Effect of Particle Size on Wood Torrefaction

By

Siti Shafriena Binti Mohd Afandi

Dissertation submitted in partial fulfilment of
the requirements for the
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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Chemical Engineering Programme
Universiti Teknologi PETRONAS
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(CHEMICAL ENGINEERING)

Approved by,

Prof. Dr. Yoshimitsu Uemura
Chemical Engineering Department
Universiti Teknologi PETRONAS

(Prof. Dr Yoshimitsu Uemura)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2006

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.

(______________________________)

SITI SHAFRIENA BINTI MOHD AFANDI

ABSTRACT

Torrefaction is a pretreatment process of biomass at temperature range of 200-300 °C with the absence of oxygen. The objective of this paper is to conduct a torrefaction experiment as a way to get a better fuel quality and to treat the biomass into high calorific value biomass. This experiment also wants to optimize the best particle size used during the experiment. The problem of biomass is that it content high moisture which result in a high mass biomass. The particle size itself gives it significant effect to relative weight lost during the torrefaction experiment. The different particle size of wood is put under an inert condition by flushing the nitrogen into the reactor. The temperature of the reactor was raised to different desired levels, i.e. 220, 250 or 300 °C at a constant rate of 10 deg/min by an electric furnace surrounding the reactor.

ACKNOWLEDGEMENT

Bissmillahirrahmanirrahim,

Alhamdulillah. Thanks to Allah SWT, whom with His willing giving me the opportunity to complete this Final Year Project which is title Effect of Particle Size on Wood Torrefaction. This final year project report was prepared for Chemical Engineering Department, University Teknologi PETRONAS (UTP), basically for student in final year to complete the undergraduate program that leads to the degree of Bachelor of Chemical Engineering. This report is based on the methods given by the university.

Firstly, I would like to express my deepest thanks to, Prof. Dr Yoshimitsu Uemura, a lecturer at Chemical Engineering Department UTP and also assign, as my supervisor who had guided be a lot of task during two semesters session 2010/2011. I also want to thanks the lecturers and staffs of Chemical Engineering Department UTP for their cooperation during my final year project. They had given valuable information, suggestions and guidance in the compilation and preparation this final year project report.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1 Background Study

Renewable energy has become more important globally especially with the current fuel and economic crisis. It is reported that fossil fuel is going to deplete in next coming 10 years. Furthermore the carbon dioxide emissions from fossil fuel are reported at an average rate of 2.1 % per year and it is forecast the rate continues to increase. [1]

Biomass is a unique fuel and has the potential to play a significant role in the future energy mix in the Malaysia. Unlike other renewable energy, biomass can provide continuous electricity generation, and is the only widespread source of renewable heat. Increased use of biomass as a source of energy (electricity and heat) will contribute to the reduction of CO2 emissions, increase energy security, and support sustainable development and regeneration of rural areas, both through increased agricultural and forestry activity and the provision of small scale localised energy and heat generation schemes.

As an alternative to fossil fuel dominant, the world now is moving towards sustainable energy sources which are biomass because of its carbon neutrality. Biomass is the alternative to replace the necessity of fossil fuel. Biomass is any natural thing that has been grown or has lived, excluding fossil fuels such as coal, oil, natural gas and many more. Biomass can be in the form of straw, biological wastes, waste paper, organic wastes from food processing, livestock farming and so many others. Biomass can be utilized to produce energy. One of biomass is wood. [2]

1.2 Problem Statement

Biomass offers much potential as a renewable fuel for displacing coal in large-scale power plants. Given that the carbon contained in biomass is taken directly from the atmosphere, the fuel is largely considered to be carbon-neutral. Biomass also contains less sulfur, nitrogen, ash, and heavy metals than coal.

However, there are currently several problems with biomass that prohibit it from being used on a larger scale for power production. It has a much lower heating value compared to coal and suffers from logistical issues related to transportation, handling, and storage. Because of high moisture contents and low energy densities, the cost of transportation to the plant is high.

In addition, the fibrous nature of biomass often causes handling problems, requiring more energy to be spent on grinding the material. Open-air storage can also be a hindrance as the hydrophilic nature of biomass can cause it to absorb more moisture over time.

Torrefaction has the potential to solve these problems by improving the properties of the fuel. It produces a higher quality product with increased heating value, increased energy density, and improved grindability properties.

Torrefaction is a mild pyrolysis process occurring at low temperatures in the range of 250 – 300°C and in the absence of oxygen. When biomass is torrefied, a portion of the volatile matter is driven off in the form of light gases and other condensable organic compounds.

To simplify, below are several problems regarding biomass waste; [3] [4]

(1) Low heating value
(2) High moisture content that will cost considerable amount during drying process
(3) Hygroscopic nature (water absorbing nature)
(4) Smoke during combustion
(5) High energy consumption for collection
(6) Raw material difficult to transport

(7) Low calorific value or energy density
(8) Heterogeneous and uneven composition
(9) Low combustion efficiency

All those limitations have led to the idea of applying torrefaction process as a pre-treatment step of decomposition of biomass. It is actually a thermal treatment process in an inert condition which is absence of oxygen at a temperature range of 200°C to 300°C. During this process it will destructs the fibrous structure and tenacity of biomass (wood). [5] This will result in a torrefied wood biomass which is;

(1) High calorific value
(2) Hydrophobic nature which is water repellant
(3) Decrease in mass
(4) Improve the grind ability

Moreover, besides the thermal conversion of biomass also logistic properties can be improved through torrefaction when torrefaction is combined with densification (pelletisation).

1.3 Objective & Scope of studies

The objectives of this experiment are:

1. To conduct a torrefaction experiment
2. To observe the effect of particle size and type of wood used

CHAPTER 2
LITERATURE REVIEW

2.1 Lignocellulosic Structure of biomass

Biomass refers to renewable energy source and biological material derived from living or recently living organism.

Wood is one of biomass which has lignocellulosic structure. Lignocellulosic is originates from plants which consists of three main sugar-based polymeric structures; hemicellulose, celluloses and lignin structure. [5]These three are mainly considered are the important chapter to understand in order to study about the decomposition mechanism of woody biomass. In plant structures lignocellulose normally forms the most dominant group of constituents on a mass basis. Lignocellulose provides mechanical strength and tenacity (toughness) to plant structures and so provides body and the opportunity to grow in height for optimal photosynthesis.

Figure 1: Lignocellulosic structure

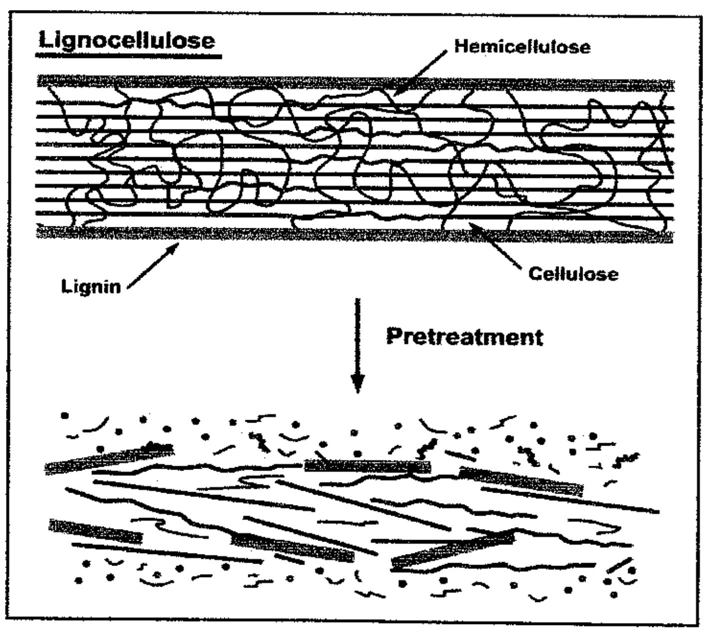


Figure 2: Detailed impression of the structure of a cell wall.

(a) Part of the cell wall and middle lamella, primary wall and secondary cell wall,

(b) Macro fibril mutual structure,

(c) Micro fibril structure,

(d) Individual cellulose polymers including micelles, and

(e) Mutual coherence of individual cellulose polymers on a micro level

(taken from: Raven and Eichhorn, 1999)

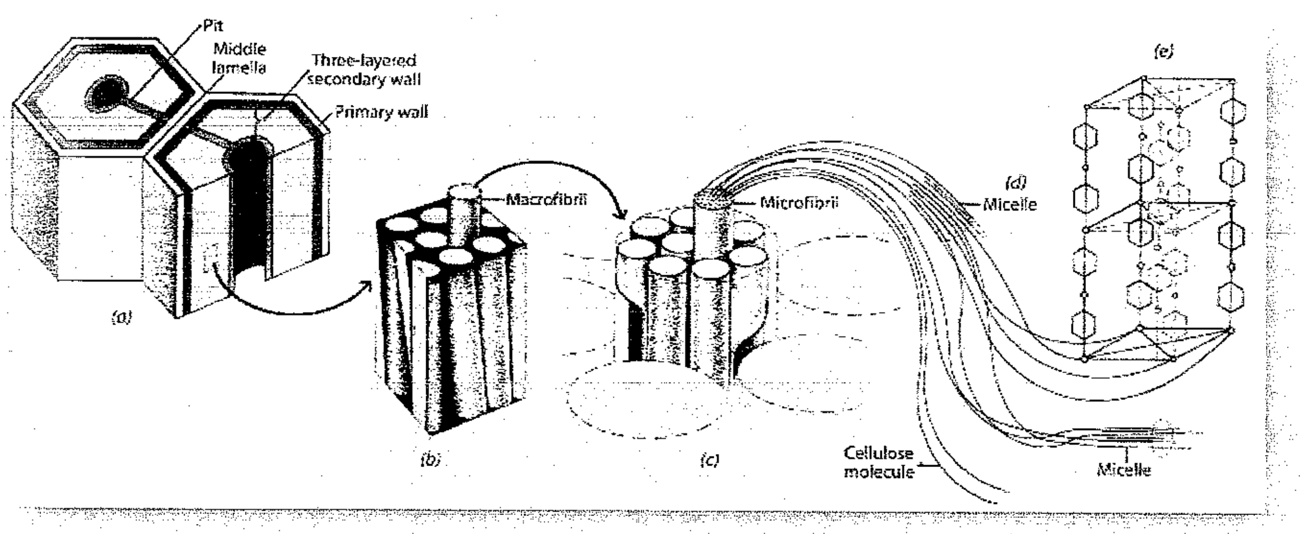


Table above summarize the overall composition of most wood and also their decomposition temperatures [6];

