THE ENERGY RECOVERY FROM DECANTER CAKES

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ABSTRACT

Harnessing energy from biomass had caught many researcher’s and scientists’ attention. Converting palm oil mill waste, decanter cakes into solid fuels is objective of this study especially to extract its potentiality to replace the existing boilers feed and to find the optimum condition that leads to the maximum energy recovery. The main steps involve in the process is pyrolysis at temperature ranges from 300°C to 600°C, the drying or heating process for 24 hours at temperature of 110°C and studying the combustion characteristics in terms of heating values and comparing it to that of the commercial solid fuels. The works carried in this research also involve the proximate analysis and semi-quantitative analysis that leads to the computation of HHV and it is compared with that from the Oxygen-bomb Calorimeter (OBC) .It also involve the combustion test of different diameter of DDCs and PDCs spheres to determine the optimum diameter. Based on the study, the decanter cakes is feasible to replace fiber and shell as boiler’s feed that promotes more than sufficient heat to dry the 70kg/ton of decanter cake in-plant and hence generates electricity with and excess steam around 289.075 kg/hr. In fact, the calculation revealed that decanter cakes are feasible to be used as a new boilers fuel when using a steam system from boiler. The fittings generated from the combination of the SEM & EDX data, TGA data and OBC data can be used to estimate the calorific values (J/g) of the solid fuels with percentage error of 0.01 % and 0.45 %. From the study, it can be concluded that the pyrolysis process of DDC did not increase the fixed carbon value and hence lowering the HHV of the solid fuels as the temperature of pyrolysis process increase. As a conclusion, the dried decanter cakes at 110°C at 5 cm in diameter gives better solid fuels characteristics in terms of the heat value and flame characteristics compared to E-Ignite charcoal briquettes and charcoal briquettes derived from coconut shell.

ABSTRAK

Kajian terperinci berkaitan tenaga daripada biomass telah mendapat perhatian banyak peyelidik dan ahli sains. Menukarkan sisa buangan kilang kelapa sawit, ‘*decanter cakes*’ kepada bahan bakar solid ialah objektif kajian ini untuk meggantikan bahan api pendidih industri yang sedia ada dan mendapatkan keadaan optimum yang membawa kepada kitaran tenaga yang maksimum. Proses utama yang terlibat dalam tujuan ini ialah ‘*pyrolysis*’ pada julat suhu antara 300ºC sehingga 600ºC, proses pengeringan selama 24 jam pada suhu 110ºC dan mengkaji ciri-ciri pembakaran bahan api solid dari aspek nilai pemanasan haba , ‘*HHV*’ berbanding bahan api komersial yg lain. Kajian topik ini juga melibatkan analisis ‘*proximate*’ dan ‘*semi-quantitative’*, dimana analisis ini membawa kepada pengiraan ‘*HHV*’ yang kemudiannya dibandingkan dengan nilai ‘*HHV*’ daripada OBC. Kajian ini juga melibatkan pembakaran bahan api solid yang berlainan diameter yang terhasil daripada DDC dan juga PDC yang berbentuk sfera, untuk mendapatkan diameter optimum. Daripada kajian, DDC mampu menggantikan ‘*fiber*’ dan ‘*shell*’ sebagai bahan api pendidih industri dimana tenaga yang terhasil melebihi tenaga yang diperlukan untuk mengeringkan 70 kg/tan ‘*decanter cakes*’ dalam kilang, malah mampu menghasilkan tenaga elektrik dengan lebihan wap air berjumlah 289.075 kg/jam. Rumus-rumus yang terhasil daripada gabungan SEM & EDX, TGA, dan OBC data sangat sesuai digunakan untuk menganggar nilai ‘*HHV*’ dengan sisihan deviasi 0.01 % dan 0.45 %. Kesimpulan yang dapat dibuat ialah ‘*pyrolysis*’ proses DDC tidak meningkatkan nilai ‘*fixed carbon’* dan mengurangkan ‘HHV’ bahan api solid pada peningkatan suhu proses’*pyrolysis*’. Kesimpulannya, DDC pada suhu 110ºC dengan 5 cm diameter menghasilkan bahan api solid yang lebih baik dari segi nilai ‘*HHV*’ dan nyalaan api berbanding E-ignite arang briquet dan juga arang briquet yang terhasil daripada tempurung kelapa.

