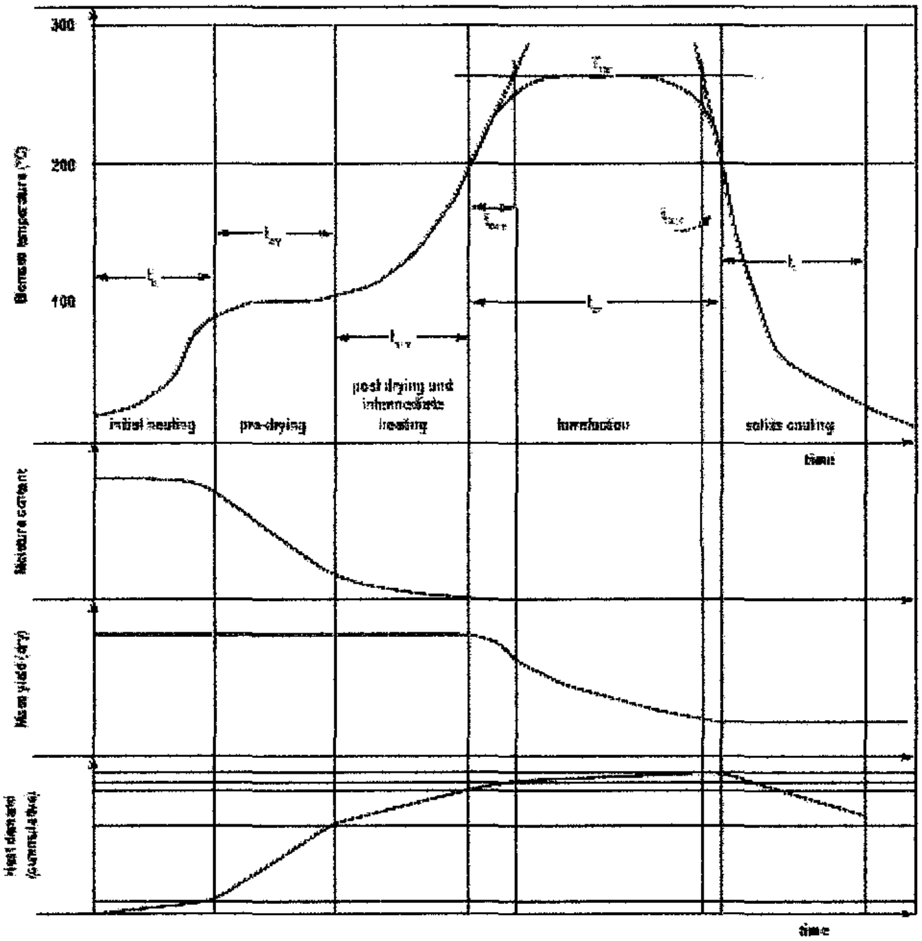


Figure 7: Stages in the heating of moist biomass from 'ambient' temperature to the desired torrefaction temperature and the subsequent cooling of the torrefied product (Source: Bergman et al, 2005).

t_h = heating time to drying,

t_{dry} = drying time,

$t_{h,int}$ = intermediate heating time from drying to torrefaction,

t_{tor} = reaction time at desired torrefaction temperature,

$t_{tor,h}$ = heating time torrefaction from 200°C to desired torrefaction temperature (t_{tor}),

t_{tor} ,c = cooling time from the desired t_{tor} to 200 °C,

tc = cooling time to ambient temperature.

i. Initial heading

The biomass is initially heated until the stage of drying of the biomass is reched. In this stage, the temperature of the biomass is increased while at the end of this stage moisture starts to evaporate.

ii. Pre-drying

Free water is evaporated from the biomass at constant rate. Its temperature remains practically constant until the critical moisture content is reached and the rate of water evaporation starts to decrease.

iii. Post-drying and intermediate heating

The temperature of the biomass is increased to 200°C. Physically bound water is released while the resistance against mass and heat transfer is within the biomass particles. The biomass is practically free of moisture after this stage. Although not shown during this stage some mass loss can be expected as light organic compounds can evaporate.

iv. Torrefaction

During this stage, the biomass is actually torrefied. This stage is entered as soon as the temperature exceeds 200°C and is ends as soon the temperature becomes below 200°C again. The stage of torrefaction is contains a heating period and a cooling period besides a period of constant temperature. The torrefaction temperature is this constant temperature which may also be a peak temperature. Devolatilisation (mass loss) starts during the heating period, continues during the period of constant temperature and stops during or after the period of cooling.

v. Solids-cooling

The solid product is further cooled from 200°C to the desired final temperature. During this period no further mass release occurs but some evaporation of adsorbed reaction products may occur.

From the Figure 7, it can be concluded that the largest heat duty is encountered during the drying of the biomass. However depends on the initial moisture content so that the stage of drying may not be present for seriously dry biomass. The second-largest heat duty is encountered during the post-drying and intermediate heating and the smallest heat duty is concerned with torrefaction itself. The required heat during the period of constant torrefaction temperature reflects the endothermic nature of decomposition reactions. However, it can also be a cooling duty as torrefaction can be exothermic as well. This depends on the type of biomass and the decomposition region.

3.3.2 Torrefaction product classification

Depending on the torrefaction conditions and the biomass properties, torrefaction products can be classified as solid, liquid and gas at room temperature. The solid phase, so called torrefied biomass, consists of original sugar structures and the reaction products, which are modified sugar structures, newly formed polymeric structures, char and ash fractions. The gas phase consists of mainly CO, CO_2, and traces of H_2, CH_4 and light aromatic components. And in the liquid phase; H_2O from biomass thermal decomposition, organics from devolatilisation and carbonisation and lipids consist. Nonetheless, torrefaction conditions, reaction time and torrefaction temperature are fairly important in product specification (Bergman et al, 2005).

Torrefied products can substitute charcoal in a number of applications:

- Fuel for domestic cooking stoves. Torrefied wood kindles very quickly, which makes the stoves management much more simple and flexible compared to wood and particularly charcoal.
- Fuel for residential heating.
- Raw material for manufacture of improved solid fuel products such as fuel pellets, compacted fireplace logs and barbecue briquettes for commercial and domestic uses. Torrefied briquettes have superior combustion characteristic as compared with ordinary briquettes.

- Fuel for industrial uses. Important advantage of torrefied wood compared to wood is its uniformity. It is as a predictable, flexible fuel with optimum combustion and transport economies. Due to the low moisture content of torrefied wood the transport cost is lower and the quality as a fuel better. It is easily packaged and transported, and thus constitutes an efficient fuel.
- With a 30-35% fixed carbon content, torrefied wood has a promising potential as a reducer.
- Torrefied biomass can be blended with coal and co-fired in a Pulverized Coal Boiler.
- The properties of torrefied biomass should lead to an improved operation in gasifiers for which the stability of the process is important.

3.3.3 Related Researches Done

According to R.Zanzi et.al, torrefied products can substitute charcoal in a number of applications such as fuel for domestic cooking stoves, residential heating, and manufacture of improved solid fuel products such as fuel pellets, compacted fireplace logs and barbecue briquettes for commercial and domestic uses. Torrefied biomass can be also used as fuel for industrial applications. With a 30-35% fixed carbon content, torrefied wood has a promising potential as a reducer. Torrefied biomass can be blended with coal and co-fired in a Pulverized Coal Boiler (PBC). Important advantage of torrefied wood compared to untreated wood is its uniformity. Due to the low moisture content of torrefied wood the transport cost is lower and the quality as a fuel better. It is easily packaged and transported, and thus constitutes an efficient fuel. The properties of torrefied biomass should lead to an improved operation in gasifiers for which the stability of the process is important.

