EFFECTS OF THERMAL TREATMENT ON DECOMPOSITION OF MALAYSIA BIOMASS

by

Muhammed Syahidan Bin Ayob

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

(Chemical Engineering)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

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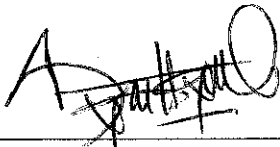
Approved by,

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(Dr. Yoshimitsu Eumura)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

July 2010

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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.

MUHAMMED SYAHIDAN BIN AYOB

ABSTRACT

Conventionally, the decomposition of biomass is done by the torrefaction process, which is the thermal treatment process at the temperature range of 225 – 300 °C that aims to produce a fuel with increased energy density by decomposing the reactive hemicelluloses fraction. However, there is no formal research was done to investigate the effect of thermal treatment at the temperature range 100 to 300 °C. The objective of this research is to investigate the effect of drying and decomposition behaviour at temperature of 100 – 300 °C thermal treatment of Malaysia biomass. Kernel shell, one of the types of biomass palm oil waste has been chosen in this experiment to study on the effect of the thermal treatment at six different treatment temperatures which are 130, 160, 190, 220, 250 and 300 °C and under three different treatment times, which are 30, 60 and 90 minutes. This project is to be carried out using tubular type reactor under nitrogen atmosphere. Several analyses on the treated samples had been carried out, which are ash-content analysis, moisture content analysis, calorific analysis, elementary analysis and energy yield analysis. The results shows that the longer treatment time will give higher quality solid fuel. However, there is no concrete prove to support the hypothesis of decomposition of biomass at the lower temperature than normal torrefaction process.

ACKNOWLEDGEMENT

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CHAPTER 1

INTRODUCTION

1.1 Background Study

Renewable energy has become more important globally especially with the current fuel and economic crisis. In Malaysia, the government has encouraged the use of renewable energy through its Five Fuels Policy plan in 1999 with the estimation of 5% utilization of renewable energy in the energy mix for year 2008 and this usage will increase to 35% in 2030 [4]. Malaysia is well positioned amongst the ASEAN countries to promote the use of biomass as a renewable energy source in her national energy mix since she is a major agricultural commodity producer in the region. The concerns over global warming and greenhouse gas also put the biomass fuels as the forefront in reduction of the pollution as biomass is considered to be CO_2 neutral [3]. Raw biomass, such as wood, straw, bagasse, peat and municipal solid waste are relatively low energy density, high moist content and difficult to comminute into small particles. As new technologies improvise, thermal treatment process known as torrefaction was introduced to encounter the problem faced on biomass fuel. [2]

The process comprises the heating of the raw biomass at the range of 225 – 300 °C, which aims to produce a fuel with increased energy density by decomposing the reactive hemicellulose fraction in biomass. In this process, the decomposition of reactive fraction in wood, cellulose, hemicellulose and lignin taking places to produce a quality product of fuels. The examples of the final product of the torrefaction process are barbeque fuels and firelighters [3].

The researches of the biomass decomposition mainly focus on the thermal treatment of biomass at the temperature range of 200 °C and above. No formal research on the decomposition of the raw biomass under 200 °C had been done, as many

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researchers simply neglect the effect of the decomposition of biomass at lower temperature. Based on the torrefaction process, the effect of the thermal treatment on composition of biomass will be studied at the temperature range of below 200 °C.

1.2 Problem Statement

Conventionally, the lowest temperature range of biomass thermal treatment has been between 200 and 300 °C, which is called torrefaction. Recent experiment had discovered that oil palm waste such as EFB, mesocarp fiber and kernel shell are decomposed even at temperature of drying, 105 °C considerably. A few researches also notice the decomposition of wood below 200 °C but neglected them as it is insignificant. Since information available on this matter is very little, this project will contribute to clarify the basic behavior of lignocellulosic biomass at the lower temperature, ranging 100 – 300 °C.

1.2.1 Significant of the Project

This project may mark a new milestone in the study of torrefaction and Pyrolysis analysis in the future. The research done in this project has no direct reference, which indicates there is no research is done as the new finding is found. This experiment will investigate and experiment the possibility and feasibility of the problem arise in the future.

1.3   Objectives and Scope of Study

1.3.1 Objective

The objective of this project is to investigate the drying and decomposition behavior for lower temperature (100 – 300 °C) thermal treatment of Malaysia which is kernel shell under air and nitrogen atmosphere.

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1.3.2 Scope of Study

The scope of study, as outlined in the above objective above, includes investigating the thermal treatment effect under temperature variation. To study the effect of thermal treatment at lower temperature, similar methodology as torrefaction will be used in the experiment, which using lab scale tubular reactor. During the experiment, the temperature will vary from 100 – 300 °C by adjusting and heating temperature of reactor. However, the heating rate during experiment will be kept constant for any heating temperature.

1.3.3 Relevancy of the Project

As there is no experiment study had been done by other researchers regarding the topic, this project is relevant in investigating the effect of thermal treatment at the temperature of 100 to 300 °C, to compare the results of the experiments, which may lead to new findings and can be extended in the future. This project will mark new milestone in torrefaction if the hypothesis of this project can be proven.

CHAPTER 2
LITERATURE REVIEW

The research and experimentation on torrefaction at 100 to 300 °C is not being done before. The lowest temperature for torrefaction is at the temperature range of 200 to 300 °C [8]. In this project, research on literature review of torrefaction is vital to understand and setting up the proper experimentation to test the hypothesis with proper condition.

