CHARACTERISTICS STUDY OF EFB BRIQUETTES AND ITS POTENTIAL USE AS DUAL FUEL IN CVCC

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently

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ABSTRAK

Sebagai sumber tenaga yng diperbaharui, biojisim mempunyai potensi untuk menggantikan bahanapi fosil dalam automotive dan penjanaan kuasa. Dalam kajian ini, gugusan buah kosong (EFB) digunakan sebagai sumber biojisim untuk dikaji di dalam ruang pembakaran kelantangan malar (CVCC). Batasan kepada biojisim berserabut iaitu mepunyai jisim dari 80-100kg/m^3 yang memberi kesusahan unruk meyimpan dan mengedar. Salah satu cara untuk meningkatkan kualiti ciri biojisim dengan menggunakan kaedah pemandatan atau dipanggil sebagai pembuatan briket. Mesin tekanan penggelek telah digunakan dalam proses pembriketan unruk menukar EFB kepada briket bantal. Briket bantal berdasarkan ciri EFB mengikut perbezaan peratusan air dan pengikat kanji ubi. Tetapi proses pembriketan tidak menjadi kerana biojisim berserabut memerlukan lebih mampatan untuk menjadi briket. Jadi, briket secara manual telah dijalankan yang mana memberi lebih takanan mampatan iaitu 100kPa berbanding dengan mesin pembriketan bantal yang hanya 40 kPa. Pembriketan secara manual menggunakan acuan yang akan dimampatkan dengan tukul untuk menghasilkan briket silider dengan komposisi air dan pengikat yang baru. Ciri kualiti seperti kekuatan mampatan dan jumlah kalori EFB dilakukan dengan ujian mampatan beban dan ujian calorimeter. Berdasarkan keputusan, briket EFB dengan campuran komposisi 120% air dan 30% kanji ubi mempunyai jumlah kalori yang paling tinggi iaitu 17.394 MJ/kg dan paling tinggi bagi beban mampatan maxima iaitu 939.66 N. Proses ini patut diteruskan dengan mengeluarkan pengeluar gas dari briket EFB to bekalkan kepada CVCC tetapi ada kekangan yang tidak boleh dielakkan. Dalam kajian ini, pengeluar gas sudah digantikan dengan gas petroleum cecair (LPG) untuk dijalankan dalam CVCC dengan diesel dalam mod bahanapi dwi untuk mengenal pasti ciri semburan dan pembakaran. Teknik visualisasi untuk mengukur ciri sembuan makroskopik seperti penembusan hujung semburan, sudut kon semburan dan lebar spray. Tekanan suntikan diesel divariasikan dari 6O MPa, 80 MPa dan 100 MPa dan disuntik ke dalam CVCC dengan LPG dibakar. Penembusan hujung untuk 100 MPa dan 80 MPa mempunyai nilai yang sama iaitu 57 mm kerana mencapai hujung jejari CVCC tetapi sudut kon semburan untuk 100 MPa paling tinggi jumlahnya yang mempengaruhi lebar semburan. Tekanan suntikan 100 MPa menhasikan api kuning yang paling besar.

ABSTRACT

As a renewable energy, biomass has potential to replace depletion of fossil fuel for automotive and power generation applications. In this study, empty fruit bunch (EFB) is used as a biomass source to become the producer gas to test into constant volume combustion chamber (CVCC). The limitations of fibrous biomass have low bulk density from 80-100kg/m^3 that give difficulties to store and transport. One of the methods to improve the biomass characteristic by using the densification process or called briquetting. Roller press machine was used in briquetting process to convert the EFB into pillow-briquette. The pillow-briquettes is based on EFB characterized at different percentage of water and binder of tapioca starch. But the briquetting process was failed due to fibrous biomass need more compression to become a briquette. So, manually briquette has been done which provide more compaction pressure of 100 kPa compared to pillow briquetting machine of 40 kPa. The manual briquetting used a mold that compacting with hammer to produce cylindrical briquette with new composition of water and binder. The quality characteristic such as compressive strength and calorific value of EFB has been done via compressive load test and calorimeter test. Based on the result obtained, EFB briquette with composition of mixture 120%W and 30%S has the highest calorific value which is 17.394 MJ/kg and highest maximum compressive load which is 939.66 N. This process should further to produce the producer gas from EFB briquette to supply into the CVCC but there is some constraint that cannot be avoided. In this study, the producer gas that had been replaced by liquified petroleum gas (LPG) to run in the CVCC with diesel to identify the spray and combustion characteristic. The visualization technique to measure the macroscopic spray characteristic such as spray tip penetration, spray cone angle and spray width. The injection pressure of diesel was varied from 60 MPa to 100 MPa and injected to the CVCC with combusted LPG. Tip penetration of 100 MPa and 80 MPa have the same value which is 57 mm due to maximum radius of CVCC but spray cone angle of 100MPa has the highest value which is 11.7mm thus affected the widest width of spray. In addition, the injection pressure of 100MPa of diesel produced biggest yellow flame.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Overview

In this chapter, it covers the introduction of biomass, biomass as a renewable energy, densification process of biomass and lastly the utilization of biomass as part of fuel in internal combustion engine (ICE).

