STUDY AND DEVELOPMENT OF PELLET FUEL FROM OIL PALM FROND

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MECHANICAL ENGINEERING

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Mohd Azuan Bin Mohamad Nor

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

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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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(Assoc. Prof. Ir. Dr. Chalilullah Rangkuti)
Supervisor

Universiti Teknologi PETRONAS
Tronoh, Perak
January 2008

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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Mohd Azuan Bin Mohamad Nor

ABSTRACT

This paper describes the study and development of pellet fuel from oil palm tree waste to be used as one of the biomass fuel. Out of various wastes that can be obtained from the palm oil industry, oil palm frond (OPF) has been identified as selected waste to be used as main material. Statistics had shown that palm oil industry is the largest commodity in Malaysia. From the total oil palm planted area of 4.17 million hectares in 2006, 138.2 million tones of wastes had been generated. However, the current method does not fully utilize the energy obtainable from the waste. Pelleting the waste is a method of densification of the loose materials through the practice of compacting to overcome the natural springiness of the material. A pellet fuel, which is in densified form, contains high energy per volume as compared to the loose form. The project studies the waste materials of oil palm frond and determines the material ratio that optimizes the chemical and mechanical properties of the pellet fuel. Altogether, three chemical properties and four mechanical properties tests and analyses were conducted. The chemical analyses serve to analyze the chemical composition of the waste materials and the mechanical tests determine the reliability of the pellets when handled, transported and stored. The chemical analyses are proximate analysis, ultimate analysis and calorific value determination whereas the mechanical properties tests are compression test, immerse test, and durability test. The results showed that oil palm frond was very potential in utilizing alternative renewable energy from the waste due to its high energy content with calorific value of 4558.23 cal/g. Studies found that the ratio of materials that gave optimum chemical and mechanical properties was 20:20:60 of shell to fiber to frond in weight percent. From the results of ultimate analysis, it also emitted less carbon and sulfur content when combustion took place. This would make this form of clean energy more environment-friendly as compared to combustion of fossil fuels. Furthermore, palm waste is a renewable energy source that will not depleted. From the cost analysis and economic evaluation for the 45,000 tonne per year production of palm waste pellet fuel, the payback time is estimated between 2-3 years. Thus, the production is considered profitable with annual net profit of RM 18.81 million and cumulative cash in of RM 154.61 million for 10 years of project life cycle.

ACKNOWLEDGEMENTS

First and foremost, all thanks to Allah The Almighty, for His blessings, this final year project has successfully completed. This one year project is able to complete within the time frame with help of many people who are willing to shared their knowledge, ideas and lend their hand to the author while completing this study. Therefore, I would like to take this opportunity to express my token of appreciation to those who directly and indirectly involved in this project.

First of all, I would like to thank both of my parents for their support upon completing this project. My deepest gratitude goes to my supervisor, Assoc. Prof. Ir. Dr. Chalilullah Rangkuti for his constant guidance and supervision.

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Hopefully, my final year project will be helpful and beneficial to people who are interested to make further study in this field. Lastly, thank you very much again and certainly, it would be impossible to complete this project without help from all of them.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Biomass is essentially non-fossil matter such as flora, fauna or any organic material which when used along with their by-products can produce biomass energy. Biomass fuels can be used to create energy directly or indirectly. They can be used as a heat source in their own right or can be burned to produce steam in order to produce electricity [1]. The use of biomass fuels can contribute to waste management as well as fuel security and help to prevent climate change, though alone they are not a comprehensive solution to these problems.

In Malaysia, biomass resources are mainly from the palm oil industry, bagasse, rice husks and wood or forest residues. The palm oil industry residues come in the form of empty fruit bunches (EFB), fruit fiber and shell, oil palm trunks (OPT), oil palm fronds (OFP) and palm oil mill effluents (POME).

1.2 Problem Statement

Palm oil industry is the largest commodity in Malaysia, which has the total oil palm planted area of 4.17 million hectares. The vast amount of 138.2 million tonnes of biomass output had been generated by this sector in 2006 [2]. These biomass wastes were found to have significant amount of energy content, thus, a method of utilizing the available energy should be developed. Furthermore, it is a form of renewable and clean energy that will benefit mankind and environment.

1.2.1 Problem Identification

Out of 138.2 million tonnes of biomass output that had been generated; oil palm frond was the major waste with the amount of 43.3 million tones (during harvesting and maintenance pruning) [2]. Currently, there is effort to utilize this waste (oil palm frond), empty fruit bunch, and oil palm trunk by returning them to the field as soil mulching and soil/water conservation practices for recycling of nutrients, increase soil organic content and improve soil properties [2]. But, this method does not fully utilize the energy obtainable from the waste.

Another effort is to utilize the energy from the fiber and shell by using them as boiler fuel [2]. However, the method of burning loose residues is not efficient and does not fully extract the energy due to low heating value of loose materials. Thus, densification of the loose residues in form of solid fuel is an encouraging solution because it increases the energy per volume which utilizes energy available to the maximum.

1.2.2 Significant of the Project

In this project, developing pellet fuel would help to solve the waste disposal problems by utilizing the energy obtainable from the palm oil industry waste. This type of solid fuel which is from palm biomass output is a form of renewable and clean energy which will not deplete and cause less environment issue. It is also an alternative to the fossil fuels which will deplete and cause pollution.

Research showed that all the palm oil mills in Malaysia use small boilers for electricity generation and the palm oil extraction processes. The common type of power plant used is a small water tube boiler. The boiler is a standard open D-type boiler, which is accessible to use any type of fuel with a few modifications [3]. Thus, the pellet fuel produced can be readily used in the existing boilers in the industry.

1.3 Objective and Scope of Study

The objective of this project is to study and develop pellet fuel from oil palm tree waste to be used as one of the biomass solid fuel.

1.3.1 Scope of Study

Out of various wastes that can be obtained from the palm oil industry, oil palm frond (OPF) has been identified as selected waste to be used as main material. Oil palm shell and fiber are to be considered as additional materials and their ratio in pellets will be determined. Various test and analyses will be conducted on fuel made of these materials to obtain a pellet with optimum chemical and mechanical properties.

1.3.2 Scope of Work

In order to successfully achieve the objective of the project, the appropriate methodology is designed based on the following scope of work:

1. Raw materials including oil palm frond as main material as well as oil palm fiber and shell are undergone pretreatment process comprising heating, grinding, sieving, and pressing or pelleting process.
2. Sample of different pulverized materials are taken to study their chemical properties.
3. Pelleting process is designed for experimental usage by pressing pulverized materials with certain maximum load.
4. Sample of pellet fuel from different materials are taken to study their mechanical properties.
5. Study is continued by combining different materials in a pellet with certain ratios. A pellet with optimum chemical and mechanical properties is obtained through selected tests and analyses.

1.3.3 The Relevancy of the Project

The project of developing pellet fuel from palm biomass output is relevant because there is great amount of palm oil industry waste in the country due to the fact that Malaysia is today the world's leading producer and exporter of palm oil. There are more than three hundred of palm oil processing mills in Malaysia [4]. Thus, lots of savings can be obtained by using palm tree waste pellets as alternative fuel for electricity generation for the industry.

1.3.4 Feasibility of the Project within the Scope and Time Frame

The project is feasible within two semesters. During first semester, sample of the pulverized materials from oil palm fronds was taken to study its chemical properties. The results then had been compared with other materials. The pelleting process and mechanical properties tests were conducted in the second part of the project. The ratio of materials that give optimum chemical and mechanical properties had been determined at the end of the project.

CHAPTER 2
LITERATURE REVIEW AND THEORY

2.1 Review of Term Biomass and Densification

2.1.1 Biomass

Biomass, contraction for biological mass is the amount of living material provided by a given area of the earth's surface. The term is most familiar from discussions of biomass energy, that is, the fuel energy that can be derived directly or indirectly from biological sources. Biomass energy from wood as shown in Figure 2.1, crop residues, and dung remains the primary source of energy in developing regions. In a few instances it is also a major source of power, as in Brazil, where sugarcane is converted to ethanol fuel, and in China's Sichuan province, where fuel gas is obtained from dung. Various research projects aim at further development of biomass energy, but economic competition with petroleum has mainly kept such efforts at an early developmental stage [5].

Figure 2.1: Wood is One of Biomass Energy

Biomass fuels work by releasing solar energy. Plants, through photosynthesis, convert solar energy to chemical energy, which fuels plant growth. People, in turn, use this stored solar energy through fuels such as wood, alcohol, and methane that are extracted from the plant life (biomass) [5].

2.1.2 Densification

The term densification essentially refers to the practice of compacting biomass fuels. Most biomass fuel sources such as wood or sawdust would usually have a low energy density and contain a lot of unwanted air. Compacting them into pellets as shown in Figure 2.2 or other more dense formats by reducing this unwanted air content not only ensures that stored biomass fuel sources are more compact and have a greater energy density but also makes handling and transportation easier and much more efficient. Once biomass has been densified, it can be used in applications such as pellet burning stoves in the home. From an industrial or commercial perspective it can be burned alongside coal in commercial furnaces and power stations [1].

Figure 2.2: Pellet is One of the Practices of Compacting Biomass Fuels

2.2 Overview of Palm Oil Industry in Malaysia

Over the last few decades, the Malaysia palm oil industry has grown to become a very important agriculture-based industry, where the country is today the world's leading producer and exporter of palm oil. Indigenous to Africa, the oil palm (*Elaeis guineensis* Jacq.) has been domesticated from the wilderness and transformed to become a plantation-based industry. During the late 1950s the expansion of the industry started as part of government's diversified cautious policy from rubber to oil palm and also to raise the socio-economic status of the expanding population in the country. Today, Malaysia is the world's largest producer and exporter of palm oil, replacing Nigeria as the chief producer since 1971 as shown in Figure 2.3. Malaysia is blessed with favourable weather conditions which prevail throughout the year which is advantageous for palm oil cultivation. Thus, it is not surprising that the highest yields have been obtained from palms grown in this region, which is far from its natural habitat [6].

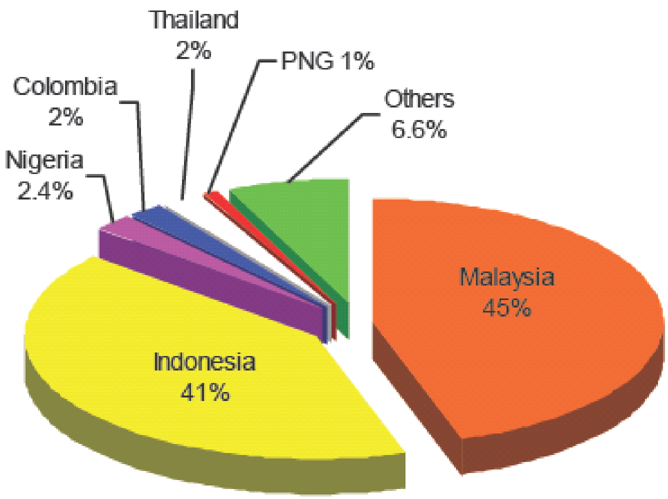


Figure 2.3: Palm Oil Producers [2]

2.3 Potential of Utilizing Energy from Palm Oil Industry Waste in Malaysia

Based on the statistics of palm biomass output in 2006 [2], palm oil industry waste has great potential that can be used for biomass-based power generation. The amount of waste generated from this industry is shown in Table 2.1.

