Torrefaction of Oil Palm Empty Fruit Bunch into Value-Added Solid Fuel

By

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Dissertation submitted in partial fulfilment of

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Approved by,

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September 2011

CERTIFICATE OF ORIGINALITY

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

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(OMAR BIN NOR AZMI)

ABSTRACT

Dependence on fossil fuel as the main energy source has led to various negative impact upon human and environment. Uncontrolled use of fossil fuel leads to emission of greenhouse gases which later caused problems such as global warming and acid rain. Instable price of fossil fuel also caused variety of problems to daily life of human. Malaysia is well known as among world largest exporter of palm oil products; therefore providing us with abundant source of palm oil wastes. These bio wastes are highly potential as a replacement for the current fossil fuel; one of it is palm oil empty fruit bunch (POEFB). However, POEFB has inferior quality as a reliable solid fuel. The qualities of concern are energy content and resistance toward degradation. Torrefaction has been identified as a suitable pre-treatment process to increase the qualities of untreated POEFB. Torrefaction is mild pyrolysis process under low oxygen condition to imitate decomposition of long hydrocarbon process in POEFB. By manipulating the residence time and operating temperature for the process, an improvement can be made on the final desired product. This study investigated the effect of the parameters i.e. at 240°C, 260°C and 280°C for 30 minutes, 60 minutes and 90 minutes on the characteristics of the solid product. The final product was characterized using Carbon, Hydrogen, Nitrogen and Sulphur (CHNS) analyzer, bomb calorific analyzer and Thermo-gravimetric analyzer (TGA).

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TABLE OF CONTENTS

TABLE OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Shortage of Fossil Fuel and Its Environmental Impacts

Dependence on fossil fuels as the main energy source has led to a global energy crisis with depleting fossil fuel supply and intense discussion on its impact on the environment. Developed countries has long started research to find an alternative to the current fossil fuel; Japan with nuclear power plant in Fukushima and Europe with advance research on biomass manipulation. With current estimation of world crude oil reservoirs available, major oil exporter like United Arab Emirates (UAE) will fail to meet the global demand by 2042. Instable fuel price has exerted negative effect on daily basic needs prices (Ling 2008).

The combustion of fossil fuels mainly from vehicles and industrial plants produced greenhouse and toxic gases; carbon monoxide, sulphur dioxide and other pollutant that contributed significantly to the Greenhouse effect and which in turn caused the global warming problem and extreme weather today. In author's opinion, with the burst of technological breakthrough, greater needs for energy will speed up the exhaustion of fossil fuel and increase the echelon of pollution.

1.2 Biomass as Alternative Fuel Source

There is an abundant amount of palm oil waste in Malaysia. Statistically Malaysia produce around 25 million tonnes of palm oil waste and 10 million tonnes are empty fruit bunches (POEFB) (Mokanatas 2010).

Palm oil waste has been identified as highly potential replacement for solid fuel for its renewability and its abundant amount. It is also considered as natural carbon fuel since the combustion produces carbon dioxide which is an integral part of the natural carbon cycle. However raw and untreated waste is very low in calorific value as compared to coal and is also not very suitable for transportations and logistics purposes (Arias 2007). It also decomposes and degrades which further reduces the calorific value of the fuel.

Therefore torrefaction process is introduced to improve these qualities for commercial use.

1.3 Pre-Treatment Process of Biomass

New discoveries and technologies have allowed researchers and inventors to explore new field of energy sources; nuclear and natural resources. In Europe, research on torrefaction has started nearly a decade ago pioneered by Netherland specifically Energy research Centre of the Netherlands (ECN). Their research focuses mainly on biomass available in Europe such as Willow tree, Oak tree and logging activity wastes. The project has led to the finding of better renewable solid fuel to be used as co-firing agents in energy plants.

These researches conducted have proved that torrefaction is indeed successful in converting raw biomass into comparable alternative solid fuel to coal (Arias 2007). The basic principle of torrefaction is slow and mild heating of biomass to induce release of trapped sync gases such as methane and carbon dioxide and chemically decompose cellulosic bonds leaving only C-C stable bonds which will produce a coal-like fuel. Prior to torrefaction process, POEFB is dried first to remove external moisture inside it to increase the efficiency of the process (Boerrigter 2006).

As a result of torrefaction process, significant reduction in mass and energy is observed. The trade off between energy loss and increase in energy density is observed. POEFB can also be improved physically by improving their grindability for logistic purposes.

1.4 Problem Statement

The qualities of biomass that we seek to improve are:

- Low calorific value
- Degradation
- High bulk volume
- Fibrous

However, there are no previous research found that documented the effect of changing the operating conditions of torrefaction process on the qualities above specifically on Malaysian Palm Oil Empty Fruit Bunch (POEFB). There was also no definite optimum operating range for torrefaction process to produce the best torrefied product from POEFB. These problems have intrigued the author to perform a research that can benefit the environment and the palm oil industry in Malaysia.