Table 2: Composition and decomposition temperature of wood structure

Type	Composition	Decomposition Temp
Cellulose	33 %.	275-350 °C,
Hemicelluloses	28 %	150 - 350 °C
Lignin	24 %	250 – 500 °C

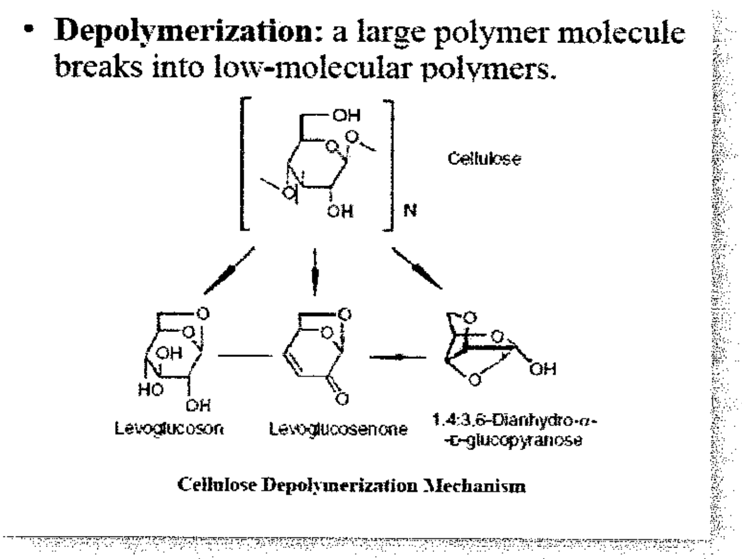
Hemicellulose is most reactive and is subjected to limited devolatilisation and carbonisation below 250 °C. Above 250 °C it is subjected to extensive devolatilisation and carbonisation. While cellulose is most thermo-stable and is subjected to limited devolatilisation and carbonisation only. Lignin its reactive is in between both others.

Loss of the tenacious nature of the biomass is mainly coupled to the breakdown of hemicellulose matrix, which bonds the cellulose fibres in biomass. [7]

2.2 Torrefaction

Torrefaction is a thermo-chemical treatment method that is earmarked by an operating temperature ranging from 200 °C to 300 °C. It is carried out at near atmospheric pressure in the absence of oxygen (inert condition) and characterized by low particle heating rates (< 50 °C/min).

Figure 11: depolymerization of cellulose



Cellulose Depolymerization Mechanism

Cellulose composition in wood often received the most attention considering the thermal decomposition of biomass; however in real cases cellulose decomposition is not the most relevant constituent during torrefaction temperature. During 200 – 300 □C, mass loss will predominantly come from the decomposition or devolatilisation of particularly hemicelluloses and some lignin. Xylan-based hemicellulose generally has its peaking rate in decomposition around 250 to 280 °C. [5] however, the thermal decomposition behavior of the individual polymers of wood (and in general biomass) may be different from their strongly interacted structure in wood itself.

When biomass is heated at such temperatures, the moisture as well as various low-calorific components contained in the biomass is driven out. Then, a process known as de-polymerization takes place: the hemi-cellulose in the biomass starts to decompose and breaks down into polymers of a lesser size, which transforms the biomass into a product with coal-like characteristics.

During decomposition of hemicelluloses there are two-step mechanism involved as was found by Di Blasi and Lanzetta(1997) [8] First reaction is depolymerization reaction which lead to altered and rearranged polysugar structures at temperature below 250°C. . The second step is the decomposition of oligosaccharides and monosaccharides at higher temperatures (250-300°C) which results in the formation of chars, CO, CO2 and water.

As a result, significantly lower energy is require to process the torrefied fuel and it no longer requires separate handling facilities. It has also been suggested that the modified fuel can be compacted into high grade pellets with substantially superior properties when compared with standard wood pellets. The process can be incorporated into a combined drying, torrefaction and pelletisation process, with both economic and energy efficiency benefits [12].

The balance between costs and energy consumption and the cost and energy benefits from a more grindable, higher calorific value fuel are therefore critical for the future of torrefaction and require thorough analysis and reliable, extensive data. A evaluation of the torrefaction of wood chips published in 2001 concluded that the environmental and heating value benefits gained by torrefaction are not significantly greater than the extra energy consumption and capital investment [13], although it did indicate potential for the torrefaction concept in fuel densification.

However, a number of other publications are optimistic about the benefits torrefaction has to offer. Torrefaction has only received significant interest in the last two decades, and has yet to become a commercial process. The majority of research to-date has focused on the compositional changes that occur in biomass, determined by proximate and ultimate analysis, along with mass and energy yields.

2.3 Torrefied Biomass

The aim of torrefaction is to get the production fuel which improved in properties compared to the original biomass feed. However this should be achieved without the losing too much in chemical energy. Hence the mass yield and energy yield would be the most important parameter to monitor. Therefore, the definition of the mass and energy yield are expressed on the basis on the organic part of the biomass, thus on dry and ash-free basis (daf):

$$\eta_M = \left(\frac{m_{char}}{m_{feed}}\right)_{daf}$$

and

$$\eta_E = \eta_M \left(\frac{LHV_{char}}{LHV_{feed}}\right)_{daf}$$

After torrefaction, the biomass will increase it calorific value or its energy density. In addition to that, the physical property such as its grind ability is increased. From a heterogeneous, it's become homogeneous as it is the same throughout and can be evenly mixed.

In combination with pelletisation, torrefaction also aids the logistic issues that exist for untreated biomass. Pelletization includes the following processes: drying, chipping, grinding and pelletizing of lignocllulosic biomass [3]. The pelleting process, has increased its bulk density.

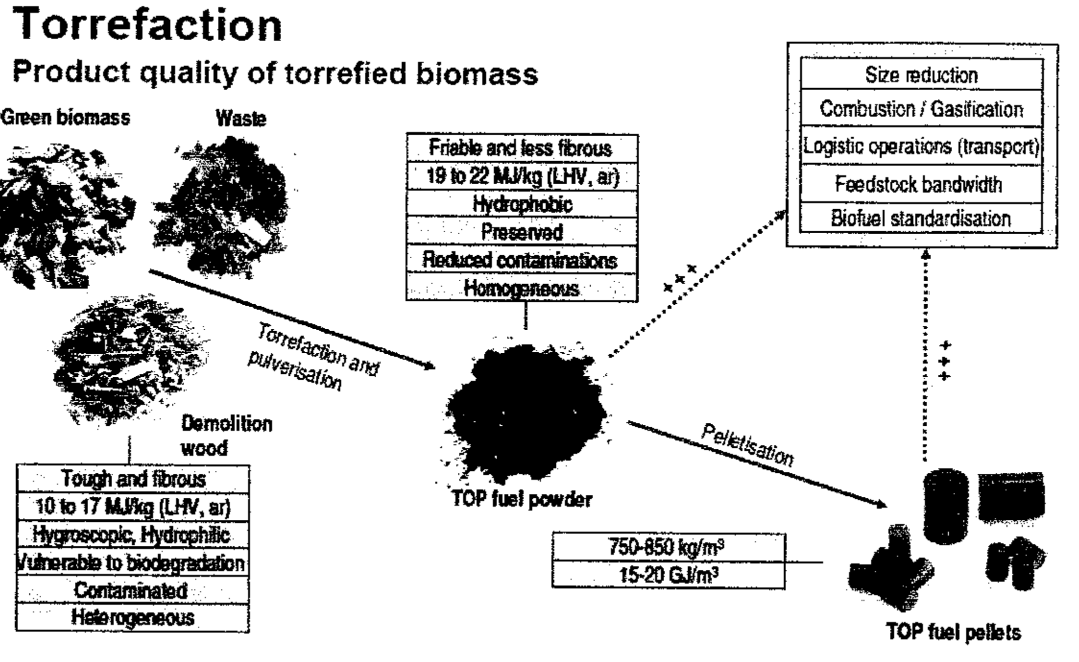


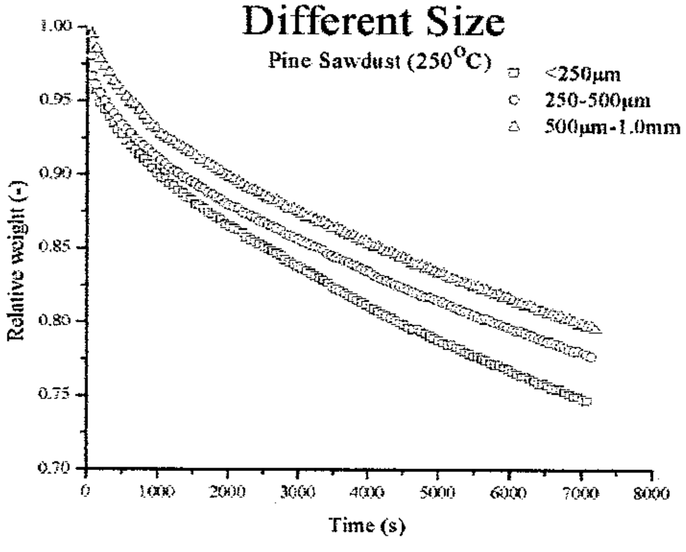
Figure 12: Product quality of biomass

Torrefaction gives 3 immediate benefits toward the untreated biomass which are:

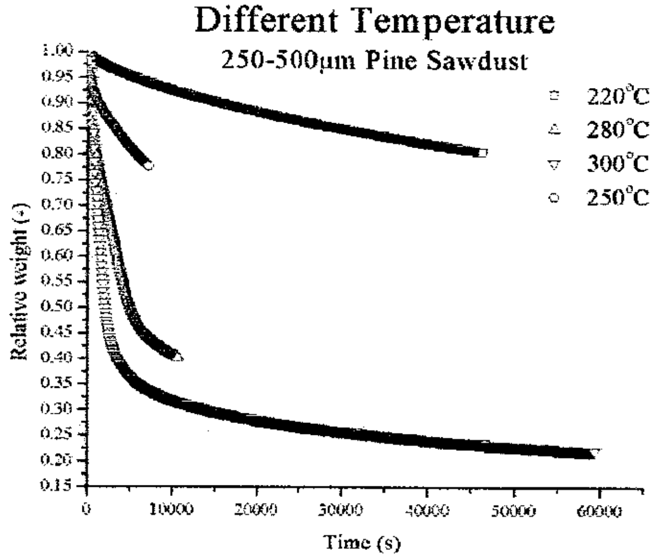
1. The calorific value (energy per unit of weight) increases considerably;
2. Torrefied biomass is easy to grind and can easily be compacted into a product with high volumetric energy density (energy per unit of volume);
3. The physical properties of torrefied biomass, such as durability, homogeneity and hydrophobic behavior are improved significantly, while the biological activity is strongly reduced.

2.4 Effect of Particle Size and Temperature

The significant of using different particle size had been shown by the previous study [9].



It it showed that the particle size use during torrefaction thus give a significant impact towards it relative weight lose during the process. From previous study, the smaller the size, the higher relative weight loses we will get during torrefaction.



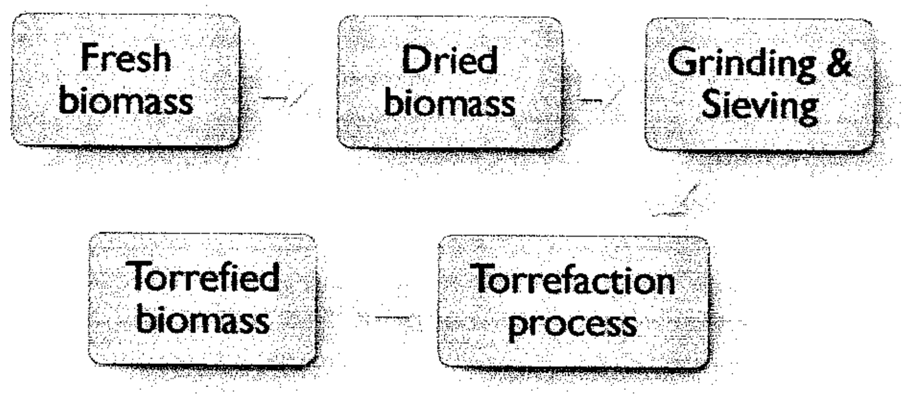
The temperature also give a significant effect towards the relative weight lose during torrefaction. The highest temperature which is 300 °C is the best temperature to conduct torrefaction experiment.

CHAPTER 3
METHODOLOGY

3.1 Project Activities

The process flow of this project is shown as follow:

Figure 5: Project activities



During torrefaction process, the procedures are as follow;

I. Fresh biomass is dried using oven in temperature of 105 Celcius.

II. Then, the dried biomass is grinded to break them into pieces. After that, the different size of wood particle is sieved to separate the wood into same sizes.

III. The different particle size of wood is tested during the torrefaction experiment. There are three types of wood and four sizes of wood particles are tested in this experiment.

IV. Torrefaction of the biomass wastes was carried out using a vertical tubular type reactor made of stainless steel, with a 2.8 cm internal diameter.

Table 2: Type and Sizes of wood

Types of wood	Particle size
Acasia	125-250 um
Meranti/Seraya	250-500 um
Golden powder/plywood	1-2 mm
-	4-8 mm

V. Then, a prescribed amount of biomass waste (3 g) was weighed, and put on a the glass wool,

VI. After flushing the reactor with nitrogen for 10 minutes, the temperature of the reactor was raised to different desired levels 250 °C at a constant rate of 10 deg/min by an electric furnace surrounding the reactor.

VII. After a 60 min torrefaction, the heater was turned off and the reactor was left to cool down to the ambient temperature.

VIII. The torrefied sample was then recovered, weighed and kept in an air-tight vessel till the characterization.

3.3 Apparatus

The apparatus used in this experiment are:

1) Reactor
2) Glass wool
3) Bomb calorimeter
4) CHNS-93
5) Microwave

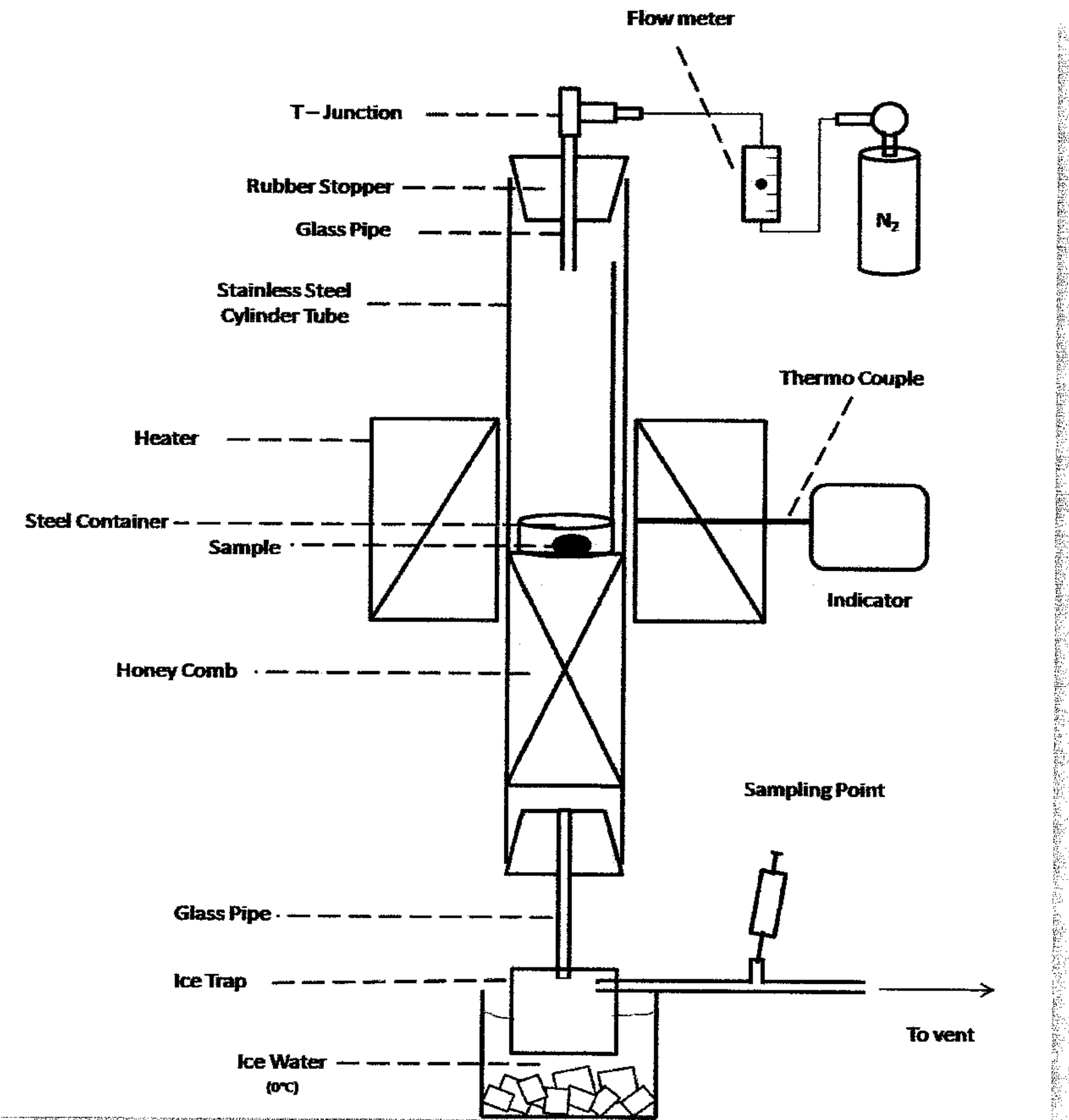


Figure 13: Reactor

Figure 7: Real Reactor in Block 4

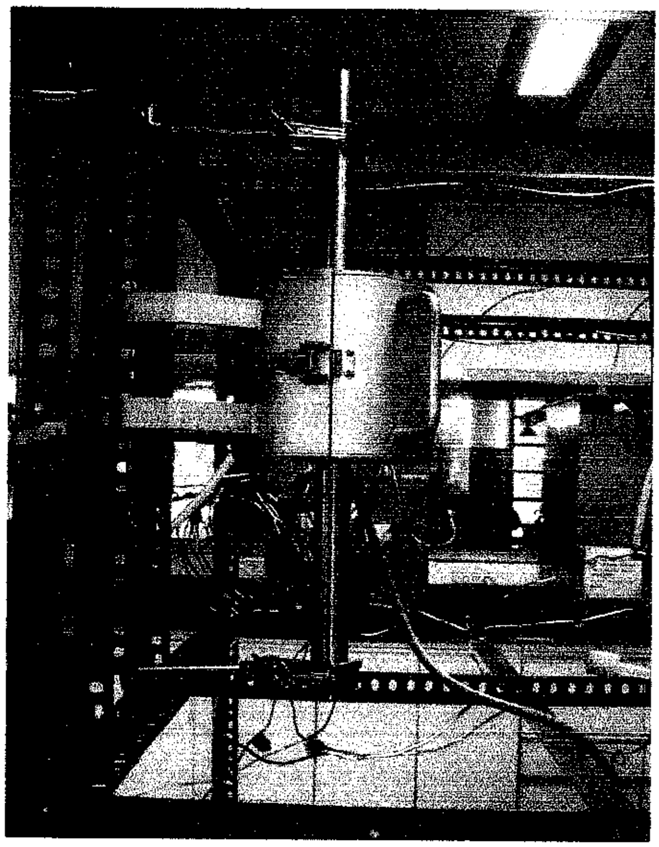
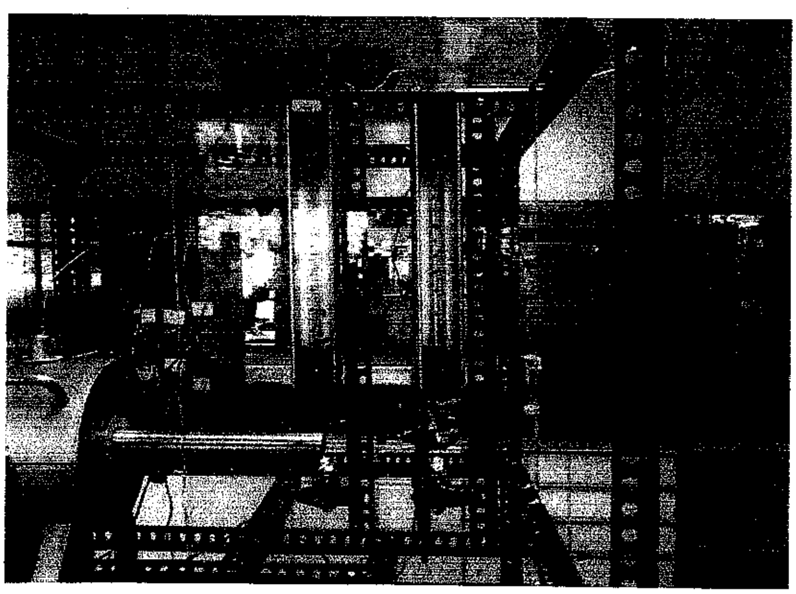


Figure 8: Nitrogen flowmeter



3.4 Characterization

Before and after the torrefaction process there five characterizations to be monitored:

Table 3: Characterization prosedures

No	characterizations	Measurement
1	Moisture content	A prescribed amount of sample (3g) was weighed in a ceramic crucible, and was placed in an electric oven maintained at 105 °C. After drying for 24 h, the sample was weighed every one hour till the decrease in weight became negligibly small.
2	Calorific value	It is measured using a bomb calorimeter, model C2000 series manufactured by IKA Werke. The calorific value from a bomb calorimeter is the high heat value (HHV), which includes the latent heat of the vapor emitted from the specimen.
3	Elementary (CHNS) analysis	It is carried out using CHNS-932 supplied by LECO Corporation. The carbon, hydrogen, nitrogen and sulfur contents were obtained from the analytical experiment. The oxygen content was calculated by the subtraction.
4	Ash content	A prescribed amount of sample (1 g) was weighed in a ceramic crucible, and was placed in an electric furnace. The temperature was raised to 700°C. After 3 h, the furnace was turned off and was allowed to cool down. The crucible containing the ash was weighed.

CHAPTER 4
RESULT AND DISCUSSION

Torrefaction has the potential to solve these problems by improving the properties of the fuel. It produces a higher quality product with increased heating value, increased energy density, and improved grindability properties.

The torrefaction experiment is conducted in this project specifically to see the best particle size to be used. There are two main portions in this project which are;

i. Characterization of biomass before torrefaction
ii. Torrefaction experiment

4.1 Characterization of biomass before torrefaction

Characterization of biomass before undergoing torrefaction is crucial to see the initial condition of the biomass. The result before was compared to the result after torrefaction. There are four characterizations which had been tested which are;

i. Ash content
ii. Moisture content
iii. Calorific value
iv. Carbon Hydrogen Nitrogen (CHN) analysis

4.1.1 Ash Content

Literally, ash content testing is an analysis to indicate the nonvolatile inorganic matter of a compound which remains after subjecting it to a high decomposition temperature. The higher ash content in the wood, the lower of the wood is converted to energy.

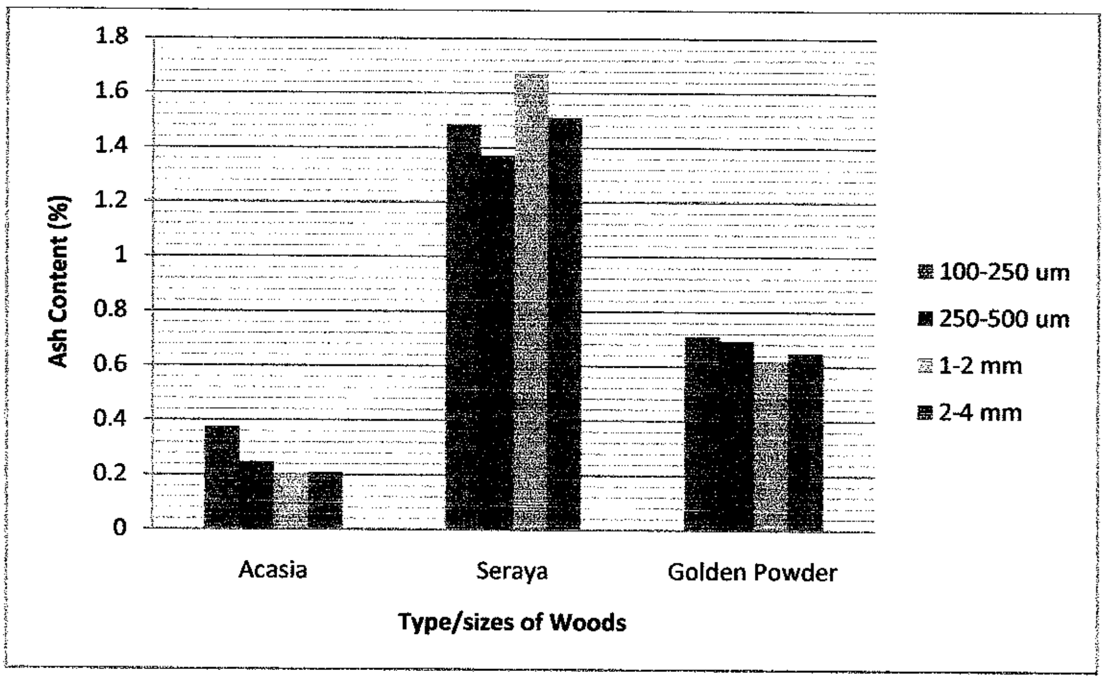


Figure 9: Ash content vs type/size of wood

In this experiment, ash content analysis has shown that Seraya has highest ash content compared to Acasia and golden powder. Ash content analysis shows that there are mineral in the wood that is not 100% change to energy. So seraya is not a good wood to be used as fuel the energy that will convert is small.

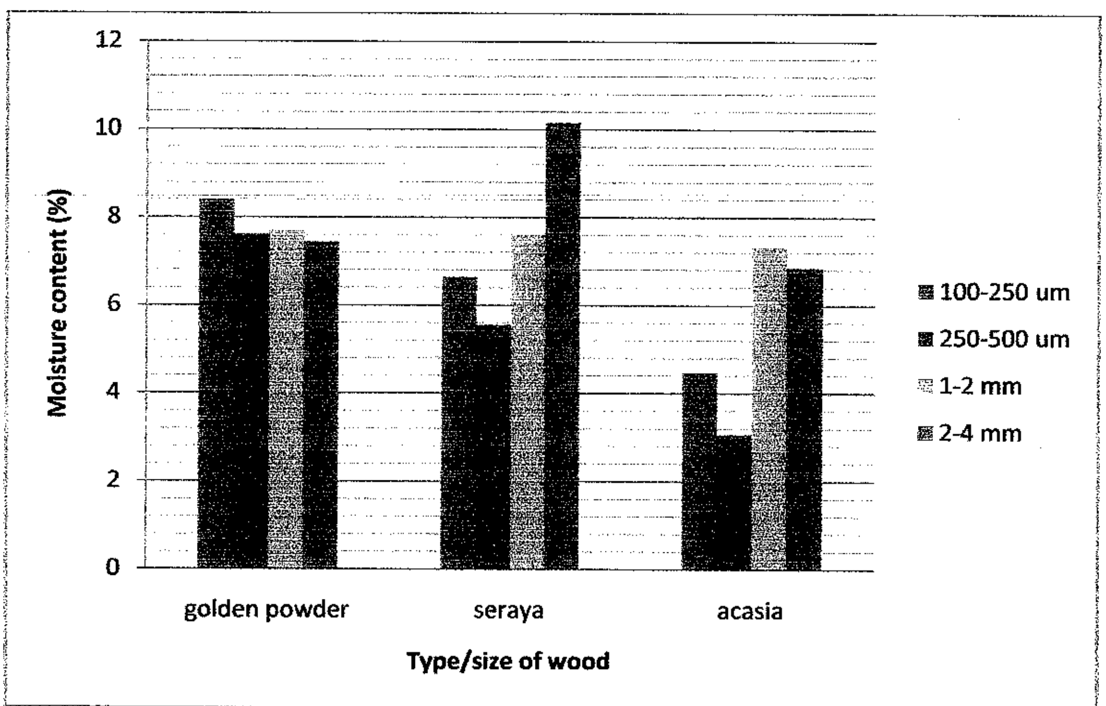
While acasia has the lowest ash content which shows that it can convert to energy really high compared to others.

