PHYSICAL AND COMBUSTION CHARACTERISTICS OF DENSIFIED PALM BIOMASS

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A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Mechanical)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

NOVEMBER 2009

To my beloved father and mother,

Your love brings me to the happy and successful life

To my beloved fiancee,

Your encouragement and patience always give me spirit to achieve success

ACKNOWLEDGEMENT

"In the name of Allah S.W.T. that the Most Gracious, and the Most Merciful"

First of all, my greatest gratitude goes to Allah S.W.T. for showing me ways of success which make me possible to complete the project report with the title "Physical and Combustion Characteristics of Densified Palm Biomass". May the peace and blessings of Allah S.W.T. be upon Prophet Muhammad Sallallahu Alaihi Wasallam.

I wish to express my deepest appreciation to my main supervisor, Prof. Amer Nordin bin Darus, my co-supervisors, Assoc. Prof. Dr Mazlan Bin Abdul Wahid and Mr. Zulkarnain Bin Abdul Latiff for encouragement, guidance, and suggestions. Without their continued support and interest, this report would be impossible to be completed.

I am very thankful to all staffs of Faculty of Mechanical Engineering for advising me about the study and all my course mates for sharing knowledge.

Special thanks to Ministry of Higher Education and Universiti Teknologi Malaysia (UTM) for sponsoring my study at UTM.

Finally, my immense gratitude to my family for their love especially my parents. Also thank you to my fiancée for her encouragement and patience.

ABSTRACT

As reported by Malaysia Palm Oil Statistics, the production of palm biomass residues increased significantly from year to year. Thus, the utilization of these residues is very important in order to prevent waste and dump areas adjacent to the palm oil mills. Meanwhile, in order to increase the energy content per unit volume, briquetting technology is expected to fulfill this requirement by compacting biomass residues into form with higher density. In this project, the utilization of empty fruit bunch (EFB) is emphasized in briquette production. It is combined with mesocarp fibre in order to obtain the higher gross calorific value of briquette. The result shows that the briquette contains EFB fibre and mesocarp fibre (weight ratio 60:40) has the compressive strength and combustion characteristics which are competitive with local commercial briquette contains mesocarp fibre and shell (weight ratio 60:40). It is found that combustion rate belongs to briquette containing proposed mixture (EFB and mesocarp fibre) is higher than the rate belongs to another one, if both of them are produced under same compaction pressure. This gives a higher heat release from the combustion of proposed briquette. Besides, all the characteristics belong to briquette contains new mixture are found to be close to the minimum requirement for making commercial briquette which stated by DIN 51731.

ABSTRAK

Sebagaimana dilaporkan oleh Statistik Minyak Sawit Malaysia, penghasilan bahan buangan sawit biomas meningkat secara mendadak dari tahun ke tahun. Oleh sebab itu, penggunaan bahan buangan ini adalah sangat penting untuk mengelakkan pembaziran dan lambakan di kilang kelapa sawit. Sementara itu, teknologi *briquetting* dipercayai dapat meningkatkan jumlah tenaga per unit isipadu melalui pemadatan bahan buangan biomas kepada bentuk yang mempunyai ketumpatan yang lebih tinggi. Dalam projek ini, penggunaan tandan sawit kosong amat ditekankan dalam penghasilan *briquette*. Ia digabungkan dengan serat *mesocarp* untuk mendapatkan nilai kalori kasar yang lebih tinggi. Hasil kajian menunjukkan *briquette* mengandungi campuran serat tandan sawit dan serat *mesocarp* (nisbah berat 60:40) mempunyai sifat kekuatan mampatan dan pembakaran yang kompetitif jika dibandingkan dengan *briquette* tempatan komersial yang mengandungi campuran serat *mesocarp* dan tempurung sawit (nisbah berat 60:40). Didapati bahawa kadar pembakaran *briquette* mengandungi campuran serat tandan sawit dan serat *mesocarp* adalah lebih tinggi jika dibandingkan dengan jenis yang satu lagi, jika kedua-duanya dihasilkan di bawah tekanan pemadatan yang sama. Ini memberikan nilai pembebasan haba yang lebih tinggi hasil daripada pembakaran *briquette* mengandungi campuran yang disyorkan. Selain itu, semua kriteria yang dimiliki oleh *briquette* dengan campuran baru yang disyorkan tadi didapati hampir dengan keperluan minimum untuk penghasilan briquette komersial sebagaimana ditetapkan oleh piawai DIN 51731.

