THE PRODUCTION OF BRIQUETTE FROM COFFEE WASTE

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13647

Dissertation submitted in partial fulfillment of the requirement for the

Bachelor of Engineering (Hons)

(Chemical)

Jan 2014

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CERTIFICATION OF APPROVAL

Production of Briquette from Coffee Waste

By

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A project dissertation submitted to the

Chemical Engineering Programme

Universiti Teknologi PETRONAS

in partial fulfillment of the requirement for the

BACHELOR OF ENGINEERING (Hons)

(CHEMICAL ENGINEERING)

Approved by,

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May 2014

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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NURSHALINA BINTI MOHD RANI

ACKNOWLEDGEMENTS

The author would like to express her gratitude towards her supervisor, Mr. Tazli bin Azizan for all the support, ideas and advices that has been given towards the author for the duration of this final year project. His sincere guidance, supervision and dedication have really helped the author in ensuring the project in successful manner.

Special thanks as well to all lab technicians for their guidance towards the author for the period of project conducted. Without their help, the author would be dealing with hard situation in order to ensure the smoothness of experiments to be performed for the entire duration of this project.

The author would like thank Mr. Chris and his employee from Ben& Lynette Maison Patisserie for their generosity to supply the waste coffee ground needed for this project. Waste coffee ground is no doubt plays the main substance in order for this project to run.

This special thanks and appreciation are also dedicated to all colleagues and my parents who directly and indirectly contributed towards the success of this project. With the full cooperation from various people above, the author has successfully achieved the objective of this project.

ABSTRACT

Biomass briquettes have been used as an alternative to firewood and charcoal. In this study, production of briquette from ground coffee waste will be carried out to determine its feasibility as fillers when mix with two sets of binders namely rice husk and waste papers. Torrefaction of coffee waste is conducted as a pretreatment process to determine its effect on the properties of torrefied coffee waste briquette. The ground coffee waste is mixed with the binder in ratio of 50:50 for each briquette combination. Paper waste binder shows its effectiveness with coffee waste the mixture during expansion test, squeeze test and shake test, producing strong and combustible briquette. Composition mixture of filler to binder influenced significantly in which the resulting efficient water boiling test, heating value, percentage of fixed carbon, ash content and volatile matter from composition 80:20 yield better result than composition 70:30. Torrefaction temperature was varied from 260℃ to 290℃ and the reaction time was studied between 30 - 60 minutes. The torrefied coffee waste briquette at both temperatures shows better combustive properties than the non torrefied briquette. During water boiling test, all briquettes unable to burn until boiling point, however the torrefied coffee briquette managed to reach maximum temperature of 70℃ within 30 minutes.

Table of Contents

ACKNOWLEDGEMENTS ii

ABSTRACT iii

List of Figure vi

List of Tables vii

CHAPTER 1 1

INTRODUCTION 1

1.1 Background of Project 1

1.2 Problem Statement 2

1.3 Objectives 3

1.4 Scope of Study 3

1.5 Relevancy of Project 4

1.6 Feasibility of the Project 4

CHAPTER 2 5

LITERATURE REVIEW 5

2.1. Coffee Waste 5

2.2. Biomass briquettes 7

2.3 Binder Selection 10

2.3.1 Rice husk 10

2.3.2 Waste Papers 12

2.4 Torrefaction 13

CHAPTER 3 16

METHODOLOGY 16

3.1 Samples 16

3.1.1 Waste coffee Grounds 16

3.1.2. Waste Papers 16

3.1.3 Rice Husks 16

3.2 Equipment 17

3.3 Experimental procedure 18

3.3.1. Binders Selection 18

3.3.2 Composition of filler to binder selection 19

3.3.3 Torrefied and non-torrefied coffee briquette......................................19

3.4 Experimental Analysis 20

3.4.1 Water boiling test 20

3.5.2 Percentage volatile matter (PVM)...20

3.5.3 Percentage Ash content (PAC)..21

3.5.3 Percentage fixed carbon (PFC) 21

3.6 Gantt Chart 22

CHAPTER 4: RESULTS AND DISCUSSION...23

4.1 Binder Selection...23

4.2 Composition of Filler to Binder Selection. 25

4.3 Briquette properties analysis 26

4.4 Calorific heat value for coffee waste briquette. 30

4.4 Performance on the Water boiling Test 32

CHAPTER 5: RECOMMENDATION 34
CHAPTER 6: CONCLUSION 35
CHAPTER 6: REFERENCES 36
APPENDICES 39
APPENDIX 4-1 39
APPENDIX 4-2 41
APPENDIX 4-3 43

List of Figure

Figure 1: Samples of briquettes from around the world 8
Figure 2: Caloric content of briquette (Mc Dougal et al., 2010) 10
Figure 3: Water boiling test for rice husk binder Vs. Firewood 11
Figure 4: Torrefaction removes moisture and volatiles from biomass, leaving bio-coal. 13
Figure 5: Biomass before torrefaction Figure 6: Biomass after torrefaction 14
Figure 7: Torrefied biomass in pellet form 14
Figure 8: Torrefied coffee beans 15
Figure 9: Torrefier 15
Figure 10: Mixture of coffee waste and rice husk failed to bind together 24
Figure 11: Briquette made from coffee waste and waste paper 24
Figure 12: Coffee waste - waste paper briquette at 70:30 mass ratios 25
Figure 13: Coffee waste - waste paper briquette at 80:20 mass ratios 26
Figure 14: Percentage volatile matter of coffee waste briquette 27
Figure 15: Percentage ash content of coffee waste briquette 28
Figure 16: Percentage fixed carbon of coffee waste briquette 29
Figure 17: Calorific Heat Value of coffee waste briquette 30
Figure 18: Calorific values of briquette charcoal and wood charcoal (Pallavi et al., 2013) 30
Figure 19: Water boiling test 33

List of Tables

Table 1: Proximate elemental and chemical structure of coffee waste 6
Table 2: Proximate elemental and chemical structure of rice husk (Wang et al., 2012) .11
Table 3: Proximate elemental and chemical structure of waste paper 12
Table 4: Properties of coffee waste and waste paper briquette 26
Table 5: Coffee waste - waste paper briquette (50:50 wt. %) 32
Table 6: Water boiling test for torrefied coffee waste briquette 32

CHAPTER 1

INTRODUCTION

1.1 Background of Project

Coffee is one of the most popular beverages consumed by millions of people every day. The waste from the brewed coffee can be found in abundance from the local houses, coffee shops up to instant coffee manufacturers and they are easily taken for free. A lot of chemical researches have been done to study the composition of coffee waste and its useful potential in bioenergy and agriculture. All of this research triggers the feasibility of coffee waste in production of biomass briquette. In this project, waste coffee is collected from local coffee shops in Ipoh and to be used for production of bio-briquette

A briquette is a block of flammable matter used as fuel to start and maintain a fire. Biomass briquettes are made from agricultural waste and are a replacement for fossil fuels such as oil or coal. There are few raw materials or agricultural waste that can be used for briquette-making such as straw leaves, tree leaves, rice husk, maize husk and banana leaves. The selection of raw material is dependent on the availability (source) and fiber-rich content of the material. The composition of briquette is divided into two which are binder and filler. In this project, the coffee waste will be used as filler and it will be bind using different binders namely rice husk and waste paper.

Coffee waste needs to be dried before it undergoes the briquetting process. This step is to avoid high moisture content that can bring adverse effect of the product, specifically to the heating value. This project will used torrefaction method prior to oven drying as a pre-treatment for the ground coffee waste. Torrefaction is a type of mild pyrolysis. This method will change the biomass properties of the coffee waste to obtain a much better fuel quality for combustion and gasification applications.

At the end of this project, coffee waste briquettes are produced from two sets of binders. One of the binders will be used in the second stage of the project work to determine the effectiveness of the briquette based on fillers to binder composition. The chosen binder will also be used in the third stage of the project work to compare the effectiveness of torrefied and non-torrefied coffee briquette. After the briquetting process, the physical and chemical properties of the briquette will be tested.

1.2 Problem Statement

In theory, fuel briquettes can be made of any organic material, and because of this, most fuel briquetting programs use distinct composition recipes for their briquettes. The filler is the main component of the briquette. The function of the filler is to control the burning rate of the briquette. The binder is made of high fiber content materials which are used to ensure the briquette stays intact. This project has selected waste paper and rice husk as binders. Waste paper is very common in fuel briquetting initiatives and can be easily obtained from the university compound or outside campus. Rice husk is widely available in Malaysia and are excellent source of fibers for binding briquette. Based on recent research, there is no specific formula to determine the right composition of binder and filler to be used for briquetting. It is also reported that coffee waste is not favorable to be used as fillers because there is a lack of processing option for the material (Nyer, 2012). By varying the composition of the filler to binder and introduce the torrefaction method, it can be inferred that the methods will enhance the combustive performance of coffee waste briquette.

1.3 Objectives

1. To study the feasibility of briquette made from coffee waste with different binders namely rice husk and waste paper.
2. To study the effectiveness of coffee waste briquette by varying the composition of filler to binder ratio.
3. To compare the effectiveness of torrefied and non-torrefied coffee waste briquette.

