Experimental Characterization of Solid Biomass-Coal Mixture Combustion

By

Chan Wei Shin

Dissertation submitted in partial fulfilment of
the requirements for the
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Universiti Teknologi PETRONAS
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

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(AP Dr. Hussain H Al-Kayiem)
Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
May 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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CHAN WEI SHIN

Acknowledgements

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Without all the assistance, the author certainly could not have completed his project successfully. Therefore, the author is grateful to all the persons above, and to others whose names was perhaps overlooked and have assisted, both directly and indirectly in making the project a success.

Abstract

This report describes the work for characterizing biomass and coal mixture combustion experimentation. The author starts with a simple introduction to the background of the field and states the problem statement, objectives and the scope of work throughout the entire final year project duration, followed by a literature review on related works done. The objectives of the project is firstly to select a number of suitable potential solid waste samples which can be used as solid fuel and by using experimentation method, discover the thermal properties and characteristics of each of the potential solid waste samples. Another objective is also to investigate the effect of different added percentage of the solid fuel to the thermal and burning characteristics of coal during combustion process. The scope of work is firstly to do background literature review on the topic, then select the materials and characterize their thermal and burning properties through combustion experimentation. A certain percentage s also then added to coal and the mixture's thermal and burning properties are also examined through the experimentation method. The author then explains the methodology of the experiment by including the process flow and Gantt chart to measure the progress of the entire project throughout the duration of 2 semesters of this project. Then, the results of all the experimentation from the Energy Content, Ultimate Analysis, Proximate Analysis and Gas Analysis are tabled and presented for comparison. All the results are discussed as well. The author concludes the report with a conclusion and recommendation for future progress.

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Chapter 1: Introduction

1.1 Background On Topic

Biomass is defined as any type of organic matter, and when is used either directly as a source of fuel, or converted to another form to be used in the combustion process is called biofuel. Biomass consists of a wide range of materials, ranging from agricultural waste, domestic waste and animal wastes. Examples include plants and its parts, municipal organic waste and also the wastes generated by animals. Specifically in Malaysia, where palm oil is of abundance, the opportunity of use of palm oil as type of biomass is wide open.

Figure 1: Different types of biomass which can be used convert to fuel.

On the other hand, coal is a type of fossil fuel which is sourced from rocks. Coal is primarily composed of carbon along with other elements such as sulphur, hydrogen, oxygen and nitrogen. Normally, this element is extracted straight from the ground either using underground mines or in open pits.

Coal is a huge resource of energy provided to the world currently, as there are many plants running all around the world to produce electricity, which are using coal as their primary source of fuel. Normally, when coal is combusted for electricity generation, the matter is pulverised first to increase the surface area for ease of combustion. The heat is then used to convert water to steam to run steam turbines for electricity generation.

Figure 2: Example of a coal plant in Bergheim, Germany.

The process of combusting coal with a certain percentage of solid biomass is called co-firing. This process has a number of advantages to the power generation industry as it provides the most effective means of reducing the net CO_2, SO_2 and NO_x emissions compared to the power plants that solely burn coal, because it has much lower concentrations of sulphur and nitrogen. Also, since biomass is relatively inexpensive, it will be cost saving to co-fire biomass along with coal as the amount of coal needed would be significantly less.

Benefits of co-firing don't stop there. Compared to power plants that use only biomass, the process allows the combustion in large scale industries and power plants and brings up the efficiencies of the plant to a much higher level. This implies that biomass combustion efficiency to electricity would be close to 33% to 37% when co-fired with coal.

1.2 Problem Statement

A team from Japan under the supervision of Professor Umera is doing a research proposal on the utilization of solid wastes as solid fuels for JAICA. The team sees the need for the utilization of solid wastes to be incorporated with coal to be used in coal power plants for power generation by co-firing of two different materials, namely coal and biomass in a certain fixed percentage to achieve a higher overall efficiency for the plant. Therefore, this project is to identify the different characteristics of the biomass-coal mixture at different mixture percentages.

1.3 Objectives

1. To identify and select a suitable potential type of solid waste that can be used as solid fuel and experiment its thermal and burning characteristics.
2. To investigate the effect of added percentage of the selected solid fuels on the thermal and burning characteristics of coal.

1.4 Scope Of Work

The following are the scope of work that I intend to accomplish throughout the project period.

1. Research on the background of co-firing coal and biomass mixture in the industry, especially in the power generation industry.
2. Select and source for biomass materials which are abundantly available and are suitable to be mixed with coal for the co-firing process to be used as experimentation specimens.
3. Conduct experimentation on the specimens by combustion and collecting data using analysis equipments such as Bomb Calorimeter, Thermo Gravimetric Analyser, Carbon, Hydrogen, Nitrogen and Sulphur (CHNS) analyser and Smoke Analyser.
4. Analyse the data to obtain the characteristics of each type of biomass.
5. Mix a fixed percentage of each biomass specimen with coal for combustion and data measured using the same equipments.
6. Analysing the data to characterize and compare relatively all the specimens tested.

Chapter 2: Literature Review

The existing process of burning coal to generate power, or coal firing is widely used as it provides a cheap and vast source of power. The general process of coal firing starts from the pulverization of the coal, which means the coal is crushed into powder and then is fed into the furnace or combustion chamber together with a specified amount of air to be burnt. Then the heat produced is used to heat up water to be turned into steam which then drives a steam turbine to generate the power required.

Figure 3: Coal Dust for the coal firing process.

On the other hand, co-firing process is the process of mixing a certain percentage of biomass with coal and combusting it to produce power. The types of biomass are important in the co-firing process and they must be chosen properly. Overall, biomass consists of different chemical compositions compared to coal. It has a higher fraction of hydrogen and oxygen, and less carbon content. Also, the composition of the biomass consists of more volatile matter, which causes it to have a more flaming combustion and less char combustion. Overall, the typical element composition of different biomass and coal is as follows:

Table 1: Element composition of different types of coal and biomass

Fuel	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Silicon	Potassium	Calcium	Chlorine
	(percent)								
Anthracite coal	91–94	2–4	2–5	0.6–1.2	0.6–1.2	2–6	0.1–0.5	0.03–0.2	0.01–0.2
Bituminous coal	83–89	4–6	3–8	1.4–1.6	1.4–1.7	2–3	0.1–0.2	0.1–0.3	0.01–0.13
Wood, clean and dry	50	6.1	43	0.2	–	0.05	0.1	0.04	–
Switchgrass	48	5.5	43	0.2	–	1.4	0.4	0.2	–

Therefore, to strike a balance of having a higher calorific value of the fuel to produce more energy per quantity of fuel burnt and releasing less amount of pollutants such as sulphur dioxide and nitrogen oxide, co-firing is essential and is being widely researched currently.

Many studies and experimentation works have been done on co-firing for the benefit of the industry. An example of experimentation is the partnership of Common Purpose Institute, University of Florida and the U.S. Department of Environment conducted an experimental biomass co-firing research at the Lakeland Electric McIntosh Unit #3 in Florida. For this experiment, the technique is to directly inject shredded wood fiber material into the pulverized coal fired furnace. They have used approximately 125 tons of shredded/chipped eucalyptus trees co-fired over a continuous 6 hour period. Below is the sample of the eucalyptus tree chips fed into the furnace alongside coal.

Figure 4: Sample of Eucalyptus Tree Chips used for Biomass Fuel

A research *(Study on energy conversion technology for Biomass, (RITE, 1998~2000))* states that throughout the world, Asia has the most abundant biomass resources, namely the plantation sector which has an equivalent of *39EJ* of energy, an equivalent to approximately *1.03 billion kℓ - petroleum*, the agricultural waste of an equivalent of *23EJ* or *0.608 billion kℓ - petroleum*, and the animal waste consisting *18EJ* or *0.476 billion kℓ - petroleum.*

[Note: 1EJ = 2.6 x 10^7 kℓ - petroleum]

It is to note that the firing of biomass of waste in the industry of power generation is promoted in order to:

1. Reduce greenhouse gases (CO_2 and CH_4) emissions and byproducts such as ash and residues.
2. Reduction of taxes on energy, fuel and emissions.
3. Promotion of sustainable energy
4. As an alternative option to waste management strategy (other than recycling)

The reasons for co-firing biomass with coal rather than biomass alone then is for

1. Technical reasons, being to obtain a higher thermodynamic efficiency
2. Not necessitating a continuous supply of biomass, meaning in the case of lack of biomass, coal can still be used.
3. More economic to retrofit existing power plants with co-firing systems.
4. Uses fuel which is more readily available and at a cheaper price in the case of having biomass sources in the vicinity or close to the plant.

