BIOMASS WASTE POTENTIAL AND ITS EFFECTIVE UTILIZATION IN MALAYSIA INCLUDING AN EXPERIMENTAL WORK ON WOOD TORREFACTION

by

Jazli Izzuddin Bin Jamaludin

Dissertation submitted in partial fulfilment of
the requirements for the
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(Chemical Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

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(Prof. Dr. Yoshimitsu Uemura)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

June 2010

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.

____
(JAZLI IZZUDDIN BIN JAMALUDIN)

ABSTRACT

This project studied on the current utilization of biomass wastes in Malaysia and discovers the potential of biomass wastes as one of the alternative energy resources. Based on the literature review that had been conducted, the utilization of biomass waste as a replacement of fossil fuel in Malaysia is very low even though Malaysia is well-known for its agricultural sector. However, in recent years interest in it has been renewed much of being focused on its efficient conversion for energy. With respect to the global issues of sustainable energy and reduction in greenhouse gases, biomass is getting increased attention as a potential source of renewable energy. However, biomass is not yet competitive with fossil fuels. In recent years, many studies on the biomass conversion for energy technology had been conducted by various researchers and some of the technology had been proven and had been implemented in Malaysia in small scale. This projected also investigated the possibility of converting biomass wastes into solid fuels by undergoing torrefaction process. Acasia wood, Seraya wood and Golden Powder wood was used to produce torrefied material and the factors affecting torrefaction were investigated. The biomass waste was dried, ground and sieved before it is heated and cooled to obtain the torrefied material. It was found that almost 100% of the calorific value in all the samples can be retained or increased by up to 10% from the original value. At the optimum condition of temperature 300^{O}C and particle size of 250µm, the torrefied material produced is viable to be promoted at a larger scale.

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND OF STUDY

Presently, the demand of energy is met by fossil fuels (i.e. coal petroleum and natural gas). However, the world fossil fuel production, beginning with petroleum and natural gas, will soon start to decline. Moreover, the use of fossil fuels has many side effects. The last thirty years has catapulted the search for a clean and renewable energy in order to keep the environment clean and to reduce the use of depletable conventional energy sources. Renewable energy sources, such as biomass is being considered as possible sources of energy to meet these challenges.

Of all alternative energy resources, biomass has a great potential today and in the future, since it is renewable, in contrast to the nature of the fossil fuels [1]. Biomass is seen as one of the best options that can provide a renewable fuel which can be utilized in a range of energy conversion technologies and also has the added advantage of being CO_2 neutral [2]. It is biodegradable and non-toxic. It has low emission profiles and thus is environmentally friendly. There are many biomass resources available in the world and Malaysia specifically and some of those are Acasia wood, Seraya wood and Golden Powder wood. These types of woods can be converted into source of energy via biomass process which is the torrefaction process. Torrefaction produces solid product of carbon sources material like biomass, retaining approximately 70% of the initial weight and 80%-90% of the original energy content [3]. This project presents the current status of the utilization of biomass waste in Malaysia and discovers the potential of biomass waste for future development. This project also studies the possibility of using Acasia wood, Seraya wood and Golden Powder wood to produce solid fuel via torrefaction. As the annual wood production in Malaysia is high, this makes the source unlimited and renewable throughout the years.

1.2 PROBLEM STATEMENT

Economic growth in Malaysia based largely on industrialization, combined with population growth and urbanization, has created an expanding demand for energy. In response, the development of the energy sector has emphasized the establishment of a secure, reliable and cost effective energy supply [4]. The need now is to ensure efficient utilization of energy resources, diversification of sources and minimization of wastage. However, in a country that has a significant amount of biomass waste resources such as Malaysia; biomass can be a very promising alternative source of renewable energy. It is rather surprising that even in a country like Malaysia where biomass waste can be easily obtained; the use of renewable energy is still very low. There has been very little necessity to curb energy use in Malaysia in the past, or to be concerned about energy use efficiency, as rapidly expanding use of energy was seen as a measure of the pace of national industrial development [4]. Those problem mentioned has brought to this study on the effective utilization of biomass waste in Malaysia and its potential in the future.

1.3 OBJECTIVES

There are several main objectives of this project:

- To study on the current status of biomass waste utilization in Malaysia
- To analyze the potential of biomass as renewable source of energy in Malaysia.
- To study on the biomass conversion technology implemented in Malaysia
- To conduct laboratory experiment via Torrefaction Process.
- To study the possibility of using Acasia wood, Seraya wood and Golden Powder wood to produce solid fuel via torrefaction

1.4 SCOPE OF STUDY

Scope of study for this research project is to perform analysis on the effectiveness of biomass waste utilization in Malaysia only and does not include any other country in the world.

The study on biomass conversion technology is done by conducting literature review on the proven biomass energy conversion technology which has been implemented in Malaysia in recent years.

The experimental work will focus on the wood waste (i.e. Acasia wood, Seraya wood and Golden Powder wood). The analysis of this study is based on the literature review and followed by the experimental work to study the possibility of using these woods to produce solid fuel via torrefaction. The results of the experimental are being analyzed based on thermodynamic model.

CHAPTER 2: LITERATURE REVIEW

2.1) CLEAN DEVELOPMENT MECHANISM (CDM)

2.1.1) What Is Green House Effect ?

The greenhouse effect is a natural physical phenomenon that is essential to life on Earth. Without it, the average temperature of the Earth's surface would be around -18°C, rather than the current 15°C. Among the gases of natural origin that contribute to the greenhouse effect, the most significant are water vapour and carbon dioxide (CO_2) and, to a lesser extent, ozone (O_3), methane (CH_4) and nitrous oxide (N_2O).

Intergovernmental Panel on Climate Change (IPCC), a group of scientific experts assembled in 1988 by the World Meteorological Organization and the United Nations Environment Programme, a growing number of observations reveal an overall global warming trend and several climate system changes. New elements confirm that most of the global warming observed in the last 50 years is due to human activity, with local repercussions known as "climate change".

To fight the global phenomenon that is climate change, two major agreements have been adopted by the international community, the United Nations Framework on Climate Change, adopted in 1992 in Rio, and more recently, the Kyoto Protocol, adopted in 1997. In contrast to the UNFCCC, the Kyoto Protocol sets quantified and binding commitments for limiting or reducing GHG emissions of anthropogenic origin for countries that are developed or in the transition process towards a market economy, for the 2008 - 2012 commitment periods [5,6].

2.1.2) Introduction to CDM

The CDM was established under Article 12 of the Kyoto Protocol. Among the mechanisms, only CDM aims at promoting co-operative measures between the industrialized (Annex I) and the developing (non-Annex I) countries. As a non-Annex I country, the CDM is thus the only mechanism under Kyoto that is relevant for Malaysia. The CDM has been proposed with the twin objectives of helping Annex I countries to achieve their emission reduction targets and at the same time helping non-Annex I countries to promote sustainable development in their economies. The CDM idea is to facilitate co-operative projects between developed and developing countries for reduction of GHG emissions, with the opportunity for additional financial and technological investments in GHG reduction projects. The greenhouse gas reductions achieved by each CDM project will be quantified in standard units, to be known as "Certified Emission Reductions (CERs)". It involves the trading of emission reductions that are resulting from a specific project (called CERs once such reductions are certified) to countries that can use these CERs to meet their targets. In return for the CERs, there will be a transfer of money to the project that actually reduces the greenhouse gases [5,6].

2.1.3) CDM in Malaysia

Malaysia is a Party to the United Nations Framework on Climate Change and has ratified the Kyoto Protocol on 4 September 2002. Malaysia has been following the negotiations and development of climate change issues very closely due to the numerous implications that can and will arise from the agreements achieved. As a developing country, Malaysia has no quantitative commitments under the Kyoto Protocol at present. However, through the Clean Development Mechanism (CDM), Malaysia could benefit from investments in the GHG emission reduction projects, which will also contribute towards the country's sustainable development goals, the overall improvement of the environment and result in additional financial flows. CDM projects result in certified emission reduction

(CERs) that can be traded in the international market. Like any other trade, these CER units accrued through the CDM are a commodity. These CERs will provide mutually shared benefits between developing and developed countries [5,6].

2.1.4) How does the CDM affect Malaysia?

Industrialized countries have gradually developed domestic policies to comply with the Kyoto protocol. Most countries are however still not meeting their target and looking for emission trading options. This has led to a growing demand for carbon credits, especially after the entry into force of the Kyoto Protocol. Non-Annex I countries like Malaysia are well-placed to supply such carbon credits. Malaysia ratified Kyoto Protocol on 4 September 2002 and is thus a Party to the Kyoto Protocol. At present, as a developing country Malaysia is not subjected to any commitments towards reducing GHG emissions. However, as a Party to Kyoto, Malaysia can voluntarily participate in the CDM and benefit from investments in the GHG emission reduction projects. This implies that extra revenues can be generated for renewable energy projects, energy efficiency projects, waste management projects, etc. Such projects also contribute towards the overall improvement of the environment and to some extent bring additional economic and social benefits.

It is the prerogative of the host country to decide whether or not a project contributes to sustainable development. Therefore, the government of Malaysia can ensure that only those projects that are deemed to contribute to sustainable development can actually benefit from the CDM. Project developers will benefit directly from the extra revenues that the project can bring.

The additional funding channeled through the CDM could assist Malaysia in reaching its sustainable development objectives, such as cleaner air and water, improved land use and in many cases, reduced dependence on fossil fuels. In addition to catalyzing green investment priorities in developing countries, the

CDM offers an opportunity to make simultaneous progress on climate, development and local environmental issues.

For project developers in developing countries, the CDM can be used to modify planned or projected investments into projects with lower emissions of GHGs. Together this makes a win-win situation for all parties [5,6].

2.2) BIOMASS RESOURCES IN MALAYSIA

The term "biomass" means any plant derived organic matter available on a renewable basis, including dedicated energy crops and trees, agricultural food and feed crops, agricultural crop wastes and residues, wood wastes and residues, aquatic plants, animal wastes, municipal wastes, and other waste materials [7].

There are five major sectors that contribute to biomass energy in Malaysia; Oil palm cultivation, forestry (wood), rubber cultivation, paddy cultivation, animal farming and urban wastes. In addition to that, several sectors have been studied in the same reference. They are coconut cultivation, cocoa cultivation and sugarcane cultivation. Figure 1 shows the biomass wastes resources in Malaysia

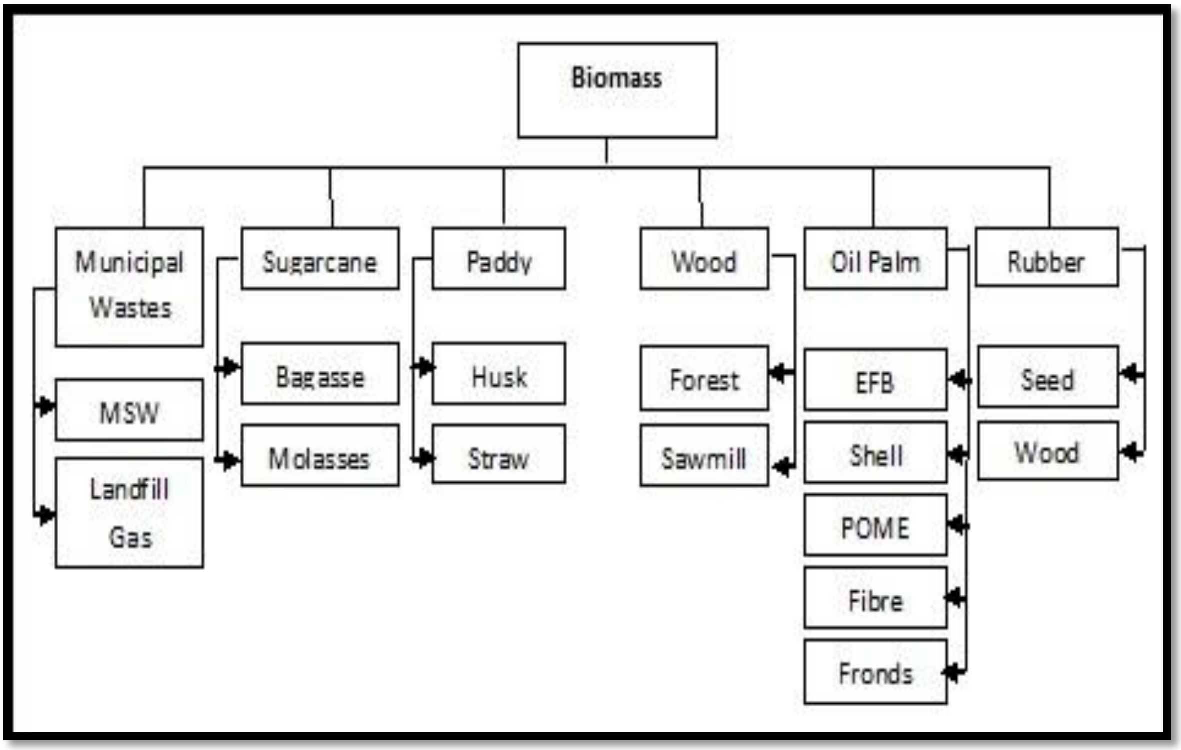


Figure 1: Biomass waste resources in Malaysia.

