Characterization of Various Biomass Sources for Co-Gasification

by

Mohamad Amin Bin Razak

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

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Universiti Teknologi PETRONAS
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
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(MECHANICAL ENGINEERING)

Approved by,

(Ir. Dr Shaharin Anwar Sulaiman)

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.

MOHAMAD AMIN BIN RAZAK

ABSTRACT

Issues on the fast depletion of fossil fuel and lots of problem especially on the global warming phenomena had become a crucial discussion in this century. These situations have prompted many developed and developing country to find alternative energy sources which are renewable and environmental friendly. Biomass is seen as having a big potential to develop especially in Malaysia due to abundance supply of biomass sources. Biomass energy, or bio-energy, is the energy stored in non-fossil organic materials. Gasification is one of the techniques in Thermo-chemical Process which is a process of conversion of solid carbonaceous fuel into combustible gas by partial combustion. Malaysia has recently ventured into usage of biomass energy and most of the biomass based plants in Malaysia use sources from oil palm cultivation residue. However, there may be some situations that these sources fail to fulfil the increasing energy demand. With that, some of the back-up sources are crucial that the biomass based plant will not stop the production. Malaysia also has very substantial potential for biomass energy utilization given its equatorial climate that is ideal for dense tropical forest growth and agricultural vegetation. However, there is lack of study is done toward all of these resources since most biomass power plant in Malaysia just using residue from oil palm sector. The objectives of the present project are study the characteristic of several potential biomass sources in Malaysia by mean of its chemical and physical properties and to study on suitability of mixing two or more biomass feed in gasifier. This study also aimed on a study on suitability of one gasifier to handle different biomass at different time. Four experiments had conducted which is calorific test, CHNS analysis, proximate analysis and bulk density test. All of the experiments were conducted to evaluate the chemical and physical properties of samples so that characterization of the samples can be made. The result of this project can be conclude that three type of samples which are weed, dry leave-A and coconut fibre have a potential to be develop as biomass feed stock since having a good calorific value, a good carbon, sulphur and nitrogen content and a good bulk density value.

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ABBREVIATIONS

CHNS	Carbon, Hydrogen, Nitrogen, Sulphur
FYP	Final Year Project
HHV	Higher Heating Value
LHV	Lower Heating Value
OPF	Oil Palm Frond
TGA	Thermogravimetry Analysis

CHAPTER 1

INTRODUCTION

1.1 Project Background

The fast global climate change due to the green house effect had become a crucial discussion in this century. Excessive green house effect is an effect done by excess green house gases which is majorly contribute by excessive utilization of fossil fuel. There is also an issue about the fast depletion of fossil fuel which cause the price is not stable. This situation had prompt many developed and developing country to find alternative energy sources which is renewable and environmental friendly so that increased energy demand can be supported. People in the world start to swing their perception on energy consumption by putting this factor as the primary characteristic on energy choice Biomass is seen having a big potential to develop especially in Malaysia due to abundance supply of biomass sources.

Biomass energy, or bio-energy, is the energy stored in non-fossil organic materials such as wood, straw, vegetable oils and wastes from the forest, agricultural and industrial sectors (Chapo, 2008).

There are three primary ways to convert biomass to energy (Qian et al, 2007);

1. Thermal Process

The oldest and most common way is to burn biomass to create heat. This can be used directly for heating, cooking and industrial processes, or indirectly to generate electricity. At biomass power plants, biomass is burned in a boiler to produce high pressure steam, which, in turn drives a turbines to generate electricity. *Examples of processes:* Combustion of woods and combustion of coals

2. Thermo-chemical Process

Done by heating (not burning) plant matter, it is possible to break down biomass into gases, liquids and solids, which can be further processed into gas and liquid fuels like methane and alcohol. Biomass reactors heat biomass in a low or zero oxygen environment to produce a fuel gas (mostly methane), which can then fuel steam generators, combustion turbines, combined cycle technologies or fuel cells. *Example of processes:* direct combustion, gasification, fast pyrolysis (fluidization), high pressure liquefaction.

3. Biochemical Process

Adding bacteria, yeasts and enzymes to biomass liquids causes biomass materials to ferment and change into alcohol. A similar process is used to turn agricultural products into ethanol (grain alcohol), which is then mixed with gasoline to make an ethanol-gasoline blend. When bacteria are used to breakdown biomass, methane is produced and can be captured from landfills and sewage treatment plants produce fuel for heat and power. *Example of processes:* methane fermentation and alcoholic fermentation.

Gasification is one of the techniques in thermo-chemical process which is a process of conversion of solid carbonaceous fuel into combustible gas by partial combustion (Babu, 2008). Gasification system basically consists of a gasifier unit, purification system and energy converters; burner or engine (refer appendices). Gasification is an incomplete combustion and it produces carbon monoxide (CO), hydrogen (H_2), and traces of methane (CH_4). This mixture is called syngas or also known as producer gas. Syngas are capable of supporting further combustion which usually occurs in a separate location or chamber (Balamohan, 2008). Syngas that produce are capable to run internal combustion engine (both compression and spark ignition). It also can be used to produce, in an economically viable way, methanol which is an extremely attractive chemical which is useful both as a fuel for heat engines as well as chemical feedstock for industries (Balamohan, 2008).

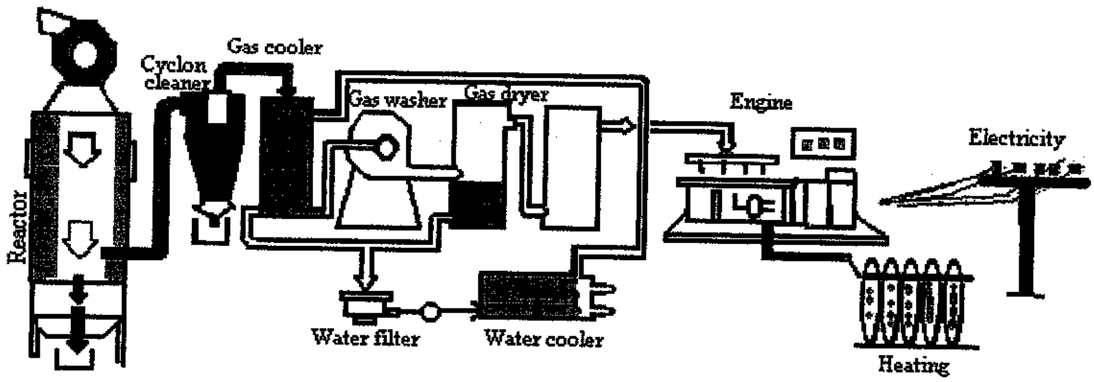

Figure 1.1: Overview Process of Gasification (Chandrakant, 2007)

A number of biomass based energy conversion system for combined heating and power generation are already in existence, however most biomass plants use biomass feed very much the same way as the fossil fuel for firing in a boiler to produce heat or steam (Zulkifli, 2004). Some companies have also used the technique of biomass gasification for power generation using internal combustion engine, but did not take off in large scale due to the constraints on the engine capacity and thus limiting the load below 1 MW (Rahman, 2005).

1.2 Problem Statement

Although Malaysia had taken an action to start practicing biomass energy sources as an energy source, it still considered as new and stills much to improve. Most of the biomass based plant in Malaysia used sources from oil palm cultivation residue (Shuit and Kamaruddin, 2009). Residue from oil palm cultivation had been researched and proved on its potential to become a biomass feed source. These sources seem as a high potential as biomass sources due to its unique chemical and physical properties and its abundance of availability. However, there might be in some situation that these sources fail to fulfil the demand. With that, some of the back-up sources are crucial so that the biomass based plant will not stop the production.

There are many other potential biomass sources in Malaysia since it location but the issue is on how good and suitable the sources can replace the existing biomass sources. Malaysia has very substantial potential for biomass energy utilization given its equatorial climate that is ideal for dense tropical forest growth and agricultural vegetation. Big areas of dense tropical forest in Malaysia contribute lot of organic waste every year. Agricultural Sector also contributes toward a big number of biomass sources in Malaysia. Currently, most of the waste from agriculture sector is disposed of through incineration and dumping, and only a small amount is used for energy generation for the industry's own consumption (Balamohan, 2008). The situation is that there is lack of study is done toward all of these resources since most biomass power plant in Malaysia just using residue from oil palm sector. In order to start practicing other biomass sources in biomass energy generation, the properties of each of them need to be studied.

1.3 Objective

The objectives of the present project are study the characteristic of several potential biomass sources in Malaysia by mean of its chemical and physical properties and to study on suitability of mixing two or more biomass feed in gasifier. This study also aimed on a study on suitability of one gasifier to handle different biomass at different time.

1.4 Scope of Study

There were three parts on the scope of study which is a study of potential biomass sources in Malaysia that have not been exploited by mean of its chemical and physical properties, a study on practiced biomass sources in Malaysia from outsource also by means of its chemical and physical properties and a compatibility study of a potential biomass sources in Malaysia with the practiced biomass sources.

The research of potential biomass sources for biomass gasification was by means of its chemical and physical properties. Among the interesting parameters in the chemical analysis is energy content of the samples, carbon content, sulphur content, calorific value, moisture, volatile matter, fixed carbon and ash content. The physical analysis would research into determining the frond bulk density value. The results from the present study can be applied for future study on a large scale gasification system.

For a study of practiced biomass sources in Malaysia, its chemical and physical properties were find from outsource research made by the other. Among the potential outsources is Journal from internet, journals from library and past Final Year Project (FYP) dissertation of other student.