2.1 Structure and Composition of Biomass

For this research, the study on structure and composition of wood will be focused to indicate the general idea on the composition of the biomass. There are 3 distinguish zone that will be decomposed during the thermal treatment of wood. On microscopic scale, wood cells are composed of microfibrils, bundles of cellulose molecules coated with hemicellulose and lignin took place in between the microfibrils. These 3 layers of wood will decompose through heating period with different level of temperature. Hemicellulose, most reactive compounds decompose at 225 – 325 °C while cellulose and lignin decompose at 305 – 375 °C and 250 – 500 °C respectively. It is said that the thermal treatment at 185 – 225 °C [1] will increase the durability, mechanical dimensional stability and water repellent characteristics of wood. Based on *Figure 1*, depolimerization, recondensation of hemicellulose and glass transition or softening process of lignin happens at 200 °C while no changes observed on cellulose at the same temperature. A slight decomposition of hemicellulose is observed, but no valid data that can be used to support the observation.

A study was done on effect of densification on composition of wood showed the amount of total lignin increased after desorption, but also not significantly. Generally,

mature wood samples tended to lose 2 to 3.5 % of their hemicelluloses during desorption, with southern pine recording the highest losses. As a result of these hemicellulose losses, there was an increase in percent of lignin and cellulose content resulting from desorption.

Different type of biomass contains different composition of cellulose, hemicellulose and lignin. Based on the study [7], the torrefaction on different type of the biomass will result different scheme of decomposition of active composition. The study on bamboo, willow, coconut shell and wood exhibit different behavior of decomposition at certain temperature

2.2 Lab Scale Tubular Reactor

For the experiment, lab scale tubular is designed and built in order to do the thermal treatment for the biomass at lower temperature with small scale. This reactor is significant to observe and record the effect of the treatment on the sample. The reactor is consists of nitrogen gas supply, a tubular reactor, ice traps for tar and water, and a gas sampling point [9].

A stainless steel pipe with the diameter of one inch is used as the heating medium for the reactor and being heat – up by the heater that controlled by thermocouple inserted through the reactor to measure the wall temperature of the tube during the experiment. Ice trap is placed at the outlet of the reactor to capture the tar and water vaporized due to the thermal treatment. This is vital to test on the tar generated through the experiment to indicate the decomposition of the samples [9].

Nitrogen is acted as the inert gas for the experiment, to ensure there is no oxygen during the experiment. Before the experiment, air in the reactor was replaced by nitrogen gas,

which was allowed to flow into the reactor until the concentration of oxygen at the exit was less than 1% [9].
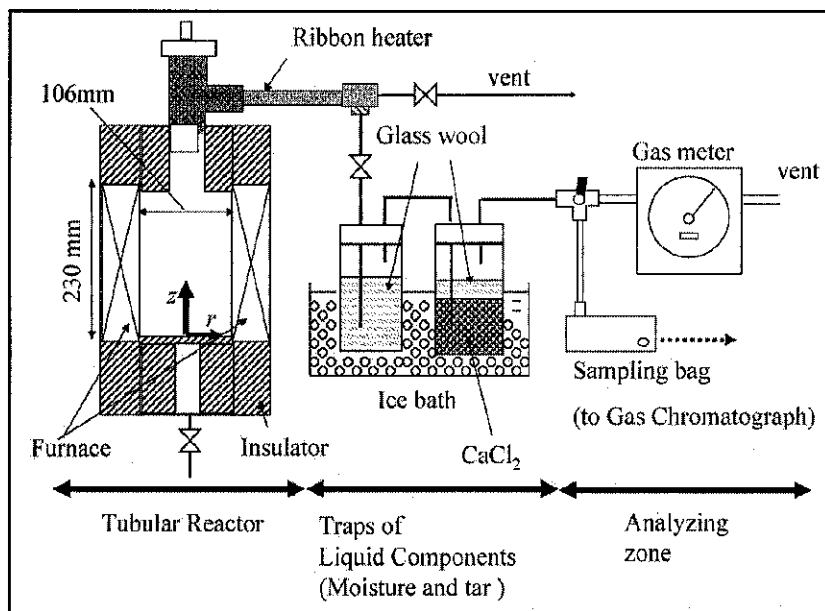
Figure 2.1: Lab Scale Tubular Reactor

2.3 Torrefaction Process

In this experiment, torrefaction will be used as the reference experiment, where the method of torrefaction experiment will be applied to study the weight loss of the sample.

Torrefaction is a thermal treatment step in the temperature range of 225 – 300 °C, which aims to produce a fuel with increased energy density by decomposing the reactive hemicellulose fraction [8]. This experiment is carried out using many different devices; however, TGA is seen as the most effective equipment. The process is being carried out under nitrogen.

Torrefaction can be carried out under different gaseous atmospheres. Nitrogen or hot gases released during the thermal treatment are employed most of time. It avoids exothermic reactions that are likely to occur in presence of oxygen. When exothermic reactions take place, a fast and uncontrolled increase in temperature of the material occurs. However, chemical reactions involved during torrefaction as well as final properties of the material depend strongly on the temperature of the wood [6].