There are strong reasons for selecting biomass as the first of the renewable energy sources to be developed for large scale application. Some of these are: (i) availability of biomass resources in abundant supply industry; (ii) availability of clean technology for power generation from biomass; (iii) availability of working experience in using biomass for heat and power generation in the country; (iv) application of biomass power generating system contributes zero net carbon loading to the atmosphere. This is because the mass of biomass used in power generation must be balanced by the mass of new biomass growth in order to sustain the system. Looked at from another angle, the mass of carbon released to the atmosphere will be completely absorbed by new plant growth which will be needed for fuel in the future. Hence biomass power generation system is in principle environmentally benign. Moreover, handling technologies, collection logistics and infrastructure are important aspects of the biomass resource supply chain [7].

2.3) AVAILABILITY OF PALM OIL BIOMASS IN MALAYSIA

The oil palm fruit is reddish in colour and about the size of a large plum, but it grows in large bunches. One bunch usually weighs between 10 and 40 kg. Each fruit consists of a single seed (the palm kernel) and surrounded by a soft oily pulp. Oil is extracted from both pulp of the fruit, which can be made into edible oil, and kernel, which is used mainly for soap manufacturing [8].

Palm oil has now become world’s largest source of edible oil with 38.5 million tonnes or 25% of the world total edible oil and fat production [9]. Thus, oil palm has now become a major economic crop which triggered expansion of plantation area in Malaysia and Indonesia. In year 2006, Malaysia is the second largest producer of palm oil with 15.88 million tonnes or 43% of the total world supply [10]. In 2007, productive oil palm plantations in Malaysia are 4.3 million hectares, a 3.4% increase from year 2006 which stood at 4.2 million hectares [11].

With the growth of palm oil production in Malaysia, the amount of residues generated also shows a corresponding increase. One hectare of oil palm plantation can produce about 50–70 tonnes of biomass residues [12]. Therefore, oil palm industry is currently producing the largest amount of biomass in Malaysia with 85.5% out of more than 70 million tonnes [13]. Other types of biomass generated in Malaysia are from the wood and sugarcane industry, municipal solid waste and others.

The type of biomass produced from oil palm industry includes empty fruit bunches (EFBs), fibre, shell, wet shell, palm kernel, fronds and trunks. Due to the huge amount of biomass generated yearly, Malaysia has the potential to utilize the biomass efficiently and effectively to other value added products. Currently, there are already various technologies available to convert oil palm biomass to various types of value added products.

On the other hand, oil palm biomass also has a very good potential to be converted into renewable energy sources, considering the calorific value of each component. Based on simple calculation, oil palm biomass has a total energy potential of about 15.81 Mtoe (million tonne of oil equivalent). Taking an efficiency of 50%, the energy generated from oil palm biomass may reach almost 8 Mtoe. In the year 2006, Malaysia's energy demand is 40.4 Mtoe (million tonne of oil equivalent) [14]. This means that oil palm biomass can provide almost 20% of the total energy demand in Malaysia. If all the 8 Mtoe energy produced by oil palm biomass is converted into energy replacing petroleum crude oil, Malaysia can save up to about RM 7.5 billion per year. Therefore, this clearly shows the potential of oil palm biomass as one of the major source of energy in Malaysia. Its renewable nature makes it even a more important energy source

2.4) POTENTIAL UTILIZATION OF BIOMASS IN MALAYSIA

Due to huge quantities of biomass generated from the oil palm industry, it will be a waste if biomass is not properly utilized. In the following section, possible utilization of oil palm biomass will be presented. Basically, oil palm biomass can be converted to a wide range of value added products that can be clustered into three main categories namely bio-based value added products, bio-fuel and as direct fuel for power generation.

2.4.1) Energy Related Product

a) Bio fuels

Synthetic bio-fuels are synthetic hydrocarbons or mixture of synthetic hydrocarbons produced from renewable sources such as biomass. Biomass can be used to make bio-fuels as an alternative to partially replace fossil fuels. There are 5 types of bio fuels that can be produced using oil palm biomass which include bio-ethanol, bio-methanol, bio-briquettes, hydrogen gas and pyrolysis oil [15].

Bio-ethanol is made by fermenting any biomass high in carbohydrate content (starches, sugar or celluloses) through a process similar to brewing. Oil palm biomass especially Empty Fruit Bunch (EFB) is rich in sugar and lignocellulose content. Research shows that after the production of xylose from EFB through acid hydrolysis, the EFB residue can be further utilized for production of second generation bio-ethanol [16]. Bio-ethanol is mostly used as fuel additive to cut down a vehicle’s carbon monoxide and other smog-causing emission.

Apart from bio-ethanol, bio-methanol can also be produced from biomass. Bio-methanol is most suitable for application in spark ignition engines due to its high octane rating [17]. There are a number of methods to convert biomass to bio-methanol, but the most likely approach is gasification. Gasification involves vaporizing biomass at high temperatures and then removing impurities from the hot gas and passing it through a catalyst which converts it into bio-methanol [18]. Demand for bio-ethanol and bio-methanol as alternative fuel in Malaysia is still low since most of the vehicles in Malaysia are still running on petrol. Because of the low demand, there is currently no large-scale production of bio-ethanol and bio-methanol in Malaysia.

Converting biomass into a uniform and solid fuel through briquetting process appears to be another attractive solution in fully utilizing oil palm biomass. It can be densified into briquettes at high temperature and pressure using screw extrusion technology. Biomass briquettes can be used for household and industrial heating unit operation such as boiler. Research shows that briquettes made from 100% pulverized EFB exhibited good burning properties. Generally, converting biomass into briquettes will increase its energy content while reducing moisture content by at least 5% and 38%, respectively, compared to its raw material [19]. Advantages of using biomass briquettes include low cost, available all year around, high calorific value, longer burning duration and most importantly more environment friendly [20]. Therefore, palm biomass briquettes can become a potential renewable energy source in the future.

Gasification of biomass is one of the new technologies for producing hydrogen [21]. Hydrogen may be used as fuel in almost any application replacing fossil fuels especially as feedstock for synthesis of clean transportation fuels or as a gaseous fuel for power generation [22, 21]. The benefits of using hydrogen instead of diesel or petrol as transportation fuel is higher engine efficiencies and zero emissions [23]. Nevertheless, full benefits of hydrogen as a clean, versatile and efficient fuel may only be realized if hydrogen is produced from renewable sources such as biomass [22]. The latest gasification technology to convert oil palm biomass into hydrogen gas is via supercritical water technology. However, production of hydrogen from biomass in Malaysia is still at the early stage of research.

Basically all conversion technologies described above are currently being practiced in Malaysia either in the commercial sector or still in research stage such as biomass gasification using supercritical water for further improvement. This shows that Malaysia is well positioned to take advantage of her enormous output of biomass from the oil palm industry

b) Directly as Fuel

Oil palm biomass such as EFB, mesocarp fibre (MF) and palm kernel shell (PKS) can be used to produce steam for processing activities and for generating electricity [24]. However, due to their characteristics, some of these fuel resources have to be pre-treated before they can be burned in the boiler. Basic pre-treatment process that is required for effective use of biomass includes shredding machine to reduce the size of EFB and drying to reduce moisture content. In Malaysia, there are currently more than 300 palm oil mills operating with self-generated electricity from oil palm biomass. The electricity generated is not only for their internal consumption (crude palm oil extraction) but also sufficient for surrounding remote areas [25]. The system required for generating electricity from biomass consists of a combustion system (boiler and furnace), steam turbine and generator [26]. Many projects on using biomass to generate electricity have been or will be launched in Malaysia. Up to year 2004, under Small Renewable Energy Power Program (SREP), 62 projects have been approved and out of these projects, 25 of them used oil palm biomass as fuel source [25]. This indicates that Malaysia is focusing on using oil palm biomass as energy source to generate electricity.

Therefore, if all industries in Malaysia can replace or partially replace fossil fuel with oil palm biomass to generate energy, then emission of CO_2 in Malaysia will decrease significantly. Malaysia can then achieve her vision to be a developed country without degrading the environment.

2.4.2) Bio-based value added product

One possible utilization of biomass is to produce bio plastic or also known as polyhydroxyalkanoates (PHAs) or polylactate (PLA). Currently there is a joint research and development in Malaysia by University Putra Malaysia, Felda Palm Industries Sdn. Bhd. and Kyushu Institute of Technology for production of bio plastic using oil palm biomass [27]. Bio plastics have similar characteristic as petroleum-derived plastic and can be used for production of foil, moulds, tins, cups, bottles and other packaging materials [28]. However, the advantage of bio plastic is that it is 100% biodegradable and can be recycled, composted or burned without producing toxic by-products.

Besides, biomass can also be incinerated for its ash which serves as a very good fertilizer or soil conditioner. This is because biomass itself contains certain macro and micronutrients that are required for plant growth. In fact, incinerating biomass to obtain its ash is currently the common practice in Malaysia as this can offset the increasing cost of inorganic fertilizers. In some place, biomass is not incinerated, but mulch and directly thrown back to oil palm plantations [29].

Biomass also can be used as fillers in thermoplastics and thermoset composites. These composites have wide applications in furniture and automobile components. Progress in this area of research finally reached to commercialization stage when PROTON (Malaysian national carmaker) entered into agreement with PORIM (Palm Oil Research Institute of Malaysia) to develop thermoplastic and thermoset composites and used it in PROTON car [30].

In addition, oil palm biomass or ash derived from it can be converted into adsorbents for toxic gas and heavy metal removal. Some researchers have conducted study on utilizing oil palm ash (OPA) as an absorbent for removing pollutant gasses such as sulphur dioxides and nitrogen oxides. OPA is produced after combustion of oil palm fibre and shell as boiler fuel to produce steam for palm oil mill consumption. The OPA was found to contain high amount of silica, calcium, potassium and alumina that can be utilized to synthesize active compounds that are responsible for sorption of pollutant gasses into the absorbent [31,32]. Apart from that, it was also reported that charcoal derived from biomass can be coated with chitosan and can be used effectively to remove heavy metal especially chromium from industrial wastewater. This is due to the presence of some functional groups such as carboxylic, hydroxyl and lactones in oil palm shell that have a high affinity towards metal ions [33]. However, application of biomass as adsorbents is still in research stage and not being commercialized yet.

2.5) TORREFACTION PROCESS

Torrefaction is a thermochemical treatment of biomass at 200 to 300 °C. It is carried out under atmospheric conditions and in the absence of oxygen. In addition, the process is characterized by low particle heating rates (< 50 °C/min). During the process the biomass partly decomposes giving off various types of volatiles. The final product is the remaining solid, which is often referred to as torrefied biomass, or torrefied wood when produced from woody biomass.

Figure 2 provides a typical mass- and energy balance of torrefaction. Typically, 70% of the mass is retained as a solid product, containing 90% of the initial energy content. 30% of the mass is converted into torrefaction gases, but contains only 10% of the energy content of the biomass. Hence a considerable energy densification can be achieved, typically by a factor of 1.3 on mass basis. This example points out one of the fundamental advantages of the process, which is the high transition of the chemical energy from the feedstock to the torrefied product, whilst fuel properties are improved. This is in contrast to the classical pyrolysis process that is characterized by an energy yield of 55-65% in advanced concepts down to 20% in traditional ones.