On the other hand, the co-firing of biomass and coal has an effect on the operations and reliability of the power plant components which must be taken into consideration, depending on each plant. The components to be noted are:

1. Steam generator or boiler
    - Fuel storage and handling system, and boiler might contain slagging/fouling and also corrosion. This might affect the performance and the integrity of the boiler at high temperatures.
2. Flue gas cleaning
    - Catalysts and dust precipitators might contain huge amount of deposits or residue which need to be cleared frequently.
3. Excessive amounts of dangerous gas emissions
    - Ntrogen Oxide (NOx) emission in the fuel mix
    - Carbon Monoxide (CO) emission

Therefore, depending on each country and governments, the legislation governing the use of co-firing biomass differs, as well as the type and quantity of biomass allowed to be used.

A research done by W R Livingston for Mitsui Babcock on the 2004 status of biomass-coal co-firing situation in existing power stations in Britain states that generally the biomass ratio is less than 10% currently using the pre-blending approach due to the behaviour of the biomass during combustion in the plant.

The analysis of the elements in the fuel and the efficiency of the boiler for both coal only and co-firing are as follows:

Table 2: Analysis of Ultimate Fuel Properties

Element:	Measurement	Eucalyptus	Coal
Carbon	(% wt.)	24.91	74.24
Hydrogen	(% wt.)	2.73	4.57
Oxygen	(% wt.)	19.81	5.33
Nitrogen	(% wt.)	0.11	1.43
Sulfur	(% wt.)	0.04	2.14
Ash	(% wt.)	0.94	7.45
Moisture	(% wt.)	51.46	4.83
Higher Heating Value	(BTU/lb)	4,238	13,305

Table 3: Effects by Fuel on Boiler Efficiency

Test Name:	Measurment	Coal Only	Co-Firing
Dry Gas	%	5.61	5.74
H2 & H2O in Fuel	%	3.94	4.76
Moisture in Air	%	0.15	0.15
Unburned Carbon	%	0.50	0.50
Radiation	%	0.16	0.16
Total Heat Loss	%	10.37	11.32
Boiler Efficiency	%	89.63	88.68

It is to be noted that the efficiency drops a little as there is a relatively high amount of moisture in the eucalyptus tree chips (52.46% wt in this experiment) which does affect the burning rate of the furnace.

A study done by Ms Chin Yee Sing of the UTP's Mechanical Engineering department concludes that the energy released and combustion rate differs with palm waste briquettes and bio briquettes (consists of 50% coal and 50% biomass). In my study, I will assume the combustion at full air flow rate for standardization, and also the briquettes combusted was at a weight totalling 100g.

Table 4: Combustion Rate and Energy Released by Different Types of Briquettes

Briquette Type	**Energy Released (kJ)**	**Combustion Rate (kJ/s)**
Palm Waste Briquette	400.85	0.1591
Bio Briquette	605.83	0.1803

Therefore, as in Table 4, we can note that the briquette with coal content combusts at a higher rate and releases significantly more energy for the same weight of briquette combusted. This can be concluded to show that coal releases a significantly higher amount of energy per weight combusted compared to palm waste. Therefore, in my project, if I were to use palm waste together with coal for co-firing, I can expect the energy released per weight of fuel combusted to be lower than that of coal itself.

2.1 Analysis on potential wastes for Biomass fuel

A few types of biomass are being identified and some literature review is being done to for characterization. The characteristics chosen to compare different biomass' properties such as calorific value, moisture content, ash content and Carbon Dioxide (CO_2) content. A high calorific value, low moisture, ash and CO_2 content is optimum. This is so that the combustion process can occur easily and the amount of energy produced is significantly high with least effect to the environment. The samples reviewed are:

1. Palm Oil Fruit Fibre
2. Palm Oil Fruit Shell
3. Palm Oil Fronds
4. Palm Oil Trunk
5. Palm Oil Empty Fruit Brunch (EFB)
6. Palm Oil Leaf
7. Chicken Waste

Palm Oil

Palm Oil is found abundantly in countries such as Malaysia. It is a type of plant oil derived from the pulp of the fruits of palm trees. Palm Oil can be used for many purposes, mainly for cooking and also as biomass fuel.

Figure 5: A Palm Oil Tree

As one of the main emerging market leader, Malaysia is starting to promote the use of biomass fuel by opening a biodiesel plant to produce fuel with palm oil content. Many parts of the palm oil tree and fruit can be used to produce biomass fuel, namely the shell, leaves, trunk and fruits itself. Specific components of the palm oil is the fibre which is from the fruit of the palm oil, the shell of the fruits, the fronds from the leaves of the tree, the trunk of the tree, the empty fruit brunch and also the effluent produced from the fruit brunch during processing.

Palm Oil Fruit Fibre – Palm Oil fruit fibre is a non hazardous biodegradable material which is extracted from the fruit of the Palm Oil through processes after the fruit is extracted for its oil. The fibre obtained is dried and is ready to be combusted.

Palm Oil Fruit Shell – The shell is also obtained from the fruit of the palm oil and it is being removed of its other unwanted parts. The shell is also dried before combusted.

Palm Oil Fronds – Palm oil fronds are generally from the leaves of the palm oil trees. The fronds are readily available all year round as the palm trees are often pruned of their leaves during the harvesting of fresh fruit brunches. The tree leaves are reduced to fronds to ease the burning of them.

Figure 6: The leaf of a palm oil tree.

Palm Oil Trunk – The trunk is the backbone of the palm oil tree and it is big. Therefore, the potential energy for combustion that can be produced is large.

Figure 7: Oil Palm Trunks

Palm Oil Empty Fruit Brunch – The Empty Fruit Brunch (EFB) of the palm oil can also be used as a source for biomass combustion. It is suitable as it is produced in large quantities, meaning that there is no short of supply for EFB. When the fruit is being extracted, the empty fruit brunch is left and instead of being thrown, it can be used as a fuel source.

Figure 8: Palm Oil Empty Fruit Brunch (EFB)

Palm Oil Leaf – The Palm Oil Leaf is the large section extended from the trunk before the fronds.

Currently, the materials can be obtained through different sources. The palm oil fruit fibre and shell can be obtained through an oil palm estate, FELCRA Nasaruddin which is located near Bandar Sri Iskandar. Other samples, such as the palm oil tree trunk, leaf and fronds can be obtained in UTP. However, palm oil Empty Fruit Brunch (EFB) and has to be obtained through a palm oil mill.

Chicken Waste

Chicken waste is relevant as it is easy to obtain samples in Malaysia because of the sheer number of chickens being bred for human consumption. The animals will surely produce a substantial amount of waste which is sufficient for sampling.

However, the waste has to be obtained in a form of raw sludge which comes from wastewater treatment process which is highly hydrated to approximately 99%. Therefore, before the experimentation can be done, the samples will have to be dried and dewatered through pressing and filtering process. Then only the dried samples can be used for experimentation. The samples are proposed to be obtained through chicken farms surrounding Tronoh.

Therefore, different types of potential samples are characterized with the said criteria in mind.

Experimentation will be conducted on all samples and they will be mixed with coal.

2.2 Experimentation Equipments Review

1. **Bomb Calorimeter**

   A type of constant-volume calorimeter used to measure heat of combustion of a sample. The calorimeter works by using electrical energy to ignite the sample and allows it to burn. As the sample is burning, it produces the heat to heat up the surrounding air inside the bomb. The air then heats up the water between the bomb and the vessel. The change of temperature in the water is used to measure the amount of heat produced by the combustion or burning process. With this, the calorific value of the sample can be determined. The equipment is located at the UTP's Academic Complex at the Chemical Engineering Block.

Figure 9: A Bomb Calorimeter

2. **Thermo Gravimetric Analyser (TGA)**

   It is an analyser which heats up a sample and measures and determines the change in weight in relation to the change in temperature. It constantly measures precisely three variables which are the weight of the sample, the current temperature and the change in temperature. With that the effect of the temperature to the change in weight can be determined, and at which point the weight loss is most apparent. This equipment is used as a proximate analysis to obtain the biomass' thermal decomposition characteristics.

   The analyser consists of a pan which the sample is placed on and is being heated in a built in electric oven with a small thermocouple to ensure accurate temperature reading. The temperature is then raised gradually and the weight percentage at that particular time is also being recorded. There TGA is located at block 17.

Figure 10: A Thermo Gravimetric Analyser

3. **Carbon, Hydrogen, Nitrogen, Sulphur (CHNS) Analyser**

   The analyser is used for ultimate analysis of the material. It determines the elemental compositions of the material, which are carbon, hydrogen, nitrogen and sulphur. The analyser measures the percentage of each of the elements in the material. This analyser also uses the same process as the thermo gravimetric analyser, which is the combustion process to break down the substances to simple compounds which are then measured.

   The analyser works by having a sample in a capsule, which is then combusted in a reactor at very high temperatures, close to about 1000°C. Then, a flash combustion will occur in the compartment which is temporarily enriched with oxygen. The products of the combustion, which are CO_2, SO_2, and NO_2 are carried away by a constant flow of carrier gas such as helium that passes through a glass column packed with an oxidation catalyst (tungsten trioxide, WO_3) and a copper reducer, which is maintained at the combustion temperature. Here, the oxides are reduced to their elemental compositions. They then can be measured of their content.