All these chemical and physical properties were compared among each of the biomass sources to see the trend and potential of the biomass sources. This method also can use to identify the similarity and difference between them and they were categorized base on their same range in its properties so that each category can be said as supporting each other.

CHAPTER 2

LITERATURE REVIEW

Usage of conventional fuel had brought lots of problem to world where one of main problem is the increasing of carbon dioxide in atmosphere which causes global warming and had contributed many global problems. Furthermore, conventional fuel had start depleting while the energy demand keep increasing everyday which cause every country in the world start to do a research on the other potential energy supply to satisfy the energy demand.

2.1 Energy Issue

Depletion of conventional energy sources had become a crucial issue in this decade. World oil production and people demand toward energy sources seem like runners in Peak Oil Marathon. Peak Oil theory is a point at which the Earth's oil supply begins to dwindle where at this point; production of oil no longer continues the upswing that helped create the modern world as we know it. Instead, the upswing becomes a downturn. And if demand continues to grow while production begins to decline, world will have a problem (Clark, 2008). Many countries had change from net exporter to net importer of oil since its national oil demand had overcome the oil production. For example, in 1956, M. King Hubbert predicted that the United States' production of oil would peak between 1965 and 1970. It peaked in 1971 and has been in decline ever since, closely following the curve Hubbert predicted. As a result, the United States imported about 58 percent of the petroleum it used in 2007 (Clark, 2008). In 1996, Mackenzie also has done a computer analysis of world oil which he has combined with a review of published estimates of oil reserves. He concludes that for Estimated Ultimate Recovery (EUR) world's peaking could occur around 2014 (Bartlett, 2009). Figure 2.1 below shows on the estimated energy demand in Malaysia up to 2030. We can see the energy demand is keep increasing every year while the main energy supply is known keep depleting

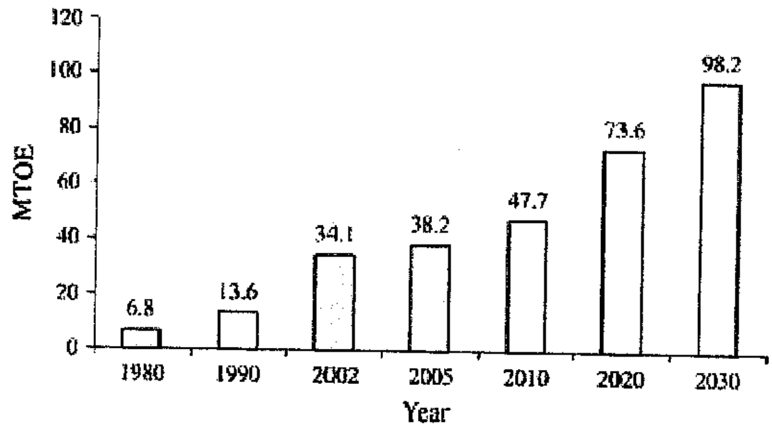

Figure 2.1: Estimated Energy Demand in Malaysia up to 2030 (Shuit et al., 2009)

Furthermore, excessive utilization of fossil fuel which classified as non-environmental friendly cause an excessive green house green house effect which prompt to global warming issue. The greenhouse effect is the heating of the surface of a planet or moon due to the presence of an atmosphere containing gases that absorb and emit infrared radiation. Thus, greenhouse gases trap heat within the surface-troposphere system.

2.2 Global Warming Issue

Two greenhouse gasses that indentify as main causes of this problem are carbon dioxide and methane. Carbon dioxide and methane concentrations in 2005 exceeded their natural ranges of the last 650,000 years. Much of this increase in concentration is due to burning fossil fuels (Strickland and Grabianowski, 2008). The safe level of atmospheric carbon dioxide is no more than 350 ppm (parts per million), and it may be less. Carbon dioxide amount is already 385 ppm and rising by about 2 ppm per year (Hansen, 2008). In other part, Intergovernmental Panel on Climate Change (IPCC) had stated that methane's concentration in the atmosphere in 2005 was 1,774 ppm. Although there is not as much methane as carbon dioxide in the atmosphere, methane can absorb and emit twenty times more heat than carbon dioxide (Strickland and Grabianowski, 2008). Figure 2.2 shows the statistic of Carbon Dioxide emission in Malaysia.

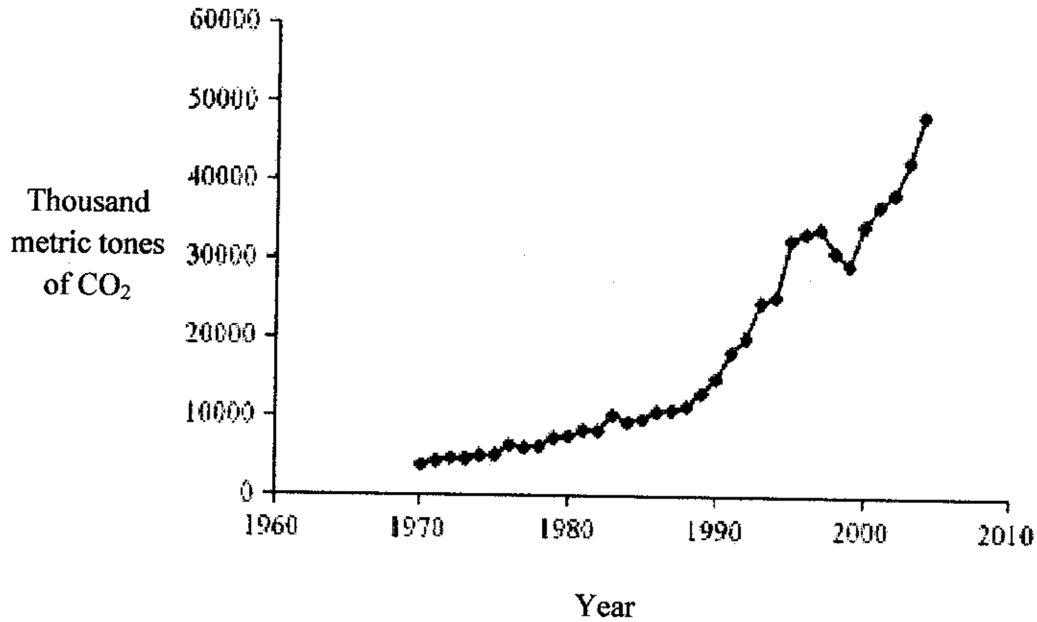

Figure 2.2: Statistic of Carbon dioxide emission in Malaysia from 1997 until 2006 (Shuit et al., 2009)

2.3 Biomass

Biomass energy, or bio-energy, is the energy stored in non-fossil organic materials such as wood, straw, vegetable oils and wastes from the forest, agricultural and industrial sectors (Chapo, 2008). Biomass is considered a renewable energy source because it is made from organic materials, such as trees, crops and even garbage. Usage of biomass energy is considered as environmental friendly because although it process emit carbon dioxide, but the carbon dioxide released will recycle back by photosynthesis process by plants which considered as a fast process. So, biomass energy is part of current bio-cycle of life (Solare, 2007). So carbon dioxide form from bio-energy can be said as a natural element produce on earth surface (Chapo, 2008). Unlike fossil fuel, although it has their origin in ancient biomass, they are not considered biomass by the generally accepted definition because they contain carbon that has been out of the carbon cycle for a very long time (Solare, 2007). Their combustion therefore disturbs the carbon dioxide content in the atmosphere. Furthermore, biomass has low sulphur content, thus thermal conversion of biomass emits low SOx unlike combustion of diesel and coal (Alimuddin, 2008)

Biomass is seen as one of the alternative energy that can replace energy from fossil fuel. One of the main reasons is because its sources are commonly available and it is locally produce by either naturally or from agriculture sector. An additional benefit is the fact biomass almost always breaks down relatively quickly to its natural elements. This means a biomass fuel spill would be far less damaging than an oil spill, particularly in the long run (Leipoldt, 2009). The usage of biomass energy from agriculture sources also seem can reduce the pollution problem that contributes by cultivation sector since as we knows cultivation sector produce a lots of waste every year and nowadays there is a lack of ways in managing the waste (Faridah, 2008).

Due to the fact that Malaysia will exhaust its oil and gas reserves in the future, Malaysia has intensified its research on renewable energy sources especially on utilization of oil palm biomass. The use of renewable energy sources is a vital element in providing a long-term solution to Malaysia's energy needs and for promoting sustainable development. Presently in Malaysia, many programs and projects on utilization of oil palm biomass have been launched or are already in the planning stage (Kamaruddin, 2009). For example, is Biomass energy plant in Lumut. PGEO Group Sdn. Bhd. (PGSB) is a major edible oil refiner and exporter in Malaysia. In year 2005, PGSB has completed construction of a biomass-fired steam generator plant in Lumut. The plant obtained its biomass waste from neighboring 16 palm oil mills via fuel purchase agreement (Shuit and Kamaruddin, 2009).