1.5 Objectives

The objective of this project is to:

i. To analyze and characterize the chemical and physical properties of Malaysian Palm Oil Empty Fruit Bunch (POEFB).

ii. To profile the effect of changing parameters of torrefaction on the solid fuel characteristics.

1.6 Scope of Studies

The characterization of biomass and the solid product was conducted via:

- Proximate analysis.
- Ultimate analysis.
- Bomb calorimetric test.
- Thermogravimetric analysis.

These tests were conducted on biomass before and after the torrefaction to determine the optimum operating condition that can produce the best treated solid fuel. The torrefaction process was conducted at mild temperature between 200°C and 300°C and residence time between 30 minutes and 90 minutes (Boerrigter 2006).

CHAPTER 2

LITERATURE REVIEW

2.1 Palm Oil Empty Fruit Bunch (POEFB)

Empty fruit bunches from palm oil has recently been identified as possible source of renewable energy through process of torrefaction because of its availability and logistic reasons. According to Malaysia Palm Oil board official website, production of palm oil products are around 4,500,000 tonnes in 2009 and it continues to increase (Malaysia Oil Palm Board 2009). Currently, raw POEFB is used as composting material for plantation soil and also as fuel for the palm oil processing plant. Empty fruit bunch consist of three main structure; hemicelluloses, lignocelluloses and celluloses with decreasing reactivity (Bergman 2005). Generally the composition is 45-50% cellulose and about equal amount (25-35%) of hemicelluloses and lignin. Characteristically POEFB is clean, biodegradable and has high level of moisture and residue oil content (Suhaimi 2001). Therefore, they need to be processed first before being introduced as a practical energy source.

2.1.1 Water/Volatile Matter Content

Water content in empty fruit bunch is approximated around 5-10% and volatiles such as methane and ethane accounts to almost 70-80% of total weight. This analysis was based on the proximate analysis of Oil Palm waste from Malaysia (Hussain 2006; Yan 2006). The presence of water content; intrinsic and extrinsic contributed to the hygroscopic character of empty fruit bunches. During drying phase and torrefaction process, the removal of water content reversed their characteristic from hygroscopic to hydrophobic to slow down degradation process. Removal of volatile matters is the main contributor of energy content reduction. Usually the volatiles released during the process are captured and synthesised. Initially the weight loss is contributed by release of intrinsic moisture and decomposition of some reactive hemicelluloses. At higher residence time, less reactive hemicelluloses decompose forming gases such as ethane and methane as proven by experiment using Eucalyptus (Arias 2007). By increasing the temperature and residence time of torrefaction process, the percentage of moisture and volatile matter inside the POEFB sample decreases. However, the percentage of ash and fixed carbon increases with increasing temperature and residence time.

2.1.2 Heating Value

The yield of mass and energy of empty fruit bunch after torrefaction is highly dependent on temperature and residence time used during the process. Mass and energy yield is typically around 0.8 and 0.9 respectively, meaning that energy densification is observed as depicted by research by B. Arias. With increasing temperature and residence time, the mass and heating value yield decreases and most significantly at the time range of 0 to 30 minutes and high temperature 280°C. At the end of the experiment conducted, the calculated mass yield is found lower than the heating value yield proving the energy densification concept earlier. Depending on the torrefaction condition, Lower Heating Value (LHV) of biomass can be increase from 17-19 MJ/kg to 20-23 MJ/kg (Bergman 2005).

High temperature reduces heating value yield significantly (Arias 2007). At higher temperature, the energy loss is compensated by the improvement of physical properties such as grindability.

2.1.3 Grindability

Due to the fibrous nature of the raw empty fruit bunch, it is hard to grind them into smaller size. As torrefaction process proceeds, empty fruit bunch loses its fibrous nature due to the decomposition of long carbon chain. Its particles become more spherical by decreasing their length but not the width. As temperature and residence time increase, the particle size reduces proportionally (Arias 2007). With the reduction of size, problem with handleability and poor flow properties of the empty fruit bunch was solved. With torrefaction, energy consumption by the cutting mill is reduced by 70-90% thus increasing its capacity by 7.7-15 times. Energy Centre of Netherlands (ECN) also developed a technology called Torrefaction and Pelletisation (TOP) which produce biomass in energy dense pellet containing up to 15-18.5 GJ/m^3 (Bergman 2005).

2.2 Torrefaction Process

Torrefaction is a pre-treatment of biomass carried out at specific temperature in the absence of oxygen, atmospheric condition and low particle heating. Torrefaction is different from drying in the sense that drying is done with the presence of oxygen and combustion is possible. However, drying is also essential in removing moisture content to improve the efficiency of torrefaction process. The product of torrefaction is biomass with improved chemical and physical properties.

