Development of Fuel Briquette from Palm Oil Mill Waste Mixed with Other Biomass Fuels

By

Muhamad Faisal bin Ali

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
Mechanical Engineering Programme
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(MECHANICAL ENGINEERING)

Approved by,

____
(Dr. Suhaimi bin Hassan)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

MAY 2012

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.

MUHAMAD FAISAL BIN ALI

ABSTRACT

Palm oil is extracted from the fresh fruit bunch (FFB) by using mechanical process, where a mill commonly handles 60 to 100 mt per hour of FFB. The modern palm oil mill is based on concepts developed in the early 50's. An average size of FFB weights is about 20-30 kg and contains about 1000-2000 fruits. They are harvested based on harvesting cycles, and delivered to the mills on the same day. The proper handling of FFB will determine the quality of crude palm oil.

The products generates from palm oil mill are crude palm oil and kernels, as primary product and biomass as secondary product. A typical mill has many operation units. This comprises of sterilization, stripping, digestion and pressing, clarification, purification, drying and storage. Palm oil industry generates vast amount of palm biomass. Converting palm biomass into a solid fuel through briquetting process should be attractive in upgrading its properties and add value. The major by products produced by the production of crude palm oil (CPO) are palm oil mill effluent (POME), empty fruit branch (EFB), palm kernel shell and mesocarp fibre. Mostly, this biomass, especially EFB, palm kernel shell and mesocarp fibres are utilized as fuel in the mill [1].

Realizing the potential of EFB to generate fuel, briquettes will produced by mixing the EFB with rice husk and coconut shell. Their physical and chemical properties, mechanical strength and burning characteristics will be analysed. In this research, the author will study the characteristics of these biomasses and their potential to yield biomass energy [1].

ACKNOLEDGEMENT

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

ABBREVIATIONS

CHNS	Carbon, Hydrogen, Nitrogen and Sulphur
XRF	X-Ray Fluorescence
CPO	Crude Palm Oil
CV	Calorific Value
EFB	Empty Fruit Bunch
FFB	Fresh Fruit Bunch
POME	Palm Oil Mill Effluent
FASC	First American Scientific Corporation
GHG	Green House Gas
RE	Renewable Energy
CIRP	Christmas Island Rock Phosphate
MOP	Muriate of Potash
E	Empty Fruit Bunch (EFB)
R	Rice Husk
C	Coconut Shell

CHAPTER 1

INTRODUCTION

1.1 Project Background

Malaysian palm oil industry has grown up tremendously over the last four decades. Since then, Malaysia has succeeded to maintain its position as among the world's premier palm oil production country. However, this industry also generated vast quantities of palm biomass, mainly from milling and crushing palm kernel. In order to reduce the quantity of industry waste as well as maximize the usage of biomass, producing biomass briquettes is one of the appropriate solutions.

Biomass briquetting is the densification of loose biomass material to produce compact solid composites of different sizes with the application of pressure. Briquetting is conducted with the application of pressure, heat and binding agent on the loose materials to yield the briquettes. In order to discover the benefits of briquettes, the several facts below can be referred:

i) This is one of the alternative methods to save the consumption and dependency on fuel wood.

ii) They are easy to handle, transport and store.

iii) They are uniform in size and quality.

iv) This process helps to solve residual disposal problem.

v) Fuel wood and deforestation can be reduced.

vi) Indoor air pollution id decreased.

1.2 Problem Statement

While extracting crude palm oil (CPO) from the fresh fruit bunch (FFB), it will generates large amount of wastes, for example empty fruit bunch (EFB) (23%), mesocarp fibre (12%), shell (5%) and palm oil mill effluent (POME) (60%) for every tonne of FFB processed in the mills [2]. For every tonne of palm oil produced from fresh fruit bunches, a farmer harvests around 6 tonnes of waste palm fronds, 1 tonne of palm trunks, 5 tonnes of empty fruit bunches (EFB), 1 tonne of press fiber (from the mesocarp of the fruit), half a tonne of palm kernel endocarp, 250 kg of palm kernel press cake, and 100 tonnes of palm oil mill effluent (POME) [3].

EFB contains high amount of nutrients. In the past, the EFB are burnt to produce ash, which used as fertilizer. But, the burning of EFB leads to the environmental issues such as air pollution. It is reported that one of the major sources of Green House Gas (GHG) in Malaysia has been contributed from the palm oil mill wastewater treatment system [4].

EFB is one of the palm oil wastes than can be used for producing biomass briquette. However, it has high moisture content and this will reduce the burning efficiency. EFB has the moisture of 57.2% and this will decrease the calorific value. The physical properties of EFB and the other samples can be referred in the Table 1.

Table 1: Biomass samples used and their physical properties [5]

		Calorific value HHV MJ/kg		Elementary and ash analysis (wt%) using dried sample					
Biomass	Moisture (%)	Wet	Dry	C	H	N	S	O	Ash
EFB	57.2	10.57	17.02	45.53	5.46	0.45	0.044	43.40	5.12
Mesocarp Fibre	37.2	13.33	19.61	46.92	5.89	1.12	0.089	42.66	3.32
Kernel shell	21.4	16.14	19.78	46.68	6.86	1.01	0.060	42.01	4.38

1.3 Objective & Scope of Study

The scope of this study will be focusing on the study of the EFB, rice husk and coconut shell characteristics and their potential of producing biomass energy by mixing the biomasses with different rate of ratio.

The objectives of this project are:

i) To study the characteristics of EFB, rice husk and coconut shell.

ii) To develop biomass briquette from the combination of EFB with rice husk or coconut shell or both biomasses.

iii) To study the performance of biomass briquette by conducting several tests and experiments.

1.4 Feasibility of the Project

The research is a zero cost research whereby the samples are collected from a palm oil mill, rice factory and coconut processing centre which are near to the university. However, several equipment required to be purchased to carry out the experimental works as they are unavailable in the university. The research will be carried out according to the planning and allocated time frame by the following Gantt chart in page 22 and 23.

CHAPTER 2

LITERATURE REVIEW

2.1 Production of Fresh Fruit Bunches (FFB)

The key sub-processes involved in the development of plantations for the production of fresh fruit bunches (FFB) are shown in Figure 1 and the main activities for each step are summarized below:

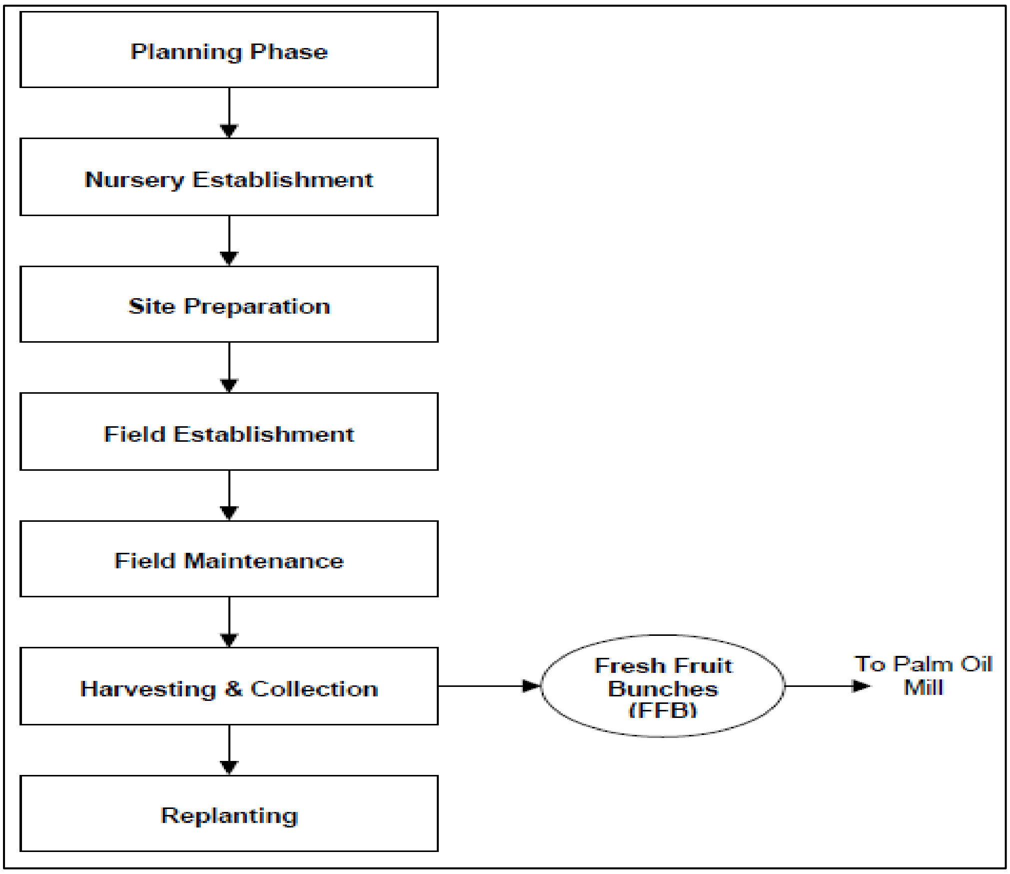


Figure 1: Processes in the production of Fresh Fruit Bunches [6]

2.2 Production of Crude Palm Oil

After harvesting, it is important that the FFB are processed quickly. It is done to prevent a rapid rise in free fatty acids (FFA) which could adversely affect the quality of the CPO. Palm oil mills are generally located in the plantations to facilitate timely transportation and effective processing of FFB. The palm oil milling process involves the physical extraction of palm products namely, crude palm oil and palm kernel from the FFB. The process begins with sterilization of the FFB. The fruit bunches are steamed in pressurized vessels up to 3 bars to arrest the formation of free fatty acids and prepare the fruits for subsequent sub-processes.

The sterilized bunches are then stripped of the fruitlets in a rotating drum thresher. The stripped bunches or EFB are transported to the plantation for mulching while the fruitlets are conveyed to the press digesters. In the digesters, the fruits are heated using live steam and continuously stirred to loosen the oil-bearing mesocarp from the nuts as well as to break open the oil cells present in the mesocarp. The digested mash is then pressed, extracting the oil by means of screw presses. The press cake is then conveyed to the kernel plant where the kernels are recovered.