1.4 Scope of Study

In summary, the scope of study is based on the objectives. There are three stages of process work required to be done:

Stage 1: Making two sets of coffee waste briquettes using rice husk and waste papers as binders. Binder that gives the strongest briquette and able to combust will be chosen and proceed with the next two stages.

Stage 2: Making two sets of coffee waste briquette based on different composition of filler to binder. The compositions of filler to binder ratio used in this stage are 70:30 and 80:20 respectively.

Stage 3: Making two sets of torrefied coffee waste briquette based on two different temperatures which are of 260°C and 280°C. The binder used in Stage 3 is the same as in Stage 2 but the composition of filler to binder is the same for both sets of torrefied coffee briquette.

The two binders are used in this project because they are readily available, cheap, higher binding effect and burn effectively with less smoke. Approximately 6000g of coffee waste is used in this project. Water boiling test will be conducted for all briquettes. The parameters used to study the characteristics of the briquette are time taken to light up the briquette, amount of smoke produced, flame characteristic, length of time to boil 200ml of water and length of time taken for the briquette to burn completely into ashes. The chemical properties of the briquette will be characterized based on percentage of volatile matter, ash content, fixed carbon and heating value.

1.5 Relevancy of Project

By doing this research, we can determine the feasibility of making briquette from coffee waste and to know the factors that contribute to its effectiveness as biofuel. The results that will be obtained from this experimental project can be used to identify which condition that favors the production of coffee waste briquette. There are few advantages that noticeably will help for future enhancement especially for binder selection and pre-treatment process of the ground coffee waste.

1.6 Feasibility of the Project

This project is required to be done within eight months effectively from January 2014 until August 2014. During the first four months, this project is more focusing on paper work and depth understanding of the literature. The project is initiated by understanding the concept of briquette and torrefaction by studying this information from journals, books and technical papers. The research is conducted stage by stage to ensure better understanding of the project. During this period, materials and sample collections are conducted from time to time.

The experimental work will be commenced starting from May 2014 and onwards. Further studies and analysis will be done as well. It is within the authors capabilities to execute this project with the help and guidance from the supervisor and the master students who are either directly or indirectly involved in this project.

It is assumed that the project is feasible within the scope and time frame provided if there is no issue with regard to equipment function and material availability. The proposed Gantt chart with the milestone can be referred in Chapter 3.

CHAPTER 2

LITERATURE REVIEW

2.1. Coffee Waste

According to International Coffee Organization, approximately 150 million of coffee bags were produced around the world in 2013 ("Coffee Exporting Countries: Total Production Crop from 2008 to 2013,"). The highest coffee producers are Brazil, Vietnam and Columbia. The amount of coffee waste is directly increasing in proportion to the coffee consumption growth. Coffee grounds are dealt with as household waste that may be incinerated and then moved to landfill. Although few coffee grounds are used as compost and deodorizer, they can be made into a renewable energy.

Coffee waste comprises of materials produced from the process of harvesting coffee until coffee production (Chalker-Scott, 2009). Examples of coffee waste are pulp and peel (from the coffee fruit or 'cherry'), coffee hulls and husk (covering the coffee bean or seed) and coffee effluent (the waste water used in several of the stages of coffee manufacture). These wastes had been used in many research studies mainly for agriculture(Chalker-Scott, 2009; Davies, 2011) and biofuel (Kwon, Yi, & Jeon, 2013; Oliveira, Franca, Camargos, & Ferraz, 2008). Coffee contains a tremendous number of chemicals, with over 1000 aroma compounds (Davies, 2011). 10% of coffee ground contains Nitrogen-rich protein that can help in seed germination and plant growth. The rich carbon-to-nitrogen composition in coffee ground which is 11:1 provides an ideal condition for plant growth (Chalker-Scott, 2009).

Beside its usages in crops plantation as organic fertilizers, oils can be extracted from coffee waste to produce biofuels (Abdullah & Bulent Koc, 2013; Bok, Choi, Choi, Park, & Kim, 2012; Oliveira et al., 2008; Passos & Coimbra, 2013; Romeiro et al., 2012; Tsai, Liu, & Hsieh, 2012). According to Abdullah and Koc (2013), the residue after brewing the coffee grounds contains 13% (db.) of oil. The oil contains fatty acid methyl ester which is similar to soybean oil. The oil from coffee waste can be extracted using Soxhlet extraction and two phase oil extraction.

Apart from oil extraction, coffee was can be torrefied to increase its thermochemical and physical properties (Tsai & Liu, 2013). It has been reported that torrefaction temperature has a significant impact upon thermochemical property and true density of coffee waste. In the study by Wen-Tien Tsai and Sii-Cew Liu (2013), the calorific value of the torrefied biomass increased with temperature (max Temperature; 563K or 290°C). As they increased the temperature from 563K to 593K, the carbon content in the coffee residue is significantly increased.

Table 1 shows the proximate elemental and chemical structure analyses of coffee waste. (Tsai et al., 2012)

Table 1: Proximate elemental and chemical structure of coffee waste

Properties	Coffee waste
Moisture (wt. %)	11.52±0.43
Volatile matter (wt. %)	79.52±0.01
Fixed carbon (wt. %)	8.23
Ash (wt. %)	0.73±0.20
Caloric value (MJ/kg)	23.5
Ultimate Analysis (wt. %)	
C	52.54±0.43
H	6.95±0.03
O	34.82±0.1
N	3.46±0.01
S	0.10
Chemical structure (wt. %)	
Helocellulose	47.2±0.2
Lignin	39.4±0.5

2.2. Biomass briquettes

A briquette is a block of flammable matter which is used as fuel to start and maintain a fire. During the first and second world wars, briquettes were discovered to be an important source of energy. Briquettes can be used for any thermal application where coal can be utilized. Biomass briquettes can be used as a fuel to displace firewood, charcoal, or other solid fuel (Nyer, 2012). Environmental and ecological problems are the major issues of concerns associated with exploitation of these fuels. As environmental awareness becomes more socially prevalent, many countries have shifted to a more sustainable and 'greener' energy sources. Compared to coal, biomass briquettes are said to produce lesser greenhouse gases such as carbon dioxide and nitrogen oxide (Singh, Kim, Kamide, & Sharma, 2009).

Apart from little effect on the environment, biomass briquettes served many advantages compared to natural fossil fuels. For instance, bio-briquettes are fairly resistant to water degradation. Water resistance plays an important role for transportation and storing purposes. Bio-briquettes made from biomass mixtures with coal and lignite have better physico-mechanial properties and combustion properties compared to coal or lignite alone. The bio-briquettes have lower ignition temperatures and serves well for boilers, combustors and cooking (Singh et al., 2009).

Briquettes can be made from agricultural waste such as sawdust, rice husk, coffee pulps, straw or hay and coconut shell. The availability of these agriculture waste means that biomass briquettes can be manufactured or produced from any countries. Several biomass briquetting programs have been demonstrated around the world such as China and India (Eriksson & Prior, 1990; Owen M., 2010; Singh et al., 2009; Stolarski et al., 2013; Wilaipon, 2009). The Legacy Foundation plays a big support in provide training, technology and media services for biomass fuel briquette production ("Legacyfound.org "). Figure 1 shows samples of briquettes made from different types and composition of biomass from a few countries.

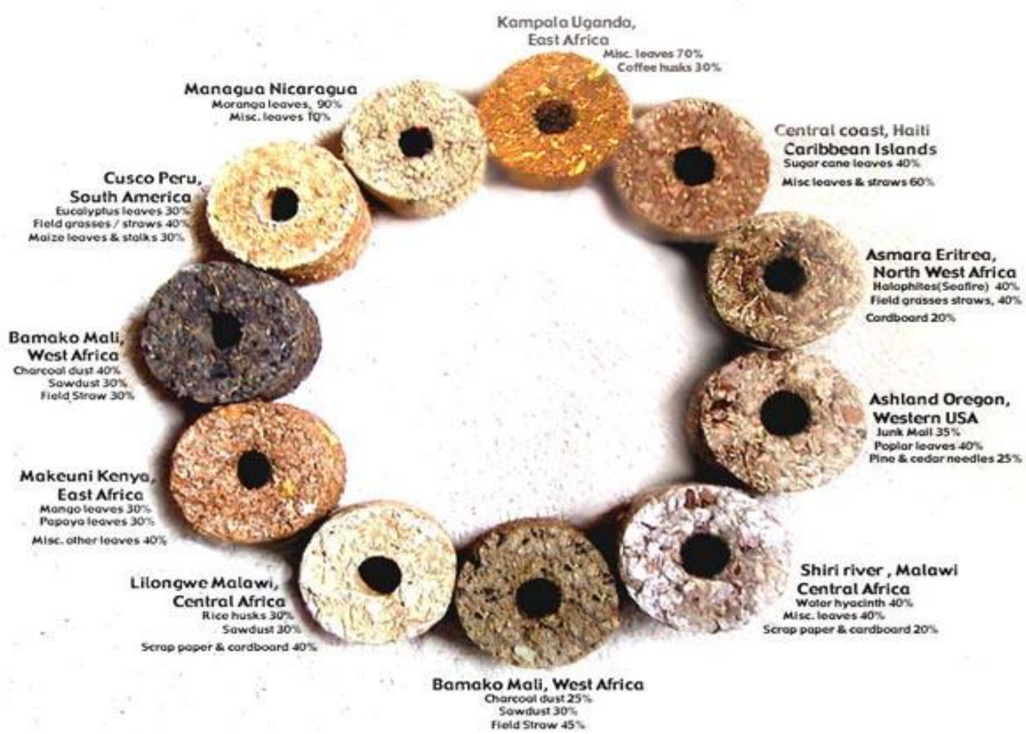


Figure 1: Samples of briquettes from around the world

Briquettes are produced using briquetting machine. The most common techniques used for briquetting are roller press (Singh et al., 2009), piston press and screw press machines (Eriksson & Prior, 1990). These machines use high pressure to transform loose biomass into compact solid biofuel. The briquetting produced by a piston press are completely solid while screw press briquettes have a concentric hole, which gives better combustion characteristics due to a larger specific area. The screw press briquettes are also homogenous and do not disintegrate easily. Having a high combustion rate, these can substitute for coal in most applications and in boilers. Briquettes can be produced with a density of 1200Kg/m^3 from loose biomass of bulk density 100 to 200 Kg/m^3. A higher density gives the briquette a higher heat value (KJ/Kg), and makes the briquettes burn more slowly as compared to the raw materials from which the briquettes are made (Pallavi.H.V, 2013).