Based on Ayla Uslu(2005), torrefaction technology is not commercially available yet. However, torrefaction history dates back to the late 1980's when the upgrading of wood and briquettes by means of torrefaction was investigated at the Asian Institute of Technology, Bangkok, Thailand. Another study was held in Brazil. The Grupo Combustíveis Alternativos (GCA) at the University of Campinas in Brazil used a bench unit for biomass torrefaction (Bioenergy, 2002). Those studies provided information about the product quality. The only commercially applied torrefaction plant, PECHINEY, was built up in 1980s in France.

Several torrefaction experiments using wood briquettes were performed by Felix Fonseca Felfli, Carlos Alberto Luengo and Jose Antonio Suárez and Pedro Anibal Beatón. In this process the biomass hemicellulose is degraded, maintaining its cellulose and lignin content [Bourgeois, 1984; Doat, 1985]. In this manner, briquettes are converted into a more stable product with higher energy content. The torrefied briquettes weight yield lies between 43 and 94 %, and energy yields ranged from 50 to 97 % depending on the operating parameters. After torrefaction the briquettes showed an increase of approximately 15 % in heating value, and a decrease of approximately 73 % in equilibrium moisture. It was shown that torrefied briquettes achieved hydrophobic character and remained unaffected when immersed in water. This research also provides information on proximate and elemental analysis, showing that temperature has more influence than residence time. The aforementioned data indicate that torrefaction is a feasible alternative to improve energy properties of ordinary briquettes and prevent moisture absorption during storage

This led to the idea of applying torrefaction as a biomass pretreatment step. Torrefaction is a thermal treatment at a temperature of 200 to 300°C, at near atmospheric pressure and in the absence of oxygen. This mild thermal treatment not only destructs the fibrous structure and tenacity of the biomass (wood), but is also known to increase the calorific value and to invert the hydrophilic nature. During the process, the biomass partly devolatilises which leads to a decrease in mass, but the initial energy content of the biomass is mainly preserved in the solid product (fuel). The latter is of great importance to the overall energy efficiency of the biomass-to-biosyngasconversion chain.

CHAPTER 4

METHODOLOGY/ PROJECT WORK

The project is divided into 3 steps which are sample pretreatment step, sample analysis step, and experimental procedure by Fix Bed Activation Unit (FBAU). Raw material and product sample will be analyzed by using few types of equipment such as bomb calorimeter, Halogen Moisture Analyzer (HMA) and CHNS analyzer. Apart from that, some proximate analysis needs to be carried out to analyze the volatility matter, fixed carbon content and also ash content of the products using Thermal Gravimetric Analyzer (TGA).

4.1 Sample Pretreatment

Methodology

1. Empty fruit bunch fibers were separated from the bunch by cutting the fiber with knife.
2. Then, EFB fibers were washed to separate the sample from physical impurities and volatile component.
3. The sample is heated inside a heater at a temperature of 100°C for 24hours to remove water content inside the sample and weighted regularly to determine the moisture content of the sample after being heated for few hours. The temperature of drying process is control in the range of 110°C to 120°C to avoid damaging the sample.
4. Step 3 is repeated until the weight of the sample is constant. If the weight is not constant after 24hours, the sample has to continue undergone the drying process. This is done in order to make sure all the moisture content is dried out.
5. Samples were then ground and sieved using sieve shaker ranging from 125μm to 500μm and screened into fraction.
6. The various particle sizes of empty fruit bunch were recorded and grouped into 3 groups.
7. Treated empty fruit bunch will then stored in air tight containers such as desiccators to maintain low moisture content of the samples.

4.2 Ultimate Analysis

The ultimate analysis is done on the solid to know the component content within the biomass sample (empty fruit bunch) in terms 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. The result of the ultimate analysis is shown in Table 5.

4.3 Moisture Content Analysis

The analysis on the moisture content of three different sample sizes was carried out for 15 minutes by using HR73 Halogen Moisture Analyzer. Good product is determined by having low moisture content.

4.4 Calorific Value Analysis

The calorific 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. For this study, empty fruit bunch gross calorific values were determined by using Bomb Calorimeter instead of using Dulong formula:

$$Q_{GCV}\ (\mathrm{MJ/kg}) = 33.83C + 144.3\left(\frac{H - O}{8}\right)$$

Where:

C: mass fraction of carbon
H: mass fraction of hydrogen
O: mass fraction of oxygen

The result of the calorific value of EFB is shown in Table 8.

4.5 Experiment by using Fixed Bed Activation Unit (FBAU)

Methodology

1. Three samples with different particular size are weighted and put in a crucibles.
2. The reactor outlet is 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 and homogenous burning.
4. The reactor outlet tube 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 indicating that these valves are opened.
8. Valve 2, 3 and 4 on the panel remain closed by switching off the buttons.
9. Nitrogen gas flow is controlled at 0.3ml/min by using flow meter controller attached to the panel.
10. Once the nitrogen flow is stable, the reaction temperature is set to 250°C.
11. The reaction will take place at different reaction time which is 1.5 hours and 3 hours with different temperature which is 250°C and 280°C.
12. Step 11 and 12 are repeated with different temperature and reaction time.
13. Once the reaction has reached its desired reaction time, the sample is pinched down to the room temperature. The cooling process takes about 4 to 5hours.

14. After the temperature has cooled down, the reactor outlet tube is untied and the product from the reactor outlet is collected.
15. The product is weighted to determine the weight loss of the sample.

4.6 Proximate Analysis by using Thermo Gravimetric Analyzer (TGA)

The proximate analysis is often used to determine the amounts of volatile material, ash and fixed carbon in the biomass. The ash content is important for the heating value, as heating value decreases with increasing ash content.

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:

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

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.

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

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 reference base.

Methodology

1. TGA is weighted before the experiment. Weight is denoted as W_1
2. 10 mg of EFB sample is placed into the sample pan.
3. Sample is heated from 50°C to 800°C under sweeping gas rate of $40 cm^3/min$.
4. The aqueous and oil phases is separated and weighted and gas yield is calculated from material balance
5. Percentage of torrefaction yield, char yield, oil yield, gas yield and collected water is determined.
6. Torrified solid formed is collected on steel wool and were held torrefaction temp until no 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.

CHAPTER 5

RESULTS & DISCUSSION

5.1 Ultimate Analysis

Ultimate Analysis of Empty Fruit Bunch (EFB)				
Particle size (μm)	C (%)	H (%)	N (%)	S (%)
125	44.15	6.909	1.647	0.571
250	43.80	6.693	1.331	0.571
500	44.17	6.605	1.141	0.144

Table 5: Carbon, Hydrogen, Nitrogen and Sulphur content in Empty Fruit Bunch

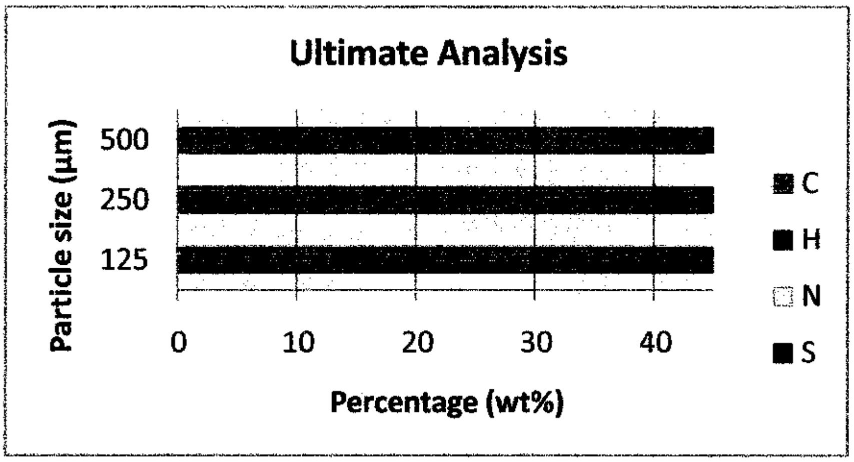


Figure 8: Carbon, Hydrogen, Nitrogen and Sulphur content in EFB

Based on the results, all samples have the highest initial carbon content prior to the torrefaction process. Almost the particle sizes of EFB are having same percentage of carbon, hydrogen, nitrogen and sulphur component because the same raw material (empty fruit bunch) is used. In order to investigate the effect of torrefaction on the component of empty fruit bunch in terms of fixed carbon content, further analysis will be conducted on the torrefied product by using Thermogravimetric Analyzer (TGA).