Torrefaction is involving the multi - step reaction in order to decompose active component in biomass, which are hemicellulose, cellulose and lignin. The process occurs with the intermediate process during the torrefaction where biomass is converted into intermediate reaction product before yielding char as the final product. The first reaction is substantially faster than the second reaction and the reaction is expected to occur in continuous manner [1].

$$A \xrightarrow{k_1} B \xrightarrow{k} C$$

with $A \xrightarrow{k_{V_1}} V_1$ and $B \xrightarrow{k_{V_2}} V_2$
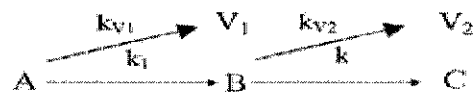
The solid yields are given by:

$$y_1 = \frac{k_1}{k_1 + k_{V_1}}$$

$$y_2 = \frac{k_2}{k_2 + k_{V_2}}$$

The most recent modification is discussed proposed that torrefaction is involving tar cracking in the multi – step mechanism in torrefaction. The literature suggested that the decomposition of cellulose will produce intermediate reaction product of active – cellulose and being decompose to char, tar and gas as below [8];

$$CELLULOSE \xrightarrow{K_1} ACTIVE\ CELLULOSE \underset{K_3}{\overset{K_2}{<}} \begin{array}{l} TAR \xrightarrow{K_4} GAS \\ CHAR+GAS \end{array}$$
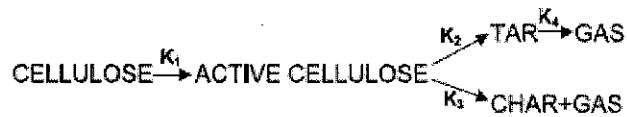
Torrefied biomass has several advantages in different markets, which makes it a competitive option compared to conventional biomass (wood) pellets. The torrified biomass contains higher energy density; 18 - 20 GJ/m3 compared to 10 - 11 GJ/m3 driving a 40 - 50% reduction in transportation costs [8]. Torrefied biomass also can be produced from a wide variety of raw biomass feedstock while yielding similar product properties. The main reason for this is that about all biomass contains lignocelluloses. All biological activity is eliminated reducing the risk of fire and stopping biological decomposition.

2.4 Pyrolysis

Pyrolysis is the chemical decomposition of condensed substances by heating that occurs spontaneously at high enough temperatures. The word is coined from the Greek-derived elements *pyro* "fire" and *lysys* "decomposition".

Pyrolysis is a special case of thermolysis, and is most commonly used for organic materials, being then one of the processes involved in charring. The pyrolysis of wood, which starts at 200–300 °C (390–570 °F),[1] occurs for example in fires or when vegetation comes into contact with lava in volcanic eruptions. In general, pyrolysis of organic substances produces gas and liquid products and leaves a solid residue richer in carbon content. Extreme pyrolysis, which leaves mostly carbon as the residue, is called carbonization.

This chemical process is heavily used in the chemical industry, for example, to produce charcoal, activated carbon, methanol and other chemicals from wood, to convert ethylene dichloride into vinyl chloride to make PVC, to produce coke from coal, to convert biomass into syngas, to turn waste into safely disposable substances, and for transforming medium-weight hydrocarbons from oil into lighter ones like gasoline. These specialized uses of pyrolysis may be called various names, such as dry distillation, destructive distillation, or cracking.

Pyrolysis also plays an important role in several cooking procedures, such as baking, frying, grilling, and caramelizing. And it is a tool of chemical analysis, for example in mass spectrometry and in carbon-14 dating. Indeed, many important chemical substances, such as phosphorus and sulfuric acid, were first obtained by this process. Pyrolysis has been assumed to take place during catagenesis, the conversion of buried organic matter to fossil fuels. It is also the basis of pyrography.

Pyrolysis differs from other high-temperature processes like combustion and hydrolysis in that it does not involve reactions with oxygen, water, or any other reagents. However, the term has also been applied to the decompositon of organic material in the presence of superheated water or steam (hydrous pyrolysis), for example in the steam cracking of oil.

Since pyrolysis is endothermic [9], various methods have been proposed to provide heat to the reacting biomass particles:

- Partial combustion of the biomass products through air injection. This results in poor-quality products.

- Direct heat transfer with a hot gas, ideally product gas that is reheated and recycled. The problem is to provide enough heat with reasonable gas flow-rates.
- Indirect heat transfer with exchange surfaces (wall, tubes). It is difficult to achieve good heat transfer on both sides of the heat exchange surface.
- Direct heat transfer with circulating solids: Solids transfer heat between a burner and a pyrolysis reactor. This is an effective but complex technology.

CHAPTER 3
PROJECT WORK

3.1 Research Process

The research process starts with stating the hypothesis after choosing the problem. Then, the author has to formulate the research design which is mainly related to laboratory experiment in the synthesis period. After the synthesis period, the product will proceed to be characterized under specific parameters. After that, available data and information are collected from reliable sources, followed by analysis and interpretation of result obtained from the characterization. A systematic documentation is important in order to produce a good report. A series of experiment is conducted to examine the hypothesis. The results of the experiments is then being analyzed and discussed.

3.2 Project Activities

Project activities for this project are mainly on documentation of literature review which is related to the project and experimental works. Literature review is a formal survey of professional literature and review theories and research already done on the topic. A thorough literature search which covers the background studies of thermal treatment method, specifically torrefaction process is conducted in order to obtain a clear picture of what the project is all about. The experimental works consist of experimenting the appropriate variables to approved the proposed hypothesis.

3.3 Materials

For this experiment, Kernel Shell is used as the raw material. The samples are being prepared particle sizes for the experiment. The experiment will use a lab – scale tubular type reactor, under various temperatures and inert atmosphere.

Figure 3.1: Raw Kernel Shell

3.4 Methodology

For this experiment, the procedure is divided into three major steps; (1) Biomass samples preparation, (2) Designing and assembly of tubular reactor and (3) Experiment using lab – scale tubular type reactor.