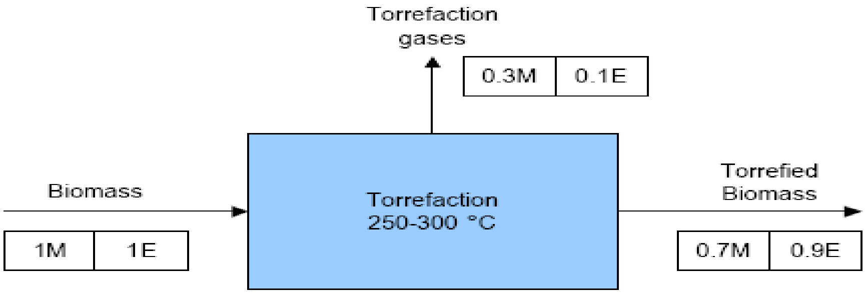


Figure 2: A typical mass- and energy balance of the torrefaction process on as received basis.
Symbols: E = energy unit, M = mass unit [34].

The key-property that makes torrefied biomass attractive for co-firing in existing coal-fired power stations is its superior grind ability compared to untreated or fresh biomass. After torrefaction biomass has lost its tenacious nature and partly its fibrous structure (Bergman *et al*, 2005). Through torrefaction, biomass becomes more alike coal and so its size reduction characteristics. Besides, the devolatilization during torrefaction results in an increase of the calorific value on mass basis, as the reaction products are rich in oxygen (e.g. H_2O, CO_2, acetic acid).

Biomass is completely dried during torrefaction and after torrefaction the uptake of moisture is very limited. This varies from 1-6% depending on the torrefaction conditions and the treatment of the product afterwards. The main explanation of the hydrophobic nature of the biomass after torrefaction is that through the destruction of OH groups the biomass loses its capability of hydrogen bonding. Moreover, unsaturated structures are formed which are non-polar. It is likely that this property is also the main reason that torrefied biomass is practically preserved and biological degradation, as often observed for untreated biomass, does not occur anymore. The most reactive biomass polymer during torrefaction is hemicellulose. After torrefaction it has reacted completely to alternative char structures and volatiles. Most of the weight loss can be contributed to hemicellulose with the effect that torrefied biomass mainly consists of cellulose and lignin. Hence the lignin content has increased.

Although torrefaction leads to increased energy density on mass basis, during torrefaction only little shrinkage can be expected so that the volume of produced torrefied biomass is decreased only slightly. From experimental analysis (reported in Bergman *et al.* 2005) the density of torrefied biomass is ranging from 180 to 300 kg/m^3 or generally 10-20% lowers than the used feedstock (when dried). Despite the higher calorific value, the volumetric energy density is not improved (typically 5 GJ/m^3). Torrefied biomass is more brittle of nature compared the biomass it was derived from. This is crucial for establishing the desired grindability, but has the drawback of decreased mechanical strength and increased dust formation [34].

2.5.1) Added value of torrefied biomass

Torrefied and densified biomass has several advantages in different markets, which makes it a competitive option compared to conventional biomass (wood) pellets [35]:

a. Higher energy density

Energy density of 18 - 20 GJ/m^3 compared to 10 - 11 GJ/m^3 driving a 40 - 50% reduction in transportation costs.

b. More homogeneous composition

Torrefied biomass can be produced from a wide variety of raw biomass feedstocks while yielding similar product properties. The main reason for this is that about all biomass are built from the same polymers (lignocelluloses). In general (woody and herbaceous) biomass consists of three main polymeric structures: cellulose, hemicelluloses and lignin. Together these are called lignocelluloses. The chemical changes of these polymers during torrefaction are practically similar resulting in similar property changes.

c. Hydrophobic behaviour

Torrefied biomass has hydrophobic properties, and when combined with densification makes bulk storage in open air feasible.

d. Elimination of biological activity

All biological activity is eliminated reducing the risk of fire and stopping biological decomposition.

e. Improved grind ability

Torrefaction of biomass leads to improved grind ability of biomass. This leads to more efficient co-firing in existing coal fired power stations or entrained-flow gasification for the production of chemicals and transportation fuels.

CHAPTER 3: METHODOLOGY

3.1) PROJECT ACTIVITIES

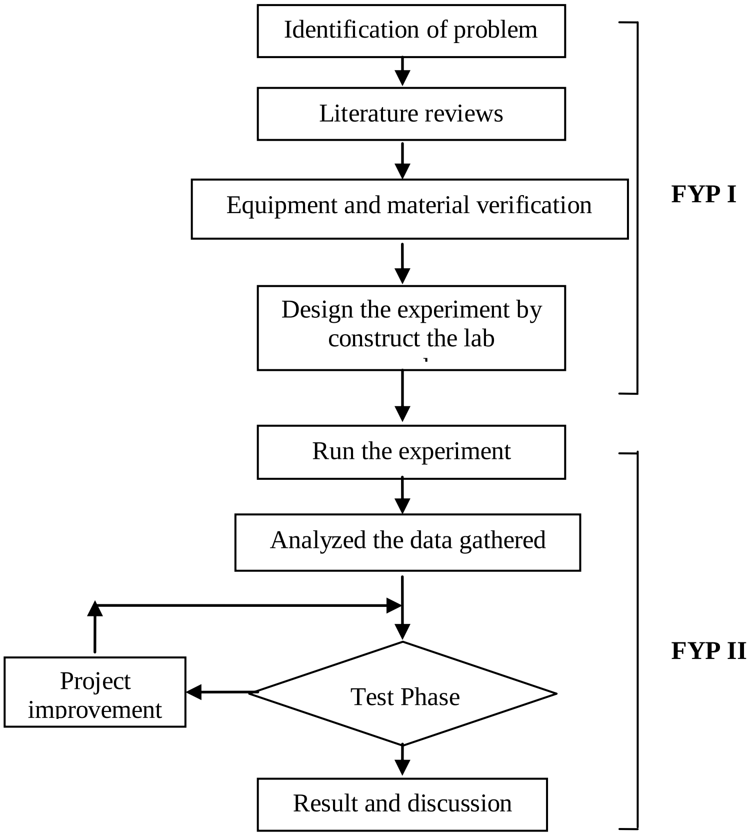


Figure 5: Summary of project activities for Final Year Project

3.2) EXPERIMENTAL WORK PROCEDURE

The biomass waste of Acasia wood, Seraya wood and Golden Powder were obtained from a local supplier (Ikutmaju Sdn. Bhd., Sabah). It was grinded into smaller particles and finally sieved into two mesh sizes i.e. 250 and 500 µm, respectively. A prescribed amount of waste (around 1.7 g) was weighed, and put in a crucible. The crucible was placed at the center of the reactor. After flushing the air in the reactor with nitrogen, the temperature of the reactor was raised to different desired levels of 250 or 300ºC at a constant rate of 10 ^{O}C/min by an electric furnace surrounding the reactor. After 0.5 hour / 1.5 hour torrefaction, the heater was turned off and the reactor was left to cool down to the ambient temperature. Then the torrefied sample was recovered, weighed and kept in an air tight vessel. Throughout the procedure described above, 0.5 L/min of nitrogen was flowed through the reactor. The torrefied material was then cooled to room temperature and reweighed to determine the weight loss from the material due to the torrefaction process. The schematic diagram of the Fixed Bed Activation Unit is shown in Figure 3

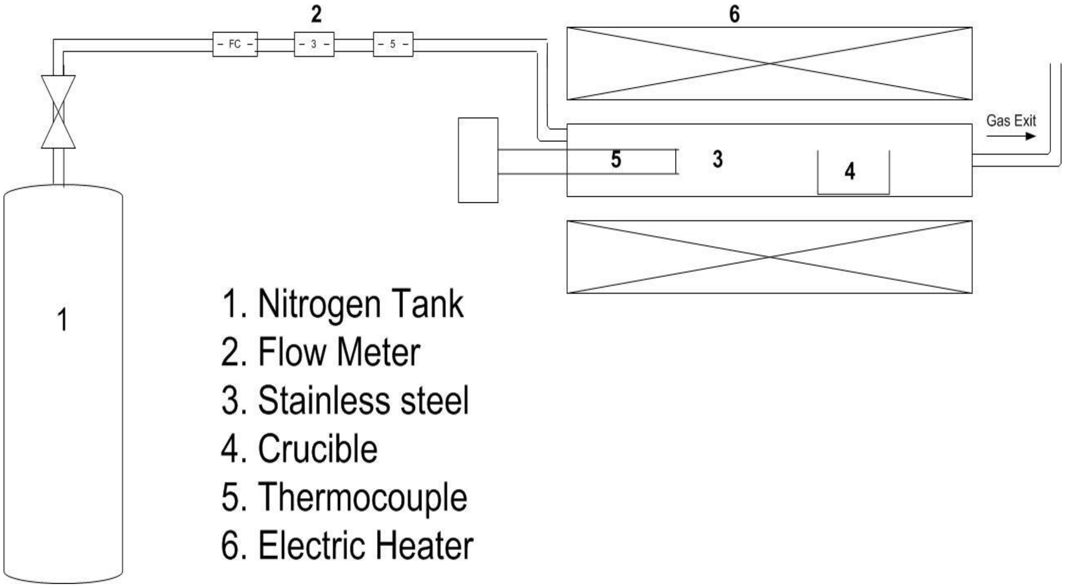


Figure 4: A schematic diagram of the Fixed Bed Activation Unit

3.2.1 Sample Analysis

(a) Ultimate Analysis

The ultimate analysis was conducted by using Carbon Hydrogen Nitrogen Sulphur (CHNS) Analyzer. The samples were weighed around 1.5 milligrams to 2.0 milligrams in aluminium container prior entering the analyzer. The analyzer will then display the composition of that carbon, hydrogen, nitrogen, and sulphur contained within the material in percentage value. The oxygen composition is calculated by difference method.

(b) Calorific Value Analyses

The calorific value of biomass sample before and after undergoing torrefaction was determined using Bomb Calorimeter by IKA which technology approved by DIN 51900, ASTM 240D, ISO 1928 and BSI.

(c) Mass Yield Percentage Analyses

The mass yield percentage of the heated material is determined by weighing the initial and final mass of the sample before and after heating.

Percentage of mass yield = $\frac{\mathrm{B}}{\mathrm{A}} X\ 100$

Where;

A: weight of the sample before heating, g

B: weight of the sample after heating, g

(d) Ash Content Percentage Analyses

The ash content was measured as follows. A prescribed amount of sample (1 g) was weighed in a crucible, and was placed in an electric furnace and the temperature was raised to 700ºC. After 3 hours, the furnace was turned off and was allowed to cool down; the crucible containing the ash was weighed.