There is no definite correlation to determine the right composition and type of binders and fillers for briquetting technique. Binder is a binding agent responsible to hold the briquettes together. The binding material can be any fibrous organic material. The material must be processed in order to hold and bind the briquette. Usually the materials will be soaked in water and partly decomposed. Fiber rich materials are recommended to be used as binder. A lot of different materials can be used for briquette-making, for example, agricultural residues like ground nut shells, straw, tree leaves, grass, rice and maize husks and banana leaves. Binder can either be used by itself or mixed with filler.

Coffee husk has been used as fillers in briquettes (Nyer, 2012; Pallavi.H.V, 2013). Unlike binder, filler is used to enhance the combusting performance of the briquette. For example, banana peel is used for binders while rice husk, maize cob, sugarcane bagasse or groundnut shell can be used as fillers (Idah & Mopah, 2013).

According Nyer (2012), there is no formula for how much binder and filler must be used for proper combustion. There are many factors that drive the necessary composition including how the material is prepared and the local preferences. Suggested test to determine whether the each composition of briquette is physically intact and formed a durable fuel is by squeeze test, expansion test and shake test. In his project, he used paper, cardboard, cow dung, corn husk and banana peel and binders. Sawdust and coffee husk are used as fillers. Each binder and filler was combined with and without the addition of charcoal fines in attempt to enhance the rate of combustion. The result shows that paper, cardboard and banana peel were the most effective binders after undergoing a set of integrity test.

Some of the briquette can consist of fillers alone. Mc Dougal et al. (2010) conducted a study on effect of briquette composition on heating value. They produced briquettes made entirely from wastepaper and another briquette made from mixture of wastepaper and biomass. Their result shows that wastepaper-biomass briquette with composition (3:1) has higher heating value than wastepaper briquette. Figure 2 shows the results obtained by Mc Dougal and friends. Based on the graph, they also compared the heating value of wastepaper briquettes with other biomass briquettes such as wood pallet and sawdust.

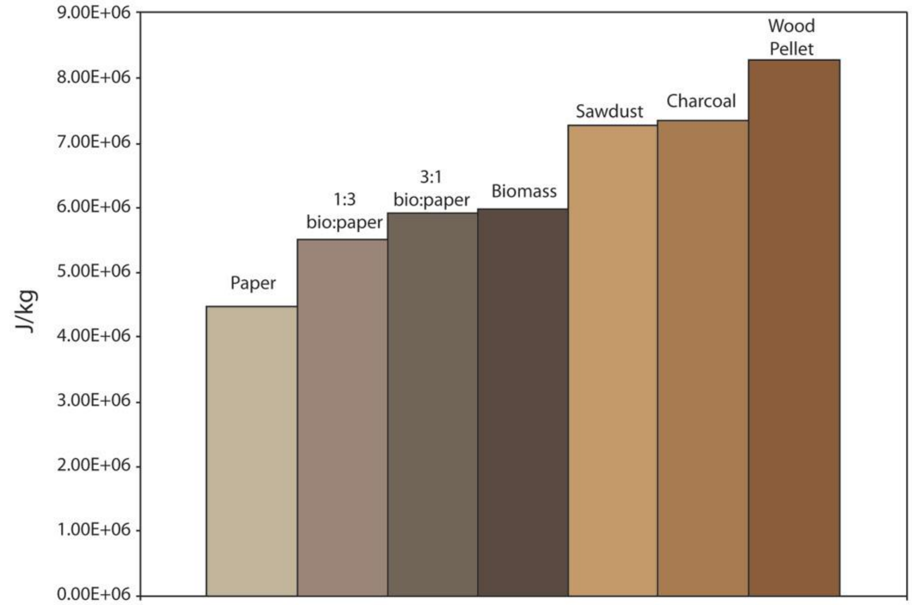


Figure 2: Caloric content of briquette (Mc Dougal et al., 2010)

2.3 Binder Selection

2.3.1 Rice husk

Rice husk is the outermost layer of protection enveloping a rice grain. It is a yellowish color and has a convex shape. Other names for rice husk are rice hull and chaff. Vietnam and Thailand are the largest rice producer in Asia, covering almost 92%. In 2013, approximately 5.4 million tons of raw husks are available in Vietnam alone. Rice husk can be taken for free or purchase in bulk from the rice husk seller such as ricehusk.com ("FAQ. Rice Husk Information.,") and Western Refractories Private Limited ("Expandable Rice Husk Ash,"). The rice husk can be torrefied (Huang, Chen, Chiueh, Kuan, & Lo, 2012; Wang, Huang, Chiueh, Kuan, & Lo, 2012) and used in making briquette (T.G. Ibrahim, 2012). Research conducted by D.B. Yahaya and T.G. Ibrahim (2012) shows that rice husk can be used as fillers instead of binders. They had produced two sets of rice husk briquette using starch and gum Arabic as binders. Based on Figure 2, their results showed that both set of rice husk briquette took 15 minutes to boil 2 liters of water comparative to firewood, it required 21 minutes to boil the same quantity of water.

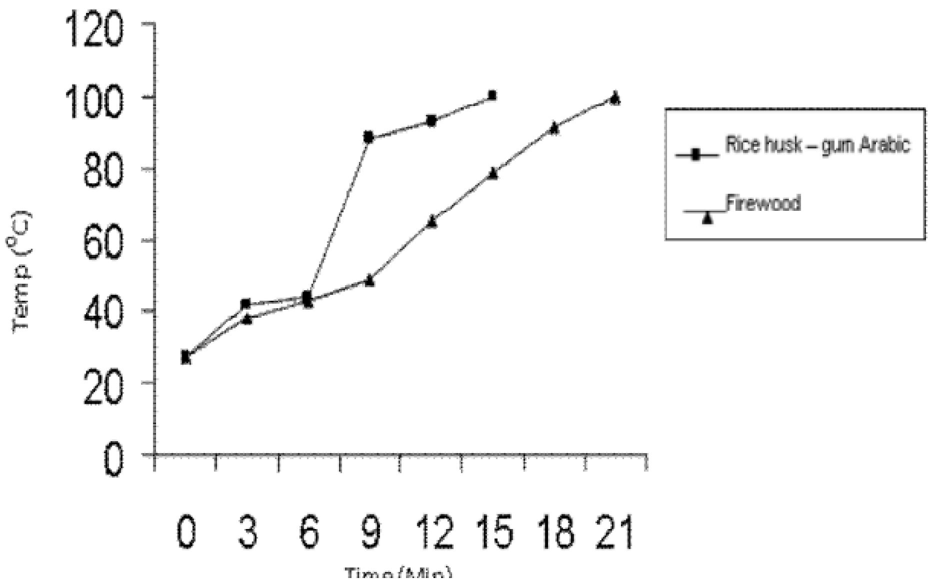


Figure 3: Water boiling test for rice husk binder Vs. Firewood

The general compositions of rice husk are given in the table 2 below:

Table 2: Proximate elemental and chemical structure of rice husk (Wang et al., 2012)

	Rice Husk
Moisture (wt. %)	6.44
Volatile matter (wt. %)	80.45
Fixed carbon (wt. %)	8.60
Ash (wt. %)	10.95
Caloric value (MJ/kg)	17.4
Ultimate Analysis (wt. %)	
C	44.04
H	6.55
O	43.94
N	0.24

2.3.2 Waste Papers

Paper is a material made of cellulose pulp derived mainly from wood or certain grasses. Waste paper can be found in many forms such as newspaper, office paper, magazine and cardboard. The composition polysaccharides of each waste are different to one another. Due to that matter, waste paper can be fermented to produce bioethanol (Wang L.). In terms of biofuel, waste paper is a common material used in biofuel briquette. Briquettes made entirely of shredded paper are soaked with just enough water to cover the material and left for a certain period of time. The amount of time required to soak the paper is depending on the ratio of biomass added to the waste paper. As the number of biomass to waste paper pulp increased, the amount of time required soaking the material for successful molding also increase (Owen M., 2010).

Table 3 shows the general composition of waste paper obtained from literature (Demirbaş, 1999). Demirbaş A. have conducted researches on waste paper and found that the optimum pressure for briquetting waste paper is 780 MPa. The moisture content for the briquette is 18%.