3.4.1 Biomass samples preparation
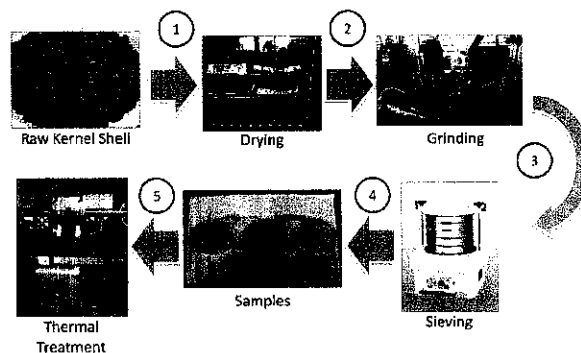
Figure 3.2: Flow Chart of Sample preparation

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The above flow chart shows the flow of the sample preparation. the sample preparation consists of three main stages, which are; (1) Drying, (2) Grinding. and (3) Sieving. Raw kernel shell being weighed to take the initial weight and dried in the oven for 24 hours at temperature of 105 °C. After 24 hours, the samples are weighed every one hour until there is no change in weight, indicating no moisture content in the samples. The dried samples are then being grinded using grinding machine. After grinding, the samples are being sieved using sieve and shaker equipment at the particle size range of 125 - 250 μm. The prepared samples is then being analyzed using Bomb Calorimeter, Ash- Content Analysis using muffle furnace and CHNS equipment to take initial composition of the samples before undergone the experiment.

3.4.2 Designing and assembly of tubular reactor

A lab – scale tubular type reactor is design and assembled to run the experiment for the selected samples, based on the result of thermal treatment experiment of the biomass. The reactor is consists of nitrogen gas supply, a tubular reactor of stainless steel pipe with 46 mm internal diameter, ice traps for tar and water, and a gas sampling point. A stainless steel pipe with the diameter of one inch is used as the heating medium for the reactor and being heat – up by the heater that controlled by thermocouple inserted through the reactor to measure the wall temperature of the tube during the experiment. Ice trap is placed at the outlet of the reactor to capture the tar and water vaporized due to the thermal treatment.

Figure 3.3: Finished Tubular reactor

3.4.3 Experiment using Lab – Scale Tubular Type Reactor
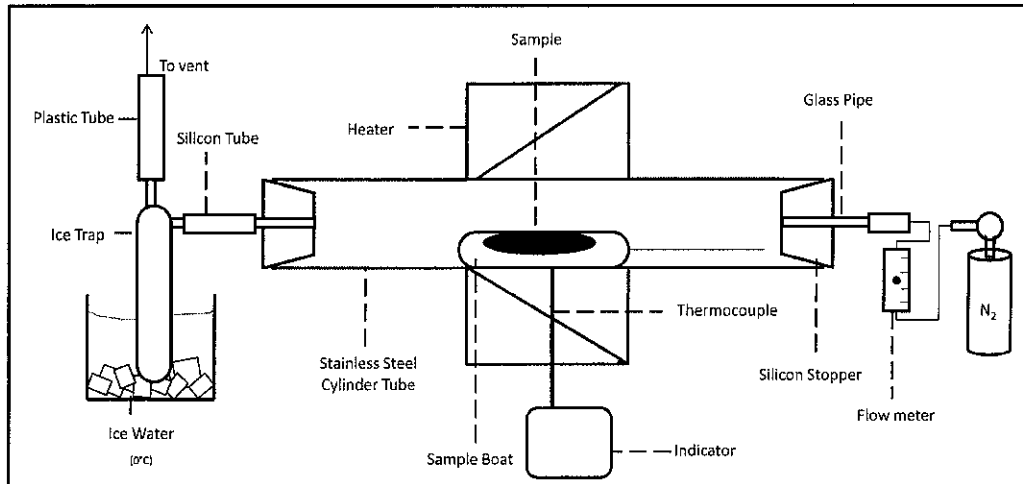
Figure 3.4: Process Flow of the Tubular Reactor

The reactor is operated fully under nitrogen atmosphere. The nitrogen flow rate entering the horizontal tubular type reactor of stainless steel pipe with 46 mm internal diameter is being set to 150 ml/min. The sample is weighed to the weight range of 2 to 3 grams being put into a sample boat with a long rod holder is prepared. The sample is placed at the center of the reactor to ensure the efficient heat transfer during the experiment. The flow rate of the nitrogen into the reactor is set to 150 ml/min to for 15 minutes to flush all oxygen in the reactor. After 15 minutes, the nitrogen flow rate is decreased to 100 ml/min at the operating condition of the experiment. The flow rate is remains constant throughout the experiment. The heater is first being set to 30 °C for 5 minutes and the heating rate for the heater is 10 °C for every 60 seconds up to desired temperature for each run. During the experiment, the treatment time is varied. The experimental conditions are as in the table below:

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Table 3.1: Summary of the Experimental Condition

RT (min) TEMP (°C)	30	60	90	120
130				
160				
190				
220				
250				
300				

After the treatment time is reached, the heater temperature is then being cooled to 30 °C for the reactor to cool off. When the reactor temperature reached 30 °C, the sample is taken out to be weighed and analyzed using Bomb Calorimeter, ash – content using muffle furnace and CHNS analyzer.

CHAPTER 4
RESULTS AND DISCUSSION

The literature review for this project covers on the study of the composition of the biomass in general, lab scale tubular reactor and the torrefaction process based on the journal available on the internet. The literature review is the most important step as this is the starting point of the experiment and literature review is needed in order to familiarize on the topic for the experiment.

The decision of the selection of methodology had been decided after reviewing a few methodologies used in the related experiments and the selection of thermal treatment process using lab scale tubular reactor fits the need of the experiment which is to observe and record the slightest decomposition of the samples as the small amount of sample is used for each run in this experiment.

The design and assembly of the tubular reactor is done with the assistance of the supervisor to ensure that the experiment can be conducted smoothly. As the reactor is not available in the lab, the assembly of the reactor took longer time as expected and the reactor is completed and ready to be used.

The sample preparation of biomass sample is prepared ahead before the assembly of the reactor as the sample preparation is the simplest process in this project and it can be done within one week. The samples prepared are sufficient to be used for each run in this project.