Table 2.1: Main Industry Distribution of Biomass Energy Project in South-East Asia (Charlos and Do, 2009)

Country	Industry					
	Rice	Sugar	Palm oil	Wood processing factories	Small power producer	Others
CAMBODIA						
No of project	1	0	0	0	0	0
Capacity (MW)	2	0	0	0	0	0
Indonesia						
No of project	1	3	4	0	2	1
Capacity (MW)	6.3	18.2	23.7	0	16.2	64
Loas						
No of project	1	5	0	0	1	1
Capacity (MW)	1	10	0	0	1	1
Malaysia						
No of project	1	0	12	3	9	0
Capacity (MW)	1.5	0	82.2	16	57.5	0
Philippines						
No of project	4	6	1	4	5	1
Capacity (MW)	4	127.5	25	4	120	1
Singapore						
No of project	0	0	0	0	0	3
Capacity (MW)	0	0	0	0	0	4
Thailand						
No of project	6	30	1	1	40	9
Capacity (MW)	44.9	478.4	0.9	1	777.2	36.3
Vietnam						
No of project	2	3	0	2	0	2
Capacity (MW)	8	9	0	0.4	0	10.6
Total Southest Asia						
No of project	16	47	18	10	57	17
Capacity (MW)	67.7	643.1	131.8	21.4	971.9	116.9

2.4 Gasification

Gasification is a process that converts carbonaceous materials such as coal, petroleum, or biomass, into carbon monoxide and hydrogen by react the raw material at high temperatures with a controlled amount of oxygen (Phillipe, 2001).

The essence of gasification process is the conversion of solid carbon fuels into syngas by thermo-chemical process. The thermo-chemical conversion process of biomass leads to a gas called producer gas with typical composition of 20% CO, 20% H_2, 2% CH_4, 12% CO_2, and rest nitrogen (IISc, 2010). This gas is cooled to ambient temperature and can be transported over economically meaningful distances of 50 to 100 m for being used in one location or several locations (IISc, 2010). The gasification of solid fuel is accomplished in air sealed, closed chamber, under slight suction or pressure relative to ambient pressure.

In gasification process, air is introduced in the oxidation zone contains, besides oxygen and water vapors, inert gases such as nitrogen and argon. These inert gases are considered to be non-reactive with fuel constituents. The oxidation takes place at the temperature of 700-2000°C (Quaak et al., 2008)

Biomass gasification has advantages over other methods of producing energy. It serves as an alternative technology for renewable energy using palm oil mill biomass. In addition the emission levels from biomass gasification are much lower than the conventional incineration or boiler chimney. Biomass gasification system has helped many developing countries to improve their balance of payment (Dassapa, 2004). However, none of the industrial or small-scale plants yet built have exceeded 33% efficiency (Ganesh, 2006)

Heterogeneous reaction takes place between oxygen in the air and solid carbonized fuel, producing carbon monoxide. Plus and minus sign indicate the release and supply of heat energy during the process respectively:

$$C + O_2 \rightarrow CO_2 \qquad + 406 \text{ [MJ/kmol]} \qquad (2.1)$$

Hydrogen in fuel reacts with oxygen in the air blast, producing steam.

$$H_2 + \frac{1}{2} O_2 \rightarrow H_2O \qquad + 242 \text{ [MJ/kmol]} \qquad (2.2)$$

In reduction zone, a number of high temperature chemical reactions take place in the absence of oxygen. The principal reactions that take place in reduction are mentioned below.

Boudouard reaction

$$CO_2 + C \rightarrow 2CO \qquad - 172.6 \text{ [MJ/kmol]} \qquad (2.3)$$

Water-gas reaction

$$C + H_2O \rightarrow CO + H_2 \qquad - 131.4 \text{ [MJ/kmol]} \qquad (2.4)$$

Water shift reaction

$$CO_2 + H_2 \rightarrow CO + H_2O \qquad + 41.2 \text{ [MJ/kmol]} \qquad (2.5)$$

Methane production reaction

$$C + 2H_2 \rightarrow CH_4 \qquad + 75 \text{ [MJ/kmol]} \qquad (2.6)$$

Main reactions show that heat is required during the reduction process. Hence, the temperature of gas goes down during this stage. If complete gasification takes place, all the carbon is burned or reduced to carbon monoxide, a combustible gas and some other mineral matter is vaporized. The remains are ash and some char or unburned carbon.

2.5 Chemical and Physical Properties of Biomass Feed

There are lots of issues of biomass gasification process from the research on the potential of biomass sources, biomass feed preparation, storing, until gasifier design. Key to a successful on solving each issue is to understand properties and thermal behavior of fuel as fed to the gasifier (Chandrakant, 2007). The most important properties relating to the thermal conversion of biomass are moisture content, calorific value, volatile matter content, ash content, elemental composition, and bulk density (Quakk et al., 2010).

Beside the properties of samples in this project, some properties values are also collected from various sources of other research. All of these are projecting the properties of each of the biomass sources. Most of the sources stated had already proved on its feasibility as a biomass feed stock so that it is good to make a compatibility study with samples used in this project. However, all these values might vary depending on the characterization procedures and the origin of the biomass samples (Liao, 2005). The function of characterization procedure had been eliminate by repeating a works from previous research at resulting on the almost the same result with them. However, function origin of biomass samples is quite hard to be eliminated since lot things need to be considered. Origin of biomass samples including type of soil use, ambient temperature, fertilizer used, and species of them.

All of properties values collected from other research can be referred in appendices Table A-1 to Table A-6.

2.5.1 Chemical Properties

There are lots of chemical properties of biomass feed affect the characteristic for gasification process. These properties are very useful especially in designing the suitable gasification system for each of the biomass sources.

Moisture content of biomass is the quantity of water in the material, express as a percentage of the material's weight. Moisture content can be expressed as percentage of the 'dry and ash free' since it related to the weight of the dry biomass and the moisture content always affect the other value of biomass source as a fuel (Quakk et al., 2010). Theoretically, almost all kinds of biomass with moisture content of 5-30% can be gasified; however, not every biomass fuel leads to the successful gasification (Chandrakant, 2007). The moisture content of the most biomass feed depends on the type of fuel, it is origin and treatment before it is used for gasification (Chandrakant, 2007). Moisture content of the fuel is usually referred to inherent moisture plus surface moisture.

The moisture content below 15% by weight is desirable for trouble free and economical operation of the gasifier (Mckendry, 2001). Higher moisture contents reduce the thermal efficiency of gasifier and results in low gas heating values. Igniting the fuel with higher moisture content becomes increasingly difficult, and the gas quality and the yield are also poor.

Normally, Energy contents are expressed as Lower Heating Value (LHV) where this is closest to the actual energy yield in most cases. Higher Heating Value (HHV, which including condensation of combustion products) is greater by between 5% and 10%, depending mainly on the hydrogen content of the fuel (UDE, 2007). For most biomass feedstocks this difference appears to be 6-7%. The appropriateness of using LHV or HHV when comparing fuels, calculating thermal efficiencies, etc. really depends upon the application. For stationary combustion where exhaust gases are cooled before discharging (e.g. power stations), HHV is more appropriate. Where no attempt is made to extract useful work from hot exhaust gases (e.g. motor vehicles), the LHV is more suitable. In practice, many European publications report LHV, whereas North American publications use HHV (GCEP Energy Assessment Analysis, 2005). Energy content of fuel is obtained in most cases in an adiabatic, constant volume bomb calorimeter. The values obtained are higher heating values (HHV) which include the heat of condensation from water formed in the combustion of fuel (Chandrakant, 2007). Biomass fuels contain higher proportion of hydrogen and oxygen, compared with carbon, which reduces the energy value. It is said that carbon–oxygen and carbon–hydrogen bonds contain lower energy than in carbon–carbon bonds. So, the calorific value of biomass is in the range of 16–20 MJ/kg (Liao et al., 2005). Fuel with higher energy content is always better for gasification. So this chemical property will give the information about the potential of the biomass sources.

Volatile matter refers to the part of the biomass that is released when the biomass is heated up from 400°C to 500°C (Quakk et al., 2010). Volatile matter and inherently bound water in the fuel are given up in pyrolysis zone at the temperatures of 100-150 °C forming a vapor consisting of water, tar, oils and gases (Chandrakant, 2007). Fuel with high volatile matter content produces more tar, causing problems to internal combustion engine. Volatile matters in the fuel determine the design of gasifier for removal of tar (Chandrakant, 2007). Biomass typically has high volatile matter content (up to 80%) compared to coal (less than 20%) (Quakk et al., 2010). Most oxygen is released in combined form with volatiles. About 50% energy is contributed by gas phase combustion through volatile. Rate of release of volatiles is high and different for different biomass. Therefore, provisions of air, mixing are critical (Ganesh, 2006). Volatile elements such as Na and K are main constituents of aerosols. Volatile minor elements (As, Cd, Hg, Pb, Zn) play a major role in gaseous and especially aerosol emissions as well as in deposit formation, corrosion and ash utilization or disposal (Liao et al., 2005).

A mineral content of fuel which remains in oxidized form after combustion of fuel is called ash. Ash also can name as inorganic component which express in the same way as moisture content. In practice, ash also contains some unburned fuel. Ash content and ash composition have impact on smooth running of gasifier (Unified Bio-energy Terminology, 2004). Melting and agglomeration of ashes in reactor causes slagging and clinker formation. If no measures are taken, slagging or clinker formation leads to excessive tar formation or complete blocking of reactor. The composition of ash affects its behavior under the high temperature of gasification (Quakk et al., 2010). Major ash forming elements which is Al, Ca, Fe, K, Mg, Na, P, Si, and Ti are of relevance for the ash melting behaviour, deposit formation and corrosion (Liao, et al. 2005). So, ash content also is a property need to be considered before gasifier design.