Table 2.1: Estimated Palm Biomass Output in 2006 [2]

Waste Materials	**Estimated Amount (Million tonnes, Mt)**
Oil Palm Fronds (OFP)	43.3
Oil Palm Trunks (OPT)	9.4
Shell	4.3
Fiber	10.7
Empty Fruit Bunch (EFB)	17.4
Palm Oil Mill Effluent (POME)	53.1
TOTAL	**138.2**

In 2006, the total oil palm planted area increased by 2.8% to 4.17 million hectares. The area expansion occurred mainly in Sabah and Sarawak with a combined growth of 4.5% compared to 1.6% in Peninsular Malaysia. Sabah remained the largest oil palm planted state with 1.24 million hectares or 30% of the total planted area [7]. This fact had shown that the palm oil industry in Malaysia is still expanding and Malaysia will remain as the major palm oil producer. The waste amount generated will not decrease but will continue to increase in the near future. Thus, this sector is very potential in generating energy from waste.

Research had shown that palm biomass output have high heating values as shown in Table 2.2. This significant value of energy content make them good fuel source and has the potential to be utilized.

Table 2.2: Heating Values of Oil Palm Biomass Output [8]

Biomass	Calorific Value (kJ/kg)	Main uses
Fiber	19068	Fuel
Shell	20108	Fuel
Empty Fruit Bunches (EFB)	18838	Mulch

2.4 Chemical and Mechanical Properties Tests and Analyses

For this project, several tests and analyses had been done to study the chemical and mechanical properties, as shown Figure 2.4. The chemical analyses are analytical determination most commonly used for industrial characterization of coal whereas the mechanical analyses are methods to determine the transporting, handling and storing characteristics of a pellet fuel.

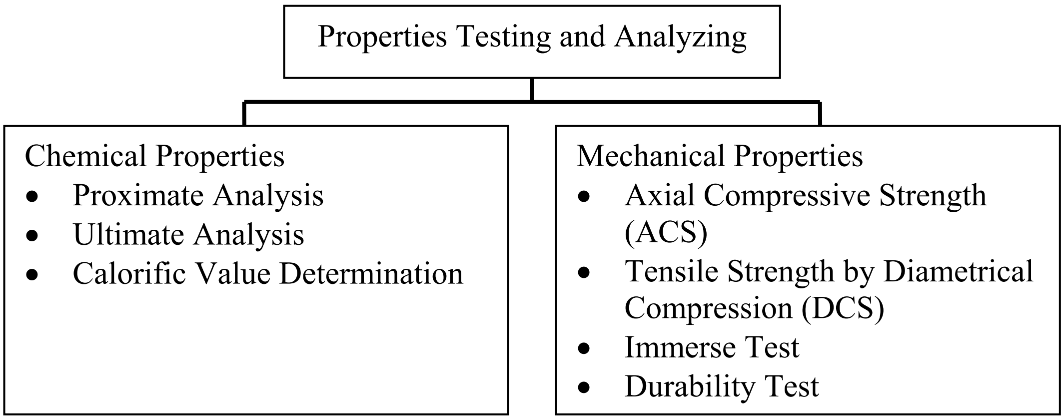


Figure 2.4: Tests and Analyses to Evaluate Chemical and Mechanical Properties

2.4.1 Chemical Properties Tests and Analyses

The chemical properties tests and analyses that had been done in this project were proximate analysis, ultimate analysis, and calorific value determination. They were done by using the Thermo Gravimetric Analyzer (TGA), the LECO CHNS 932 Analyzer, and Bomb Calorimeter respectively.

The proximate analysis is the simplest mean for determining the distribution of products obtained during heating the material. It separates the products into four groups [9]:

1. Water or moisture
2. Volatile matter consisting of gases and vapors
3. Fixed carbon consisting of the carbonized residue less ash
4. Ash derived from the mineral impurities in material

Proximate analysis is an empirical technique in which the mass of a substance is heated at a controlled rate and the mass or weight percent loss is recorded as a function of temperature or time [10]. Typical result from proximate analysis is as shown in Figure 2.5.

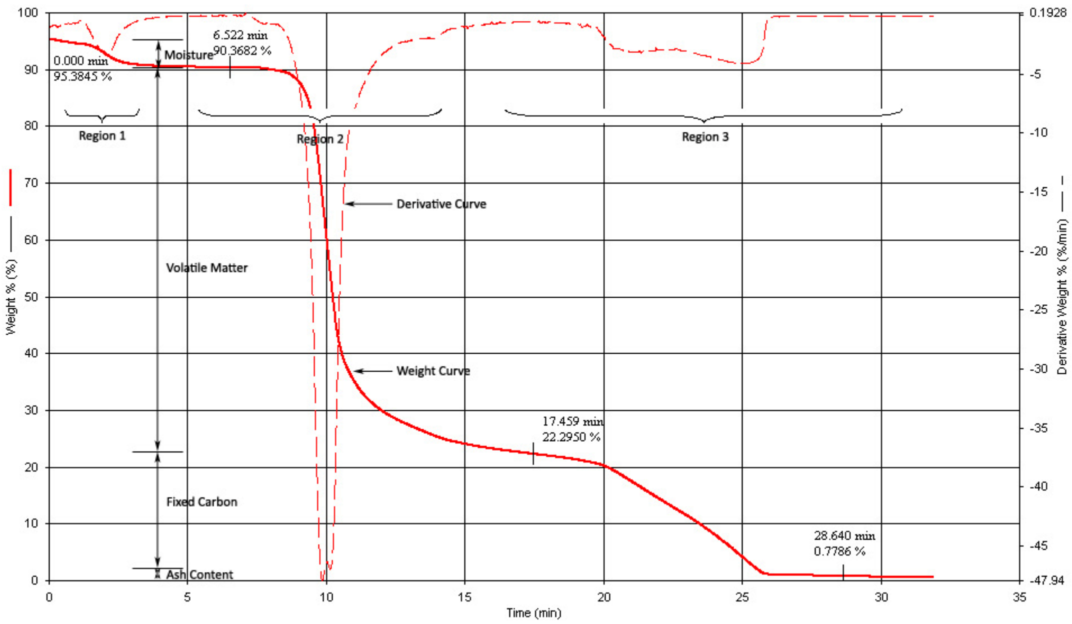


Figure 2.5: Typical Result of Proximate Analysis

The weight loss of the material tested can be read from the weight curve and percentage of moisture content, volatile matter, fixed carbon, and ash content can be calculated. The burning profile of the material can be obtained from the derivative weight curve. ‘Region 1’ shows the time where moisture is released. After the moisture releasing region, the burning profile can be divided into rapid burning region, which is ‘Region 2’ and slow burning region, which is ‘Region 3’. In the rapid burning region, weight loss is fast and reaches a maximum value due to the volatile matter content. In the slow burning region, burning rate decreases because the formation of ash that covers the material and thus, oxygen diffusion into the material has decreased.

The ultimate analysis, however, express the composition of the material as sampled in percentages of carbon, hydrogen, nitrogen, and sulfur. The carbon includes that present in the materials as well as a minor amount that may be present as mineral carbonates. Oxygen in the materials is usually estimated by subtracting the sum of carbon, hydrogen, nitrogen, and sulfur from 100. Many of the analyses discussed can be performed with modern instruments in a short time [9].

Gross calorific value of the material is the heat produced by complete combustion of a unit quantity, at constant volume, in an oxygen bomb calorimeter under standard conditions. It includes the latent heat of the water vapor in the products of combustion. Since latent heat is not available for making steam in actual operation of boilers, a net calorific value is sometimes determined [9].

The calorific value obtained by using the bomb calorimeter could be taken as the maximum extractable energy due to the nature of the test that happens in a high-pressure environment. The optimum environment causes rapid burning and energy loss is a minimum. For practical usage, the chemical energy in the material can be converted into useful power by gasification or direct burning.

Electricity produced from gasification is more complex than using direct combustion or steam cycle process. Thus, the result is that biomass gasification power systems will have higher investment cost. In this project, the pellet fuel which is one type of solid fuel was targeted for industrial boiler usage, where direct burning was applied.

2.4.2 Mechanical Properties Tests and Analyses

The mechanical properties of pellet fuel are very important when handling, transporting, and storage the pellets are concerned. The mechanical strength of a pellet is studied under compression test, which are the Axial Compressive Strength (ACS) and Tensile Strength by Diametrical Compression (DCS), where maximum compressive load that can be sustained by a pellet is obtained. Other mechanical property such as impact resistance is studied under durability test. Water resistance of pellet fuel is studied under immerse test.

For most of the tests and analyses, the procedures and test parameters were adapted from researches that modified the testing procedures from American Society for Testing and Material (ASTM) standard. The parameters in TGA analysis were set based on ASTM E 1131-98, Standard Test Method for Compositional Analysis by Thermogravimetry. Calorific value determination was based on ASTM D 5865-04, Standard Test Method for Gross Calorific Value of Coal and Coke. Other tests procedures were obtained form the researches where modifications had been done. For the compression test, the tests were designed based on the standard test methods for compressive and splitting tensile strengths of concrete cylindrical specimens (ASTM C 39-03 and ASTM C 496-04). The durability test could refer to and modified from ASTM E 1288-89, Standard Test Method for The Durability of Biomass Pellets.

CHAPTER 3
METHODOLOGY

3.1 Flow Chart of Methodology

The flows of procedures of conducting the project within two semesters are as shown in Figure 3.1 on the next page.

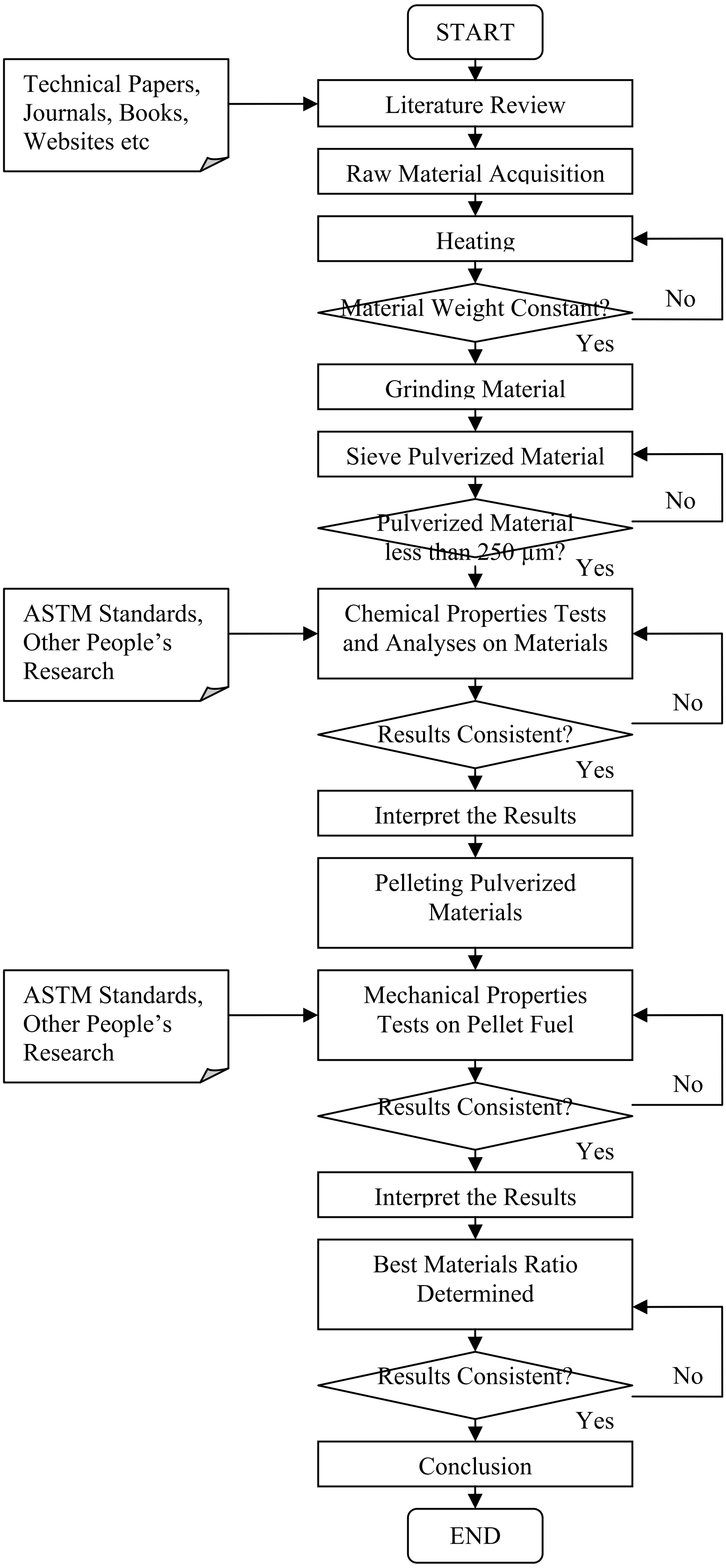


Figure 3.1: The Project Flow

3.2 Pretreatment Process

The raw materials that had been identified for being tested and analyzed are oil palm frond, shell, and fiber, where oil palm frond as the main material, and shell as well as fiber were considered to be the additional materials. However, in this project, only oil palm frond had been analyzed its chemical properties. The results then were compared to the data of chemical properties of other materials, which were obtained from the previous project. The pruned frond or oil palm frond (OPF) was taken from the nearest oil palm estate as shown in Figure 3.2 below.