According to Tharatron Kongkeaw and Suthum Patumsawad, the content of carbon in the solid product increases at higher temperature of the torrefaction and longer residence time while the content of hydrogen and oxygen decrease, increasing the calorific value of the torrefied biomass. The content of CH_4, H_2, C_xH_y, and CO in the product gases increases when the temperature is increased while the content of CO_2 decreases.

5.2 Moisture Content Analysis

In order to investigate the effect of particle size, reaction time and temperature on the moisture content of empty fruit bunch, some analyses have been conducted on the raw material and torrefied EFB which having different particle sizes, reaction time and temperature. The same analysis steps are repeated for 3 times for each 15 minutes to get an accurate percentage of moisture content.

Moisture Content (%)					
Particle size (μm)	Initial (Raw material)	250°C at 1.5 hours	250°C at 3 hours	280°C at 1.5 hours	280°C at 3 hours
125	96.35	91.20	91.77	89.96	92.81
250	96.75	92.99	92.43	92.19	94.12
500	96.62	93.47	90.89	90.52	93.40

Table 6: Moisture Content of EFB Before and After Torrefaction

Moisture Content (%)					
Particle size (μm)	Initial	1.5 hours		3 hours	
		250°C	280°C	250°C	280°C
125	96.35	5.35	6.63	4.75	3.67
250	96.75	3.89	4.71	4.47	2.72
500	96.62	3.26	6.31	5.93	3.33