Elemental composition such as Carbon, Sulphur, Hydrogen and Nitrogen of the biomass sources are also important characteristic of biomass sources. High carbon content would highlight the possibility of the biomass sources to become a fuel source for the gasification process (Chandrakant, 2007). Low sulphur content would portray the potential of the palm fronds as an environmental friendly renewable energy source as sulphur would and react with water, oxygen and oxidants to form acidic compound as found in acid rains (Balamohan, 2008).

Reactivity determines the rate of reduction of carbon dioxide to carbon monoxide in the gasifier. There are number of elements which act as catalyst and influence the gasification process. Small quantities of potassium, sodium and zinc can have large influence on reactivity of the fuel (Chandrakant, 2007).

2.5.2 Physical Properties

Physical properties are crucial to be determined in order to find out the best way of sample preparation and storing method.

There are lots of ways in preparing the biomass sources before and proceed to gasification process. Some famous form that always been used is powder form, compaction form and grinding form. Each of them will have various characteristic of its chemical and physical properties (Phani et al., 2009). Selecting the best form for biomass feed should be look on to the chemical and physical properties. Physical properties such as bulk density value will give information on the potential of the biomass feed form where high bulk density value represents a high energy-for-volume value (Balamohan, 2008). Chemical properties of each form also need to be study for selecting the best biomass feed form. It is had been recognized that bulk density has considerable impact on gas quality, as it influences the fuel residence time in the fire box, fuel velocity and gas flow rate (Phani et al., 2009).

Bulk density is defined as ratio of dry material to bulk volume and is relevant for the volume needed for transportation and storage (Unified Bio-energy Terminology, 2004). Bulk density varies significantly with moisture content and particle size of fuel (Phani et al., 2009). Volume occupied by stored fuel depends on not only the bulk density of fuel, but also on the manner in which fuel is piled. It is also recognized that bulk density has considerable impact on gas quality, as it influences the fuel residence time in the fire box, fuel velocity and gas flow rate (Chadrakant, 2007). Together, heating value and bulk density determine the energy density which is the potential energy available per unit volume of the biomass (Quakk et al., 2010). In general, biomass energy densities are approximately one-tenth that of fossil fuels such as petroleum or high-quality coal (Quakk et al., 2010).

CHAPTER 3

METHODOLOGY

3.1 Project Scheduling and Flow

The feasibility of coconut fibre, weed, paddy husk and four type of dry leave mixture for biomass gasification were investigated by means of chemical and physical analysis. Prior to the investigation by conducting experiments, the basic analysis method and procedures involved are studied by means of literature review. For the first half of the semester the chemical analysis of the samples were investigated by means of Ultimate Analysis and Calorific Test. The second half of the study was further investigate the feasibility of the fronds by means of Proximate Analysis. Physical analysis was aimed to determine the fronds bulk density value and the drying characteristic under various conditions. Gasifier used for the gasification process was a downdraft gasifier type. The proposed Gantt chart is as shown in Figure 3.1 and Figure 3.2.

No	Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of project topic	■	■	■	■	■									
2	Preliminary Report Submission					●									
3	Data Gathering and research on topic		■	■	■	■									
4	Confirmation on scope of study					■	■								
5	Research on potential biomass sources						■	■	■	■	■				
6	Research on the methodology							■	■	■					
6	Sample preparation									■	■				
7	Submission of Progress Report I								●						
8	Ultimate analysis										■	■			
9	Calorific Analysis											■	■		
10	Proximate Analysis												■	■	
11	Seminar												●		
12	Submission of Interim Report														●

Figure 3.1: Project flow for Semester 1

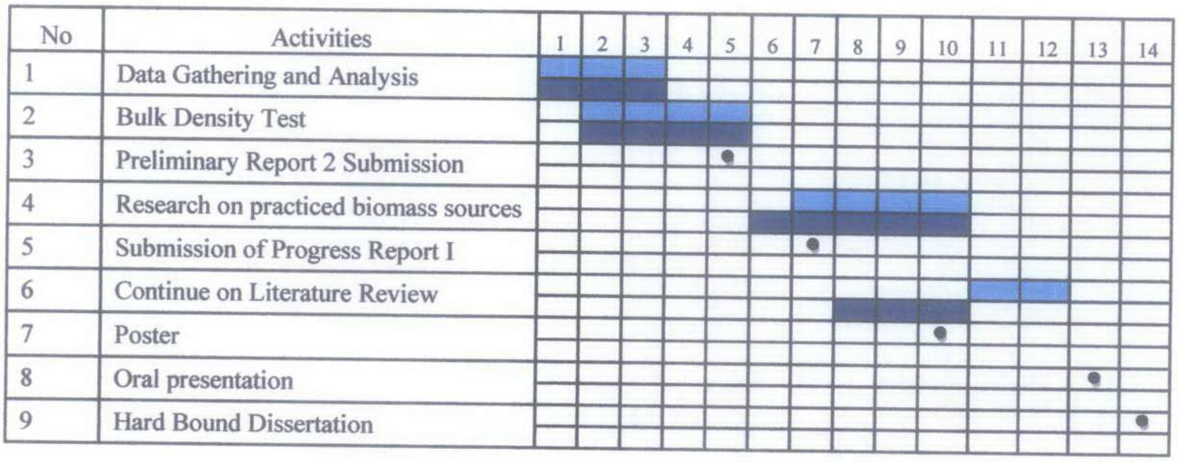

Figure 3.2: Project flow for Semester 2

Legend:

■ : Progress Work

■ : Planned Work

● : Milestones

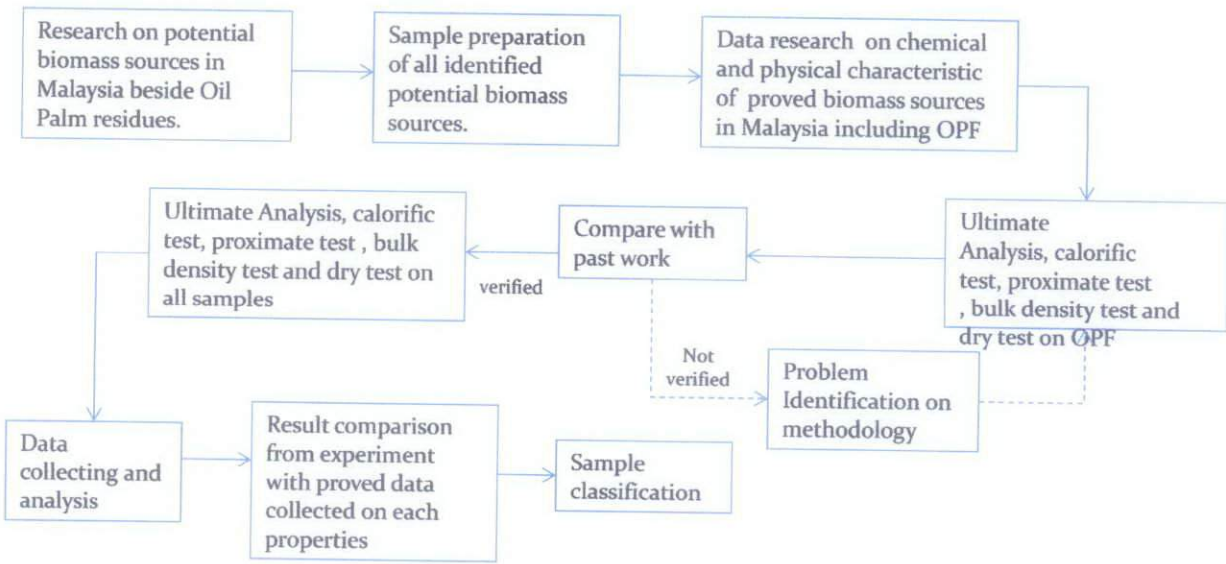

Figure 3.3: Flow Chart of Project

3.2 Sample Preparation for Analysis

All the samples were left to dry under the sun for a period of 3 days to ensure a dry sample. The samples were further dried in an oven at 55°C for a period of 24 hours. This is referred as the pre-treatment process in which the moisture content in the fronds is completely eliminated.

The samples are undergone first stage of grinding to prepare it in powder form using a Granulator. Picture of Granulator can be referred to Figure A-1 in appendices. The granulated samples are then turned into its powdery form using a Rock Lab Grinder. Picture of the Granulator and Rock Lab Grinder used can be referred to Figures A-2 and A-3 in Appendices

3.3 Chemical Analyses

Chemical analysis is necessary to justify the feasibility of using every sample in a gasification system. In the present work, chemical analysis will include, Ultimate Analysis, Calorific test, and Proximate Analysis. Each of the analysis would be discussed in the following sections.

3.3.1 Ultimate Analysis

The purpose of preparing a fine dry power is to analyze the chemical compositions of the samples. The ultimate analysis was performed using the Leco CHNS-932 machine. The CHNS machine works based on the principle that high temperature combustion is used as the means of removing the elements from the material. This analysis will report the (carbon, hydrogen, nitrogen, and sulphur) content in the samples. The parameter for ultimate analysis was set according to ASTM D 3176-89. Step in conducting this experiment are describe as below:

1. Samples need to be ensured in the powder form.
2. One capsule is taken and weighted. The weight value at weight machine is tare.
   Picture of capsule can be referred in Figure 3.4

3. One type of sample is selected and put in the capsule. The weight of the capsule fill with sample is weighted.
4. Capsule is compacted until there is no more air inside.
5. Step 1 to 4 is the repeated to other samples.
6. All samples are then placed in the machine. The weight value for each sample is entered in the machine.
7. Start the experiment as the all the weight value is entered.
8. Experiment takes approximately 20 minutes for each sample. The reading of Carbon, Hydrogen, Nitrogen and Sulphur content for each sample is taken after experiment is finished.