Figure 3.2: Acquisition of Oil Palm Frond (OPF) from the Nearest Estate

The pretreatment process involved heating the raw materials to eliminate moisture by using oven as shown in Figure 3.3. The materials were heated to 105°C above the water vaporization temperature of 100°C for 2 to 3 hours to ensure all moisture being removed. The materials were weighed every hour, until their mass became constant.

Figure 3.3: Material Being Heated by Oven to Eliminate Moisture

The dried materials then were pulverized using granulator as shown in Figure 3.4 and mortar grinder for duration of 2 to 3 minutes as shown in Figure 3.5.

Figure 3.4: Granulator

Figure 3.5: Mortar Grinder

The pulverized materials then were sieved by using automatic sieving machine as shown in Figure 3.6 to obtain particles size of less than 250µm.

Figure 3.6: Automatic Sieving Machine

3.3 Pelleting Process

As been mentioned in previous report, pelleting the pulverized materials shall be done by using twin screw extruder to produce pellet fuel. But, due to incapable of that equipment to produce pellet from materials used, alternative equipment which is Autopallet Press Machine as shown in Figure 3.7 was used.

Figure 3.7: Autopallet Press Machine

For the sieved powder to be pressed into pellet, 1 g of powder was measured by using a digital weighing machine. The powder then was poured into a 13 mm I.D. cylindrical stainless steel mold as shown in Figure 3.8 held in the press machine. The maximum load of 2000 kg, equivalent to 140 Mpa, was applied. Load was increased gradually to the maximum by 100 kg automatically. The machine was set to hold at maximum load for 30 seconds. Once the pressing process had finished, the produced pellet was unloaded from the mold.

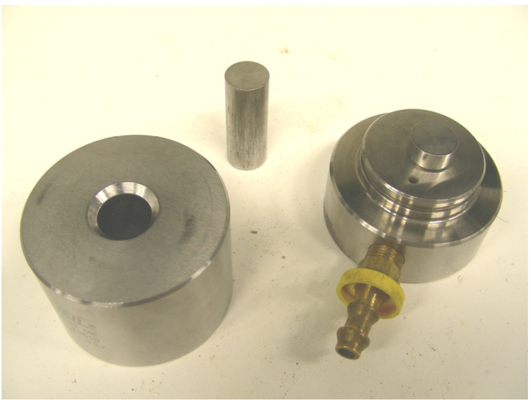


Figure 3.8: A 13 mm I.D. Cylindrical Stainless Steel Mold

3.4 Procedures and Equipment Involved in Properties Tests and Analyses

Many different tools and equipments had been used in this project to analyze the chemical properties of materials and mechanical properties of pellet fuel.

3.4.1 Chemical Properties Tests and Analyses

The Thermo Gravimetric Analyzer (TGA) as shown in Figure 3.9 was used for proximate analysis where the percentage of moisture content, volatile matter, fixed carbon, and ash content were determined. The basic principle of thermo gravimetric analysis module is to record mass loss during programmed time or temperature profile. Changes in mass indicate moisture loss and phase changes which occur at set temperature indicative of the compound.

It can be used to determine water crystallization, follow degradation of materials, and determine reaction kinetics, study oxidation and reduction. Adding to that, the burning characteristics of material can be obtained by applying derivative thermo gravimetric techniques. The parameters used for this proximate analysis were based on ASTM E 1131-98, Standard Test Method for Compositional Analysis by Thermogravimetry.

Figure 3.9: Thermo Gravimetric Analyzer (TGA)

Ultimate analysis reported chemical composition of material in percentage of carbon, hydrogen, nitrogen, and sulfur. It was done by using a LECO CHNS 932 machine as shown in Figure 3.10. The machine works based on the principle that high temperature combustion is used as the means of removing the elements from the material. In the combustion process, a nominal 2 mg sample is encapsulated in a tin or silver capsule. The sample is placed in the sample loading chamber and held there until a dose of oxygen has been released. The sample is then dropped into the furnace at the same time the oxygen arrives. The sample is combusted by the heated oxygen-rich environment.

Figure 3.10: LECO CHNS 932 Machine

The products of combustion in the CHNS analysis are CO_2, H_2O, N_2, and SO_X. The gases, which are carried through the system by the helium carrier, are swept through the oxidation tube packed with either tungsten trioxide (which adds oxygen) or copper sticks (which removes oxygen), to complete the conversion to SO_2. The H_2O is swept through the non-dispersive infrared absorption detection system where it is measured, Anhydrone then removes the H_2O and the remaining gases are swept through the SO_2 and CO_2. Lecosorb and Anhydrone leaving the helium carrier gas and N_2 remove the CO_2 and the H_2O. The N_2 is measured by thermal conductivity. Adjustments for blank, calibration, and weights are applied to the final integrated signal and the answers are displayed as weight percent carbon, hydrogen, nitrogen and sulfur [11].

In this project, less than 2 mg of pulverized material was loaded into the capsule and flatten. A few capsules were loaded into the machine each time and the machine would automatically capture a capsule at one time to be analyzed.

The bomb calorimeter as shown in Figure 3.11 is the most common device for measuring the heat of combustion or calorific value of a material. With this apparatus a test specimen of specified mass is burned under standardized conditions. The heat of combustion determined under these conditions is calculated on the basis of the observed temperature rise while taking account of heat loss. The combustion process is initiated inside an atmosphere of oxygen in a constant volume container, the bomb, which is a vessel built to withstand high pressures. It is immersed in a stirred water bath, and the whole device is the calorimeter vessel. The calorimeter vessel is also immersed in an outer water bath. The water temperature in the calorimeter vessel and that of the outer bath are both monitored [12].

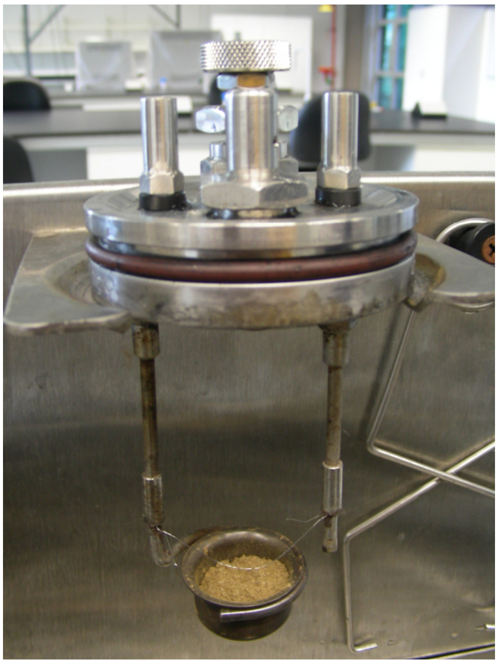
Figure 3.11: Bomb Calorimeter

The basic principles behind bomb calorimeter are [13]:

1. supply oxygen to the sample to ensure it burns completely
2. burn the sample quickly so that the heat produced has little time to diffuse into the surrounding environment before measuring the total change in the water temperature
3. enclose the reaction inside a strong chamber to contain the high pressure of the rapidly-burning sample

The strong chamber is a steel vessel capable of withstanding high pressure of gas inside as well as the explosive force of the burning reagents inside. It is also called a constant volume calorimeter since the reaction occurs within a rigid vessel (bomb) which volume cannot change. The bomb calorimeter submerges the reaction inside an insulated container of water. An electrical heating device starts the reaction inside a sealed reaction vessel and the temperature rise of the water which surrounds it is measured. The combustion process is initiated inside an atmosphere of oxygen in a constant volume container, the bomb. It is immersed in a stirred water bath. The water temperature in the calorimeter vessel and that of the outer bath are both monitored.

In this project, samples that weight less than 2g were taken and loaded into clean crucible which was then placed into the sample holder. Fuse wire was place on top of the sample without touching the sample, like shown in the Figure 3.12. Then the O-ring was place into the combustion chamber and locked with the bomb cap. The combustion chamber was pressurized before combustion took place. The combustion chamber was placed into the water bath with combustion vessel fuse connected and the burning process started. The results obtained were printed out automatically.



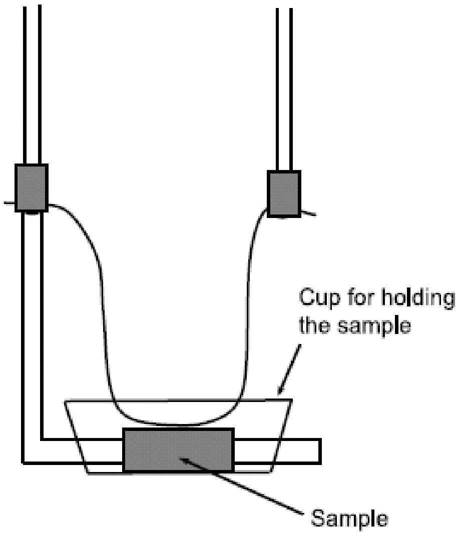


Figure 3.12: Sample Preparation for Bomb Calorimeter

3.4.2 Mechanical Properties Tests and Analyses

Mechanical properties tests and analyses included compression test, which are the Axial Compressive Strength (ACS) and Tensile Strength by Diametrical Compression (DCS), durability test, and immerse test. The procedures of the tests were mostly from the previous researches and modifications from ASTM standards.

The Axial Compressive Strength (ACS) and Tensile Strength by Diametrical Compression (DCS) were determined in a rigid-frame controlled load equipment at a load rate of approximately 0.5 kN/s. These tests were designed based on the standard test methods for compressive and splitting tensile strengths of concrete cylindrical specimens (ASTM C 39-03 and ASTM C 496-04) [8].

Cylindrical pellets were submitted to uniformly distribute increasing axial and diametrical compressive forces in suitable testing machine named Zwick 100 Universal Testing Machine as shown in Figure 3.13, until the pellets were broken. The strength was expressed as the maximum load sustained by the pellets in kN [8].

Figure 3.13: Zwick 100 Universal Testing Machine

The water resistance of the pellets was tested by immersing them in a beaker filled with distilled water at room temperature. A pellet was placed slightly above the water level and released. The pellet would start disintegrating in water and the time for it to fully disintegrate and disperse in water was taken by using a stop watch.

In the durability test, the pellets were dropped from a height of 1.85 m into a plate for 4 times. The ratio of final weight of material remained in the plate after four drops to the initial weight of a pellet was obtained by using a digital weighing machine and durability of that particular pellet could be calculated by the following formula [14]:

$$Durability(\%) = \frac{weight\_of\_material\_remained\_in\_plate\_after\_4\_drops}{initial\_weight\_of\_material} \times 100\%$$

The tests and analyses done to study the chemical and mechanical properties of pellet fuel are summarized as shown in Table 3.1.