Figure 11: A CHNS Analyser

4. **Gas Analyser**

The gas analyser is used in the analysis of gas produced as the result of combustion of the biomass and coal. The analyser is able to measure levels of gases' existence such as carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2), hydrocarbon (HC), air fuel ratio and more, depending on the type of analyser used. The analyser's detector is placed at the exit where the gases from the combustion go out. The detector will detect the levels of each different type of gas and display the measurements of it.

Figure 12: A Portable Handheld Gas Analyser

The working of the equipment is as follows:

1. The analyser is set up and its components installed correctly.
2. The unit is switched on and the analyser will automatically calibrate its sensors to ensure accurate measurements.
3. Once the analyser is correctly set up, the equipment is ready to be used and the probe is set into the exhaust of the fuel burner. The pump will suck gases to its sensors and the values of the measurements will appear but will change as the content of gas changes. Therefore, to print or obtain a result, a HOLD button is pressed and the readings are obtained.
4. Once finished, the equipment is then left on, and the probe is removed and allowed to be cooled. When readings return to ambient levels, the analyser is then switched off.

Chapter 3: Methodology

3.1 Analysis Technique

For this project, I will be using the experimentation method where the characteristics of each type of biomass will be determined through an experiment for each of the sample selected. There will be 7 different types of samples chosen for the analysis.

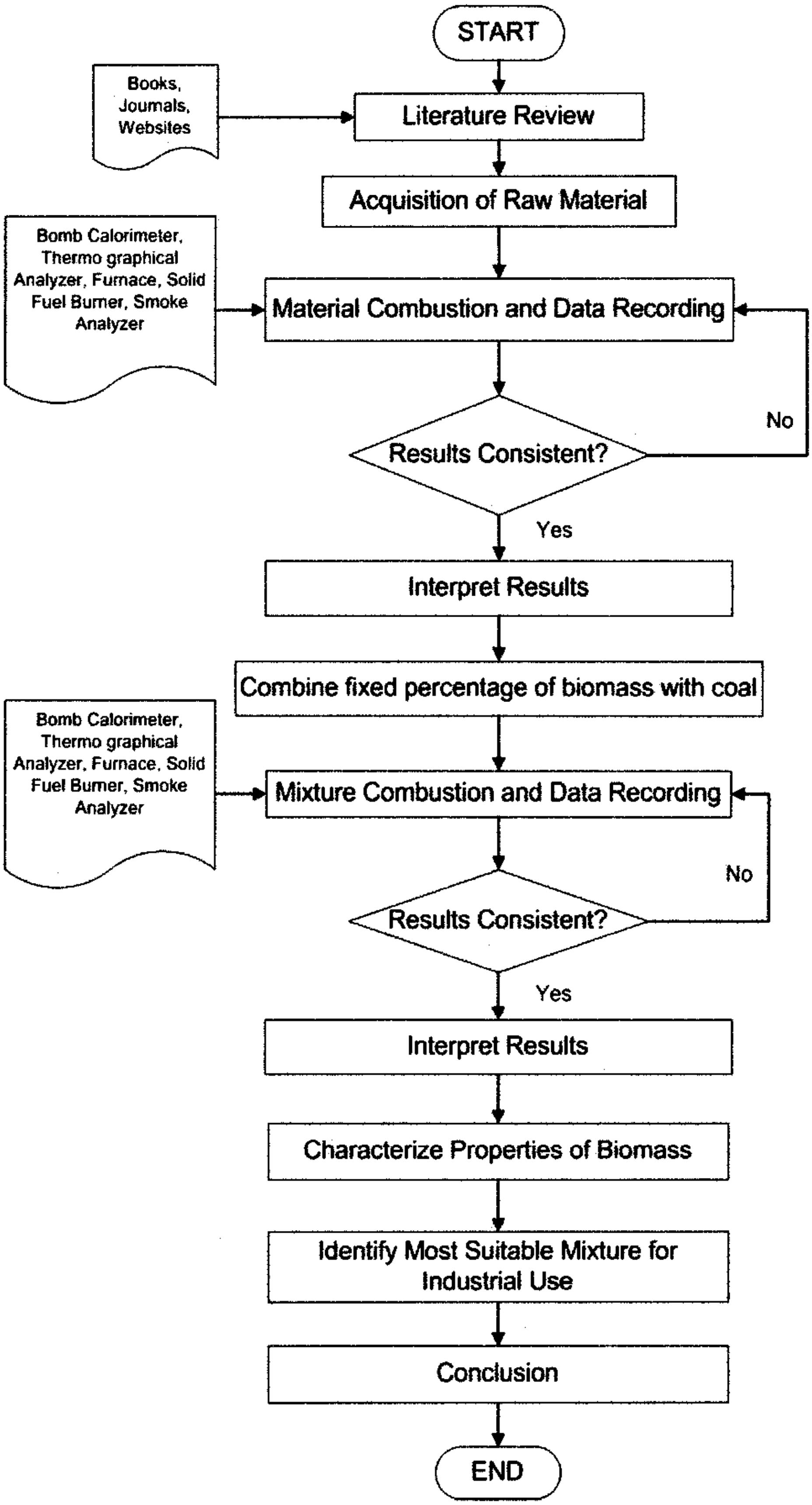
Then, the samples chosen are mixed with coal according to a preset amount (2%, 5%, 10% and 15% of biomass for each sample). The selected biomass samples will be combusted in a controlled environment and all the necessary data recorded. The data includes the heat of combustion (or calorie content of the fuel), properties of the smoke produced such as carbon content, the moisture content, ash content and volatile matter quantity.

The reason for the gap in the increment of biomass percentage to the coal is so that the difference is significant enough for analysing of results. Also, since the current practice generally uses less than 10% of biomass into coal, the effect of the relatively higher biomass percentage on the combustion characteristics of coal can be known as well. For each experiment, the data required will be noted down.

3.2 Tools Required

1. Bomb Calorimeter
2. Thermo Gravimetric Analyzer (TGA)
3. Oven/Dryer
4. Gas Analyzer

3.3 Execution Flow



3.4 Gantt Chart

FYP 1

No	Task Details	Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic		■													
2	Research Work			■	■	■	■	■	■	■	■	■	■	■	■	
3	Preliminary Report Submission	20 Aug 2010				■										
4	Sourcing of Materials						■	■	■	■	■	■	■			
5	Obtaining Required Materials									■	■	■	■	■	■	
6	Experimental Activities for Biomass Types												■	■	■	■
7	Submission of Progress Report	20 Sept 2010								■						
8	Seminar	24 Sept 2010								■						
9	Interim Report Submission	1 Nov 2010													■	
10	Oral Presentation	8 Nov 2010														■

FYP 2

No	Task Details	Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Experimental Analysis of Biomass-Coal Mixture Combustion															
2	Submission of Progress Report 1	18 July 2011														
3	Analysis of Experimental Works															
6	Submission of Poster	5 August 2011														
7	Submission of Dissertation Softbound	17 August 2011														
8	Oral Presentation	22 August 2011														
9	Submission of Hardbound Dissertation															

Chapter 4: Results

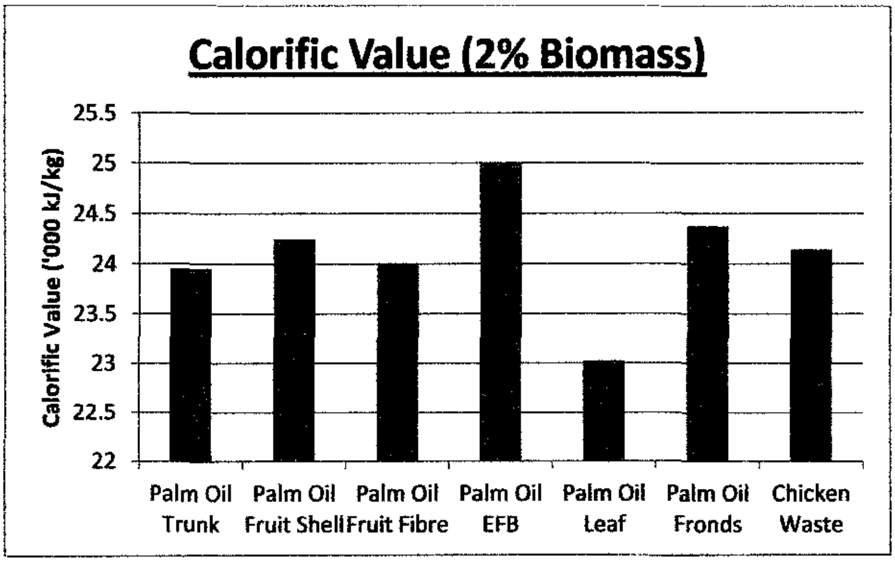
Experimentation is being conducted, with the results being recorded down. The results are as follows:

4.1. Bomb Calorimeter (Energy Content Analysis)

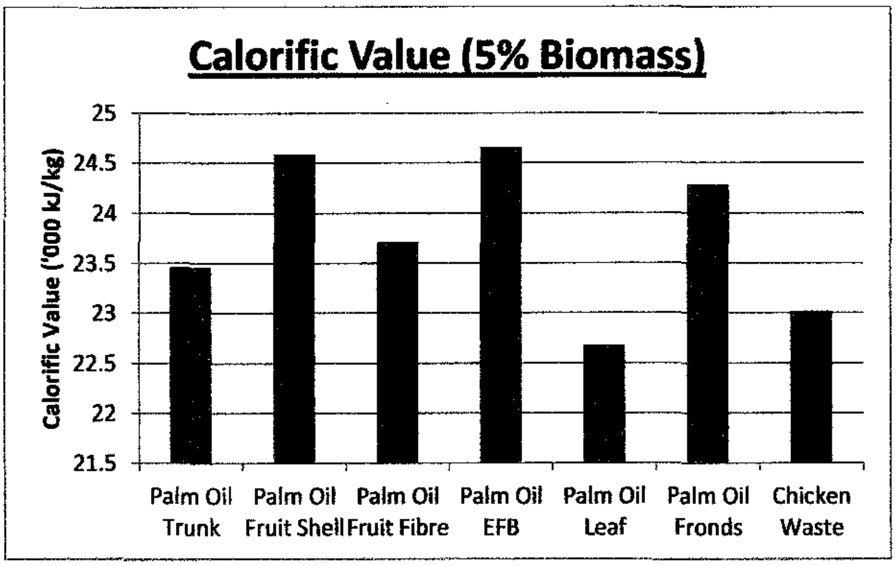
The results are represented graphically in weight percentages to compare the calorific value for different samples with the same amount of biomass percentage. Coal has a calorific value of **25863 kJ/kg.**

The calorific value for all the materials are categorised to different percentages for ease of comparison.

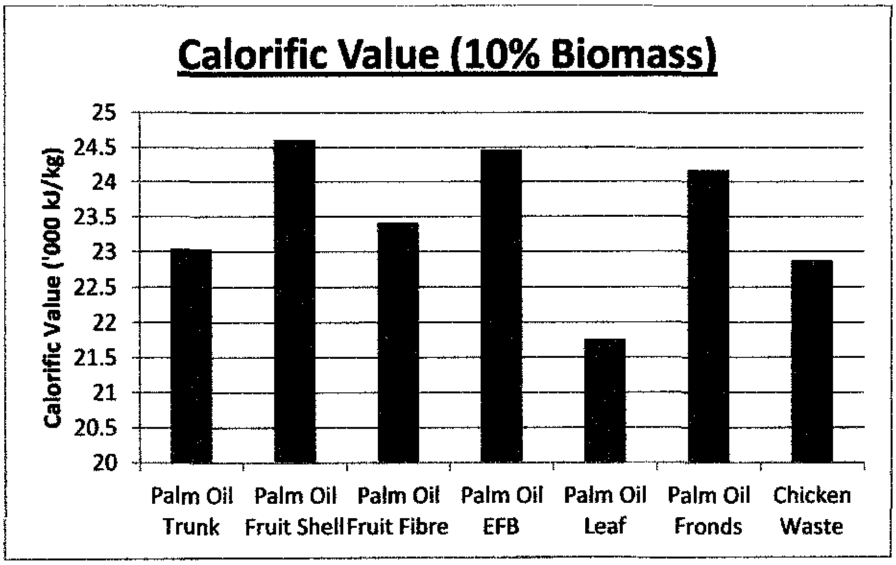
2% Biomass



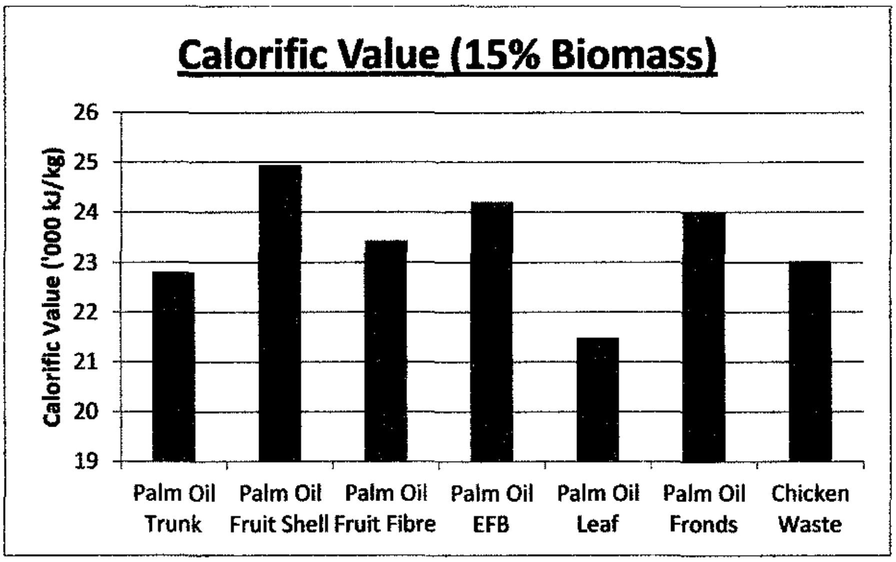
5% Biomass



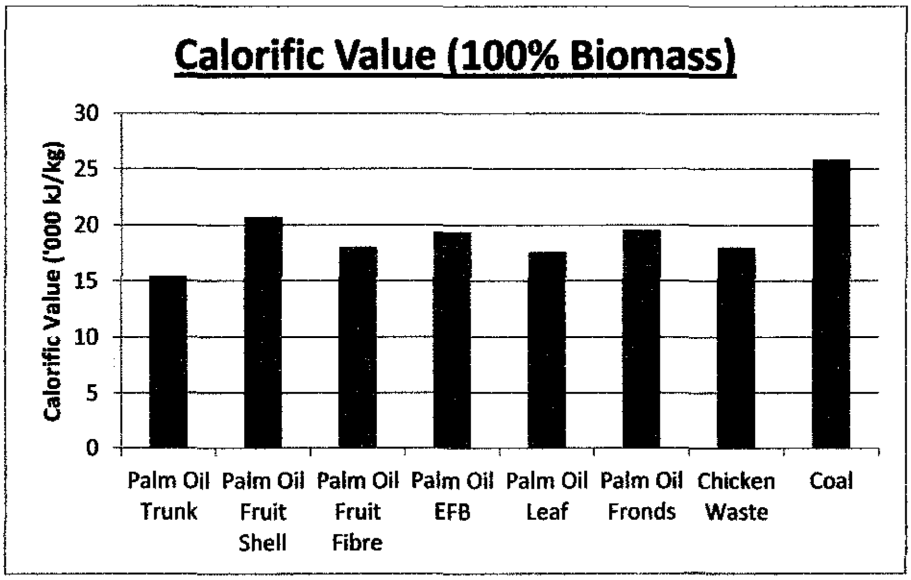
10% Biomass



15% Biomass



100% Biomass



From the charts we can conclude that the Palm Oil Empty Fruit Brunch, upon mixture produces the most amount of energy (highest Calorific Value) compared to the rest, especially at low biomass levels (2% 5% biomass content). However, it is to note that the Palm Oil Fruit Shell provides a higher calorific value as the biomass content increases. This means that the higher the biomass weight percentage in the mixture, the higher the energy content of the mixture. This is especially proven when biomass-coal mixture is at 15%-85%. Palm oil leaf exhibits the least energy content throughout the different mixture percentages.

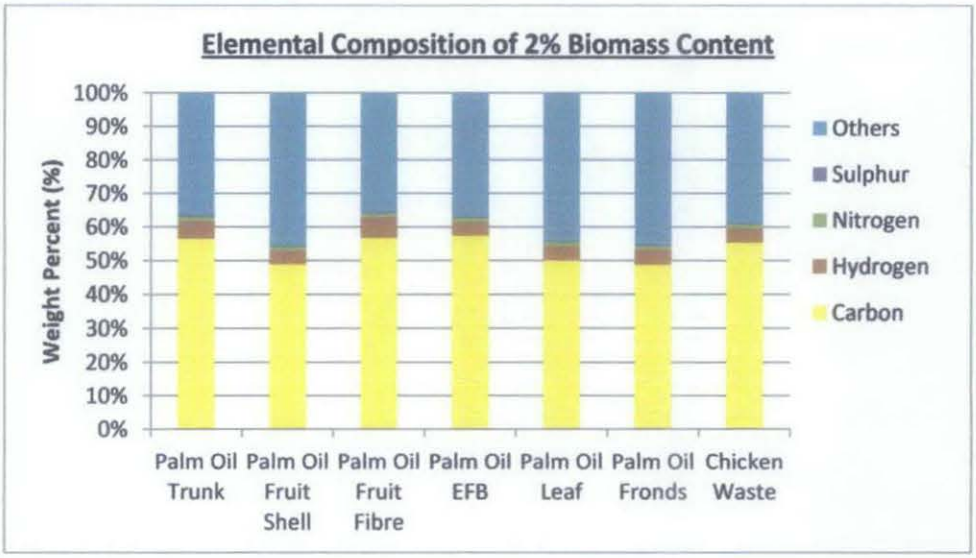
Upon comparison of all pure biomass content, the Palm Oil Fruit Shell shows the most potential to be co-fired with coal. Although it has less calorific value than pure coal and cannot replace it, this still is the most plausible to be used as a co-firing biomass.