The oil from the press is diluted and pumped to vertical clarifier tanks. The clarified oil is then fed to purifiers to remove dirt and moisture before being dried further in the vacuum drier. The clean and dry oil is ready for storage and dispatch. The sludge from the clarifier sediment is fed into bowl centrifuges for further oil recovery. The recovered oil is recycled to the clarifiers while the water/sludge mixture which is referred to as POME is treated in the effluent treatment plant (ETP). The press cake is conveyed to the depericarper where the fibre and nuts are separated. Fibre is burned as fuel in the boiler to generate steam. The nuts are cracked and the shell and kernel are separated by means of a winnower and hydro-cyclone. The clean kernels are dried prior to storage [6]. The Figure 4 shows the crude palm oil milling process in the flow chart manner. This figure explains the clear information of this process.

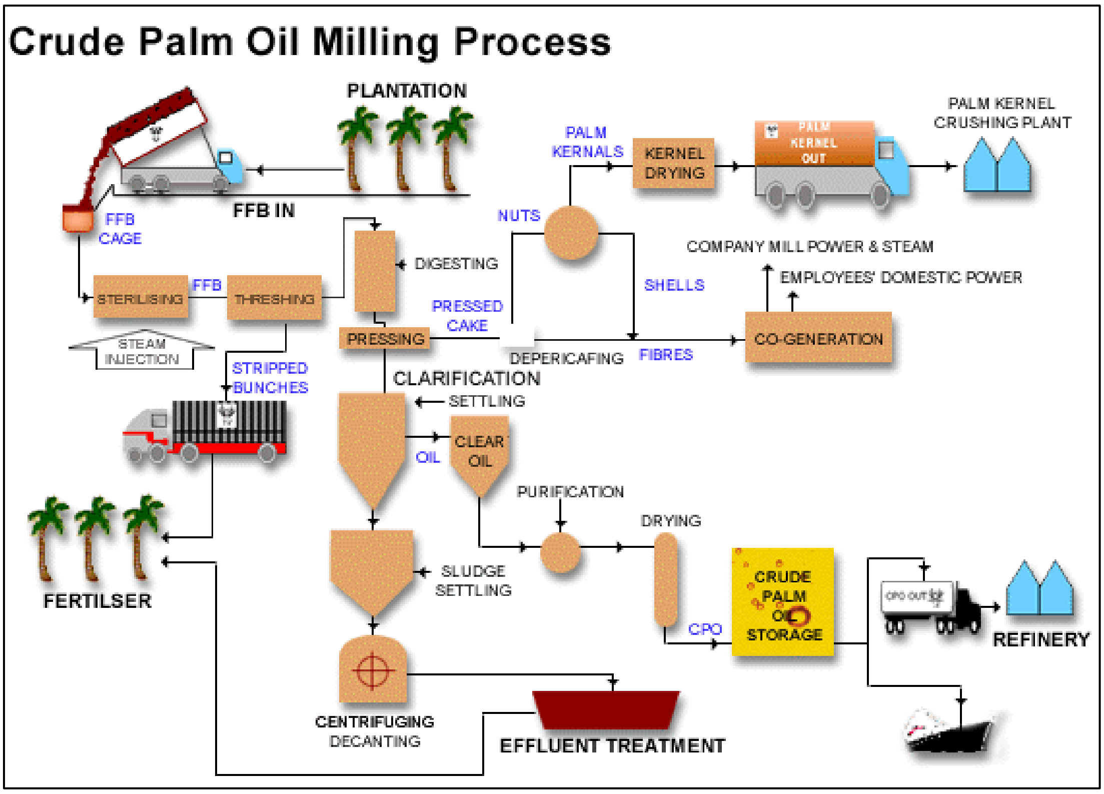


Figure 2: Crude palm oil milling process [12]

2.3 EFB as Fuel for Renewable Energy Power Generation

EFB is becoming a popular source of fuel for renewable energy (RE) power generation. The rapid depletion of fossil fuel and most developed nations are pursuing the development of biomass as an alternative method of power generation. Malaysia has a ready source of biomass in EFB conveniently collected and available for exploitation in all palm oil mills. When convert the energy in the most efficient manner, Malaysia is well on the way to this most important sustainable source of energy for this century. The main achievement of using biomass-based RE power generation is the reduction in greenhouse gas emissions (GHG).

In Sabah, large quantities of palm waste called EFB are available from plantations where palm oil is produced. In its raw state, EFB is both very fibrous and wet. If it could be dried, it would be an excellent fuel for power boilers. FASC Malaysia has installed a KDS machine in the 14 MWe TSH Biomass Power Plant in Kunak, Malaysia, for the purpose of drying EFB. Called the KDS MF-777, it dries and shreds EFB so that it can be burned as a fuel. At present, only one-sixth of the fuel input needed by the TSH power plant is supplied by the KDS MF-777. The KDS

MF-777 processes 3750 kg/hr of raw EFB having a moisture content of 52 % and produces 3000 kg/hr of shredded EFB which has a moisture content of 40 % - this is dry enough for burning on a grate. The power consumption of the MF-777 is only 200 kW, under these operating conditions. This translates to a drying energy consumption of only 960 kJ per kg of water removal (= 414 BTU/lb) or only 44 % of the latent heat of water! No other dryer technology can match the low energy consumption of the KDS MF-777. It is well-known among power plant engineers that every percentage point of moisture in the fuel causes 0.5-1 % reduction in the electricity produced. Thus, the estimated maximum possible increase in the TSH power plant output because of drying the fuel in the KDS MF-777 is 0.84-1.68 MWe. Thus, a net overall increase in the total power generated becomes possible due to the KDS MF-777. Therefore, the cost of the KDS equipment can be recouped from the extra revenue from the increased electricity production [11].

The Table 2 shows the nutrient content of EFB. Nitrogen, phosphorus, potassium, magnesium and calcium are the example of the nutrient contained with small percentage of composition.

Table 2: Nutrient content of EFB [9]

	Nutrient Content of EFB	Composition as a percentage of dry matter (%)
1	Nitrogen (N)	0.44
2	Phosphorous (P)	0.144
3	Potassium (K)	2.24
4	Magnesium (Mg)	0.36
5	Calcium (Ca)	0.36

2.4 Conversion of EFB into Fertilizer

In terms of fertilizer value, one tonne of EFB is equivalent 8 kg urea, 2.9 kg CIRP, 18.3 kg MOP and 4.7 kg kieserite. Besides being rich in plant nutrients, it also improves soil physical and chemical properties in the following manner when used as mulch [10].

i) Increases soil organic matter content.

ii) Improves soil structure.

iii) Increase infiltration and aeration.

iv) Reduces run-off.

v) Improves soil water retention.

vi) Increases soil fauna micro activity.

vii) Increases cation exchange capacity.

viii) Reduces soil temperature fluctuation.

2.5 Rice Husk as the Alternative Source of Energy

Rice husk, which accounts for 20% by weight of rice, comes from rice milling process as by-product. Generally, a large amount of rice husk is dumped as waste which results in waste disposal problem and methane emissions. Moreover, the low density of rice husk can cause it to be air-borne easily resulting in breathing problems, if inhaled. Rice husk can be converted to a useful form of energy to meet the thermal and mechanical energy requirement for the mills themselves. This helps minimize the waste problem in addition to converting rice husk to a renewable energy resource. Due to the environmental and economic scenarios, the Thai government has supported renewable energy production from indigenous sources. One project that has been conducted under this support is a 10 MW pilot plant in Roi-Et province, using rice husk as feedstock for water tube boiler type. Approximately 255 tons of rice husks are supplied daily from the nearby rice mill (located 2 km from the power plant) as the main source and others from 7 to 125 km. The water supply (138 tons) is from the Shi river water and 24 MWh of electricity are required for power production in one day. The maximum power production capacity is 10.2 MW and the minimum is 6.5 MW, depending on raw materials availability [8].

Table 3: Element composition of rice husk sample [12]

Parameter	Result	Standard Deviation	Basis
C	42.2%	0.99	Dry
H	5%	0.06	Dry
O	36%	2.16	Dry
N	0.7%	0.15	Dry
S	-	-	Dry
Total Moisture	11%	1.11	As received
Heating Value	13.78 MJ/kg	0.07	Dry

This alternative can reduce the dependence of the fossil fuels such as petroleum and coal. Their remaining sources are reducing and in the future, they will totally extinct from this world. The using of alternative energy therefore should be taken into serious consideration. The example coal grades with their heating value are shown in Table 4. From this table, it is known that the heating values of coal are relatively high. However their sources are going into depletion, thus the alternative energy discovery is seriously important nowadays.

Table 4: Heating value of selected coal. [13]

Coal Grade	Heating Value	
	(Btu/lb)	(kJ/kg)
Anthracite	12910	30080
Semi-Anthracite	13770	32084
Low-volatile bituminous	14340	33412
Medium-volatile bituminous	13840	32247
High-volatile bituminous A	13090	30499
High-volatile bituminous B	12130	28262
High-volatile bituminous C	10750	25047
Subbituminous B	9150	21319
Subbituminous C	8940	20830
Lignite	6900	16077

2.6 Coconut Shell as the Alternative Source of Energy

It is regretted that 90% of coconut (empty fruit bunches, fibers, fronds, trunks, shell) was discarded as waste and either burned in the open air or left to settle in waste ponds. This way the coconut processing industries waste according to him contributed significantly to CO_2 and methane emissions. Based on economic as well as environmental related issues, efforts should be directed worldwide towards coconut management issues i.e. of utilization, storage and disposal. Moreover, coconut is becoming an important agricultural product for tropical countries around the world as a new source of energy-biofuel. Previously, coconut shell was burnt as a means of solid waste disposal which contributed significantly to CO_2 and methane emissions. However as the cost of fuel oil, natural gas and electricity supply has increased and become erratic, coconut shell has come to be regarded as source of fuel rather than refuse. The various element contents in coconut shell as shown in Table 5 proves the high potential of this biomass as the potential fuel source. Presently, the Nigeria coconut shell is used as a source of fuel for the boilers [9].

Table 5: XRF analysis of coconut shell ash [13]

Element	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	Na_2O	SiO_2	MnO	ZnO
%	15.6	0.57	12.4	0.52	16.2	0.45	45.05	0.22	0.3

CHAPTER 3

METHODOLOGY

This project research can be divided into nine main parts. They are sample preparation, moisture removing, grinding, study of sample's element content, production of sample of briquettes, calorific value test, burning test and drop test.