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4.1 Results and Discussion

Based on the methodology proposed for this project, kernel shell is used as the sample at six temperature variables and three different treatment times to be done for this experiment. Five analyses had been done on the torrefied samples, which are the ash – content analysis, CHNS analysis, calorific value analysis, mass and energy yield and moisture content. The analysis had been done on the sample before and after the torrefaction process. Based on the analyses, the table below shows the physical properties of the kernel shell.

Table 4.1: Physical Properties of the Kernel Shell

Analysis	Value
Moisture Content – raw material (wt%)	25.95
Ash Content	4.86
CHNS (wt%)	
• Carbon	47.21
• Hydrogen	5.58
• Nitrogen	0.97
LHV Value (MJ/kg)	18.67

4.1.1 Calorific and CHNS Analysis

The results of calorific, CHNS and ash analyses for the dried and torrefied samples are listed in Table 4.2 to 4.4 below.

Table 4.2: Results of Calorific Value for Torrefied Kernel Shell

Temperature (°C)	Calorific Value (MJ/kg^{-1})		
	30 min	60 min	90 min
130	16.597	19.580	17.002
160	16.298	16.911	18.897
190	17.966	18.791	19.772
220	18.775	19.531	19.066
250	19.731	19.675	19.732
300	21.915	22.001	22.317

Table 4.3: Results of CHNS Analysis for Torrefied Kernel Shell

Temperature (°C)	C	H	N	C	H	N	C	H	N
	30 min			60 min			90 min		
130	33.95%	4.17%	0.60%	44.47%	5.83%	0.66%	36.00%	4.22%	0.69%
160	52.79%	6.93%	0.69%	45.95%	5.93%	0.68%	44.74%	5.38%	0.63%
190	48.21%	6.27%	0.65%	46.33%	5.81%	0.71%	47.51%	5.53%	0.53%
220	44.87%	6.56%	0.42%	44.99%	6.66%	0.59%	52.48%	6.45%	0.44%
250	52.93%	5.75%	0.47%	55.96%	6.25%	0.53%	60.39%	5.16%	0.45%
300	56.20%	6.36%	0.52%	58.47%	7.56%	0.74%	61.61%	8.17%	0.63%

Table 4.4: Ash Content Analysis for Torrefied Kernel Shell

Temperature (°C)	Ash Content		
	30 min	60 min	90 min
130	4.46	3.91	5.01
160	3.49	4.86	4.98
190	4.31	3.77	4.05
220	4.33	4.19	4.47
250	2.79	4.5	3.75
300	3.47	4.26	4.03

The value obtained from calorific analysis using bomb calorimeter is the high heat value (HHV), which includes the latent heat of the vapor emitted from the sample. The HHV values are then being converted to low heat value (LHV) using equation (1) below [10];

$$LHV = HHV - (21.987 w_H + 2.443 w_w) \tag{1}$$

Where,

LHV is Low Heat Value in Mg/kg,

HHV is High Heat Value in MJ/kg,

w_H is hydrogen mass fraction,

w_w is free water fraction

The LHV is more realistic than HHV, because LHV does not contain any contribution from the latent heat of the vapor. Below is the LHV values calculated using the equation (1).

Table 4.5: LHV Value for Torrefied Kernel Shell

Temperature (°C)	LHV Value (MJ/kg^{-1})		
	30 min	60 min	90 min
130	15.68	18.30	16.08
160	14.78	15.61	17.72
190	16.59	17.51	18.56
220	17.33	18.07	17.65
250	18.47	18.30	18.60
300	20.52	20.34	20.52

In order to discuss more specifically, the calorific value, the CHN contents obtained from CHNS analysis and the ash content analysis using muffle furnace are plotted against the torrefied temperature in Figure 4.3 to 4.5, respectively.
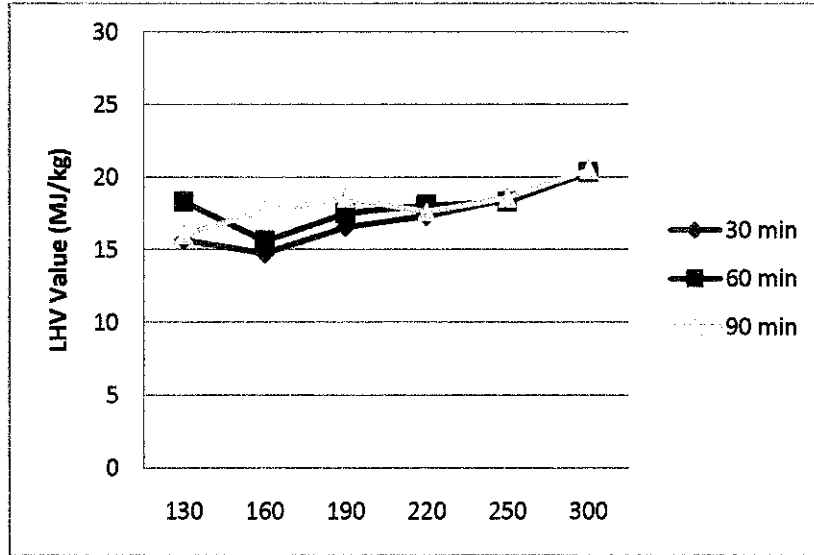
Figure 4.1: Calorific Analysis for Torrefied Kernel Shell
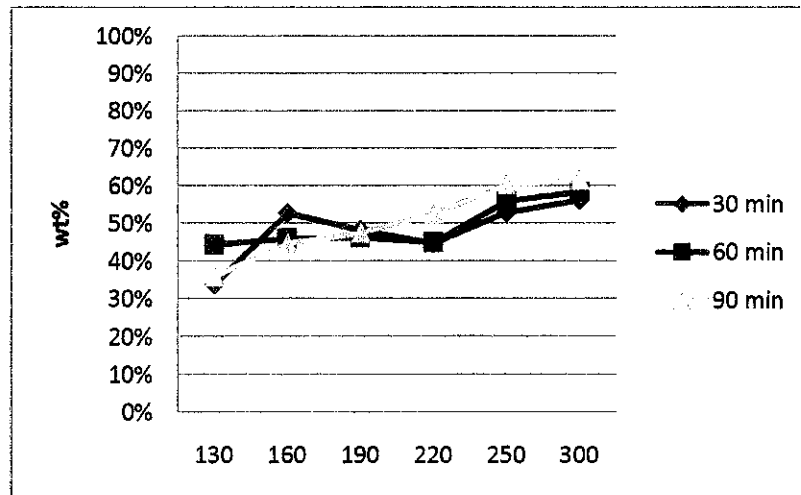
Figure 4.2: CHNS Analysis (Carbon) for Torrefied Kernel Shell