4.2. CHNS Analyzer (Ultimate Analysis)

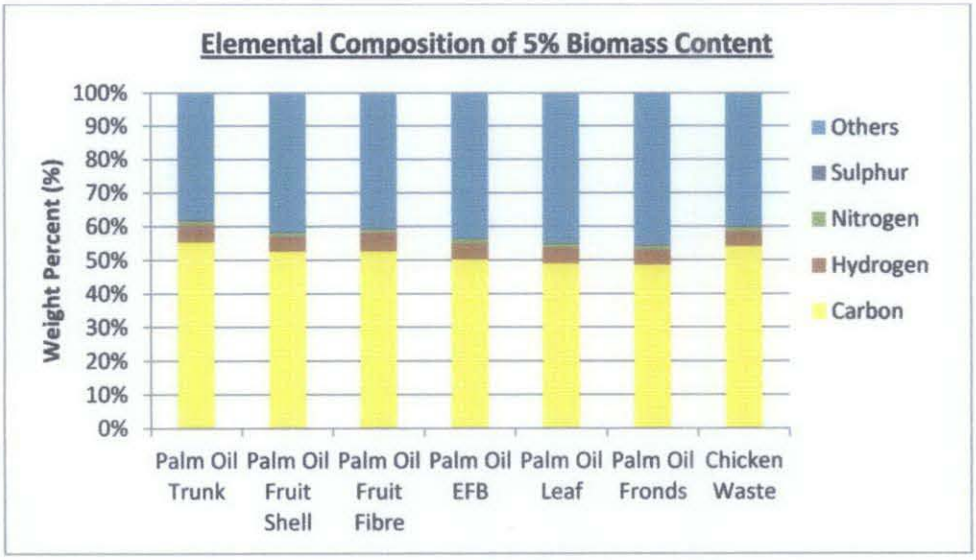
For coal, the carbon content is 73.37%, Hydrogen of 6.032%, Nitrogen with 8.450% and a sulphur content of 1.222%.

The pure biomass and biomass-coal mixture are also graphically represented in different weight percentages to facilitate comparison.

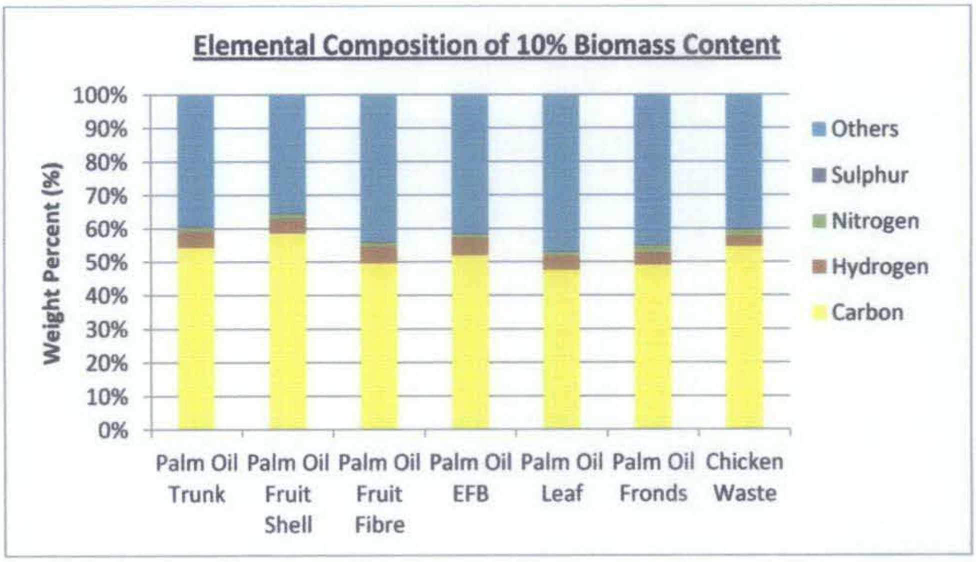
2% Biomass



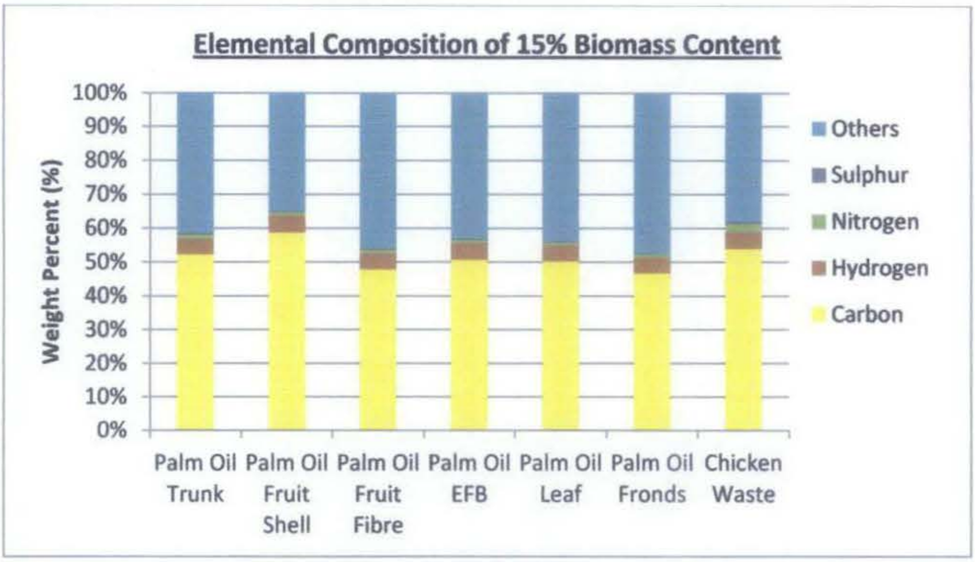
5% Biomass



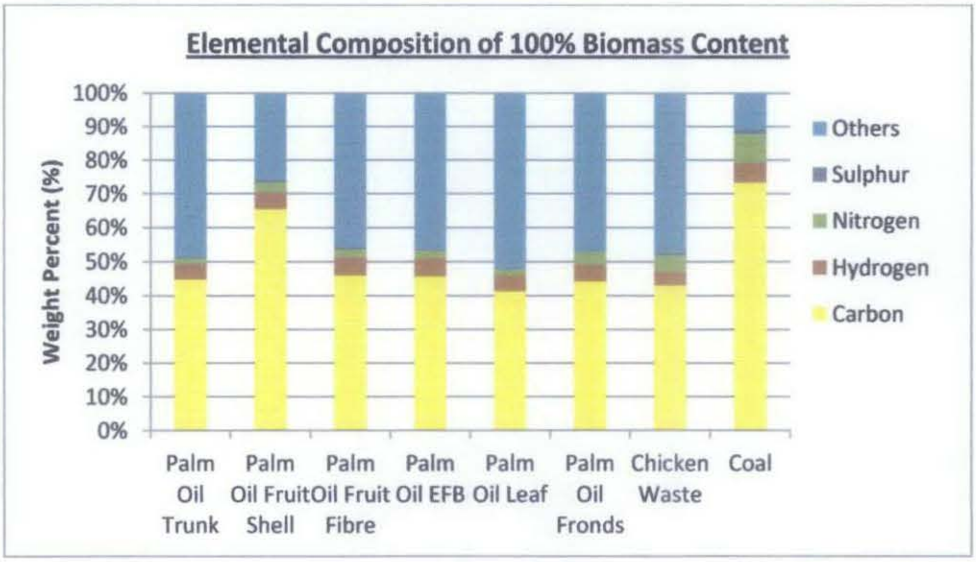
10% Biomass



15% Biomass



100% Biomass



From the charts, it can be seen that the main elemental components in all of the samples are Carbon content, and 'Others' (such as sugars and other trace elements). The main concern here is the coal content, and also nitrogen content. This is because the carbon and nitrogen content in the samples play a large role in determining the amount of Carbon Dioxide (CO_2) and Nitrogen Oxide (NO_x) released to the atmosphere.

Compared with coal, whose carbon content is staggeringly high at approximately 73%, even a little (2%) biomass changes the carbon content to the range of 50-60%. Further biomass introduction reduces the carbon content per unit mass only a little.

However, when looking at the pure biomass content comparison, it is noted that the Palm Oil Fruit Shell contains a large amount of carbon content compared to other types of biomass. This means that similar to coal, the Palm Oil Fruit Shell will produce a higher amount of Carbon Dioxide compared to other biomass types.