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T	-	Temperature
$\dot{m}$	-	Mass burning rate or combustion rate
wt%	-	Weight percentage
p	-	Compaction pressure
η	-	Efficiency
m	-	Mass

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CHAPTER 1

INTRODUCTION

1.1 Background

Nowadays, the high price for world oil and natural gas which is expected to persist in the future encouraged the utilization of renewable energy. At the end of 2008, world oil price fell sharply due to the slow world economy as reported by EIA (2009). However, the price is projected to increase after the reformation of world economy. The figure below shows the energy prices from 1980 to 2030 based on 2007 dollars.

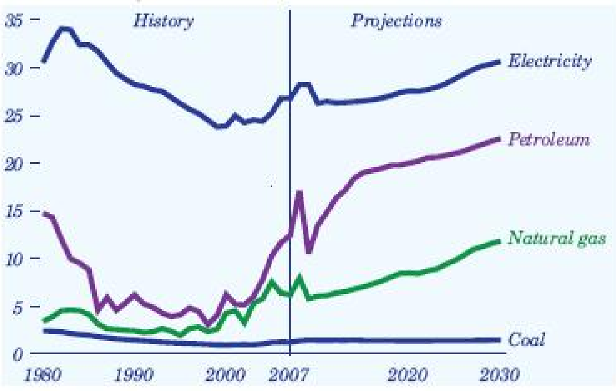

Figure 1.1: Energy prices for 1980-2030 in 2007 dollars per million Btu (EIA,2009).

Besides, the use of fossil fuel would lead to serious environmental problem. Therefore, most people around the world are seeking the potential alternative fuel which can substitute fossil fuel in the future, as reported by Khan et al. (2009). Gevorkian (2007) described that the environmental problem would lead to global climate change, which causes the occurrence of drought and also may worsen the existing air quality problem.

Based on Figure 1.2, it is predicted the fossil fuel consumption still remains highest until year 2030. However, the renewable energy consumption is expected to increase from year to year, which shows how important this alternative energy in the future as stated by EIA (2009).

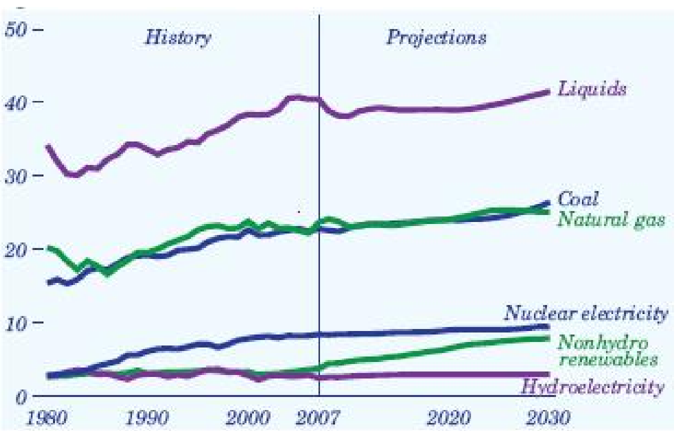

Figure 1.2: Energy consumption by fuel, 1980-2030 in quadrillion Btu (EIA, 2009).

EIA (2009) also reported that the renewable fuels which are used by world population are wood, municipal waste and biomass residues. Hydroelectricity, geothermal, solar and wind are utilized for electric power generation. Meanwhile, in the transportation sector, utilization of ethanol for biomass-based diesel also becomes popular. The use of renewable energy as mentioned above increased from approximately 6 quadrillion in year 2007 to almost 10 quadrillion BTU in year 2030.