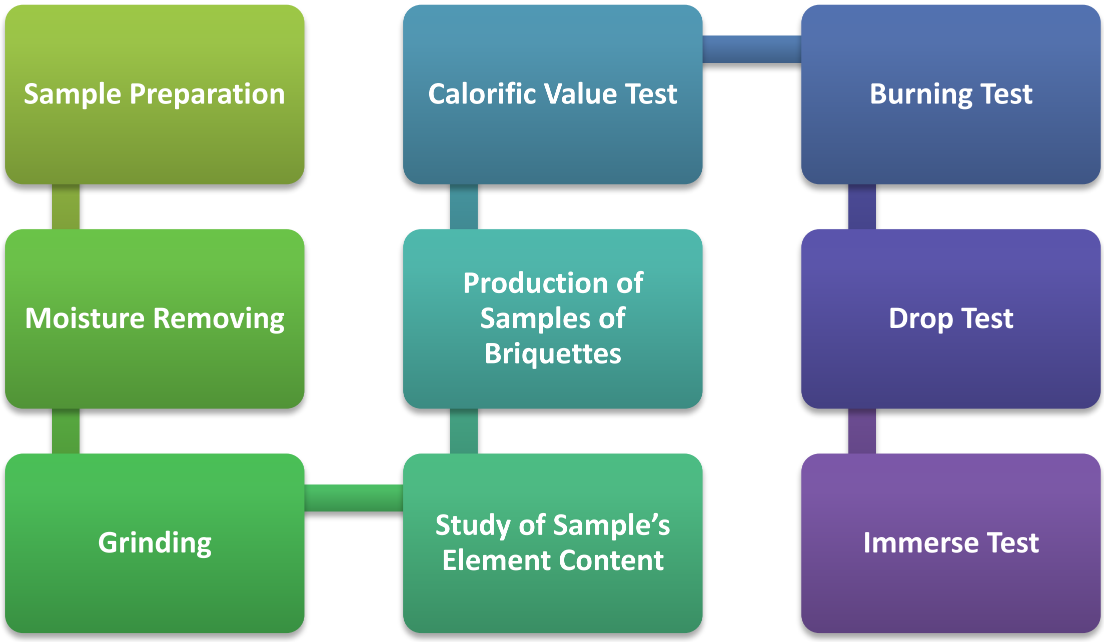


Figure 3: Process of develop biomass briquette

3.1 Process of Develop Biomass Briquette

3.1.1 Sample Preparation

EFB, rice husk and coconut shell are collected from the suitable locations near to UTP area. The high quality of samples should be chosen for the research to obtain accurate result and produce good quality of briquettes.

3.1.2 Moisture Removing

Part of the EFB, rice husk and coconut shell will be put in the oven to remove the moisture content. The moisture content of the samples can be calculated by subtracting the weight of samples (before entering the oven) with the new weight (after removing the moisture content). The moisture content of the samples is calculated by using the following equation and the calculation example is shown by using the EFB data [14].

$$\textit{Moisture content} = \left(\frac{w1 - w2}{w1}\right) \text{x } 100\%$$

Whereby

w1 = weights of samples before removing moisture content

w2 = weights of samples after removing moisture content

3.1.3 Grinding

The samples are grinded into powder form by using the grinder. This is important part to make the biomass briquette because the Autopallet Press Machine can only produce the briquette after the samples has been grind into the powder form.

3.1.4 Study of Sample's Element Content

XRF/CHNS machine will be used to study the element content of the EFB, rice husk and coconut shell. The data collected will be recorded and compared with the reference data.

3.1.5 Production of Samples of Briquettes

There are 12 types of samples are to be tested. Dry samples are the samples where the moisture content is removed while wet samples are the samples where the moisture content is not removed. The dry samples are to be used in the production of briquettes. 10±0.5 gram of each sample will put in the mould of the Autopallet Press Machine. The load is set to 75 kN force. The, the mould will be put in the hydraulic press of the Autopallet Press Machine. Five briquettes will be made for each type of sample. The height of the briquette produced are measured and recorded. The volume or size of the briquette is determined by using the formula:

$$Volume,\ V = \pi r^2 h$$

Whereby

r = radius of the briquette

h = height of the briquette

The weight of the produced sample briquettes will be determined to calculate the density of the samples. The formula to calculate the density is

$$Density,\ \rho = \frac{mass}{volume}$$

The typical briquette for this project is shown in Figure 4.

Figure 4: A typical briquette for this project.

3.1.6 Calorific Value Test

The EFB, rice husk and coconut shell samples will be tested. The purpose is to make sure the sample collected can be burned and the calorific value can be determined. Bomb calorimeter is used to verify the calorific value of samples. 1.0 g of the pure EFB, coconut shell and rice husk will be tested. The samples can be used in the other process if the calorific values are successfully determined. The second section is to verify the calorific value of the samples. The briquette will be grinded, and then 1.0 g of sample is tested. The weight of sample is keyed-in by using the prompt screen of bomb calorimeter before the process gets started. The calorific value, which is shown at the prompt screen, will be recorded. Three tests will be run for each type of sample and the process is repeated by using sample with different mixture ratio.

3.1.7 Burning Test

The purpose of this test is to test the ignitability and time take to burn the sample to ash. Bunsen burner will be used in this test. The briquette will put on the wire gauze and the Bunsen burner is ignited. Every 5 seconds, the briquette will be removed and placed on a piece of tissue paper to test whether the briquette has ignited or vice versa. The interval time is recorded until the briquette is ignited. The briquette is burned and the stop watch is started. When the briquette is burned until become ash, the stop watch will be stopped and the time is recorded. The ash content of the samples will be calculated by using this formula [15]:

$$\text{Ash content (\%)} = \frac{\text{final weight}}{\text{initial weight}} \times 100\%$$

3.1.8 Drop Test

The objective of drop test is to find out the brittleness of the samples. The brittleness of the briquettes plays an important role in the transportation, handling and storing of the briquettes. It is executed by dropping the briquettes from 1 meter height location for three times per briquette. The briquette will be weighed after each drop. Then, the result will be collected and analysed [16].

3.1.9 Immerse Test

The purpose of immerse test is to measure its durability when it is immersed under water. There will be a few cases when flood occurred and affect the storage container where the biomass briquettes are kept. Referred to this situation, immerse test will be done to examine the briquette's condition after immersed under water for one minute per briquette. The briquette characteristics after immerse test are recorded.

3.2 Equipment Needs for Research

i) XRF/CHNS machine – to evaluate the elements contain in the EFB, coconut shell and rice husk.

ii) Grinder – to grind the specimens. In this project, 2 type of grinder are used:

1) Granulator – to break hard and large sample into smaller size and smoother condition of sample. In this case, coconut shell and EFB can be grinded in the granulator. The rice husk is already smooth; we don't have to put it into this machine.
2) Mortar Grinder – to grind the specimen of EFB, coconut shell and rice husk into powder form. Only by this form, the biomass briquettes can be produced.

iii) Oven – to remove the moisture of the samples.

iv) Bunsen – to light the samples.

v) Autopallet Press Machine – to produce briquettes.

vi) Bomb calorimeter - to get the calorific value of the samples.

The pictures of equipment are shown as in the following figures:

Figure 5: Oven

Figure 6: Grinder

Figure7: Autopallet press machine

Figure 8: CHNS machine

Figure 9: Bomb calorimeter

3.3 Feasibility of Plan

For the time being, all tasks in the Gantt chart for FYP 1 are running smoothly according to the plan. In this part, only two main tasks are been executed; which are collection of the raw material and study of EFB, rice husk and coconut shell characteristics. The sample's collection process from the respective plant and factories are successfully done without any major difficulties.

On the other hand, the tasks in the Gantt chart for FYP 2 are going efficiently according to the plan except for the production of briquettes and study of sample's element content. The mould required for producing briquettes is missing and unable to be found by the lab technician. Thus, I need to fabricate the new mould by using the stainless steel solid cylinder. This fabrication process is taken place at the manufacturing lab and consuming about two weeks to be completed. The production of biomass briquettes is carried out in week 8. Furthermore, the XRF machine in block 17 was break down and the progress of machine service is still in doubt. The alternative solution of this problem is to use the CHNS machine in block 4 (chemical engineering department). The test will be carried out in week 9.

3.4 Gantt Chart & Key Milestone for FYP 1

Weeks / Tasks	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Topic selection & allocation														
Understand the process involved in palm oil processing														
Submission of Extended Proposal														
Collect EFB, rice husk and coconut shell														
Proposal Defence														
Study the characteristics of EFB, rice husk and coconut shell														
Submission of interim draft report														
Submission of interim report														

3.5 Gantt Chart & Key Milestone for FYP II

Tasks \ Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Sample Preparation		■	■	■	■	■	■	■						
Production of briquettes of sample								■	■					
Drop test								■	■					
Calorific Value Test								■	■					
CHNS Test								■	■					
Submission of Progress Report								■						
Burning Test									■	■				
Submission of FYP poster											■			
Submission of draft report												■		
Project Dissertation (soft bound)													■	
Submission of Technical Paper													■	
Oral Presentation														■
Project Dissertation (hard bound)														■

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Sample Preparation

The initial weight and final weight of EFB, rice husk and coconut shell are recorded in Table 6 and the moisture contents of the samples are calculated.

Table 6: The initial weight, final weight & moisture content of the samples

Samples	Initial weight, w_1 (g)	Final weight, w_2 (g)	Moisture content (%)
EFB	100	67.649	32.351
Rice husk	100	86.965	13.035
Coconut Shell	100	81.711	18.289

The moisture content of the samples is calculated by using the following equation and the calculation example is shown by using the EFB data.

$$\textit{Moisture content} = \left(\frac{w1 - w2}{w1}\right) \times 100\%$$

$$= \left(\frac{100 - 67.649}{100}\right) \times 100\%$$

$$= 32.351\ \%$$

From the data obtained from moisture removing experiment, all samples are showing reduction in weight value after drying process in the oven. This means that the biomass samples are having moisture in their initial condition. These samples called wet samples. The calorific value of the samples cannot be determined by the bomb calorimeter if the samples found wet. Furthermore, this will affect the result of the other tests, such as burning test and CHNS test. Thus, it is important to remove the moisture content of samples to produce biomass briquettes, and then the most accurate results can be yielded. The dry samples will be used for the other tests. The Figure 10 shows the comparison between the initial weight and the final weight of biomass samples.