4.3. Thermal Gravimetric Analysis

The analysis is done on all pure samples only due to time constraint. Also, due to equipment constraints (Thermal Gravimetric Analyser could not reach a temperature high enough to completely combust coal), this analysis is only done on the palm oil wastes and chicken manure only.

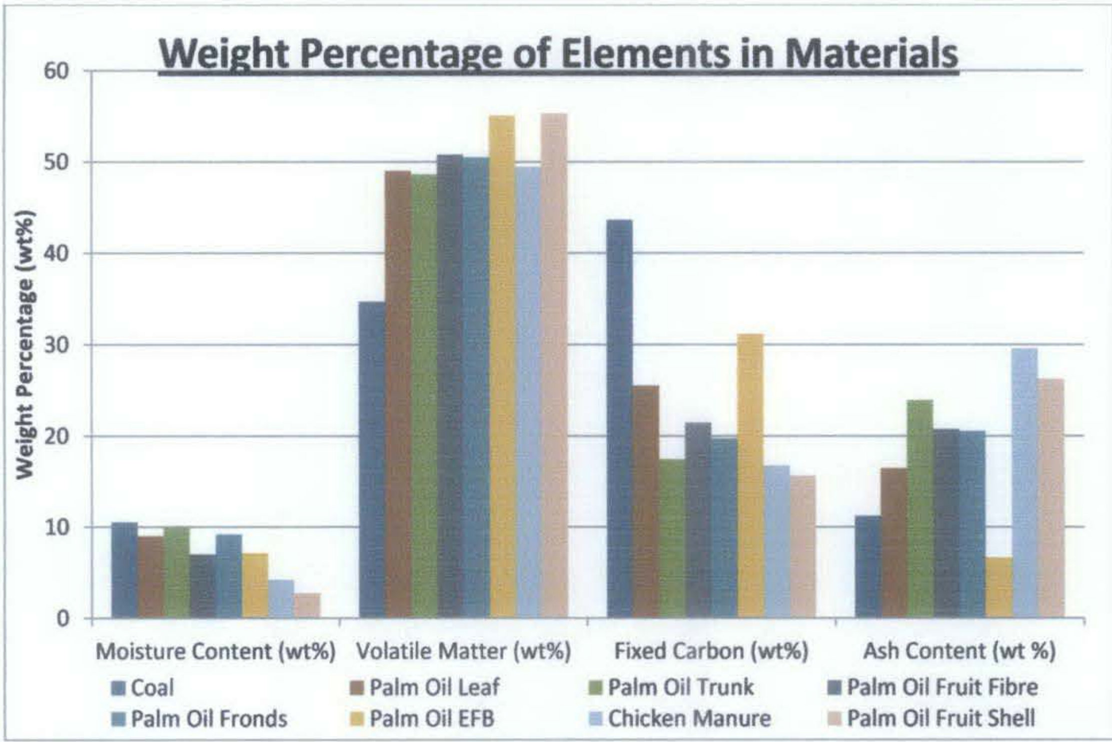
However, from study *(Coal Gasification 2nd Edition bt Chris Higman and Maarten van der Burgt, Gulf Professional Publishers, 2008)*, the sub bituminous coal contains a total of **10.5% moisture, 34.7% Volatile Matter, 43.6% Fixed Carbon and 11.2% Ash**. *(all percentages are in weight percentages, wt%)*, and the degradation temperature is rated to be approximately 260°C *(from proximate analysis)*. With that, the other biomass samples' proximate analysis properties are as such:

Overall, we can summarize the important points in the analysis.

Sample	Moisture Content (wt%)	Volatile Matter (wt%)	Fixed Carbon (wt%)	Ash Content (wt %)	Degradation Temperature (°C)
Coal	10.5	34.7	43.6	11.2	260
Palm Oil Leaf	9	49	25.55	16.45	200
Palm Oil Trunk	10	48.62	17.44	23.94	250
Palm Oil Fruit Fibre	7	50.8	21.46	20.74	180
Palm Oil Fronds	9.2	50.5	19.75	20.55	230

Palm Oil EFB	7.1	55.1	31.2	6.6	222
Palm Oil Fruit Shell	2.75	55.31	15.66	26.28	280
Chicken Manure	4.2	49.44	16.77	29.59	270

Graphically, the weight percentages are shown as follows:



From the results we can note the difference between each characteristic of each different sample. Firstly, the moisture content is very low in both the Palm Oil Fruit Shell and also Chicken Manure. This is also reflected in their Degradation Temperature. This means that it is more difficult (higher temperature needed) to combust these materials, but once combusted, they produce a larger amount of energy.

Palm Oil Fruit Shell, and Palm Oil Empty Fruit Brunch (EFB) has among the highest amount of volatile matter (mainly hydrocarbons) and this is the part where the combustion is at its greatest and most energy is produced at this stage. Following that, the carbon left after volatile matters are driven off are called the fixed carbon.

Generally the amount of fixed carbon is lesser than volatile matter and this part is where the combustion slows. However, we can see that the Palm Oil EFB has a surprisingly large amount of Fixed Carbon compared to other sample types.

Also, the ash content, which is the leftover of the combustion process, in the Palm Oil Fruit Shell and Chicken Manure is slightly higher than the other samples, whereas the Palm Oil EFB as a very low ash content. It is to note that biomass combustion produces relatively low quality ash compared to that of coal. Therefore, it is important to control the amount of biomass to be co-fired with coal to maintain the ash quality, as good ash from combustion can be sold to the construction industry (roofing and concrete addition).

Chapter 5: Conclusion

Overall, this project stands to be an interesting one. Throughout the experimentation process, I believe I have achieved good progress. Also, with the guidance of my FYP supervisor and co-supervisor, I am glad to have embarked on this project and conduct my part well for the UTP's research.

The biomass – coal co-firing concept is starting to be used by several coal firing plants around the world. This shows that biomass is capable of supplementing the use of coal, thus reducing costs and the emitting of dangerous gases. Some findings from the research that I have conducted can give an idea on the properties of each different type of biomass, including the energy content, elemental properties and emission properties.

From the findings, we can see that the mainly the palm oil empty fruit brunch (EFB) and palm oil fruit shell produces a **high amount** of energy and carbon content, and also highest amount of volatile matter. Even upon mixture with coal they show these properties consistently. These are properties showing a good candidate for energy generation. In other words, these are the two materials that should be studied further for their benefits for the use of energy generation.

Other parts of the palm oil such as the palm oil leaf and trunk shows a much less amount of energy content, and for the palm oil leaf, a low carbon content as well. These materials are more suitable to be used in applications requiring lower energy content but produce low emission levels. Other samples of mixtures include the palm oil fruit fibre, fronds and chicken waste can also be used for energy generation, but in a smaller scale application since their energy content is still considerably lower than parts such as the palm oil EFB and fruit shell.

With that, I hope that this project and all its findings will be of great assistance and reference for future researchers and those requiring the information.

Chapter 6: Recommendation

I would like to recommend that further experimentation to be done through **gas analysis** to find out the **emission gas released** by each of the sample types as this is detrimental to the feasibility of mixtures to be used for energy generation since a huge importance is placed in the amount of pollutant gases released. Aside from that, the **Proximate Analysis (TGA)** should be done on **all different mixture percentages** to add on to the pure samples only done so far. This is so that a better picture of the different mixture's degradation and ash properties can be obtained and the different mixtures better characterized.

More analysis should also be done to verify the extent of benefits of the palm oil EFB and fruit shell and its exact optimum percentage of mixture to obtain an overall balance between the amount of energy generated per biomass weight combusted and also the amount of pollutant emissions released per biomass weight combusted.

Also, further studies can be made on the feasibility of each biomass type to be used in the co-fired power plants, including **cost and returns calculations**. This will determine the feasibility of the biomass and coal mixture economically.