1.1.1 Introduction to Biomass

Energy is used to perform work, by converting it from one form to another which we can use, such as burning coal to produce heat. Energy can be divided into two categories which are renewable and non-renewable resources. The examples of renewable resources are wind, wave biomass, geothermal and solar energy. While, for non-renewable resource is fossil fuels such petroleum oil, coal and natural gas. Today, most of the energy are strongly dependent upon non-renewable energy resources for operation of transportation, factories and power generation. As fossil fuels diminish over time and their use can negatively affect the environment which releases a lot of harmful gas called carbon dioxide CO_2 when it burned, the uses of renewable energy should be considered as main source to partially replace or complement the use of fossil fuel since they can be used again and again and making less damaging the environment.

Biomass is a suitable alternative to replace fossil fuel because it offers energy security, good waste management and reduces greenhouse gases emission. Biomass is an organic matter produced by plants, there derivatives and from animal and human waste. It can be considered as a carbon-neutral fuel, because plants and trees extract carbon dioxide (CO_2) from the atmosphere and store it while they grew up and when this biomass is used in various application for energy production then they release $CO_2$to atmosphere and at the same time it is balanced by capturing CO2 for growth plant and trees[1]. The source of biomass fuel are crops residues, forest waste, animal waste, municipal solid waste, food waste, plant waste and vegetable seeds. Biomass can be converted into heat and power by choosing appropriate method. Fig. 1 shows the utilization of biomass to get various outputs[2].

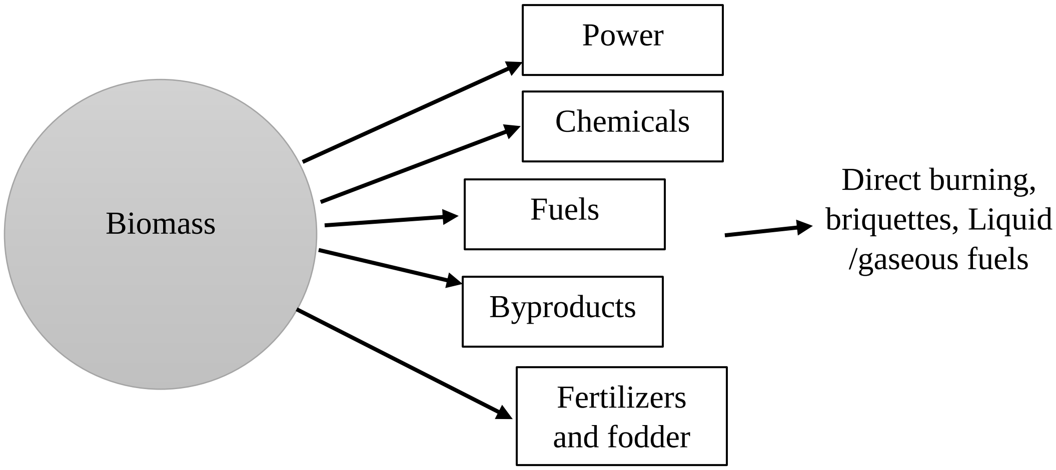


Figure 1. 1: Utilization of biomass resources [3]

1.1.2 Biomass as a Renewable Energy

As non-renewable sources such as petroleum oil, natural gas and coal are depleting, it is critical to replace them with renewable energy. One of the methods is by using biomass sources like empty fruit bunches (EFB) to become usable energy to replace the fuel-based oil. Biomass contains stored energy from the sun and it can re-grow over a relatively brief period compared to fossil fuels which take hundreds of millions of years to form[4]. Because of the concept that the plant material used can be replace through re-growth, so carbon dioxide that is emitted from burning the harvested biomass can be absorbed by the new plant growth[5].

This is the advantage of biomass source since minimum production of biomass waste generated in Malaysia per year is 168 million tons[6]. In general, palm oil waste is the highest percentage and the other contributors from agricultural and forestry by-products, such as wood residues, rice, and sugar cane industry wastes[6]. There is a lot of waste produced in our country which can be converted into biomass sources but for now, the awareness to manage these residues is still low since most of power generators and vehicle fuel are still using source from fossil fuel. Unfortunately, sometimes these residues have been managed to be burnt. Thus, promoted to environmental pollution such as haze and at the same time rise the global warming issue.

1.1.3 Densification of Biomass

Some of plant residue can be converted to fuel using the biomass densification process which this process improves the handling characteristics of the materials for transport, storage, etc. Biomass densified via two main process; mechanical densification and pyrolysis. Mechanical densification involves applying pressure to mechanical densify material while pyrolysis involves heating the biomass in the absence of oxygen[7]. Mechanical densification is the most common method used since the cost of production is less expensive compared to pyrolysis. Some of factors that affected the cost of densification technologies are size of densification plant (tonnes/year), operation time (hours/day), equipment cost, personal cost and raw material cost[8]. Biomass densification processes can be classified into baling, pelletization, extrusion, and briquetting which are carried using a bailer, pelletizer, screw press, piston or a roller press. Pelletization and briquetting are the most common processes used for solid fuel applications[9]. Pelletization uses smaller dies approximately 30 mm to convert the raw or pre-treatment biomass into pellet. Basically there are two types of pellet presses; the ring die and the flat die where both dies remain stationary and the roller rotate but in only certain cases ehere the roller remain stationary[9]. Briquettes are similar to pellets but differ in size due to the die of briquettes are bigger than pallets around 25 mm or greater when the biomass produce from either hydraulic press, mechanical piston press, roller press, or screw extrusion. In addition, biomass briquette produce by the screw extrusion has the higher storability and energy density properties compared to biomass briquette produce by piston press[7]. The main disadvantage for both common processes; palletization and briquette, in industrial furnaces is ash slagging due to alkali content that made from biomass[10]. On the other hand, to optimize the energy content and bulk density at once improve the densification process of biomass are chopping or grinding, drying the biomass till get the moisture content about

5% to 20%, mix with binding agent, steaming and torrefaction[11]. All the above methods known as pre-treatment which usable for certain biomass to produce good fuel.