Torrefaction yield is highly influenced by its operating condition; temperature, residence time, inert rate and heating rate. These conditions in actuality affect the process of devolatilization and decomposition of trapped volatile matters and long carbon chains. The greater the energy being supplied to the mass, the more chemical reactions takes place. However, different biomass has different composition of celluloses; therefore different operating conditions will yield the best product. The product will be improved in areas such as calorific value, grindability and chemical resistance towards degradation.

Torrefaction is usually done in furnaces with inert gas supplies attached to their main chamber. Sample of dried product is placed inside the main chamber and heated according to the operating condition. Inert gas is constantly supplied throughout the process to main low oxygen condition. In this project, a simple tube furnace is used.

The reactions happening during torrefaction process are devolatilization and decomposition of large polymeric chain which contributed to the loss of mass and improvement of grindability.

2.2.1 Reactions

At the temperature of 400°C and below, dehydration is the main reaction that can be observed. This was concluded from the result of ultimate analysis of Oil Palm Kernel Shell (PKS) sample where oxygen percentage reduced dramatically in 300-400°C temperature interval and then remained fairly constant afterwards (Yan 2006). Reduction of moisture results in reversal of character from hygroscopic to hydrophobic, improving empty fruit bunch resistance to degradation. Above 400°C, decomposition of polymeric chain and weak alkyl bonds; decarbonylation and decarboxylation reaction takes place. Formation of light volatile such as methane, hydrogen and carbon dioxide was observed by the increase of these species in the gas product analysis with increasing temperature from 400°C to 800°C. Formation of carbon dioxide and carbon monoxide decreases with increasing temperature. However starting from 800°C all gas species percentage remain constants towards 1000°C. With the decomposition of polymeric chain, empty fruit bunch restructured to a compound similar to coal or peat. The solid composition that remained contains the highest percentage of energy of around 80-90% of total energy content (Bergman 2005).

2.2.2 Parameter Effects and Analysis

In order to determine the efficiency of the torrefaction process, analyses were conducted to gauge the improvement of chemical and mechanical properties of the biomass. The basic analyses used by previous researchers like B. Arias, P.C.A. Bergman and H. Yan are proximate and ultimate analyses. These analysis determine the composition of the biomass where proximate analysis calculate the percentage of moisture, volatile, ash content and fixed carbon while ultimate analysis calculate the CHNSO composition. Significant reduction in oxygen and hydrogen composition was observed at higher temperature and residence time.

Calorific value or LHV of biomass is also commonly tested. By using bomb calorimeter device we can calculate the energy content of the biomass. A sample of around 5g torrefied mass is burnt in constant rate in bomb calorimeter to determine its energy content. Torrefied mass yields higher energy content per unit mass.

Lastly, grindability test was done by introducing biomass into a cutting mill and passing through set of sieves. Torrefied mass shows better result than raw biomass where higher percentage was recorded for smaller particle size.

2.3 Application of Torrefied Empty Fruit Bunch

The improved fuel quality of torrefied empty fruit bunch attracts application in combustion and gasification processes. However, the most promising application is the use of torrefied empty fruit bunch as co-fuel in coal-fired power stations and entrained flow gasification (Bergman 2005). These applications requires torrefied empty fruit bunch to be supplied in powder form and some costly adjustment needs to be added to the available plant in order to incorporate the usage of torrefied biomass.

CHAPTER 3

METHODOLOGY

The experiment was done to prepare samples of torrefied empty fruit bunch under different torrefaction parameters; temperature and residence time. Following the torrefaction process, analyses are done to investigate the properties of the product samples after the torrefaction process.