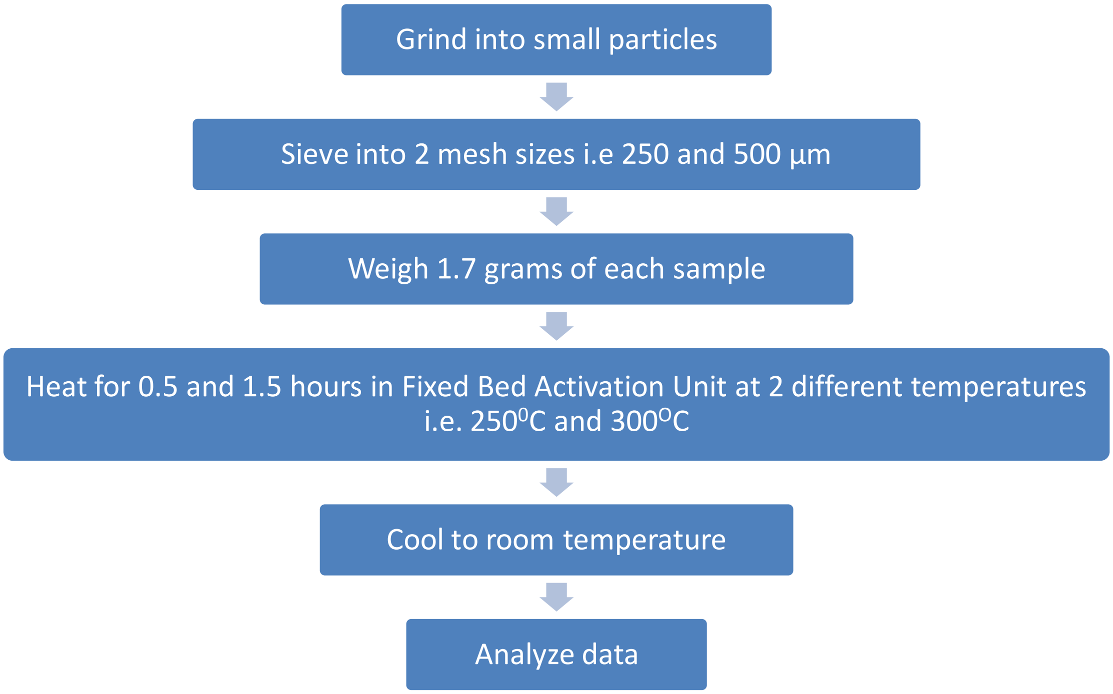


Figure 5: Torrefaction process experimental procedure

3.3) PROJECTMILESTONE

Table 1: Suggested Milestone for the First Semester of 2-Semester Final Year Project

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Topic	🟪	🟪						MID SEMESTER BREAK							
2	Preliminary Research Work		🟪	🟪	🟪											
3	Submission of Preliminary Report				🟦											
4	Seminar 1 (optional)					🟪	🟪	🟪								
5	Project Work					🟪	🟪	🟪		🟦						
6	Submission of Progress Report															
7	Seminar 2 (compulsory)										🟪	🟪	🟪	🟪		
8	Project work continues									🟪	🟪	🟪	🟪	🟪		
9	Submission of Interim Report Final Draft														🟦	
																🟦
10	Oral Presentation															

🟦 Suggested milestone

🟪 Process

Table 2: Suggested Milestone for the Second Semester of 2-Semester Final Year Project

No.	**Detail/ Week**	**1**	**2**	**3**	**4**	**5**	**6**	**7**		**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Project Work Continue	🟪	🟪	🟪					**MID SEMESTER BREAK**							
2	Submission of Progress Report 1				🟦											
3	Project Work Continue				🟪	🟪	🟪	🟪								
4	Submission of Progress Report 2									🟦						
5	Seminar (compulsory)										🟪	🟪	🟪			
5	Project work continue									🟪	🟪	🟪	🟪			
6	Poster Exhibition											🟦				
7	Submission of Dissertation (soft bound)													🟦		
8	Oral Presentation														🟦	
9	Submission of Project Dissertation (Hard Bound)															🟦

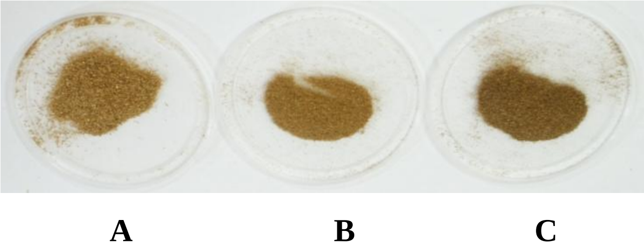
🟦 Suggested milestone

🟪 Process

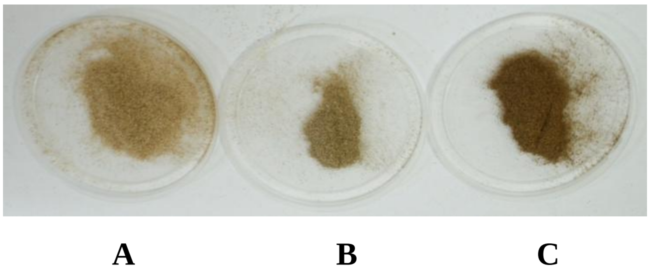
CHAPTER 4: RESULT AND DISCUSSION

4.1) APPEARANCE OF TORREFIED SAMPLES

a) Acasia Wood



b) Seraya Wood



c) Golden Powder Wood

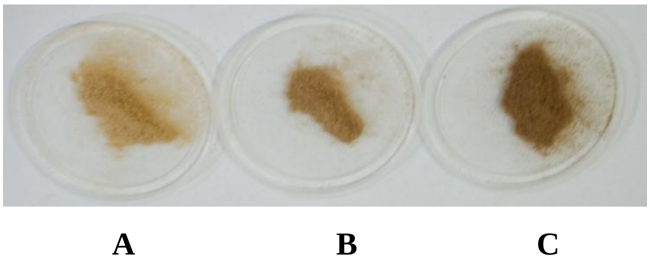


Figure 6: Colour change of samples

In this study, three types of woods were torrefied. In Figure 6, photos of all the samples including raw materials and torrefied samples are exhibited. A is the photo of the raw materials. B and C are samples observed when heated in the fix bed activation unit at temperature 250°C and 300°C respectively.

The colour of samples becomes darker as the temperature of heating increases. As temperature increases, the sample begins to be browned off and gives off moisture, carbon dioxide and large amounts of acetic acid with some phenols. The colour turns into darker due to the increasing carbon content of the heating sample.

4.2) CALORIMETRY, ELEMENTARY AND ASH ANALYSIS

Table 3: Results of calorimetry, elementary and ash analyses for 3 types of wood torrefied for 0.5 hours

Biomass	Treatment	Calorific Value [J/g]		Elementary and ash analysis [wt%]											Mass Yield, wt%	Energy Yield, wt%
		LHV	ΔLHV	C	ΔC	H	ΔH	N	ΔN	S	ΔS	O	ΔO	Ash Content, wt%		
Acasia Wood	Fresh Grinded	18488.0		43.12		6.11		0.53		0.0682		50.17		0.91		
	Dried	18131.0		44.78		5.97		0.45		0.0440		48.76		0.87	93.90%	92.08681
	Torrefied at 250C [500um]	19415.5	1284.5	46.82	2.04	5.89	-0.08	0.43	-0.02	0.0165	-0.0275	46.85	-2.48	0.81	82.94%	87.10091
	Torrefied at 250C [250um]	19425.0	1294.0	48.32	3.54	5.81	-0.16	0.43	-0.02	0.0260	-0.0180	45.41	-3.92	0.73	88.82%	93.32153
	Torrefied at 300C [500um]	20261.0	2130.0	49.16	4.38	5.53	-0.44	0.39	-0.06	0.0135	-0.0305	44.91	-4.42	0.81	81.76%	89.60079
	Torrefied at 300C [250um]	20149.5	2018.5	49.24	4.46	5.69	-0.28	0.42	-0.03	0.0100	-0.0340	44.64	-4.69	0.76	75.89%	82.71017
Seraya Wood	Fresh Grinded	17952.0		44.71		5.91		0.66		0.0412		48.68		0.89		
	Dried	17818.0		44.12		5.89		0.59		0.0630		49.34		0.77	98.43%	97.69528
	Torrefied at 250C [500um]	17756.0	62.0	45.42	1.30	5.98	0.09	0.46	-0.13	0.0360	-0.0270	48.11	-2.36	0.81	95.29%	94.24962
	Torrefied at 250C [250um]	18637.0	819.0	46.52	2.40	5.63	-0.27	0.49	-0.10	0.0305	-0.0325	47.34	-3.13	0.73	94.71%	98.32388
	Torrefied at 300C [500um]	18392.0	574.0	47.05	2.93	5.85	-0.04	0.44	-0.15	0.0280	-0.0350	46.64	-3.83	0.81	85.29%	87.38044
	Torrefied at 300C [250um]	18227.5	409.5	46.25	2.13	5.82	-0.07	0.39	-0.20	0.0240	-0.0390	47.52	-2.95	0.76	90.00%	91.38118
Golden Powder Wood	Fresh Grinded	18488.0		42.19		6.11		0.43		0.0413		51.23		0.97		
	Dried	18937.0		41.22		6.23		0.39		0.0391		52.12		0.67	94.12%	96.4058
	Torrefied at 250C [500um]	19379.0	442.0	45.68	4.46	5.89	-0.34	0.32	-0.07	0.0420	0.0029	48.07	-5.68	0.48	90.59%	94.95584
	Torrefied at 250C [250um]	19539.0	602.0	46.21	4.99	5.96	-0.27	0.30	-0.09	0.0430	0.0039	47.50	-6.25	0.78	90.00%	95.11629
	Torrefied at 300C [500um]	19672.0	735.0	48.60	7.38	5.75	-0.49	0.34	-0.05	0.0405	0.0014	45.28	-8.48	0.44	81.76%	86.99604
	Torrefied at 300C [250um]	20060.0	1123.0	49.68	8.46	5.77	-0.46	0.30	-0.09	0.0370	-0.0021	44.21	-9.54	0.78	86.47%	93.82238

Table 4: Results of calorimetry, elementary and ash analyses for 3 types of wood torrefied for 1.5 hours

Biomass	Treatment	Calorific Value [J/g]		Elementary and ash analysis [wt%]											Mass Yield, wt%	Energy Yield, wt%
		LHV	ΔLHV	C	ΔC	H	ΔH	N	ΔN	S	ΔS	O	ΔO	Ash Content, wt%		
Acasia Wood	Fresh Grinded	18488.0		43.12		6.11		0.53		0.0682		50.17		0.91		
	Dried	18131.0		44.78		5.97		0.45		0.0440		48.76		0.87	93.90%	92.08681
	Torrefied at 250C [500um]	19679	1548.0	45.31	0.53	5.75	-0.21	0.422	-0.03	0.0428	-0.0012	48.47	-0.29	0.91	93.49%	99.51264
	Torrefied at 250C [250um]	19715	1584.0	45.45	0.67	5.70	-0.27	0.413	-0.04	0.039	-0.0050	48.40	-0.36	0.80	93.01%	99.18283
	Torrefied at 300C [500um]	19732	1601.0	46	1.22	5.72	-0.25	0.383	-0.07	0.042	-0.0020	47.85	-0.90	0.59	91.11%	97.24051
	Torrefied at 300C [250um]	19744	1613.0	46.03	1.25	5.56	-0.40	0.378	-0.07	0.033	-0.0110	47.99	-0.76	0.53	89.93%	96.03948
Seraya Wood	Fresh Grinded	17952.0		44.71		5.91		0.66		0.0412		48.68		0.89		
	Dried	17818.0		44.12		5.89		0.59		0.0630		49.34		0.77	98.43%	97.69528
	Torrefied at 250C [500um]	19712	1894.0	44.23	0.11	5.65	-0.23	0.571	-0.02	0.063	0.0000	49.48	0.14	0.72	90.15%	98.98824
	Torrefied at 250C [250um]	19776	1958.0	44.97	0.85	5.61	-0.28	0.534	-0.06	0.072	0.0090	48.81	-0.53	0.80	89.14%	98.19701
	Torrefied at 300C [500um]	19811	1993.0	44.66	0.54	5.57	-0.31	0.525	-0.06	0.044	-0.0190	49.19	-0.14	0.72	88.90%	98.10594
	Torrefied at 300C [250um]	19867	2049.0	45.72	1.60	5.53	-0.36	0.51	-0.08	0.012	-0.0510	48.23	-1.11	0.67	88.72%	98.18406
Golden Powder Wood	Fresh Grinded	18488.0		42.19		6.11		0.43		0.0413		51.23		0.97		
	Dried	18937.0		41.22		6.23		0.39		0.0391		52.12		0.67	94.12%	96.4058
	Torrefied at 250C [500um]	19582	645.0	47.89	6.67	5.53	-0.70	0.44	0.05	0.029	-0.0101	46.11	-6.01	0.74	93.78%	99.32929
	Torrefied at 250C [250um]	19621	684.0	48.13	6.91	5.26	-0.96	0.367	-0.02	0.033	-0.0061	46.20	-5.92	0.80	92.95%	98.64625
	Torrefied at 300C [500um]	19644	707.0	48.54	7.32	5.11	-1.12	0.311	-0.08	0.025	-0.0141	46.01	-6.11	0.71	92.66%	98.45376
	Torrefied at 300C [250um]	19671	734.0	48.62	7.40	5.09	-1.14	0.19	-0.20	0.012	-0.0271	46.09	-6.04	0.68	90.19%	95.96103

The results of calorimetry, elementary and ash analyses for the dried and torrefied samples are listed in Table 3 and 4. For all the three type of biomass waste (Acasia, Seraya and Golden Powder), in general torrefaction resulted in higher calorific value and a higher carbon content.