1.1.4 Utilization of Biomass as fuel in Internal Combustion Engine (ICE)

There are few techniques to utilize biomass as part of the fuel in internal combustion engine which is in a form of gaseous fuel such as direct combustion, biomass gasification, anaerobic digestion and ethanol production[12]. In direct combustion process, oxygen supplied is generally higher than that of stoichiometric limit and can be applied to cultivate biomass wastes. Besides, this technique requires biomass with moisture present around 15% or less. Thus, drying of biomass is required prior to combustion. The energy flow of combustion process is when dried and cut biomass mixes with oxygen then become heat of combustion[3].

Secondly, biomass gasification is a thermal process of converting dry biomass feedstock into a mixture of gases that can be burnt in internal combustion engines and gas turbines. Biomass can be burnt directly to get heat energy but with gasification, there are certain advantages such as the resultant gaseous fuel can be used in an engine directly. Since gas engines are readily available, through biomass gasification one can produce electricity while for directly burning biomass, it needs boiler for making steam and then a steam turbine[13].

Next, anaerobic digestion is a biological process that produces a gas that composed of methane (CH_4) and carbon dioxide (CO_2). It is a complex biochemical reaction carried out in a number of steps by several types of microorganisms that require little or no oxygen to live. During the process of biogas, principally approximately 65% CH_4 and 30% CO_2, is produced and mixture of both making more than 90% while the remaining such as H_2S, N_2, H_2, methyl mercaptans and 0_2. The amount of biogas produced varies with the amount of organic waste fed to the digester (air tight chamber) and the temperature influence the rate of decomposition[12].

Lastly, in contrast to biogas production, fermentation takes place in the presence of air and known as aerobic digestion. During fermentation, hydrolysis process takes place to convert cellulose to alcohols. Ethyl alcohol can be produced from a variety of sugar by fermentation with yeasts. Molasses is diluted with water to sugar contents of about 20% by weight, acidified to pH 4.5 and then mixed with yeast culture (5% by volume) in a fermentor. Ammonia is used to reduce acidity. When 8-10 per cent alcohol is accumulated, then liquid is distilled, fractionated and rectified 2.5 liters of cane molasses produces about one liter of alcohol. Ethanol is easier to transport and store than hydrogen, fuel may be a practical way to provide hydrogen to fuel cells in vehicles or for remote stationary applications[12].

1.2 Problem statement

Issues associated with fossil fuels are not only about depletion, it is also about the emission of pollutants from the combustion of fossil fuels such as CO, CO_2, NOx and so forth. The emission of pollutants will impact the environment such as asid rain, haze, global climate change and ozone depletion and these environmental problems are harmful to human being.

Many researches have been done in order to reduce the non-renewable energy consumption by utilizing renewable energy resources like biomass due to some advantages over the non-renewable energy resources. Firstly, the advantage of biomass energy is carbon neutral which mean it does not contribute to global warming due to biomass is a part of the carbon cycle[14]. The amount of carbon released from the biomass fuels was similar to the amount of carbon absorbed by plants during their life cycle and the carbon neutralise back by the other plant. Next, biomass sources is available in massive quantities all over the world compare to fossil fuels which depletion over the years. Since fossil fuels in the category of non-renewable energy which it will extinct soon but source of biomass can be replant to get their output and also maintain the natural resource by being responsible in its use[14].

The researches that deals with the utilization, characterization and analysis of biomass resources as alternative liquid fuels such as palm oil, sun flower oil, corn oil etc. for internal combustion engine application have been increasing lately. However, not many of them have dealt with the potential utilization of biomass producer gas as gaseous fuel in the internal combustion engine. In order to determine the suitability of biomass producer gas as fuel in the engine, detail study is required to investigate the properties of biomass materials and to determine the best heating value that can be obtained from them. The improvement of heating value and other properties of biomass can possibly be achieved through densification of the biomass materials via briquetting and palletization. For the cost-effectiveness in the production of biomass material as engine fuel, a widely abundant biomass can be utilized and studied such as Empty Fruit Bunches (EFB), wood chips or rice husk. The main challenge is to characterize these types of biomass materials so that their properties are suitable for the production of good producer gas to be input into the engine. In addition, the study of spraying and combustion characteristics of biomass producer gas as dual fuel with diesel fuel is still scarce in the literature and the experimentation of spraying and combustion characteristics of biomass producer gas in this project is another critical challenge to be fulfilled particularly in the Constant Volume Combustion Chamber (CVCC).

1.3 Research Objectives

The objectives of this study are as follow:

1. To characterize empty fruit bunches (EFB) as the potential biomass resource that includes pre-treatment processes such as drying and crushing as well as water/binder composition for briquetting of EFB.
2. To test the properties of EFB briquettes for the best production of biomass producer gas as gaseous fuel to the engine.
3. To develop the experimental rig and to study both spraying and combustion characteristics of dual fuel in Constant Volume Combustion Chamber (CVCC).