Table 3.1: List of Properties and the Corresponding Test/Analysis and Equipment

Property Studied	Test/Analysis Done	Equipment Used
1. Chemical Composition	Proximate Analysis	Thermo Gravimetric Analyzer (TGA)
	Ultimate Analysis	LECO CHNS 932 Machine
2. Burning Profile	Derivative Thermo Gravimetry	Thermo Gravimetric Analyzer (TGA)
3. Energy Content (Heating Value)	Calorific Value Determination	Bomb Calorimeter
4. Compressive Strength	Axial Compressive Strength (ACS)	Zwick 100 Universal Testing Machine
	Tensile Strength by Diametrical Compression (DCS)	Zwick 100 Universal Testing Machine
5. Water/Humidity Resistance	Immerse Test	Beaker Stop Watch
6. Durability	Durability Test	Weighing Machine Plate

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Results of Pelleting Process

From pelleting process, by using the 13 mm I.D. cylindrical stainless steel mold held in Autopallet Press Machine, with a maximum load of 2000 kg or 140 Mpa, the resulting made pellets were as shown in Figure 4.1 below. Each pellet was approximately 1 g with the average thickness of 8 mm.

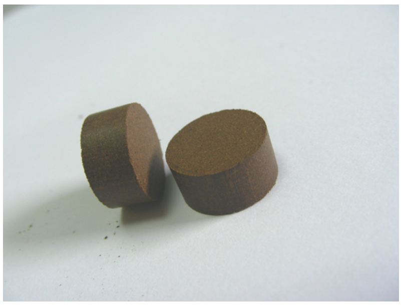


Figure 4.1: The Resulting Made Pellets using 13 mm I.D. Cylindrical Stainless Steel Mold

4.2 Results of Chemical Properties Tests and Analyses

In this project, sample of the pulverized materials from oil palm fronds was taken to study its chemical properties. The results then had been compared with other materials – coal, saw dust, palm fiber and shell from the previous project. The data were taken from the project by Chin Yee Sing, titled Energy from Waste – Development of Alternative Fuel Briquettes from Agricultural Waste.

4.2.1 Proximate Analysis

The proximate analysis reported the percentage of moisture content, volatile matter, fixed carbon, and ash content of five different materials as shown in Figure 4.2.

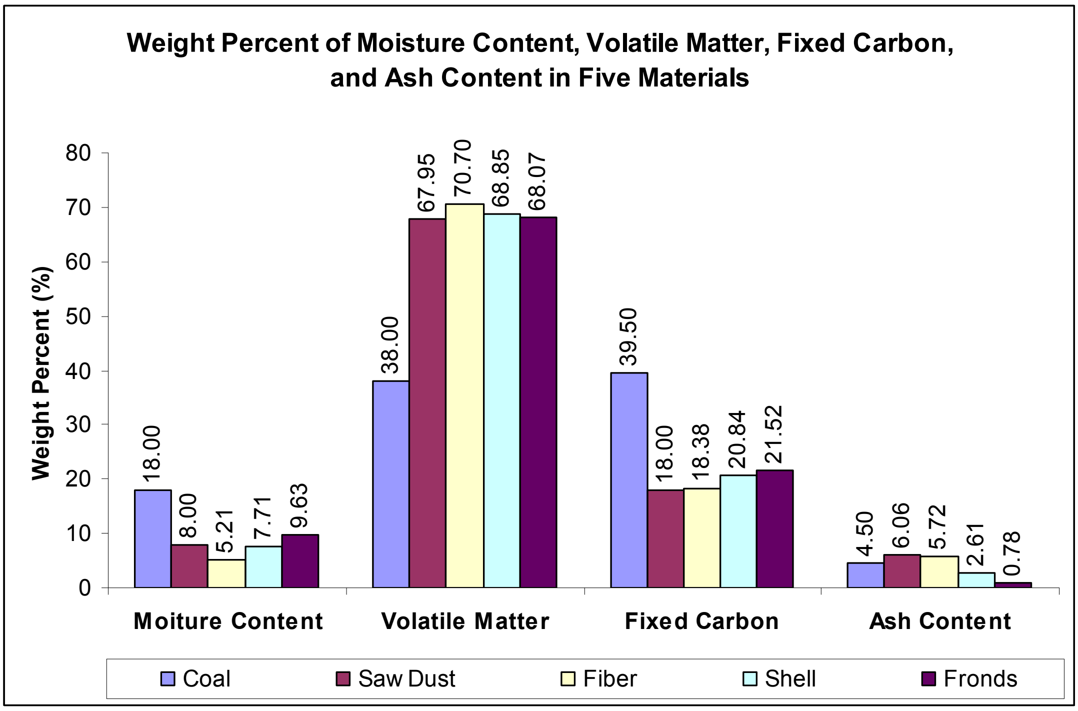


Figure 4.2: Proximate Analysis of Five Different Materials

4.2.2 Ultimate Analysis

Ultimate analysis was performed to obtain the compositions of materials in terms of carbon, hydrogen, nitrogen and sulfur. The results of the analysis are shown in Figure 4.3.

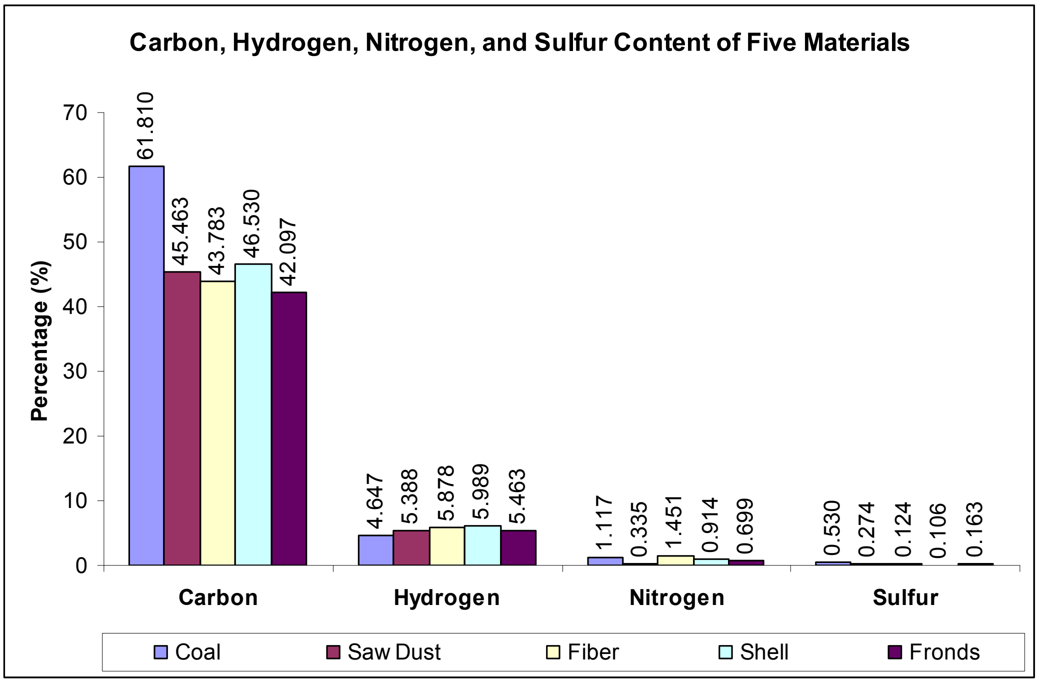


Figure 4.3: Ultimate Analysis of Five Different Materials

4.2.3 Calorific Value Determination

The energy content or calorific value of materials, as determined by using a bomb calorimeter, is shown in Figure 4.4.

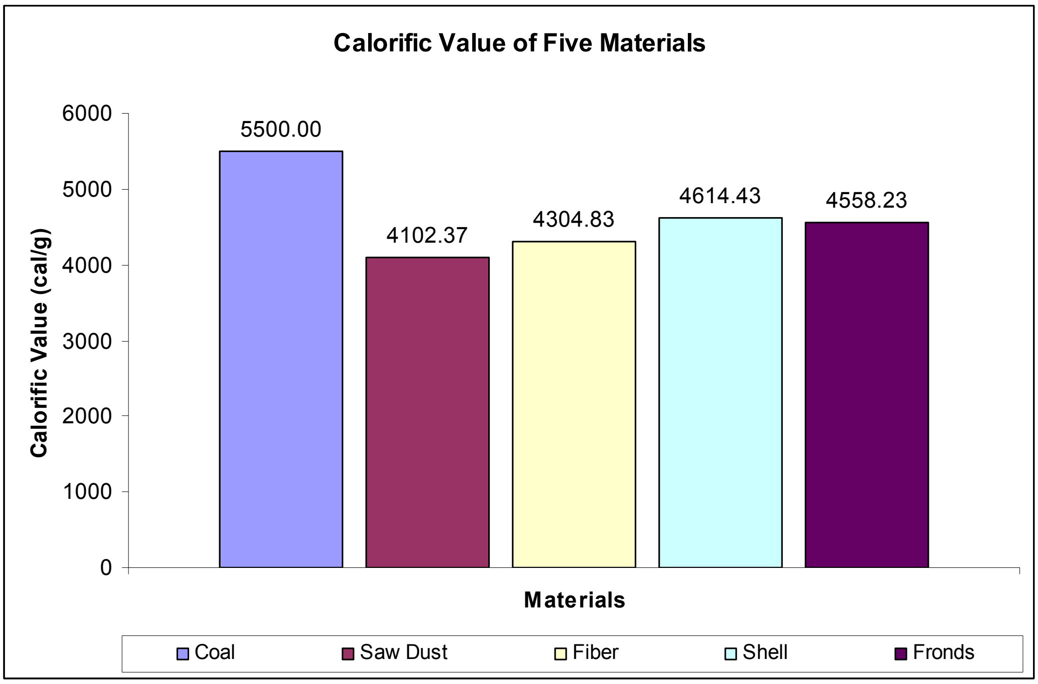


Figure 4.4: Calorific Values of Five Different Materials

4.3 Results of Mechanical Properties Tests and Analyses

4.3.1 Axial Compressive Strength (ACS)

Axial Compressive Strength (ACS) test was done to determine the maximum compressive strength that sustained by the pellet before it shattered. The results were as shown in Figure 4.5.