There are several alternative energy which are expected can substitute fossil fuel in the future. For instance, hydro, solar, wind, biomass and ocean thermal energy. Among these energy sources, biomass is the only carbon-based sustainable energy and the wide variety of biomass enables it to be utilized by most people around the world. However, the contribution of biomass in world energy demand today mere approximately 10% to 15% which equivalent to about 45 ± 10 ExaJoule. Currently, only 7 ExaJoule of biomass energy is used for supplying heat, electricity and fuels for transportation and boilers as stated by Hamelinck et al. (2005). Therefore, the potential of biomass energy for commercial use is still under investigation.

In Malaysia, currently the utilization of renewable energy has several advantages including enhancing profit margins and eliminating the cost burden for managing waste disposal. In the Eight Malaysia Plan (2001-2005), renewable energy had been announced as the fifth fuel in the total energy supply. Great efforts were undertaken to encourage the utilization of renewable resources such as biomass, biogas and solar for electric generation. In Malaysia, the main sources of renewable energy are biomass residues such as agriculture wastes (palm oil waste, wood waste, rice husks and many others) and also municipal solid waste and energy from the sun. In year 2002, palm oil for instance, generates a lot of process residues such as fibre (5.4×10^6 tonne per year), shell (2.3×10^6 tonne per year) and empty fruit bunches or EFB (8.8×10^6 tonne per year). However, Husain et al. (2002) reported that all of these residues were not being utilized efficiently and would cause the air pollution by pile burning in the open air and much was damped in areas adjacent to the mill. However, it contributes significantly in the palm oil plantation as manure due to its high potash content. Generally, fresh fruit bunch contains (by weight) approximately 21% palm oil, 6-7% palm kernel, 14-15% fibre, 6-7% shell and 23% EFB. Based on Malaysian Oil Palm Statistics, in year 2005, the quantity of palm residues produced increased about two times of residues produced in 2002.

Recently, Chairman of Federal Land Consolidation and Rehabilitation Authority (FELCRA), Datuk Tajuddin Abdul Rahman announced that 11,000 hectares of land in Sarawak will be developed with palm plantation in year 2010. Therefore, the total land areas for palm plantation in Sarawak will be 55000 hectares in year 2010, which occupies 36% of total FELCRA’s land in Malaysia as stated in Utusan Malaysia Online (2009). From this encouragement, definitely the quantity of palm biomass will increased and therefore, the utilization of this renewable energy is very significant.

EIB (2008) mentioned that many companies had taken advantages by investing for renewable technologies. For instance, Bekok Kiln Drying and Moulding Sdn. Bhd. had converted a fuel oil boiler to one that burns wood waste. Due to that, they could save up to RM 2 million annually. Awana Kijal Golf & Beach Resort had installed a solar water heating system which saving energy cost up to RM 400,000 per year.

As described by EPU (2006), in the Ninth Malaysia Plan (2006-2010), the perspective on the importance of renewable energy remains unchanged. Emphasis is given on reducing the dependency on petroleum products by increasing the use of alternative fuels. Even though crude oil and petroleum products were main contributor to the total energy supply which increased from 2003 petajoule in year 2000 to 2526 petajoule in year 2005, the dependency on petroleum products and crude oil had decreased while that of coal and coke increased, as shown in Table 1.1. This pattern is expected to continue in following years due to the effort and encouragement by Malaysia Government in promoting the use of renewable energy.

Table 1.1: Primary Commercial Energy Supply by Source

Source	Petajoules			% of Total			Average Annual Growth Rate (%)	
	2000	2005	2010	2000	2005	2010	8MP	9MP
Crude Oil and Petroleum Products	988.1	1,181.2	1,400.0	49.3	46.8	44.7	3.6	3.5
Natural Gas[2]	845.6	1,043.9	1,300.0	42.2	41.3	41.6	4.3	4.5
Coal and Coke	104.1	230.0	350.0	5.2	9.1	11.2	17.2	8.8
Hydro	65.3	71.0	77.7	3.3	2.8	2.5	1.7	1.8
Total	**2,003.1**	**2,526.1**	**3,127.7**	**100.0**	**100.0**	**100.0**	**4.7**	**4.4**

Source: Ministry of Energy, Water and Communications and Economic Planning Unit

Notes: [1] Refers to the supply of commercial energy that has not undergone a transformation process to produce energy.
[2] Excludes flared gas, reinjected gas and exports of liquefied natural gas.