In order to discuss more specifically, the calorific value, the CHO contents and the ash content (the change against the dried sample) are plotted against different conditions of torrefaction in Figure 7 to 12, respectively.

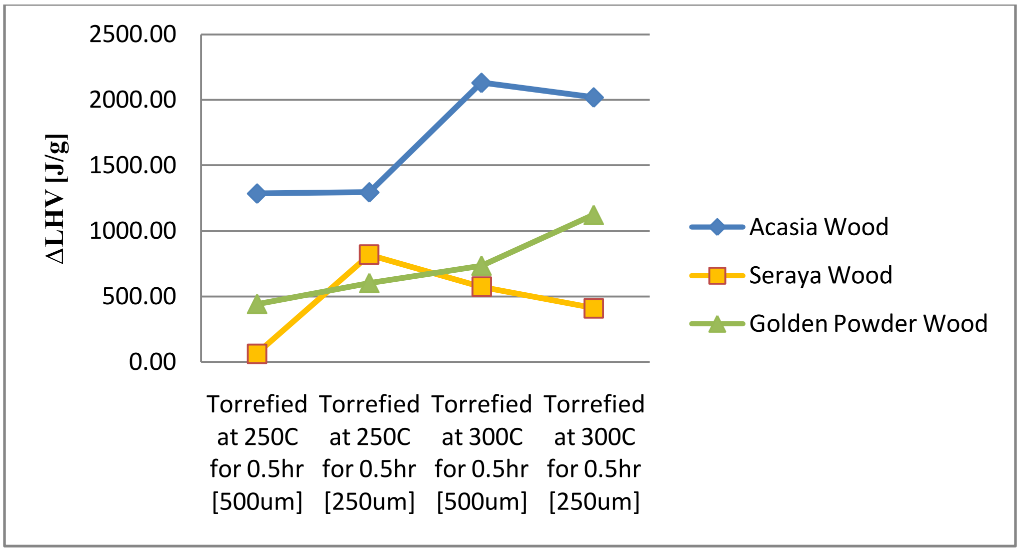


Figure 7a: Change in Low Heating Value (LHV) at different temperature and particle size for 0.5hr retention time

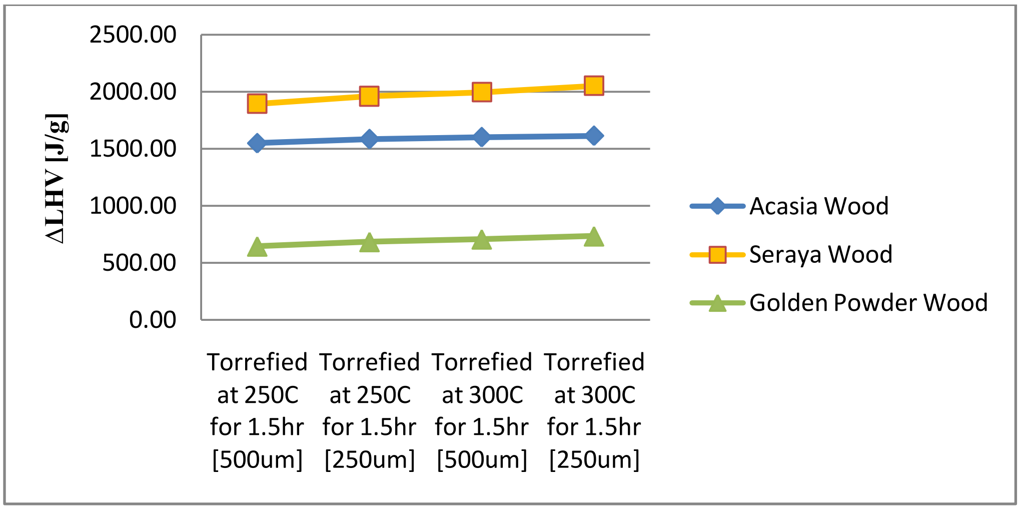


Figure 7b: Change in Low Heating Value (LHV) at different temperature and particle size for 1.5hr retention time

From Figure 7, it is found that the tendency of ΔLHV against different conditions of torrefaction is similar quantitatively among the three types of biomass wastes used in this study for the 1.5 hours retention time torrefaction condition. As for the samples heated for 0.5hours, the trend of data is different for all three types of woods. The difference may due to the difference in temperature distribution during the heating process in the Fixed Bed Activation Unit. The heating value of all the samples increases with increasing temperature and smaller particle size except for one exception. This is mainly due to the carbon content increase and oxygen content decrease. The hydrogen, nitrogen and sulphur content decreases as torrefaction proceeds (Figure 8 to 11). The decrease in hydrogen and oxygen is due to dehydration and de-carbon dioxide from the biomass during the torrefation. It is obvious that either carbon dioxide or water emission will result in decrease in hydrogen (H) and oxygen (O) contents of the woods.

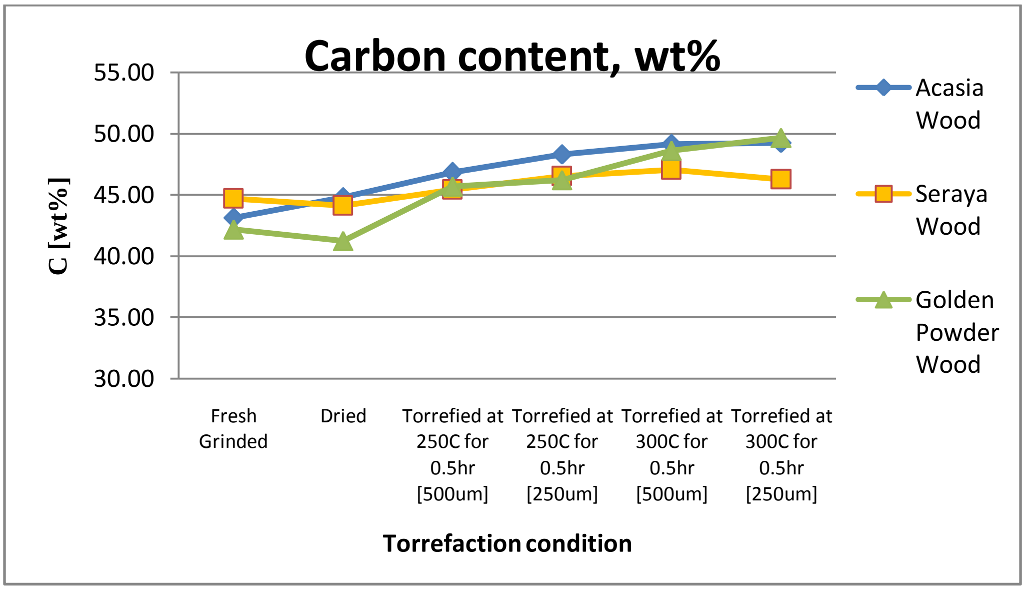


Figure 8a: Carbon content at different temperature and particle size for 0.5hr retention time

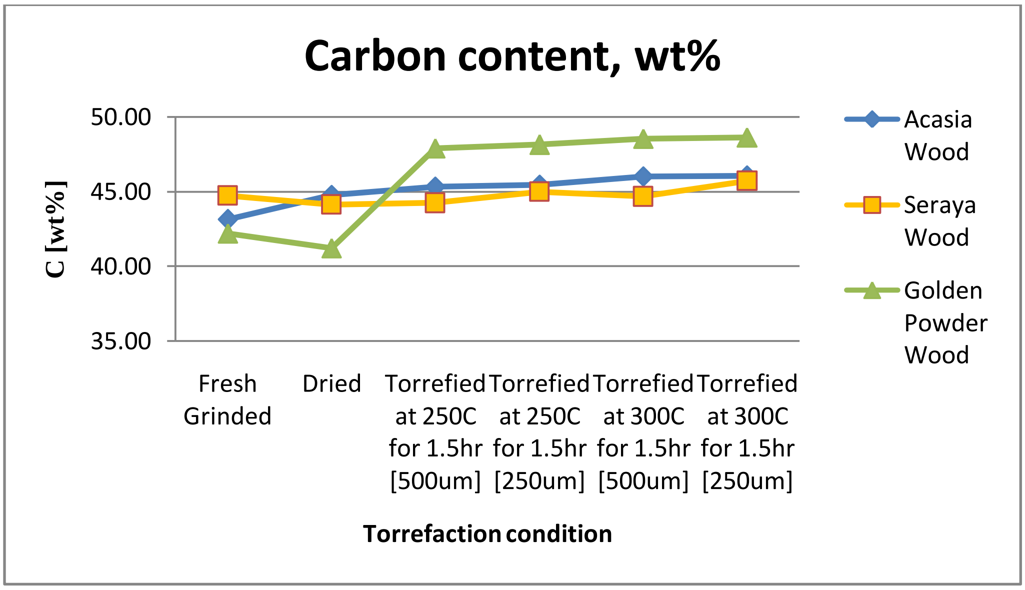


Figure 8b: Carbon content at different temperature and particle size for 1.5hr retention time

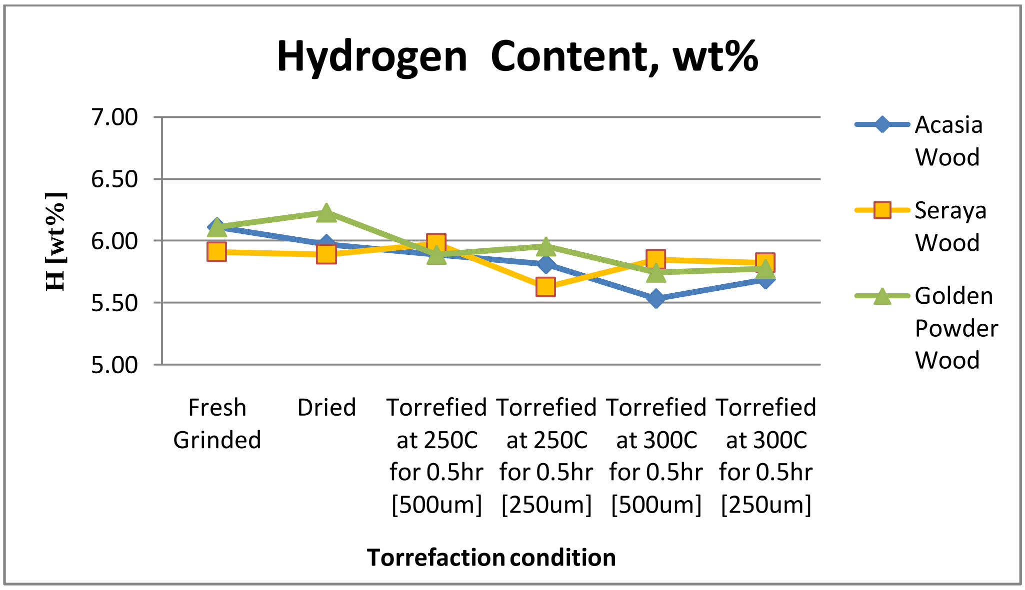


Figure 9a: Hydrogen content at different temperature and particle size for 0.5hr retention time