4.1.2 Moisture Content

Water content or moisture content is the quantity of water contained in a material. Moisture content is the most important property with respect to the process energy efficiency. Only for very dry biomass feedstock (10-15% wt), lower efficiencies are to be expected.

Higher moisture content in the wood is not good because it will slow down the residence time and there will not much wood particle which will be torrefied.

Figure 10: Moisture content vs type/sizes of wood



4.1.3 CHNS Analysis

CHNS analysis is conducted using CHNS-932 supplied by LECO Corporation. The result above shows the carbon contains in every type of wood. It shows that acasia has the largest range of carbon. It is parallel with ash contain values. If the ash contain is higher, the carbon contain will be lower. while acasia has the lowest ash contain, but it contains highest value if carbon.

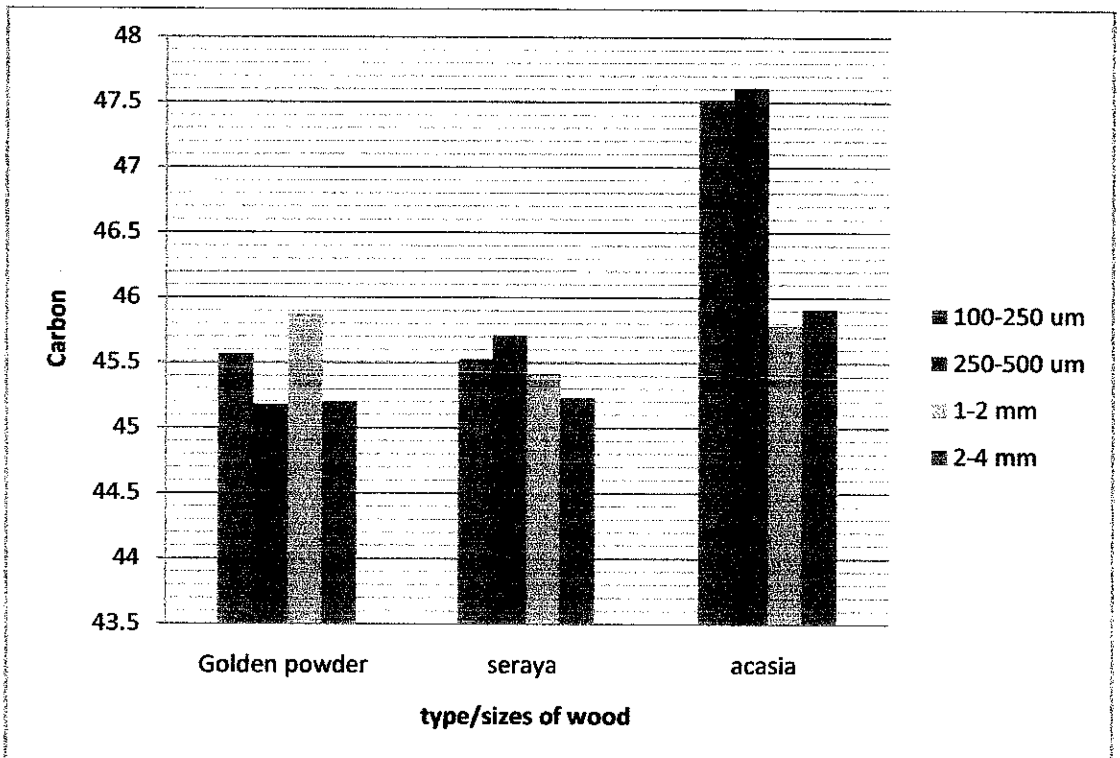


Figure 11: carbon vs type/sizes of wood

The table below shows the other result of hydrogen and nitrogen contain in the every type and size of wood.

Type/Size of wood	**C**	**H**	**N**
Golden powder (100-250 um)	45.57	6.76	0.14
Golden powder (250-500 um)	45.18	6.48	0.13
Golden powder (1-2 mm)	45.87	6.40	0.12
Golden powder (2-4 mm)	45.20	6.44	0.17
seraya (100-250 um)	45.53	6.48	0.19
seraya (250-500 um)	45.71	6.66	0.17
seraya (1-2 mm)	45.42	6.79	0.47
seraya (2-4 mm)	45.23	6.77	0.39
acasia (100-250 um)	47.52	6.78	0.38
acasia (250-500 um)	47.61	6.74	0.38
acasia (1-2 mm)	45.79	6.80	0.39
acasia (2-4 mm)	45.91	6.62	0.35

Table 4: CHNS analysis result

4.1.4 Calorific value

The calorific value of a fuel is the quantity of heat produced by its combustion - at constant pressure and under "normal" conditions. The combustion process generates water vapor and certain techniques may be used to recover the quantity of heat contained in this water vapor by condensing it.

The Higher Calorific Value supposes that the water of combustion is entirely condensed and that the heat contained in the water vapor is recovered. The Lower Calorific Value supposes that the product of combustion contains the water vapor and that the heat in the water vapor is not recovered.

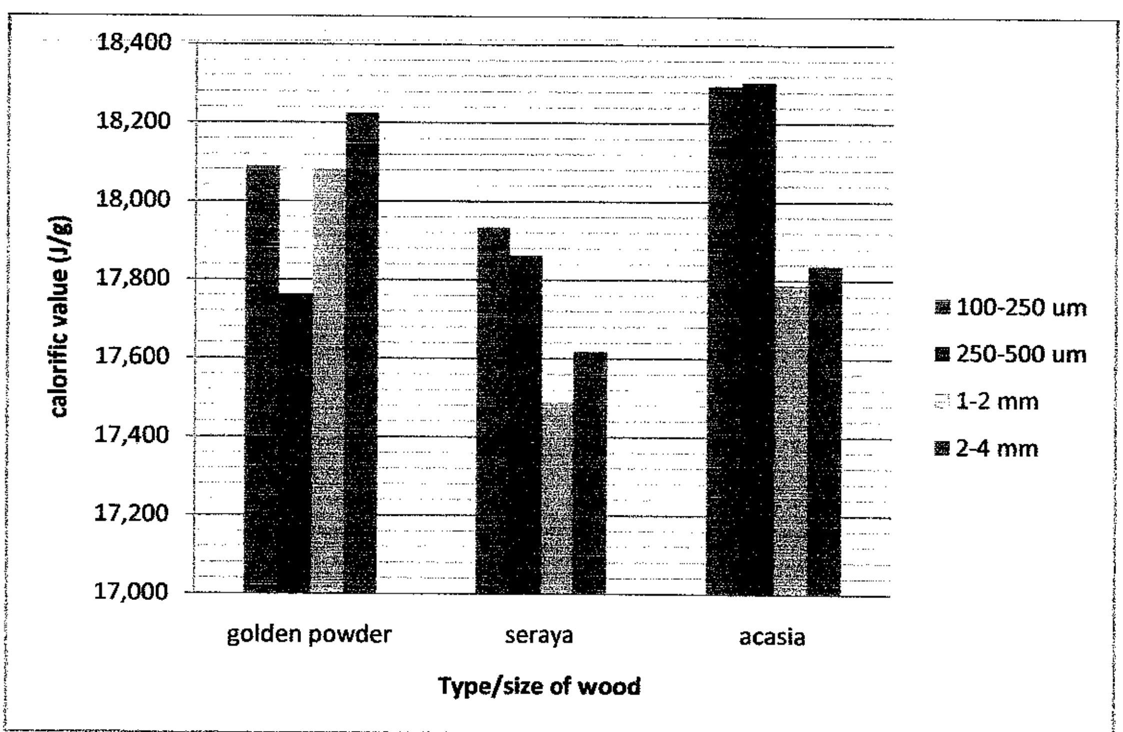


Figure 12: calorific value vs type/sizes of wood

4.2 Torrefaction Experiment

Torrefaction experiment is conducted only for golden powder with different sizes particle. The flowrate also is the same for golden powder run no GP 001 to GP 003 but for golden powder run no GP 004 to GP 005 is change to 20 and 15 to see if there any gaseous product detected.