From Figure 4.1, it shows that the calorific value of treated biomass is increased with higher temperature.. The increase of the calorific value is contributed by the increase of carbon weight percentage in the biomass obtained in CHNS analysis (Figure 4.2). However, the LHV value after the thermal treatment is observed to be lower than the untreated biomass, which is 18.67 MJ/kg (refer Table 4.2) at temperature of 130 till 250 °C at all three treatment times. Only the

thermal treatment at 300 °C shows the higher calorific value compare to the untreated biomass.

Ash Content Analysis
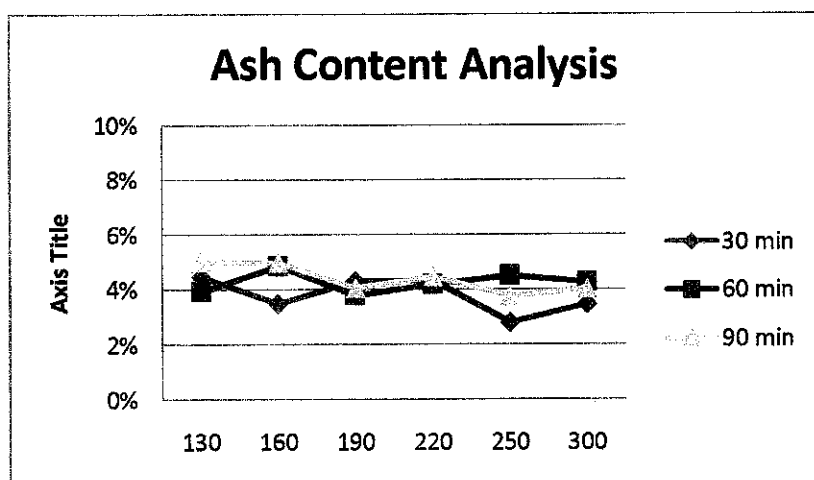
Figure 4.3: Ash Content Analysis for Torrefied Kernel Shell

For ash content analysis, the value for torrefied biomass is lower than the fresh biomass, which is 4.86 wt%. The decrease of ash content value (refer Table 4.4 and figure 4.5) could imply two possibilities; the loss of major components in the kernel shell ash due to vaporization or accompanied with the tar sol during the torrefaction and a major component in the Kernel Shell ash was converted into a higher-volatile form, and then was lost during the ash measurement at 700°C.

4.1.2 Yield of Torrefaction

The mass and energy yields of the dried and torrefied samples were calculated, based on equations (2) and (3), respectively [12] .

$$Mass\ Yield\ (\%) = \frac{Weight\ of\ sample\ after\ torrefaction}{Weight\ of\ sample\ before\ torrefaction} \times 100 \qquad (2)$$

$$Energy\ Yield\ (\%) = Mass\ Yield \times \frac{CV\ of\ torrefied\ biomass}{CV\ for\ untreated\ biomass} \times 100 \qquad (3)$$

Below is the data from the calculation and the data obtained from the experiment is then being plotted. The graphs are shown as below;

Table 4.2: Mass Yield Analysis of torrefied Kernel Shell

Temp, °C	Mass Yield (wt %)		
	30	60	90
130	94.96%	91.99%	91.93%
160	94.09%	91.13%	90.62%
190	93.85%	85.28%	77.40%
220	93.71%	92.66%	85.00%
250	92.19%	90.11%	87.12%
300	92.05%	88.79%	81.02%

Table 4.3: Results of Energy Yield

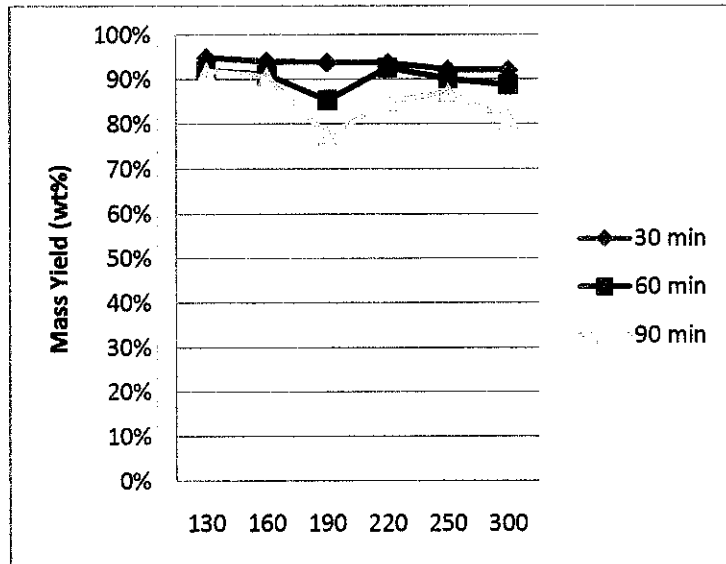| Temperature (°C)	Energy Yield		
	30 min	60 min	190 min
130	83.95%	98.01%	86.11%
160	76.47%	83.60%	94.89%
190	83.39%	93.81%	99.40%
220	87.00%	96.77%	94.54%
250	91.20%	98.03%	99.62%
300	101.17%	108.94%	109.92%