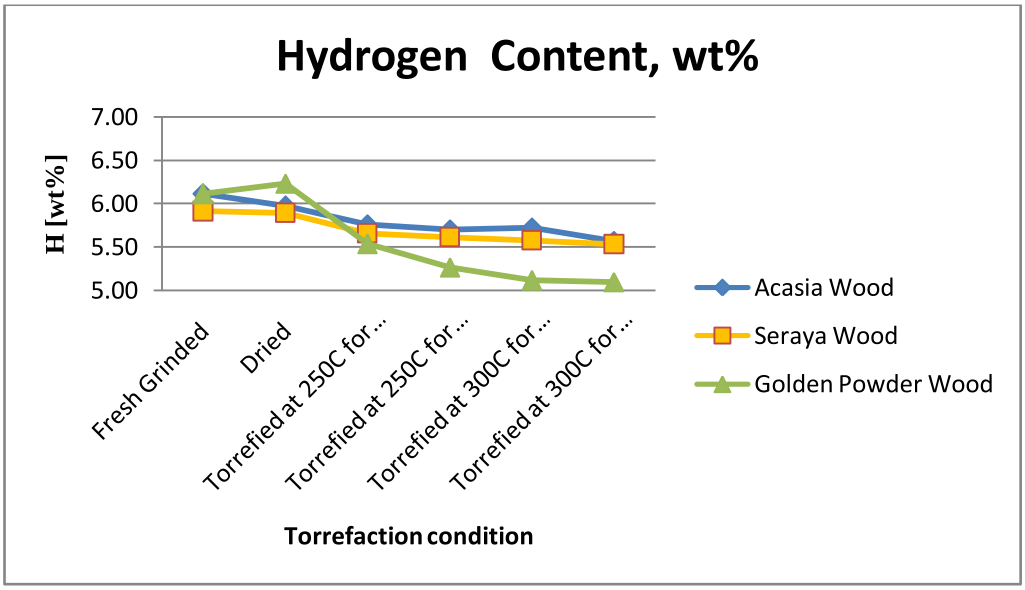


Figure 9b: Hydrogen content at different temperature and particle size for 1.5hr retention time

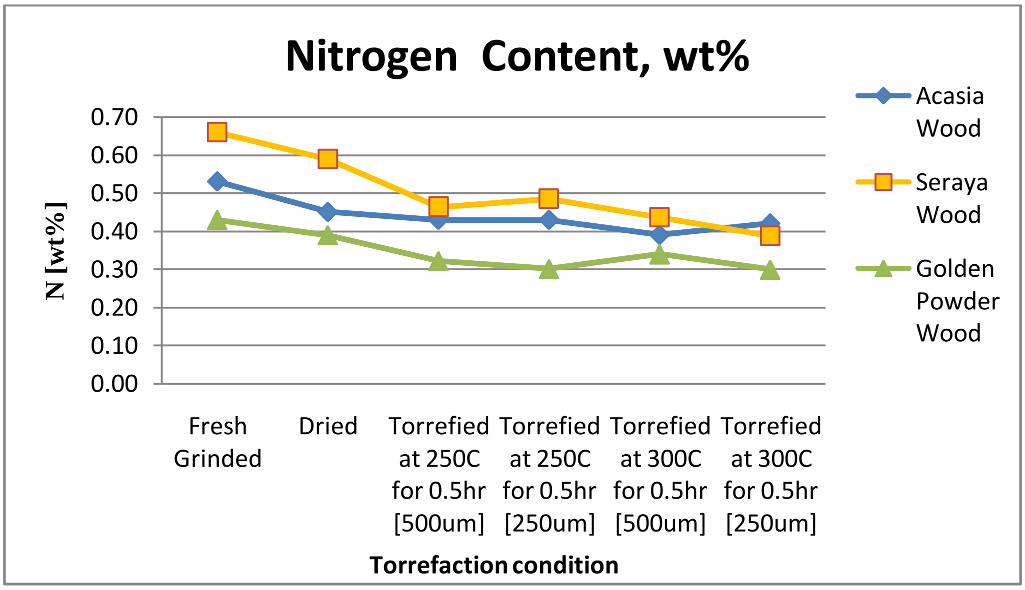


Figure 10a: Nitrogen content at different temperature and particle size for 0.5hr retention time

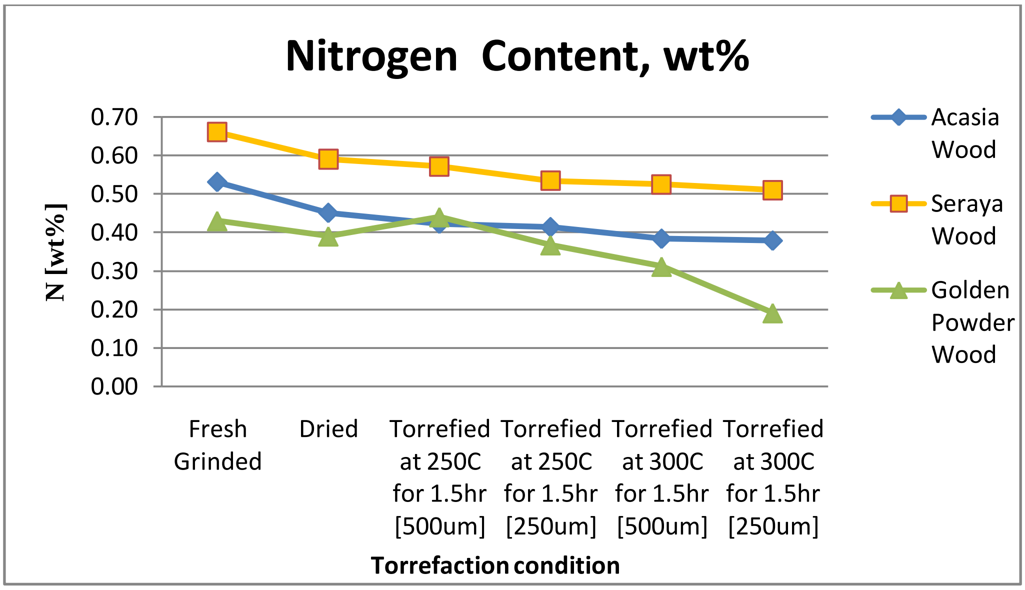


Figure 10b: Nitrogen content at different temperature and particle size for 1.5hr retention time

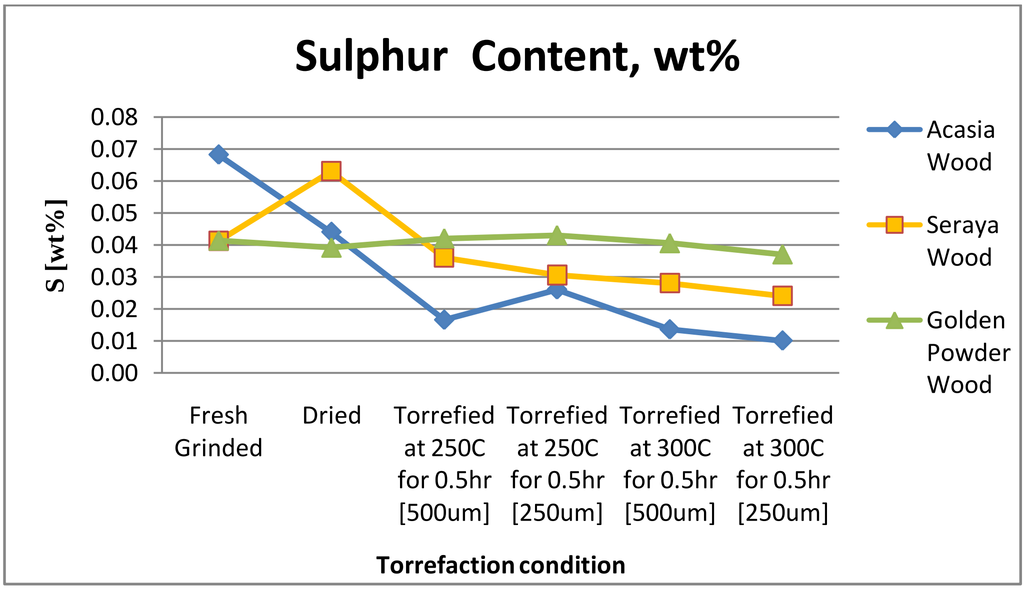


Figure 11a: Sulphur content at different temperature and particle size for 0.5hr retention time

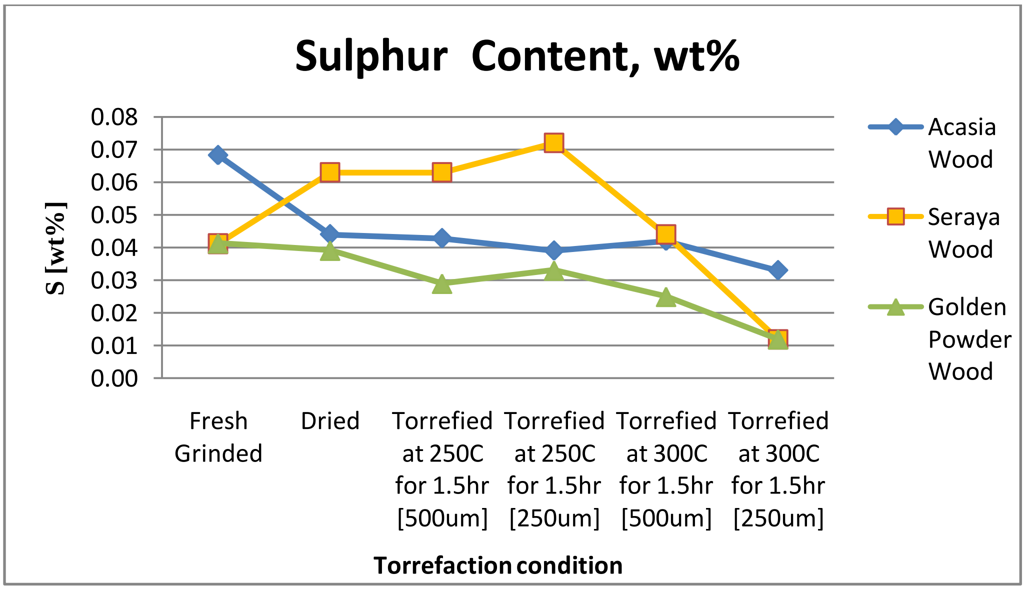


Figure 11b: Sulphur content at different temperature and particle size for 1.5hr retention time

The torrefied materials still exhibit carbon and oxygen content as the major composition while others remain as minor ones. According to Patrick et. Al [37], in torrefaction process biomass loses relatively more oxygen and hydrogen compared to carbon. Water from dehydration is the best example, but also all organic reaction products (acetic acid, furans, and methanol) and gases (mostly CO_2 and CO) contain a considerable amount of oxygen. Therefore, torrefied material has higher carbon content and lower oxygen content compared to the fresh sample. Due to removal of water and CO_2, the composition of torrefied material has a lower Oxygen/Carbon and Hydrogen/Carbon ratio.

According to Harun et al [36], rapid breakdown of the biomass structure increase tremendously at higher temperature, leaving the decreased amount of torrefied product. This is because the reaction achieves complete conversion to form more stable form of solid at high temperature. Besides, at higher temperature, greater amount of fresh samples is oxidised with other component exist in it. With high burn off-rate, most of the original sample has undergone complete reaction with oxygen. Therefore, more water and gas are released from the wood sample as the temperature increases. That is why hydrogen and nitrogen components decrease while the carbon content increases.

Theoretically, the smaller the particle size, the higher the surface and contact area exposed to the heating process as well as the reaction to take place. High surface area can induce more evaporation of water and other volatile products such as CO_2 and CO to leave the sample quickly and thus, resulting in lower volatile matter in the products and higher fixed carbon content. The removal of those water and volatile matter reduces the hydrogen and nitrogen content as well as Oxygen/Carbon ratio.