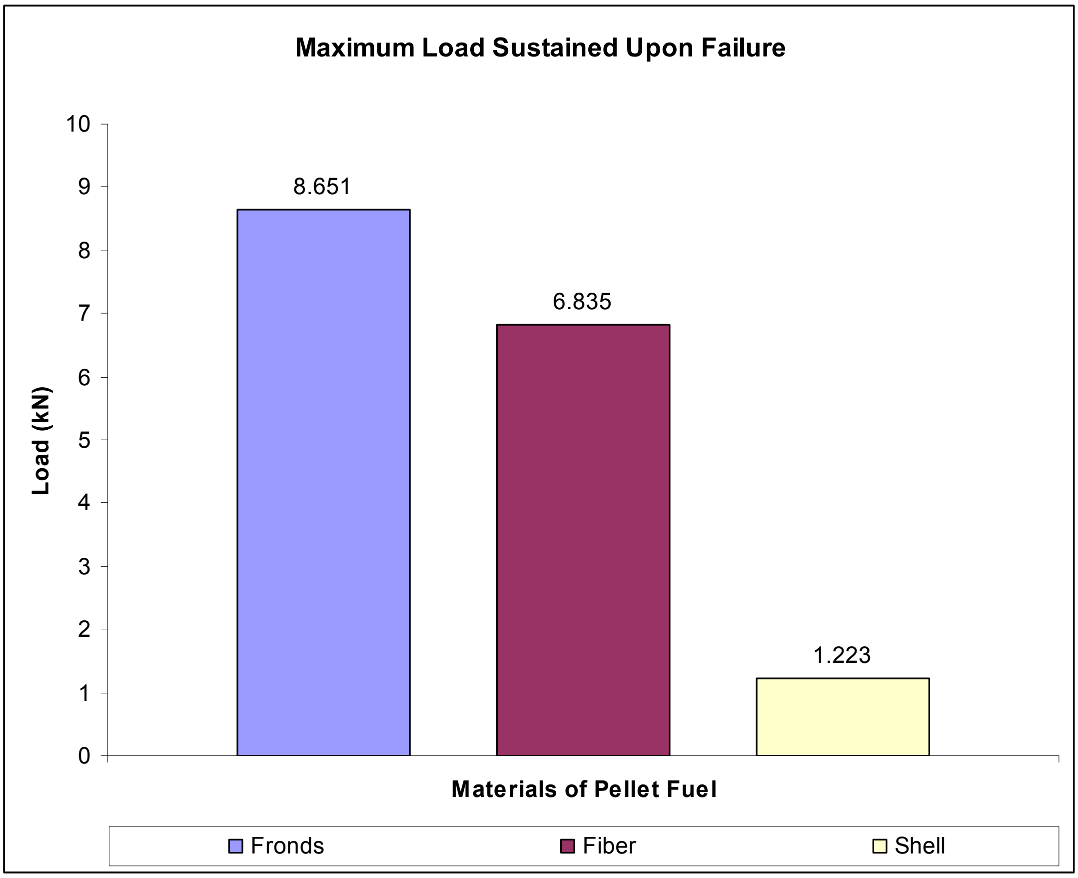


Figure 4.5: Results of Axial Compressive Strength (ACS) Test

4.3.2 Tensile Strength by Diametrical Compression (DCS)

Tensile Strength by Diametrical Compression (DCS) test was conducted to determine the diametrical compressive strength that sustained by the pellet before it failed. The results were as shown in Figure 4.6.

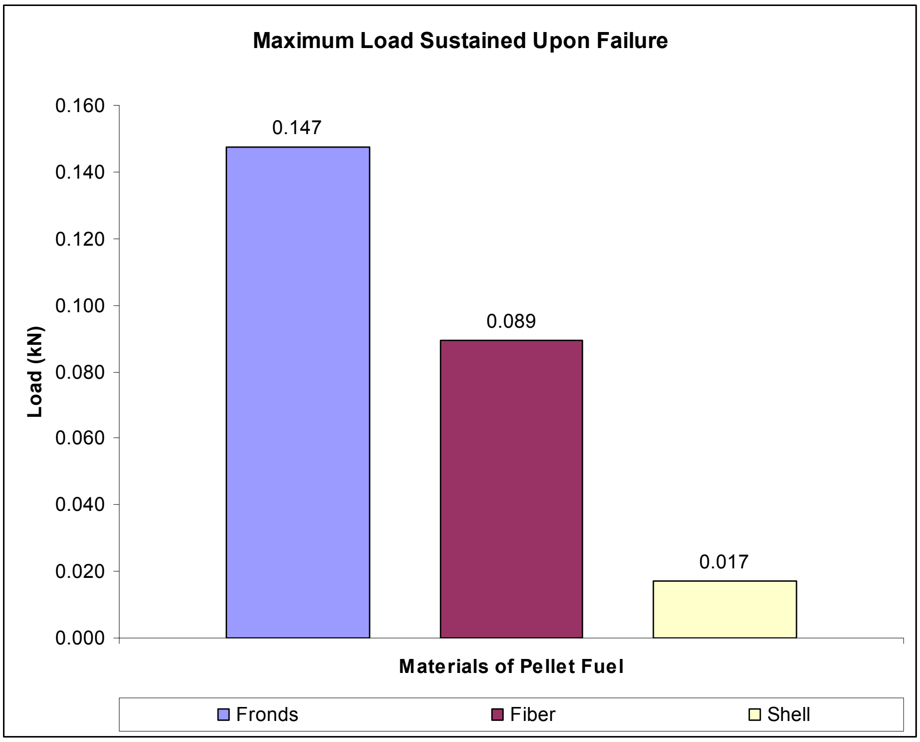


Figure 4.6: Results of Tensile Strength by Diametrical Compression (DCS) Test

4.3.3 Immerse Test

Immerse test was done by recording the time a pellet fuel required to fully disintegrate in water. The results were as shown in Figure 4.7.

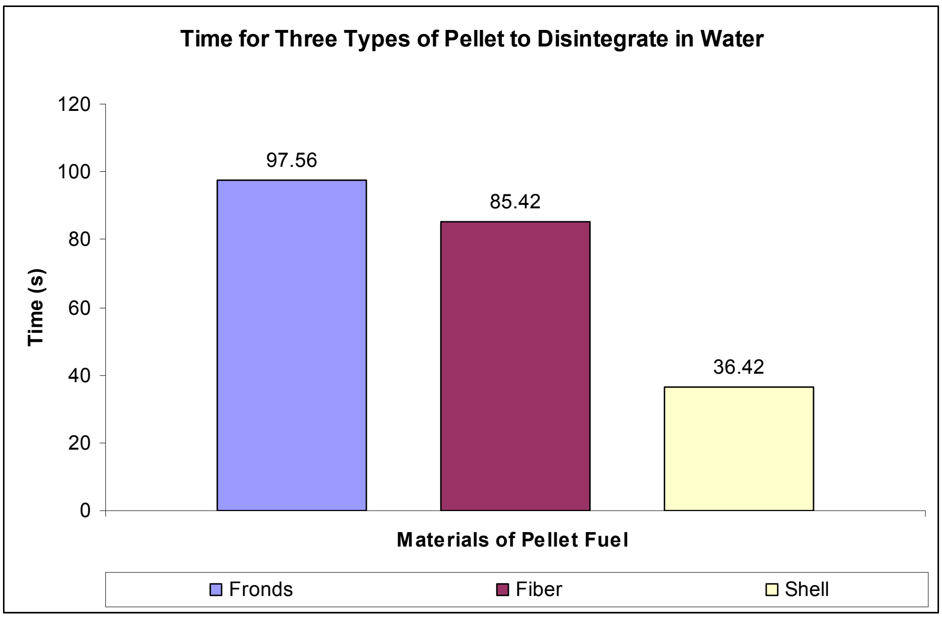


Figure 4.7: Immerse Test Results

4.3.4 Durability Test

Durability test was done by determining ratio of final weight of material remained in the plate after four drops to the initial weight of a pellet. The results of durability test were as shown in Figure 4.8.

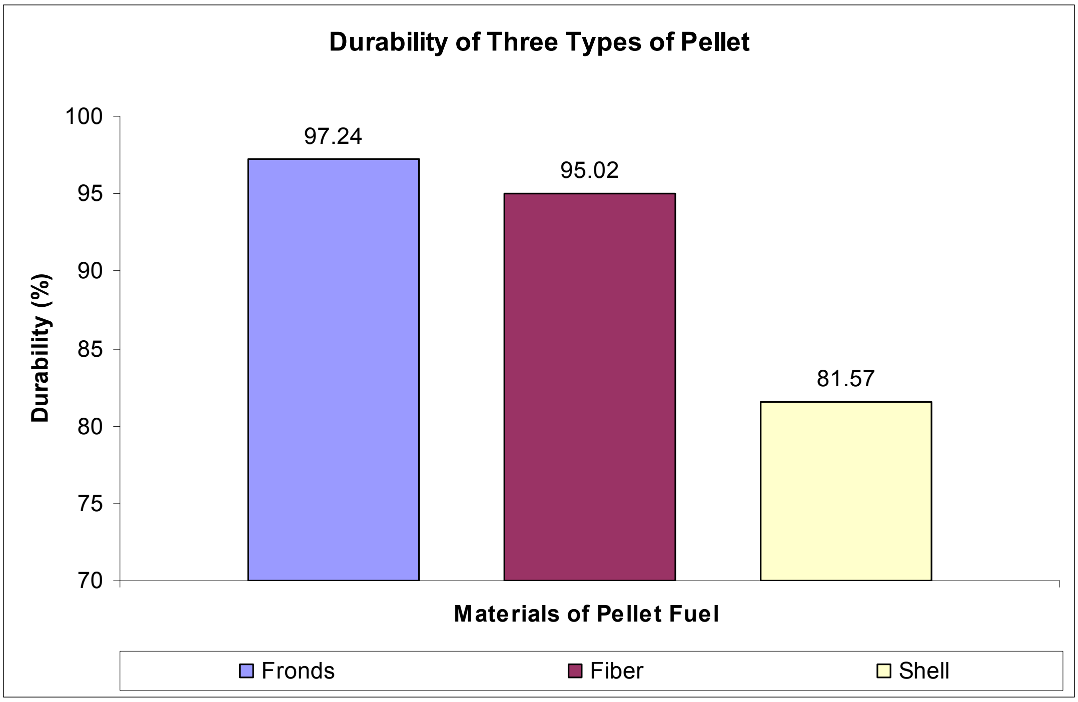


Figure 4.8: Durability Test Results

4.4 Discussions of Results

4.4.1 Chemical Properties Tests and Analyses

The thermo gravimetric analysis is an empirical technique using Thermo Gravimetric Analyzer (TGA) in which the mass of a substance or material is heated at a controlled rate in an appropriate environment. It is recorded as a function of time. Mass losses over specific temperature ranges in a specific atmosphere provide a compositional analysis of that substance. From the proximate analysis of five different materials, it was found that oil palm fronds had significantly low amount of ash content. Fronds had ash content as low as 0.78%; followed by shell, 2.61%; coal, 4.50%; fiber, 5.72% and saw dust which had highest percentage of 6.06%.

High ash content is likely to reduce the ignitibility of the pellet fuel, which is a contrast to fuel property that should be combustible and easily ignitable. Adding to that, fronds had 9.63% of moisture content below the coal which was 18.00%. Although its moisture content was higher than other 3 materials, it was still acceptable due to its low moisture content. Thus, pelleting oil palm fronds is a good initiative.

Ultimate analysis of materials was done by conducting CHNS analysis, where the chemical compositions of materials were represented by percentage of carbon, hydrogen, nitrogen, and sulfur. From the results, excluding the coal (61.810%), oil palm shell showed the most carbon content (46.530%), followed by saw dust (45.463%), oil palm fiber (43.783%), and finally oil palm frond (42.097%). The high carbon content of oil palm shell was most probably due to the oil content that remained in the shell even after pressing the oil palm fruit in the mill. The hydrogen content of all materials was almost the same, which had value around 5.000%. For all materials, the nitrogen content was low, with values less than 1.500%. The sulfur content was very low for all materials, with coal having the greatest amount (0.530%).

The low sulfur content in the waste would make this form of renewable energy more environment-friendly as compared to combustion of fossil fuels because of less sulfur dioxide emission which when reacts with water, oxygen and oxidants to form acidic compounds that cause acid rain. Furthermore, oil palm fronds had the lowest carbon content compared to other materials. It showed that the amount of carbon dioxide released will significantly lower when combustion of this material took place. It will make the production of pellet fuel from the oil palm fronds provided the renewable and clean energy sources.

One of the most important characteristics of a fuel is its calorific value, which is the total amount of heat that a material can give off when it burns completely. From the results, excluding the coal (5500.00 cal/g), oil palm shell had the highest value (4614.43 cal/g), followed by oil palm frond (4558.23 cal/g), oil palm fiber (4304.83 cal/g), and then finally saw dust with the lowest calorific value (4102.37 cal/g). The high calorific value of oil palm shell was most probably due to excess of oil content after oil palm fruit processing. From the test, it had been proved that oil palm frond also had high calorific value of 4558.23 cal/g and it was good alternative to produce pellet fuel.