Figure 4.4: Mass Yield Analysis for Torrefied Kernel Shell
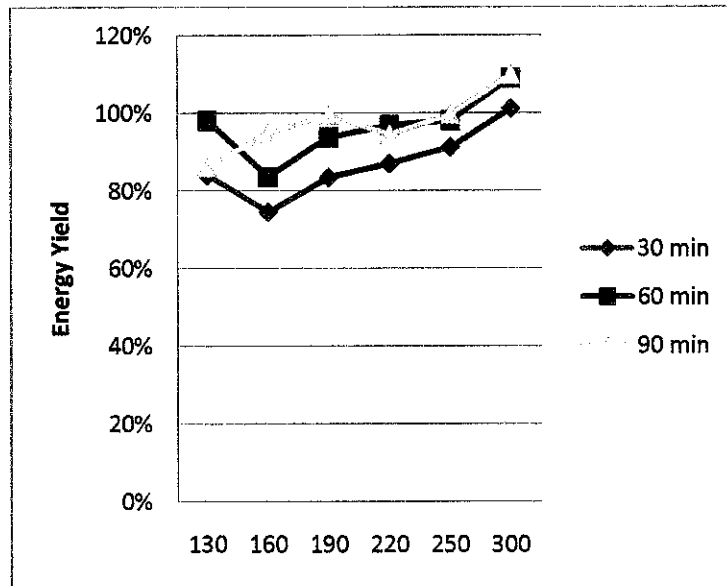
Figure 4.5: Energy Yield Analysis for Torrefied Kernel Shell

Based on the data obtained from the experiments and the graph plotted, the trend set by the experiment is as the temperature increases, the mass yield will be decreasing. The mass yield also is observed to be decreasing as the longer treatment time for the experiment is set. The results is consistent with the trend of decreasing mass yield as the experimental temperature increases caused by the increased of energy being supplied during the experiment is higher. The high energy density will result more decomposition of the biomass. [2] There is possibility that the increased of the mass yield is caused by the loss of the moisture content in the biomass.

The graph also shows the difference between the three different treatment times at the same temperature. From the graph, it is observed that the longer treatment time will result the decrease of mass yield. This is caused by more time is being given to the samples to react and decomposed in longer period of treatment time compare to the shorter treatment time.

The mass yield for kernel shell is below 100%, which implies that the mass of torrified biomass is lower than untreated biomass. There are two main

causes for the decrease in mass of the dried or torrefied samples. One is moisture loss, another thermal decomposition to form volatile or gaseous products such as H_2O, CO, CO_2, acetic acid and other organics [11].

The energy yield in Fig. 4.5 ranges from 77 to 110% depending on the treatment time and temperature. The energy yield of the dried samples would be 100%, if only moisture loss occurs during the treatment. At lower temperature, it is observed that the energy yield is below 100%. For further discussion, the analysis on the moisture content is done to study on the decrease of the energy yield. The graph of moisture content versus temperature is then being plotted.
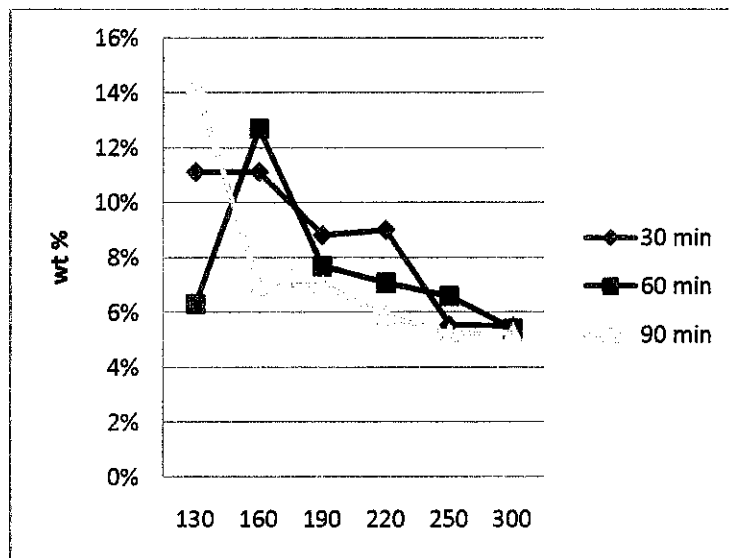
Figure 4.6: Moisture Content Analysis for Torrefied Kernel Shell

Based on the moisture content analysis, it is observed that the moisture content is decreased with the increase of temperature. The highest moisture content is at 14 wt% where the temperature is 130 °C and the treatment time is set at 30 minutes while the lowest moisture content recorded at the temperature of 300 °C for the 90 minutes treatment time. The high moisture content for the

torrefied biomass at lower temperature may be caused by the poor storage of the samples and too long storage time. The air-tight plastic container is used to store all samples. However, long storage time had caused the samples contact with the oxygen and moisture content in the atmosphere as the plastic container is permissible to the moisture in the atmosphere.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

Based on the experiment conducted for this project, it is concluded that there is no visible and concrete prove to support the findings of the decomposition of palm oil waste at lower temperature. The analysis of the treated biomass show that treated biomass at low temperature gives lower calorific value than the untreated biomass. This is caused by the insufficient energy supplied to the biomass during the torrefaction process for reaction and decomposition to take place. Higher temperature is needed to decompose kernel shell. This is proved from the results and discussion of the experimentation done at the temperature of 300 °C that shows low mass yield that suggest decomposition had taken place and the increase of the calorific value, HHV higher than untreated biomass.