1.4 Scopes of Project

In this project, EFB will be processed to become biomass briquette and the characteristics of EFB briquette will determined such as ash content (%), moisture content (%), volatile matter (%), fixed carbon (%) and calorific value (kJ/kg) also quality of EFB briquette heating value and mechanical strength. The characteristic and quality of EFB briquette will be compared to coconut shell and rubber seed kernel briquette. The research also focusing on the downdraft gasifier operation to combust to produce the producer gas (PG). Downdraft gasifier is the appropriate system due to produce PG in low content of tar. Next, the main CVCC will be set up visualize the spray and combustion characteristic of PG from EFB briquettes combustion. Using this technique, microscopic parameter such as spray tip penetration, spray angle, and spray width.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Overview

In this chapter, the information and results from various sources about the biomass briquette especially using empty fruit bunch (EFB) as a source of biomass are discussed. Besides, the study of duel fuel mode in the internal combustion engine (ICE) and constant volume combustion chamber (CVCC) also discussed in this chapter. The contain from these sources are very useful as a reference in this study.

2.2 Waste Product from Palm Oil Industries

The oil palm plantation has become important agricultural crop in Malaysia since it is already become one of the key economic expansion for this country[15]. Palm oil that produced in Malaysia that readily accepted by globally has exported this oil more than 140 countries[16]. Thus, cultivation of oil palm has been widely done where it can be seen almost evert part in this country due to some agencies have involved in this field such as Malaysia Palm Oil Board (MPOB), Malaysia Palam Oil Council (MPOC) and others.

The high demand of palm oil and at the same time Malaysia controlled 45% of total palm oil production in the world according to the Malaysia Palm Oil Board (MPOB) has affected the waste production which estimated 26.7-million-ton solid mass and approximately 30 million-ton of palm oil mill influent were generated in 2004[17]. Palm oil is extracted from Fresh Fruit Bunch (FFB) which 5.8 ton of FFB produces 1 ton of crude palm oil and after processing oil from FFB and some of residues produced from FFB such as fiber (30%), shell (6%), decanter cake (3%) and empty fruit bunch (EFB) (28.5%)[17].

2.2.1 Empty Fruit Bunch (EFB) and its characteristics

EFB is one of the residue produced from the fresh fruit bunch which it has irregular shape and fibrous material. The physical properties that commonly associated with EFB are it weighs about 3.5 kg and has a thickness of 130 mm [18] and can vary from 170 to 300 mm long and 250 to 350mm wide [19]. Because of the biological growth of EFB combined with the steam sterilization at the mill, so it makes the EFB saturated with water [20]. The moisture content of EFB is around 67% where it is quite high that make the heating value low, so pretreated of EFB is necessary before it can be considered as a good fuel[20]. Table 1 below shown the properties of EFB that already been compiled which contain moisture contain, proximate analysis, ultimate analysis and chemical composition

Table 2. 1: Properties of empty fruit bunch (EFB)[21]

Properties		Values
Moisture (%)		2.40 - 14.28
Proximate analysis (%^{a})	Volatile matter	70.03 - 83.86
	Fixed carbon	8.97 - 18.30
	Ash	1.30 - 13.65
Ultimate analysis (%^{b})	C	43.80 - 54.76
	H	4.37 - 7.42
	O^d	38.29 - 47.76
	N	0.25 - 1.21
	S	0.035 - 1.10
Chemical composition (%^{a})	Cellulose	23.7 - 65.0
	Hemicellulose	20.58 - 33.52
	Lignin	14.1 - 30.45
	Extractive	3.21 - 3.7

Where,

^{a} = Weight percent on a dry basis

^{b} = Weight percent on a dry and ash-free basis

^{d} = by difference

Moni et et al., (2014) studied about potentials of selected Malaysia biomasses as co-gasification fuels with oil palm frond in a fixed bed downdraft gasifier. In this research, the secondary solid fuels to support the main fuel which is oil palm frond (OPF) and biomass fuels were discussed in term of proximate analysis, ultimate analysis as shown in Table 2.2 and lastly scoring-and-rank as shown Table 2.3 for every biomass fuels. This is to identify which biomass fuels would be compatible with OPF to produce syngas using co-gasification process in which run two fuels at the same time in the gasification process. Biomasses were selected based on certain characteristics such as morphology, carbon and hydrogen ration, calorific value, moisture content, supply and accessibility, and process requirements based on the specification of a 30 kW downdraft gasifier at Universiti Teknologi PETRONAS.

Table 2. 2: Elemental components and calorific values (CV) of Malaysian biomasses[22]

Type	Proximate analysis. wt. %				Elemental Components, wt. %					CV, MJ/kg	Amount, Mton/year
	FC	VC	MC	Ash	C	H	N	S	O		
Rice Husk	18.03	50.97	13.08	0.44	38.74	5.83	0.55	0.06	93.56	14.97	0.44
Paddy straw	9.22	59.97	8.47	0.78	33.48	6.01	1.46	0.15	92.38	13.74	0.78
Bagasse	15.91	80.19	52.2	0.12	42.93	5.82	0.68	0.06	93.44	15.25	0.12
EFB (Empty fruit bunch)	9.89	84.61	66.26	2.61	40.73	5.75	1.4	0.22	51.9	18.6	2.61
PMF (Palm mesocarp fiber)	11.38	81.52	45.23	18.74	40.97	5.93	0.77	0.51	51.82	18.66	18.74
OPF (Oil palm front)	12.91	83.19	71.43	6.31	42.1	5.46	0.7	0.13	51.91	15.59	6.31
OPT (Oil palm trunk)	11.42	76.84	75.9	4.19	40.64	5.09	2.15	0	53.12	17.27	4.19
PKS (Palm kernel shell)	14.87	81.03	17.5	6.41	49.65	6.13	0.41	0.48	43.33	20.4	6.41
Sawdust	16.2	78.8	16.3	>1.0	47.2	6.5	0	0	46.3	20.45	>1.0
Note: FC: fixed carbon; VM: volatile matter; MC: moisture content; CV: calorific value											