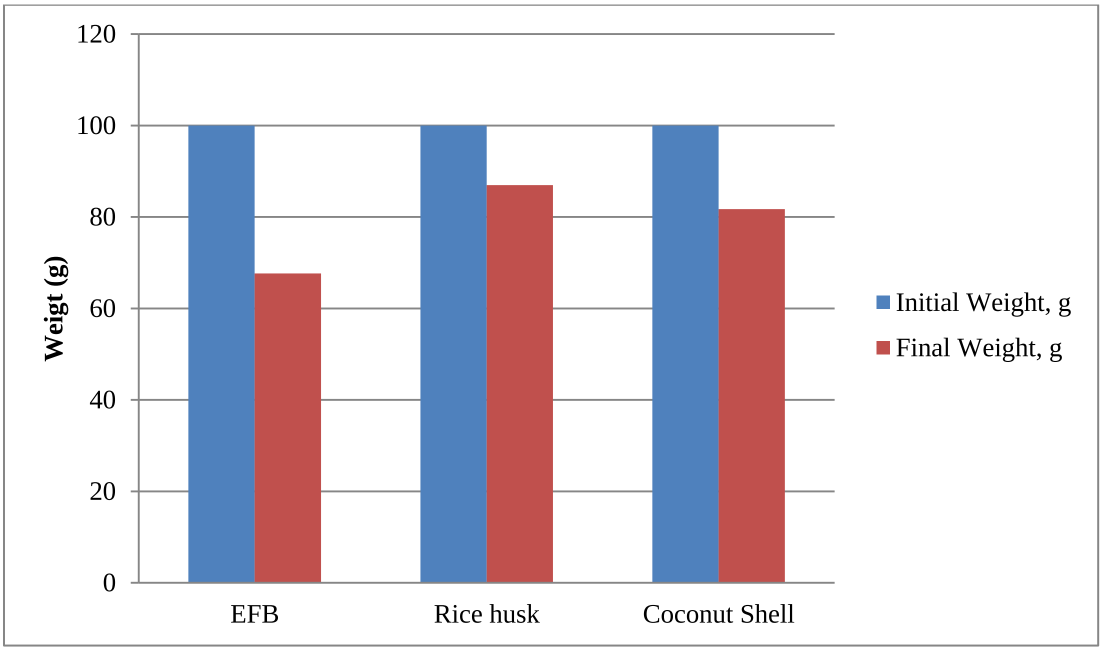


Figure 10: Graph of initial weight & final weight of samples

From the moisture content data of the three different types of samples, we can find out the moisture content of the EFB is the highest compared to coconut shell and rice husk.

The moisture content of samples that obtained from the experiment is known as experimental values of moisture content. The moisture content data are compared with the theoretical data which taken from the Literature Review section and the other available references. These can be arranged in the Table 7 as follows:

Table 7: Experimental moisture content and theoretical moisture content

Sample	Experimental Moisture Content (%)	Theoretical Moisture Content (%)
EFB	32.351	57.200
Rice Husk	13.035	11.000
Coconut Shell	18.289	7.000

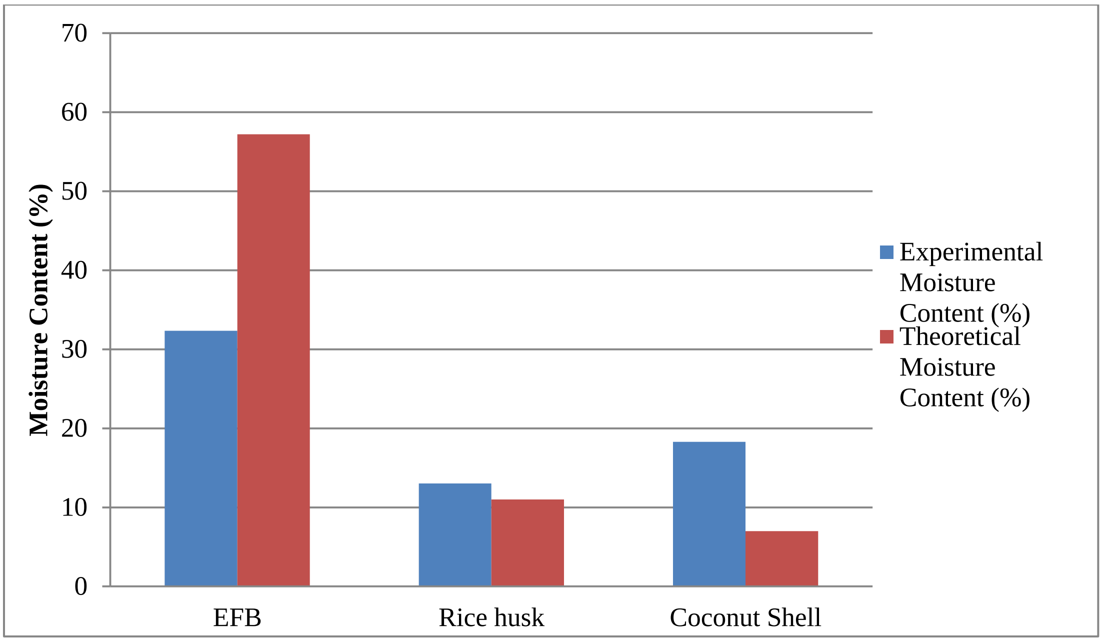


Figure 11: Graph of experimental vs. theoretical moisture content (%)

The Figure 11 explains the difference between experimental moisture content and theoretical moisture content. The theoretical moisture content for EFB is higher than the experimental value; however the theoretical moisture contents for rice husk and coconut shell are lower. The percentage difference of moisture content between experimental moisture content and theoretical moisture content are recorded in Table 8.

Table 8: Percentage difference of moisture content (%)

Sample	Experimental Moisture Content (%)	Theoretical Moisture Content (%)	Percentage Difference (%)
EFB	32.351	57.200	-76.81
Rice Husk	13.035	11.000	15.61
Coconut Shell	18.289	7.000	61.73

The percentage different between the experimental value of moisture content and theoretical value of moisture content is calculated by using the following equation and the calculation example is shown by using the rice husk data.

$$Percentage\ different = \frac{experimental\ (\%) - theoretical\ (\%)}{experimental\ (\%)} \times 100\%$$

$$= \frac{13.035 - 11.000}{13.035} \times 100\%$$

$$= 15.61$$

The moisture for EFB itself which newly discharge from crude palm oil mill may reach as high as 70% moisture, apart from steam water moisture; it also consists of small amount of crude palm oil. This is why some of the crude palm oil mill wants to further proceed to press the EFB for further salvage the crude palm oil. After press and shredded, the moisture for shredded EFB fibre may reduce to 50-55%, again also may fluctuate depends on the press machine and shredded machine design and maintenance status [13]. However the yielded moisture content of EFB is just about 22.4%. This value is about 76.81% less than the theoretical value of moisture content. This is probably due to the exposure of EFB under the sunshine for quite long time before it is taken from palm oil factory. Similarly, the experimental values of coconut shell and rice husk moisture content are slightly different from the theoretical values. These data may be affected by the surrounding condition and the storage location of the samples at the initial places.

12 types of sample’s ratio are provided within the required weight percentage. Five briquettes are produced for each ratio to be used for the sample’s tests that will be handled to obtain the best ratio of briquette in terms of reliability, durability, ignitability and the time taken to become ash.

4.2 Study of Sample’s Element Content

The carbon, hydrogen, nitrogen and sulphur content in the samples are tested by using the CHNS machine. The results are shown in Table 9 to 12. These data are also being plotted on the graphs in Figure 12 to 15.

Table 9: The Carbon content (%) in the samples.

Samples (%)	Carbon Content (%)		
	Test 1	Test 2	Mean
E (100)	47.37	46.62	47.00
R (100)	40.01	39.92	39.97
C (100)	46.81	46.83	46.82
E : R (75 : 25)	44.30	43.69	44.00
E : R (50 : 50)	42.52	42.39	42.46
E : R (25 : 75)	40.40	38.81	39.61
E : C (75 : 25)	45.78	45.79	45.79
E : C (50 : 50)	45.84	47.15	46.50
E : C (25 : 75)	45.70	46.39	46.05
E : R : C (50 : 25 : 25)	44.60	44.96	44.78
E : R : C (25 : 50 : 25)	41.96	42.14	42.05
E : R : C (25 : 25 : 50)	42.29	43.73	43.01

Table 10: The Hydrogen content (%) in the samples.

Samples (%)	Hydrogen Content (%)		
	Test 1	Test 2	Mean
E (100)	5.455	5.221	5.338
R (100)	5.734	5.042	5.388
C (100)	4.433	4.435	4.434
E : R (75 : 25)	5.955	5.354	5.655
E : R (50 : 50)	5.046	4.876	4.961
E : R (25 : 75)	4.109	5.030	4.567
E : C (75 : 25)	5.943	5.479	5.711
E : C (50 : 50)	4.457	4.471	4.464
E : C (25 : 75)	6.683	6.166	6.425
E : R : C (50 : 25 : 25)	5.346	5.228	5.287
E : R : C (25 : 50 : 25)	4.928	4.793	4.861
E : R : C (25 : 25 : 50)	4.372	4.444	4.408

Table 11: The Nitrogen content (%) in the samples.

Samples (%)	Nitrogen Content (%)		
	Test 1	Test 2	Mean
E (100)	1.679	1.495	1.587
R (100)	0.816	0.842	0.829
C (100)	0.349	0.386	0.368
E : R (75 : 25)	1.082	1.164	1.123
E : R (50 : 50)	1.104	0.905	1.005
E : R (25 : 75)	0.897	0.834	0.866
E : C (75 : 25)	0.968	1.148	1.058
E : C (50 : 50)	0.691	0.756	0.724
E : C (25 : 75)	0.717	0.516	0.617
E : R : C (50 : 25 : 25)	0.890	0.922	0.906
E : R : C (25 : 50 : 25)	0.916	0.900	0.908
E : R : C (25 : 25 : 50)	0.637	0.774	0.706

Table 12: The Sulphur content (%) in the samples.

Samples (%)	Sulphur Content (%)		
	Test 1	Test 2	Mean
E (100)	0.120	0.038	0.079
R (100)	0.090	0.045	0.068
C (100)	0.012	0.007	0.010
E : R (75 : 25)	0.101	0.072	0.087
E : R (50 : 50)	0.033	0.002	0.018
E : R (25 : 75)	0.003	0.040	0.022
E : C (75 : 25)	0.105	0.088	0.097
E : C (50 : 50)	0.050	0.065	0.058
E : C (25 : 75)	0.055	0.041	0.048
E : R : C (50 : 25 : 25)	0.007	0.023	0.015
E : R : C (25 : 50 : 25)	0.044	0.024	0.034
E : R : C (25 : 25 : 50)	0.001	0.009	0.005

By comparing the results obtained from the experiment (100% EFB and 100% rice husk) with the data in Table 1 and Table 3 respectively, it is observed that there has the small different rate of data between the study and the literature. The physical properties of EFB and rice husk depend on the environment condition; hence this small difference is acceptable.

From the data in Table 11 and Table 12, it is found that the percentage of Nitrogen and Sulphur are relatively low. This shows that these biomass samples will not create major pollution in the environment, especially when burning of samples are being done. Therefore, these samples are suitable to be used for developing biomass briquette.