The differences in thermal treatment conditions show that the longer treatment time will give lower mass yield and higher energy yield for torrified biomass. The longer treatment time gives longer time for the reaction and decomposition to take place thus giving higher calorific value for the treated biomass.

There are a few recommendations to be made based on this project in order to smoothen and increase the quality of the research. The proposed recommendations are:

- Proper storage of the prepared sample.
  The sample both treated and untreated is stored in the plastic container which is not air tight container. The sample is required to be stored in air tight container to avoid any oxygen to reach the sample. This is to avoid any oxidation on the sample that will affect the experimentation results and analysis. It is proposed that the sample is contained in ad glass container with air tight cap for better storage.

- Analysis on the vapor products to do the extensive analysis on the torrefaction. During the experiment, there are liquid found in the ice trap, which is the vapor product of torrefaction process. The analysis of the vapor product is not being done due to improper planning.

- Using the Empty Fruit Bunch (EFB) as the raw material for the experiment. Based on the problem statement of the project, the findings of decomposition of biomass at drying temperature are based on the result of the EFB. It is more likely the experiment to shows the expected results if EFB is used as the raw material.

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APPENDICES

Appendix I

Table for Raw Data of Mass Yield, Moisture Content and Calorific Value

Temp, °C	Residence Time, min	Mass Yield			Moisture Content			Calorific Value		
		Initial Weight, g	Final Weight, g	Mass yield, %	Initial weight, g	Final weight, g	Moisture Content, wt%	Run 1 (MJ/kg)	Run 2 (MJ/kg)	Average (MJ/kg)
130	30	2.1939	2.0833	94.96%	1.17	1.04	11.11%	16.876	16.317	16.597
160		2.1487	2.0218	94.09%	1.26	1.12	11.11%	16.152	16.444	16.298
190		2.0715	1.9442	93.85%	1.02	0.93	8.82%	18.221	17.712	17.966
220		3.2357	3.0321	93.71%	1.11	1.01	9.01%	17.81	19.74	18.775
250		3.3731	3.1097	92.19%	1.08	1.02	5.56%	20.22	19.242	19.731
300		3.4368	3.1637	92.05%	1.09	1.03	5.50%	18.979	24.851	21.915
130	60	2.2421	2.0624	91.99%	1.11	1.04	6.32%	19.688	19.472	19.580
160		2.1687	1.9763	91.13%	1.26	1.10	12.70%	18.021	15.801	16.911
190		1.7679	1.5077	85.28%	1.04	0.96	7.69%	18.721	18.861	18.791
220		3.2821	3.0413	92.66%	1.13	1.05	7.08%	17.298	21.764	19.531
250		3.6606	3.2986	90.11%	1.06	0.99	6.60%	18.79	20.56	19.675
300		3.7001	3.2853	88.79%	1.11	1.05	5.41%	23.025	20.977	22.001
130	90	2.3654	2.1744	91.93%	1.05	0.90	14.29%	18.005	15.999	17.002
160		3.4324	3.1103	90.62%	1.15	1.07	6.96%	18.312	19.482	18.897
190		4.2217	3.2674	77.40%	1.09	1.01	7.04%	19.998	19.546	19.772
220		3.4351	2.9197	85.00%	1.19	1.12	5.88%	19.006	19.126	19.066
250		3.2114	2.7978	87.12%	1.14	1.08	5.26%	18.598	20.866	19.732
300		3.3476	2.7122	81.02%	1.13	1.07	5.31%	21.331	23.303	22.317

Table for Raw Data of the CHNS Analysis

Temp, °C	Residence Time, min	Carbon (wt%)			Hydrogen (wt%)			Nitrogen (wt%)		
		Run 1	Run 2	Average	Run 1	Run 2	Average	Run 1	Run 2	Average
130	30	37.48	30.42	33.95	4.73	3.61	4.17	0.67	0.52	0.60
160		51.62	53.95	52.79	6.70	7.15	6.93	0.66	0.72	0.69
190		42.17	54.25	48.21	5.46	7.07	6.27	0.57	0.73	0.65
220		43.07	46.66	44.87	6.00	7.12	6.56	0.39	0.44	0.42
250		50.74	55.12	52.93	5.72	5.77	5.75	0.44	0.50	0.47
300		60.12	52.28	56.20	5.00	7.71	6.36	0.55	0.49	0.52
130	60	53.06	35.87	44.47	7.00	4.66	5.83	0.70	0.62	0.66
160		47.99	43.90	45.95	6.21	5.64	5.93	0.70	0.66	0.68
190		45.98	46.67	46.33	5.78	5.84	5.81	0.71	0.71	0.71
220		44.91	45.07	44.99	7.07	6.25	6.66	0.61	0.57	0.59
250		55.14	56.77	55.96	4.94	7.55	6.25	0.39	0.67	0.53
300		58.71	58.22	58.47	8.01	7.11	7.56	0.78	0.69	0.74
130	90	41.75	30.24	36.00	4.98	3.45	4.22	0.77	0.60	0.69
160		36.38	53.09	44.74	4.30	6.45	5.38	0.52	0.73	0.63
190		47.02	47.99	47.51	5.05	6.00	5.53	0.55	0.51	0.53
220		53.76	51.20	52.48	6.22	6.67	6.45	0.44	0.44	0.44
250		59.78	61.00	60.39	5.99	4.33	5.16	0.49	0.41	0.45
300		63.21	60.01	61.61	7.77	8.56	8.17	0.71	0.54	0.63