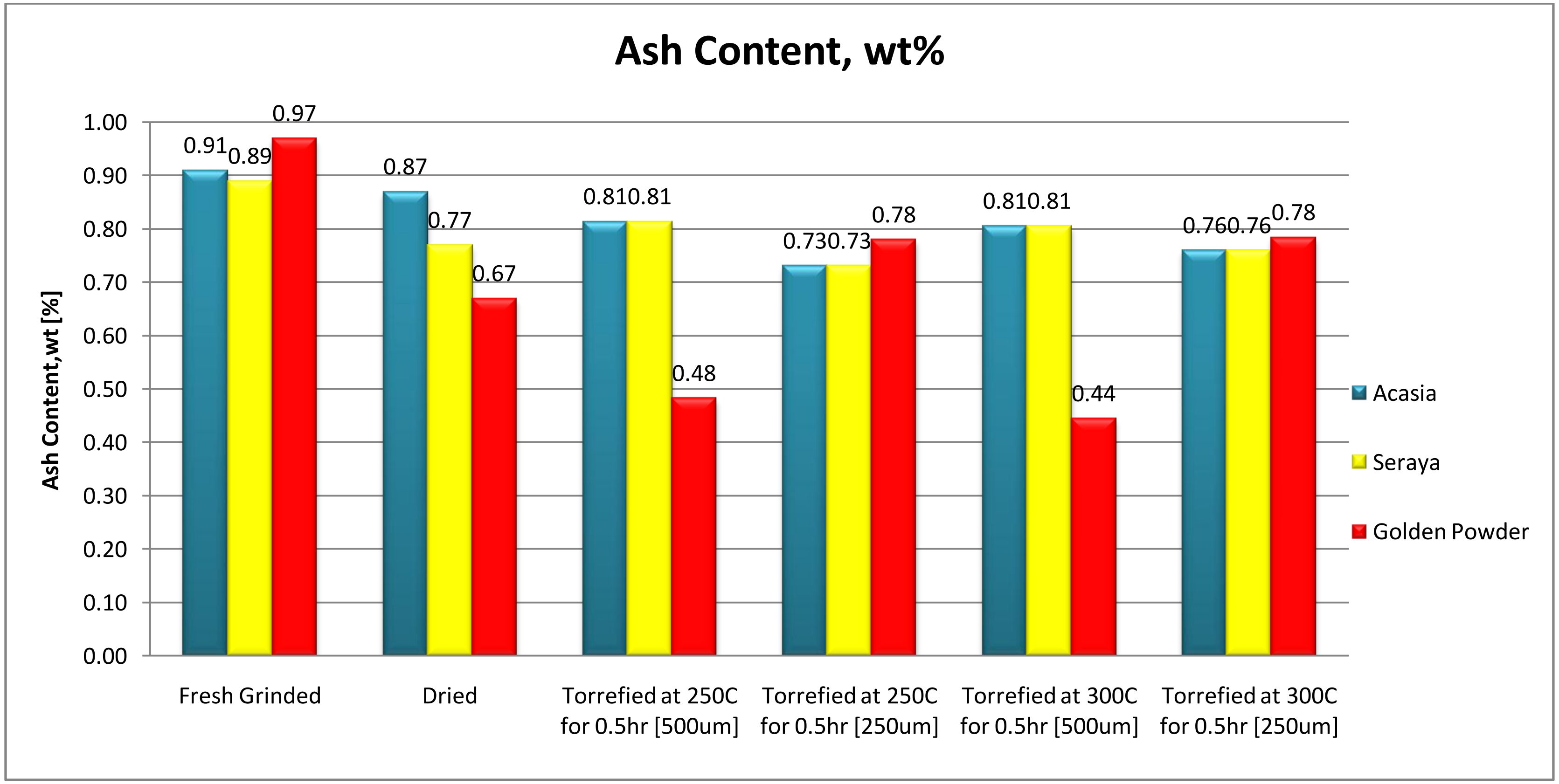


Figure 12a: Ash content at different temperature and particle size for 0.5hr retention time

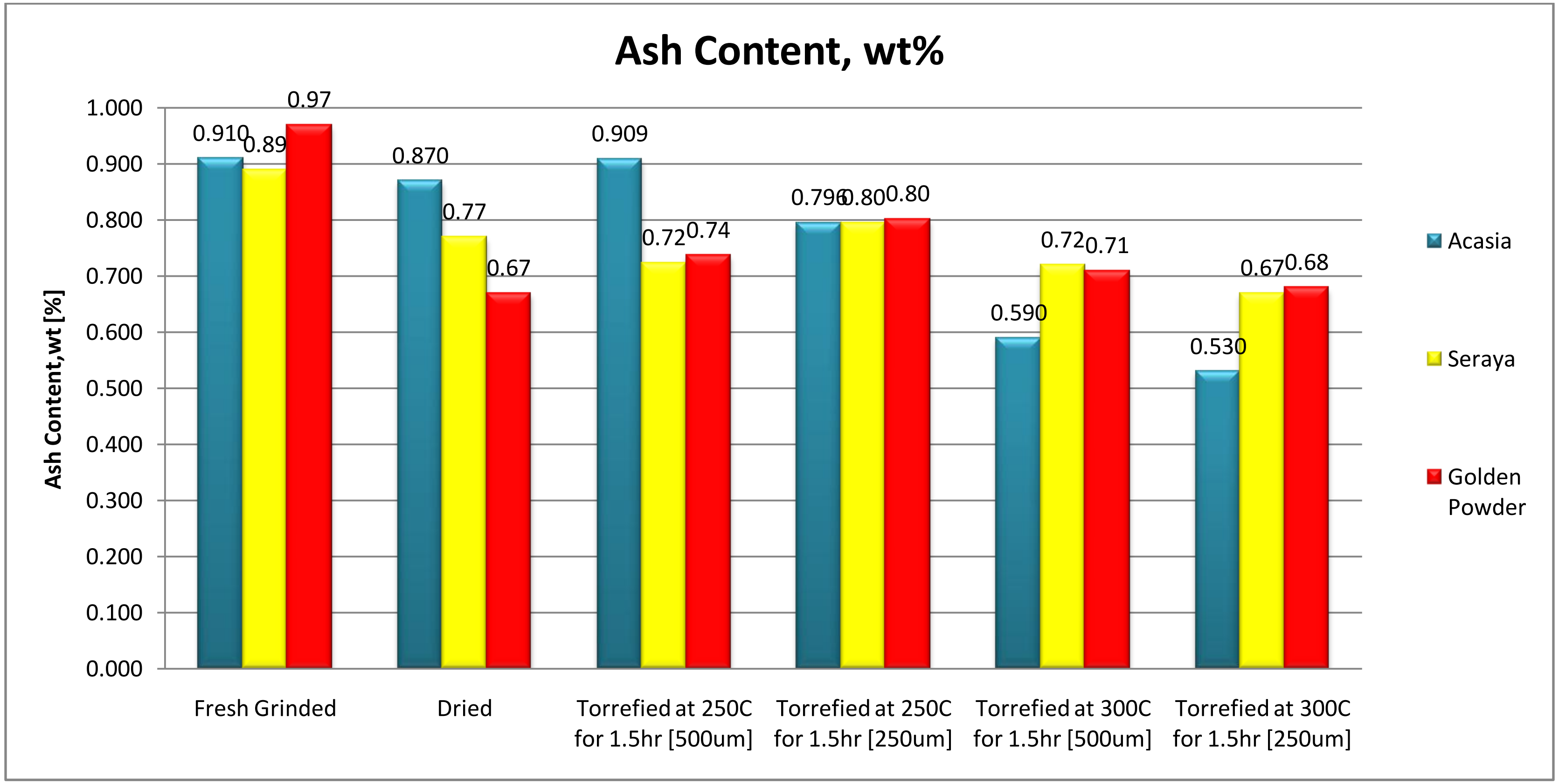


Figure 9b: Ash content at different temperature and particle size for 1.5hr retention time

From Figure 12, it is found that in general the ash content decreases as torrefaction proceeds. If ash is not emitted from the biomass during torrefaction, the ash content must increase in the torrefied samples. The result in Figure 12 implies two possibilities. The first is that a major component in the woods ash was lost (vaporized itself or accompanied with the tar sol) during the torrefaction. The second is that a major component in the woods was converted into a higher volatile form, and then was lost during the ash measurement at 700^{O}C.

4.3) YIELD OF TORREFACTION

The mass and energy yields of the dried and torrefied samples were calculated, based on equations used by Bridgeman *et al*. [37]. The mass and energy yields (Y_{masss} and Y_{ene}) are defined by (1) and (2), respectively.

$$Y_{mass} = 100 \text{ x } (\text{mass after drying or torrefaction /mass of wet sample before the treatment}) \qquad (1)$$

$$Y_{ene} = Y_{mass} \text{ x } (LHV \text{ after treatment } / \ LHV \text{ before treatment}) \qquad (2)$$

Figs. 13(a and b), 14(a and b) and 15(a and b) show the mass and energy yields under different conditions for Acasia wood, Seraya wood and Golden Powder wood, respectively.

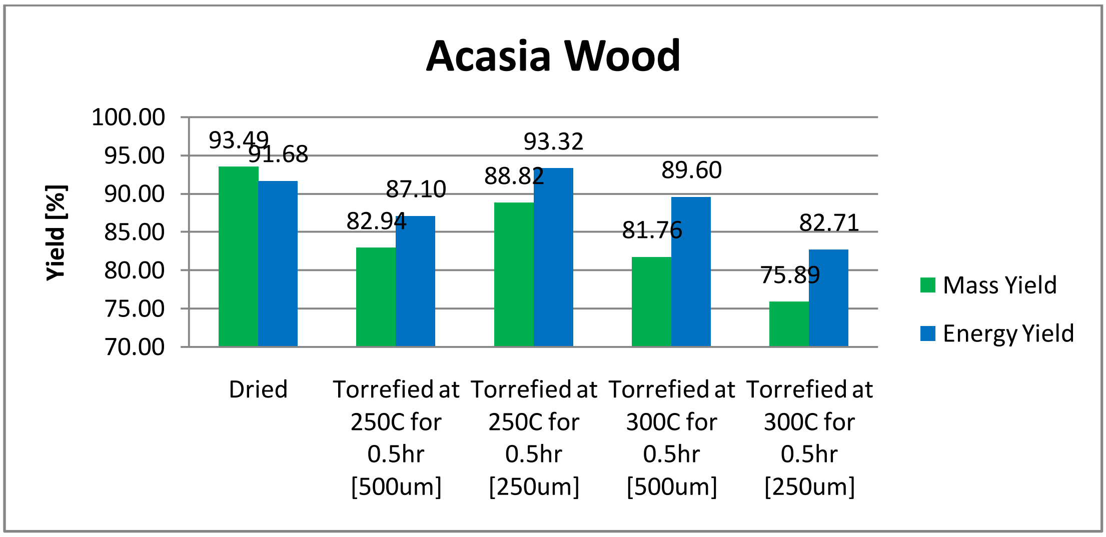


Figure 13a: Mass and energy yield at different temperature and particle size for Acasia wood for 0.5hr retention time

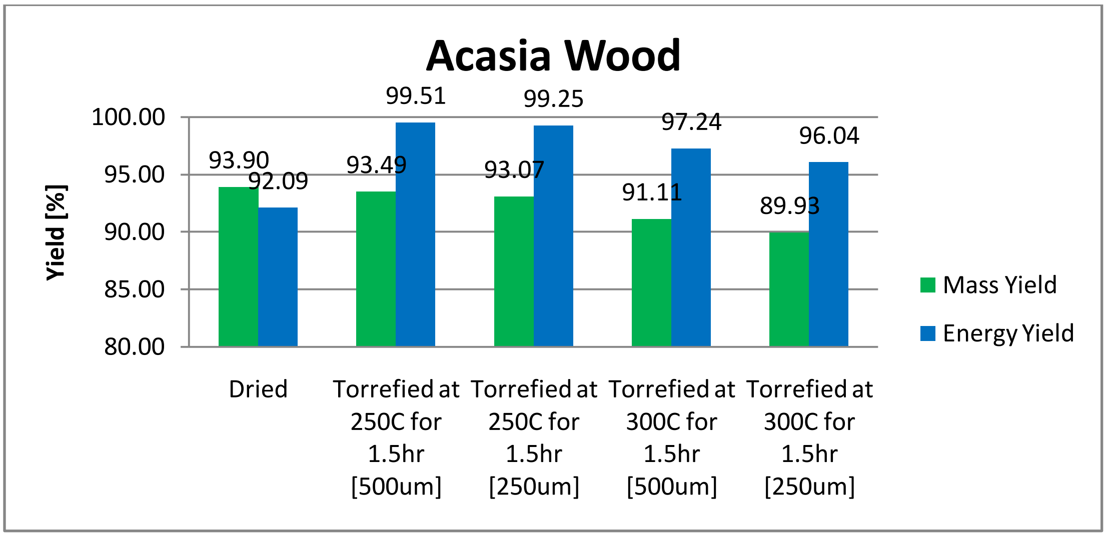


Figure 13b: Mass and energy yield at different temperature and particle size for Acasia wood for 1.5hr retention time