(EPU, 2006)

1.2 Biomass

"Biomass" can be applied to both animal and vegetable derived material. Biomass is a biological material derived from living, or recently living organisms. In the context of biomass for energy, however this is often used to mean plant based material as explained by BEC (2008).

Due to the variety of biomass energy resources, comprehensive classification system is greatly needed to facilitate the behaviour prediction of biomass by identifying to which class it belongs. William (1992) and Jenkins et al. (1998) had proposed two classification systems based on the origin of the biomass and their properties.

Based on the origin, biomass fuels can be generally divided into four primary classes:

i) Primary residues: By- products of food crops and forest products such as wood, straw, cereals, maize etc.

ii) Secondary residues: By-products of biomass processing for production of food products or biomass materials such as saw and paper mills, food and beverage industries, apricot seed etc.

iii) Tertiary residues: By-products of used biomass derived commodities such as waste, demolition wood etc.

iv) Energy crops.

Meanwhile, the classification based on properties can be categorized into:

i) Wood and woody fuel such as hard and soft wood and also demolition wood.

ii) Herbaceous fuels such as straw, grasses, stalks etc.

iii) Wastes such as sewage sludge etc.

iv) Derivates such as waste from paper and food industries

v) Aquatic such as kelp etc.

vi) Energy crops (specifically cultivated for energy purposes).

Biomass composed cellulose, hemicelluloses, lignin, lipids, proteins, simple sugars, starches, water, hydrocarbon, ash and other compounds. They vary in concentration of each compound depends on species, type of plant tissue, stage of growth and growing condition. Due to the carbohydrate structure of biomass, it is highly oxygenated with respect to the conventional fossil fuels including hydrocarbon liquids and coals. Most of the biomass does not differ much to each other in terms of bulk composition of carbon, hydrogen and oxygen. Dry weight percentages for carbon (C), hydrogen (H) and oxygen (O) are 30 to 60%, 5 to 6% and 30 to 45% respectively. C, H and O shares can be different for certain fuels. For example, Faaij et al. (1997) described that the biological breakdown and plastic fraction would lead to higher C content. Nitrogen is a micronutrient for plants and can be found together with sulphur and chlorine in quantity usually less than 1% dry matter. Compared to coal, biomass generally has less carbon, more oxygen, silica, chlorine and potassium, less aluminium, iron, titanium and sulphur, and sometimes more calcium. However, as reported by Khan et al. (2009), certain biomass types contain trace amounts of contaminating species depending upon the source of the fuel. For instance, heavy metals (cadmium, lead etc.) are commonly found in woody fuels from paints plays significantly in pollutant emission especially in sewage sludge combustion.

Biomass energy is a form of solar energy because it depends on photosynthesis. The energy from sunlight is transformed by green plants into chemical energy by converting carbon dioxide form air and also water from ground into energy-rich organic compounds such as cellulose, starch, lignin and many others. During the combustion of biomass, carbon dioxide and water will be produced and heat energy (which origin from sun) is released. Therefore, biomass is perceived as natural battery for storing solar energy. The battery will last indefinitely as long as biomass is produced continuously in a sustainable manner.

Photosynthesis process occurs and fulfils the equation below:

Carbon Dioxide + Water + Energy (Solar)=Biomass + Oxygen

$$CO_2 + H_2O + \text{Light...chlorophyl...} \longrightarrow (CH_2O) + O_2 \qquad (1.1)$$

When the biomass is combusted, the process above is reversed and heat energy is released.

Ravindranath and Hall (1995) explained that biomass can be converted into solid, liquid and gaseous fuels with the help of some physical, chemical and biological conversion processes. The practical objective of this biomass materials conversion is to transform a carbonaceous solid material which originally difficult to handle, bulky and low energy concentration, into the fuels which having improved physic-chemical characteristics that very suitable for utilization as fuel. There are four thermo chemical methods of converting biomass namely pyrolysis, gasification, liquefaction and direct combustion. Each of these thermo chemical methods produces a different range of products and employs different operating configurations, as shown in Figure 1.3. The basis of a fuel or chemical production system is that the feedstock is converted to useful primary energy. Then, this primary energy is used either as such, or further converted, upgraded or refined in subsequent processes to give a higher quality and higher value secondary product.