Type	Run No	Size	Date of Run	Temperature
Golden Powder	GP 001	100-250 um	10/8/2011	250 °C
Golden Powder	GP 002	250-500 um	11/8/2011	250 °C
Golden Powder	GP 003	1-2 mm	12/8/2011	250 °C
Golden Powder	GP 004	2-4 mm	15/8/2011	250 °C
Golden Powder	GP 005	2-4mm	16/8/2011	250 °C

Table 5: Result of torrefaction experiment

Residence Time	N_2 Flowrate	Mass Before (g)	Mass After (g)	Mass Yield
60 min	100 ml/min	3.56	2.92	81.92
60 min	100 ml/min	3.01	2.26	75.29
60 min	100 ml/min	2.97	2.50	84.11
60 min	20 ml/min	3.02	2.63	87.01
60 min	15 ml/min	3.01	2.62	86.68

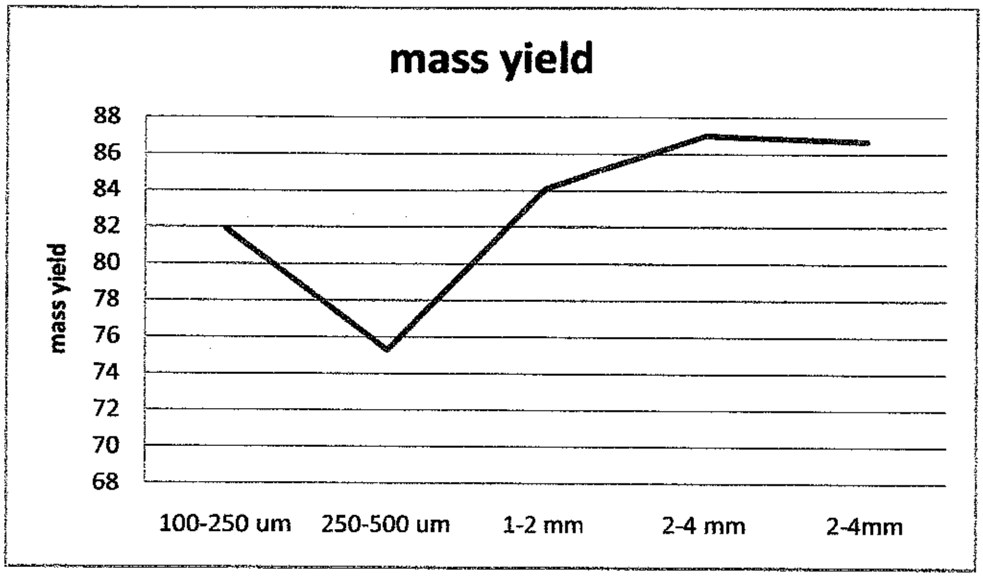


Figure 13: the mass yield vs particle size

The lower the particle size, the lower the mass yield. But in this project, the lowest particle size shows the other ways around. This is maybe due to error during experiment. The other particle size shows as the right yield according to theoretical.

Graphs below show the temperature profile of every sample during torrefaction experiment. These graphs are important to see the temperature profile of every sample because the surface temperature is slightly with the inner temperature.