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APPENDIX

Appendix 1: Calorific Value of Biomass-Coal Mixture

Pure material

No.	Material	Weight (g)	Energy Content (J/g)
1	Coal	0.9191	25863
2	Palm Oil Trunk	0.5473	15411
3	Palm Oil Fruit Shell	1.0657	20764
4	Palm Oil Fruit Fibre	0.6800	18091
5	Palm Oil EFB	0.4215	19424
6	Palm Oil Leaf	0.5115	17630
7	Palm Oil Frond	0.5615	19604
8	Chicken Waste	0.7730	18064

Mixture

No.	Material	Biomass Content (%)	Weight (g)	Energy Content (J/g)
1	Palm Oil Trunk	2	1.0750	23956
		5	1.2247	23462
		10	1.0316	23042
		15	1.0088	22820
2	Palm Oil Fruit Shell	2	1.0241	24249
		5	1.0314	24587
		10	1.0959	24615
		15	1.0120	24950
3	Palm Oil Fruit Fibre	2	1.0454	24002
		5	1.0700	23717
		10	1.0590	23423
		15	1.0414	23433
4	Palm Oil EFB	2	1.0493	24996
		5	1.0850	24659
		10	1.0331	24472
		15	1.0401	24210
5	Palm Oil Leaf	2	1.0247	23025
		5	1.0411	22683
		10	1.0467	21761
		15	1.0647	21485
6	Palm Oil Fronds	2	1.0569	24378
		5	1.0913	24282
		10	1.0396	24176
		15	1.0567	23985
7	Chicken Waste	2	1.0329	25145
		5	0.7487	23022
		10	0.7583	22878
		15	1.0423	23031

Appendix 2: Ultimate Analysis of Biomass-Coal Mixture

Pure material

No.	Material	Weight (mg)	Percent Carbon (%)	Percent Hydrogen (%)	Percent Nitrogen (%)	Percent Sulphur (%)
1	Coal	1.974	73.37	6.032	8.450	1.222
2	Palm Oil Trunk	1.573	44.81	4.609	1.689	0.136
3	Palm Oil Fruit Shell	1.880	65.57	4.91	2.877	0.624
4	Palm Oil Fruit Fibre	1.931	45.97	5.086	2.475	0.587
5	Palm Oil EFB	1.679	45.66	5.208	2.364	0.086
6	Palm Oil Leaf	1.694	41.41	4.562	1.718	0.027
7	Palm Oil Frond	1.920	44.23	4.952	3.684	0.058
8	Chicken Waste	1.603	43.07	3.956	4.949	0.581

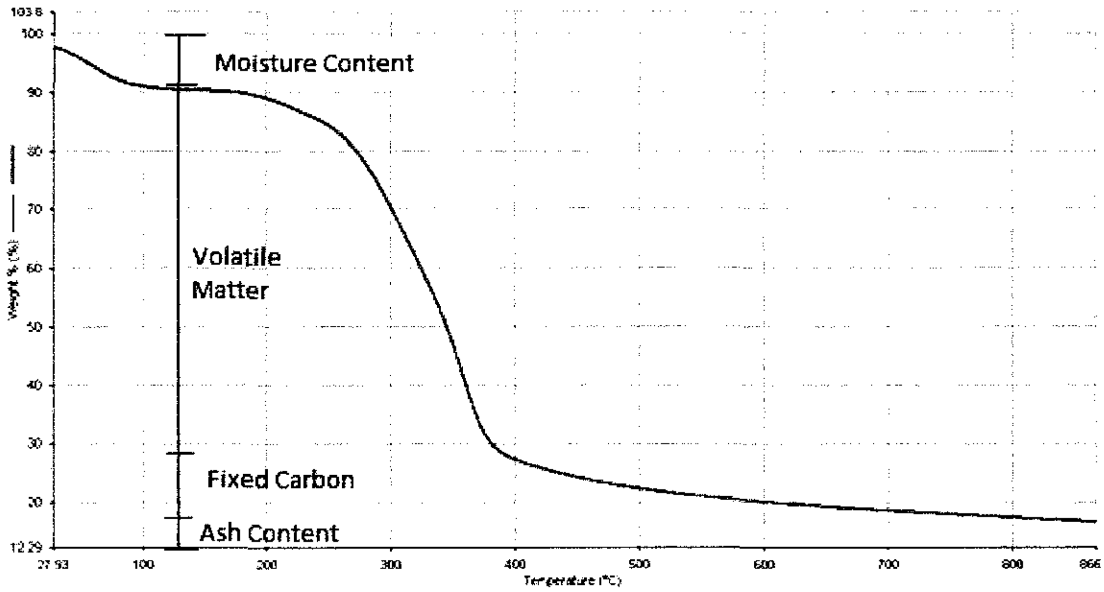
Mixture

No.	Material	Biomass Content (%)	Weight (mg)	Percent Carbon (%)	Percent Hydrogen (%)	Percent Nitrogen (%)	Percent Sulphur (%)
1	Palm Oil Trunk	2	1.632	56.48	5.277	1.110	0.612
		5	1.923	55.37	5.073	1.200	0.319
		10	1.727	54.36	4.837	1.021	0.473
		15	1.978	52.26	4,637	1.074	0.602
2	Palm Oil Fruit Shell	2	1.859	48.89	3.999	0.993	0.347
		5	1.609	52.60	4.445	1.079	0.289
		10	1.816	58.64	4.461	1.181	0.561
		15	1.832	58.72	4.867	1.020	0.286
3	Palm Oil Fruit Fibre	2	1.821	56.74	6.099	1.158	0.535
		5	1.829	52.67	5.332	1.042	0.444
		10	1.945	49.59	5.069	0.995	0.446
		15	1.896	47.89	4.713	1.014	0.322
4	Palm Oil EFB	2	1.801	57.31	4.151	1.127	0.488
		5	1.564	50.21	4.795	1.1787	0.092
		10	1.766	52.01	5.055	1.010	0.484
		15	1.720	50.72	4.847	1.069	0.468

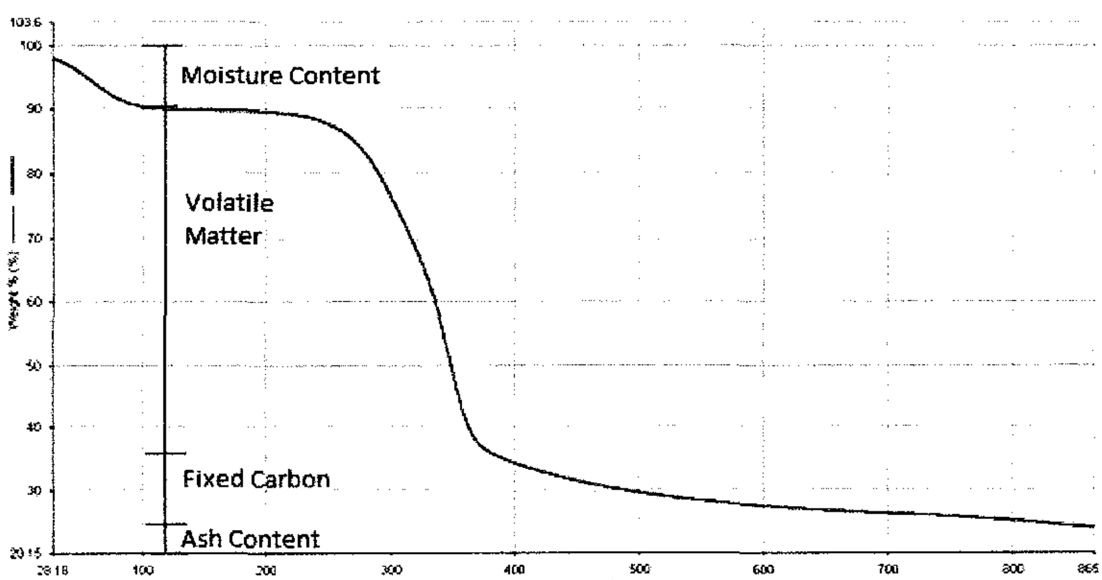
5	Palm Oil Leaf	2	1.614	49.94	43.53	0.948	0.472
		5	1.799	49.04	4.625	0.913	0.504
		10	1.685	47.48	4.438	0.783	0.329
		15	1.709	50.29	4.578	0.833	0.403
6	Palm Oil Fronds	2	1.834	48.73	4.435	1.057	0.261
		5	1.919	48.59	4.486	1.081	0.310
		10	1.995	48.99	3.919	1.832	0.456
		15	1.911	46.66	4.677	0.920	0.190
7	Chicken Waste	2	1.758	55.22	4.315	1.187	0.377
		5	1.716	54.10	4.436	1.188	0.383
		10	1.935	54.59	3.251	1.644	0.685
		15	1.829	54.01	4.781	2.501	0.582

Appendix 3: Proximate Analysis of Biomass-Coal Mixture (%Weight vs Temperature)