Table 2. 3: Ranking of selected biomass based on selection criteria[22]

Type	VM	MC	CV	C/H	AP	SA	DR	BD	Score	Rank
PKS	6	6	8	9	6	1	0	0	36	1
PMF	7	5	7	3	8	1	1	0	32	2
OPF	8	2	4	7	9	1	1	0	32	-
Sawdust	4	7	9	5	4	1	0	1	31	3
EFB	9	3	6	4	7	1	1	0	31	4
OPT	3	1	5	8	5	0	1	0	23	5
Bagase	5	4	3	6	1	0	1	0	20	6
Rice Husk	1	8	2	2	2	0	0	1	16	7
Paddy Straw	2	9	1	1	3	0	0	0	16	8

Note: VM: volatile content (highest=9, lowest=1); MC: moisture content (highest=1, lowest=9); CV, calorific value (highest=9, lowest=1); C/H, carbon-hydrogen ratio (highest=9, lowest=1); AP, annual production (highest=9, lowest=1); SA, supply availability (all time=1, seasonal=0); DR, drying requirement (yes=0, no=1); BD, briquetting/densification requirement (yes=0, no=1);

Since this study is focusing on EFB, certain highlight characteristic base on table 2.3 will be discussed. Firstly, the volatile matter of EFB has the highest score. Volatile matter that refers to the components of carbonaceous fuel that are released in gaseous form at high temperature in absence of air which amount of volatile matter proportionately helps in easier ignition of fuel [23]. Even though the C/H ratio scoring for EFB at the middle class, but it does not affect much since the calorific value of EFB still at the top rank. The CV of biomass depends on the percentage of carbon and hydrogen which are the main contributors to the heat energy value of biomass material [24].

2.3 Empty Fruit Bunch (EFB) Briquette Study

Nasrin et al., (2011) investigated the raw materials used in production of palm biomass briquettes that were analyzed to determine their physical and chemical properties. The raw materials including empty fruit bunch (EFB), in fibrous form and palm shell were mixed in certain ratios and densified into briquettes at high pressure using piston press technology in a palm oil mill. The blending ratios of shell to EFB (w/w%) for the production trials were fixed at 20, 30, 40 and 60 %. From the analysis, it was found that the average calorific values and specific densities for blending ratios of 20 to 60% ranged from 17994 to 18322 kJ/kg and from 1179 to 1225 kg/m3. Overall the presence of high shell in palm biomass briquettes increased the calorific value, specific density and quality of the briquette as well. Table 2 shows the general specification and calorific value of the raw materials and results of the analyses of palm biomass briquettes.

Table 2. 4: General Specification and Calorific value of the raw materials and results of the analyses of palm biomass briquettes[25]

Biomass briquettes	Ash content (%)	Moisture content (%)	Volatile matter (%)	Fixed carbon (%)	CV (kJ/kg)
EFB fibre (Feedstock) and 100% EFB fibre briquette	6.43	15.8	80.21	13.05	17660
shell (Feedstock)	4.36	9.25	77.36	18.21	18590
Palm briquette-shell ratio, 20%	6.35	6.76	79.65	13.3	17995.3
Palm briquette-shell ratio, 30%	6.12	6.55	79.53	13.8	18049.7
Palm briquette-shell ratio, 40%	5.99	6.13	78.55	14.22	18106.8
Palm briquette-shell ratio, 60%	5.5	5.52	78.08	14.93	18322.7
Sawdust briquette (control)	<4.00	<7.00	-	-	18936
DIN 51731	<0.70	<10.00	-	-	>17500.0

The experiment is carried out by producing binderless EFB briquettes due to 10% to 20% of lignin is available in EFB fiber [26] which indirectly used as a natural binder [27]. This method to maintain overall quality of the product and production process but this will affect the EFB briquette which resulted low physical strength and surface properties of briquette and in order to have good physical appearance and, strength and density it must be blend with certain percentage of total weight with palm shell. Table 3.4 shown the ultimate analysis for palm biomass briquettes which contains the carbon, hydrogen, sulphur, and oxygen in form of percentage.

Table 2. 5: Ultimate analysis for palm biomass briquettes

Biomass briquettes	Carbon (%)	Hydrogen (%)	Nitrogen (%)	Sulphur (%)	Oxygen (%)
100% EFB fibre	54.10	5.85	0.58	0.09	36.50
Palm shell	58.20	5.45	0.40	0.05	32.10
Briquettes 30% shell	55.70	5.78	0.46	0.04	34.86
Briquettes 30% shell	56.05	5.78	0.44	0.04	34.51

2.4 Spray and Combustion Investigation using visualization technique

There are various techniques that can be applied to visualize and monitor the spray and combustion phenomena within the CVCC and optical engine. Different information will be provided by different technique, but the visualization technique is most frequent technique used for macroscopic characteristic of fuel spray and combustion observation. By applying visualization technique, the digital imaging can be produced either in continuous recording or solid state by using high speed camera to get the acquire color or shadowgraph photos of the fuel spray and the combustion process [28]. Table 4 shows comparison between PIV, LIF, PDPA and Visualization techniques that had been done by the other researchers to obtain different parameter in the study of spray and combustion characteristic into the CVCC [28].