Table 7: Percentage of Moisture Content Reduction of EFB After Torrefaction

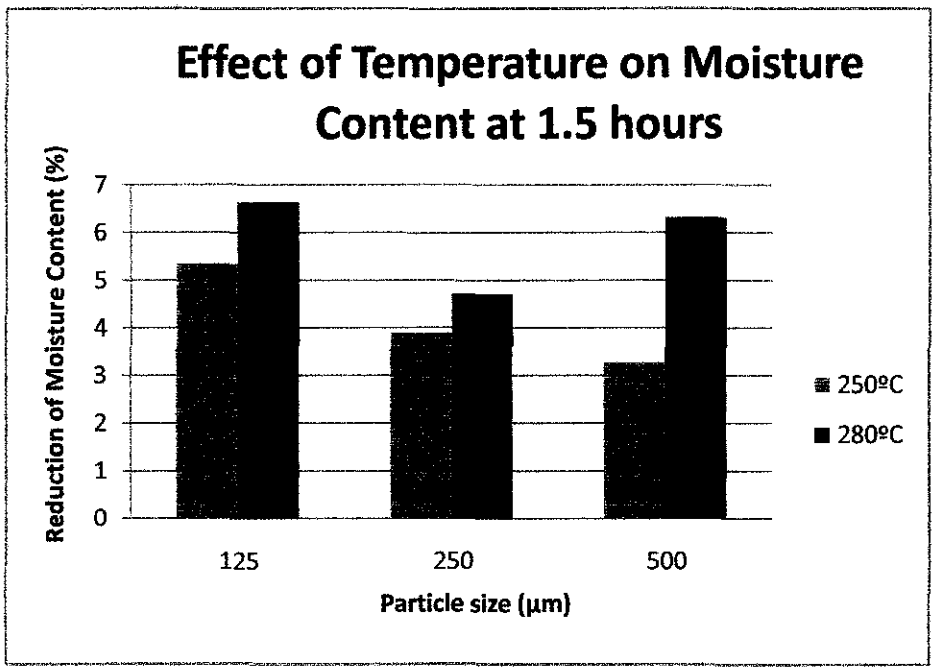


Figure 9: Effect of Temperature on Moisture Content at 1.5 hours

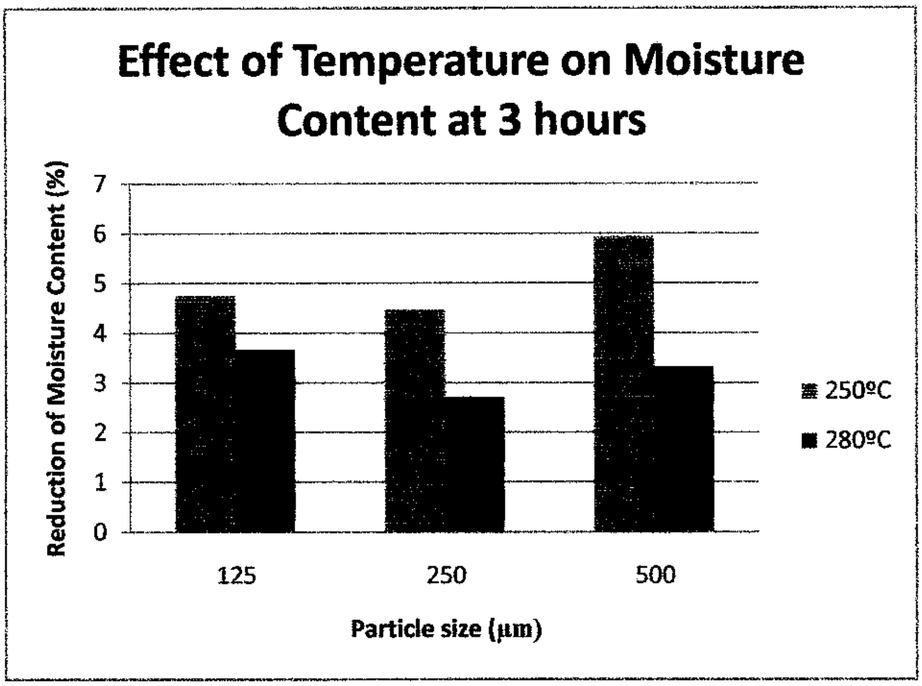


Figure 10: Effect of Temperature on Moisture Content at 3 hours

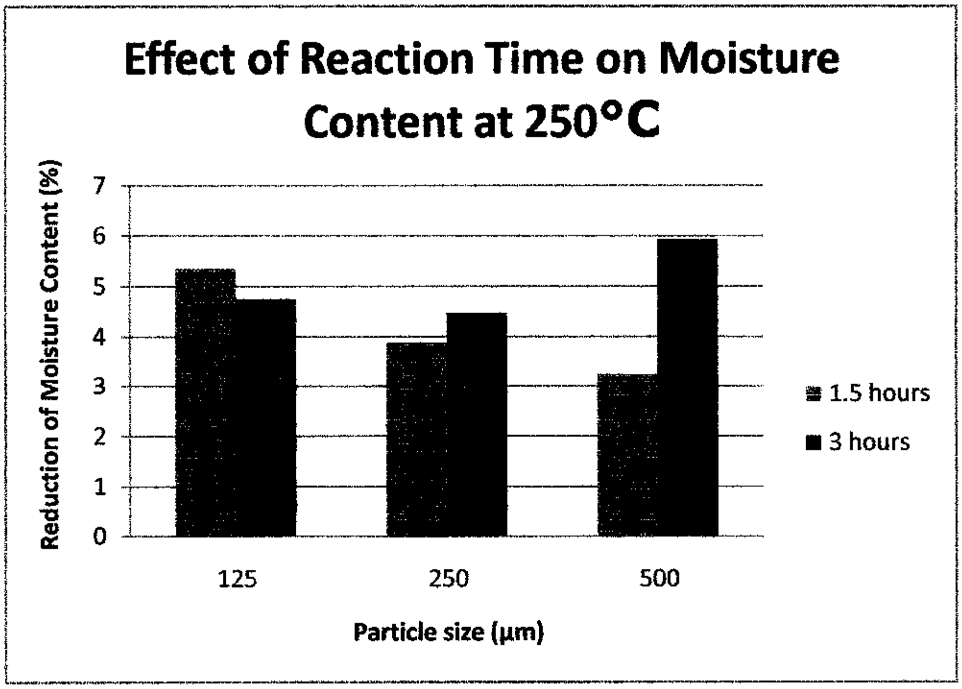


Figure 11: Effect of Reaction Time on Moisture Content at 250°C

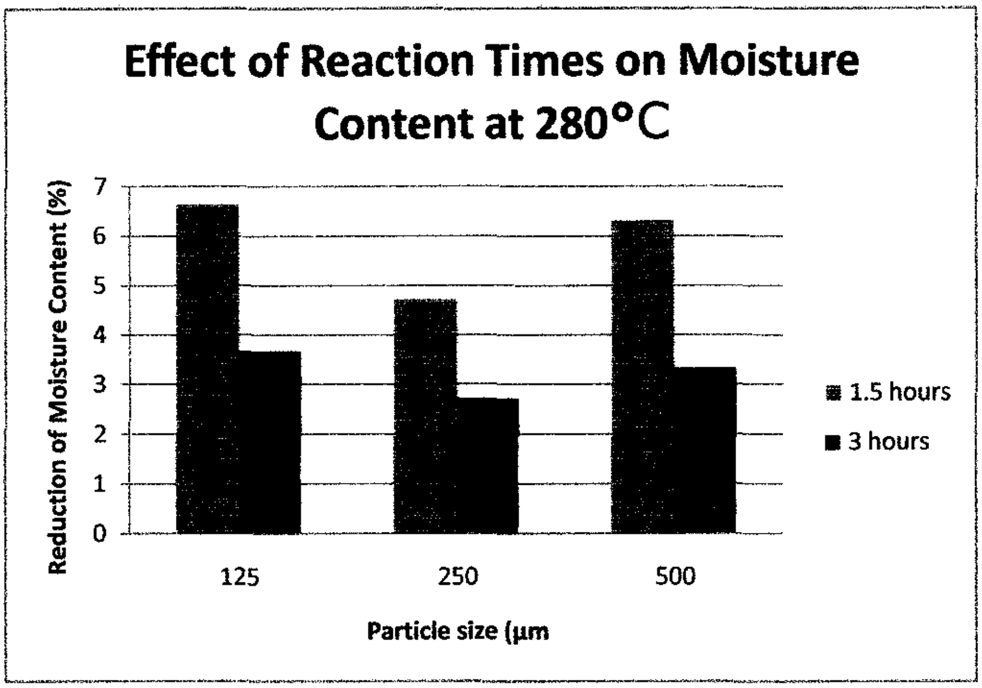


Figure 12: Effect of Reaction Time on Moisture Content at 280°C

From the Table 6, it can be observed that empty fruit bunch with particle size of 125 µm has the lowest moisture content (89.96%) after undergoing torrefaction at 280°C within 1.5hours meaning that its moisture content can be reduced as high as 6.63%. It also can be observed that moisture content of empty fruit bunch with the largest size of 500 µm was reduced to as high as 5.93% after being heated at 250 °C within 3 hours. By this observation, it can be concluded that biomass sample was lost most of the moisture content during the torrefaction.

The torrefaction process aims at a hydrophobic product, which prevents it from regaining humidity from the air during storage. Table 6 shows the amount of moisture in the torrefied samples after being torrefied for 1.5 hour and 3 hour at different temperature. The result shows that the product has absorbed small amounts of moisture; however the moisture content is much less compared to the content of moisture of the raw material (approx. 5%).

According to Bergman et. al. (2005), biomass is completely dried during torrefaction and after torrefaction the uptake of moisture is very limited. Depending on the torrefaction conditions which vary from 1-6% wt. The main explanation for this is that by the destruction of many OH groups in the biomass through dehydration reactions, torrefied biomass has lost the capability to form hydrogen bonds with water. In addition, more unsaturated structures are formed which are non-polar and hence it has become hydrophobic to a certain extend. It is likely that this property is also the main reason that torrefied biomass is practically preserved and rotting, which is often observed for untreated biomass, does not occur anymore.

5.3 Calorific Value Analysis

Calorific value of Empty Fruit Bunch (J/g)					
Particle size (μm)	Initial (J/g)	250°C		280°C	
		1.5 hours	3 hours	1.5 hours	3 hours
125	17784	19410	19223	18153	18473
250	17875	18668	21849	21884	19397
500	17292	17954	20636	17749	21847

Table 8: Calorific Value of Empty Fruit Bunch

From the Table 8 and 9, it is showed that calorific value increasing after undergoing different temperature which is 250°C and 280°C, reaction time which is 1.5and 3hours.

Particle size (μm)	Initial (J/g)	250°C		280°C	
		1.5 hours	3 hours	1.5 hours	3 hours
125	17784	9.14	8.09	2.07	3.87
250	17875	4.44	22.23	22.43	8.51
500	17292	3.83	19.34	2.64	26.34