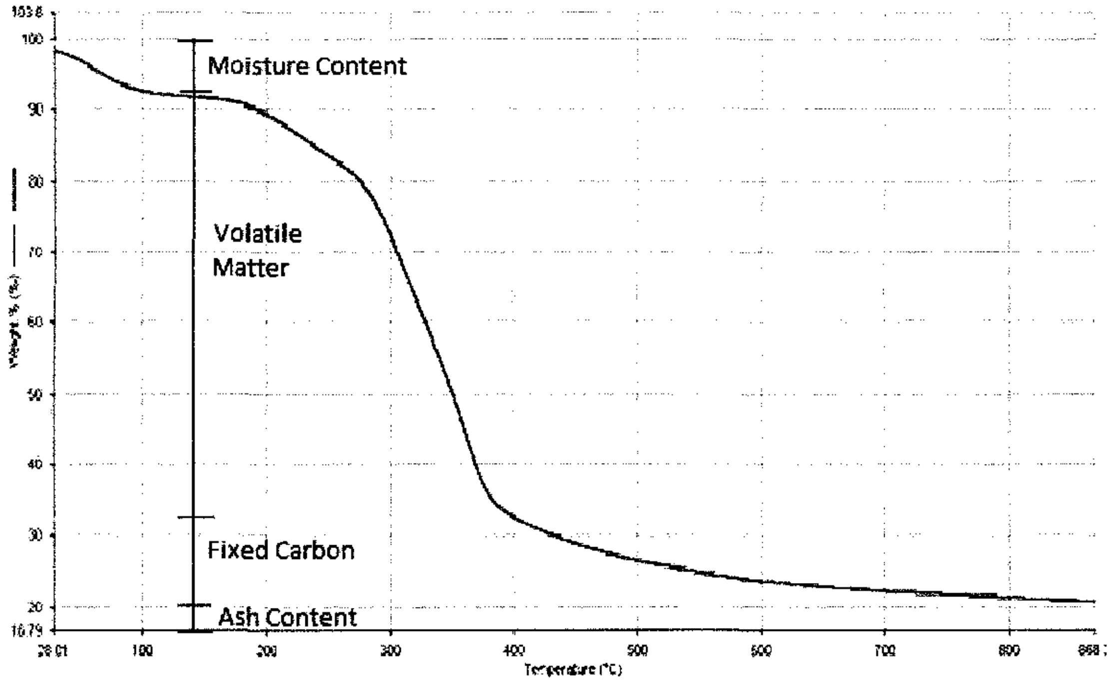
Palm Oil Leaf



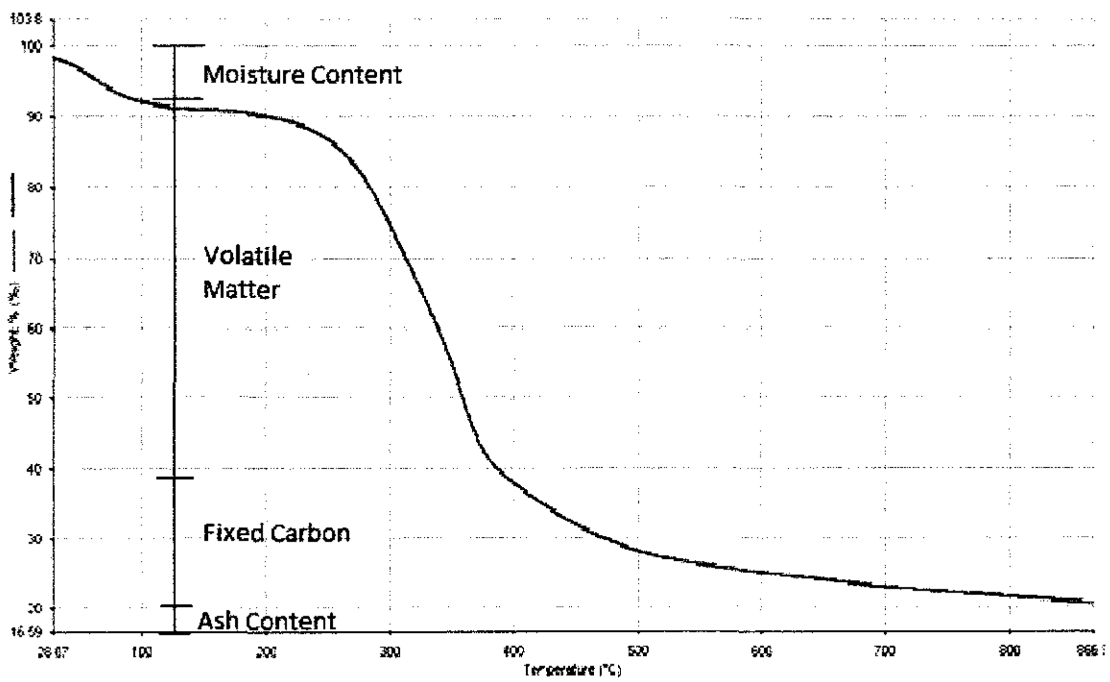
Palm Oil Trunk



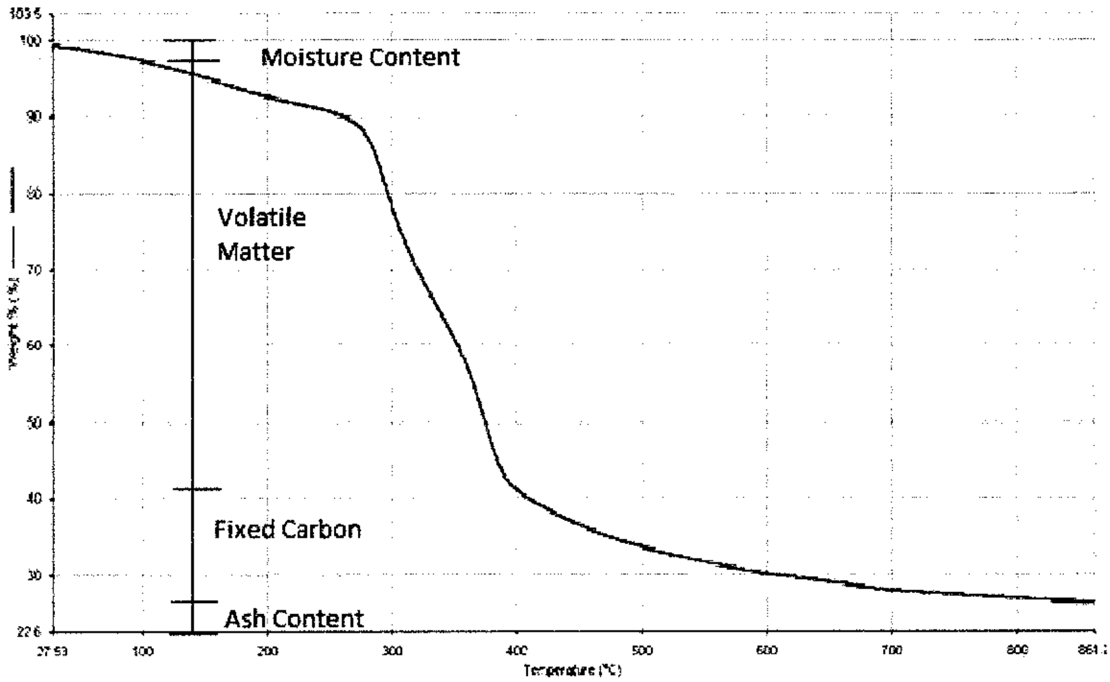
Palm Oil Fruit Fibre



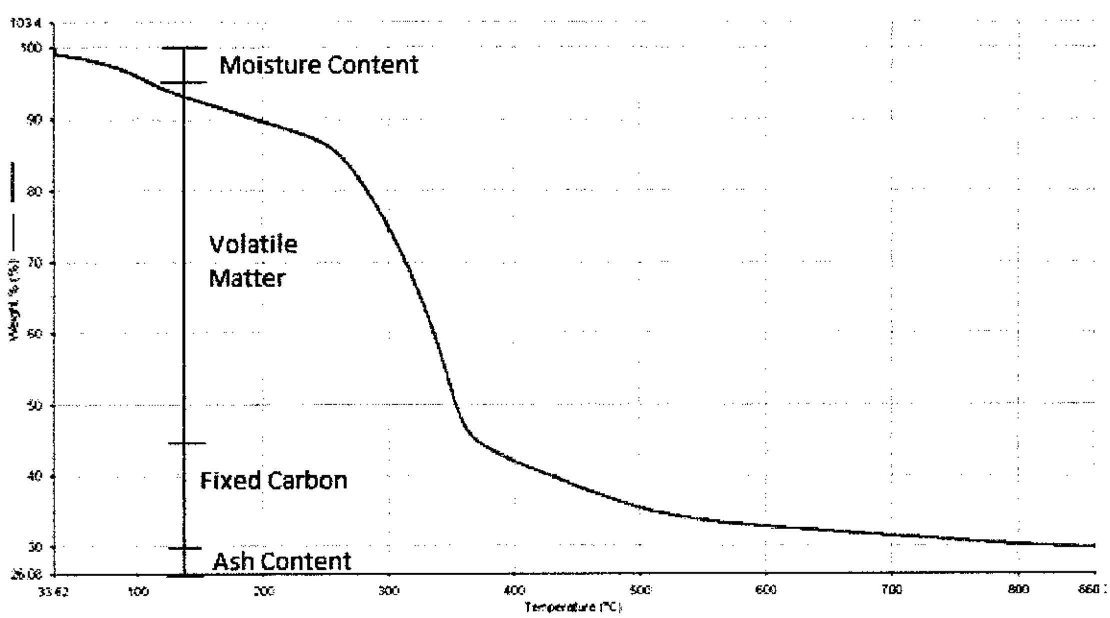
Palm Oil Fronds



Palm Oil Shell



Chicken Manure



Palm Oil Empty Fruit Brunch (EFB)