The Figure 12-15 shows the element content of the selected briquettes; which are 100% EFB, 75:25 EFB to rice husk, 75:25 EFB to coconut shell and 50:25:25 EFB to rice husk to coconut shell.

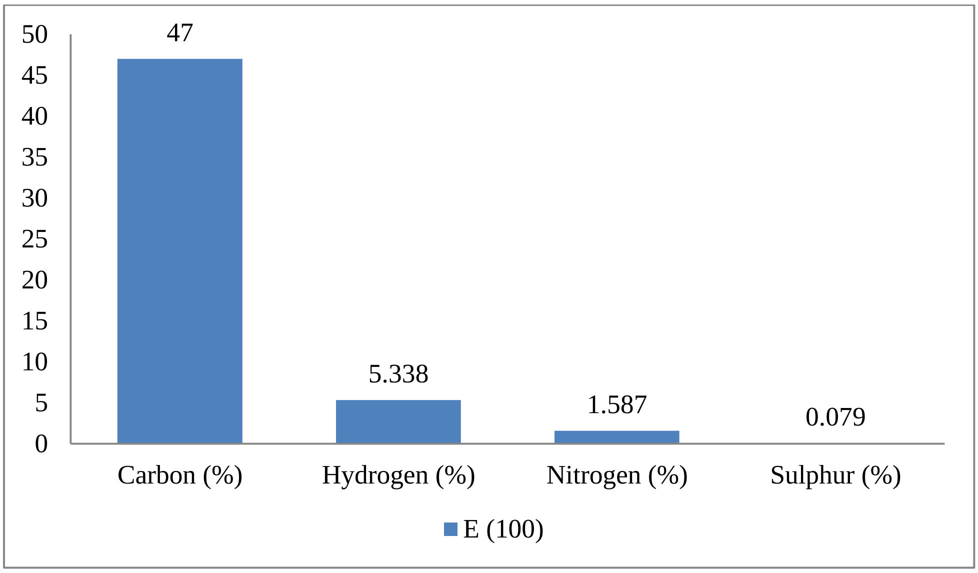


Figure 12: Element content of EFB.

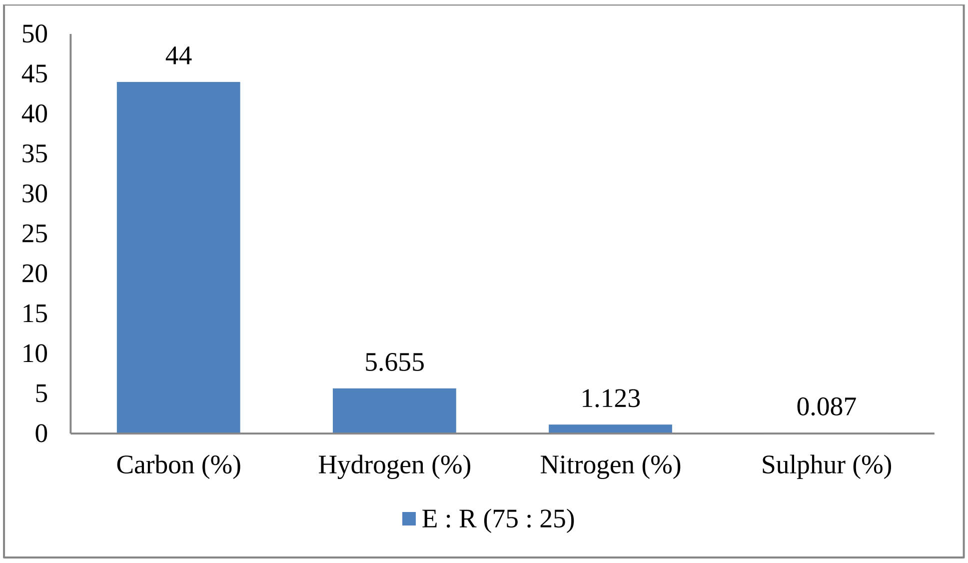


Figure 13: Element content of 75:25 EFB to rice husk.

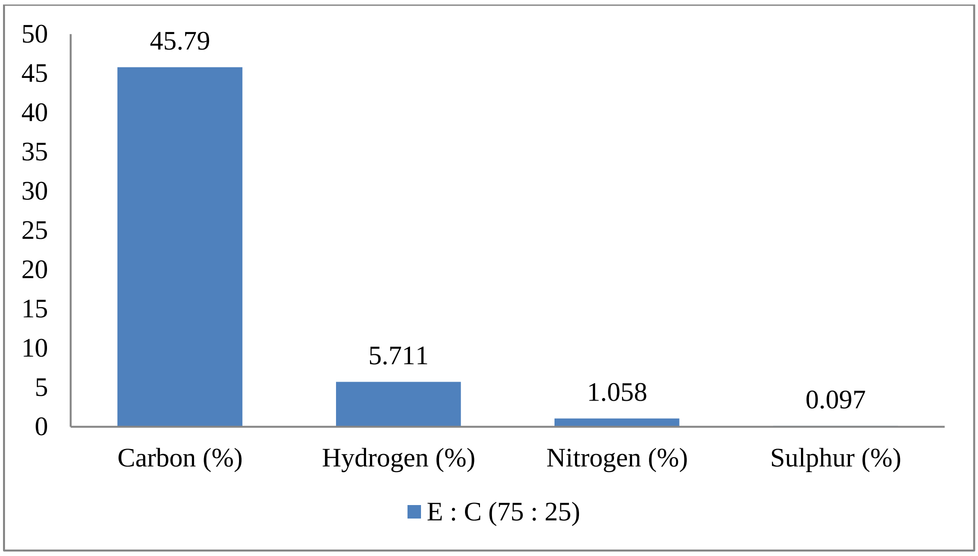


Figure 14: Element content of 75:25 EFB to coconut shell.

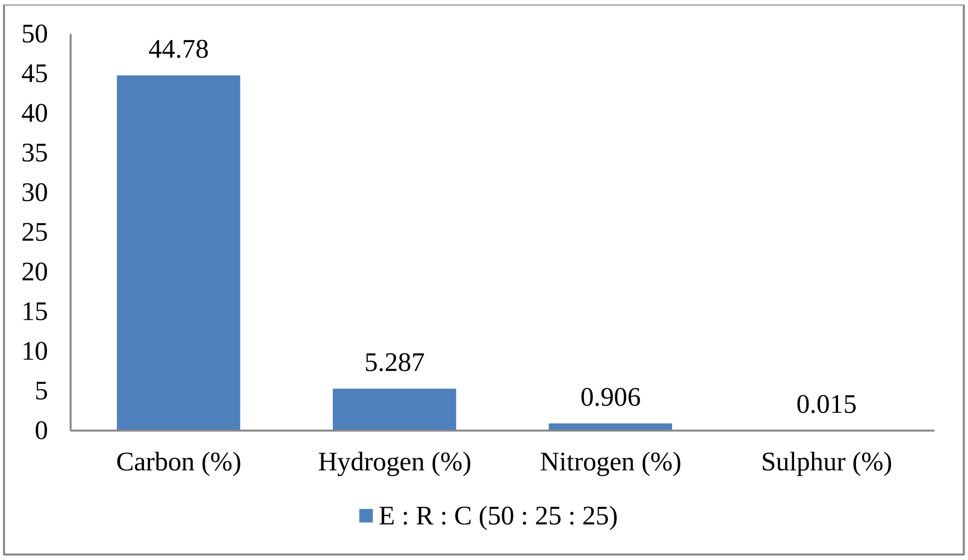


Figure 15: Element content of 50:25:25 EFB to rice husk to coconut shell.

4.3 Production of Briquette

The weight and height of briquettes are recorded in Table 13 and Table 14. The diameter of briquettes is 40 mm and force applied is 75 kN.

Table 13: The weight of briquettes produced.

Samples	Weight of Briquettes, w (g)				
	No. 1	No. 2	No. 3	No. 4	No. 5
E (100)	10.2249	10.2900	10.3522	10.2772	10.2733
R (100)	10.2461	10.2542	10.2643	9.8623	9.2370
C (100)	10.0201	10.2707	9.9231	9.6238	10.0790
E : R (75 : 25)	10.2624	10.2787	10.2600	10.2773	10.2844
E : R (50 : 50)	9.9422	9.9640	9.9478	9.8950	9.9430
E : R (25 : 75)	9.8654	9.9022	9.9010	9.9180	9.9105
E : C (75 : 25)	10.1401	10.1896	10.1952	10.1392	10.3420
E : C (50 : 50)	10.1353	10.0461	10.0399	9.9015	9.9981
E : C (25 : 75)	9.8648	9.8262	9.8445	9.8359	9.7357
E : R : C (50 : 25 : 25)	10.0128	10.0183	10.0272	10.0234	10.0100
E : R : C (25 : 50 : 25)	9.8737	9.8800	9.8661	9.8704	9.8733
E : R : C (25 : 25 : 50)	9.8500	9.8550	9.7480	9.8738	9.7933

From the data in Table 13, the weight of briquettes produced is within the range of 9.24 g to 10.35 g. Although the initial weight of samples is measured in the range of 9.95 g to 10.05 g (±5 g of weight range), the final weight of briquettes obtained is a bit strayed away from the initial range.

Table 14: The height of briquettes produced.

Samples	Height of Briquettes, h (mm)				
	No. 1	No. 2	No. 3	No. 4	No. 5
E (100)	7.0	7.8	8.0	7.5	7.1
R (100)	7.2	7.2	7.3	7.0	6.6
C (100)	7.5	7.5	7.0	7.0	7.5
E : R (75 : 25)	7.0	7.2	6.8	7.1	7.2
E : R (50 : 50)	7.1	7.3	7.2	7.0	7.1
E : R (25 : 75)	7.0	7.5	7.2	8.0	7.8
E : C (75 : 25)	7.5	7.6	7.8	7.5	8.0
E : C (50 : 50)	7.5	7.5	7.4	7.0	7.2
E : C (25 : 75)	7.4	7.2	7.3	7.2	7.0
E : R : C (50 : 25 : 25)	7.4	7.4	7.5	7.5	7.1
E : R : C (25 : 50 : 25)	7.4	7.5	7.0	7.2	7.4
E : R : C (25 : 25 : 50)	7.4	7.5	7.1	7.5	7.3

From the data in Table 14, the height of briquettes produced is within the range of 6.6 mm to 8.0 mm. This is shows that the size of briquettes produced is reasonable and just a bit difference from one briquette to another briquette.