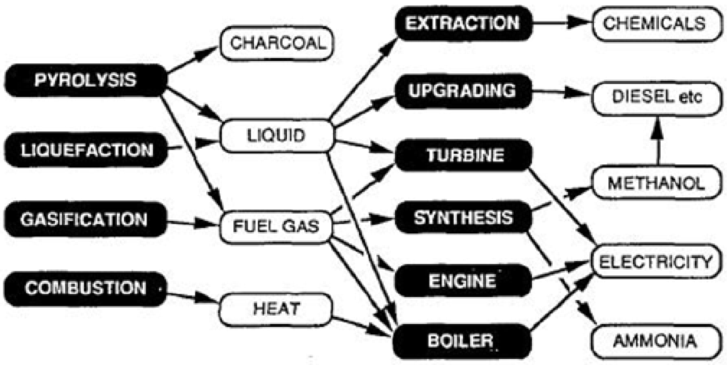

Figure 1.3: Products from thermo chemical biomass processing (Bridgwater , 1996).

1.3 Fundamental Combustion of Biomass

Combustion may be defined as a complex and fast spontaneous chemical reaction of the oxidation-reduction type with large energy release. Such reaction mainly involves the carbon and hydrogen elements of any fuel which considered as reducers and atmospheric oxygen which plays a role as oxidizer.

The main objective of the biomass combustion is to transform the chemical latent heat of the reactants, which is known as Heating Value into sensible heat. This process occurs by direct radiation to the walls of the combustion chamber and/or by convection using the reaction products as a heat carrier. It is also can be converted directly into mechanical work during thermodynamic process. The hot gases from biomass combustion may be used for small combustion units and water heating in small central heating boilers for electricity generation.

Demirbas (2004) mentioned that biomass combustion is considered very important today as it provides substantial benefits especially for environment. Biomass absorbs atmospheric carbon dioxide recycling and does not contribute to the greenhouse effect. It consumes the same amount of CO_2 from the atmosphere during growth as is released during combustion.

Biomass offers very significant advantages as a combustion feedstock due to the high volatility of the fuel and the high reactivity of both the fuel and the resulting char. However, if it is compared with fossil fuels, biomass contains much less carbon and more oxygen and has a low heating value.

The main point of solid fuel combustion process such as biomass combustion is the realization that only fuel gases burn and release heat, and the liquids and solids do not burn but actually consume heat in the drying and volatilization processes. The heat consumption is needed for them to be chemically converted into fuel gases. This phenomenon is illustrated in Figure 1.4. This figure shows the close loop cycle. The key intermediates are the volatiles, carbon monoxide and hydrogen. Therefore, the key to biomass combustion is the rate at which fuel gases are evolved from the solid biomass and char.

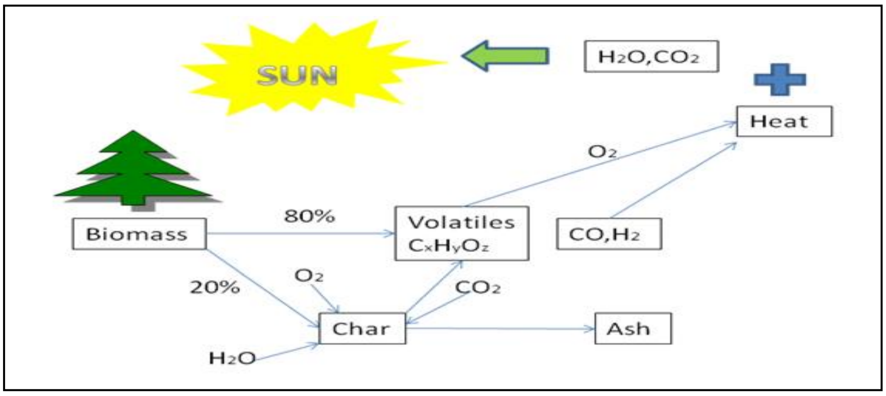

Figure 1.4: Biomass combustion cycle (Ralph, 2003)

1.4 Densification (Briquetting)

Khan et al. (2009) reported that physical properties of biomass vary greatly and properties such as density, porosity, friability and internal surface area depend on types of biomass. Meanwhile, bulk density, particle size and shape distribution are influenced by fuel preparation methods.