Table 2. 6: Comparison of visualization techniques for fuel spraying and combustion characteristics[28]

Techniques	Application and parameters obtain	Disadvantages and Limitations
Visualization	Spray and combustion visualization. Macroscopic parameter such as spray geometry, penetration depth, will impingement, and subsequent combustion.	Macroscopic spray parameters only.
PIV	Fuel sprays flow. Instantaneous whole field velocities.	Difficult to implement on dense sprays.
LIF	Fuel consumption. Liquid and vapour fuel.	Quenching at high pressures and difficult to calibrate.
PDPA	Fuel sprays droplet size measurement. Fuel droplet size and velocity, density, volume flux and time resolved.	Not suitable for high density sprays.

2.4.1 Spray and Combustion Characteristics of Dual Fuel Mode in a Constant Volume Combustion Chamber (CVCC)

Soid, S.A and Zainal Z. A, (2012) was studied about spray characteristic of Refined Palm Oil (RPO) in a CVCC and compared to conventional fuel such as gasoline and diesel. They are using an optical CVCC with spray measurement to measure spray tip penetration, spray cone angle and spray area of liquid fuel. The starting injection pressures were studied at 20, 30 and 34 MPa. Macroscopic spray characteristics of gasoline, diesel and palm oil blends with diesel from 20 to 100% pure palm oil were tested separately and they were found that spray development of palm oil blends is highly affected with increasing of palm oil in the blends. In addition, tip penetration and cone angle of blends were found to decrease by about 50 to 30%, respectively compared to diesel, and improved at higher injection pressure. High viscosity of palm oil influenced spray shape evolution, spray tip penetration, spray cone angle and spray area[29]. For this research, it only focusing on spray characteristic of palm oil in a CVCC which influence to spray shape evolution, spray tip penetration, spray cone angle and spray area.

Desantes et la., (2009) was studied about the DI diesel injection process that biodiesel blends with 5.75% of rape methyl ester called B5, another with 30% of RME (B30), and a pure rape methyl ester fuel called RME. The diesel injection process occurred in a stand injection system derived from a-stroke DI commercial diesel engine. From the results show that the fuel properties like density and kinetic viscosity are highly affected the injection parameters. In addition, blended biodiesel with RME had the longer penetration, narrower cone angle and smaller spray volume when compared to other blends[30].

Gao et al., (2007) was studied about the spray properties of different blends between ethanol and gasoline under various ambient conditions which the blends varies from 25% of gasoline to 100% as well as pure gasoline. The experimental results show that at low ambient pressure, made the better evaporation. This due to spray angle increases and the main spray tip penetration decreases when the ethanol fraction in blend increase. However, under elevated pressure condition, there is no difference occur in the spray penetration among blends[31]. The all above studies was done by using the same technique which is direct visualization technique to capture the results that have been done into a CVCC.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Overview

This chapter provides a detailed description of methods about the whole briquetting process of empty fruit bunch (EFB) which start with preparation of EFB material until the end of drying process of EFB briquettes. Then, the tests of quality characteristic for EFB briquettes and spray and combustion process using liquified petroleum gas (LPG) and diesel in dual fuel mode in constant volume combustion chamber (CVCC) will be discussed.

3.2 Raw Biomass Material Preparation

In this study, raw material used is EFB only. Raw material of EFB is collected from the palm oil mill which from Taclico Company Sdn. Bhd., Padang Serai, Kedah.

3.2.1 Preparation of Empty Fruit Bunch (EFB)

Preparation of raw EFB consist of a few steps which are started with soaking process, drying process and lastly size reduction process. This preparation steps were carried out to ensure that the densification process of EFB run smoothly. But after collecting the raw material, it is stored under closed storage with room temperature condition and at the dry place to ensure that there is no fugus appeared on the material.

Firstly, preparation of EFB started with soaking process which soaked into tap water. This process just takes place about 3 hours. This process is to clean up the raw material from the impurities that attached on it and at the same time, the moisture content of raw material of EFB can be aligned uniformly. The soaking process of raw EFB as shown in Figure 3.1.

Figure 3. 1: Soaking Process

Next, after 3 hours of soaking process, the tap water is drained out from the basin and the wet weight was taken. After that, raw EFB gone through drying process which placed it all under the sunlight for 2 to 3 days as shown in Figure 3.2. This process is to ensure that the high moisture contain from previous process is reduce until the percentage of moisture contain of raw EFB reached below than 10% when compare with the weight of EFB after drying process. This is the formulae to calculate the percentage of moisture contain after the drying process:

$$Moisture\ Content = \frac{w - d}{w} \times 100\%$$

Where,

w = wet weight

d = weight after drying

Figure 3. 2: Drying process

Then the raw EFB had to go through the size reduction process which ground using grinding machine where the size of raw EFB is about 20mm to 60mm. The grinder machine is available in Bio-Energy Laboratory, School of Mechanical Engineering, USM which using a blade mill mechanism that can be referred in Figure 3.3 below and Figure 3.4. Unfortunately, the size did not reduce much due to the light weight and their hairy shape which made it easily to pass through the blade smoothly. So, this method was carried on using the industrial blender which also available in the Bio-Energy Laboratory where the size had reduced to below than 20mm. This method was carried out to ensure that the mixing process will run smoothly due to binder need to cover the entire surface of each EFB so that each layer of EFB attach firmly each other.