4.4 Calorific Value Test

The Calorific Value of the EFB, rice husk, coconut shell and mixture of these biomasses are listed in Figure 16 to 19. All samples that been tested are consist of dry samples. One test has been run for each sample by using bomb calorimeter. 30 minutes are needed to finish every test and obtain required result.

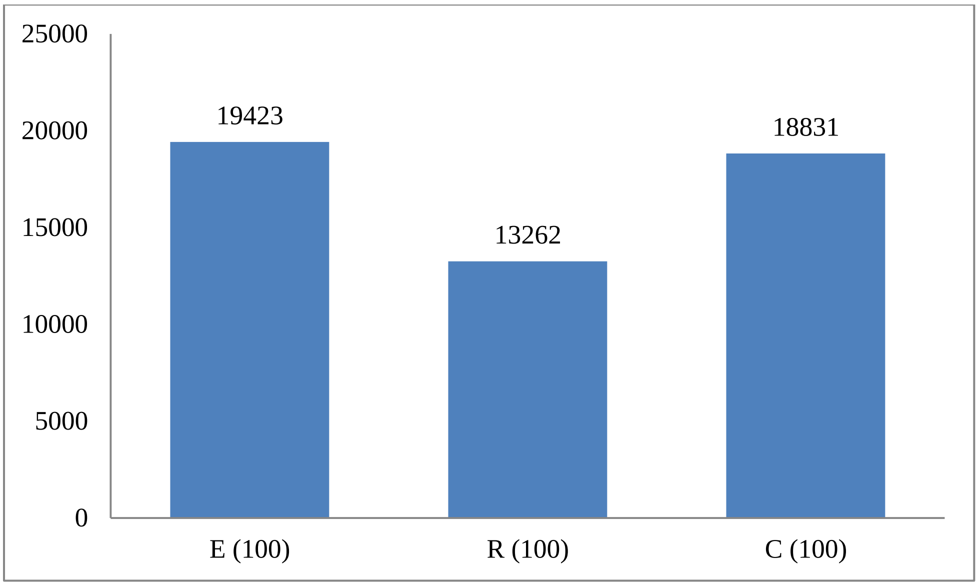


Figure 16: Calorific value of 100% EFB, rice husk and coconut shell.

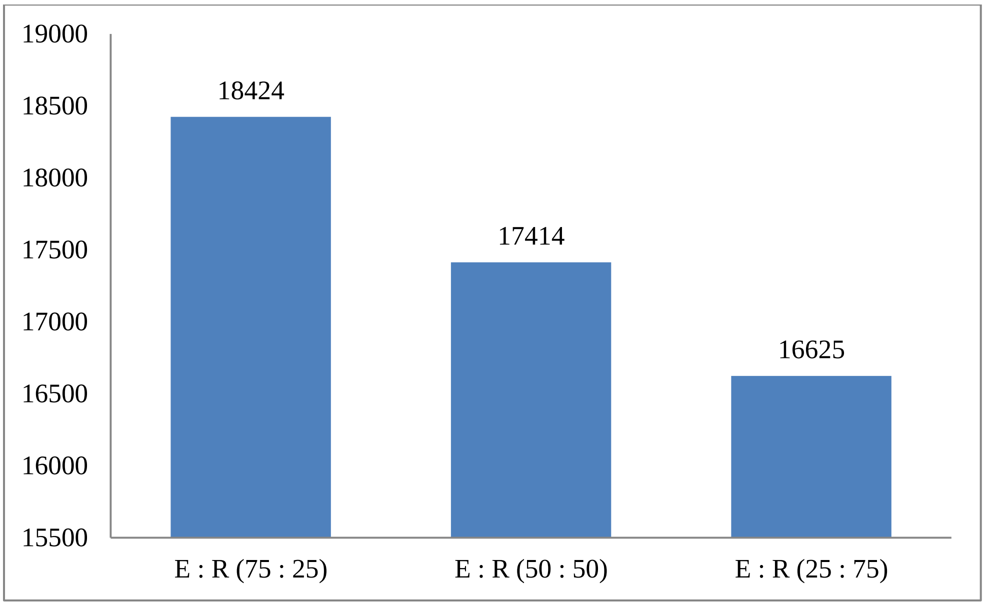


Figure 17: Calorific value of EFB to rice husk.

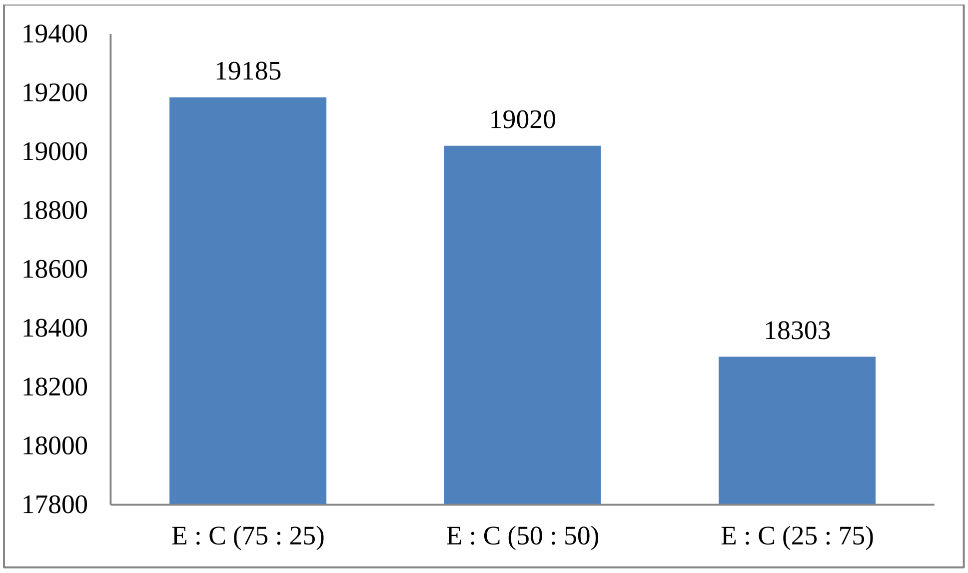


Figure 18: Calorific value of EFB to coconut shell.

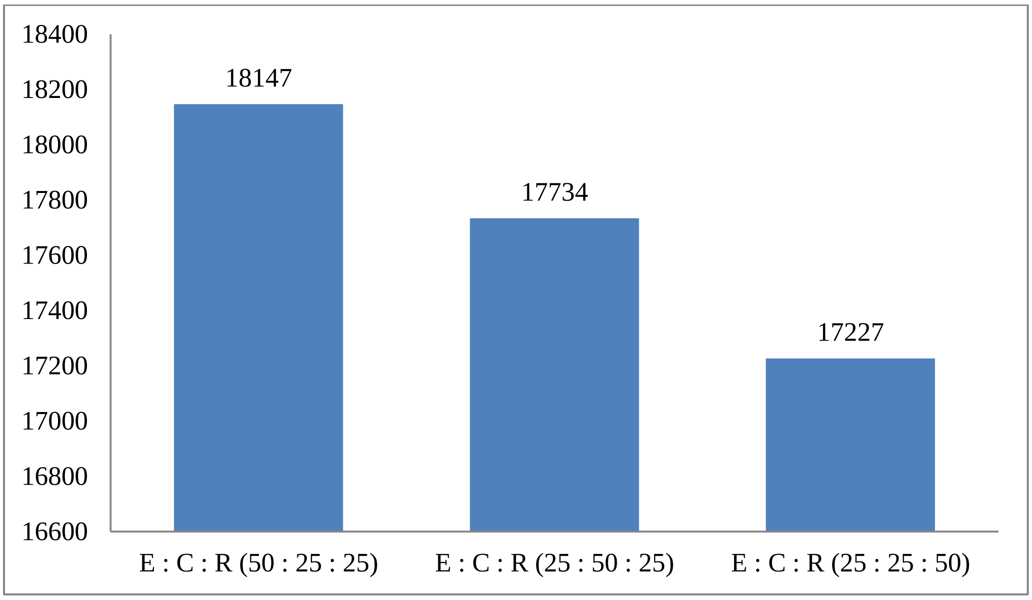


Figure 19: Calorific Value of EFB to rice husk to coconut shell.

From the Figure 16 to 20, it is found that the calorific value of EFB and coconut shell is relatively high, even if combined with the other samples with respective ratios. The rice husk shows the lowest rate of calorific value. If the combinations of EFB and coconut shell samples are compared with the combinations of EFB and rice husk samples, the results show the same trend. The sample contain rice husk has the lower calorific value than the sample contain coconut shell. From the mixture of three samples (EFB, rice husk and coconut shell), the sample dominated by rice husk (50%) has the lowest calorific value (17227 kJ/kg) compared with the other two samples (18147 kJ/kg and 17734 kJ/kg respectively). As compared with coal, which is the common type of fuel with the average calorific value of 26986 kJ/kg, the calorific value of biomass briquettes are less.

4.5 Burning Test

The ignitibility time, the time taken to burn briquette into ash and the ash content are recorded in the Table 15. The method to calculate the ash content is shown by using the data of 100% EFB.

Table 15: The ignitibility time, time taken to burn to ash and ash content of samples.

Samples (%)	Ignitability Time (s)	Time taken to burn to ash (s)	Initial weight (g)	Final Weight (g)	Ash content (%)
E (100)	45	363	10.3522	0.8268	7.99
R (100)	57	363	10.2643	1.7143	16.70
C (100)	10	274	10.2707	0.5985	5.83
E : R (75 : 25)	43	421	10.2600	0.8772	8.55
E : R (50 : 50)	23	341	9.9640	1.0204	10.24
E : R (25 : 75)	33	382	9.9022	1.1920	12.04
E : C (75 : 25)	52	359	10.1952	0.6670	6.54
E : C (50 : 50)	31	332	10.0399	0.6948	6.92
E : C (25 : 75)	23	346	9.8445	0.6274	6.37
E : R : C (50 : 25 : 25)	43	317	10.0234	0.9026	9.00
E : R : C (25 : 50 : 25)	33	422	9.8704	1.0484	10.62
E : R : C (25 : 25 : 50)	32	322	9.8550	0.8287	8.41

$$\textit{Ash content (\%)} = \frac{\textit{final weight}}{\textit{initial weight}} \times 100\%$$

$$= \frac{0.8268}{10.3522} \times 100\%$$

$$= 7.99\%$$

From the data in the Table 15, it is observed that the ignitibility time of 100% rice husk is the highest and its time taken to be burnt into ash is same as the 100% EFB. The ignitibility time of a good quality biomass briquette has to be short as possible. Then, the time taken to burn to ash should be as longest as possible. However, the calorific value of 100% rice husk is the lowest among the biomass briquettes produced. Theoretically, its value of time taken to burn into ash must be shorter than EFB and coconut shell. This difference result occurred due to its density which is the highest (average value of 1.1238 g/cm^3) compared to the pure EFB and coconut shell. High value of density will yield the longer time of burning. The largest value of ash content is shown by the 100% rice husk (16.70%). The amount of ash affects the ignitibility of the briquette, where the high content of ash reduces the briquette's ignitibility. Therefore, the rice husk that showed the highest ash content might not be a good candidate for fuel briquette.