Table 9: Percentage of Calorific Value at Different Reaction Time on 250°C

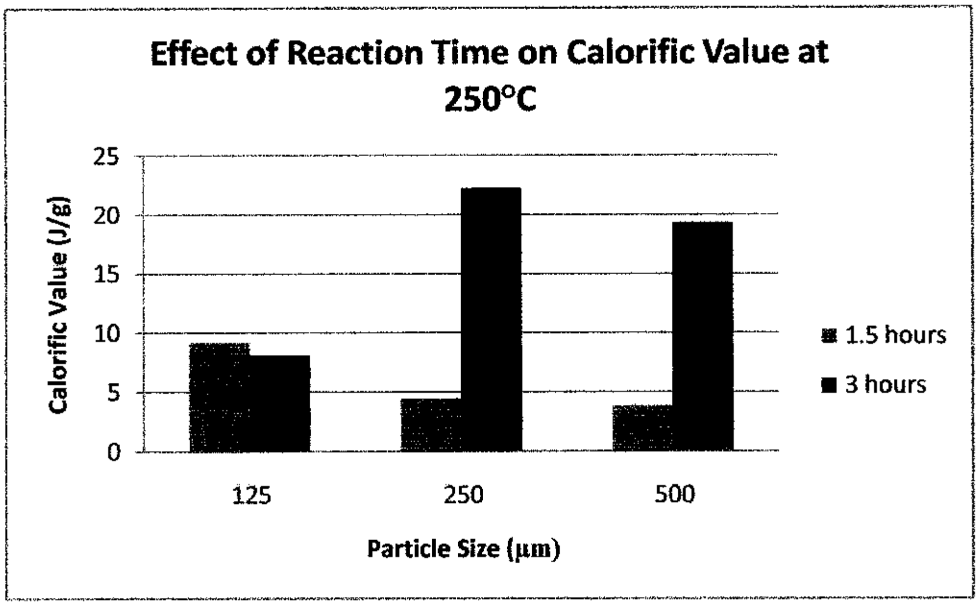


Figure 13: Effect of Reaction Time on Calorific Value of EFB at 250°C

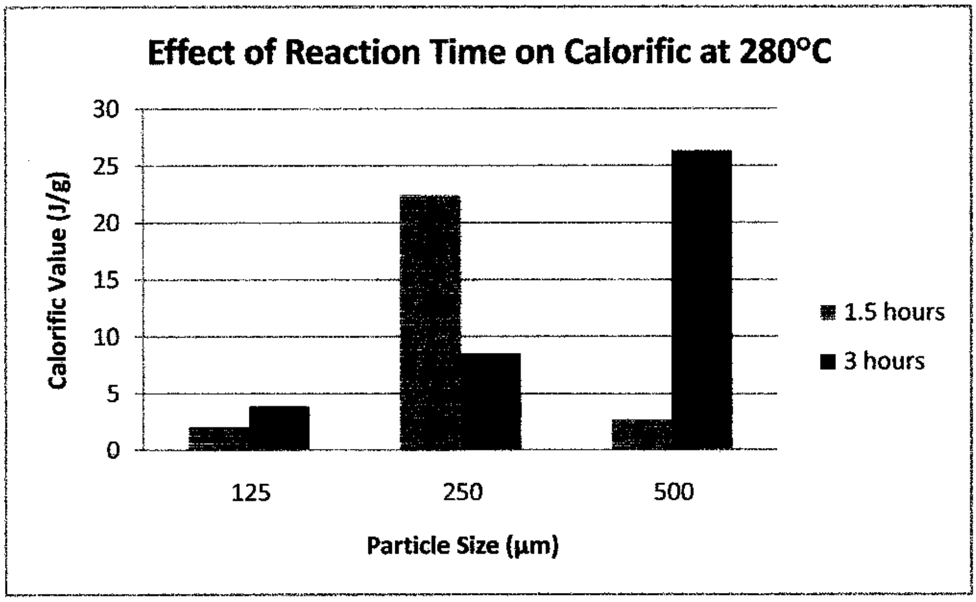


Figure 14: Effect of Reaction Time on Calorific Value of EFB at 280°C

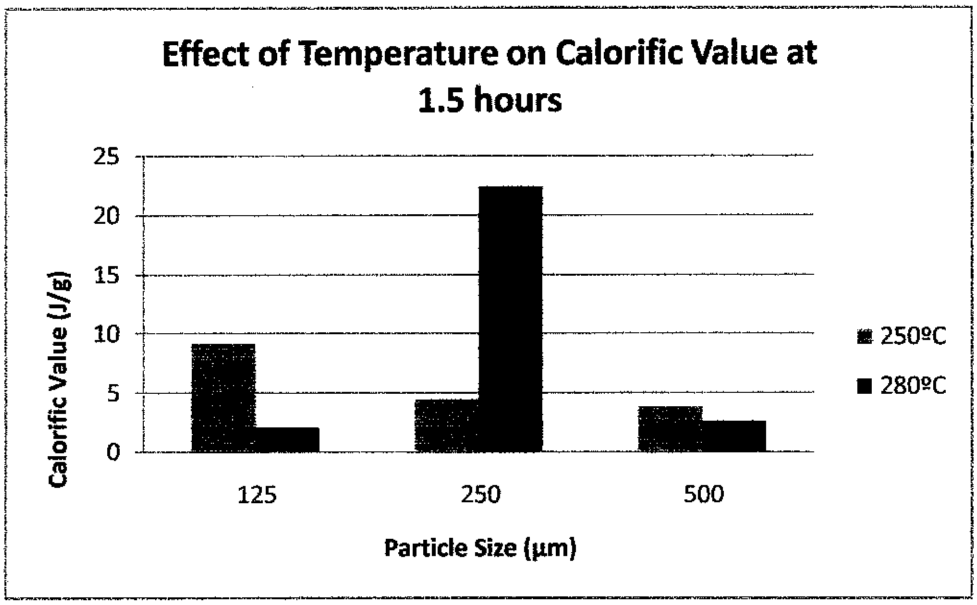


Figure 15: Effect of Temperature on Calorific Value of EFB at 1.5hours

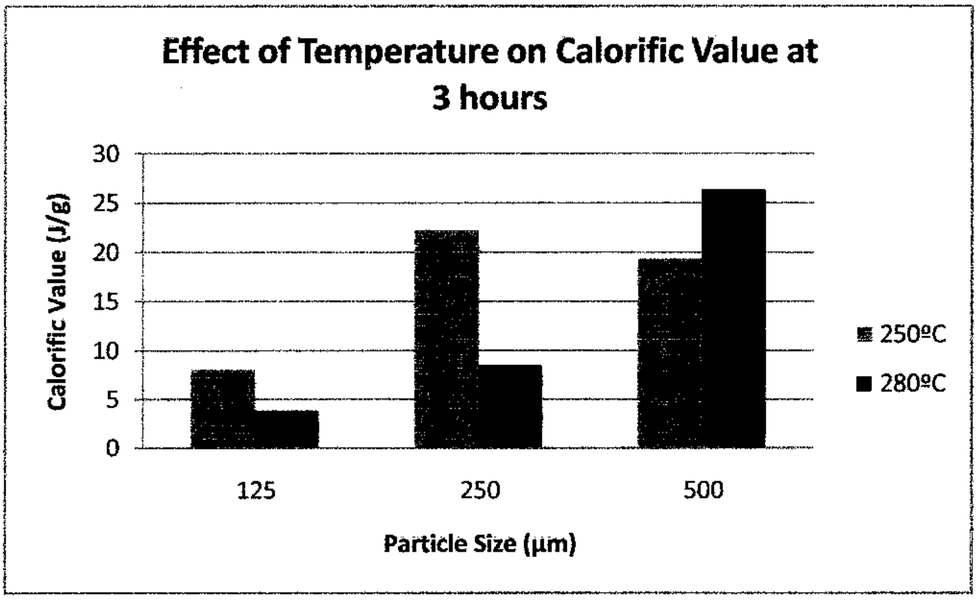


Figure 16: Effect of Temperature on Calorific Value of EFB at 3hours

The calorific value of biomass sample for torrefied material before and after torrefaction process is indicated in Table 8. Based on the results, in comparison of initial calorific value of different particle size of biomass sample, 250μm has the highest value which is 17875 J/g, followed by 17784 J/g being the second highest, and the lowest is 17292 J/g. However, the calorific value will be varied after torrefaction takes place. Therefore, further analysis has been done on the torrified products which having different temperature and reaction time. It clearly shows that the torrefaction process led to an increment in calorific value of the biomass samples by up to 26.34%. The quite high calorific value of empty fruit bunch shows the potentiality of it as biofuel. Thus, the calorific value (CV) of the solid product increases with the temperature. More significant effect on the CV is observed at temperatures 280°C. Also when the reaction time was increased, the CV was higher. According to R. Zanzi et al, it is said that content of carbon increase the calorific value of the torrified biomass.

