BIO-CHAR PRODUCTION FROM OIL PALM STEM USING FLASH PYROLYSER

By

Shariffudin bin Abd Rasid

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Chemical Engineering)
September 2011

Universiti Teknologi PETRONAS,
Bandar Seri Iskandar,
31750 Tronoh,
Perak Darul Ridzuan.

CERTIFICATION OF APPROVAL

BIO-CHAR PRODUCTION FROM OIL PALM STEM USING FLASH PYROLYSER

By

Shariffudin bin Abd Rasid

A project dissertation submitted to the
Chemical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CHEMICAL ENGINEERING)

Approved by,

(Prof. Dr. Yoshimitsu Uemura)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
September 2011

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.

SHARIFFUDIN BIN ABD RASID

ABSTRACT

Pyrolysis of oil palm stem waste will be carry out in the fluidized bed reactor in the presence of nitrogen as a fluidized gas. The product yield will be investigated after the experiment. This experiment was carrying out at 450°C and with biomass particle size is 0.15mm-0.5mm. Before start the experiment, the feedstock will be analyze base on moisture content, ash content, calorimetry value and elementary analysis. The products of this process are bio-oil, gases and char. The results of this experiment will compare with the literature review. The char yield was affected by the residence time of the fluidized bed reactor. Very high reactor residence time will led to higher bio-char production. The ultimate analysis also conducted to the product.

ACKNOWLEDGEMENT

First and foremost, highest thanks to The Almighty, the source of life, wisdom and hope for giving the author the strength and patience to pursue and complete this Final Year Project in blue colours.

The author's utmost gratitude goes to the author's supervisor, Prof. Dr. Yoshimitsu Uemura for the informative supervision and valuable knowledge throughout the project. Without his guidance and patience, the author would not be succeeded to complete the project.

The author's sincere thanks to Chemical Engineering Department of Universiti Teknologi PETRONAS (UTP) for providing this chance to undertake this remarkable final year project.

Special thanks also to Mr. Wissam for his kind cooperation and assistance in tutoring the author throughout the project. For the entire lab technologies in Chemical Engineering, thank you for assisting the author in completing her project.

Last but not least, special credit goes to the author's parents, family members and friends, who had dedicatedly provided the author with additional support and encouragement throughout this project either directly or indirectly. Thanks again to all, your kindness and helps will always be remembered.

Table of Contents

LIST OF TABLES

LIST OF FIGURE

CHAPTER 1: INTRODUCTION

1.1 Background of the study

Biomass is the mass of living organisms present in a particular area or ecosystem. Nowadays biomass becomes popular because of its characteristic in the production of energy. People depend on supply and reliable energy for home, business and transport. One of the examples of biomass is oil palm stem. Since Malaysia is the largest producer and exporter of palm oil in the world with market share of about 50 and 58 percent, respectively (Amiruddin, 2003). In 1997, Malaysia produced about 13.2 million tons of oil palm biomass including trunk, fronds, and empty fruit bunches (Kamaruddin, 1997). It is very important to study the usage of this waste because it has the potential to become one of the economic sources in this country. According to British Petroleum (BP), world oil reserves stand at 1238 billion barrels. In 2008, yearly world oil production stands at 31 billion barrels. If the production holds constant and no new oil is found, the oil is only sustain for 40 years. It means, the oil sources might be depleted till 2050. Therefore, there is a need to boost the development and deployment of renewable energy in order to ensure the energy security.

1.2 Problem Statement

1.2.1 Problem identification

Malaysia is the largest producer and exporter of palm oil product in the world where contributed 83.5% of production and 89.6% of palm oil trade in the word (Amiruddin, 2003). One potential biomass source that is abundant in Malaysia is oil palm waste. This waste can be categorized into two types:

1. Waste from harvesting and replanting activity in plantation field.
2. Waste from milling process to obtain palm oil.

With a huge number of waste annually produced it will have a significant effect on the environment due to the greenhouse gas that are released during the decomposition of the waste.

1.2.2 Significant of the project

By referring to the problem identification, through this project, we can look into more detail the usage of the oil palm stem in the bio oil production. Thus, this project will explore and examine bio char yield from oil palm stem by using pyrolysis process at 450°C.

1.3 Objective

1. To study the production of bio-char from oil palm stem using flash pyrolyser.
2. Compare the yield of bio-oil, bio-char and gases produce in the experiment.

1.4 Scope of Study

The scope of study is mainly focusing on:

- Fluidized bed reactor.
- Stem that is the raw material in this experiment.
- Bio-char yield.