Table 3: Proximate elemental and chemical structure of waste paper

	Waste paper
Lignin (wt. %)	15.8
Cellulose (wt. %)	73.2
Ash (wt. %)	2.7
Caloric value (MJ/kg)	14.7
Ultimate Analysis (wt. %)	
C	44.7
H	6.1
O	48.1
N	0.4

2.4 Torrefaction

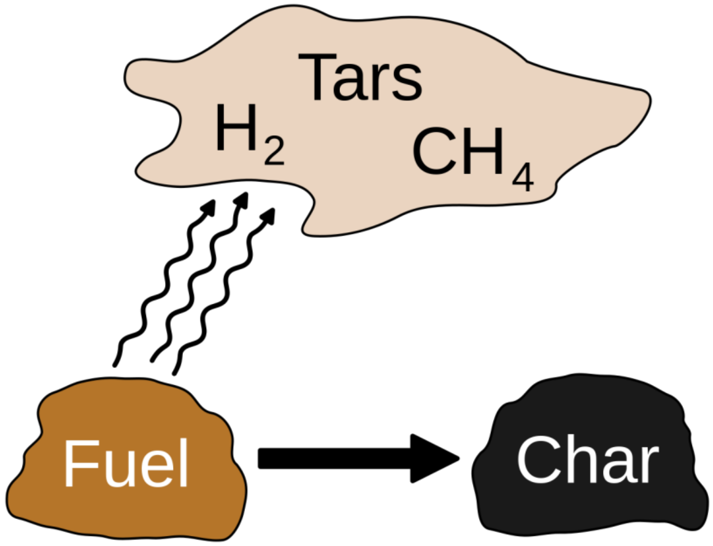


Figure 4: Torrefaction removes moisture and volatiles from biomass, leaving bio-coal.

Torrefaction of biomass was originally developed in the 1980s. The word torrefaction is derived from the French verb “torrefier”, meaning to roast, and is chiefly used for describing the process of roasting coffee beans ("On Torrefaction of Biomass,"). Itis a thermal pretreatment process where raw biomass is heated in an inert atmosphere at the temperature range of 200–300°C (Bergman & Kiel, 2005). Nitrogen is the most commonly used purge gas to provide a non-oxidizing environment (Chen, Lu, & Tsai, 2012). Torrefied products are said to be hydrophobic, preventing it from absorbing water during storage and making it resistant to rot and fermentation. Figure 4 shows during torrefaction process, the water contained and superfluous volatiles in biomass is removed to obtain a much better fuel quality for combustion and gasification applications. The volatiles are coming from the decomposition of biopolymers which are cellulose, hemicellulose and lignin.

Figure 5 and Figure 6 show the biomass of a wood chips before and after torrefaction. The shape of the torrefied woods remain the same but the physical appearance of the torrefied biomass differs in terms of color. Grind ability of biomass can be improved by torrefaction thus allow the product to be densified into pallets (A. Dutta). Pelletized torrefied products can be referred as briquette. The form is lighter, drier and stable in storage as opposed to the biomass they are made of. Figure 7 shows example of torrefied biomass in pellet form. Briquetting and pelletizing can increase the mass, energy density and improves the hydrophobic properties of the torrefied biomass.

Figure 5: Biomass before torrefaction

Figure 6: Biomass after torrefaction

Figure 7: Torrefied biomass in pellet form

A number of companies are testing various methods to produce high quality biomass using torrefaction such as Dutch Torrefaction Association, DTA ("Dutch Torrefaction Association "), Topell Energy ("Topell Energy BV,") and Energy research Centre of the Netherlands ("ECN,"). DTA is producing Biocoal, a torrefied biomass fuel that can replace traditional coal made from fossil fuel. The Biocal has many advantages such as biologically inactive, low chlorine and sulfur content and hydrophobic. In torrefaction process, the coffee is gently roasted up to temperature of 280°C until it becomes brittle and give its distinctive aroma (Ravilious, 2008). During this process, the substance is dried to humidity content of <5%. Figure 8 shows the color change of coffee beans as the torrefaction temperature increases. The final product is the remaining black dry solid which is referred to as “torrefied biomass” or “bio-coal”.

Figure 8: Torrefied coffee beans

Figure 9 shows the torrefier that can be found in Chemical Engineering Block (Block 4), Universiti Teknologi PETRONAS. The machine consists of a reactor, condenser, thermocouple, and gas tank which supply the Nitrogen gas.

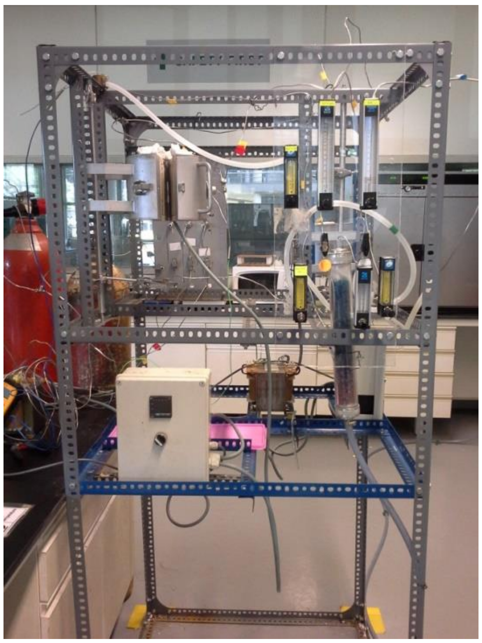


Figure 9: Torrefier

CHAPTER 3

METHODOLOGY

3.1 Samples

3.1.1 Waste coffee Grounds

Waste coffee ground samples were obtained from coffee shops around Ipoh, Perak. Most of the coffee shop owners use Arabica coffee beans. Approximately 500g of waste coffee ground samples were used in this study. Used coffee grounds do not store too well due to their high water content (Genziuk, 2011). Once the coffee wastes are collected, the grounds were pretreated by oven-drying at 105°C for 24 hours and kept in an airtight container. This is to prevent mold formation and protect from property changes.

3.1.2. Waste Papers

200g or more of waste paper is collected from any available resources. The waste paper is striped into pieces and then soaked in water until it turns into pulp. The soaked material is tested for readiness by pressing a scoop of the mash by hand. The mash that held its form in the palm of the hand is ready to be used for briquetting

3.1.3 Rice Husks

200g of rice husk is sieved to remove impurities such as pieces of wood, bone, metal and separate the dust into large and fine pieces. The large pieces of rice husk are grounded to a fine semi powder form. Just like waste paper, rice husk will be soaked in water until it turns into mash pulp.

3.2 Equipment

1. Oven

   Oven is used to dry the coffee waste. Oven drying for coffee waste briquette will be conducted if the sun drying is not sufficient to dry the product.

2. Torrefaction Machine (reactor)

   This reactor can be found in Block 4, UTP. Application of this equipment can be done under supervision from the postgraduate students.

3. Briquette Machine

   This equipment can be found in Block 16, UTP. Application of this equipment requires permission and guidance from the lab technician.

4. Bomb Calorimeter

   Bomb Calorimeter will be used to measure the calorific heat content of the briquettes and the torrefied coffee wastes.

5. Measuring jug

   Measuring jug is one of the equipment that will be used in water-boiling test. The jug is used to measure 200mL of water for each water-boiling experiment

6. Thermometer

   Thermometer is used to calibrate the degree of temperature produced when the briquette is combust during water-boiling test.

7. Stop watch

   Stop watch will be used to measure the time taken for the briquettes to boil 200ml of water and time take for it to completely burn into ash

8. Weighing balance

   Weighing balance is used to measure the weight of materials and briquettes.

3.3 Experimental procedure

In this study, there are three steps of experimental procedure which have to be conducted. The procedures of each of the experiment are nearly the same but with different types and composition of filler and binder. Experiment procedures are as per described below:

3.3.1. Binders Selection

The first stage of the experiment is to determine either rice husk or waste paper makes the best binder when mix with coffee waste. The end product of this experiment is to produce two sets of coffee briquettes using two different binders; rice husk and waste paper.

The compositions of filler to binder for both sets of briquettes are the same. The ratio for coffee waste to waste paper and coffee waste to rice husk is 50:50 (wt.)

The initial test to determine if the binder and filler has sufficient bond to hold together is by doing three sets of test (Nyer, 2011);

Squeeze Test: Place a small handful of the wet mixture in the palm of the hand and squeeze it. If any of the material oozes through the fingers then the material is too decomposed.

Expansion test: This test is done right after Squeeze Test. Open the hand and observes the mixture. If the material expands more than roughly 10% of its size then the material is not fully decomposed.

Shake Test: After the Shake Test, hold the top half of the material. Lightly shake the material vertically several times. If the material falls apart, there are not enough fibers holding the mixture together. New composition of binder to filler must be used.

Once the tests have been done, the materials then mold into briquette and left to dry. The dried briquette will be further tested using bomb calorimeter and water-boiling test. The binder that contributes to the better performance of coffee waste briquette will be used in the second and third stage of experimental work.