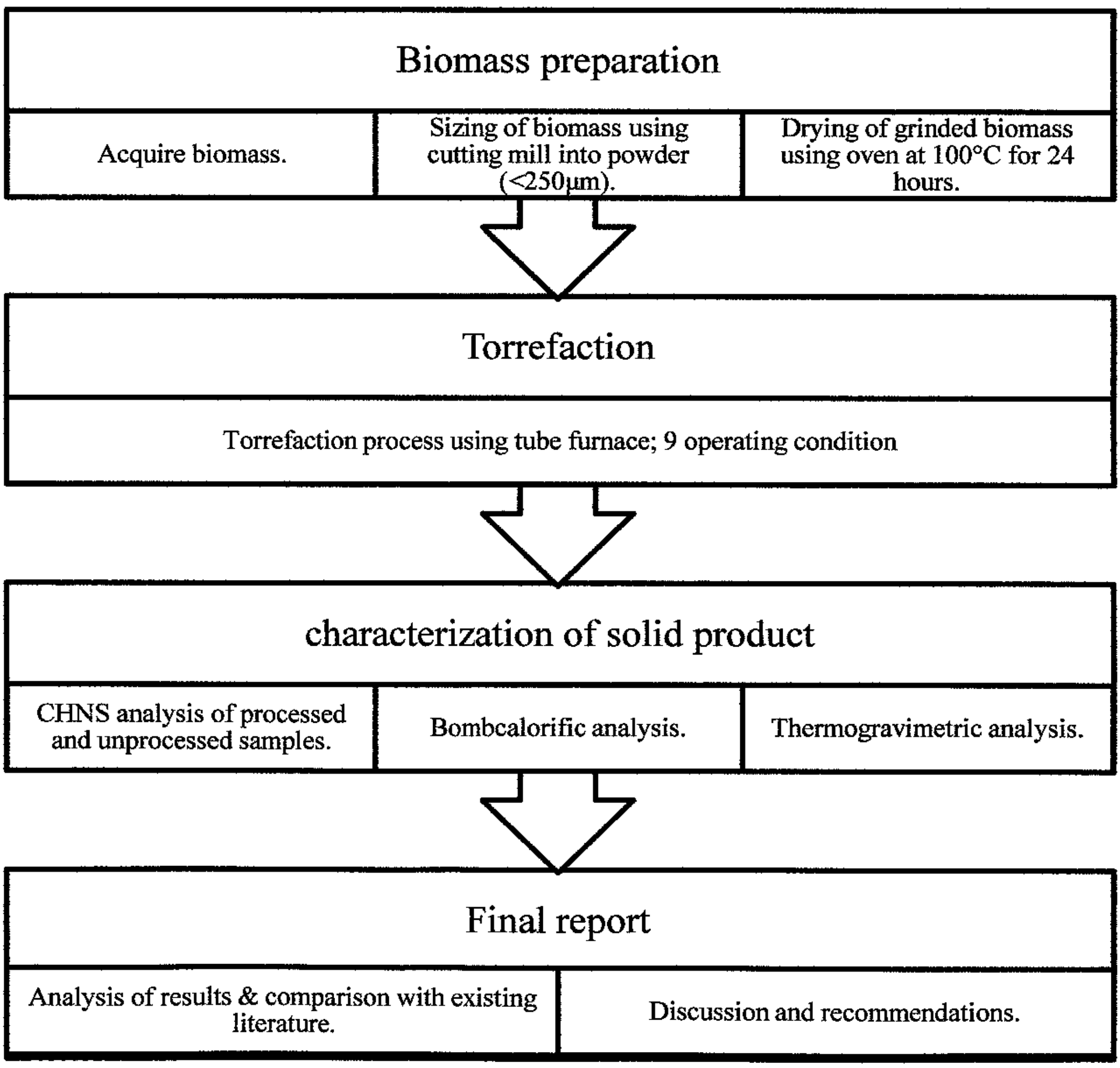

Figure 1 Project flow

3.1 General Methodology

Before torrefaction is done, the raw empty fruit bunch is prepared first. Raw EFB is first grinded into small dust approximately 250µm and smaller. Once the sample preparation is done, the dried empty fruit bunch underwent torrefaction process. Finally the torrefied products were tested with different analyzers; Carbon, Hydrogen, Nitrogen, Sulphur (CHNS) analyzer, Thermal Gravitational Analyzer (TGA) and Bomb Calorimeter Analyzer.

3.1.1 Sample Preparation

Drying of raw empty fruit bunch was done to remove extrinsic moisture content. Required apparatus are weighing apparatus, grinder, oven and large sample dish. This preparation process is in accordance to journal by B. Arias, 2007.

1. Raw empty fruit bunch was cleaned to remove physically visible impurities.
2. Cleaned empty fruit bunch was grounded into smaller particle size sample using grinder and sieved using a 250µm mesh.
3. Grinded empty fruit bunch was weighed and the weight was recorded.
4. Grinded empty fruit bunch was placed inside a big sample dish and dried inside the oven at temperature of 100°C with heating rate of 10°C/min for 24 hours.
5. After 24 hours, the oven was turned off and the dried sample was allowed to cool down to room temperature before being removed from the oven.
6. Dried empty fruit bunch was weighed again and the weight was recorded and compared with the pre-drying data.
7. Dried empty fruit bunch was stored inside a low humidity cabinet.

3.1.2 Torrefaction Process

Dried empty fruit bunch was torrefied inside tube furnace at predetermined conditions. The required apparatus are sample boat, tube furnace and weighing scale. This torrefaction procedure is as suggested by B. Arias, 2007 and parameters are as suggested by P.C.A. Bergman, 2005.