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LIST OF ABBREVIATIONS/TERMINOLOGY/SYMBOLS

T	- Temperature
D	- Diameter
cm	- Centimeter
J	- Joule
Min	- Minute
S	- Second
Cal	- Calorie
kW	- Kilowatt
Kcal	- Kilocalorie
Kg	- Kilogram
g	- Gram
%	- Percentage
DDC	- Dried Decanter Cake
PDC	- Pyrolysed Dried Decanter Cake
DC	- Decanter Cake
HHVs	- Higher Heating Values
SEM	- Scanning Electron Microscope
EDX	- Electron Diffusion X-ray
OBC	- Oxygen-Bomb Calorimeter
TGA	- Thermogravimetric Analyzer

MC - Moisture Content

FC - Fixed Carbon

VM - Volatile Matter

AC - Ash Content

FC+VM- Fixed Carbon and Volatile Matter (hydrocarbon-like chain)

FFB - Fresh Fruit Bunch

Ee - Electricity Required to Process FFB

Er - Energy to Produce Steam

Ep - Potential Energy Conversion

Hu - Calorific Value

Huf - Calorific Value of Fiber

Hus - Calorific Value of Shell

LHV - Lower Heating Value

Mf - Fiber Production per hour

Ms - Shell production per hour

me - Steam Required to Generate Electricity

mp - Steam Required to Process FFB

mo - Potential Steam Obtained

ηb - Boiler Efficiency

& - And

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CHAPTER 1

INTRODUCTION

1.0 Introduction

Protecting the environment has been the priority of many sectors in our endeavor to ensure sustainable development. Implementation of green energy development based on the use of biomass from the palm oil tree especially decanter cake is in the right path in adopting a holistic approach in the promotion of renewable energy and for the energy recovery in palm oil mill (POM). Malaysia's demand for energy is relatively high in comparison with most developed countries- Japan, Taiwan, USA, Indonesia, Thailand energy intensities were 0.11, 0.22, 0.28, 0.33, and 0.35 ktoe per US$ million, and Malaysia is about 0.40 kton per US$ million respectively. Projections of maximum energy demand were 10775 MW, 20870 MW, and 40515 MW for the year 2000, 2010, and 2020 respectively (Jaafar. M.Z, 2001). And hence the energy intensity (energy use per unit GDP) has worsened over time, while the electricity elasticity in terms of use growth rate to GDP growth rate has been about 1.5 over several decades. And because of that, Malaysia is now looking for the renewable energy and the most promising one is by using the palm oil tree wastes such as fiber and shell or maybe the decanter cake as a new boiler fuels to generate electricity in POM.

Instead of using fiber and shell as boiler's fuel, this work is interested in converting decanter cake from the processing wastes into alternatives fuel for electricity generation for this industry. Alternatively, in order to minimize the environmental pollution from the decanter cake generated from the palm oil mill and also to extract its energy content, the wastes can be burned. However it cannot be burned directly due to its disadvantages characteristics such as low energy density, high moisture contents and problems in handling, storage and transportation. And the investigation from the research from the previous authors' state that it can be densified in form of soft pellets called bio-briquettes to improve the energy density, to increase the heat capacity in terms of the capability to retain heat for a longer period and maintain higher temperatures to facilitate easy ignition of fresh fuel charges before it can be used as boiler fuels (Saptoadi. H, 2006). This is also in line with the primary national energy policy objectives, to promote and encourage the efficient utilization of energy as well as discourage wasteful and unproductive patterns of energy consumption (Yusoff. S, 2006). The subject of this undergraduate research is the energy recovery from decanter cake.

1.1 Problem Statement

Malaysia is the world's largest producer and exporter of palm oil, replacing Nigeria as the chief producer since 1971 (Yusoff. S, 2006). And within the last few years, environmental issues are increasingly becoming more important in Malaysia since the crude palm oil (CPO) mill can cause much environmental pollution from its residues such as decanter solids. Decanter cakes are very difficult for storing, handling and even burning because of the high moisture content levels in the residue and when associated with the organic contents in the decanter cakes, it causes air pollution and exert polluted gaseous like ammonia gaseous. And because of that, it's hard to utilize and harness the energy content from the residues into valuable products like bio-briquette before squeeze out the moisture contents. The drying method for removal of water from decanter cakes is also a major problem. Even though some CPO mills convert the decanter cake into fertilizer and animal feed (Chavalparit. O, 2000), the tons of the waste still in excess contributes to large land area consumption. As a result of a growing awareness of the interconnectivity of POM environmental factors, principles of sustainability, industrial ecology, eco-efficiency, and green chemistry and engineering are being integrated into the development of the next generation of materials, products and processes for the energy recovery by turning the waste into the solid fuel.

1.2 Research Objectives

The objectives of the research are:

1. To develop in-plant process to form the decanter cake into solid fuel (theoretically).
2. To determine the optimum condition that leads to maximum energy recovery from combustion of decanter cake based solid fuel.

1.3 Research Scopes

In order to achieve the objectives, the scopes of the study are identified as follows:

1. Temperature range (300ºC to 600ºC) used in pyrolysis processes.
2. The possible alternatives for in-plant drying
3. Size (diameter) range of converting decanter cake into solid fuels.
4. Calorific values of DDCs and PDCs at elevated temperatures.
5. The proximate analysis and semi-quantitative analysis of samples.
6. The possible fittings based on proximate analysis and semi-quantitative analysis.
7. The heating values of solid fuels derived from decanter cakes and other commercialized solid fuels.

At the end of the study, the finding of this research will help in manufacturing the bio-briquettes from the decanter cake for the energy recovery purpose which is the main concern of this study.