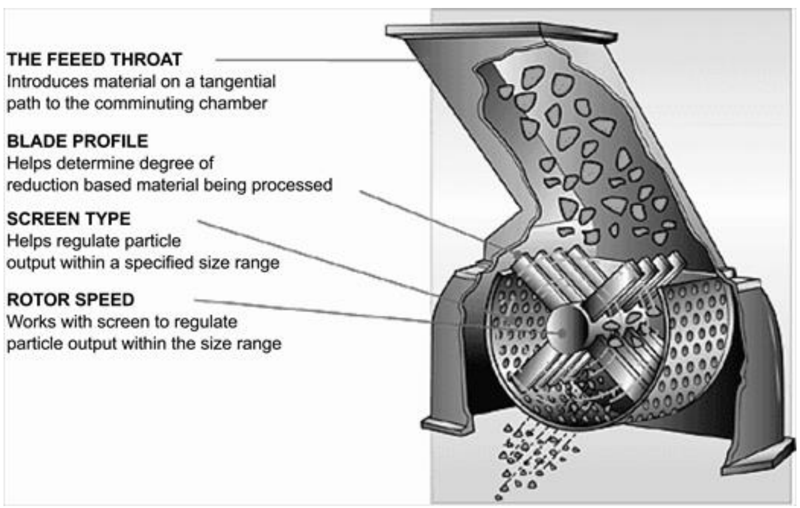
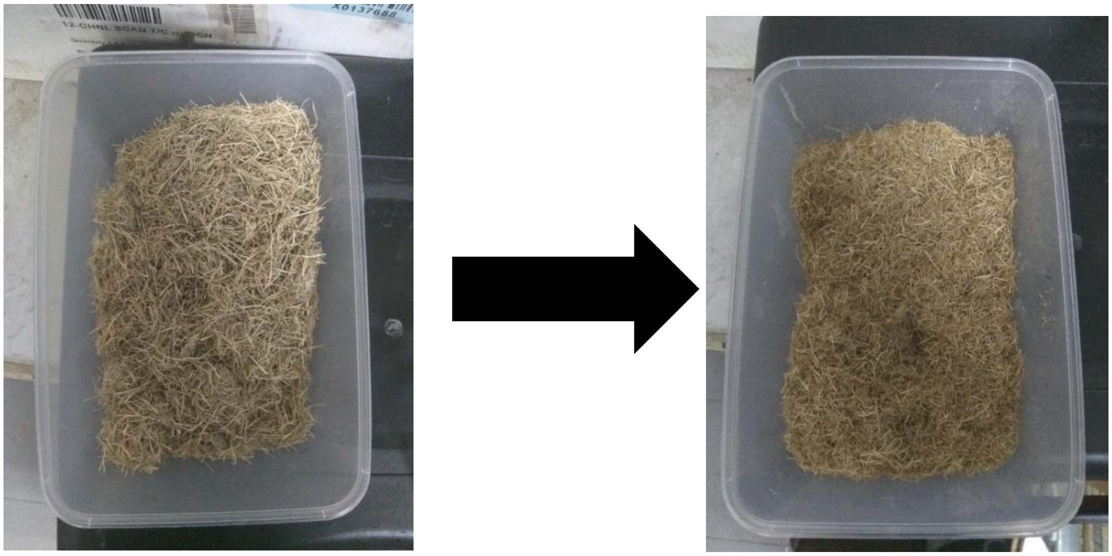


Figure 3. 3: Mechanism of grinder[32]

Figure 3. 5: Grinder in Bio-Lab

Figure 3. 4: Industrial Blender



Size of EFB between 20mm-60mm

Size of EFB below 20mm

Figure 3. 6: Size of before and after size reduction process

3.2 Mixing Process

Mixing process is a process to mix the biomass material with a binder which in this study binder consist of tapioca starch and water. The binder used to mix with biomass material have different percentage composition of tapioca starch and water which to identify the difference outlook bonding structure of EFB briquette. The percentage of composition of tapioca starch and water is based on the weight of the biomass material used during the briquetting process. Since this study is to compare the strength between EFB and torrefied coconut shell (CS) and torrified rubber seed kernel (RSK) so the percentage composition of tapioca starch and water also the weight of biomass used which based on 1 kg as shown in Table 3.1 and Table 3.2.

Table 3. 1: Percentage composition of binder for torrefied CS[33]

Mixtures	Torrefied Coconut Shell (1 kg)	
	Percentage of tapioaca starch (%)	Percentage of water (%)
Mixture 1	15	110
Mixture 2	15	120
Mixture 3	15	130
Mixture 4	20	110
Mixture 5	25	110
Mixture 6	20	120
Mixture 7	25	120

Table 3. 2: Percentage composition of binder for torrefied RSK[33]

Mixtures	Torrefied Rubber Seed Kernel (1 kg)	
	Percentage of tapioaca starch (%)	Percentage of water (%)
Mixture 1	15	110
Mixture 2	15	120
Mixture 3	15	130
Mixture 4	20	110
Mixture 5	25	110
Mixture 6	20	120
Mixture 7	25	120

The type of starch used is tapioca starch which originated from the cassava root and water is referred as tap water with room temperature condition. Firstly, tapioca starch and water are weighed according to the percentage composition based on weighed of biomass used onto the weighing scale. Then, stirred both of mixture until blended well before heating them. The mixture is put into the pot, and they were heated until the mixture become molten solution. After a few minutes, after the molten solution formed, the binder is put at the side to make it cooled down a bit. While waiting the binder to cooled down, 65% of water is mixed into the raw EFB base of weight of raw EFB used and lastly, the binder and raw EFB with 65% of water is mixed together until fully blended.