GP001

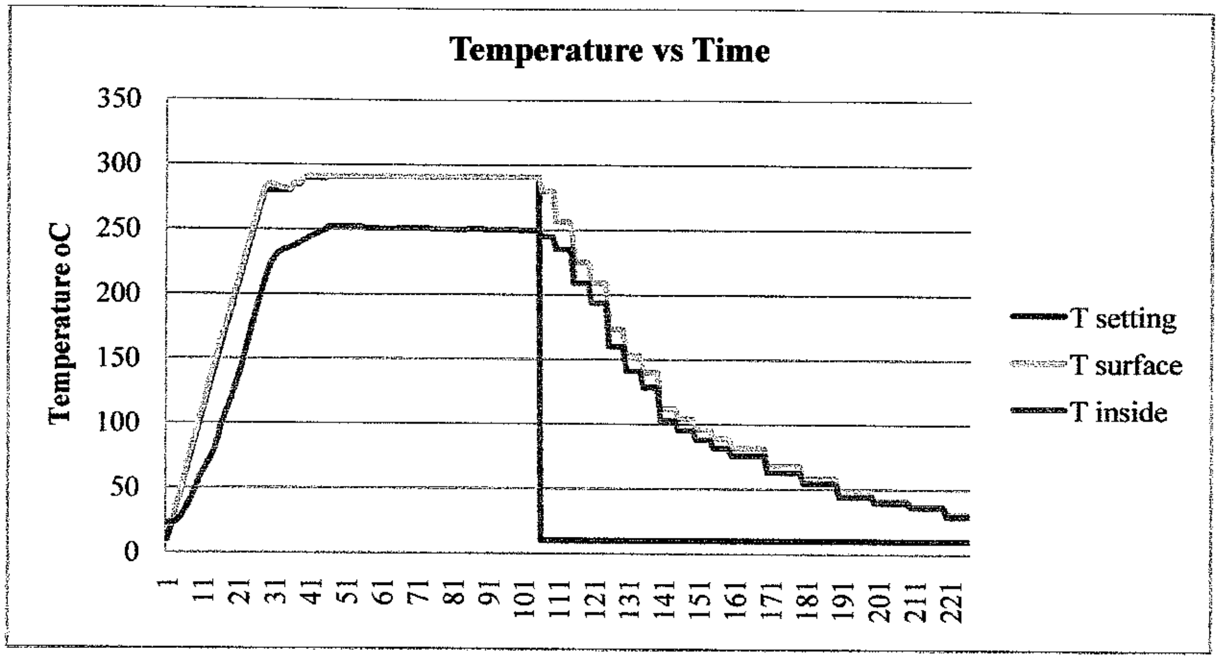


Figure 14: GP 001

GP002

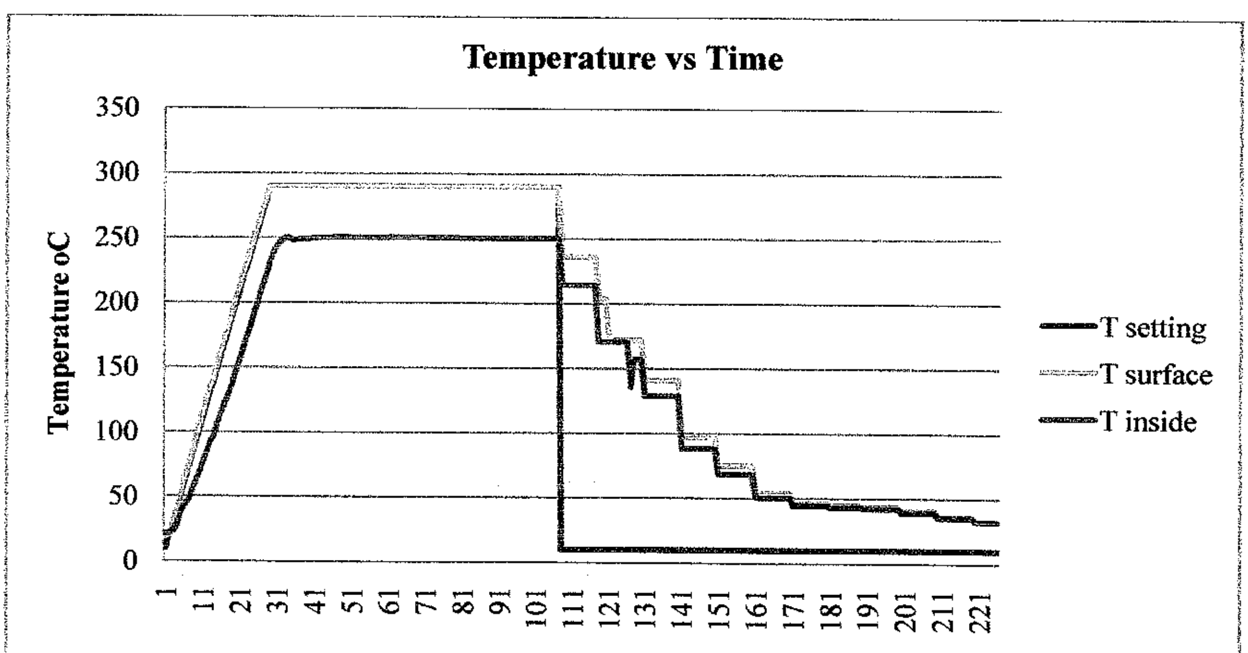


Figure 15: GP 002

GP 003

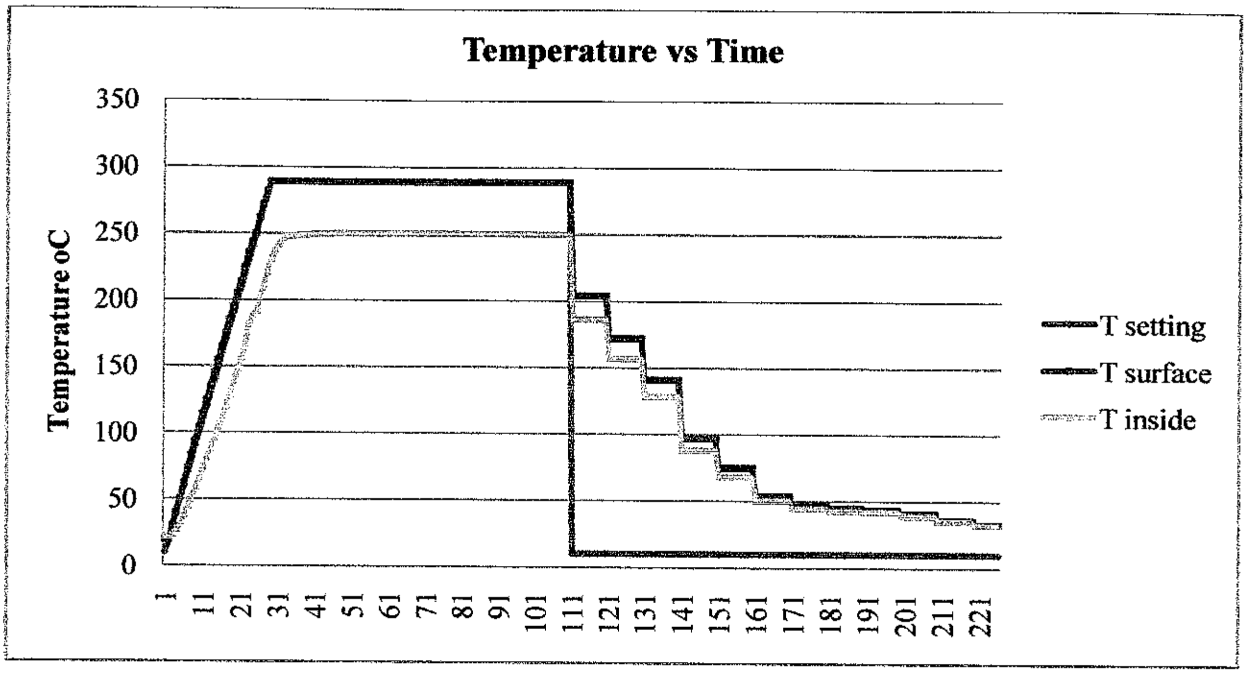


Figure 16: GP 003

GP004

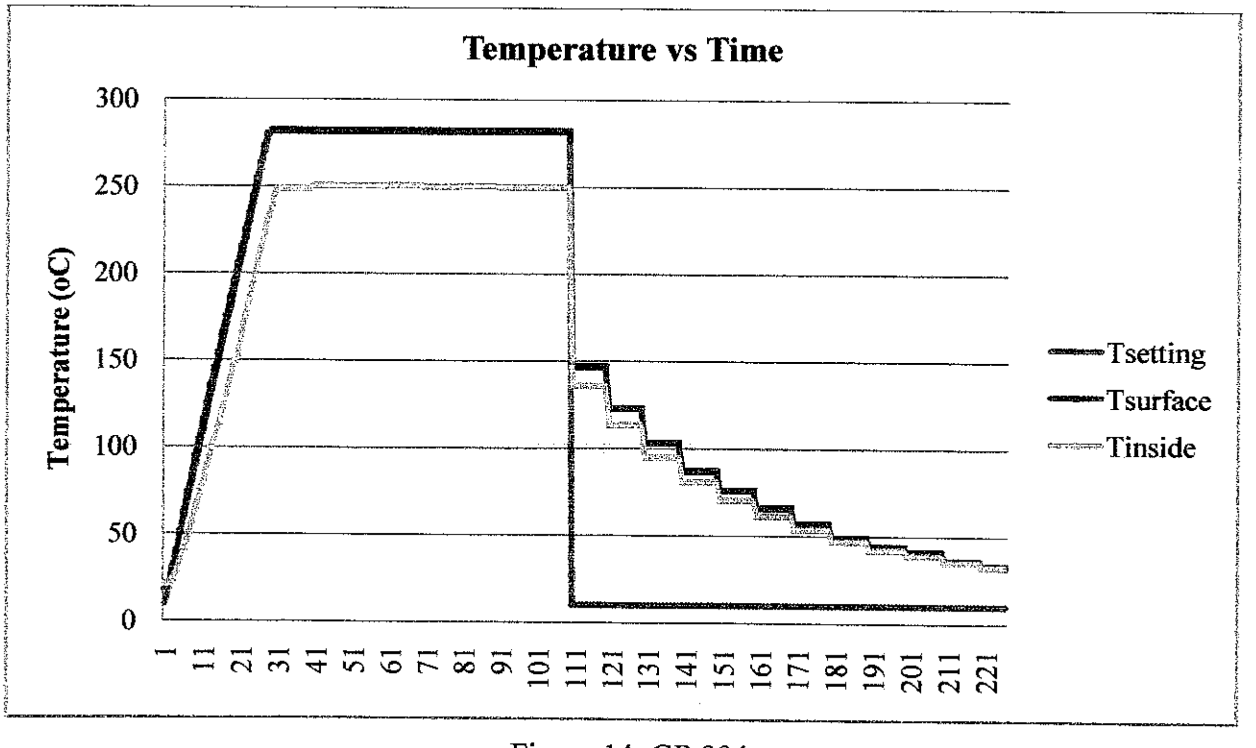


Figure 14: GP 004

GP 005

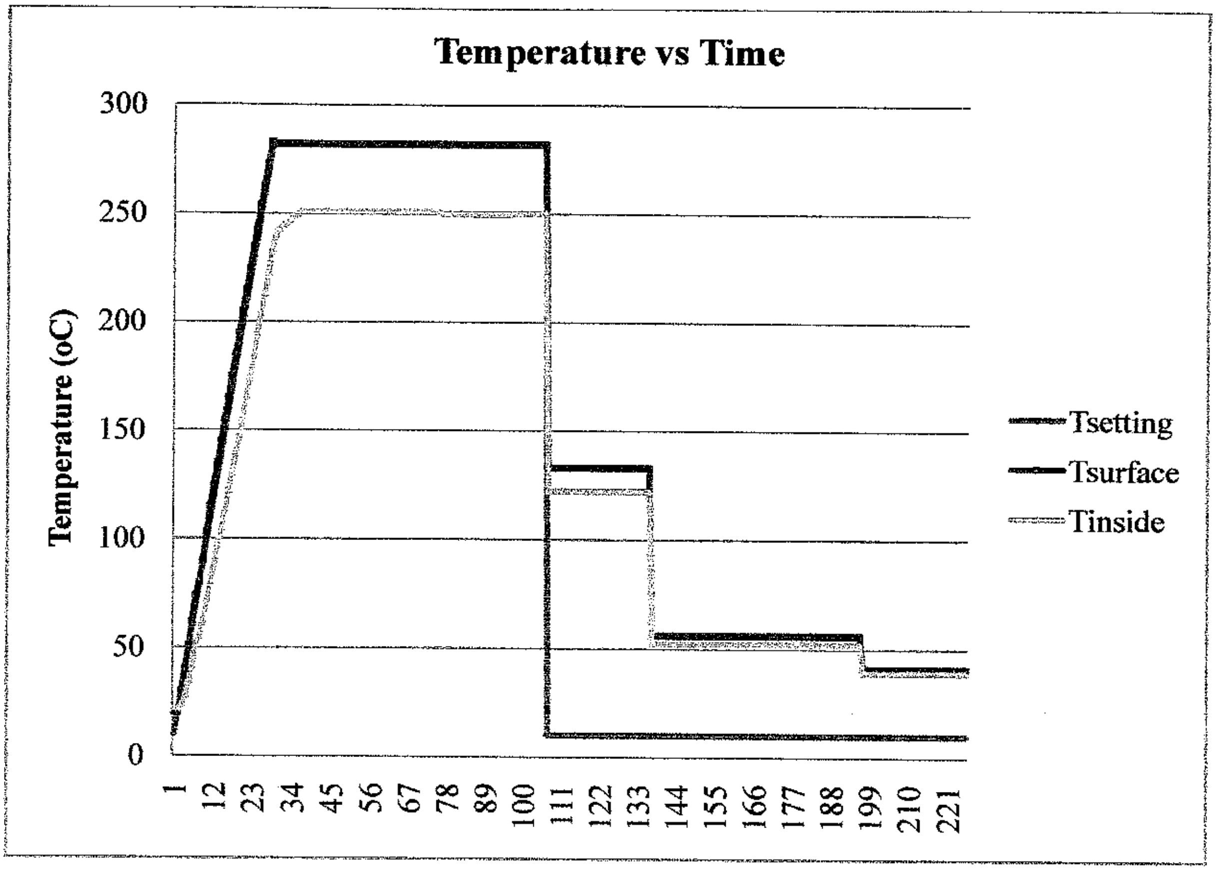


Figure 18: GP 005

4.3 Characterization of biomass after torrefaction

4.3.1 Ash Content

The ash content after torrefaction is varying for each particle size due to inconsistency.

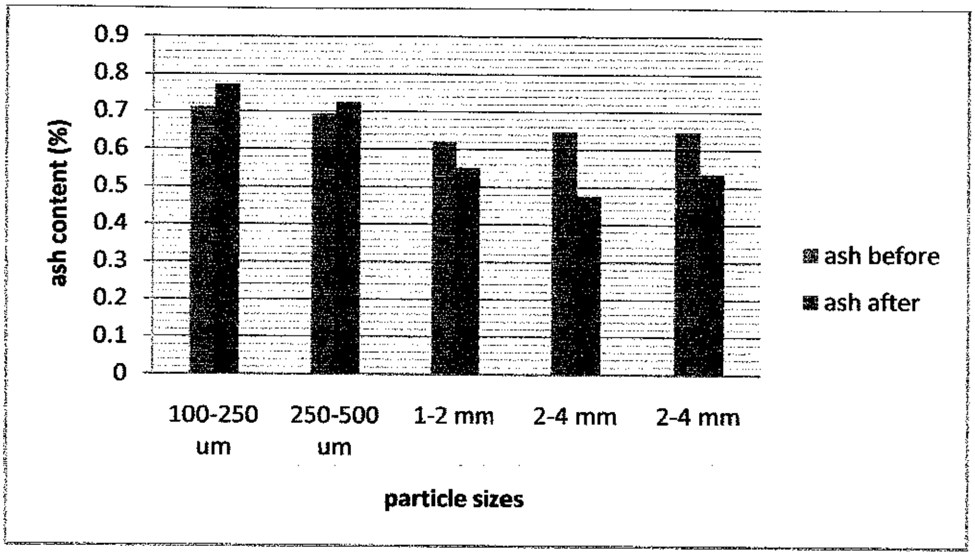


Figure 19: Ash content vs particle size

4.3.1 Moisture Content

The moisture content of all particle size is lower than before.