1.4 Rational and Significance

Briquetting of biomass can be considered from the perspective of economics, reliability and ease of operation. By forming the biomass into the solid fuel or known as bio-briquette, it will reduce the amount of decanter cake in palm oil mill (POM), the cost of handling, transportation and also the associated pollution. Bio-briquette is a very good alternatives fuel for POM since it can be used as a new renewable energy to generate electricity in palm oil industries and increase the plant efficiency. Hence it can be used by the local industries. The basic use can be to substitute wood and coal and thereby conserve natural wealth.

CHAPTER 2

LITERATURE REVIEW

2.0 Alternatives for Decanter Cake's in-Plant Drying

Solid waste and by-products generated in the palm oil extraction process are empty fruit bunches (EFB), fibers, shells, decanter cake and ash from the boiler. Drying the decanter cake is not easy in POM. The high moisture content of decanter cake causes more steam and heat to be applied in order to dry and used as fuels for boilers. The alternative ways that is efficient and economic to develop in-plant drying of the residue is still being investigated and lots of parameters on boiler design and selection need to be measured.

Currently, the pressed fibers and shell are use as fuels to generate steam and energy required for the operation of the mill with surplus energy left over. The dry calorific values are 18.6 GJ/ton and 20.8 GJ/ton of fibre and shell respectively (Ma AN, 1999). Thus the total energy from shell and fiber of a palm oil tree is 14 GJ. From the processing of 1 ton of FFB/h the mill produces 140 kg of fiber and 60 kg of shell per hour. And when 30 tons of FFB/ h mill generated, it contributes to 4200 kg of fiber and 1800 kg of shell per hour and when used as boiler fuels, there is more than sufficient steam to generate electricity for the milling process and the excess steam from the boiler is 925 kg/h (Mahlia. T. M.I *et al.,* 2001). Thus the boiler produces high pressure and temperature steam which expands in a backpressure steam turbine and produces enough electric power for the internal needs of the mill and the exhaust steam from the turbine goes to an accumulator which distributes the steam to various processes in the mill (Chavalparit. O, 2000). This exhaust steam can be used to dry the decanter cake.

Another alternative that similar to the removal of moisture contents of EFB before it can be used as boiler feeds is by shredding followed by mechanical pressing. This method claimed more efficient than drying. Hence, steam drying is not recommended. The drying involves high consumption of steam due to evaporation of water, which requires latent heat extracted from the steam generated and hence the flue gases from the boiler chimneys can also being used as a heat source for drying decanter cake (Yusoff. S, 2004).

The next alternative is by selecting new boiler parameters. Currently, the steam pressures used in conventional POM boiler are 21 bar boiler pressure and turbine exhaust pressure of 3 bar which result in 10% thermal efficiency. It is well known that the high end pressure rating for a medium pressure steam boiler is 42-bar without much metallurgical problems arising from high pressures and associated stress. As high boiler pressures give high thermal efficiencies, more exhaust steam will produce and it is prudent to select the best available pressure within metallurgical limits to dry the decanter cake (Mahlia. T.M.I *et al.*, 2001). Most of the alternatives mentioned will be studied theoretically in this undergraduate research in order to solve the in-plant drying issue of the decanter cakes. The entire alternative's process flow diagrams are illustrated in the Appendix A1.

2.1 The Concept of In-Plant Drying

The in-plant plant or formerly known as on-site drying is much closely related to energy recovery. Energy recovery defined as the full utilization of waste heat like steam to support the other process that requires heat in the mill in order to minimize the heat loss efficiently. For example, in Malaysia there are POM that recovers the energy in the steam generated from the fiber and shell as feed boiler to support the sterilization processes (Yusoff. S, 2006).

2.2 Biomass

The term biomass covers a large number of materials with highly different properties which can be used as fuels. These materials can be classified into a few main categories, each of which can be divided into several types:

1. Wood from forestry
2. Residues from wood and food industries
3. Agricultural residues
4. Energy crops (Madsen, 1998).

The fundamental process of biomass accumulation within the context of energy is based on photosynthesis. This is the process by which plants convert solar energy into biomass, as the sun is the source of most renewable forms of energy. The green plant is the only organism able to absorb solar energy with the help of the green pigment, i.e. chlorophyll. It converts this energy into chemical energy of organic compounds with the aid of carbon dioxide and water (Kaltschmitt and Reinhardt, 1997).

Biomass can be defined as all renewable organic matter including plant materials, whether grown on land or in water, animal products and manure, food processing and forestry byproducts, and urban wastes (Kitani and Hall, 1989). Another definition of biomass includes terrestrial plants whose harvest index is principally tons of lignocelluloses material per hectare-year. This group is made up of woody and herbaceous plants (Ranny, 1992). Plant components containing lignocelluloses supply thermal energy directly through incineration, or supply gaseous or liquid fuels indirectly after conversion (Sonnenberg and Graef, 1998).