As explained by Bhattacharya et al. (1996), densification is known as the process of compaction of residues into a product of higher density than the original raw material. It is a process that can improve the storage and transportation of biomass fuel. The products obtained from densification are called briquette, pellet and bale.

Cattaneo (2003) mentioned that briquetting is compressing the materials into small logs with a diameter of between 30mm and 100mm and of any length depending on the technology used, either screw or piston compression. The materials are simply compressed either by using additives or not. The briquetting processes have been developed in two ways. Europe and USA normally use the path of mechanical compression (hydraulic or piston) while the East usually choose worm screw processing. Briquettes are usually used for both domestic and industrial section including fireplaces, stoves and boiler for steam and hot water generation.

Smaller diameter is normally called pellets (Figure 1.6) and very big diameter (Figure 1.5) is normally called bale. Figures below show the image of densification products.

Figure 1.5: Baled straw (Suttie, 2000)

Figure 1.6: Wood pellet (Biomass Commodities Corporation, MA, United States.)

Figure 1.7: Sawdust briquettes (http://endingcharcoal.wildlifedirect.org/)

Densification such as briquetting also is a useful process to overcome problems such as relatively low heating values per unit volume, process control difficulties, feeding control, storage, expensive transportation and limitation of technologies applied. It also helps to solve the problem of residue disposal and also reduces deforestation by providing a substitute for fuel wood as described by Bhattacharya et al. (1996). Therefore, the bulk density issue is the major aspect needs to be considered when improving the heating values per unit volume, feeding control and many others. For instance, Werther et al. (2000) reported that the bulk densities of chopped straw and rice husks are very low, which are about 50-120 and 100-125 kg/m^3 respectively. These values are very low if compared to the bulk densities of coals, which are 560-600 kg/m^3 for brown coals and 800-900 kg/m^3 for bituminous coals. Table 1.2 below shows the bulk densities and heating values achieved in these processes.

Table 1.2: Comparison of densification techniques for straw

	Bulk Density, kg/m^3	Heating Value, MJ/m^3
Baling	70-90	970-1300
Briquetting and Pelletization	450-650	6480-10080

(Wilen et al., 1987)

Balatinecz (1983) reported that almost similar results can be achieved from briquetting and pelletization. Even though pelletization offers advantages such as higher press output and acceptance of materials with wider range of moisture contents, this process requires chopping and milling. Meanwhile, briquetting may require only chopping process. The briquetting machine's design is also simpler if compared with machine for pelletization.

Khan et al. (2009) mentioned that pretreatment before the densification process influence the moisture content, ash content, particle size and sometimes even the degree of contamination. For instance, straw washing can reduce the salt content such as chlorine and alkali content. Particle size and shape are all important properties for pre-combustion such as feeding and fuel preparation, and combustion process.

There are variety of pretreatments exist based on combustion technology. There are sizing through shredding, crushing and chipping to meet process requirements. Besides, drying also plays an important role for fulfilling the requirement.

1.5 Binding mechanism

The densification of the biomass at high pressure determines the mechanical bond and causes the adhesion between particles increased. This would lead to the formation of the intermolecular bonds in the contact zone. The binding forces that act between the individual particles in densified products can be classified into five groups which are as follow:

i) Solid bridges
ii) Attraction forces between solid particles
iii) Mechanical interlocking bonds
iv) Adhesion and cohesion forces
v) Interfacial forces and capillary pressure

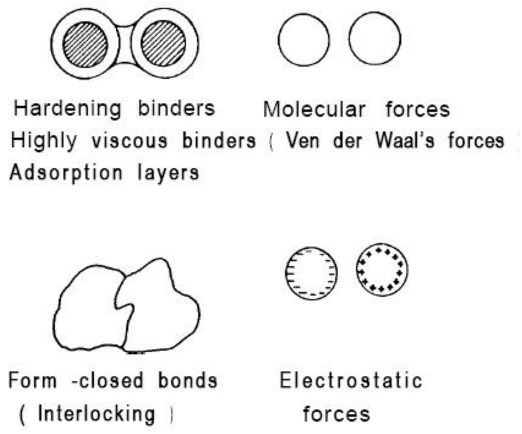

Figure 1.8: Binding mechanisms (Grover and Mishra, 1996)