1.5 The Relevancy of the Project

Since the world oil crisis around 1970, many researches have been done regarding the new alternative to produce oil with another source. One of the alternatives is pyrolysis process. Pyrolysis is about converting the biomass that is natural waste into usable oil. In this project, oil palm stem (lignocellulose biomass) is converted to the bio oil using the pyrolysis process.

CHAPTER 2: LITERATURE REVIEW

2.1 Lignocellulose Biomass

Lignocellulose biomass refers to the plant biomasses that consist of cellulose, hemicellulose and lignin. Lignocellulose is the main source of renewable resource with several applications, including as fuel and feedstock (Broda, 1992). In this experiment, lignocellulose biomass will be converted into bio oil by using pyrolysis process.

Bio-oils are multicomponent mixtures comprised of different size molecules derived primarily from depolymerization and fragmentation reactions of three key biomass building blocks: cellulose, hemicellulose, and lignin (S. Czernik, 2003). Cellulose, hemicellulose and lignin form the foundation of the cell wall and provide strength and toughness to the plant structure.

From the previous study, hemicellulose started its decomposition easily with weight loss mainly happen at 220-315°C follow by cellulose at 315-400°C and lignin at 900°C (Haiping Yang, 2006).

Figure 1 has shown the composition and its percentage in the lignocellulose biomass.

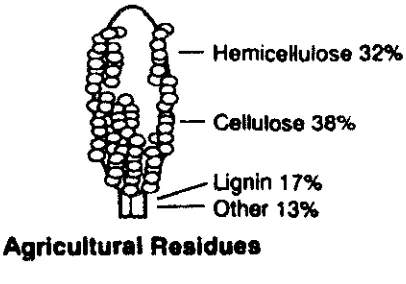


Figure 1: Composition of cellulosic biomass types (McMillan, 1994).

2.2 Pyrolysis process

Biomass fast pyrolysis is of rapidly growing interest in Europe as it is perceived to offer significant logistical and hence economic advantages over other thermal conversion processes. This is because the liquid product can be stored until required or readily transported to where it can be most effectively utilized (A.V. Bridgwater a, 1999).

Fast pyrolysis is a thermal decomposition process that occurs at moderate temperatures with a high heat transfer rate to the biomass particles and a short hot vapor residence time in the reaction zone (S. Czernik, 2003). In the 1990s, several fast pyrolysis technologies have reached near-commercial status.

This process is an advanced conversion technology that has the ability to produce a clean, high calorific value gas from a wide variety of waste and biomass streams [1]. Fast pyrolysis refers to pyrolysis at temperature of about 500°C (Hyeon Su Heo a, 2009) and has three main products which include bio-oil, char and various gases [2].

Liquid production requires very low vapors residence time to minimize secondary reactions of typically 1 s, although acceptable yields can be obtained at residence times of up to 5s if the vapors temperature is kept below 400°C. The essential features of a fast pyrolysis process are (A.V. Bridgwater a, 1999):

- Very high heating and heat transfer rates, which usually requires a finely ground biomass feed;
- Carefully controlled pyrolysis reaction temperature of around 500°C in the vapors phase, with short vapors residence times of typically less than 2 s;
- Rapid cooling of the pyrolysis vapors to give the bio-oil product.

2.3 Fluidized Bed Reactor

A **fluidized-bed reactor (FBR)** is a combination of the two most common, packed-bed and stirred tank, continuous flow reactors. It is very important to chemical engineering because of its excellent heat and mass transfer characteristics. In a fluidized-bed reactor the gas velocity must be above the minimum bubbling fluidizing velocity, which was estimated to be 0.6cm/s (Hyeon Su Heo a, 2009). This type of reactor is ideal for highly exothermic reactions because it eliminates local hot-spots, due to its mass and heat transfer characteristics mentioned before. It is most often applied in immobilized-enzyme catalysis where viscous, particulate substrates are to be handled [3].

The pyrolysis unit comprised the reactor vessel system and associated auxiliary systems for biomass feeding and injection, char collection, vapor condensation for bio-oil recovery, and instrumentation for data acquisition and control. (Akwasi A. Boateng, 2007, p. 1892). **Figure 2** show the reactor design and layout of the process.