Biomass fuels composing of cellulose and hemi-cellulose are much more highly oxygenated and less aromatic than coals (Hall and Overend, 1987). Biomass materials generally contain a lower percentage of carbon and a higher percentage of oxygen than fossil fuels. The result is a lower heating value per unit mass of biomass compared with fossil fuels. This means that more biomass fuel must be handled and processed to obtain an equivalent unit of usable energy (Unger, 1994).

The use of biomass as a source of energy is of interest world-wide because of its environmental advantages (Coll *et al.,* 1998). During recent decades, biomass use for energy production has been proposed increasingly as a substitute for fossil fuels. Biomass can also offer an immediate solution for the reduction of the CO2 content in the atmosphere (Gemtos and Tsiricoglou, 1999). It has two other main advantages: firstly its nearly unlimited availability, and secondly the fact that it can be used without essential damage to the environment (Nendel *et al.,* 1998). In addition to its positive global effect by comparison with other sources of energy, it presents no risk of major accidents, as nuclear and oil energy do (Ghislain, 1994). Biomass is a renewable resource compared with the fossil energy resources. By comparison with the other renewable energy resources such as solar and wind energy, biomass is a storable resource, inexpensive, and with favourable energetic efficiency (BMFT, 1986; Brökeland and Groot, 1995; Scholz, V. and Berg, W. 1998).

Its use in energy production could generally be a more advantageous option over fossil fuel. The emission levels of various polluting gases are far lower due to the low amounts of nitrogen (N) and sulphur (S) contained in this fuel. The combustion of biomass such as hay, miscanthus, or hemp generates ashes that can be used as fertilizer. The main nutrients in these ashes are potassium (K) and phosphorus (P) (Hasler *et al*., 1998). In most developing countries, biomass combustion provides the largest component of total national fuel use. It is burned to provide heat for cooking, crop drying, factory processes etc. (Twidell and Weir, 1986). In rural areas, biomass is likely to be the cooking fuel for many years to come. Many towns and villages throughout the world depend on this fuel. Liquid and gas fuels offer an alternative to biomass fuel in these areas, but at higher cost (El Bassam, 1998).

2.3 Pyrolysis Process and Its Products

The thermal decomposition or pyrolysis of waste solids in the absence of air occurs in most burning systems. Pyrolysis defined as a destructive distillation process effected by the application of heat in an insufficiency of air to yield gaseous, liquids and solid products. As cellulose pyrolysis begins (at about 200◦C), partially oxidized tars are evolved. As the temperature increases, these products further decompose or crack, forming simpler, more hydrogen-rich gaseous compounds and solids carbon. The solid residue approaches graphitic carbon in chemical composition and physical structure (Walter R. Niessen, 2002).

Whether the overall pyrolysis process of a given solid is endothermic or exothermic depends on the ultimate temperature attained. For most materials, the process is endothermic at lower temperatures and exothermic at higher temperatures.

The time required for pyrolysis of solid wastes can be estimated that the rate is controlled by the rate of heating. The pyrolysis time is defined here as the time required for the center temperature to rise by 95% of the initial temperature difference between the specimen and the surroundings. The effect of specimen size is evident, thus showing differences expected with size reduction. The effect of gas velocity is also significant and illustrates that in mass burning, where relative gas-solid velocities may range from 0.1 to 0.4 min/sec, slow pyrolysis times would be expected. The relatively long pyrolysis time calculated for small particles at very low (0.01 min/sec) relative velocity suggest strongly that other heat transfer mechanism (especially radiation) can become of primary importance (Walter R. Niessen, 2002).

The liquid product of pyrolysis is known to contain a complex mixture of alcohols, oils, and tars known as pyroligneous acids. The composition is highly dependent upon refuse composition, heating rate and ultimate temperature. The heat content of the liquid per pound of refuse decreases as the pyrolysis temperature increases. Hence, the yield, composition, and calorific value of gaseous pyrolysates depend upon the type of material, the heating rate, and the ultimate temperature. The experiment revealed that the heating value of cellulosic materials (represented by newsprint) first decreases, then increases with increasing heating rate (Walter R. Niessen, 2002).

The solid product or char resulting from pyrolysis is an impure carbon. The proximate analysis for char to be similar to coal, with the rank of the corresponding coal increasing as the ultimate pyrolysis temperature increases. Char formed at 480◦C is comparable to certain bituminous coals, whereas pyrolysis at 925◦C produces an anthracite-like product. High heating rates produced chars with large macroporosities, more open pore structure and larger macropore surface areas (Demirbas. A, 2000).

As the temperature increases, the gas yield increasing, tar produced decreasing, condensed liquid decreasing and char obtained decreasing too (Demirbas. A, 2000). And the carbon and fixed carbon contents of char from biomass increases with increasing of pyrolysis temperature which results in a greater heating value when the biomass samples were nut shells, hazelnut, walnut and almond because the higher heating values (HHVs) of the chars from the samples were correlated with their lignin contents. There was a highly significant linear correlation between the HHVs of the samples and their lignin contents (Demirbas. A, 2000). In simple words, the products calorific values and amount yield of biomass from the pyrolysis process depends on the type of biomass pyrolysed.