3.3.2 Composition of filler to binder selection

The second stage of the experiment is to determine the effect of composition of filler to binder. The composition ratio is manipulated according to the following

1. 70: 30 (wt. of waste coffee to wt. of binder)
2. 80: 20 (wt. of waste coffee to wt. of binder)

Similar to experimental procedure in stage 1, each mixture will undergo the three physical integrity tests (Nyer, 2011). After the material is mold into briquette, the efficiency of the two briquettes will be determined using bomb calorimeter and water-boiling test. Water-boiling test will be explained in **section 3.4.1.**

3.3.3 Torrefied and non-torrefied coffee briquette

The third stage of the experimental procedure is to determine the effect of torrefied and non-torrefied coffee briquette. The procedure for torrefaction of coffee waste is as follow:

1. Withdraw the condenser from oven, let it cool to room temperature
2. Weight to an approximate 3g of waste coffee ground
3. Insert the stand and glass wool into reactor
4. Place the waste coffee ground into the reactor
5. Attach the reactor to heater
6. Connect thermocouple to the reactor
7. Weight the condenser and connect it to the reactor
8. Flush the reactor with 100ml/min of Nitrogen gas for 15 minutes.
9. After 15 minutes, lower the gas flow rate to 30ml/min
10. Increase the temperature to desired level at 10°C/min
11. When reach the desired temperature, hold the temperature for 30 minutes
12. After 30 minutes, reduce the temperature to 20°C

In this experiment, the desired temperatures for this experiment are 260°C and 280°C. Therefore, the torrefaction of coffee waste will be done twice thus producing two sets of torrefied coffee waste briquettes. The calorific value of torrefied coffee waste is measured using oxygen bomb calorimeter.

It is noted that the binder selection and composition are based on the result obtained from experimental work stage 2 and stage 3. The briquetting process is similar for all stages

3.4 Experimental Analysis

The physical and combustion properties of the briquettes will be examined and recorded.

3.4.1 Water boiling test

The water boiling test measures the time taken for a briquette from different drying methods to heat and boil 200ml of water. The first two samples (from stage 1) are stacked in a fabricated stove. (Coffee waste-waste paper) briquette is stacked in the first stove with (coffee waste-rice husk) is stacked in another stove. Two aluminum pots containing 200ml of water each were mounted on the stoves. The stoves were ignited and as soon as the flames were stabilized for two minutes, a stop watch was activated. The initial temperatures of the water were noted and thereafter readings were obtained at 3 minutes interval using a thermometer. During this process, the amount of smoke produced, flame characteristics and length of time taken for the briquettes to burn completely into ashes are observed and recorded. The water boiling test was terminated after attaining boiling point. The accumulated soot is removed by washing the stove. With similar process, the results from the second and third stage of the experiment will be used and the procedure is repeated.

3.5.2 Percentage volatile matter (PVM)

To determine the PVM, 2g of briquettes sample in a crucible were placed in the oven until a constant weight is obtained. The briquettes were now kept in the oven at a temperature of 550°C for 10 minutes and weighed after cooling and the PVM was determined with the formula:

$$PVM = \frac{B - C}{B} X\ 100\%$$

Where;

B is the weight of oven dried sample and

C is the weight of sample after 10min in the furnace at 550°C

3.5.3 Percentage Ash content (PAC)

The PAC was also determined by heating 2g of the briquette sample in the oven at a temperature of 550°C for 4hrs and weighed after cooling. The PAC was determined:

$$PAC = \frac{D}{B} X\ 100\%$$

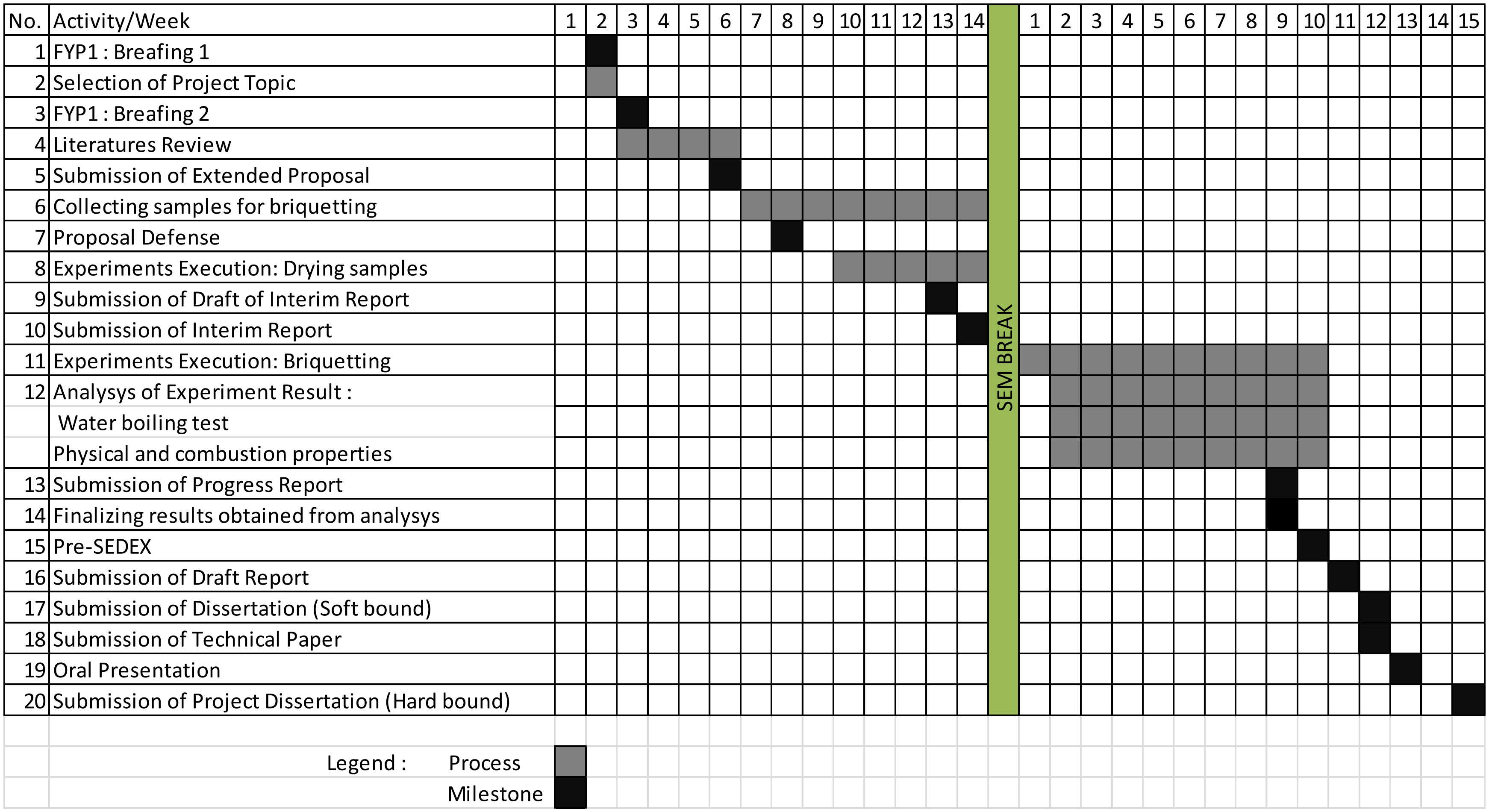
Where D is the weight of ash and B is the weight of oven dried sample

3.5.3 Percentage fixed carbon (PFC)

The PFC was calculated by subtracting the sum of percentage volatile matter (PVM) and percentage ash content (PAC) from 100

$$PFC = 100 - (PVM + PAC)$$

3.6 Gantt Chart



CHAPTER 4: RESULTS AND DISCUSSION

4.1 Binder Selection

Three tests have been done to predetermine the feasibility of using waste paper and rice husk as binder for coffee waste. A simple press machine is used to make the briquette. The hand press machine is self-fabricated using caulk gun, poly vinyl chloride pipe (PVC), rubber stopper and wire mesh filter. The PVC is predrilled with holes and placed in the caulk gun. The presoaked mixture is loaded into the PVC pipe and compressed by squeezing the trigger. The compaction occurred as the plunger move along the gun, squeezing out the water from the mixture. The compression reaches its final pressure once the trigger is stuck. The mold is manually pushed out of the PVC and placed onto a drying tray.

It has been observed that the combination of rice husk and coffee waste have failed the three consecutive tests which are squeezing, expanding and shaking test. Despite the size of the rice husk has been reduced to semi powder form, the mixture is not well blend with each other and difficult to stay intact during briquetting. As shown in figure 10, the product of the combination of rice husk and coffee waste is very brittle and likely to reform back to powder form once they are dried. Thus, no briquette is successfully obtained from this mixture. It should be stressed that rice husk can be a good material for briquette production however; it is merely suitable to be used as binder. As been cited in the literature review, rice husk is mixed with other binding material to form a better quality briquette.

Coffee waste and waste paper have passed the squeezing, expansion, and shake test. It has been observed that the mixture is easy to blend with each other once the waste papers turned into slurry. The briquettes obtained from the mold after oven drying were strong and well formed. The product of 50g of coffee waste and 50g of shredded waste paper can produce 6 small blocks of briquettes. The total weigh of the briquettes is 76.34g.

The efficiency of this briquette is tested based on its percentage volatile matter (PVM), percentage ash content (PAC), percentage fixed carbon (PFC) and heating value (Hv). The results for these parameters are shown in Table 4;

The first stage of this project has shown that waste paper is the right material to be used as binder for the production of briquette from coffee waste. From this on forward, waste paper is be used for the second and third stage of experimental project.