Depending upon the temperature and reaction time, the calorific value can be chosen. In general, the longer the reaction time, the higher the caloric value, but also the more mass of the raw material is converted. Generally, the higher the caloric value of the raw material, the less mass is desirably lost. It advantageously appears that especially EFB material as starting material is relatively easily and homogeneously torrefied.

5.4 Product Yield Analysis

The collected torrefied solid product was weighed and characterized. The influence of the experimental conditions (temperature, reaction time and particle size) on the product distribution and on the properties of the products was studied. The experimental procedure repeated for four times by changing temperature (250°C- 280°C) and reaction time (1.5- 3hours). Weight loss of the sample determined once the product is collected from the FBAU to obtain a product yield.

Run	Temperature (°C)	Reaction Time (hour)	Particular size (μm)	$Mass_{before}$ (g)	$Mass_{after}$ (g)	Product Yield ($Mass_{before}$ - $Mass_{after}$/ $Mass_{before}$)x100%
1	250	1.5	500	6.0	5.1532	14.11
			250	6.0	5.4453	9.25
			125	3.0	2.8276	2.87
2	250	3	500	6.0	5.8775	2.04
			250	4.0	3.3615	15.96
			125	4.0	3.5808	10.48
3	280	1.5	500	3.0	1.5970	46.77
			250	3.0	1.5030	49.90
			125	2.0	1.8534	7.33
4	280	3	500	2.5	1.6194	35.22
			250	2.5	1.8108	27.57
			125	2.5	2.3128	7.49