1. Dried empty fruit bunch was placed inside the sample boat and weighed. The weight was recorded.
2. The sample boat was positioned inside tube furnace combustion chamber and the chamber was sealed tightly.
3. The furnace was turned on.
4. Nitrogen flow was initiated from the nitrogen gas cylinder into the furnace chamber. 0.5L/min of nitrogen flow was maintained for 10 minutes.
5. The furnace target temperature was set to 240°C and temperature cut point at 10°C above the target temperature.
6. The residence time was set to 30 minutes.
7. Furnace heater was switched on along with the timer. During the experiment, the flow of nitrogen was maintained at 0.5L/min throughout.
8. Once the timer is up, the furnace was allowed to cool down to room temperature.
9. The product was removed and weighed. The data was compared with the pre-torrefaction data.
10. Step 1 to 9 was repeated for residence time of 60 minutes and 90 minutes.
11. Step 1 to 10 was repeated for temperature of 260°C and 280°C.

3.1.3 Proximate Analysis (TGA)

Proximate analysis is done to determine the composition of the sample; volatile matter, ash and fixed carbon content. The equipment required to do this analysis is Thermal Gravitational Analyzer (TGA). This methodology is as explained by the laboratory technician following the equipment manual.

1. Ceramic crucible is first calibrated in order to determine the zero weight.
2. 4.0 to 5.0 grams of sample is placed inside the crucible and placed inside the furnace chamber.
3. Nitrogen gas was flowed through the chamber continuously while the temperature inside the chamber was set to 50°C.

4. Once the weight of the sample has stabilized, the weight is set as the sample weight.
5. The temperature was increased from 50°C to 110°C with heating rate of 60°C/min.
6. The temperature was maintained at 110°C for 3 minutes.
7. The temperature was increased to 950°C with heating rate of 100°C/min.
8. The temperature was maintained at 950°C for 15 minutes and the nitrogen gas supplied was switched to oxygen gas simultaneously when the temperature reached 950°C.
9. The plot of Weight Percentage vs. Temperature was obtained and saved.
10. Moisture, volatile matter and ash contents were calculated by the software using data from the plot.

3.1.4 Ultimate Analysis (CHNS)

Ultimate analysis is done on empty fruit bunch to know the atomic composition of the samples in term of percentage. The analysis is done using Carbon, Hydrogen, Nitrogen and Sulphur (CHNS) analyzer. This methodology is as explained by the laboratory technician following the equipment manual.

1. Tin capsule was weighed and tare to zero.
2. Approximately 5 samples of 2 mg of standard were prepared.
3. Tin capsule was carefully folded and compressed while ensuring no tear and air bag observed at the tin capsule.
4. Step 1 to 3 was repeated for empty fruit bunch samples.
5. Prepared samples were placed into the slot inside the analyzer.
6. Weight of the samples were input into the analyzer (weight does not include tin capsule's).
7. Each run completed in 3 minutes.

Standard Operating Procedure (SOP)

1. Helium, oxygen and compressed air supply are set to 40 psi.

2. The ambient monitor was checked for proper values.
3. Carbon dioxide, hydrogen and sulphur IR were maintained between 7.5 to 9.2 volts.
4. The oxidation furnace temperature was set to 1000°C.
5. The reduction furnace temperature was set to 650°C.
6. Leak check was run if required.
7. 'Auto/Manual' switch was set to 'Auto' when using carousel or 'Manual' when samples were loaded individually.
8. Gas switch was set to analyse position.
9. Once furnace temperature is stable, blank analysis on standard samples was done followed by the empty fruit bunch samples.

3.1.5 Calorific Value Analysis (Bomb Calorimeter)

In order to determine the energy content and densification of energy per unit mass, Bomb Calorimeter analyzer was used. This methodology is as explained by the laboratory technician following the equipment manual.

1. Equipment was switched on. Oxygen tank was fully opened. Tank pressure indicator was maintained at 30 kg/cm^2.
2. The water level inside the equipment was maintained above the indicator line. Water was top-up if necessary.
3. Plastic crucible was weighed and recorded as W_c.
4. Empty fruit bunch sample was weighed between 0.5 to 1.0 g and recorded as W_b.
5. A cotton twist was tied at a string inside the bomb.
6. Crucible containing the sample was placed inside the bomb.
7. The cotton twist was buried in the sample.
8. The bomb was closed tightly with its cover.
9. The bomb was attached into the bomb calorimeter.
10. 'Sample' tab at monitor was pressed and the following data was keyed in:

a. Weight of sample (excluding plastic crucible weight).

b. Gross calorific value of cotton twist; 50J, Qextran1

c. Weight of plastic crucible times gross calorific value of plastic crucible, Qextran2.