The Figure 20-23 shows the graphs of ignitibility time and time taken to burn to ash for all briquettes.

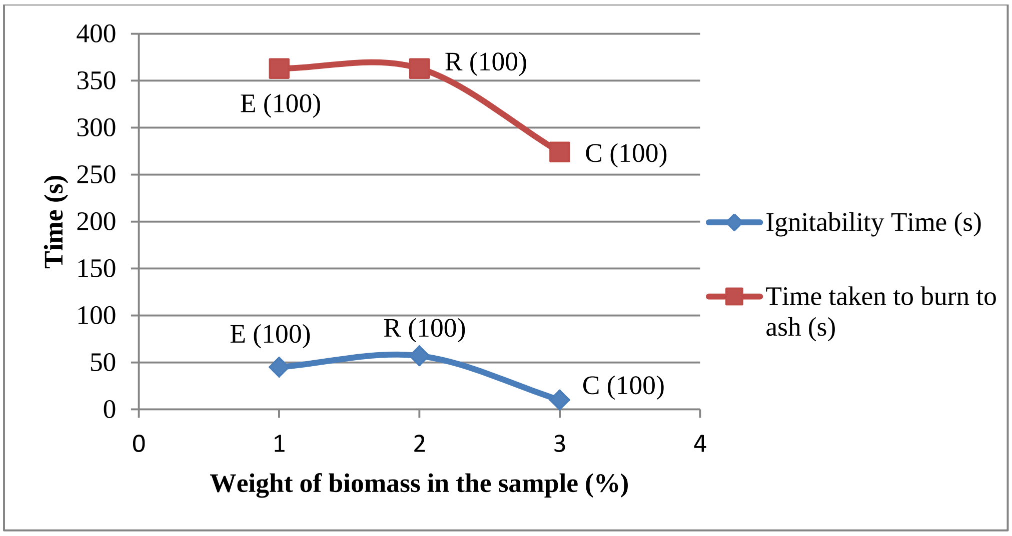


Figure 20: Time graph of 100% EFB, rice husk and coconut shell.

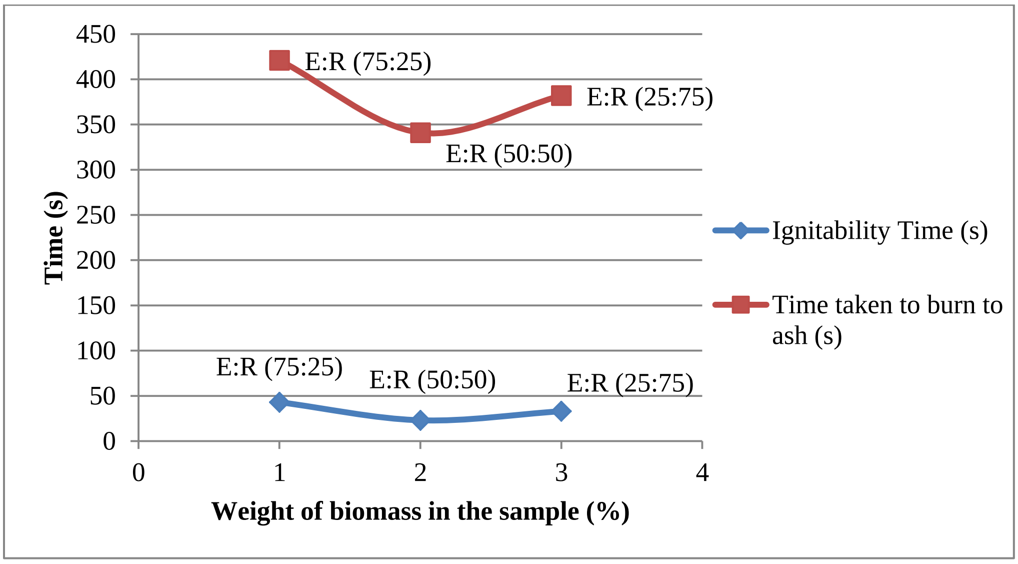


Figure 21: Time graph of EFB to rice husk.

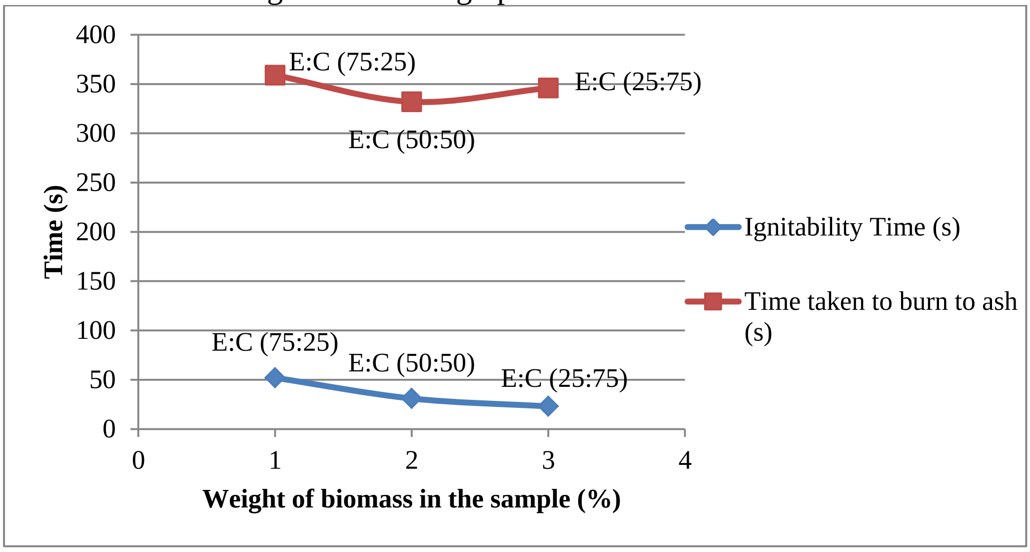


Figure 22: Time graph of EFB to coconut shell.

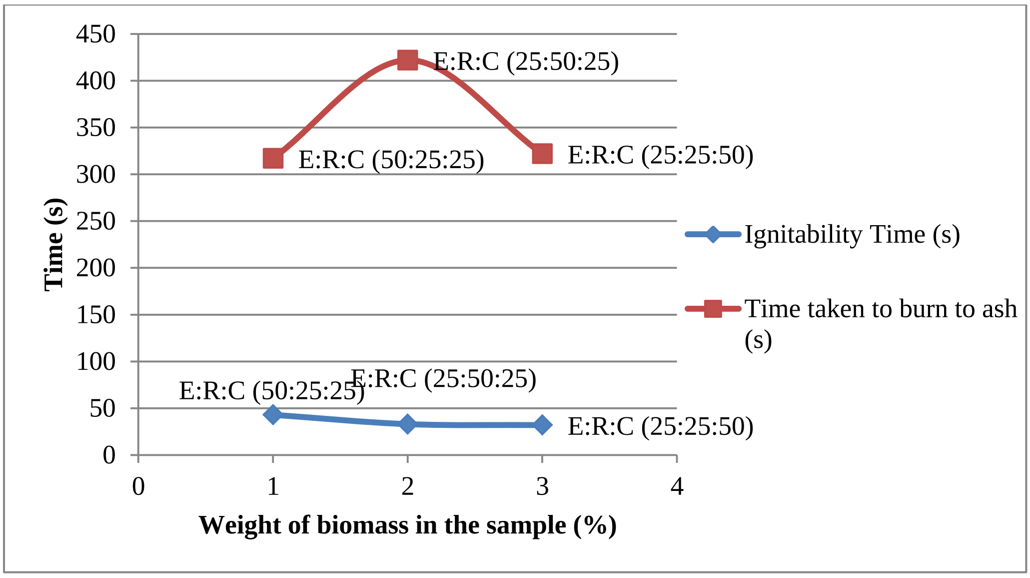


Figure 23: Time graph of EFB to rice husk to coconut shell.

4.6 Drop Test

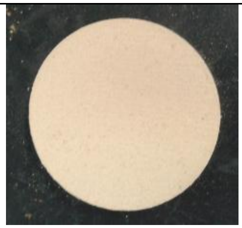
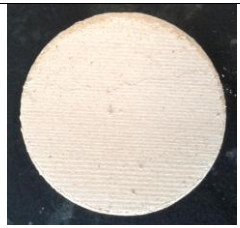
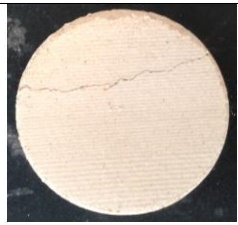
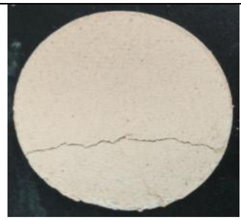
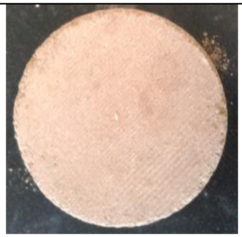
The results of the test are shown in Table 16. From the results obtained from the test, the 100% coconut shell and 25: 75 EFB to coconut shell are the most brittle briquettes. Parts of the briquettes are broken too much after the second drop test. After the third drop test, the briquettes are broken into many small pieces. Thus, the briquettes are not able to be weighted and fail to continue to the next drop tests.

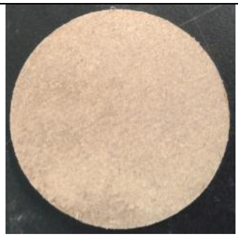
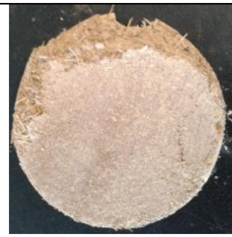
The 50:50 EFB to rice husk has the best results compared to the other briquettes. There has no any major physical defect found on the briquette after the drop test has been completed. After the third drop test, minor crack is found on the briquette. The crack becomes more obvious after the fourth drop test; however it does not break into small pieces.