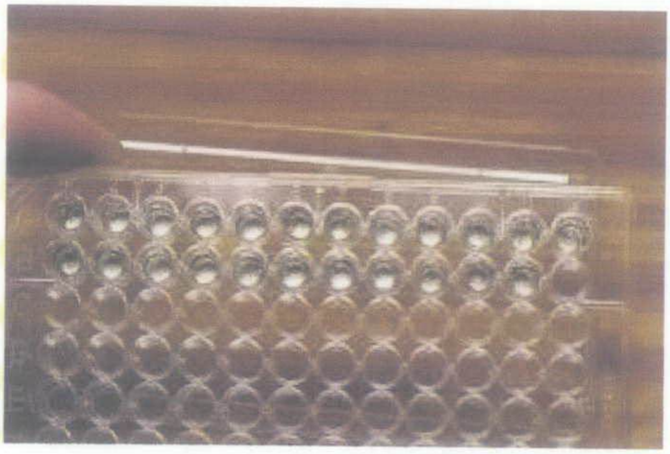

Figure 3.4: Capsule used in CHNS analysis

3.3.2 Calorific Test

To determine the amount of energy stored in the each sample, a Calorific Value Test would be done using a LECO AC-350 Bomb Calorimeter. Gross Calorific value of a fuel specimen is the heat produced by a complete combustion of a unit quantity of sample, at a constant volume, in an oxygen bomb calorimeter under standard condition. The parameter for the calorific test was done according to ASTM D 5865-07, Standard test Method for Gross Calorific Value of Coal and Coke. Picture of LECO AC-350 Bomb

Calorimeter machine can be referred to Figure A-4 in appendices. Step in conducting this experiment are describe as below:

1. Machine is turn on and wait to be stabled
2. Ceramic Bowl is weighted and the weight value at weight machine is tare.
3. While waiting for machine to stable, samples can be prepared. Take one type of sample and place some amount of them into a ceramic bowl. The ceramic bowl with samples is then weighted. The amount of samples in ceramic bowl is then adjusted so that the weight of the sample between 5 to 10gram. The final reading of sample weight is taken.
4. The thread is then tight to wire connecting the two conductors as shown in figure 3.5. The ceramic bowl is placed on its sit and the thread is then need to be buried inside into the sample.
5. The bomb conductor is then placed into its container and locked.
6. The Bomb is then tightened into the bomb sit. Wait until the machines give a 'Ready' signal. Start button is pushed to start the experiment.
7. Then the experiment is finished, the bomb is unlocked and opened. All the area in the bomb needs to be cleaned and dried.
8. Reading of Higher Heating Value of the samples is taken
9. Step 2 to 8 is repeated for the other samples

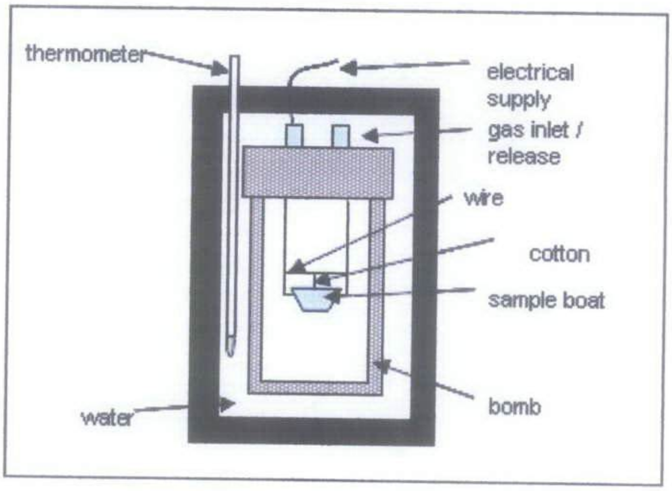

Figure 3.5: Schematic Diagram for Bomb Calorimeter (Eco-Beach Project, 2008)

3.3.3 Proximate Analysis

Proximate analysis is to be carried out to determine the percentage of moisture, volatile matter, fixed carbon and ashes in the each sample. Proximate analysis is an empirical technique in which the mass of substance is heated at a controlled rate and the mass loss is recorded as a function of time. The parameter of TGA analysis were set based on ASTM E 1131-98, Standard Test Method for Compositional Analysis by Thermo-gravimetry. The basic principle of a TGA analysis module is to record mass loss during programmed time or temperature profile.

3.4 Physical Analysis

Physical analysis for the present research would include the determination of the sample's hardness value and also determining the best storing method by means of its density. Result of the physical properties of each sample will further justified the potential of the samples to become a biomass sources.

3.4.1 Bulk Density Analysis

Bulk Density Analysis is an experiment conducted to determine the density of three storing product form that had been identified which is powder form, compaction form, and grinding form. Bulk density is defined as the weight per unit volume of loosely fuel. Fuels with high bulk density are advantageous because they represent a high energy-for-volume value (Balamohan, 2008). The Bulk density value will reflect on the potential of storing product form of the biomass sources. Besides, storing and transportation are also crucial aspects influence by bulk density value since the number of the biomass feed was in abundance. The high bulk density value also need in order to calculating the economical cost of biomass process especially in transportation and storing. It is also recognized that bulk density has considerable impact on gas quality, as it influences the fuel residence time in the fire box, fuel velocity and gas flow rate (Chandrakant, 2007).

The bulk density of the samples is determined by measuring the sample weight with a lab scale and measuring its volume using Archimedes principle or geometrical measurement.

For Archimedes principle, the sample was drenched in water and the displacement volume was measured using a lab measuring cylinder. Three tests were conducted to assess the repeatability and the set of three runs would be done to obtain the average bulk density value.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Sample Collection and Preparation

Seven samples which are coconut fibre, weed, paddy husk and four type of dry leave mixture had been collected. Three different location or type is collected to see the different on each type or species properties. Each of these samples is prepared as in Section 3.2.

4.1.1 Dry leave

Dry leave is collected from 3 different places all around UTP. Below are detail on the location and the dry leave.

Table 4.1: Locations and Trees Species for Dry Leave Collected

	A	B	C	D
Location	UTP's Lake	Building 5 academic complex	Parking area pocket C	All (mixture of A, B and C)
Trees	Scorodocarpus borneensis (kulim), Heritiera littoralis (dungun), grass.	Strombosia javanica (dedali), Sterculia cordata (kelumpang), grass	terospermum diversifolium (bayur), grass	Mixture of A,B and C

Each of the samples is prepared base on the procedure in Section 3.2. Four samples had been prepared from dry leaves which are dry leave from location A, location B, location C and mixture of all of them. The picture of each samples prepared can be refer to Figure A-9 to Figure A-12 in Appendices.

4.1.2 Rice Husk

Samples are collected from Paddy Processing Factory at Bandar Bahru, Kedah. Three samples are taken from different places of paddy collected. Each sample is prepared base on the procedure in Section 3.2. Picture of the sample can be referred to Figure A-8 in appendices.

4.1.3 Coconut Fiber

Coconut fiber is collected at three places which are Coconut Supplier at Taman Maju (beside PETRONAS station), Coconut supplier at Tronoh Town and Teluk Batik area. The picture of the samples can be referred to Figure A-13 in appendices.

4.1.4 Weeds

Weed is collected from the UTP's gardener around UTP. Three different locations of weeds are taken which is from Village 3 area, Pocket D area and Parking Pocket C area. The picture of the samples can be referred to Figure A-7 in appendices.

4.2 Bulk Density Result

Every bulk Density test was run three times and the average density was calculated from the three results. The Standard deviation is then calculated. From the result, the standard deviation of Coconut fiber, Weed and Rice Husk were low compared to standard deviation value from Bulk Density Test for four types of dry leaves. This thing happened due the fact that the dry leave is consist of some mixture of several dry leave which lead to bigger error in the average bulk density test.

Table 4.2: Bulk Density Value of Coconut Fiber from Experiment

	Run 1	Run 2	Run 3
Mass of sample, kg	3.0	4.3	4.7
Displaced water volume, L	7.28	10.38	11.43
Density, kg/m3	412	414	411
Average Density, kg/m3	412.33		
Standard Deviation, kg/m^3	1.247		

Table 4.3: Bulk Density Value of Weed from Experiment

	Run 1	Run 2	Run 3
Mass of sample, kg	4.0	3.6	5.1
Displaced water volume, L	5.94	5.37	7.62
Density, kg/m^3	673	670	669
Average Density, kg/m^3	670.67		
Standard Deviation, kg/m^3	1.70		

Table 4.4: Bulk Density Value of Rice Husk from Experiment

	Run 1	Run 2	Run 3
Mass of sample, kg	5.1	4.3	4.7
Displaced water volume, L	9.38	7.87	8.61
Density, kg/m^3	544	546	546
Average Density, kg/m^3	545.33		
Standard Deviation, kg/m^3	0.943		

Table 4.5: Bulk Density Value of Dry Leave A from Experiment

	Run 1	Run 2	Run 3
Mass of sample, kg	4.2	4.4	5.6
Displaced water volume, L	7.43	7.75	9.84
Density, kg/m³	565	568	569
Average Density, kg/m³	567.33		
Standard Deviation, kg/m³	1.690		