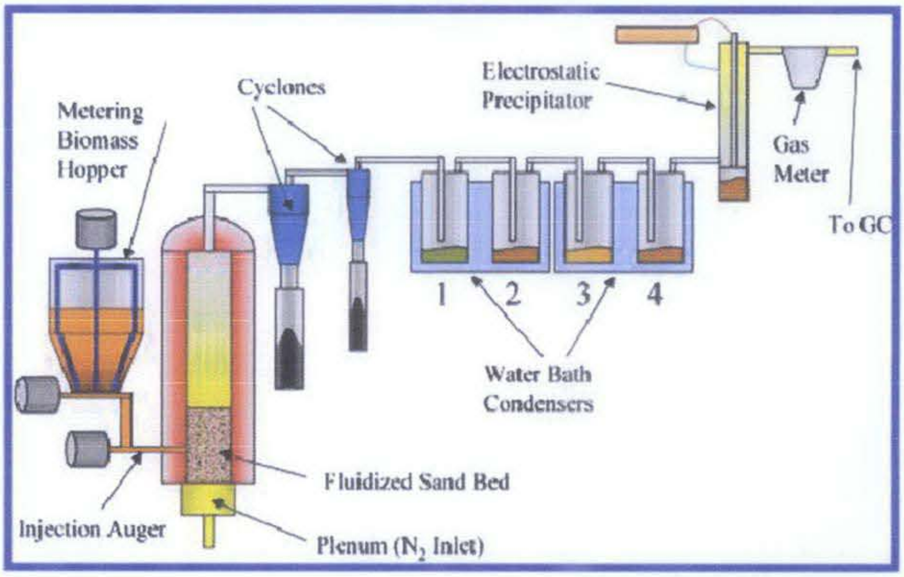


Figure 2: Reactor design and layout: (Akwasi A. Boateng, 2007, p. 1891)

2.3.1 Feed System

The feed was dispensed by a feeder screw auger system manually controlled with an auto control capability. The screw feeder/auger provided the capability to dispense the feed to a variable speed controlled injection auger with an interchangeable diameter that ensured quick discharge of ground biomass into the reactor vessel. (Akwasi A. Boateng, 2007, p. 1893)

2.3.2 Product Collection System

The char was collected by cyclone separators mounted in series. They also served as the main gas cleanup system that separated the solids from the gas stream prior to condensation.

The cyclones were followed by condenser train system **(Figure 3)** comprising four canisters in series. They were inserted into a water bath chilled with dry ice. Final capture of pyrolysis oil was accomplished using an electrostatic precipitator (ESP) (Akwasi A. Boateng, 2007, p. 1893).

Figure 3: Four canisters in series (Akwasi A. Boateng, 2007, p. 1892).