Figure 10: Mixture of coffee waste and rice husk failed to bind together

Figure 11: Briquette made from coffee waste and waste paper

4.2 Composition of Filler to Binder Selection.

An approximate weight of 100grams mixture of coffee waste and waste paper is used as dry basis. In this experiment, old newspaper is used as binder. The paper is weighted accordingly before they are shredded into small pieces and left to soak in water for 24 hours.

The first composition mixture is conducted using 80:20 part coffee waste to waste paper. The briquette is produced by mixing 20g of waste paper and 80g of coffee waste. During the physical integrity test; squeezing, expanding and shaking, the mold has passed the tests and the briquetting is well done. This mixture has produced 6 blocks of briquettes with the total weight of 112.20g (dry weight).

The second composition mixture is conducted using 70:30 part coffee waste and to waste paper. 70g of coffee waste is mixed with 30g of waste paper. As the same as the first mixture, the second mixture also passed the physical integrity test. The product from this mixture produce 9 blocks of briquettes with the total weight of 91.20g.

Figure 12 and 13 shows production of briquette at different composition mixture

Figure 12: Coffee waste - waste paper briquette at 70:30 mass ratios

Figure 13: Coffee waste - waste paper briquette at 80:20 mass ratios

4.3 Briquette properties analysis

The summary of the effect on composition of filler to binder is tabulated in Table 4. **Appendix 4-1** until **Appendix 4-3** shows the calculation to obtain the value of these properties.

Table 4: Properties of coffee waste and waste paper briquette

Properties of briquettes	Mixture of coffee waste and waste paper				
	50:50	70:30	80:20	260°C	290°C
Volatile matter, PVM (%)	2.26	2.31	2.66	2.50	2.60
Ash content, PAC (%)	97.17	96.83	96.55	96.92	96.77
Fixed carbon, PFC (%)	0.57	0.86	0.79	0.58	0.63
Calorific Heat Value (J/g)	16325	18656	19656	21315	23061

To observe the differences in properties between each briquette, a set of graphs are prepared as below.

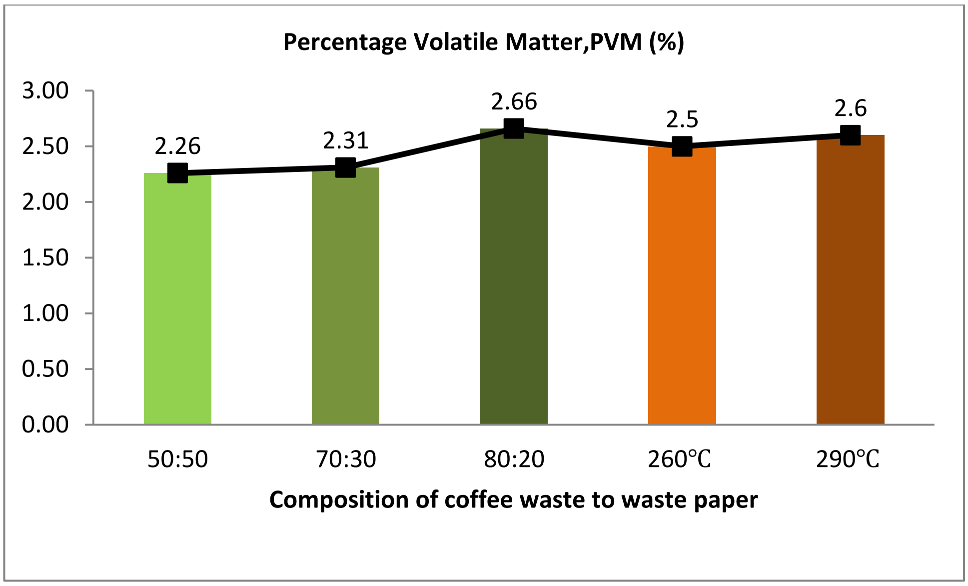


Figure 14: Percentage volatile matter of coffee waste briquette

Figure 14 shows the percentage volatile matter of coffee waste briquette with different composition to waste paper. For the non-torrefied coffe briquette, the briquette with composition ratio 80:20 has the highest percentage of volatile matter which is 2.66%. This value is significantly higher than the other two samples. The lowest percentage volatile matter is 2.26% for the briquette with composition ratio of 50:50. The briquette with composition of 70:30 coffee wastes to wastepaper has a PVM value of 2.31%.

The briquette for torrefied coffee waste has little variation on percentage volatile matter compared to the non torrefied coffee waste (80:20). Both sets of torrefied briquette have PVM value lower than the non torrefied coffee was briquette by 5%.

Volatile matter content has significance influence on the burning characteristic of biofuel (Loo, 2008). According to Pallavi H.V et. al (2013), fuels with high volatile matter have low heating value and a good quality charcoal should have volatile matter range from 20 to 25%. Pallavi and his colleagues have conducted a research on briquetting agricultural waste using coffee husk and bagasse and compare them with commercial wood charcoal. They have found that coffee husk has the lowest volatile matter with 23% while wood charcoal has the highes PVM value with 37.59%. Briquette with high volatile content is easier to ignite but may burn with smokey flame while low volatile briquette is difficult to ignite and burns with less smokes. The fuels related to smokeless grade are known to contain no more than 20% volatile substances (Inavov et al., 2003).

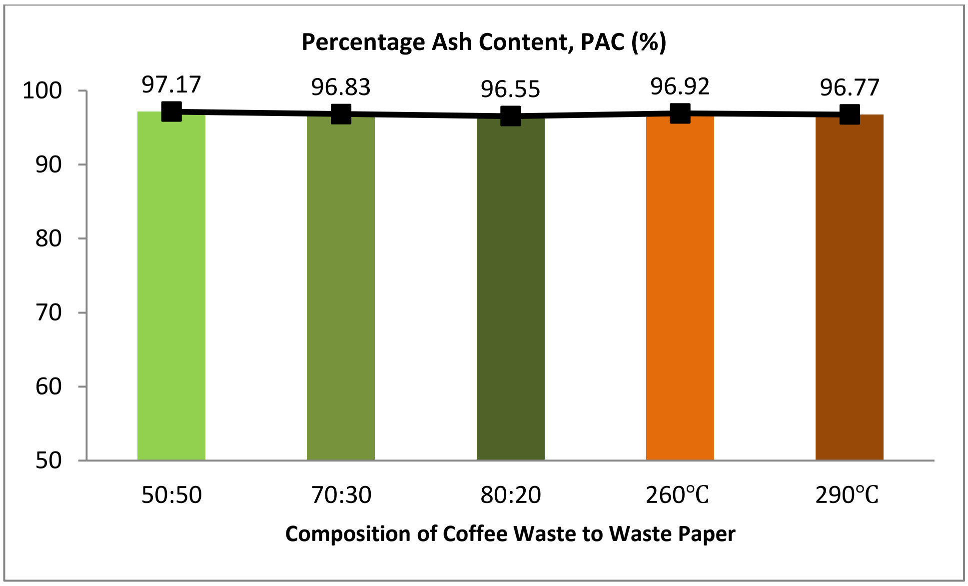


Figure 15: Percentage ash content of coffee waste briquette

The graph in figure 15 shows the percentage of ash content for 5 sets of briquette. The least percentage of ash content for non torrefied coffee briquette was recorded for the briquette with composition of 80:20 which is 96.55%. The value is significantly lower than the other two briquettes due to higher content of coffee waste and less waste paper. In general, waste paper produce high content of ash when burn. The briquette with high composition of waste paper which is 50:50 has the highest percentage of ash content; 97.17%. This is followed by the briquette with ratio 70:30 that has a value of 96.83% for ash content. Taking basis of filler to binder composition of 80:20, the product of torrefied coffee waste briquette at both temperature shows minimum effect on the ash content. Nevertheless, torrefied coffee at 290°C produces lower ash content than torrefied coffee at 260°C by 15%.

Ash content in the briquette normally causes an increase in the combustion remnants in the form of ash, thereby lowering the heating effect of the briquette (Ivanov et al., 2003). It takes in form of impurity that will not burn therefore have significant influence on the heat transfer to the surface of a fuel as well as the diffusion of oxygen to the fuel surface during combustion. In general, ash content for a good quality charcoal should be ranged from 3 to 4% (Pallavi.H.V, 2013). The higher the briquette’s ash content, the lower its calorific value (Loo, 2008). Based from the results obtained, it can be said that all the briquettes are not fit to be used for combustion. Briquettes with high ash content are not suited for thermal utilization as they produce higher dust emission and affect the combustion volume and efficiency. The high value may be due to some errors while conducting the experiment and result calculations.