4.4.2 Mechanical Properties Tests and Analyses

Compression tests were done on the pellet fuel to determine the maximum load a pellet could sustain before failure. The results showed that the palm waste pellet made of frond could sustain the highest compressive load which were 8.651 kN axially and 0.147 kN diametrically, followed by fiber, 6.835 kN axially and 0.089 kN diametrically, and finally shell, 1.223 kN axially and 0.017 kN diametrically. From the tests, it showed that frond was better than shell and fiber in terms of compressive strengths, both in axial and diametrical.

Immerse test was done to compare the water-resistance of the three different types of pellets. The time at which a pellet fully disintegrated in water was recorded. All pellets disintegrated in water and the loose particle sank to the bottom of the beaker. The result from immerse teat revealed that palm waste pellet had low water resistance. Thus, these pellets must not be subjected to water or humid air. The pellets produced had to be stored in proper packaging and they do have a limited lifetime under humid conditions.

Durability test was done to study the percentage of material still intact after subjected to several drops from a certain height. In this study, all pellets were dropped four times from a height of 1.85 m. The weight of material that remained intact in the plate was taken and durability could be calculated. From the test, it was found that frond pellet had the greatest durability, which was 97.24% compared to fiber and shell. The greater durability of a pellet, the more difficult it is for a pellet to be broken into pieces. During storage, it is possible that the pellets are subjected to drop and other mechanical impact. Thus, good durability is important to hold the pellet in shape.

4.5 Results of Palm Waste Pellet with Different Material Ratio

For this experimental activity, palm fiber and shell were used as additional materials to the oil palm fronds. The ratios of these two materials to fronds studied were 20:80, 30:70, and 40:60. The ratios were determined in terms of weight percent. Some important results of chemical and mechanical properties tests and analyses are as shown in Figure 4.9, Figure 4.10 and Figure 4.11.

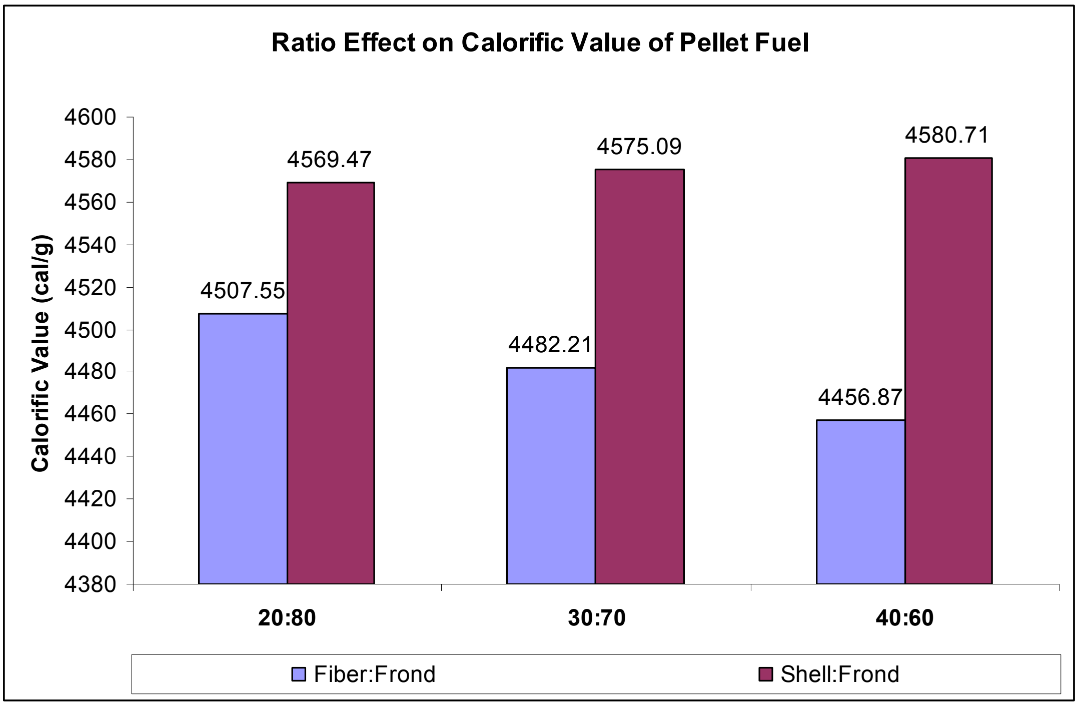


Figure 4.9: Calorific Values of Three Different Materials Ratios

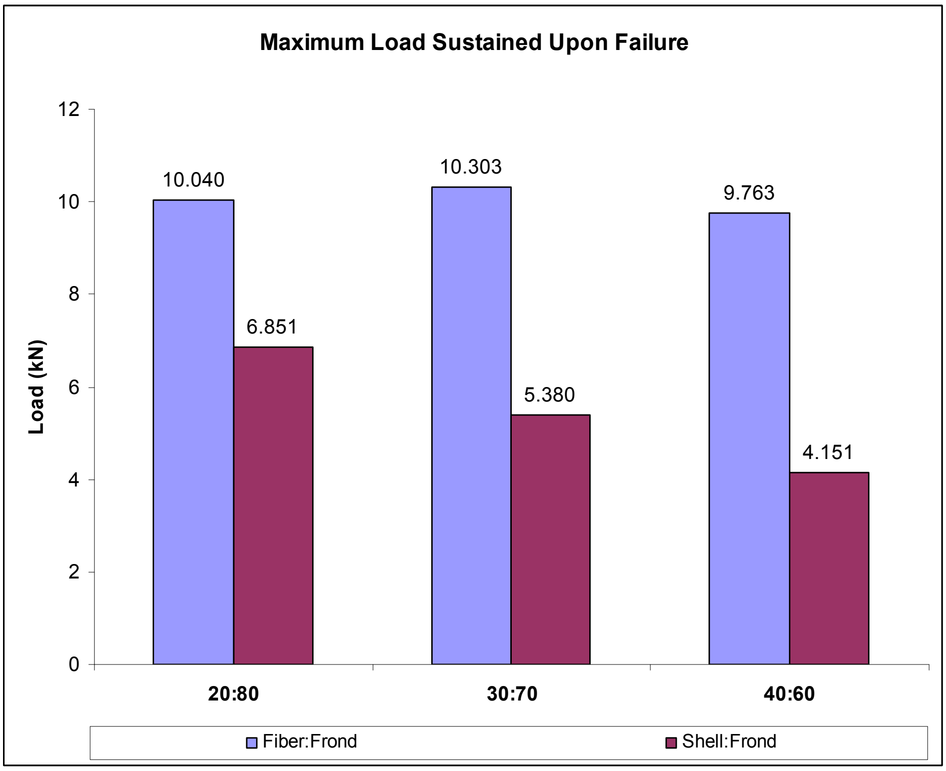


Figure 4.10: Results of Axial Compressive Strength (ACS) Test of Pellet Fuel with Different Materials Ratios

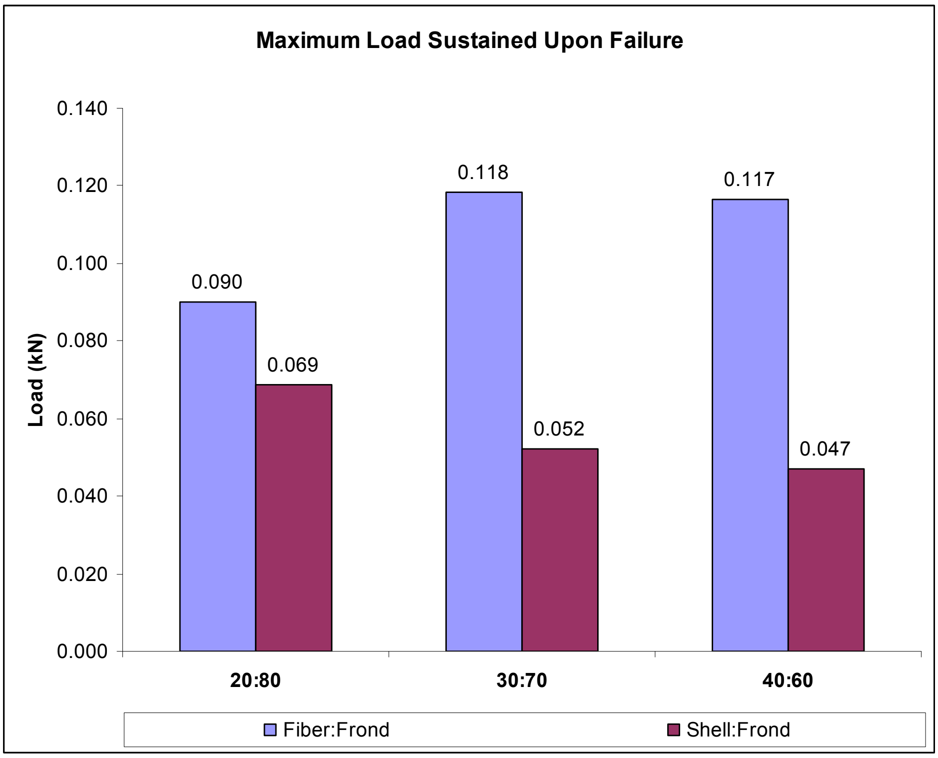


Figure 4.11: Results of Tensile Strength by Diametrical Compression (DCS) Test of Pellet Fuel with Different Materials Ratios

4.6 Discussions of Palm Waste Pellet with Different Material Ratio

From the calorific value determination, the palm waste pellet with 40:60 of shell to frond ratio gave the highest calorific value of 4580.71cal/g. Increment of the percentage of shell in pellet resulted the increment of calorific value of the pellet fuel. On the other hand, increment of the percentage of fiber in pellet resulting the decrement of calorific value of the pellet fuel. However, three different ratios in both of materials were just only slightly different in value.

Compression tests results showed that the palm waste pellet with 30:70 of fiber to frond ratio could sustain the highest compressive load which were 10.303 kN axially and 0.118 kN diametrically. Among the ratios of shell to frond, the pellet with 20:80 of shell to frond ratio could sustain the highest compressive load which were 6.851 kN axially and 0.069 kN diametrically. From the results, it showed that mixture of fiber and frond was better than the mixture of shell and frond in terms of compressive strengths, both in axial and diametrical.

The palm waste pellet with 40:60 of shell to frond ratio was the best ratio in terms of energy content, and the palm waste pellet with 30:70 of fiber to frond ratio was the best ratio in terms of mechanical strength. In determining the optimum ratio, the priority was given to energy content first, followed by mechanical properties. Thus, after analyzed all the results obtained, considering mixing all three materials in the pellet, the palm waste pellet with 20:20:60 of shell to fiber to frond ratio was given optimum chemical and mechanical properties. For a 1 g pellet, the overall composition of the optimum palm waste pellet was 0.2 g shell, 0.2 g fiber and 0.6 g frond.

4.7 Cost Analysis for Producing Pellet Fuel

It is important to note that there is no concrete pellet production costing for local market found currently. Thus, the cost analysis was done based on wood pellet facility costs reported by Mani et. al. (2006) [15] and Urbanowski (2005) [16]. All currency values reported in this section have been converted to Malaysian Ringgit. When converting from the Canadian currency, a rate of RM 3.27 was used.

4.7.1 Wood Pellet Facility Costs

The wood pelleting process is highly scalable. As a result, pelleting facilities can be found with production capacities ranging from one tonne per hour up to 20 tonne per hour. Economies of scale have been shown to work against mills with production rates of less than 3 or 4 tonne per hour (Mani et. al., 2006). Urbanowski (2005) notes that work by the US government has shown that capital costs for a one tonne per hour mill can be as high as RM 58.87 per tonne. This compares to the RM 42.51 per tonne he calculated for a 4 tonne per hour mill.

Mani et al. (2006) observed, in contrast to Urbanowski (2005), that a higher production capacity does not substantially increase the capital cost (on a per tonne basis). Rather, the economies of scale are mostly gained in the operating costs. Mani et al. (2006) discuss the effects of scale in terms of personnel costs. They indicate a pellet plant with a 10 tonne per hour capacity has personnel costs of RM 13.08 per tonne. Substantially lower than a 2 tonne per hour mill with personnel costs of RM 52.32 per tonne (Mani et al., 2006).