2.4 Briquetting

Briquetting is a process of making briquettes. In this section, it covers the principle and technologies involve in briquetting process, and the characteristics of the bio-briquettes.

2.4.1 Principle and Technologies

Densification is a method of pre-treating loose, bulky biomass materials and bringing them into a form suitable for use in available combustion equipment. The handling characteristics of material for transport, storage etc. are also improved (Hulscher *et al.,* 1992). The density depends mainly on pressure. In the presses, especially in briquetting without binding agents, external compressive forces are applied and transmitted through the aggregate of the particles, compacting them. Increasing this force will increase the density and the binding forces between the particles (Lindley and Vossoughi, 1989, Clauß, 2002).

There are different forms of compressed materials. These forms are cubes, pellets and crumbles. American society of Agricultural Engineers (ASAE, 1991) defined these forms as follow:

1. Cubes: An agglomeration of ungrounded ingredients. The configuration of the agglomeration may take any form
2. Pellets: An agglomeration of individual ground ingredients, or mixture of such ingredients, commonly used for animal feed
3. Crumbles: Palletized feed reduced to granulate form

The best known forms of the compressed materials are pellets and briquettes. In general there is no difference in properties between them. The small-length pressed materials are called pellets and the course materials are called briquettes. The use of briquetting for the conversion of agricultural residues is comparatively recent. Briquetting makes these wastes easier to transport, to handle and to store.

2.4.2 Characteristics of Bio-Briquette

There are many factors to consider before a biomass qualifies for use as feedstock for briquetting. Apart from its availability in large quantities should be combustible, mass and energy concentration should be great (Jankovic. S, 1997) it should have the following characteristics:

1. Low moisture content

Moisture content should be as low as possible, generally in the range of 10-15 percent. High moisture content will pose problems in grinding and excessive energy is required for drying. If the feed moisture content is around 8-10% and the resulting briquettes after compaction process will have 6-8% moisture content. The significant of bio-briquettes having more than 10% of moisture contents, the solid fuels result in easily cracks, poor and weak and the operation is erratic. Excess steam is produced at higher moisture content leading to the blockage of incoming feed from the hopper, and sometimes it shoots out the briquettes from the die. Therefore, it is necessary to maintain optimum moisture content (Grover. P.D and Mishra. S.K, 1996).

In the briquetting process water also acts as a film type binder by strengthening the bonding in briquettes. In the case of organic and cellular products, water helps in promoting bonding by van der Walls' forces by increasing the true area of contact of the particles. In fact, the surface effects of water are so pronounced that the success or failure of the compaction process depends solely upon the moisture content of the material. The right amount of moisture develops self-bonding properties in lignocellulosic substances (Sen, 1987) at elevated temperatures and pressures prevalent in briquetting machines. It is important to establish the initial moisture content of the biomass feed so that the briquettes produced have moisture content greater than the equilibrium value, otherwise the briquettes may swell during storage and transportation and disintegrate when exposed to humid atmospheric conditions.

2. Ash content and composition

Biomass residues normally have much lower ash content (except for rice husk with 20% ash) but their ashes have a higher percentage of alkaline minerals, especially potash. These constituents have a tendency to devolatalise during combustion and condense on tubes, especially those of super heaters. These constituents also lower the sintering temperature of ash, leading to ash deposition on the boiler's exposed surfaces (Grover. P.D and Mishra. S.K, 1996). The ash content of different types of biomass is an indicator of slagging behavior of the biomass. The greater the ash content, the greater the slagging behavior. But this does not mean that biomass with lower ash content will not show any slagging behavior. The temperature of operation, the mineral compositions of ash and their combined percentage determine the slagging behavior. If conditions are favorable, then the degree of slagging will be greater. Minerals like SiO_2 Na_2O and K_2O are more troublesome. Many authors have tried to determine the slagging temperature of ash but they have not been successful because of the complexity involved. Usually slagging takes place with biomass fuels containing more than 4% ash and non-slagging fuels with ash content less than 4%. According to the melting compositions, they can be termed as fuels with a severe or moderate degree of slagging (Grover. P.D and Mishra S.K, 1996).

3. Biomass Particle Size

The material or biomass comes in many sizes and it should be granular and uniform so that it can flow easily in bunkers and storage silos. The biomass material with 10-20% powdering component (<4 mesh) gives the best result. The larger particles cause the screw press, piston press and hydraulic press to jam and needs lots of maintenance to repair. Another fact, the particles with different size improves the packing density, dynamics and contributes to higher static strength. The result from the experiment also reveal that if the particles sizes are obtains less than 1 micrometer, it does not suitable to use for briquetting since it is less dense, more cohesive and non-free flowing entities (Grover. P.D and Mishra. S.K, 1996).