CHAPTER 3: METHODOLOGY

3.1 Research Methodology

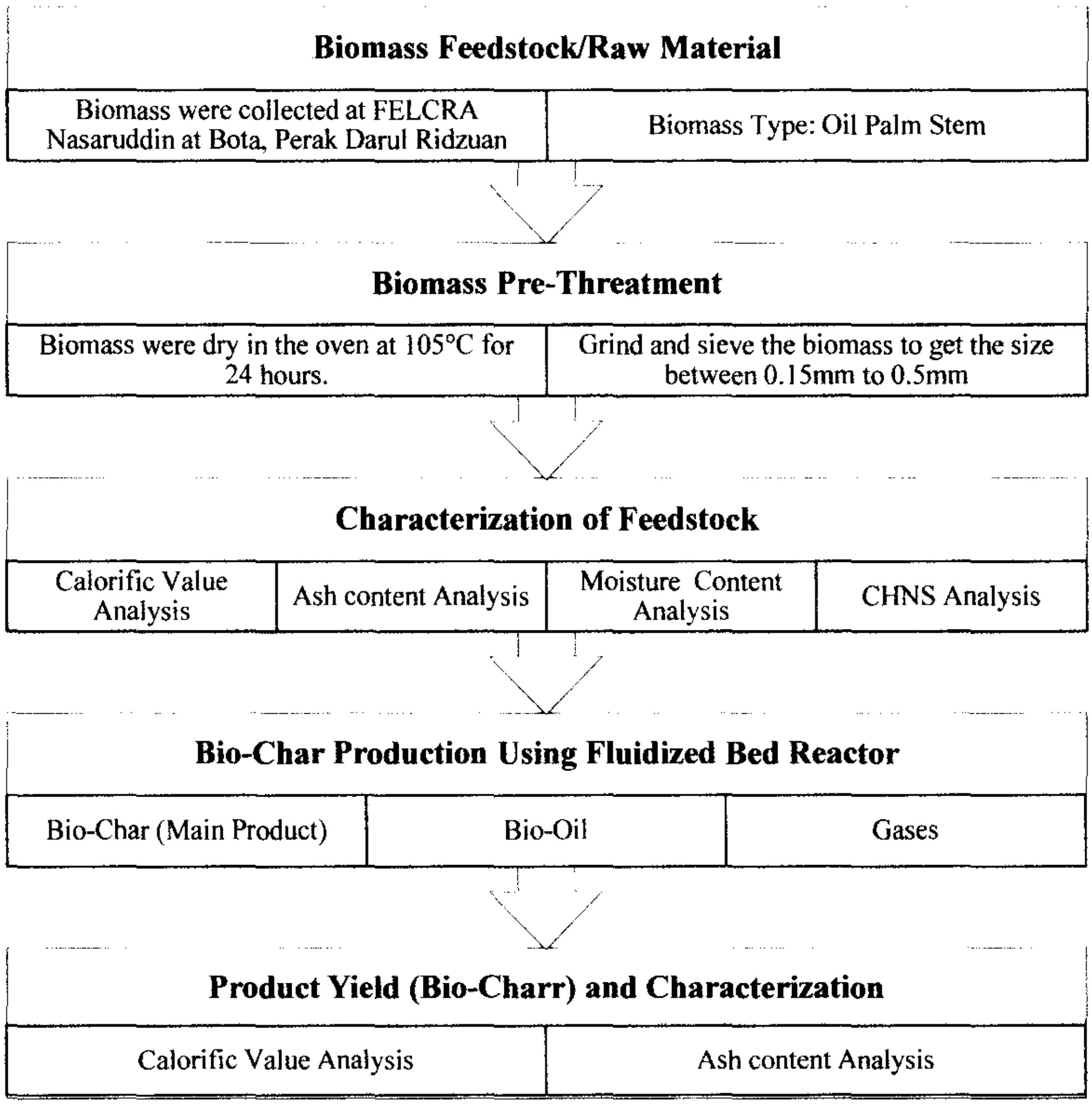


Figure 4: Flow chart of the research methodology

A) Biomass feedstock/Raw material

Oil palm stem was used as feedstock for bio-char production in this study. The feedstock was supplied by FELCRA Nasaruddin palm oil mill, located at Bota, Perak.

B) Biomass Pre-Threatment

The feedstock was dried for 24 hours with the temperature of 105 °C in a drying oven. Then, the feedstock was grinded and sieve into a size fraction of 0.15 – 0.5mm.

C) Biomass feedstock characterization

Moisture content analysis: This analysis is to measure the moisture content in the feedstock. Moisture content analysis is referred to ASTM E 871 – 82. The feedstock was dried in drying oven for 24 hours (plus 1 hour until hour 27) with the temperature of 105 °C. The moisture of content the feedstock was determined by equation 1:

$$((W_{\text{biomss}} - W_{\text{biomass@27h}}) / W_{\text{biomass}}) \times 100\% \qquad (1)$$

Ash content analysis: Total amount of minerals present within the feedstock was determined using ash content analysis. This analysis is referred to ASTM E 1755 – 95. The feedstock was heated in furnace for 3 hours with the temperature of 700 °C. The ash content of feedstocks was determined by equation 2:

$$(W_{\text{ash}} / W_{\text{biomass}}) \times 100\% \qquad (2)$$

Calorimetry analysis: Calorimetry analysis is to measure the calorific value or the amount of energy released when a feedstock is completely combusted under specified conditions by using Bomb Calorimeter C5003 IKA-Werke.

Elementary analysis: To determine the composition of carbon, hydrogen and nitrogen in the feedstock. The composition carbon, hydrogen and nitrogen of the feedstock were determined by using CHN 2400 Perkin Elmer.

D) Bio-char production using fluidized bed reactor

The experimental setup consists of three main parts which are:

1) Fluidized bed reactor made of stainless steel with diameter of 108mm and a length of 763mm. The reactor has four jacket heaters with PID controller to raise and maintain the temperature to the desire temperature.

In this model the reactant gas enters the bottom of the bed and flows up the reactor in the form of bubbles. As the bubbles rise, mass transfer of the reactant gases takes place as they flow (diffuse) in and out of the bubble to contact the solid particles, where the reaction product is formed. The product then flows back into a bubble and finally exits the bed when the bubble reaches the top of the bed.