11. Once the monitor displays 'Start', the 'Start' tab was pressed to start the equipment.

12. After 15 minutes, a reading appeared in J/g unit. The reading was recorded.

13. Step 3 to 12 was repeated for other samples.

3.2 Gantt Chart

No.	Detail/ Week	1*	2*	3*	4*	5*	6*	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	Acquisition of POEFB (~10 kg of raw POEFB)	■																			
2	Grinding of POEFB using cutting mill into powder (<250μm)		■	■	■	■															
3	Drying of POEFB using oven at 100°C for 24 hours						■														
5	Torrefaction of POEFB at 240°C, 260°C and 280°C for 30, 60 and 90 minutes							■	■	■	■	■									
6	Mass loss calculation after torrefaction process							■	■	■	■	■									
7	Ultimate analysis of samples using CHNS analyzer												■	■							
8	Calorific value analysis of samples using Bomb calorimeter														■	■					
9	Proximate analysis of samples using TGA analyzer																■	■			
10	Analysis and interpreting data of analyses																		■	■	■

Table 1 Gantt chart and Milestone of Project

*Weeks of the previous semester

CHAPTER 4

RESULT AND DISCUSSION

4.1 Analysis of POEFB

Figure 2 POEFB before grinding and drying

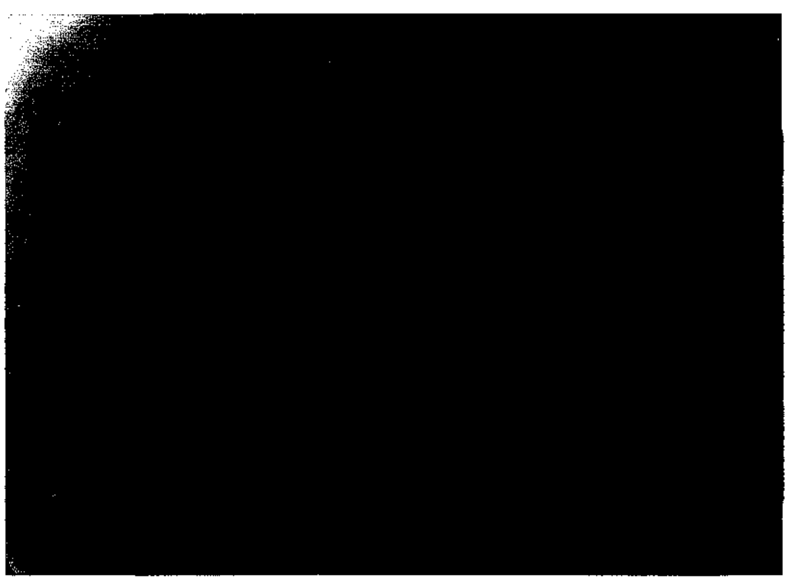

Figure 3 POEFB after grinding and drying

Based on the comparison between Figure 2 and Figure 3, we can see that the dried and grinded POEFB shows smaller and rounder shape as compared to the raw POEFB. This observation proves that drying and torrefaction can improve grindability of the biomass treated. Grindability will in turn improve handleability and logistic suitability of the biomass.