Mixed the binder before heating

Binder formed molten solution

Mixed the raw EFB with binder until blended well

Figure 3. 7: Mixture Process of raw EFB with binder

3.4 Briquetting Process

In this process, the mold of 30 mm x 30 mm is used to form the cylindrical shape of EFB briquettes which consist of 4 holes in a mold. The process started with the fully blended EFB is being loaded into a mold and pressed it manually using a hammer. Next, the briquettes are dried up with the mold under the sunlight about 20 to 30 minutes to make ease of briquettes remove from hole of mold. The same procedures are followed regarding to the composition in the table 3.2 for every mixture respectively. Then, product of the briquettes will be dried directly under the sun for 2-3 days to make the briquettes dry and ready to be used. The drying is essential and compulsory for the new briquettes as they are produced in a wet form that there is also composition of water in the binder. Figure 3.10 shows the manually briquetting process of EFB.

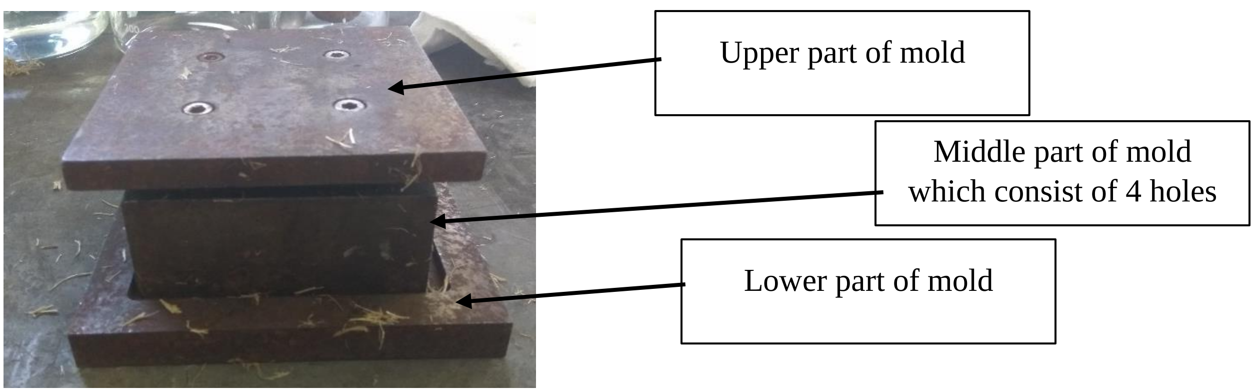
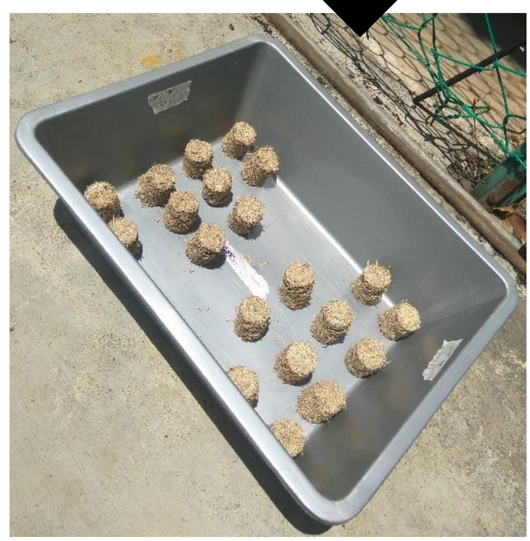


Figure 3. 8: Cylindrical shape mold for briquetting process

Fully blended EFB is being loaded into a mold

Dried under the sunlight with stacked of pressure on upside of mold

Stored briquttes in a closed storage



Drying process for briquettes

Figure 3. 9: Cylindrical briquetting process of EFB

3.5 Quality Characteristic Study

This section will discuss about the characteristic study upon the briquette that has been produced by the manually briquetting of cylindrical type. Bomb calorimeter and Ultimate testing machine (UTM) will be used to study the characteristics of the cylindrical briquettes from different type percentage composition of binder. For bomb calorimeter which available at the Heat Transfer Laboratory, School of Mechanical Engineering will test the briquette to determine it calorific value. While for the UTM which available at the Applied Mechanic Laboratory, School of Mechanical Engineering, a compressive load test will be done to test the strength of the briquette being produces.

3.5.1 Bomb Calorimeter Test

To determine the caloric value of each percentage composition of binder EFB briquette was by using the bomb calorimeter machine. The calorific value produced due to the heat or energy released by a fuel during complete combustion. This is to verify which percentage composition will produce high calorific value and also compared with journal whether raw EFB or EFB briquettes will produce high calorific value.

Procedure:

a) Took a sample of EFB briquette and prepared the briquette by cleaned up from any dirt and other contamination.
b) Then, a sample of EFB briquette is cut into small pieces and then weighed to ensure that the weight is less or equal to 1 g to fit into the crucible of the bomb calorimeter as shown in Figure 3.11.

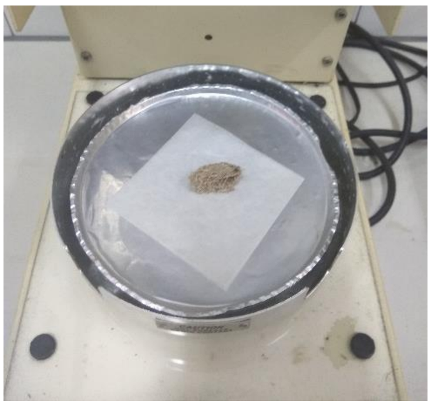


Figure 3. 10: Weighted the rise paper and briquette