Table 4.6: Bulk Density Value of Dry Leave B from Experiment

	Run 1	Run 2	Run 3
Mass of sample, kg	5.3	4.3	3.8
Displaced water volume, L	8.93	7.30	6.39
Density, kg/m³	593	589	595
Average Density, kg/m³	592.33		
Standard Deviation, kg/m³	2.494		

Table 4.7: Bulk Density Value of Dry Leave C from Experiment

	Run 1	Run 2	Run 3
Mass of sample, kg	5.0	5.4	4.6
Displaced water volume, L	7.63	8.37	7.08
Density, kg/m³	655	647	649
Average Density, kg/m³	650.33		
Standard Deviation, kg/m³	3.399		

Table 4.8: Bulk Density Value of Dry Leave D from Experiment

	Run 1	Run 2	Run 3
Mass of sample, kg	5.0	6.5	6.1
Displaced water volume, L	8.22	10.74	9.92
Density, kg/m^3	608	605	615
Average Density, kg/m^3	609.33		
Standard Deviation, kg/m^3	4.190		

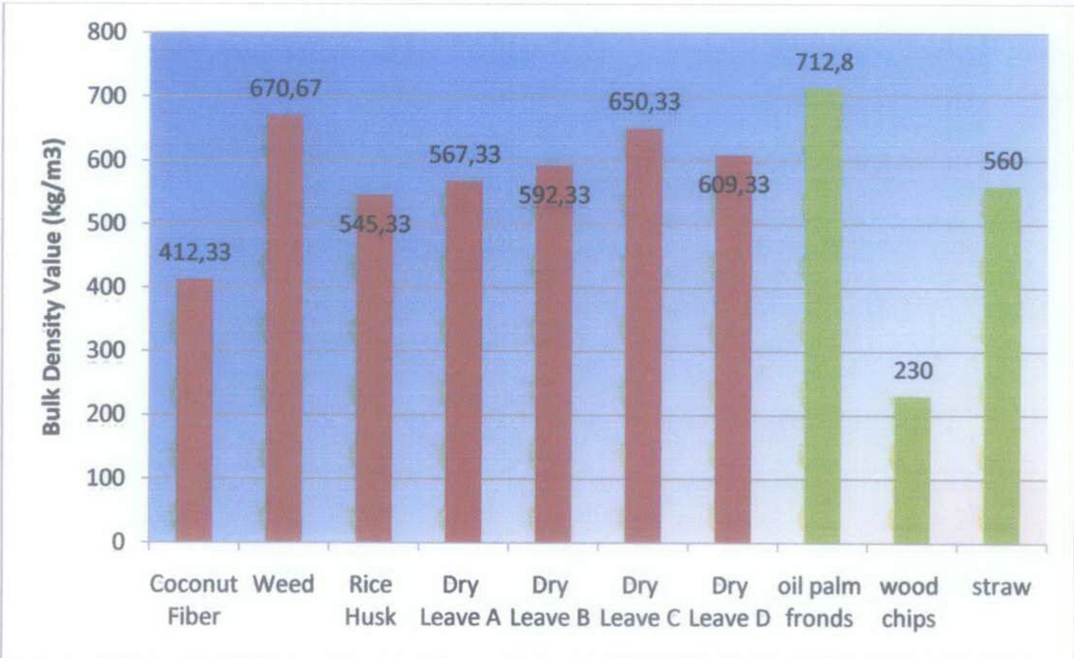

Figure 4.1: Bulk Density Value of various Biomass Sources

The average bulk density for each sample which is coconut fibre, weed, rice husk, dry leave A, dry leave B, dry leave C and dry leave D was determined to be 412.33kg/m^3, 670.67 kg/m^3, 545.33 kg/m^3, 567.33 kg/m^3, 592.33 kg/m^3,650.33 kg/m^3, 609.33 kg/m^3. A high bulk density value for a biomass fuel indicates that the fuel takes less bunker space for a given refuelling time. As the bulk density values of the biomass product bigger than 400kg/m^3 then it is suitable as the biomass sources (Quakk et al., 2010). All of the bulk density values of this experiment was fall above 400kg/m^3 which mean that all of the samples in this experiment are feasible to be practice as the biomass feed. Beside, Bulk Density Value is also relevant for the volume needed for transportation and storage. It is very important for trading and supply. As the all the value of the samples are high, the transportation and storage cost will low as it make the samples be more feasible to be a biomass feed stock.

4.3 Calorific Test Result

Each Sample is run two times for Calorific Test. Each value gets from experiment need to be deducted with 60J which is the energy value for thread use in experiment. The average of the Calorific Value of the samples was then calculated.

Table 4.9: Result of Calorific Value Test

Sample	Calorific Value (J/g)		
	1	2	Average
Rice Husk	15961	15973	15967
Coconut Fibre	17104	17092	17098
Weed	22419	22402	22410.5
Dry Leave A	20353	20358	20355.5
Dry Leave B	20323	20318	20320.5
Dry Leave C	17740	17715	17727.5
Dry Leave D	19611	19642	19626.5

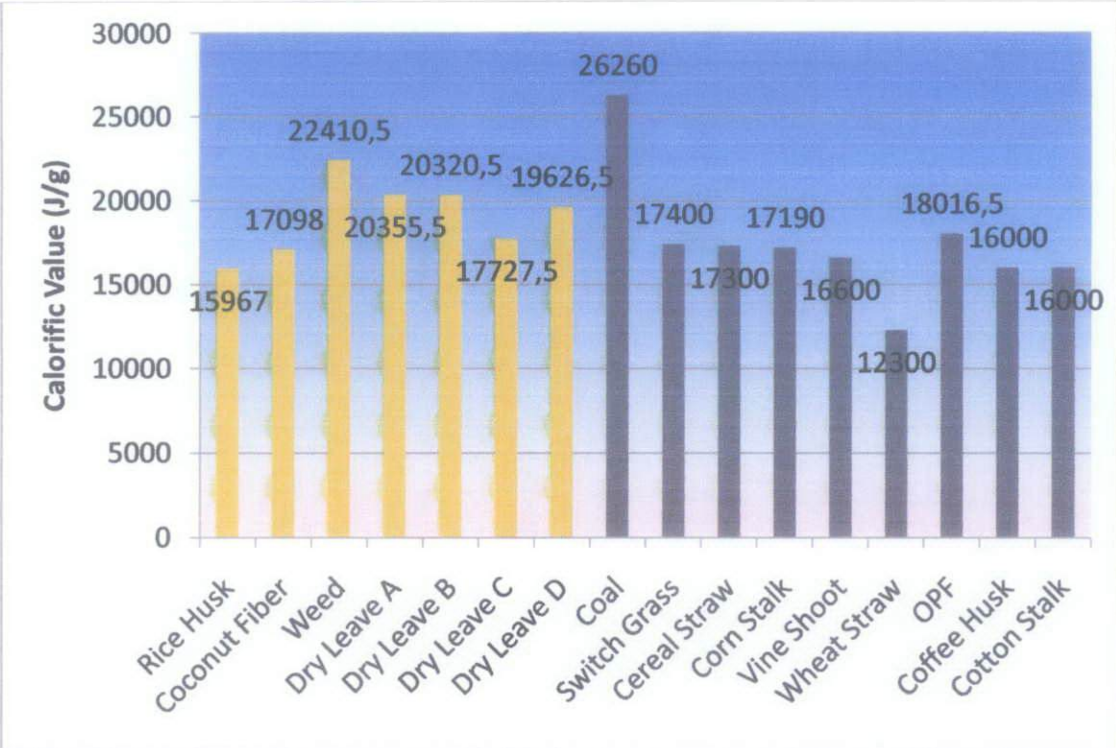

Figure 4.2: Calorific Value of Various Biomass Sources

Each sample will give various value of energy content and the expected result should be the one with higher energy content should be the one which high in carbon ratio get from CHNS test. But there is some of other factor which affects the energy content which is ash content and moisture content. The average calorific value for each sample which is rice husk, coconut fiber, weed, dry leave A, dry leave B, dry leave C and dry leave D was determined to be 15967J/g, 17098J/g, 22410.5J/g, 20355.5J/g, 20320.5J/g, 17727.5J/g, 19626.5J/g. The good biomass sources should be the high of energy content. The calorific value of biomass is in the range of 16–20 MJ/kg as it will suitable for biomass sources (Liao et al., 2005). Since all of the samples in this experiment result in calorific value more than 16 MJ/kg, all of these samples can be said having a potential to be a good biomass sources. However, there is some other factor especially the moisture content affecting the calorific value in this experiment. Since the moisture content of each sample due the failure of TGA machine, this effect cannot be predicted. However, it is assumed that this effect is a minor since each sample had been dried thoroughly in samples preparation process and this procedure confirm on the moisture content reduction below 1% of its molecular weight.

From the calorific value result and bulk density value result, the energy density can be calculated by multiplied both value. Table 4.10 shows the value of energy density of each sample.

Table 4.10: Value of Energy Density of Each Sample

Sample	Energy Density value ($x10^6$ KJ/m^3)
Rice Husk	8.7073
Coconut Fibre	7.0500
Weed	15.0301
Dry Leave A	11.5480
Dry Leave B	12.0364
Dry Leave C	11.5287
Dry Leave D	11.9590

4.4 CHNS Analysis

CHNS analysis is done two times for each sample and the average value of carbon, hydrogen, nitrogen, and sulphur is the calculated.