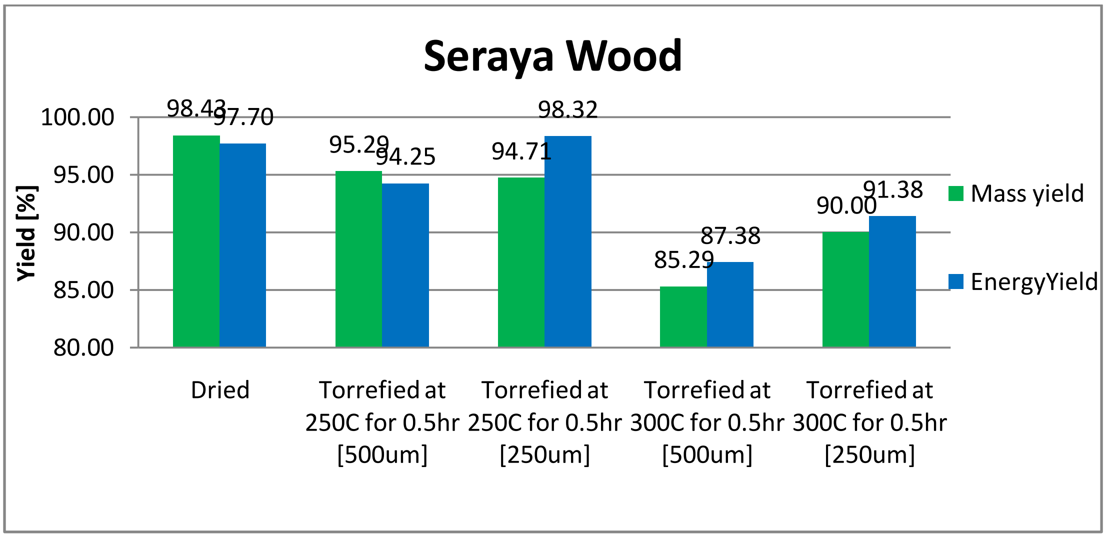


Figure 14a: Mass and energy yield at different temperature and particle size for Seraya wood for 0.5hr retention time

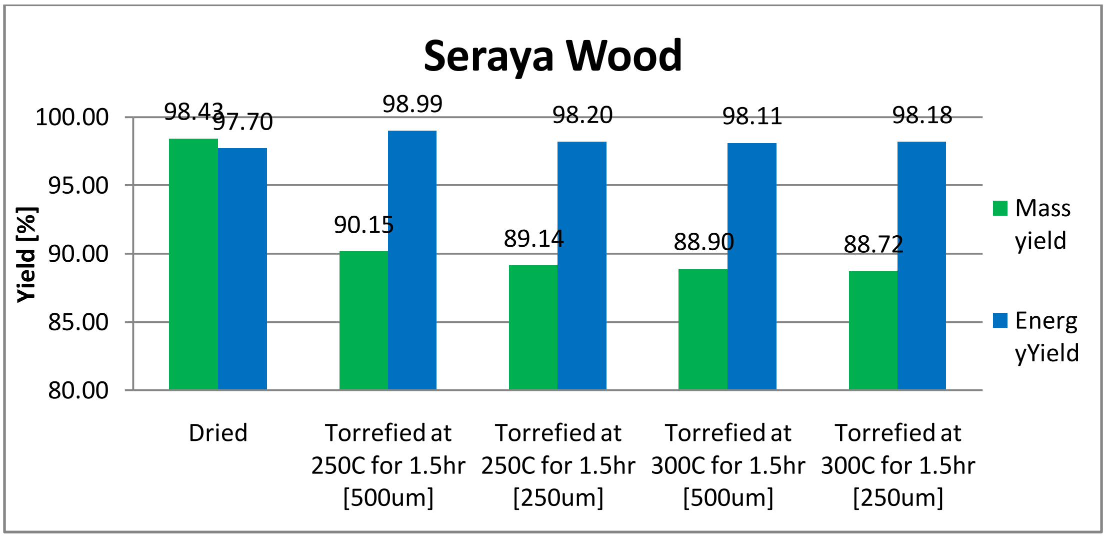


Figure 14b: Mass and energy yield at different temperature and particle size for Seraya wood for 1.5hr retention time

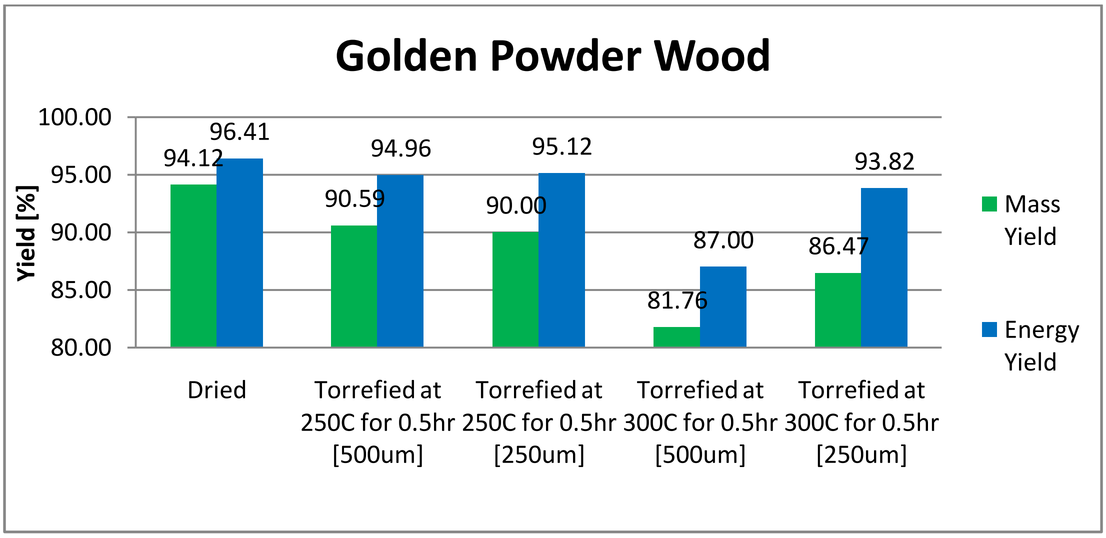


Figure 15a: Mass and energy at different temperature and particle size yield for Golden Powder wood for 0.5hr retention time

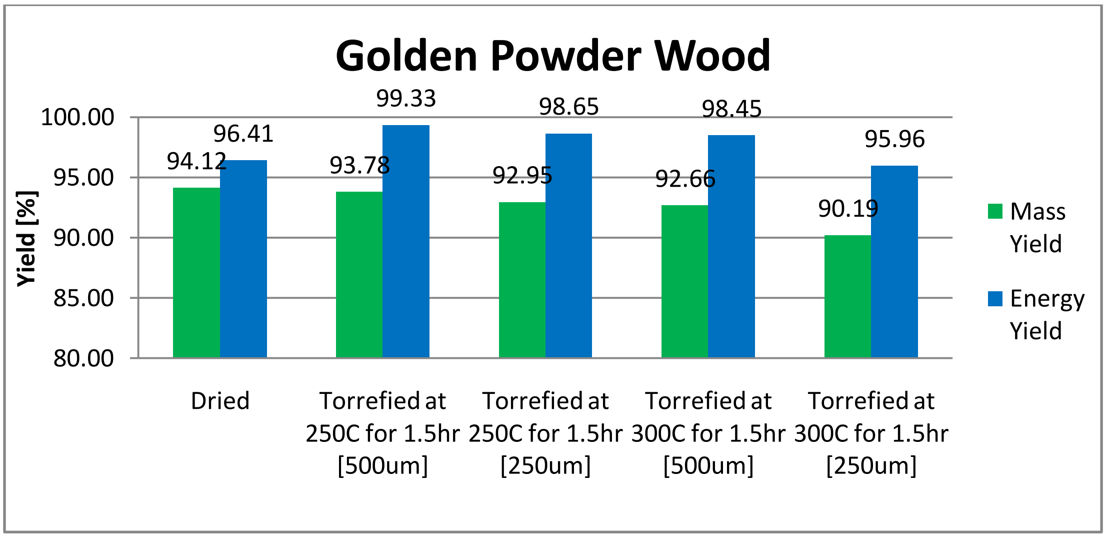


Figure 15b: Mass and energy yield at different temperature and particle size for Golden Powder wood for 1.5hr retention time

For calorific value analysis, the reading was taken by bomb calorimeter before and after torrefaction process. The raw sample calorific value before heating is 18488J/g for Acasia wood and Golden Powder wood, and 17952J/g for Seraya wood.

As shown in Fig. 10 to 12, for all the three biomass wastes, the mass yield is less than 100%, *i. e.*, the mass of torrefied samples was smaller than the corresponding wet raw material. As the torrefaction temperature increases, the mass yield decreases steadily.

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 [38]. The decrease in mass for the dried samples is thought to be mainly caused by the loss of moisture. For torrefaction at higher temperatures (250 and 300ºC), the decrease is attributed to the thermal decomposition of the hemicellulose part of the biomass [39].

Abdullah and Gerhauser reported that the ash in woods enhanced the decomposition of the woods [40]. This high ash content might have caused the lowest mass yield.

The energy yield in Fig. 13 to 15 ranges from 82.71 to 99.51% depending on the feedstock and its treatment condition. The energy yield of the dried samples would be 100%, if only moisture loss occurs during the treatment. The result of the three types of woods is quite less than 100% and is not consistent with this rule and this means the woods decomposed to some extent even during the drying.

The research done by Itebe et al. [42] that torrefaction process can retain up to 90% of the original energy is proven. In fact, the values increase with increasing temperature and reaction time. However, the calorific value decreases with increasing sample size. The higher the calorific value, the better the torrefied material will be as it provides enough energy to be an alternative fossil fuel.

According to Patrick et al [37], an increase of the calorific is the main result from the increasing carbon content and decreasing O/C ratio with the removal of water and gas during torrefaction. Depending on the torrefaction conditions, the low heating value dry of biomass, specifically wood can be increased from 17000-19000 J/g to 19000 to 23000 J/g. Also referring to R.Zanzi et al. [41], at higher temperature, the carbon content in the product increases whiles the contents of H and O decrease. H/C and O/C atomic ratios decrease with the temperature. As a result, the calorific value of the solid product increases with the temperature and at longer residence time

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

As for the conclusion, the use of renewable energy in Malaysia is growing rapidly throughout the analysis that had been conducted. In this study, the economical feasibility and sustainability of converting biomass to bio-based commercial products, synthetic bio-fuels and also for power generation have been reported. The findings show that Malaysia has the potential to be one of the major contributors of renewable energy in the world via oil palm biomass. Subsequently, Malaysia can then become a role model to other countries in the world that has huge biomass feedstock

It is observed that temperature, particle size, and residence time do affect the physical and chemical characteristics of the torrefied products. Almost 100% of the calorific value in all samples can be retained or increased by up to 10% from the original waste calorific value. At the optimum condition of temperature 300^{O}C and particle size of 250µm, the torrefied material produced is viable to be promoted at a larger scale.

There are few recommendations for the continuation of this project. Firstly, the equipments must be calibrated first before it is being used for the analyses purpose. Secondly, the Fixed Bed Activation Unit that is being used in the experiment should be equipped with a temperature sensor to measure the temperature distribution of the reactor. Lastly, the parameters of study should be added in order to study the optimum condition of the torrefied material.

As a conclusion, this project had meet its objective which are to analyse on the utilization of biomass wastes in Malaysia, analyze the potential of biomass as renewable source of energy in Malaysia, studies on the biomass conversion technology implemented in Malaysia and lastly to study the possibility of using Acasia wood, Seraya wood and Golden Powder wood to produce solid fuel via torrefaction.

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