Table 4.1 relates a facilities production rate to its annual capacity and the volume of raw materials needed. Production capacity assumes an 85% utilization rate or about 7,500 hours per year. Two types of raw material were considered because moisture content impacts the rate at which raw material can be converted into pellets. The conversion rate generally falls somewhere between one and two tonne of raw material per tonne of pellets (8% moisture content). The drier the raw material, the closer the conversion will be to a 1:1 ratio. Urbanowski (2005) notes that sawmills commonly produce a raw material mixture of 70% shavings (19% moisture content) and 30% sawdust (53% moisture content). This mixture produces a relatively dry feedstock with an average moisture content of 29% and an estimated conversion rate of 1.35 green tonnes to every tonne of pellets. Alternatively, a feedstock with an average moisture content of 45% can be converted to pellets at the rate of about 1.85 green tonnes per tonne of pellets (NEOS corporation, 1995).

Table 4.1: Production Capacity and Feedstock Requirements

Production Rate	**Production Capacity[1] (tonne / year)**	**Residual Required (green tonne / year)**	
		Dry (29% m.c.)[2]	**Wet (45% m.c.)[3]**
4 tonne/hour	29,760	40,176	53,568
6 tonne/hour	44,640	60,264	80,352
8 tonne/hour	59,520	80,352	107,136
10 tonne/hour	74,400	100,440	133,920
20 tonne/hour	148,800	200,880	267,840

[1] Based on 7440 hours per year (85% utilization)
[2] Conversation rate of 1.35 tonne of green feedstock per tonne of dry pellets (Urbanowski, 2005)
[3] Conversation rate of 1.8 tonne of green feedstock per tonne of dry pellets (NEOS corporation, 1995)

A 4 tonne per hour facility produces approximately 30,000 tonne of pellets per year and requires 40,000 green tonnes of relatively dry raw material or more than 70,000 green tonnes of wet raw material. Remember that a 4 tonne per hour mill is considered to be on the low end of economically viable. In contrast, a world class mill producing 20 tonne per hour has an annual capacity of around 150,000 tonne per year and consumes between 200,000 tonnes (dry feedstock) and 360,000 tonnes (wet feedstock) of raw materials.

According to the Wood Pellet Association of Canada, in 2005 there were approximately 319 pelleting facilities located in Europe (240 mills), the United States (62 mills) and Canada (17 mills). The average capacity of mills in Europe and the US was 7,500 tonne per year and 11,300 tonne per year, respectively. This indicates that the average facility in these countries has less than a 4 tonne per hour capacity. In contrast, the average Canadian facility had a production capacity of 55,300 tonne per year or closer to an 8 tonne per hour capability. This difference in size can be attributed to availability of raw material. Mills in Europe and the US are often built near secondary wood processing facilities (i.e., furniture plants) or small sawmills with the dual intent of serving a local market while minimizing waste. In

Canada, pelleting facilities have been designed to serve the export market and are located near world class sawmills that generate much larger volumes of sawdust, planer shavings and other whitewood residue.

The rule of thumb for building a pelleting facility states that every 10,000 tonnes of production capacity costs about RM 3,270,306.24 (Vanderklippe, 2007). This cost is comprised of far more than just the pelleting equipment. In fact, some of the most significant costs reported by Urbanowski (2005) were the buildings, peripheral equipment and the storage, conveyor and separator systems (Table 4.2). Most of the equipment associated with the actually pelleting process, besides the dryer, represents only a small portion of the investment.

It should be noted that several types of dryer technology are available. The 10 tonne per hour example (Table 4.2) reflects a costly cogeneration system that is used to lower overall energy costs. The other dryer costs represent the more common rotary drum dryer systems.

The capital costs reported by Urbanowski (2005) translate into less than RM 42.51 per tonne. In contrast, Mani et al. (2006) calculate a capital cost of RM 22.89 per tonne. It is likely that capital costs fall somewhere in between these estimates. Urbanowski's calculations compare favourably to the rule of thumb calculation but are slightly dated and based on a European source. Mani et al. (2006) numbers are more recent and sourced from North America, but they provide significantly lower estimates for the cost of buildings and storage, conveyor and separator systems. Adjustments to these costs might bring the total capital cost more in line with the rule of thumb estimate of RM 14.72 million for a facility with 45,000 tonne per year capacity (6 tonne per hour).

Table 4.2: Capital Cost Estimates

Item	Capital Cost (RM)		
	3 tonne/hour mill (Urbanowski, 2005)	**6 tonne/hour mill (Mani et al., 2006)**	**10 tonne/hour mill (Urbanowski, 2005)**
Dryer	2,289,000.00	2,961,246.60	1,1608,500.00
Hammer Mill	392,400.00	321,375.60	1,733,100.00
Pellet Machine	915,600.00	1,817,302.50	2,910,300.00
Cooler	62,130.00	214,250.40	1,177,200.00
Storage, Conveyors, Separators	1,406,100.00	654,228.90	4,218,300.00
Peripheral Equipment	2,419,800.00	1,981,816.20	2,092,800.00
Buildings	2,648,700.00	428,500.80	4,970,400.00
Total	**10,133,730.00**	**8,378,721.00**	**28,710,600.00**

Capital costs include: land cost, purchase, installation & maintenance, office construction, cost of dump trucks, forklifts and front-end loaders.

In any regard, capital costs represent only a portion of the total production costs. Estimates of production cost range from about RM 193.39 to RM 248.52 per tonne (Table 4.3) for a North American mill.

Table 4.3: North American Pellet Production Cost Estimates

Costs	4 t/hr[1] (Urbanowski)	6 t/hr[2] (Mani et al.)	8 t/hr[3] (Urbanowski)	10 t/hr[4] (Mani et al.)
	(RM / tonne)			
Feedstock Costs	68.67	75.47	94.83	104.64
Operating & Capital Costs	179.85	117.92	143.88	134.07
Total Production Costs	**248.52**	**193.39**	**238.71**	**238.71**

[1] Raw material supply zone of 65 km
[2] Raw material price based on RM 32.70/tonne at the sawmill plus of 7.5 km
[3] Raw material supply zone of up to 200 km
[4] Raw material prices reported by Sokhansanj & Turhollow, 2004 includes collection, baling, transportation and storage

These estimates illustrate the balance that must be struck between capturing economies of scale and aggregating larger volumes of feedstock. The four tonne per hour mill has the lowest raw material costs (RM 68.67/tonne) with the highest operating / capital costs (RM 179.85/tonne). Yet, the total production cost for a four tonne per hour mill (RM 248.52/tonne) is comparable to that of a 10 tonne per hour mill (RM 238.71/tonne). While the 10 tonne per hour mill is able to lower its operating / capital costs (RM 134.07/tonne), it spends more on gathering its raw material. This leads to a higher raw material cost (RM 104.64/tonne) that balances out the gains made in operating / capital costs. Collectively, this indicates that mill size is best determined by the local availability of raw material.

These estimated production costs are not the only costs incurred by pelleting facilities. Pellet producers must also distribute their product to the market. Distribution costs can nearly double the value of the pellets. Urbanowski (2005: 62) indicates a cost of RM 215.84 per tonne to get finished inventory from Northern British Columbia to the European market.

Table 4.4 provides a more detailed look at the production cost estimates developed by Mani et al. (2006). Production costs are largely determined by three items: raw materials, personnel and the drying operation. Raw materials represent about 40% of the production cost and include a payment of RM 32.70 per tonne for the raw material plus the cost of transporting the raw material an average of 7.5 km. Personnel costs represent 25% of production costs and include two production staff and three baggers per shift, as well as marketing and administrative staff. Operating the dryer represents 20% of the production cost and assumes a fuel source of wood shavings (10% moisture content) delivered for RM 130.81 per tonne.

Table 4.4: Production Cost Estimates, by Operation

6 tonne/hr – 45,000 tonne/yr	**Operating Cost**	**Capital Cost**	**Total Cost**
	(RM / tonne)		
Raw material	74.20	1.31	75.50
Drying Operation (45% MC)	29.99	9.42	39.40
Hammer Mill	2.68	0.95	3.63
Pellet Mill (6 tonne/hr)	7.19	5.46	12.65
Pellet cooler	0.82	0.49	1.31
Screening	0.20	0.43	0.62
Packing	5.23	2.16	7.39
Pellet Storage	0.03	0.26	0.29
Miscellaneous Equipment	1.28	1.60	2.88
Personnel Cost (7500 hour/yr)	48.76	0.00	48.76
Land use & Building	0.20	0.82	1.01
Total	**170.56**	**22.89**	**193.45**
Total less Raw Material	96.37	21.58	117.95

Source: Mani et al., 2006

These cost estimates provide a baseline for understanding the financial feasibility of a wood pelleting operation. This is not the same as a profitability analysis which would take into account changes in outside conditions like interest rates, exchange rates, feedstock and pellet prices, etc. These cost estimates simply provide insight to which operations are critical to a pelleting facilities success. These include raw material availability and cost, dryer costs and assessment of technology or fuel options and the cost of getting pellet to the market.

4.7.2 Operating and Capital Costs for Palm Waste Pellet Fuel Production

The operating and capital cost benchmarks cited by Mani et al. (2006) and Urbanowski (2005) should provide an appropriate benchmark for palm waste pellet fuel production. Total production costs (including feedstock, capital and operating costs) ranged from about RM 193.39 per tonne to RM 248.52 per tonne. With pellets generally retailing for RM 654.06 or more per tonne (or RM 0.65 per kg), pellet production appears to be highly viable.

As both authors indicated, raw material, personnel and drying represent the greatest portion of these production costs. As such, for a palm waste pellet fuel production to be viable it would need to be competitive in these areas. Raw material cost estimates (operating and capital) ranged from RM 68.67 per tonne to RM 104.64 per tonne (Mani et al., 2006; Urbanowski, 2005). The cost includes a minimal charge for the raw material (i.e., RM 32.70 per tonne) and the rest represents transportation. In palm waste pellet fuel production, limited competition for raw materials would minimize the nominal charge for the material (as vast availability of waste); however, transportation costs would continue to be a challenge. As such, it would be unlikely that producers could achieve a much lower raw material cost. Therefore, production facilities should be built as near as to waste sources.

For a facility with 6 tonne per hour, it produces approximately 45,000 tonne of pellets per year and requires more than 60,000 green tonnes of relatively dry raw material or more than 80,000 green tonnes of wet raw material. From Malaysia palm oil industry, 14.47 tonnes dry weight at felling, and 10.40 tonnes dry weight by annual pruning of oil palm fronds had been generated from one hectare. It concludes that a facility just requires the oil palm frond waste from 2,412.5 hectares out of total oil palm planted area of 4.17 million hectares.

The cost of drying was estimated by Mani et al. (2006) to be about RM 75.47 per tonne of pellets. This assumed the use of a dry palm waste fuel that cost RM 130.81 per tonne (delivered). Since the availability of palm waste is boundless in Malaysia, this type of fuel was very suitable to be used as the fuel source instead of natural gas. Adding to that, if palm waste pellet fuel was used as the fuel source, producers may be able to reduce more their drying costs.

Personnel costs were estimated at around RM 48.76 per tonne or about 25% of production costs (Mani et al., 2006). This estimate included two production staff and three baggers for a total of five employees per shift. The estimate also included marketing and administrative staff. If an existing palm oil sector producer in Malaysia were to enter the pellet industry, they may be able to shave some of the overhead personnel costs through synergies with existing activities. Additional savings might be achieved by selling product in the bulk form and removing the need for bagging. However, the market has evolved in such a way that consumers expect and pay more for a bagged product. As such, this may not be the best area in which to reduce production costs.