Table 10: Product Yield of Torrefied Empty Fruit Bunch after Being Heated

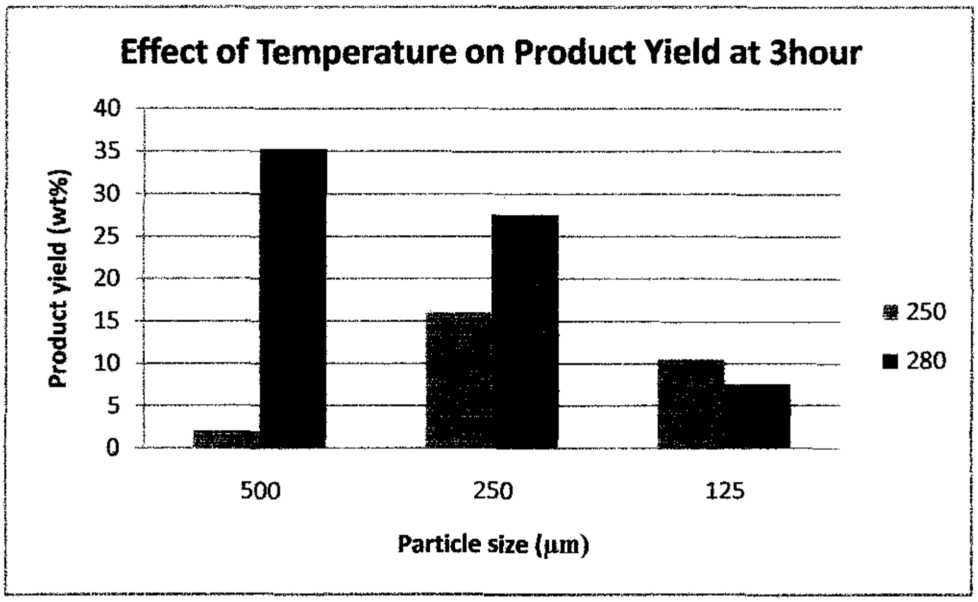


Figure 16: Effect of Temperature on Product Yield at 3hour

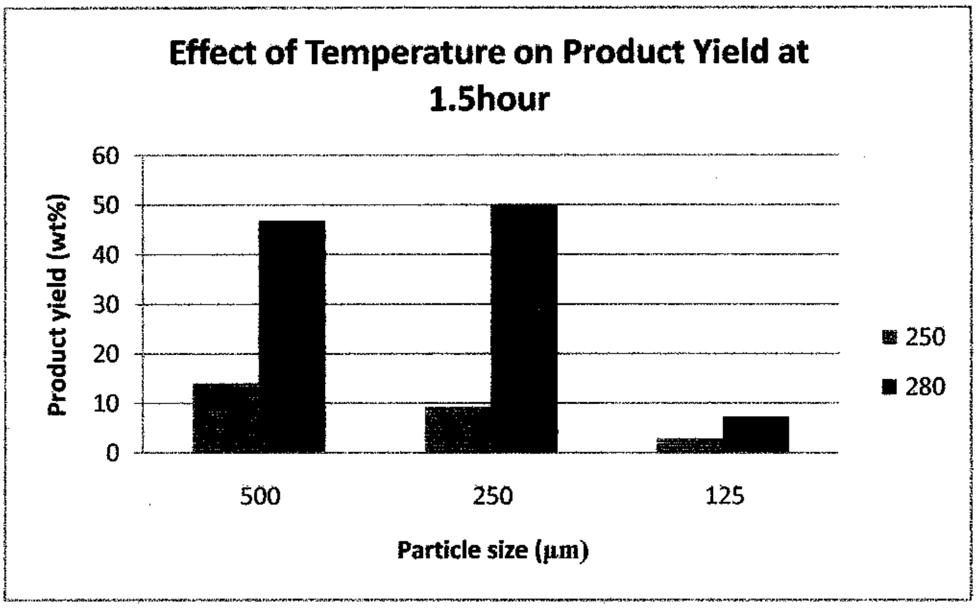


Figure 17: Effect of Temperature on Product Yield at 1.5hour

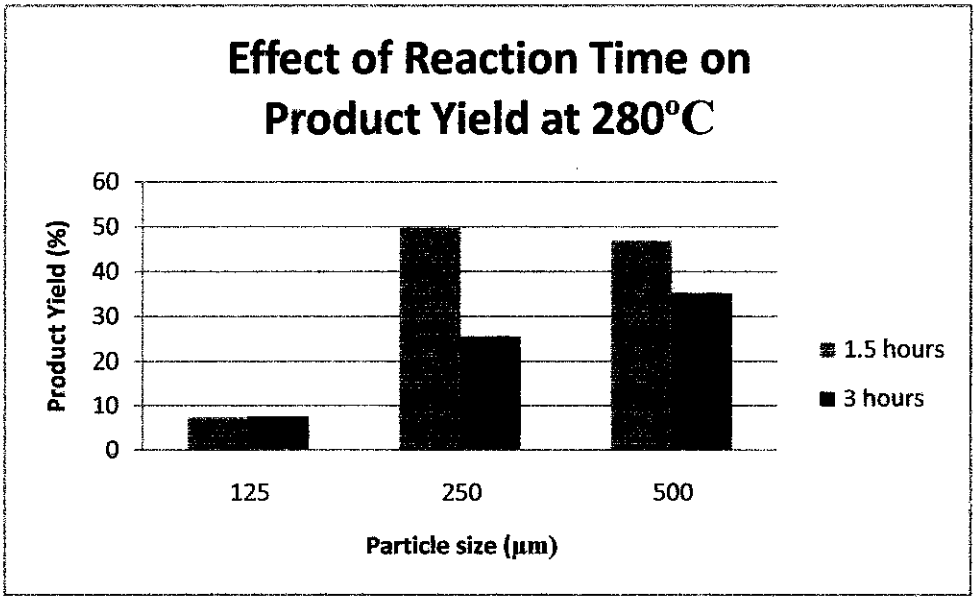


Figure 18: Effect of Reaction Time on Product Yield at 280°C

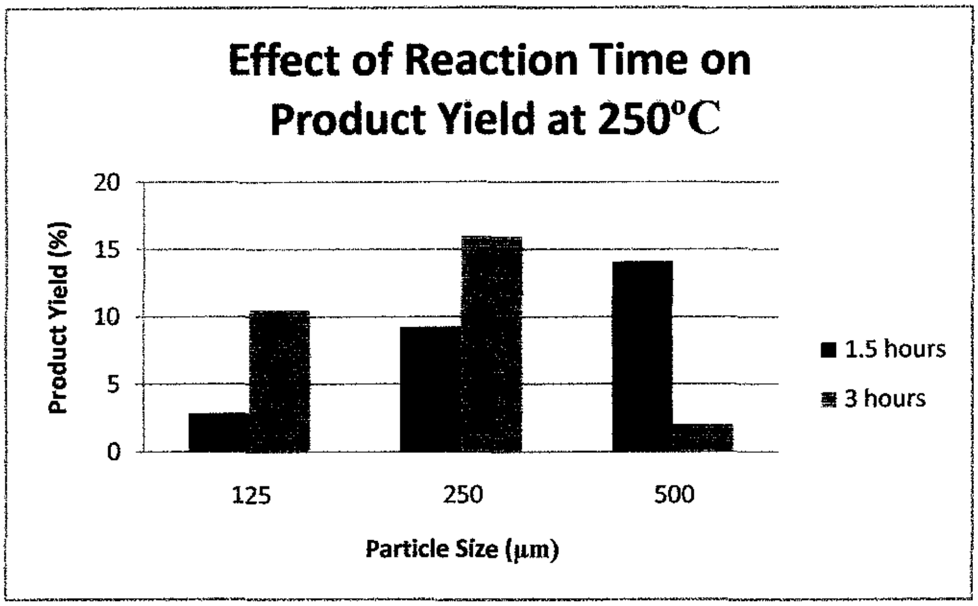


Figure 19: Effect of Temperature on Product Yield at 250°C

Based on Table 10, the product yield reached a maximum value of 49.9 wt% of initial biomass with a highest temperature of 280 °C. The lowest product yields were obtained at the temperature of 250 °C (2.04 wt% of initial biomass).

Based on the Figure 16 and Figure 17, an increment of the particle size of EFB and temperature has reducing the yield of products until 7.33- 7.49%. From the Figure 18, it was observed that as the particle size increased, product yield was increased as well. It is assumed that as the size of particle increased, there was lesser surface area for evaporation of water. This is expected since as time goes by within 1.5hour, there are still more water evaporated leaving behind the solids. Thus, the greater the particle size was, the longer time and the more heat was required to convert the raw materials to the torrefied materials. From the Figure 19, an increment of the duration of the heating at 250°C from 1.5 hours to 3 hours results also decreasing the yield of torrefied products.

According to Pentananunt et al. (1990), during the torrefaction process, the biomass partly devolatilises which leads to a decrease in mass, but the initial energy content of the biomass is mainly preserved in the solid product (char).

Based on the previous experiment that has been done by Felfli et.al, (2005), it has been shown that the composition of torrefied briquettes at 220°C does not undergo many changes. However, at higher temperatures, changes in the composition are perceptible, with the briquette hemicellulose practically degraded and cellulose depolymerization process initiated. Residence time did not affect the final composition of torrefied briquettes much, no matter what the temperature at which they are treated. For this reason, we can conclude that torrefaction temperature (TT) has a greater effect on the torrefied briquettes than residence time (RT).

According to Tharatron Kongkeaw and Suthum Patumsawad, during torrefaction process, biomass undergoes changes in physical and chemical properties. The yield of solid product decreases while the yield of gas, tar and water increases with the temperature and the residence time. It was not found a strong influence of the inert gas flow on the product distribution at the selected conditions.

CHAPTER 6

CONCLUSION

Biomass has some disadvantages as fuel (low calorific value, high moisture content, hygroscopic nature, smoking during combustion). Torrefaction is a feasible method for improvement the properties of biomass as a fuel. In this study, torrefaction experiment of empty fruit bunch was performed in a fixed bed activation unit (FBAU). The highest product yield of 49.9% was obtained at an optimum temperature of 280°C with particle size of 125μm and the reaction time of 3hours. The higher treatment temperature has led to higher product yields. The highest calorific value of the torrefied product obtained was 21849 J/g. Further proximate analysis have to be carried out to analyze the volatile matter, fixed carbon content and also ash content of the products using Thermal Gravimetric Analyzer (TGA).

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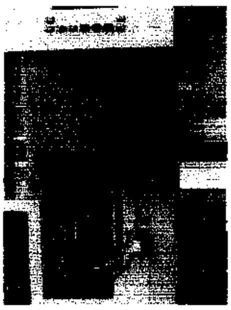
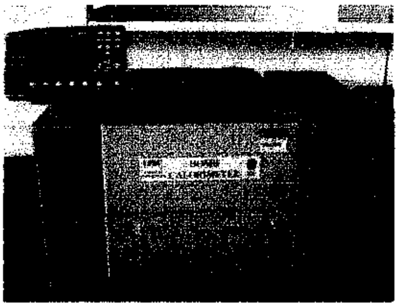
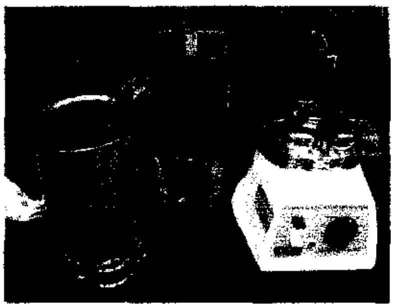
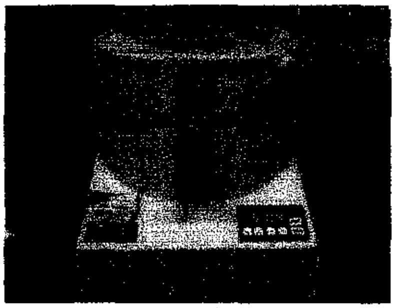
Project Activities	January 09		February 09		March 09		April 09		May 09		June 09	
Investigate properties of raw material				▨								
Conduct feasibility study on conventional method												
Conduct experiment of torrefaction process				▨	▨							
Analyze the products from torrefaction						▨	▨					
Submission of progress report I			▨									
Submission of progress report II							▨					
Poster exhibition								▨				
Submission of dissertation report									▨			
Oral Presentation												▨

APPENDIX B

List of equipments used in analysis of raw material, char and product

Equipment	Description
 Thermo gravimetric analyzer (TGA)	▪ Determined weight loss ▪ Determined degradation temperature ▪ Sample weight :10-20 mg ▪ N_2 flow rate : 20 ml/min ▪ Location : 17-02-08 ▪ Supplier : Perkin Elmer
 Bomb Calorimeter  Crucible, thread, bomb	▪ Calculate calorific value of liquid, char and sample ▪ Location : 04-02-09
 CHNS	▪ Measure nitrogen, carbon, hydrogen and sulfur ▪ Location : 05-00-01

Equipment	Description
 Blender  Grinder	▪ Blend the sample into smaller particles ▪ Location : 05-00-13
 Sieve Shaker	▪ To separate the sample into different particle size ▪ Location : 05-00-13