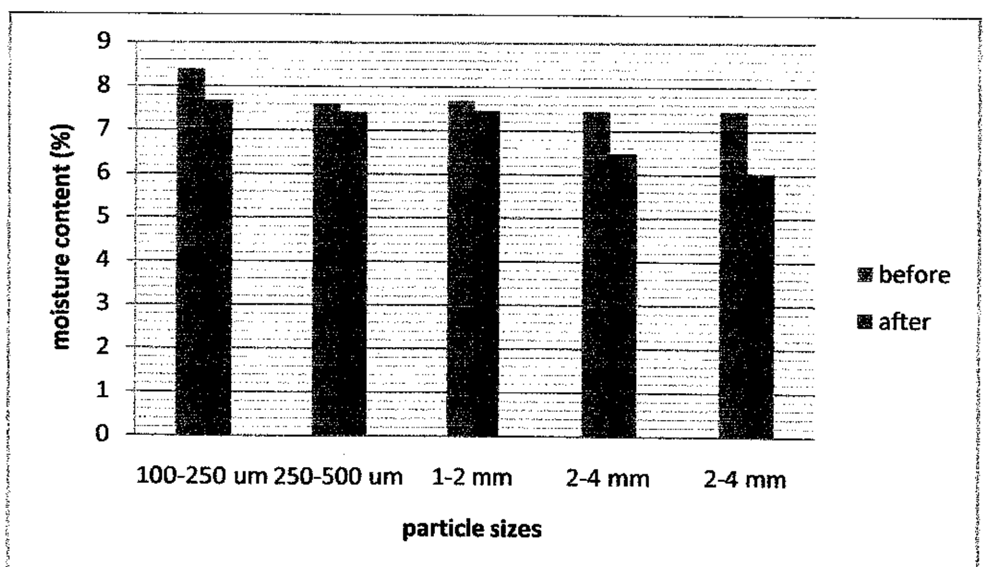


Figure 20: Moisture content vs particle size

4.3.2 CHNS Analysis

The carbon contain in all particle is increasing dramatically. This is parallel with theory which torrefaction will increase the carbon content of the wood.

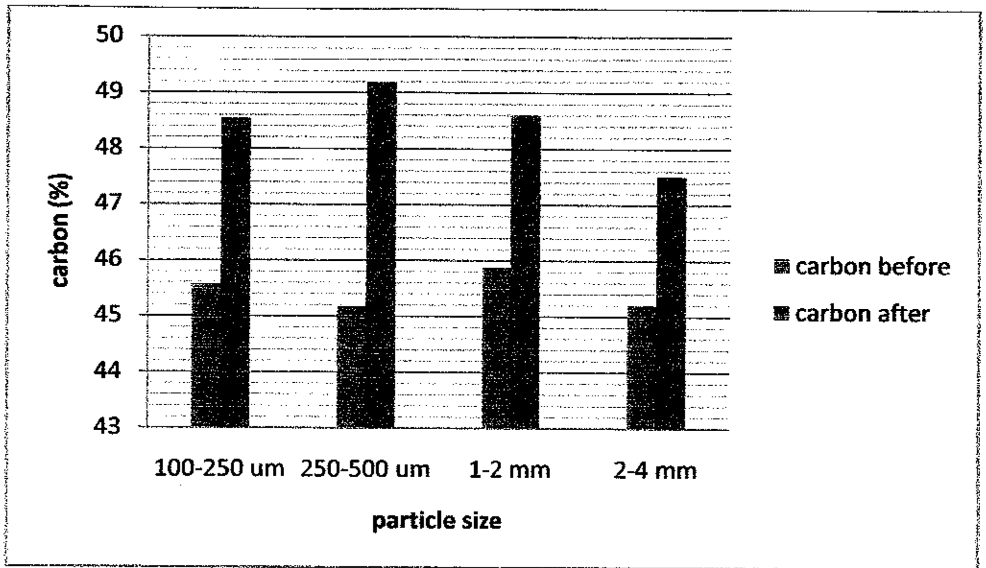


Figure 21: carbon vs particle size

The H component is decrease because it had been transforms to Hydrogen gas and water molecule.

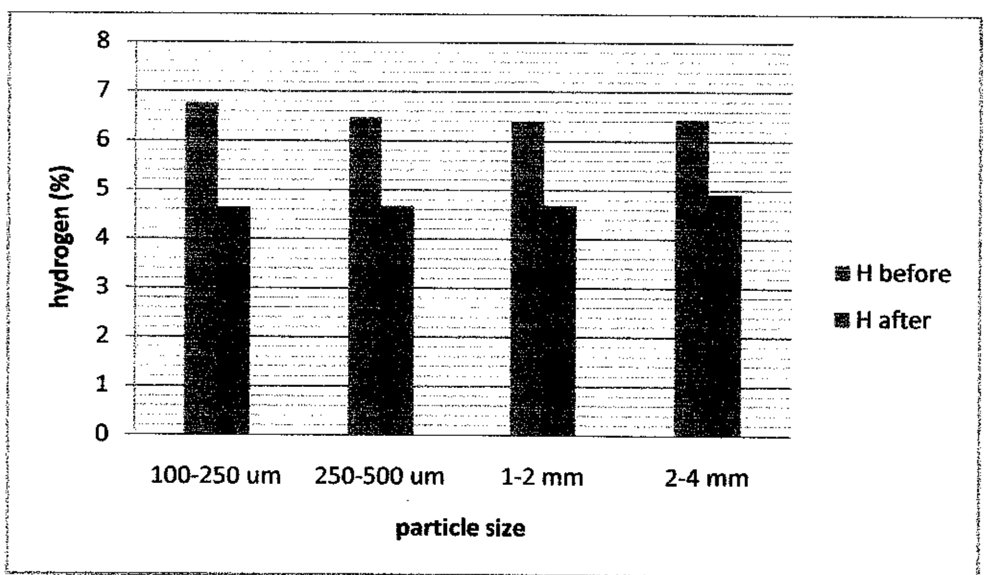


Figure 22: H vs particle size

Finally the N molecule in the biomass is slightly increase due to the decrement of H component.

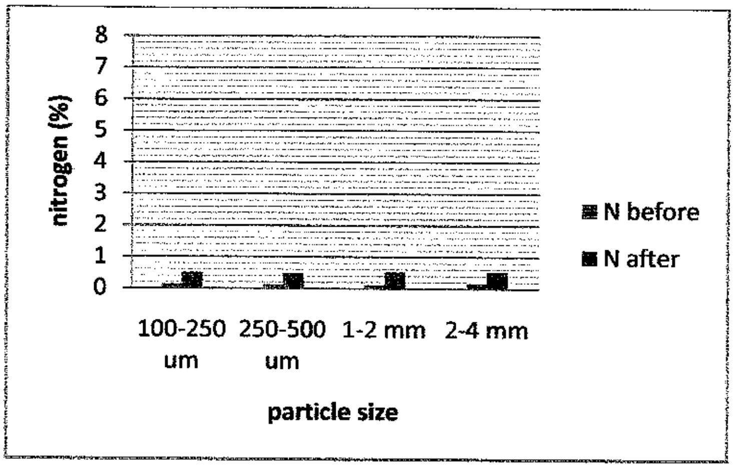


Figure 23: N vs particle size

4.3.3 Calorific value

Calorific value in all particle size is increase especially in the low range particle size.

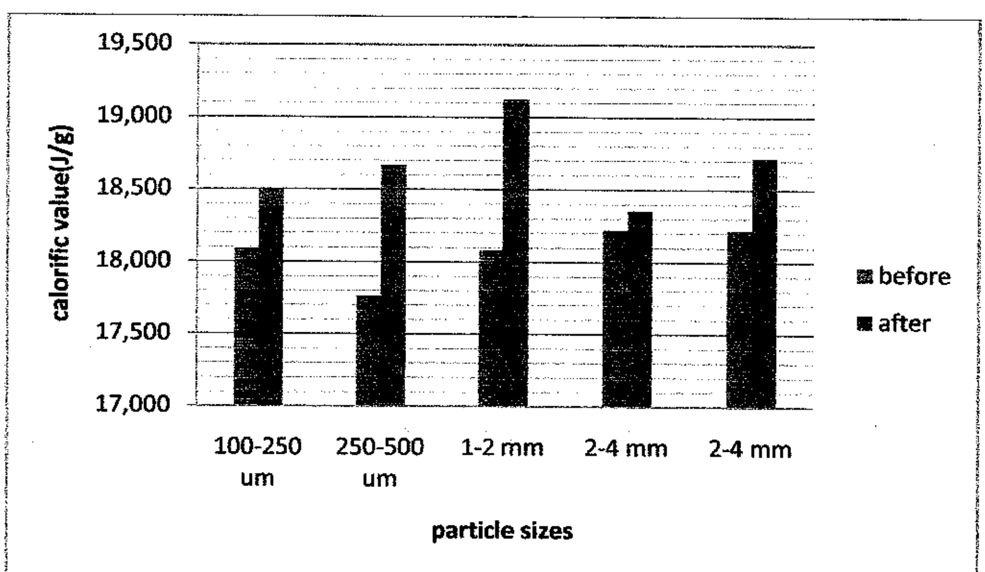


Figure 24: calorific value vs particle size

CHAPTER 5

CONCLUSION AND RECOMMENDATION

As a conclusion, Acasia with smaller particle sizes (which are 100-250 um and 250-500 um) has more calorific value content compared to golden powder and seraya. Torrefaction experiment also shows that the mass yield of particle size is lower for lower particle size.

For recommendation, this torrefaction experiment should be conducted for Acasia because acasia has the largest calorific value and higher carbon contain.

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