Each sample gives various CHNS value which carbon is the highest percentage, follow by hydrogen, nitrogen and sulphur. The main parameter here is carbon content where a sample will have higher possibilities to become a fuel source for gasification process. In addition, Low sulphur content would portray the potential of the palm fronds as an environmental friendly renewable energy source as sulphur would and react with water, oxygen and oxidants to form acidic compound as found in acid rains. So the high potential biomass sources should be high carbon content and low sulphur content. There are some of the samples where the CHNS value had been identify from the research outside Malaysia such as sugarcane in Brazil and rice husk from Thailand. The result from the previous research will be compared with this research since there might be a different in the CHNS value due to some factor such as different climate and soil.

Table 4.11: CHNS Analysis Result

Material	Carbon			Hydrogen			Nitrogen			Sulphur		
	1	2	average	1	2	average	1	2	average	1	2	average
Rice Husk	39.4	38.35	38.88	4.379	4.441	4.41	1.119	1.043	1.081	0.127	0.134	0.131
Weed	38.15	39.04	38.56	5.1	5.02	5.06	0.941	0.921	0.931	0.087	0.093	0.09
Dry Leave D	47.17	46.45	46.81	5.864	5.789	5.827	1.728	1.658	1.693	0.133	0.123	0.128
Dry Leave B	47.29	47.93	47.61	5.911	5.936	5.924	1.847	1.822	1.835	0.108	0.1	0.104
Dry Leave C	43.64	43.23	43.44	5.431	5.498	5.465	1.161	1.148	1.155	0.163	0.17	0.167
Dry Leave A	46.58	45.69	46.14	5.818	5.914	5.866	1.589	1.582	1.486	0.082	0.097	0.09
Coconut fibre	41.53	42.58	42.06	4.942	5.04	4.991	0.645	0.699	0.672	0.062	0.072	0.067

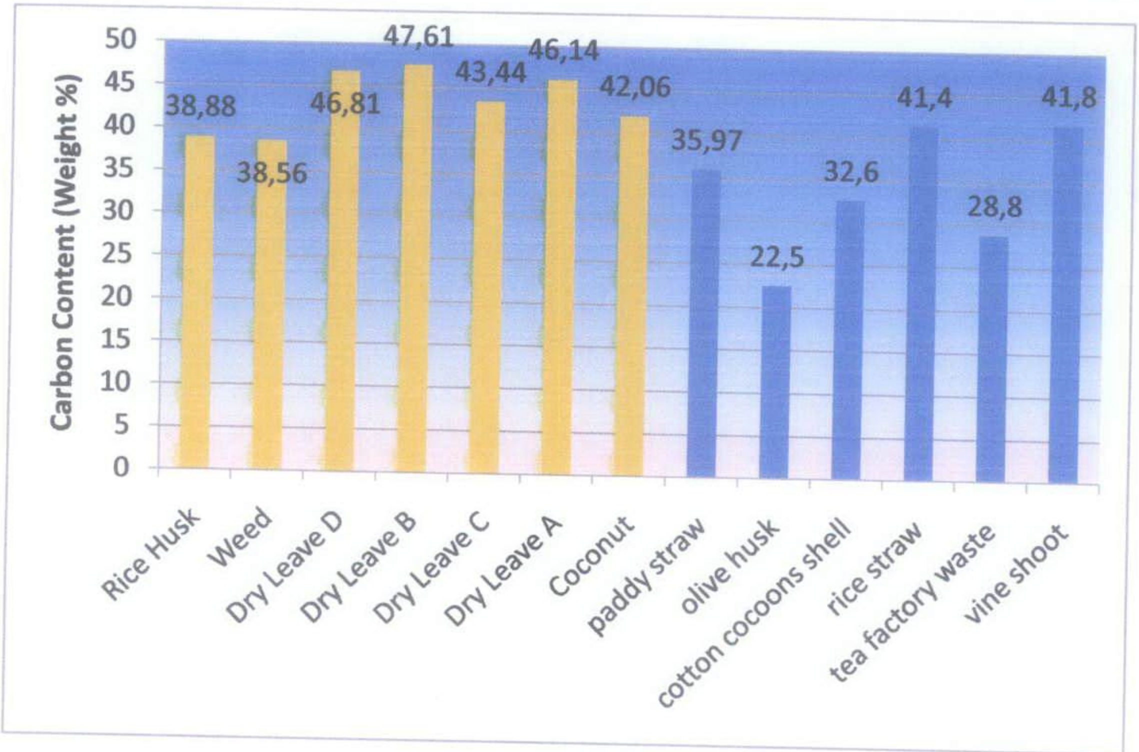

Figure 4.3: Carbon Content of Various Biomass Sources

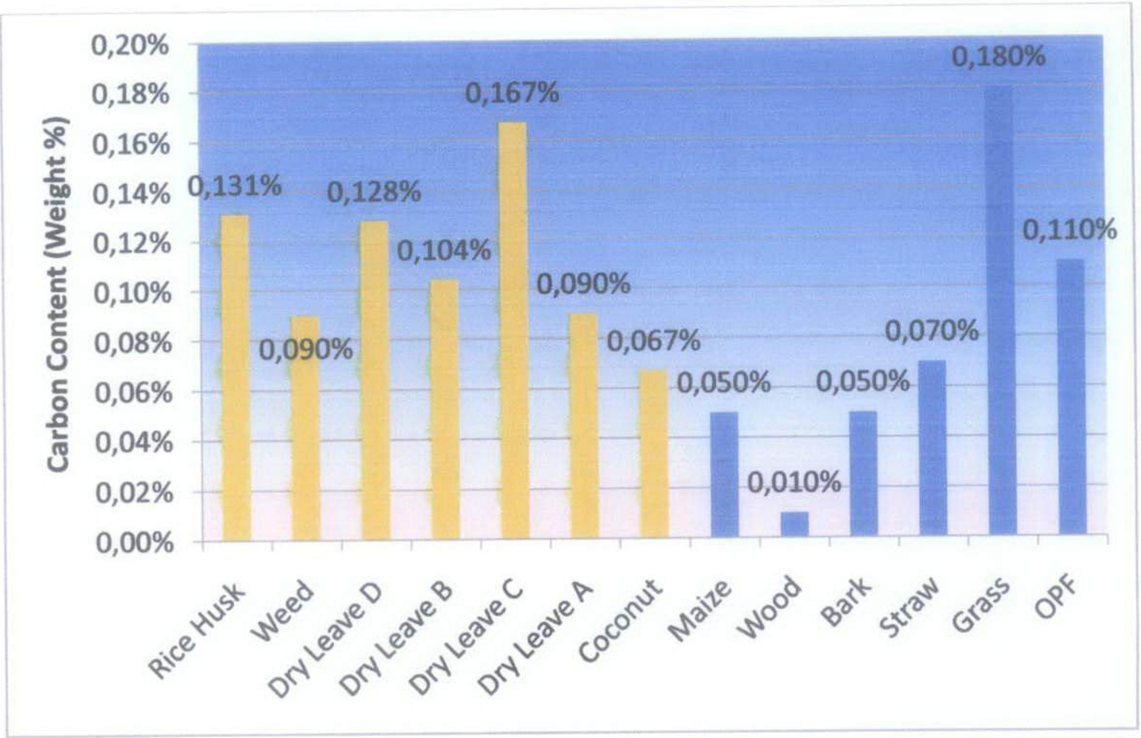

Figure 4.4: Sulphur Content of Various Biomass Sources

Carbon Content for Rice Husk, Weed, Dry Leave D, Dry Leave C Dry Leave B, Dry Leave A and Coconut Fibre are 38.88%, 38.56%, 46.81%, 47.61%, 43.44%, 46.14% and 42.06%. All this value range with in average of practise biomass sources.

Sulphur Content for Rice Husk, Weed, Dry Leave D, Dry Leave C Dry Leave B, Dry Leave A and Coconut Fibre are 0.131%, 0.09%, 0.128%, 0.104%, 0.167%, 0.09%, and 0.067%. Weed, dry leave A and Coconut Fibre are considered as low Sulphur content of biomass sources which is less than 0.1%. This reflects that they have properties as environmental friendly biomass sources.

4.5 Proximate Analysis

Each sample will have different of weight percentage of moisture, volatile matter, fixed carbon and ashes. They all vary naturally from their existence. Fuel with moisture content above about 30% makes ignition difficult and reduces the Calorific value of the product gas due to the need to evaporate the additional moisture before gasification can occur

(Mckendry, 2001). Ash contents of 12% or above will have possibility to cause slagging (Osorio, 2005) which is caused by melting and agglomeration of ashes will greatly add to the amount of labour required to operate the gasifier. Most biomass contains an average 80% volatile matter content (Renew, 2004). Fuel with high volatile matter content produces more tar, causing problems to internal combustion engine. Average value for fixed carbon for a biomass fuel is 21.1% (Richards, 2005). So, a good biomass sources should be a sample which have low moisture content, high volatile matter, low fix carbon and low ash content.