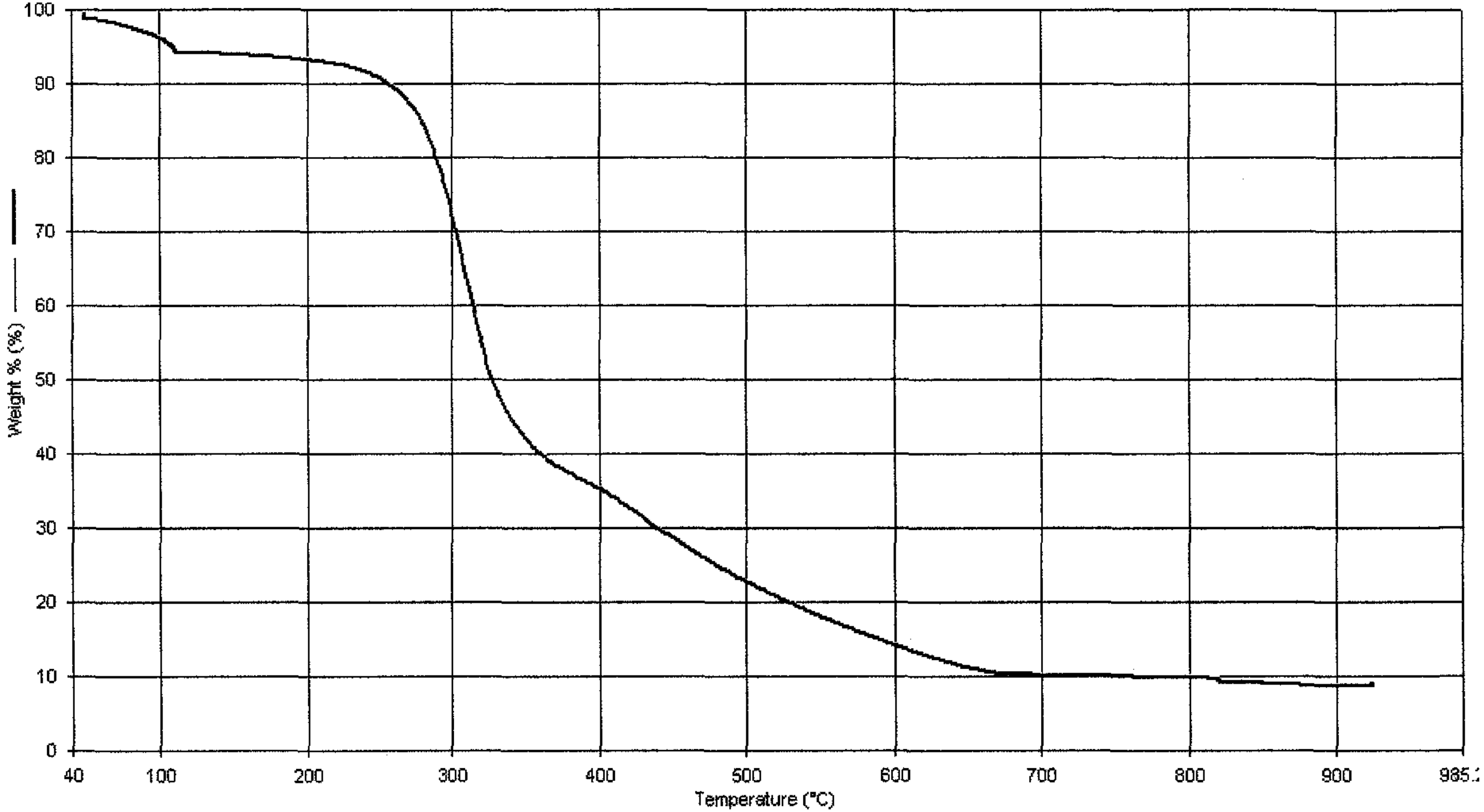


Figure 20: Weight % versus Temperature for EFB sample (125 µm)

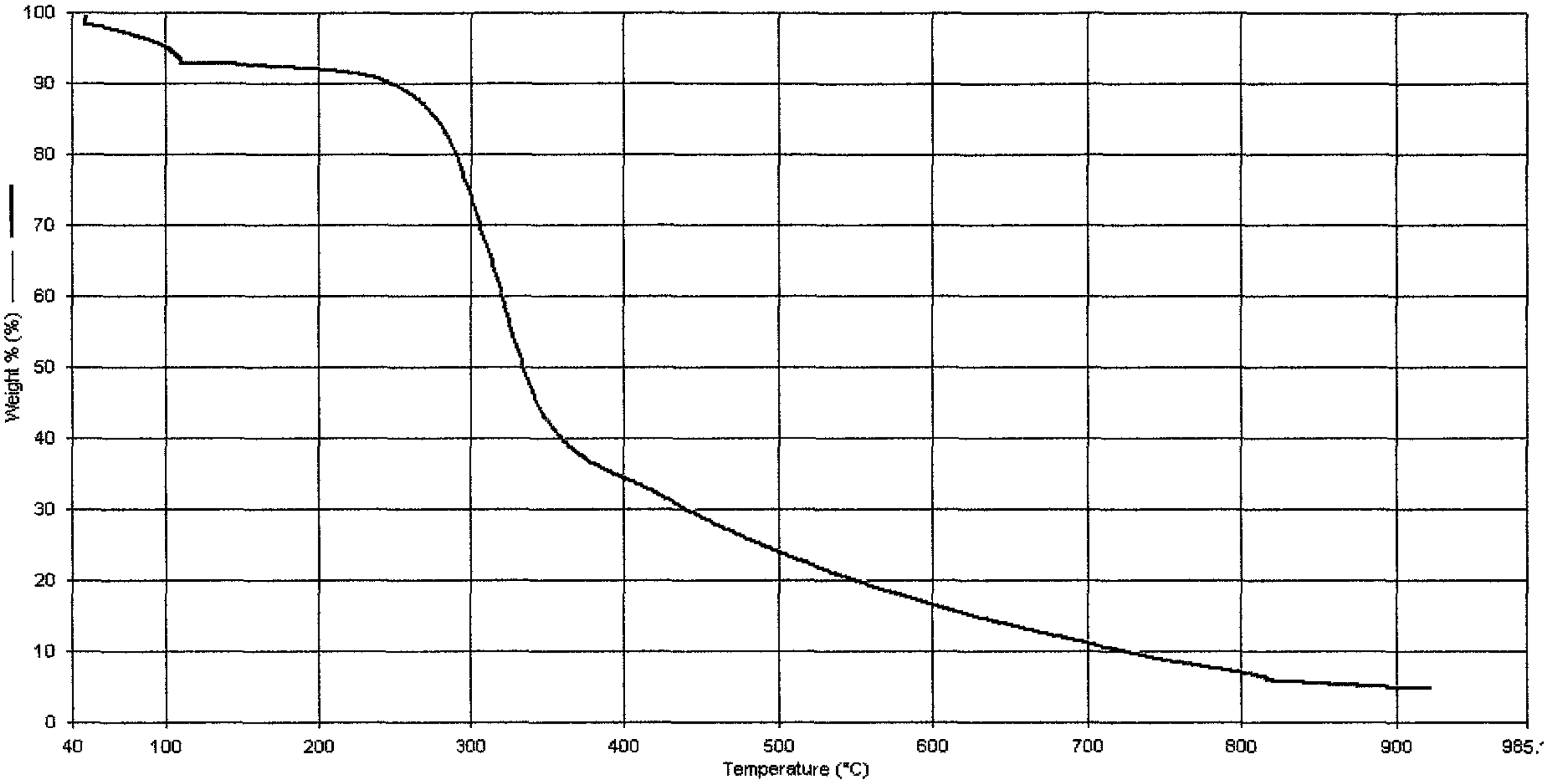


Figure 21: Weight % versus Temperature for EFB sample (250 µm)