This basic review of production costs indicates that a palm waste pellet fuel producer in Malaysia would most likely achieve costs similar to the benchmark value provided by Mani at al. (2006) and Urbanowski (2005). The best opportunity would be for existing operators in palm oil industry with access to on-site raw material for both pellets and dryer fuel. This sort of feedstock scenario would significantly reduce transportation costs, the major determinant of both raw material and dryer fuel costs. This sort of operation may also be able to transfer existing personnel and residual management costs into the new pelleting facility.

4.7.3 Economic Evaluation

One of the important things in cost analysis is the production profitability. It means, weather the project feasible or not in terms of economical view. It could be determined by evaluating payback time, one of the criteria for profitability. For this evaluation, consider the production cost estimates developed by Mani at al. (2006) for a facility with 45,000 tonne per year capacity or 6 tonne per hour. With the assumptions of no production for Year 1 (construction phase), constant retail price of RM 654.06 per tonne, constant production capacity, and constant tax of 10% through out the project life cycle of 10 years; Table 4.5 showed data of cash flow for this particular production. From these data, cash flow diagram is obtained as shown in Figure 4.12.

Table 4.5: Cash Flow Data for Facility with 6 t/hr Production Capacity

Year	1	2	3	4	5	6	7	8	9	10
Production (mill tonne)	0	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Revenue (RM mill/yr)	0	29.43	29.43	29.43	29.43	29.43	29.43	29.43	29.43	29.43
Tax (10%)	0	-2.94	-2.94	-2.94	-2.94	-2.94	-2.94	-2.94	-2.94	-2.94
Net Revenue (RM mill/yr)	0	26.49	26.49	26.49	26.49	26.49	26.49	26.49	26.49	26.49
Capital Cost (RM mill/yr)	-14.72	0	0	0	0	0	0	0	0	0
Operating Cost (RM mill/yr)	0	-7.67	-7.67	-7.67	-7.67	-7.67	-7.67	-7.67	-7.67	-7.67
Net Cash In (RM mill/yr)	-14.72	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81	18.81
Cum. Cash In (RM mill/yr)	-14.72	4.09	22.91	41.72	60.54	79.35	98.17	116.98	135.79	154.61

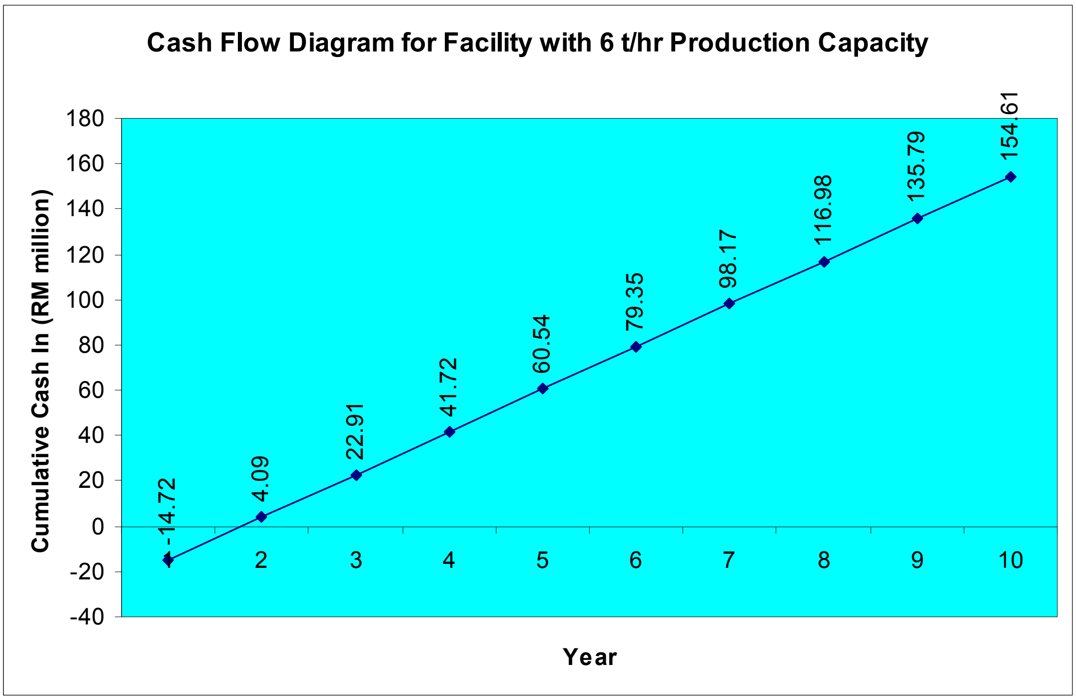


Figure 4.12: Cash Flow Diagram for Facility with 6 t/hr Production Capacity

From the cash flow diagram, the payback time is estimated between 2-3 years. Thus, the production is considered profitable with annual net profit of RM 18.81 million and cumulative cash in of RM 154.61 million for 10 years of project life cycle.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Out of various wastes from the palm oil industry that are available in abundance in Malaysia, oil palm frond (OPF) was selected to be produced as pellet fuel and to study its chemical and mechanical properties at the first place and had been compared with oil palm shell and fiber as well as saw dust and coal. The results proved that oil palm frond was very potential in utilizing alternative renewable energy from the waste due to its high energy content with calorific value of 4558.23 cal/g.

From the experimental activities, the results showed that single material of frond in a pellet was not the best pellet with good properties to be produced, and thus, combinations of material were required. Studies found that the ratio of materials that gave optimum chemical and mechanical properties was 20:20:60 of shell to fiber to frond in weight percent.

From the results of ultimate analysis, it also emitted less carbon and sulfur content when combustion took place. This would make this form of clean energy more environment-friendly as compared to combustion of fossil fuels. Furthermore, palm waste is a renewable energy source that will not depleted.

From the cost analysis and economic evaluation for the 45,000 tonne per year production of palm waste pellet fuel, the payback time is estimated between 2-3 years. Thus, the production is considered profitable with annual net profit of RM 18.81 million and cumulative cash in of RM 154.61 million for 10 years of project life cycle.

5.2 Recommendations

The following further studies on the palm waste pellet can be carried out:

1. The effects of pellet dimension. The current pellet dimension was limited by the availability of the mold. In future, maybe different molds can be made to study this effect. Adding to that, the palm waste solid fuel in form of briquettes also should be studied.
2. For more accurate results, combustion test should be carried out instead of fully depending on the results from calorific value determination alone. Combustion test will give more accurate results since the test is carried out in real condition compared to bomb calorimeter which is in high and constant pressure condition.
3. It is recommended that the pellet fuel would be commercialized and produced in big scale. The pellet fuel may be first introduced as boiler fuel in palm oil mills due to the fact that oil palm waste available as the by product of processing palm oil.
4. It is also recommended that the pellet fuel be used in power plants that are currently using coal as their main fuel source. Since the plants already have mechanisms for crushing coal, only slight modification to the current system will be required to apply the pellet fuel.
5. An automated pelleting producing system including uses of extruder machine may be attached to the existing facilities to successfully produce the palm waste pellet in industry. This will help the plants to save cost on purchasing coal, promotes efficiency and reduces pollution to environment.
6. The cost analysis was not necessary accurate since it was based on wood pellet industry cost in Canada. It was obvious that heating (or drying) process consumed the most energy requirement, thus, the moisture elimination process is recommended to be done by using solar energy, where the raw materials are dried under the sun instead of using an oven (or dryer).

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APPENDICES

APPENDIX A: RESULTS OF PROXIMATE ANALYSIS AND DERIVATIVE THERMO GRAVIMETRY

APPENDIX A

RESULTS OF PROXIMATE ANALYSIS AND DERIVATIVE THERMO GRAVIMETRY

Details of results for Proximate Analysis and Derivative Thermo Gravimetry (Graphical Burning Profile) of oil palm frond (OPF); done by using Thermo Gravimetric Analyzer (TGA) are as shown in the following figures:

Figure A-1: Weight Percent vs. Time Graph of Proximate Analysis

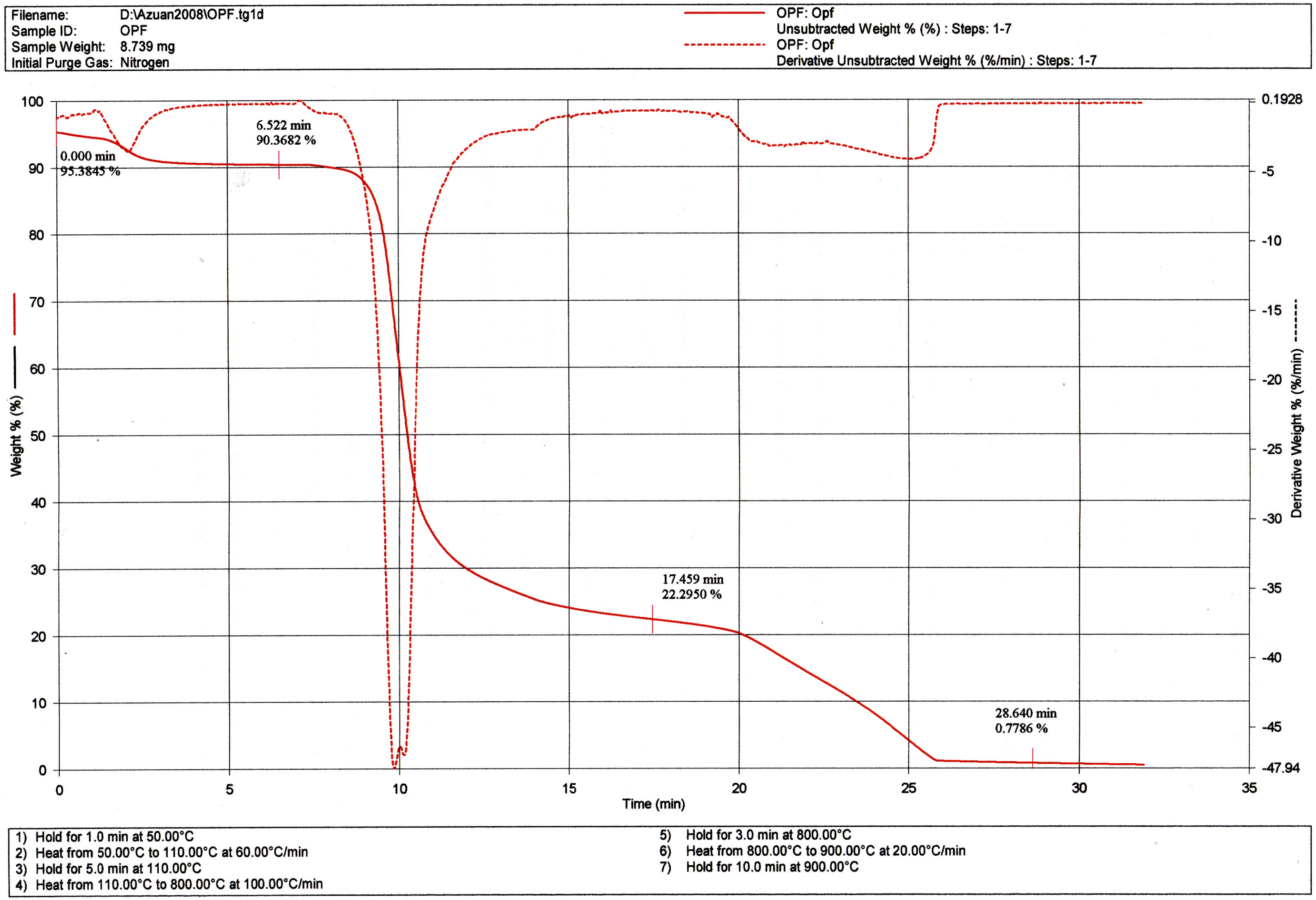

Figure A-2: Weight Percent vs. Temperature Graph of Proximate Analysis