4.2 Effect of Torrefaction on Mass Yield

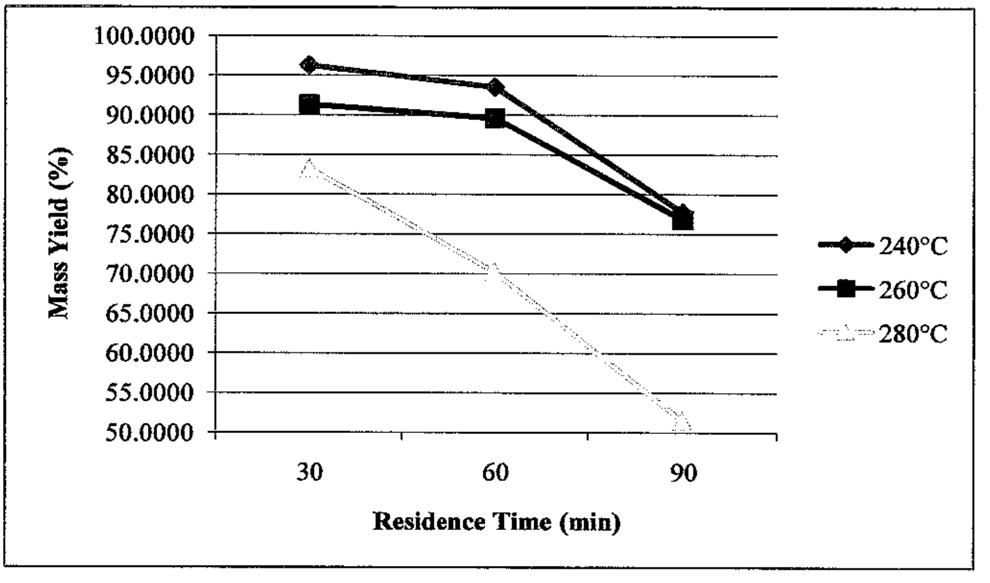

Figure 4 Variation of mass yield of torrefied POEFB

From figure 4, we can see the variation of mass yield with different final temperature and residence time. The graph shows a trend that has been observed by other researchers (Arias 2007). The torrefied product undergoes significant weight loss during the second stage of the process (60 to 90 minutes) which can be associated with the decomposition of reactive cellulose chains forming synthetic gas. This can also be confirmed by the smell observation by author during the torrefaction process where smell of methane can be perceived during the last few minutes of experiments. We can see also that the effect of temperature is very significant towards the mass yield; at 280°C mass yield is very low as compared to both products from 240°C and 260°C.

4.3 Analysis of Raw POEFB & Solid Product

The result of proximate, ultimate and calorific value analyses is compiled in Table 2. The result shows the changes in response of changing residence time and temperature.

The composition of sulphur is too low to be detected by the analyzer; therefore it is left-out from the result whereas the composition of oxygen is calculated by subtracting the composition of carbon, hydrogen and nitrogen from the total composition. The percentage of hydrogen and nitrogen remained fairly constant throughout the process except at the high temperature of 280°C where reduction can be seen in hydrogen percentage. This can be explained by the formation of hydrocarbons gas such as methane (CH_4) and ethane (C_2H_6).

We can also see that the composition of oxygen reduced significantly with increasing temperature and time. For example, the percentage of oxygen at extreme condition (280°C; 90 minutes) is 22% lower than the raw percentage. This is due to the formation of carbon monoxide and carbon dioxide gases. This reduction improves the energy quality of biomass by reducing functional group bonds and leaving only C-C bond (Yan 2006).

	Proximate Analysis			Ultimate Analysis (* use differential)				Gross Calorific Value (J/g)
Sample	Moisture (%)	Ash (%)	Volatile Matter (%)	C (%)	H (%)	N (%)	O* (%)	
Raw	1.956	4.009	91.499	41.490	5.252	1.305	51.953	18315
Dried	1.787	6.012	87.939	44.810	5.182	1.624	48.384	18434
240C,30min	1.947	6.423	87.823	43.390	5.197	1.481	49.932	17396
240C,60min	1.865	8.006	85.120	47.460	5.559	1.343	45.638	17896
240C,90min	1.693	10.122	82.187	50.140	4.035	1.684	44.141	19004
260C,30min	1.923	6.566	87.148	44.800	5.570	1.515	48.115	18131
260C,60min	1.646	9.479	82.894	44.180	4.975	1.441	49.404	18146
260C,90min	1.270	12.157	80.700	53.030	5.322	1.450	40.198	20205
280C,30min	1.843	6.738	86.991	45.490	5.074	1.484	47.952	20069
280C,60min	1.453	11.964	79.972	56.270	4.454	1.709	37.567	21765
280C,90min	1.585	17.148	73.225	63.020	4.830	1.901	30.249	22236

Table 2 Proximate analysis, ultimate analysis and gross calorific value of POEFB samples

4.4 Effect of Torrefaction on Heating Value yield

Figure 5 shows the variation of heating value yield calculated using the equation provided by B. Arias, 2007.

$$heating\ value\ yield\ (\%) = {}^{M_f}\!/_{M_o} \times {}^{GCV_f}\!/_{GCV_0} \times 100$$

The heating value yield is directly proportion to the ratio of gross calorific value of the torrefied biomass to dried biomass. Gross calorific value increases with increasing temperature and residence time; signifying the improvement of energy density of POEFB. However, there is loss in energy during the torrefaction process to the gas phase produced. The heating value yield varies from the highest at 90% at residence time of 30 minutes to the extremely low 62% at 280°C and 90 minutes operation. We can see that at high temperature of 280°C, the torrefaction reduces heating value yield significantly. This large reduction although good to the energy density of the biomass, is not very good as process yield since most of energy will be lost to the gas phase; almost 50%. The heating value yield for other temperature seems to display moderate changes throughout the process. The decrease in energy yield can be related to the amount of gas and volatile matter being produced.