Another researcher state that the briquette dimension should be as small as possible but their composing particles should be as coarse as possible because the investigation reveal that the particle size determine the briquette porosities. The smaller the particle size, the higher will be the density, and on the contrary, the lesser will be the porosity (Saptoadi. H, 2006). Hence, same results reveal that materials which are bio-briquette don't need to be especially prepared and grinding should be reduced to a minimum (Mitic, Mihajlovic, Nesic, Milanovic, 1998) so that the biomass with lower porosities will hinder mass transfer, such as drying, devolatilization and char burning process due to fewer free spaces for mass diffusion. Consequently, its combustion rates will be lower and the combustion period will be longer (Saptoadi. H, 2006).

4. External additives

The briquetting process does not add to the calorific value of the base biomass. In order to upgrade the specific heating value and combustibility of the briquette, certain additives like charcoal and coal in very fine form can be added. About 10-20% char fines can be employed in briquetting without impairing their quality (Grover. P.D and Mishra. S.K, 1996). Hence, the variety of biomass had been used to improve the mechanical strength and the energy content like calcium carbonate, beach sawdust, ash chipping, nut shell, rice shell, huskus of grape-vine and cuttings of grape-vine (Mitic and Nesic, 1997) and the result revealed that the briquettes are compact, no crumbling, no cracking in drying phase, and it is possible to cut and engrave them (Jankovic. S, 1997).

Other possible additives are calcium hydroxide, magnesium carbonate and natrium hydroxide that can use as sulfur sorbent in the combustion of briquettes. The function of sulfur sorbent is to absorb the sulfur dioxide gaseous and hence reduced the air pollution (Kim. H, 2003; Mitic, Mihajlovic, Nesic, Milanovic, 1998). The combustion characteristics can be improved by combining biomass and coal, and the experiment revealed that by adding calcium hydroxide and natrium hydroxide as desulfurization agents (DSA), the desulfurization efficiencies are over 80% with molar ratios of DSA to sulfur (Ca/S) of 2 and 3. And for same ratio, the desulfurization efficiencies is about 75% when calcium carbonate is used and the researcher claims that the combination of coal, biomass, and DSA has good flammability and durability and he also state that by using the magnesium carbonate as DSA does not show good result since the desulfurization efficiencies below 50 % (Kim. H, 2003).

Biomass briquettes can have higher density than common wood. Sometimes small amount of conventional solid fuel, such as coal or char is added into biomass briquettes to improve its heating value and combustibility. On the contrary, another research shows that in terms of energy input and pollutant emission such as particulate matters like CO, CO_2, SO_2 and NO_x, the optimum blending ratio of biomass with coal is between 10% and 30% and 40% by using natural binder which is 'cassavaca starch' (H. Saptoadi, 2006). The others binders are pyrolitic oil or tar from the pyrolysis of hazelnut shell (Demirbas. A, 1999) , and bio-binders which originated from the bio-coal suspension that obtained from coal by its biological processing (Ivan P. Ivanov, Rina G. Sudakova, Boris N. Kuznetsov, 2002) The function of binder is to facilitate stable compaction and increased the compressive strength of bio-briquette. In general, briquette durability increased with an increase in the percentage of binder material (Demirbas. A, 1999).

2.5 Coal Characteristics, Usage and Environmental Effects

‘’Coal may in fact be the most useful mineral, second only to food and water as a necessity of life’’. (Rita K. Hesley *et al.,* 1986)

2.5.1 Origin of Coal

Millions of years ago, earth was covered with swamps full of giant trees and other plants. When they died, all living things including the animals which were mainly composed of carbon, the carbon in the swamp plants was compressed and heated. This caused it to rot, exactly the way fruit and vegetables rot if kept too long. This rotting produced methane gas, also known as swamp gas. Over several thousand years, the weight of the upper layers compacted the lower layers into a substance called peat. Peat is the first step on the way to the formation of coal and other fuels. People can use peat as fuel simply by cutting chunks of it out of the ground and burning them. Ireland used to be covered with peat, which was the main source of fuel there for years. The Great Dismal Swamp in North Carolina and Virginia contains almost one billion tons of peat (David M. Haugen, 2007).

As the peat continued to be compacted by the new layers of dead plants, it became hotter. The heat and pressure gradually turned it into coal. Most of the earth’s coal was formed during one of two periods: the Carboniferous (360 million-290 million years ago) or the Tertiary (65 million-1.6 million years ago) (David M. Haugen, 2007).

2.5.2 Type and Rank of Coal

Type, rank and grade are three terms that describe the characteristics of coal. The kinds of plant material from which a coal originated, the kinds of mineral inclusions, and the nature of biochemical reaction conditions that prevailed during periods of plant decay give rise to coal types. The two main types of coal are banded and non-banded. As the name indicates, banded coal consist of discrete layers or bands composed in part of the remains of woody plant tissues, fine plant debris, and mineral charcoal or fusain. Smoother and more finely grained coals derived primarily from spores and algae constitute non-banded coal (Rita K. Hesley *et al*., 1986)

The rank to which a coal is assigned refers to the extent of metamorphosis the deposited plant and animal matter has undergone. The pressure and heat caused by protracted periods of burial or by the folding of the earth's crust brought about progressive changes in the structure of the organic material as it was converted into coal. Coal that undergone the most extensive change, has the highest rank. Chemical analyses are carried out to determine the degree of metamorphosis in a sample.