There is equipment constrain in proceeding the proximate analysis of all samples where the machine is broke down since December 2009. Until 7 May 2010, the TGA analyzer machine was still not be fixed. So, this experiment cannot be preceded.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

There were seven sample will be studied and examined which were coconut fibre, rice husk, weed and four different mixture of dry leave. Chemical and Physical properties of each samples were determined by four type of experiment which were Proximate Analysis, Ultimate analysis, Calorific analysis, and bulk density test. Each of this value will reflected on the feasibility and potential of them to be a good biomass sources. In the result, it had been shown that all the samples in this project had good calorific values which range within 16MJ/kg to 20MJ/kg. In Bulk Density Test, All of these samples resulted in a good bulk density value which above 400 kg/m^3. This shown that all of these samples have a potential as a good biomass sources since high bulk density reflect a high concentration of energy content in them and also reflect on the economical transportation and storage cost. In CHNS test, the carbon content of each samples were between the average values of practise biomass sources which was between 38% and 47%. While the value of sulphur shown a high values for rice husk, dry leave B, dry leave C and drive leave D which was more than 0.1%. While for Weed, dry leave A and Coconut Fibre were considered as low Sulphur content of biomass sources which was less than 0.1%. So weed, dry leave A and Coconut Fibre had more environmental friendly properties. Proximate Analysis cannot be proceed due to the equipment constrain. However, further study can be continue by new student especially on the dry leave A, weed and coconut fibre which seem having a potential as a biomass sources base on the result in this project. It was hoped that the present research would provide a platform for future application of the project on large scale. A successful application of the present work on a large scale system would provide an alternative way to produce energy that was renewable and environmental friendly.

5.2 Recommendations

Some weaknesses and flaw had been noted along this project and with all of them, some recommendation are raised so that the result for next research could be improved. Here are some recommendations:

5.2.1 Calorific Value vs. Moisture Content

Calorific Value which gets from Calorific Test is the higher heating value (HHV) and this value was depended on the moisture content of the samples. HHV is the energy which including condensation of combustion products. Since there was no standardize of moisture content of each samples during experiment, HHV seem not suitable for gauge in determining and comparing the energy content of the samples. In future, it was recommended to standardize the moisture content of each sample before proceeding to the Calorific Test.

5.2.2 Drying Process of Samples

In samples preparation process, Drying Process in the first stage was done by sun drying method. This was a cheap way of drying method but some of the weaknesses had been identify. Drying under the sun light was not having a constant temperature where temperature of the day was changing depend on the intensity of sun light. Due to this fact, each sample was having a various drying intensity. In future, it was recommended to the drying process by dryer where the drying process will be more standardize.

5.2.3 Powder Form vs. Real Feed Form

All experiment in chemical testing was using samples in powder form. But in gasification process, the biomass feed might not be in that form. There was a slight different in the characteristic of the samples. It was recommended to find out the relation between those two forms.

5.2.4 Composition Element

In this project, composition element of Carbon, Hydrogen, Nitrogen and Sulphur of each sample had been evaluated. However, other composition in the biomass sources had been proved gives significant effect toward properties of their properties. A study of all composition in the biomass sources such as Al, Si, Ca, Fe, K, Mg, Na and others should be conducted to see the relationship of other composition with the properties of the biomass sources.

5.2.5 Equipment Availability

There were lots of problem faced regarding the equipment constrain along this project. Some of the equipment numbers are not meet the demands of the user and even some the equipment just have one unit. So, it was recommended UTP revising again on the equipment availability of all equipments they had. Sometimes, the fixing process of the brake down machine was taking a long period of time. For examples, TGA machine was broke down since December 2009 and still not be fixed until May 2010. As recommendation, UTP should develop new system which more systematic so that the fixing process can be done faster.

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APPENDICES

Figure A-1 Granulator

Figure A-2: Rock Lab Granulator

Figure A-3: Inside View of Rock Lab Granulator

Figure A-4: AC-350 Bomb Calorymeter (BCM)

Figure A-5: Combustion Part of BCM

Figure A-6: Failure Part That Cause Explosion

Figure A-7: TGA Analyzer

Figure A-8: Leco CHNS-932 Machine

Figure A-8: Weed Sample prepared

Figure A-9: Rice Husk Sample Prepared

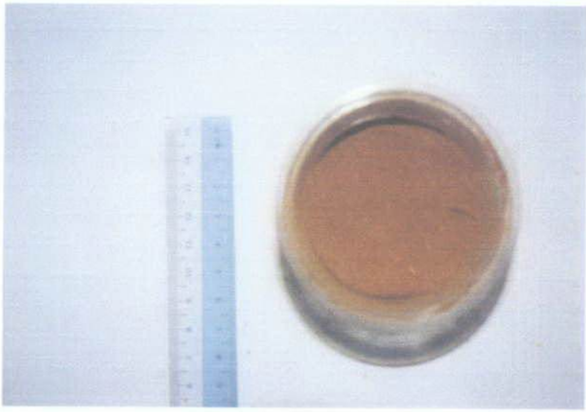

Figure A-10: Dry Leave (A) Sample Prepared

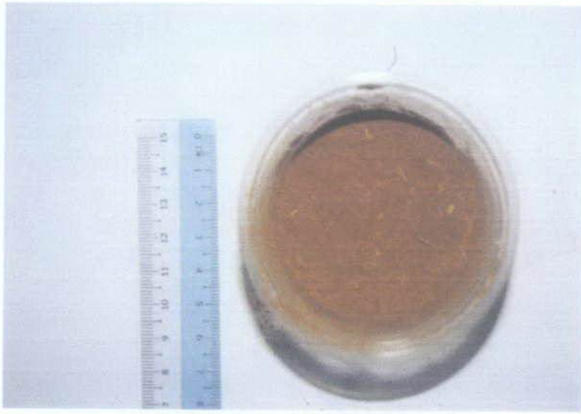

Figure A-11: Dry Leave (B) Sample Prepared

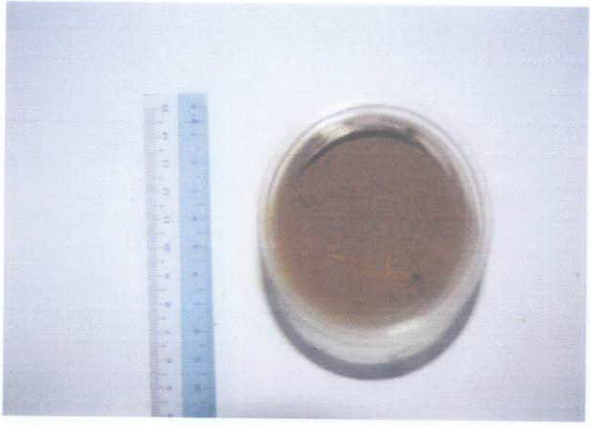

Figure A-12: Dry Leave (C) Sample Prepared

Figure A-13: Dry Leave (D) Sample Prepared

Figure A-14: Coconut Fibre Sample prepared

Table A-1: Carbon Content for Other Biomass from Outsources

Biomass feed stock	Percentage of carbon content (% weight)	References
paddy straw	35.97%	(Jigisha, 2006)
olive husk	22.5%	(Demirbas, 2001)
cotton cocoons shell	32.6%	(Demirbas, 2001)
rice straw	41.4%	(Demirbas, 2001)
tea factory waste	28.8%	(Demirbas, 2001)
vine shoot	41.8%	(Ganan, 2006)

Table A-2: Sulphur Content for Other Biomass from Outsources

Biomass Feed Stock	Percentage of Sulphur content (%weight)	References
Maize	0.05%	(Quakk et al., 2010)
Wood	0.01%	(Quakk et al., 2010)
Bark	0.05%	(Quakk et al., 2010)
Straw	0.07%	(Quakk et al., 2010)
Grass	0.18%	(Quakk et al., 2010)
OPF	0.11%	(Balamohan, 2008)

Table A-3: Calorific Value for Other Biomass from Outsources

Biomass Feed Stock	Calorific Value (KJ/Kg)	References
Coal	26260	(Mckendry, 2001)
Switch Grass	17400	(Mckendry, 2001)
Cereal Straw	17300	(Ganan, 2006)
Corn Stalk	17190	(Mckendry, 2001)
Vine Shoot	16600	(Mckendry, 2001)
Wheat Straw	12300	(Ganan, 2006)
OPF	18016.5	(Balamohan, 2008)
Cocoa Husk	13000-16000	(Quakk et al., 2010)
Coffee Husk	16000	(Quakk et al., 2010)
Cotton Stalk	16000	(Quakk et al., 2010)

Table A-4: Moisture Content for Other Biomass from Outsources

Biomass Feed Stock	Moisture Content(%weight)	References
Saw Dust	45%	(Mckendry, 2001)
Poplar	34.93%	(Mckendry, 2001)
Switch Grass	14%	(Ganan, 2006)
Bamboo	13%	(Ganan, 2006)
Coal	12%	(Ganan, 2006)
Vine Shoot	11.5%	(Mckendry, 2001)
Fir	6.5%	(Mckendry, 2001)
OPF	4%	(Balamohan, 2008)

Table A-5: Volatile Matter Content for Other Biomass from Outsources

Biomass Feed Stock	Volatile Matter Content (%weight)	References
Casuarinas	78.58%	(Osorio, 2005)
Coconut Shell	77.90%	(Osorio, 2005)
Ground Nut	73.70%	(Ganan, 2006)
Cotton Stalk	62.90%	(Ganan, 2006)
Barley Straw	46.00%	(Mckendry, 2001)
Coal	35.00%	(Mckendry, 2001)
Lignite	29.00%	(Mckendry, 2001)
OPF	51.30%	(Balamohan, 2008)

Table A-6: Ash Content for Other Biomass from Outsources

Biomass Feed Stock	Ash Content (%weight)	References
Straw	8	(Mckendry, 2001)
Sugarcane	11.27	(Mckendry, 2001)
Cotton Stalk	14	(Osorio, 2005)
Hay	14	(Osorio, 2005)
Pine	18	(Osorio, 2005)
OPF	48.21	(Balamohan, 2008)