Cattaneo (2003) explained that high viscous bonding media such as tar and other molecular weight organic liquids can form very similar characteristics to solid bridges. In the perspective of chemical nature, cohesion can be realized in the following ways:

i) The chopped biomass or stems attract the atoms and free molecules in the surrounding atmosphere.
ii) The surfaces of the materials form absorption layers which are no longer free to move remain in close contact and penetrate.

iii) The absorption occurs due to the lignin produced at high temperatures which induced by pressure. The high pressure is important in densification because it increases the area and micro-particles of contact.

Besides the processes as stated above, Van der Waals forces also play an important role which forms further chemical bonds especially if the materials (biomass) are powdered. This would help the densification process.

However, based on research by Obernberger and Thek (2004), there are cases when it is difficult to form the briquette. Therefore, binding agent is used, due to several reasons. One of the reasons is to reduce the operating costs of briquetting and to achieve a higher abrasion resistance. Binding agent also helps to obtain strong briquettes. Well-known binding agents are molasses, fibrous and oily organic wastes, sawdust, bitumen, pitch, sulphite liquor, starch, limestone, dolomite, etc. As described by Yaman et al. (2000), biomass usually has fibrous structure and shows the gluing characteristics through oily and sticky components, which facilitate to form a more dense bulk. The sticky component is called lignin or sulphuric lignin. It is a constituent in most agricultural biomass and is known as a thermo plastic polymer, which begins to soften at temperature above $100^{o}C$. Because of that, as reported by Yaman et al. (2001), biomass may behave as a binder during briquetting when it is mixed with hard material as hard coal.

As reported by Obernberger and Thek (2004), based on the study within the framework of the EU-ALTENER-project “An Integrated European Market for Densified Biomass Fuels (INDEBIF)”, it was found that most of European members such as Austria, Italy, Sweden, Spain and Norway use starch as binding agents since the starch content in briquette or pellet is a good indicator of the use of biological additives.

1.6 Briquetting Technology

High compaction technology consists of the piston press and the screw press. As explained by Cattaneo (2003), the piston press technology uses a piston powered by an electric or internal combustion engine with an oil-pressure system at high pressure. Meanwhile, in a screw extruder press, the biomass is extruded continuously by a screw through a heated taper die. Each of the stated technology has their own advantages and disadvantages. In a piston press, the wear of the contact parts such as the ram and die is less compared to the wear of the screw and die in a screw extruder press. In addition, the power consumed in the piston press is usually less than that of screw extruder as described by Grover and Mishra (1996). However, the briquette produced from screw extruder has more quality if compared with the products from piston press. Furthermore, the outer surface of briquette produced from screw press is partially carbonized which facilitate ignition and combustion. This surface also protects briquette from ambient moisture.

The piston presses are also known as ram and die technology. In this technology, biomass is punched into a die by a reciprocating ram with high pressure to obtain a briquette. The advantages and disadvantages of piston press technology are shown in table below.

Table 1.3: Advantages and disadvantages of piston press technology

Advantage	Disadvantage
The wear of the ram is considerably reduced due to less relative motion between ram and biomass.	Quality of briquettes goes down when production increased
Most cost-effective technology.	Briquettes are somewhat brittle
Different types of biomass can be processed.	Maintenance cost is high compared to screw press technology
The high level of humidity is permitted	
Uniformity of the briquette is possible	

(Grover and Mishra, 1996; Cattaneo, 2003)

Meanwhile, in the screw press technology, the biomass is extruded continuously by a screw through a taper die with external heater to reduce the friction between biomass and die surface. The strong points and drawbacks are shown in table below.