Calculations below have shown minimum fluidization velocity (U_{mf}) of the sand and biomass in the reactor.

$$\mu_{mf} = (\mu/d_p * \rho_f) * Re_{mf}$$

$$Re_{mf} = \sqrt{}(33.7^2 + 0.0408Ar) - 33.7$$

$$Ar = (d^3_p \rho_f (\rho_p - \rho_f) g)/\mu^2$$

d_p = Particle diameter of solid (m)

μ = viscocity of fluid (Pa.s)

ρ = density (f = fluid, p = particle) (kg/m^3)

Minimum fluidization velocity (μ_{mf}) for biomass in the reactor

$Ar = [(3.25*10^{-4})^3(1.25)(530-1.26)9.81]/(0.00001657)^2$

$= 810.64$

$Re_{mf} = [\sqrt{}(33.7^2 + (0.0408)(810.64))]-33.7$

$= 0.487$

$\mu_{mf} = (0.00001657)\ (0.487)/(3.24*10^{-4})(1.26)$

$= 0.0198 m/s$

Minimum fluidization velocity (μ_{mf}) for sand in the reactor

$Ar = [(2.0*10^{-4})^3(1.25)(1602-1.26)9.81]/(0.00001657)^2$

$= 571.9$

$Re_{mf} = [\sqrt{}(33.7^2 + (0.0408)(571.9))]-33.7$

$= 0.344$

$\mu_{mf} = (0.00001657)\ (0.344)/(2.0*10^{-4})(1.26)$

$= 0.0226 m/s$

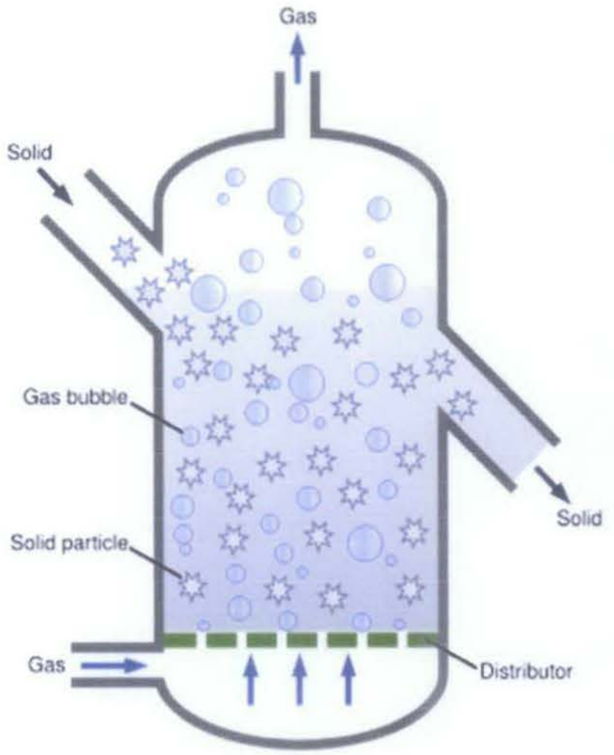


Figure 5: Fluidizing in fluidized bed reactor

2) A screw feeder for feeding biomass particle into the reactor with desire feed rate.
3) Two cyclone and six series of condenser to collect the bio-char and bio-oil respectively. The two cyclones were installed to remove the char from the gases before the gases go to the condenser to produce bio-oil.