In practice, the rank of a coal is assigned according to its fixed carbon value where it is obtained by subtracting the moisture contents, ash and volatile matter from the origin sample. Ash is the residue that remains after combustion and volatile matter is the material driven off by heating a coal sample in the absence of air in a furnace under prescribed conditions.

Volatile matter includes all the gases, other than water vapor that are evolved under the conditions of the test. It has been found that the process of coalification increases the amount of fixed carbon and generally decreases the amount of moisture content and volatile matter found in coal. The coalification series begins with lignite as the lowest-rank coal and progresses with gradual changes in fixed carbon and volatile matter to anthracite, or hard coal which has the highest rank.

Although all coal, even at the highest rank, contains moisture, the amount of moisture in a sample of coal is extremely important to its value to virtually every user. First, for every unit weight of water in a shipment of coal, less coal is being received. Since the price is paid per total unit (usually per ton) of material, the presence of more than a small percentage of moisture in coal from a particular area renders it of less commercial value. Second, once coal is ignited, the amount of heat it gives off also determines its relative value for uses ranging from domestic heating fuel to boiler fuel such as in steel industry for power generation. The conversion of water from a liquid to a vapor requires a substantial amount of heat-heat that is 'stolen' from the coal itself, again diminishing its value as a fuel. The heat content, calorific value, or the energy value of coal can be determined in a labarotay test and is recorded in British Thermal Units (BTU).

The anthracite coals have somewhat less heating value than do the medium and low medium-volatile bituminous coals. This illustrates the complex chemical nature of coal and shows that, while the amount of fixed carbon may be used to establish the rank of a coal, the amount of volatile matter and moisture content cannot be overlooked (Rita K. Hesley *et al*., 1986).

There is another type of coal; identified as 'meta-anthracite'. Meta-anthracite sometimes called superanthracite in older texts which is an organic material that has metamorphosized almost completely to graphite. It is not found in many locations and because it has a diminished heat content, is not a very valueable coal. The Narragansett Basin Region of Rhode Island and Massachussetts contain an extensive field of this kind of coal (David M. Haugen, 2007).

2.5.3 Coal Grades

The grade of coal refers to the amount and the kind of inorganic mineral impurities found bound into the coal. Among a variety of inorganic components, sulfur is perhaps the most significant. It interferes with catalytic materials used in coal conversion processes and is converted to gaseous sulfur dioxide, a toxic and corrosive pollutant, when coal is burned. Although the kinds and amounts of inorganic matter are becoming increasingly critical as ecological and environmental considerations, the rank to which a coal belongs is more frequently referred to than its grade in general discussions (Rita K. Hesley *et al*., 1986***).***

2.5.4 Issues, Challenges, and Obstacles in the Use of Coal

The demand for coal is expected to triple in the twenty first century. Coal is the only fossil fuel that is likely to be in large supply in the year 2100. The U.S. Congress has encouraged coal producers to clean up coal for fuel without causing pollution. These methods are called clean coal technologies and include the following:

1. Coal gasification, by which coal is turned into gas that can be used for fuel, leaving the dangerous solid components in the mine.
2. Coal liquefaction, by which coal is turned into a petroleum-like liquid that can be used to power motor vehicles.
3. Coal pulverization, by which coal is broken into tiny particles before it is burned.
4. Use of hydrosizers, which are machines that use water to extract (take out or remove) the usable coal from mining waste to increase the amount of coal that can be retrieved from a mine.
5. Use of scrubbers and other devices to clean before, during and after combustion to reduce the amount of pollution released into the atmosphere.
6. Use of bacteria to separate pollutants from organic components in coal so that the sulfur and other pollutants can be removed before burning.
7. Fluidized bed technology, which burns coal at a lower temperature or adds elements to the furnaces in coal plants to remove pollutants before they burn.

2.6 Fundamentals of Biomass Combustion

More than 90% of the world's primary energy supply is converted by means of combustion to provide energy services for humanity. The energy services include: materials processing including food preparation; space heating, ventilation and cooling; electricity, and transportation. The fuels used include coals, gasoline and etc (Ralph P. Overend, 2003).

Combustion is a process in which the fuel is burnt with oxygen from the air to release the chemical energy as heat (Ralph P. Overend, 2003). Biomass has one clear advantage over fossil fuels in that the emissions of carbon dioxide derived from biomass to the atmosphere are essentially in equilibrium with the uptake of carbon dioxide by the biosphere through photosynthesis. This closed loop for carbon distinguishes biomass utilization from all other carbon containing fuel (Ralph P. Overend, 2003).

Biomass combustion is one of the complex combustion systems to manage since it involves the use of solid fuels in a multi-phase reaction system with thermal and mass fluxes that have until recently defined complete analysis and simulation. For example a wood fire that has been burning for a while, demonstrates several processes going on simultaneously. At the top of the fire there will still be fresh, though this will probably be steaming and even making a hissing noise as the water evaporates from the internal structure of the wood as the fire's heat is transferred through the material.