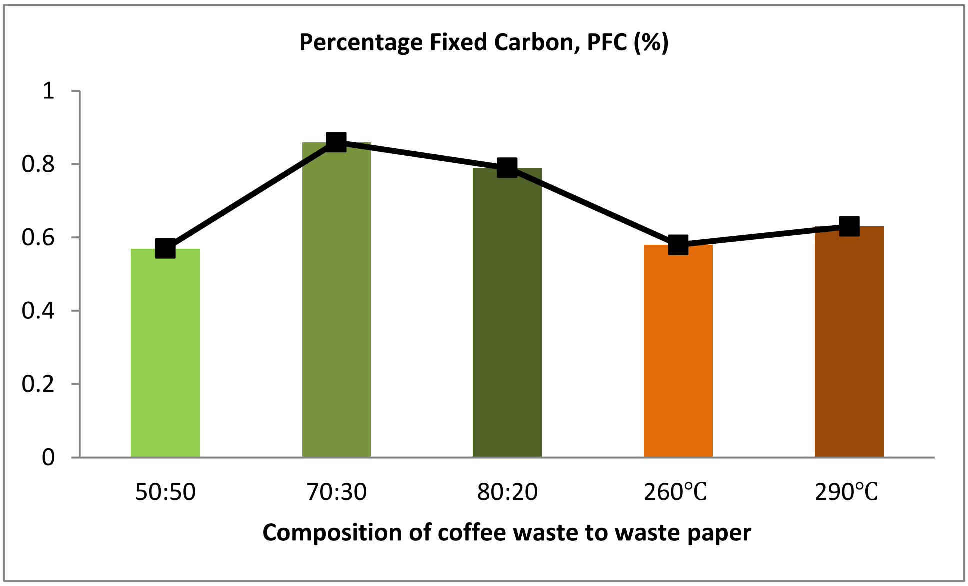


Figure 16: Percentage fixed carbon of coffee waste briquette

The graph in figure 16 shows the percentage of fixed carbon for the three different compositions of coffee waste briquette. The fixed carbon content is the carbon found in the briquette which is left after volatile matter driven off. It gives a rough estimation of the heating value of a briquette and acts as the main heat generator during burning.

The coffee waste-waste paper briquette produced from ratio 50:50 had a fixed carbon of 0.57% and the carbon content produced from briquettes with ratio 70:30 and 80:20 are 0.56% and 0.79% respectively. The torrefied coffee waste briquette at 260°C has the lowest PAC value of 0.58% while torrefied briquette at 290°C has a PFC value of 0.63%

Briquettes having low carbon content are favorable as they are environmental friendly and safe for users. However, the results obtained from this experiment shows PFC values less than 10% which is too low compared to commercial briquette. Generally, a fuel would have PFC value higher than 50%. Coffee husk briquette has PFC value of 63.9% (Pallavi.H.V, 2013). Paper briquette has a fixed carbon content of 18.2% (Ch. A. I. Raju, U.Praveena, Satya, Jyothi, & Rao, 2014). Fuels having high volatile matter is said to have has lower fixed carbon which tends to be harder, heavier, stronger and easier to ignite than fuel having high fixed carbon (Pallavi.H.V, 2013). However, the result from this experiment shows different trend whereby briquette with composition ratio of 80:20 having the highest PVM value also has the highest PFC value.

4.4 Calorific heat value for coffee waste briquette.

A bomb calorimeter is used to measure the calorific heat value for each briquette samples. The result from the experiment is shown in figure 17.

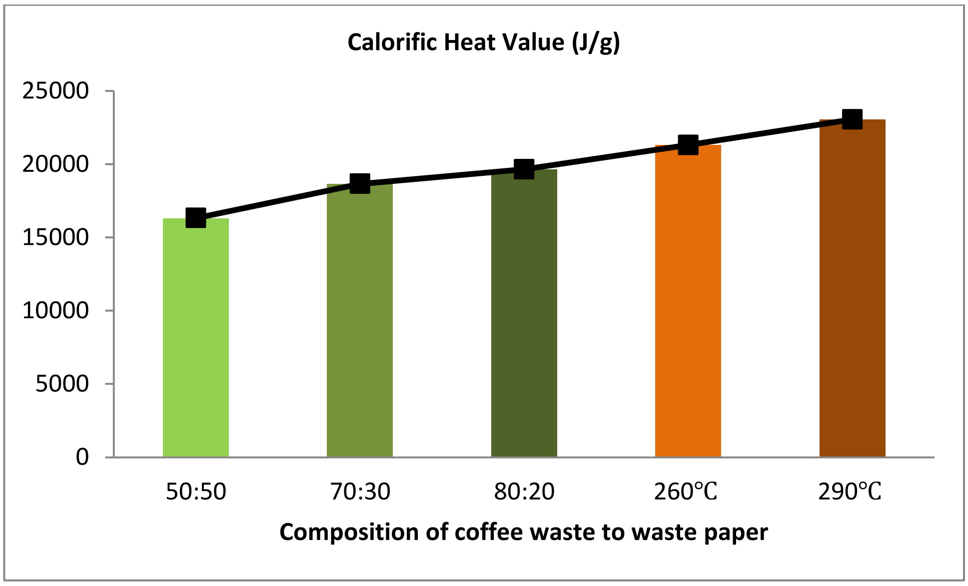
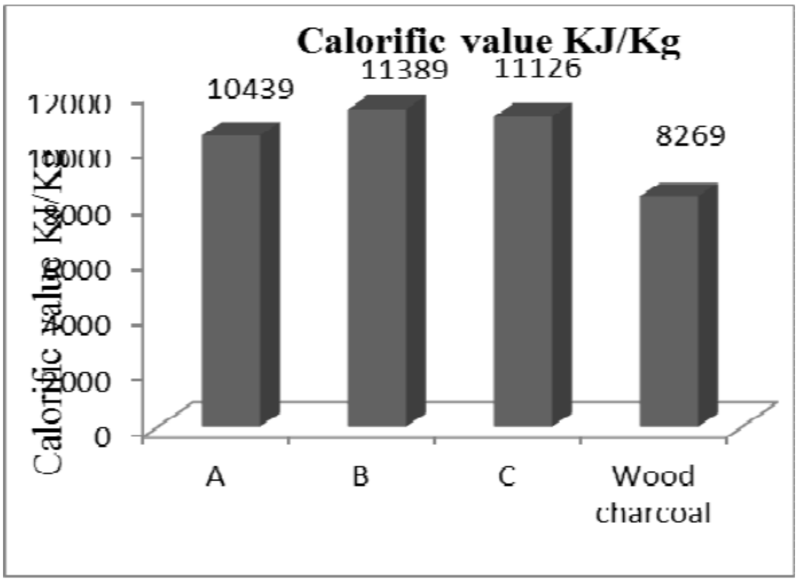


Figure 17: Calorific Heat Value of coffee waste briquette



A Bagasse; B Coffee husk; C Mixture of bagasse and coffee husk in the ratio of 3:1

Figure 18: Calorific values of briquette charcoal and wood charcoal (Pallavi et al., 2013)

The caloric value of the briquettes increased with increasing content of coffee waste. The lowest value was found to be 16325 J/g for briquette with a composition of 50:50; part to coffee waste to waste paper. The calorific value for coffee waste briquette with composition 70:30 is 18656 J/g. The briquette with composition 80:20; coffee waste to waste paper has the highest calorific content which is 19656 J/g. It should be noted that, effective thermal output can be achieved by increasing the surface area of the sample. In this experiment, approximately 15g of briquette sample is grated to increase the surface area for combustion. Figure 18 is used as comparison for calorific heat value of coffee husk and mixture of coffee husk and bagasse briquette. The calorific value of briquettes produced from bagasse and coffee husk was found to be 10439 KJ/Kg and 11389 KJ/Kg respectively. Briquettes produced from coffee husk have greater calorific value. The briquette produced from the mixture of bagasse and coffee husk in the ratio 3:1 had a calorific value of 11126 KJ/Kg. This experiment shows that mixture of two biomasses does not necessarily increase the calorific value of the briquette. Nevertheless, the briquette with higher content of coffee waste produce higher energy output than the briquettes with lower coffee waste content.

Torrefied coffee briquette successfully prove that torrefaction does increase the calorific heat value. As the torrefied temperature increase, the calorific heat value also increase In fact, the value are significantly higher than the non torrefied waste by 10,000 J (10kJ).

4.4 Performance on the Water boiling Test

Water boiling test have been conducted for three different compositions of coffee waste to waste paper. The results obtained from the test are shown in the tables 5 and 6 below.