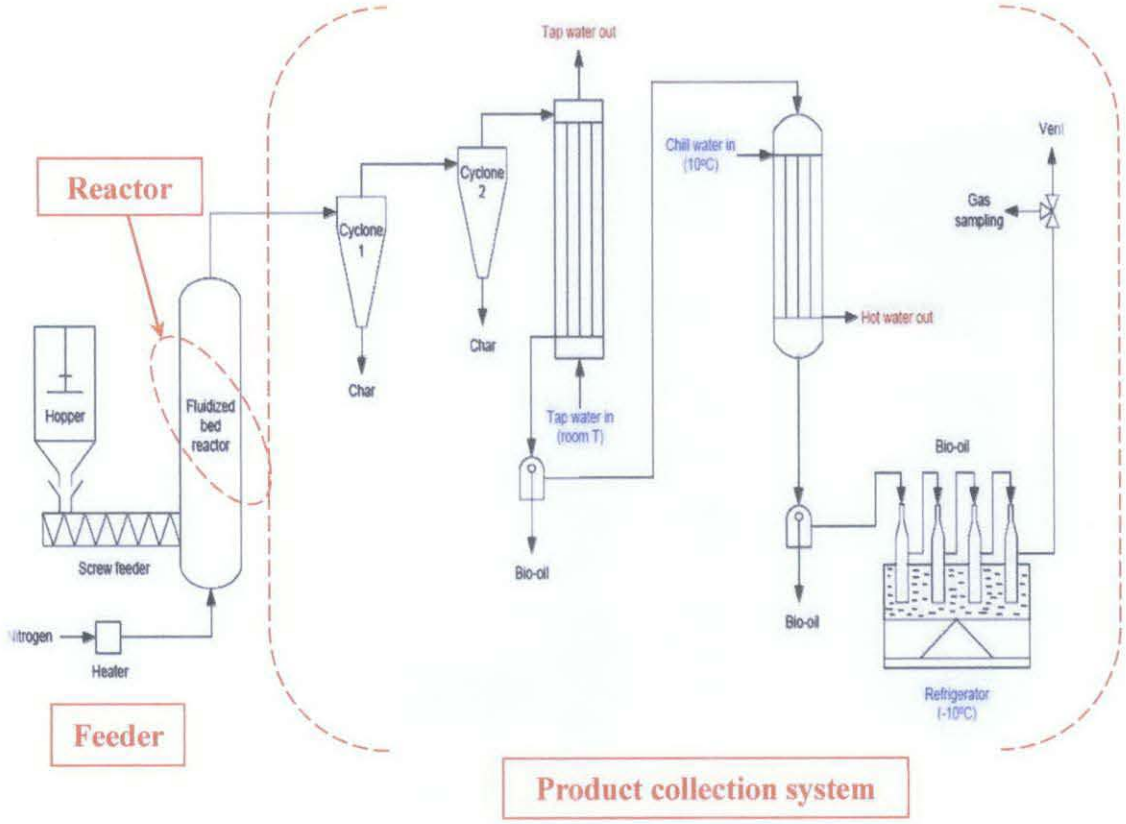


Figure 6: Schematic diagram of fluidized bed reactor

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Feedstock Characterization

Biomass feedstock used for bio-oil production in this study was palm oil stem with the fraction size of 0.15 – 0.5 mm. The feedstock has been characterized and the basic characteristics of the feedstock are listed in Table 3.

Table 1: Characteristic of 0.15-0.5mm Oil Palm Stem

Properties	Value
Diameter [mm]	0.15 – 0.5
Moisture [wt %]	6.9
Calorific value [MJ/kg]	16.84
C [wt %]	41.97
H [wt %]	5.41
N [wt %]	1.08
Ash [wt %]	2.72

Table 2: Characteristic of oil palm fronds from literature (wahid, 2007)

Properties	Value
Diameter [mm]	NA
Moisture [wt %]	Dry basis
Calorific value [MJ/kg]	NA
C [wt %]	46
H [wt %]	6
N [wt %]	NA
Ash [wt %]	3.4

Tables 2 and 3 above have shown the characteristic comparison between the oil palm stem and the oil palm fronds where the results of characteristic of oil palm fronds were get from the journal. From the tables, it shows that the ash content of oil palm fronds is higher than oil palm stem. Higher mineral content in the biomass will decrease the amount of product. The CHN analysis shows that both samples have a quite similar amount of carbon, hydrogen and nitrogen.

4.2 Fast pyrolysis product characterization

Six fractions of bio-oil samples were collected from the six condensers, respectively. The total bio-oil yield was 11.7 %. After the experiment done, there are no bio-char in the second cyclone and about 3.92g bio-char in the first cyclone and about 407.49g in the reactor. The total bio-char yield was 82.28% and 5.99% yield gases. All the bio-char samples were vigorously agitated each time before the bio-oil samples were sampled for any measurement to ensure their composition to be at the exact average. The characterization results for the two samples of bio-chars are exhibited in table below.

Table 3: Characteristic of bio-char

	Bio-char		
Property	1st	2nd	In Reactor
Calorific value (HHV) [MJ/kg]	15.509	NA	17.284
Ash [wt %]	18.17	NA	14.12
C [wt %]	45.21	NA	46.77
H [wt %]	1.836	NA	5.65
N [wt %]	1.303	NA	0.996