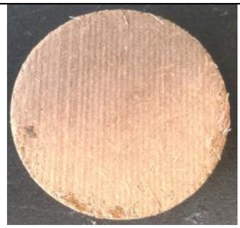
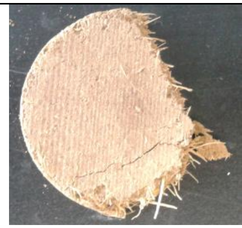
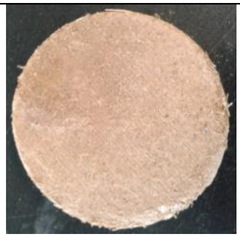
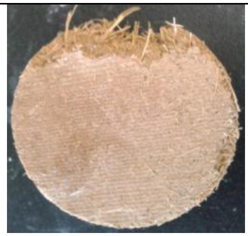
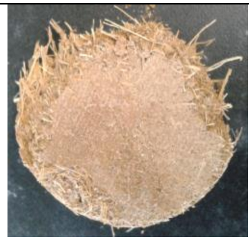
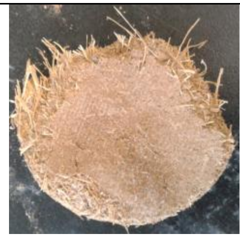
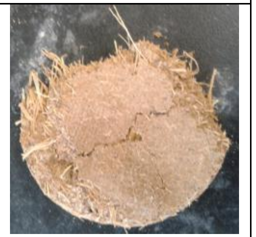
The other nine briquettes are showing almost the same characteristics after finish the drop test. Parts of the briquettes are broken into small pieces and unable to be weighed. But, the major part of then are still remains and their final weight can be measured.

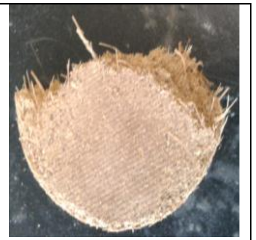
The brittleness of coconut shell occurred due to its moisture content. Compared to the theoretical value of moisture content, the coconut shell is having the lowest moisture. It means that coconut shell powder is very dry; the powder is unable to be hold together strongly and firmly. The higher moisture content in EFB and rice husk enhances the briquette's hardness and ductility. The drier the powder of biomass, the more brittle briquette will be produced.

Table 16: The results of drop test.

Samples	Image & Weight of Samples (before drop test)	Image and weight of samples (after drop test)				
		First drop test	Second drop test	Third drop test	Fourth drop test	Fifth drop test
EFB (100%)	 Weight: 10.301 g	 Weight: 10.214 g	 Weight: 10.115 g	 Weight: 9.952 g	 Weight: 9.506 g	 Weight: 7.408 g
Rice Husk (100%)	 Weight: 9.801 g	 Weight: 9.781 g	 Weight: 9.763	 Weight: 9.756	 Weight: 7.353 g	 Weight: 7.027 g
Coconut Shell (100%)	 Weight: 10.402 g	 Weight: 7.473 g	 Weight: 1.758	Fail to be weighted	Fail to be weighted	Fail to be weighted

EFB : Rice Husk (75 : 25)	 Weight: 10.296 g	 Weight: 9.989 g	 Weight: 8.658	 Weight: 7.594 g	 Weight: 6.813 g	 Weight: 5.595 g
EFB: Rice Husk (50 : 50)	 Weight: 9.911 g	 Weight: 9.885 g	 Weight: 9.839 g	 Weight: 9.759 g	 Weight: 9.680 g	 Weight: 9.047
EFB : Rice Husk (25 : 75)	 Weight: 9.830 g	 Weight: 9.754 g	 Weight: 9.133 g	 Weight: 8.508 g	 Weight: 5.567 g	 Weight: 5.409 g

EFB : Coconut Shell (75 : 25)	 Weight: 10.358 g	 Weight: 10.300 g	 Weight: 8.641 g	 Weight: 7.388 g	 Weight: 6.516 g	 Weight: 6.104 g
EFB : Coconut Shell (50 : 50)	 Weight: 10.288 g	 Weight: 9.543 g	 Weight: 9.254 g	 Weight: 6.473 g	 Weight: 6.342 g	 Weight: 6.011 g
EFB : Coconut Shell (25 : 75)	 Weight: 9.932 g	 Weight: 8.699 g	 Weight: 8.049	Fail to be weighted	Fail to be weighted	Fail to be weighted

EFB : Rice Husk : Coconut Shell (50 : 25 : 25)	 Weight: 9.987 g	 Weight: 9.840	 Weight: 9.784	 Weight: 9.640	 Weight: 8.590 g	 Weight: 5.365 g
EFB : Rice Husk : Coconut Shell (25 : 50 : 25)	 Weight: 9.786 g	 Weight: 8.606 g	 Weight: 7.920 g	 Weight: 5.737 g	 Weight: 5.466 g	 Weight: 5.339 g
EFB : Rice Husk : Coconut Shell (25 : 25 : 50)	 Weight: 9.456 g	 Weight: 8.173 g	 Weight: 7.641 g	 Weight: 6.584 g	 Weight: 6.425 g	 Weight: 5.120 g

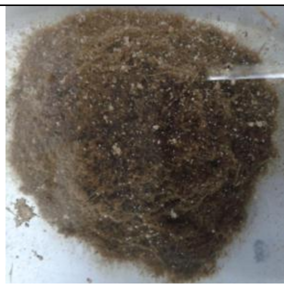
4.7 Immerse Test

For the immerse test, the water resistance of the briquettes are evaluated by observing the characteristics of briquettes when totally disintegrate in water in one minute. This property is essential as it would enable us to determine the storage method of location of the briquettes. The results from the immerse test are shown in the Table 17.

All briquettes are fully immersed in water and the loose particles sank to the bottom except the 100% coconut shell. The pure coconut shell is hardly dissolved in water. This could be contributed by the huge amount of wax applied in producing 100% coconut shell briquette. The result from the immerse test led to one conclusion. The biomass fuel briquette do not have good water resistance, thus they should be stored under cover and closed environment. The storage place with high humidity should be avoided.

Table 17: The results of immerse test.

Samples	Image of samples (before immerse test)	Image of samples (after immerse test)
EFB (100%)		
Rice Husk (100%)		
Coconut Shell (100%)		
EFB : Rice Husk (75 : 25)		
EFB: Rice Husk (50 : 50)		
EFB : Rice Husk (25 : 75)		

EFB : Coconut Shell (75 : 25)		
EFB : Coconut Shell (50 : 50)		
EFB : Coconut Shell (25 : 75)		
EFB : Rice Husk : Coconut Shell (50 : 25 : 25)		
EFB : Rice Husk : Coconut Shell (25 : 50 : 25)		
EFB : Rice Husk : Coconut Shell (25 : 25 : 50)		

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The moisture test result shows that the Empty Fruit Bunch (EFB) has the highest moisture content, either experimentally or theoretically. A good quality of biomass briquette should have low moisture content in order to produce the precise rate of calorific value and accurate time taken to complete the burning test. This is the reason of drying the samples first before mixing with the ratios given. The dry samples will produce the appropriate results and reduce the percentage of error.

The Empty Fruit Bunch (EFB) is the best material to be chosen for developing fuel briquette. Its calorific value is the highest (19423 kJ/kg) among all briquettes that been produced. In addition, it can be burned in a long time and containing few ash content. The rice husk is the least preferable material for briquette due to several factors. Its ash content is quietly large and this will reduce the ignitibility of fuel briquette. On the other hand, the results of the element content test shows that all samples contains high value of carbon and hydrogen as well as less value of nitrogen and sulphur. This shows that burning of raw EFB, coconut shell and rice husk will not create major pollution to the environment.

Furthermore, it can be concluded that a better quality of briquette could be obtained by using the combination of materials. This is shown from the tests and analysis done on various briquettes made from variety type of biomass. The energy content of biomass briquettes is exactly lower than fossil fuels (coal). Nevertheless, their potential in creating green fuel for the humankind in the future should not be neglected and a few improvements should be made in order to make it more reliable.

There are a few recommendations that can be made for the improvement of this project in the future. Further research required to be done to test the gas emission (smoke) results from the burning of EFB, rice husk and coconut shell. This is to ensure that the smoke is non-toxic, safe to the humankind and not create major health problem.

Other than that, proximate analysis should be executed by using the thermo gravimetric analyzer (TGA) machine. More results could be obtained from this test, such as the moisture, volatile matter, fixed carbon and ash content of the materials. In this project, only moisture content and ash content are successfully yielded.

Moreover, stability test can be carried out to determine how a briquette can sustain its dimensions during storage. This can determine the storage condition of the fuel briquettes to ensure that they are always in the optimum condition.

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APPENDICES

Appendix 1: Ratio quantity of EFB, coconut shell and rice husk in the briquettes.

EFB (%)	Coconut Shell (%)	Rice Husk (%)
100	0	0
75	25	0
75	0	25
50	50	0
50	0	50
50	25	25
25	50	25
25	25	50
0	100	0
0	0	100
0	25	75
0	75	25

Appendix 2: The density of briquettes produced.

Samples	Density of Briquettes, ρ (g/cm^3)				
	No. 1	No. 2	No. 3	No. 4	No. 5
E (100)	1.1622	1.0497	1.0296	1.0903	1.1513
R (100)	1.1323	1.1332	1.1188	1.1210	1.1136
C (100)	1.0630	1.0896	1.1279	1.0939	1.0693
E : R (75 : 25)	1.1665	1.1359	1.2005	1.1517	1.1365
E : R (50 : 50)	1.1142	1.0860	1.0993	1.1247	1.1143
E : R (25 : 75)	1.1214	1.0505	1.0942	0.9864	1.0110
E : C (75 : 25)	1.0758	1.0668	1.0400	1.0757	1.0286
E : C (50 : 50)	1.0752	1.0658	1.0795	1.1255	1.1049
E : C (25 : 75)	1.0607	1.0859	1.0730	1.0870	1.1066
E : R : C (50 : 25 : 25)	1.0766	1.0772	1.0638	1.0634	1.1218
E : R : C (25 : 50 : 25)	1.0617	1.0482	1.1215	1.0908	1.0616
E : R : C (25 : 25 : 50)	1.0591	1.0455	1.0924	1.0475	1.0674

Appendix 3: Calorific value of samples.

Samples	Calorific Value (kJ/kg)
E (100)	19423
R (100)	13262
C (100)	18831
E : R (75 : 25)	18424
E : R (50 : 50)	17414
E : R (25 : 75)	16625
E : C (75 : 25)	19185
E : C (50 : 50)	19020
E : C (25 : 75)	18303
E : R : C (50 : 25 : 25)	18147
E : R : C (25 : 50 : 25)	17227
E : R : C (25 : 25 : 50)	17734