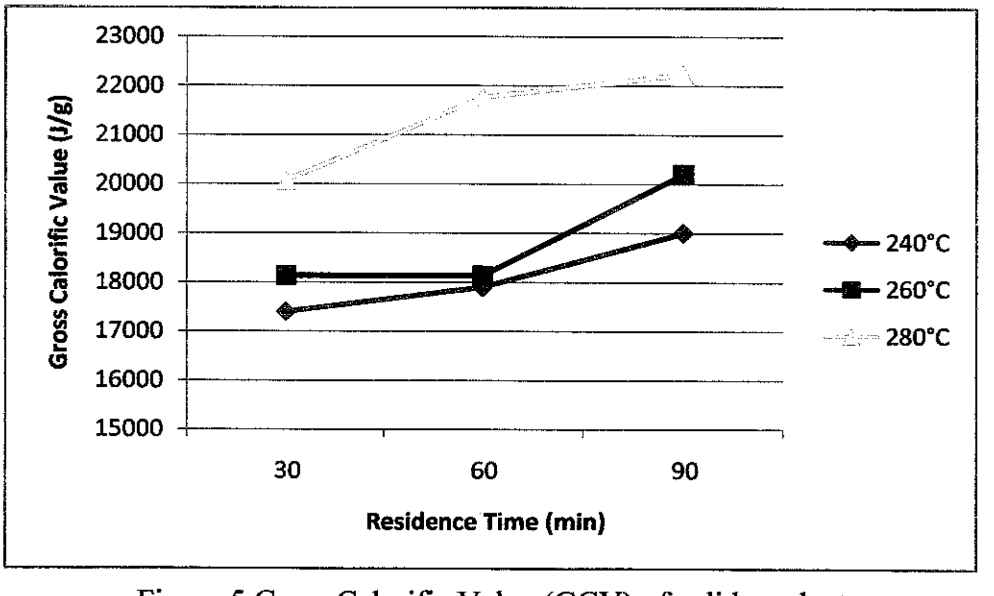

Figure 5 Gross Calorific Value (GCV) of solid product

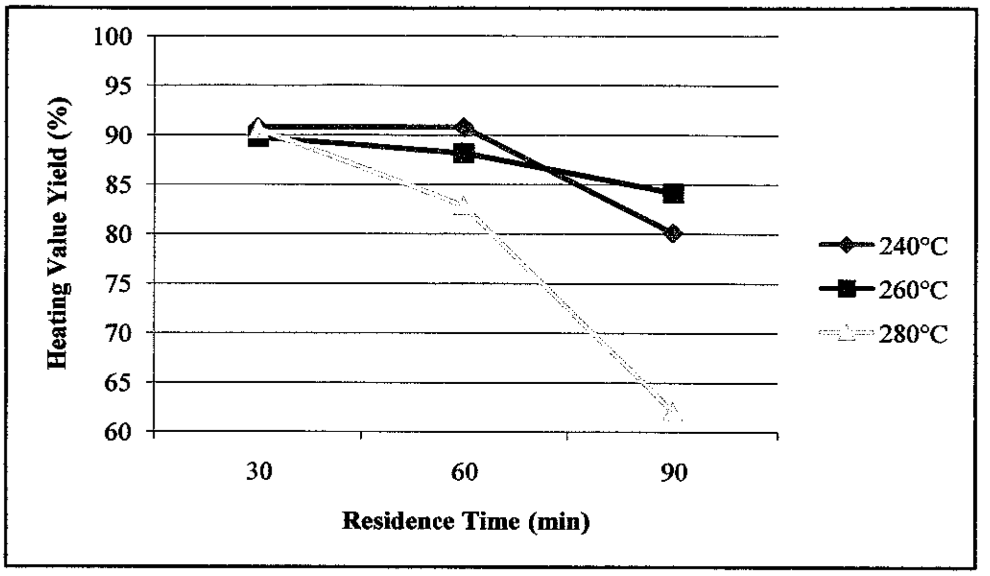

Figure 6 Variation of heating value yield of torrefied POEFB

As we can see from the results obtained, the outcome of the experiment is comparable to previous researches i.e. torrefaction of Eucalyptus by B. Arias and findings by P.C.A. Bergman from ECN institute. High temperature and residence time will decrease the mass and energy yield but improve the calorific value and physical properties of the biomass.

The chemical resistance of biomass is also improved by reducing its moisture content, which is essential in microorganism activities that lead to degradation. The torrefied biomass is also less fibrous, which improves the handleability of biomass.

We can also see that the composition of different celluloses and lignin in the biomass will affect the determination of the optimum operating condition for the biomass pre-treatment. Therefore, study on the composition of the cellulose and lignin is important and required in order to improve the torrefaction process.

CHAPTER 5

CONCLUSION

As a conclusion, the result of the experiment and analysis so far is coherent with the information obtained from literature. Mass and calorific value yield showed similar pattern as reported by previous researches done. The chemical reactions and behaviour deduced from the proximate and ultimate analyses are also in agreement with discussions in journals reviewed prior to the experiment.

In order to make this treatment process into something applicable for commercial scale, the best operating condition for each biomass i.e. rice husk, coconut shell, tree barks etc. must be determine to produce solid product that can compete with the current solid fuel. The author proposes the usage of Taguchi Array which uses the data from this experiment and similar researches to calculate the best operating condition.

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