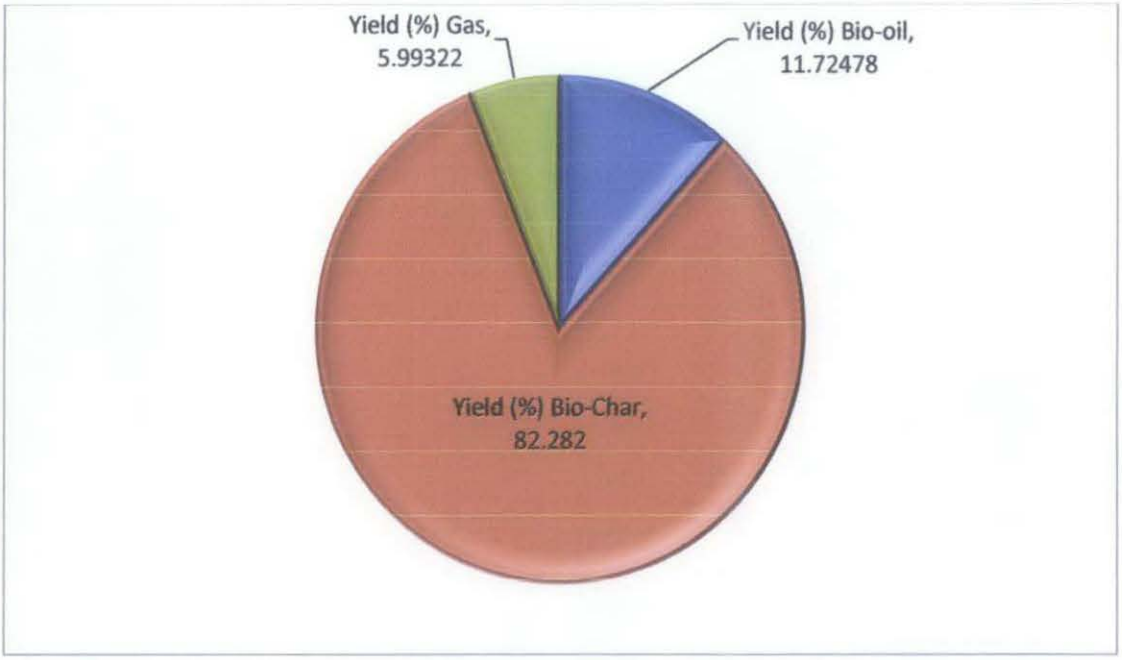


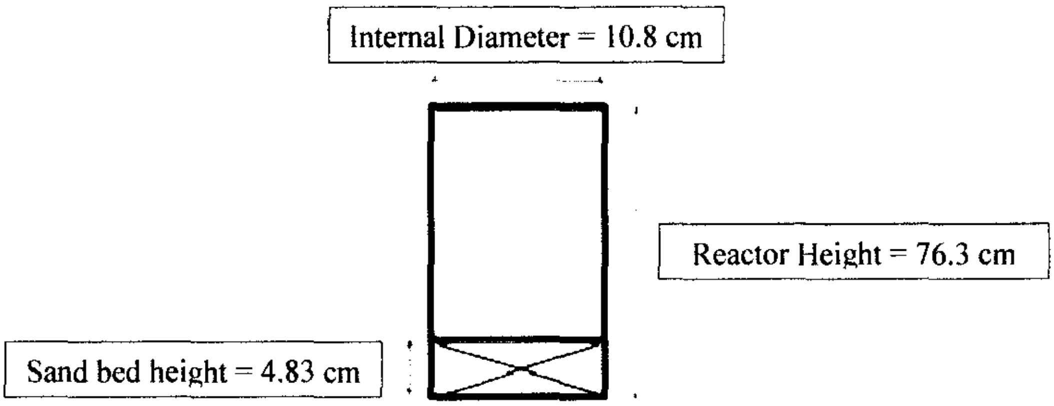
Figure 7: Product Yield %

Figure above has shown the yield % of the pyrolysis product that was conduct at 450°C in the fluidized bed reactor. About 82.282% of bio-char were produced during the experiment.