Underneath the stick that is drying, the next stick will be black, and will have shrunk in diameter with flames some distances off its surface wrapping around the still green drying stick above. The blackened stick is in the process of pyrolizing, converting the organic materials that make up wood into liquids, gaseous and chars. If the stick is pulled from the fire, the liquids on the surface will be pungent smoky smelling tar like materials, sometimes called creosote when they condensate in chimneys. As the liquids evaporate from the heat of fire, the vapors mix with air and burn in yellow and blue flames. These flames produce the majority of the heat released from the biomass. The radiation from the flames feeds back to the body of the fire to heat the sticks to evaporate more pyrolysis liquids to maintain the flames (Ralph P. Overend, 2003).

The layers of sticks below the pyrolysis zone have lost all their volatiles and are now char or carbon that is burning with a red glow. At this stage, the char still has much of the appearance of the original stick, but as the red glow continues the remaining carbon is consumed and only a white ash material remains.

The solid fuel combustion processes had been realize by Ralph P. Overend that only fuel gases burn and release heat, and the liquids and the solids do not burn but actually consume heat in the drying and volatilization processes needed for them to be chemically converted into fuel gases. Thus, the key to biomass combustion is the rate at which fuel gases are evolved from the solid biomass and char. In the pyrolysis stage, the rate of fuel gas evolution is a function of both the temperature and the intensity of the heat flux supplied to the solid surface and the pyrolysis liquids. When the char combustion stage is reached, after all of the volatiles have been removed, the char combustion rate is controlled by the velocity with oxygen, carbon dioxide and water vapor that can reach the hot char surface to produce the fuel gases, hydrogen and carbon monoxide. Then when the gases burn with oxygen from the air producing water vapor and carbon dioxide and release heat for the endothermic reactions of water vapor and carbon dioxide as they react with hot carbon in the char at temperatures almost 700ºC. And if the rate of diffusion has been overcome by the air flow, the temperature of the combustion will exceed almost 1500ºC (Ralph P. Overend, 2003).

2.6.1 Three T's: Temperature, Time and Turbulence

From the proceeding discussions, it can be seen that the above biomass combustion stages has a series of constraints, which limit the overall efficiency of heat generation and the maximum temperatures reached. To ensure the combustion is efficient as possible, it is possible to maximize the 3Ts simultaneously. The role of Turbulence is to ensure full and complete mixing of the fuel gases with oxygen in the process and ensure complete burning without diffusion limitations. Time is required as the process of drying and pyrolyzing the solids are relatively slow processes and even the combustion of the fuel gases requires a few seconds to complete. Maximizing the Temperature increases the rate of all of the reactions. In maximizing the three Ts, the highest efficiency combustion system does have a separate combustion zone from the heat transfer surfaces. The lowest efficiency systems are open fires, losing temperature by radiation into space and losing the large amount of excess air that is drawn in by convection as the hot air and the smoke rise (Ralph P. Overend, 2003).

CHAPTER 3

METHODOLOGY

3.1 Raw Material and Equipment

The raw material involve is the decanter cake and the equipments described in this chapter only involve the major equipments such as furnace, oven and OBC.

3.1.1 Decanter Cakes

The decanter cakes in Figure 3.1 are the biomass used for this research. It was derived from the palm oil mill sludge separation. The decanter itself refers to the type of sludge separator. The promising biomass was obtained from LKPP CORPORATION Sdn. Bhd located at Lepar Hilir, Kuantan Pahang.

Figure 3.1: Wet Decanter Cakes

3.1.2 Other Solid Fuels

In order to compare the heating values of decanter cakes, commercial solid fuels from charcoal, Charcoal Briquette from coconut shell and Charcoal briquettes (E-ignite) were also studied. The two mention briquettes were obtains from Gambang supermarket and were distributed by Venue Star Sdn. Bhd, a company located at Shah Alam. And the charcoal used was purchased from Gambang Supermarket.

3.1.3 Equipments

The major equipments used in this research includes the Thermogravimetric Analyzer (TGA), Oven, Furnace, Scanning Electron Microscope (SEM) & Electron Diffusion X-Ray (EDX) and the Oxygen Bomb Calorimeter (OBC). The minor equipments used include Bunsen burner, Barbeque Stove, Igniter and others.

3.1.3.1 Oven

Figure 3.2 illustrates the oven used in the drying process of decanter cake. Oven is one of the kitchen appliances used for cooking or heating. The concept of this appliance is using electric to heat the heating medium to produce sufficient heat drying the samples. The oven used can generate temperature up to 300ºC. Equipped with efficient temperature control, air flow conditions and operating condition more than 24 hours, the oven is chosen for drying the raw material in this experiment rather than using the microwave oven. Conceptually, the microwave is more efficient on heating in terms of radiation of magnetic wave generated from the electricity but due to the sample condition, it is not suitable because the samples used were high in volatile matter that easily to ignite and may cause explosion to the microwave oven.