Table 1.4: Advantages and disadvantages of screw press technology

Advantage	Disadvantage
Output is continuous	Power requirement is high if compared with power needed by piston press
Uniform briquette can be easily obtained	Low moisture content required.
Carbonization is possible	
Machine runs very smooth without any shock load	

(Grover and Mishra, 1996; Cattaneo, 2003)

The briquettes produced from both technologies basically show the exponential relationship between die pressure and density in the form

$$D = a\ lnP + b \tag{1.2}$$

where P is measured in MPa, D is the relax density which expressed in kg/m^3 and a, b are empirical constants. This relationship was proposed by Wheeler and O' Dogherty (1984). Husain et al. (2002) obtained this relationship for briquette which contains fibre and shell in the ratio of 60:40.

Osobov (1968), Faborode and O' Callagham (1986) also proposed relationship between pressure and relax density. This relationship also was proved by Husain et al. (2002) in their experiment. After the briquette of fibre and shell was removed from the die and dried at room temperature for one week, the result as shown in figure below was obtained. Figure 1.9 below shows the relationship between relax density and die pressure for three sizes of mould diameter. The relationship is in the form

$$P = a \exp (bD) \quad (1.3)$$

where P is measured in MPa, D is the relax density which expressed in kg/m^3 and a, b are empirical constants.

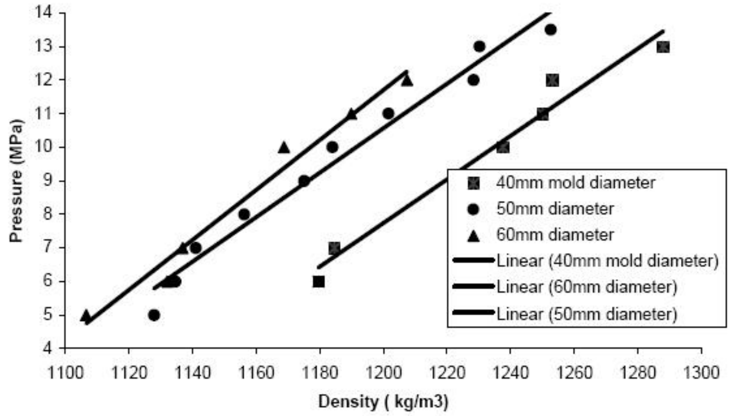

Figure 1.9: Pressure versus relaxed density for three different sizes of the briquettes (Husain et al., 2002)

Currently, as mentioned by Singh and Khare (1993), both screw press and piston press technologies are becoming more important in commercial sector. To ensure that both of these presses able to perform satisfactorily on a commercial basis, basic research to improve the piston press still need to be conducted. Machine manufacturers also must know to suit the technology used with raw material that intend to be used. In addition, Eriksson and Prior (1990) recommended that feeding mechanism also needs to be perfected to ensure that these technologies able to handle the input from feeder.

1.7 Objectives and Scopes

The objective of this research is to produce new mixture of briquette which contains EFB fibre and mesocarp fibre. It is expected that this new type of briquette is competitive if compared with the usual practice briquette at palm oil mills which contains mesocarp fibre and shell.

To ensure that these objectives can be accomplished, scopes are needed for the experimental study. The first scope is investigating the physical and combustion characteristics of briquettes with different weight ratios of empty fruit bunch (EFB) fibre and mesocarp fibre. The best ratio that fulfils the minimum requirement for making commercial briquette and suitable with local condition is selected. The second scope is comparing in term of physical and combustion characteristics between two types of briquette contain different palm biomass materials. The first type contains fibre (from the mesocarp) and palm shell in the weight ratio (60:40). This type is the usual practice briquette which will be used for comparison with the new mixture of briquette which contains empty fruit bunch (EFB) fibre and fibre from mesocarp (60:40 is selected based on experiment). Example of combustion characteristics that will be observed are combustion rate, ash content, heat release and emission level. The physical characteristics such as density and mechanical strength also will be investigated to know the durability of the briquette.

Next, is investigating the effect of compression pressure on the combustion characteristics and the physical characteristics for both types of briquette. In this project, the compression pressure ranges between 3 MPa to 11 MPa.

By utilizing EFB, this would lead to the reduction of dump areas adjacent to the mill and also can prevent such energy source from being wasted.

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