Year	Biomass Type	Reactor Design	Bio oil Yield	Char yield	Optimum Temperature
2009	Sawdust [13]	D = 80 mm H = 300 mm Capacity = 0.15kg/h	58.10%	28%	450 °C
2009	Switchgrass [14]	D = 162 mm H = 1000 mm Capacity = 5kg/h	42.60%	40%	450 °C
2007	Oil Palm Empty Fruits Branches [15]	D = 162 mm H = 1000 mm Capacity = 5kg/h	70%	12%	500 °C

Figure 8: Summary of previous experimental research on several biomasses using fluidized bed reactor fast pyrolysis

From the figure 8 above, all the previous research using fast pyrolysis process shown that bio-oil yield should have higher yield % compared to the bio-char and gases. In order to find out the error of this experiment, the reactor vapour residence time have been calculated:



$$Area = \left(\frac{\Pi}{4}\right) * 10.8^2$$

$$= 91.6\ \text{cm}^2$$

N_2 flowrate = 22 L/min = 22000 ml/min = 22000 cm^3

Superficial velocity at 25°C = (Flowrate/Area)
= 240.2733 cm/min
= 4.0 cm/s

Reactor set temperature = 450°C

Superficial velocity at 450°C = 4.0 cm/s*(273°C+450°C)/(273°C+25°C)
= 9.72 cm/s

Reactor residence time = (76.3 cm – 4.83 cm)/9.72 $\frac{cm}{s}$
= 7s

From this calculation, the residence time of the fluidized bed reactor in this experiment is 7s.

According to N. Adullah, In **slow pyrolysis** process, biomass is pyrolysed at low heating rate with a relatively long vapor residence time which leads to **less production of liquid and gas** but more on char production. This process has been used for a long time to produce charcoal otherwise for **Fast pyrolysis;** it involves rapid heating of biomass and short vapor residence time. Heating rate is around 300 ^{o}C/min and the vapor residence time is below than 2 seconds. Generally, fast pyrolysis is applied to obtain high-grade bio-oil. From the result of this experiment, long vapor residence time has led to high volume of bio-char compared to the bio-oil.

CHAPTER 5: CONCLUSION

All the data obtained will serve as basis of improvement for future work to obtain the desired results for the fast pyrolysis products and bio-oil yield.

In future work, several parameters will be investigated including a range of reactor temperature, feedstock particle size and type of biomass to determine the optimum conditions and key variables that required maximizing the liquid yield and its quality.

REFERENCE

A.V. Bridgwater a, D. M. (1999). An overview of fast pyrolysis of biomass. 1479-1493.

Akwasi A. Boateng, *. D. (2007). *Bench-Scale Fluidized-Bed Pyrolysis of Switchgrass for Bio-Oil Production*, 1893.

Akwasi A. Boateng, *. D. (2007). *Bench-Scale Fluidized-Bed Pyrolysis of Switchgrass for Bio-Oil Production*, 2.

Amiruddin, M. N. (2003). *Palm Oil Products Exports, Prices and Export Duties: Malaysia and Indonesia Compared*, 23.

Amiruddin, M. N. (2003). *Palm Oil Products Exports, Prices and Export Duties: Malaysia and Indonesia Compared*, 21.

Bridgwater, A. (1999). *Principles and practice of biomass fast pyrolysis processes for liquids. Journal of*, 51: 3–22.

Bridgwater, A. (2004). *Biomass fast pyrolysis. Thermal science*, 8-2 : 21-49.

Broda. (1992). Biotechnology in the degradation and utilization of lignocellulose. 3:219–238.

Chum, H. L. (2001). *Biomass and renewable fuels. Fuel Processing Technology*, 187-195.

Encinar, J. M. (1996). *Pyrolysis of two agricultural residues: olive and grape bagasse. Influence of particle size and temperature. Biomass and Bioenergy*, 11-5: 397 – 409.

Haiping Yang, R. Y. (2006). *Characteristics of hemicellulose, cellulose and lignin pyrolysis*, 1783.

Hyeon Su Heo a, H. J.-K. (2009). *Bio-oil production from fast pyrolysis of waste furniture sawdust in a fluidized bed*, S92.

Hyeon Su Heo a, H. J.-K. (2009). *Bio-oil production from fast pyrolysis of waste furniture sawdust in a fluidized bed*, S92.

Kamaruddin, e. a. (1997). *Improvement of oil palm fronds CTM-pulp brightness-a preliminary study. Proc. Of*, 219-230.

McMillan, J. D. (1994). *Pretreatment of Lignocellulosic Biomass*, 294.

N. Abdullah, H. a. (n.d.).

N. Abdullah, H. a. (2007). *Bio oil from fast pyrolysis of oil palm empty fruit bunches.*

S. Czernik, a. A. (2003). Overview of Applications of Biomass Fast Pyrolysis Oil. 18, 590-598.

Sensoz, S. D. (2006). Olive bagasse (Olea europea L.) pyrolysis. Bioresource. 429-436.

APPENDIX A: BIO-CHAR AT FIRST CYCLONE

APPENDIX B: BIO-CHAR COLLECTED IN REACTOR