Table 5: Coffee waste - waste paper briquette (50:50 wt. %)

	(50:50 wt. %0	(70: 30 wt. %)	(80:20 wt. %)
Time (min)	Temperature (℃)	Temperature (℃)	Temperature (℃)
0	31.9	32.1	34.3
3	39.3	39.7	37.5
6	50.7	48.3	40.0
9	61.4	55.7	44.8
12	61.6	57.8	46.0
15	61.9	62.4	50.5
18	62.0	64.5	58.9
21	62.0	65.0	60.2
24	59.6	66.1	63.3
27	55.1	65.3	65.7
30	52.0	64.0	66.7

Table 6: Water boiling test for torrefied coffee waste briquette

	260℃	290℃
Time (min)	Temperature (℃)	Temperature (℃)
0	32.2	31.5
3	54.3	58.1
6	65.3	65.5
9	71	70
12	74	75
15	75.6	76.43
18	77.5	77.8
21	78	78.8
24	77.8	79
27	77.1	78.5
30	76	77.96

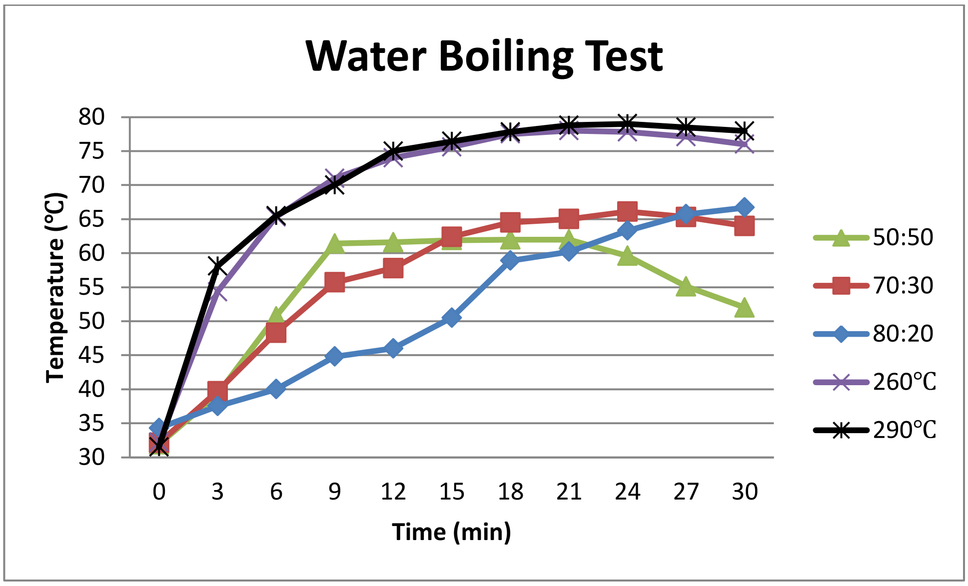


Figure 19: Water boiling test

Figure 19 shows the result obtained from water boiling test for the five sets of briquette. None of the briquettes are able to boil the water up to boiling point. It can be seen from the graph that the torrefied coffee waste briquette attained a temperature of ranging between 50°C and 60°C in 3 minutes while the non-torrefied briquette attained a temperature between 30°C and 40°C at the same time interval. In 15 minutes, the temperature of the water for torrefied coffee waste briquettes rose to 77°C, followed by 78°C in 21 minute and finally almost reaching its highest temperature; 79°C in 24 minutes. Compared to non-torrefied briquette (80:20) which burns slowly from 40°C in 6 minutes, 50.5°C in 15 minutes and finally 66.7°C in 30 minutes. From the result obtained it can be seen that all briquettes starts to decrease in temperature when reaching minute 30. Nevertheless, the torrefied coffee waste briquette shows better performance than the non torrefied briquette.

CHAPTER 5: RECOMMENDATION

Throughout this project, the author believes that this project can be further improved in the future. To obtain better quality result, the author would like to recommend as propose:

1. Water boiling test

   The current project solely examines the rise in temperature as the briquette heat the water. It is observed that none of the samples able to heat the water until it reaches the boiling point. In order to achieve the boiling point, we can reduce the volume of water or increase the load of briquette used for heating. For small size briquette, it is recommended to use less volume of water and vice versa.

   We can also examine how many loads of briquette required to boil specific volume of water and compare it with the commercial fuel. For example, how many grams of briquette and charcoal required to boil 1 Liter of water?

2. Rice husk as binder

   Rice husk can be used for production of briquette by reducing the particle size and prolonged the soaking period. The particle size for rice husk used in this project is 500 μm thus we can reduce it to 250 μm. (Ismaila et al., 2013)

3. Briquette property analysis

   The result obtained for percentage fixed carbon (PFC) and percentage ash content (PAC) in this experiment shows that all the sample briquettes are not comparable with the commercial type briquettes and not suited to be used for good combustion. The values are either far lowers (PFC) or higher (PAC) from the acceptable range. In order to get consistent results, it is recommended to use other standard formulas to find PFC and PAC and conduct the experiment using furnace and weighing balance with care.

CHAPTER 6: CONCLUSION

The main purpose of this project is to study the feasibility of briquette made from coffee waste. The binding materials used for briquetting are rice husk and waste paper is selected because they are easily available and commonly used in biomass fuel. However, waste paper is chosen as binder as the product is perfectly binds the material together an able to combust. Based on the briquette property test, the best composition for the filler to binder mixture is 80:20 which for this project; the author has used 80g of coffee waste and 20g of waste paper. This composition acts as basis for composition of torrefied coffee waste briquette. Due to the conflict of correlation between the two properties; PFC ad PAC for the non-torrefied briquettes, the author decided to use the results from the water boiling test for as the basis for composition mixture of filler to binder for torrefied coffee waste briquette. Torrefaction of coffee waste at 260℃ and 290℃ has significant effect on the calorific value of the briquette. As the composition of coffee waste to the mixture increase, the calorific heat value of the briquette also increases.

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APPENDICES

APPENDIX 4-1

1. **PVM calculation for briquette composition 50:50 (coffee waste to waste paper)**

	Weight (g)
Weight of oven dried sample	63.2626
Weight of sample after 10 mins in the furnace	61.833

$$\text{Percentage Volatile Matter} = \frac{63.2626 - 61.833}{63.2626} \text{ X } 100\%$$

$$= 2.26\%$$

2. **PVM calculation for briquette composition 70:30 (coffee waste to waste paper)**

	Weight (g)
Weight of oven dried sample	61.2599
Weight of sample after 10 mins in the furnace	59.8418

$$\text{Percentage Volatile Matter} = \frac{61.2599 - 59.8418}{61.2599} \text{ X } 100\%$$

$$= 2.31\%$$

3. **PVM calculation for briquette composition 80:20 (coffee waste to waste paper)**

	Weight (g)
Weight of oven dried sample	56.9681
Weight of sample after 10 mins in the furnace	55.4529

$$\text{Percentage Volatile Matter} = \frac{56.9681 - 55.4529}{56.9681} \text{ X } 100\%$$

$$= 2.66\%$$

4. PVM calculation for torrefied coffee waste briquette at 260℃

Binder: Waste Paper

Composition filler to binder mass ratio: 80:20

	Weight (g)
Weight of oven dried sample	64.9064
Weight of sample after 10 mins in the furnace	63.2831

$$\text{Percentage Volatile Matter} = \frac{64.9064 - 63.2831}{64.9064} \text{ X } 100\%$$

$$= 2.50\%$$

5. PVM calculation for torrefied coffee waste briquette at 290℃

Binder: Waste Paper

Composition filler to binder mass ratio: 80:20

	Weight (g)
Weight of oven dried sample	62.1464
Weight of sample after 10 mins in the furnace	60.5612

$$\text{Percentage Volatile Matter} = \frac{62.1464 - 60.5612}{62.1464} \text{ X } 100\%$$

$$= 2.6\%$$

APPENDIX 4-2

1. **PAC calculation for briquette composition 50:50 (coffee waste to waste paper)**

	Weight (g)
Weight of oven dried sample	63.2626
Weight of ash	61.475

$$\text{Percentage Ash Content} = \frac{61.475}{63.2626} \text{ X } 100\%$$

= 97.17%

2. **PAC calculation for briquette composition 70:30 (coffee waste to waste paper)**

	Weight (g)
Weight of oven dried sample	61.2599
Weight of ash	59.3202

$$\text{Percentage Ash Content} = \frac{59.3202}{61.2599} \text{ X } 100\%$$

= 96.83%

3. **PAC calculation for briquette composition 80:20 (coffee waste to waste paper)**

	Weight (g)
Weight of oven dried sample	56.9681
Weight of ash	55.0016

$$\text{Percentage Ash Content} = \frac{55.0016}{56.9681} \text{ X } 100\%$$

= 96.55%

4. **PAC calculation for briquette composition torrefied coffee waste briquette at 260**℃

   Binder: Waste Paper

   Composition filler to binder mass ratio: 80:20

	Weight (g)
Weight of oven dried sample	64.9064
Weight of ash	62.9084

$$\text{Percentage Ash Content} = \frac{62.9084}{64.9064} \text{ X } 100\%$$

= 96.92%

5. **PAC calculation for briquette composition torrefied coffee waste briquette at 290**℃

   Binder: Waste Paper

   Composition filler to binder mass ratio: 80:20

	Weight (g)
Weight of oven dried sample	62.1464
Weight of ash	60.1360

$$\text{Percentage Ash Content} = \frac{60.5631}{62.1464} \text{ X } 100\%$$

= 96.77%

APPENDIX 4-3

1. **PFC calculation for briquette composition 50:50 (coffee waste to waste paper)**

   Percentage fixed carbon = 100 - (PVM+PAC)

   = 100 – (2.26+97.17)

   = 0.57

2. **PFC calculation for briquette composition 70:30 (coffee waste to waste paper)**

   Percentage fixed carbon = 100 - (PVM+PAC)

   = 100 – (2.31+96.83)

   = 0.86

3. **PFC calculation for briquette composition 80:20 (coffee waste to waste paper)**

   Percentage fixed carbon = 100 - (PVM+PAC)

   = 100 – (2.66+96.55)

   = 0.79

4. **PFC calculation for torrefied coffee briquette at 260℃**

   Percentage fixed carbon = 100 - (PVM+PAC)

   = 100 – (2.5+96.92)

   = 0.58

5. **PFC calculation for torrefied coffee briquette at 290℃**

   Percentage fixed carbon = 100 - (PVM+PAC)

   = 100 – (2.6+96.77)

   = 0.63