CHARACTERISATION OF COAL AND BIOMASS MIXTURE FOR CO-GASIFICATIONS

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ABSTRACT

Biomass fuels can be produce by widely available raw materials which is come from different sources and wide variety of forms. Co-gasification can reduce the cost of the feedstock and reduce the problems that occur in plant operation due to the production of tar (Kumabe et al., 2006). For the pre-treatment of biomass, sample received were relatively dry for 24h under sunlight having less than 10 wt% moisture and were in the form of whole bunches. The EFB was manually chopped into small pieces. Then a grinder was used to reduce the size. For first analysis, heating value of EFB was determined by burning a weighed sample in an adiabatic oxygen-bomb calorimeter (model Parr 1341, USA). The apparent density of the EFB samples was determined using a gas pycnometer (model Micromeritics, AccuPyc II 1340) with helium as purging gas. The percentages of carbon, hydrogen, nitrogen, sulfur and oxygen (by difference) of the EFB sample were determined after complete combustion of the sample using a CHNS/O Analyzer (model LECO TruSpec CHN, USA) following the ASTM D-5291 method (Kezhong et al., 2009). The contents of moisture (dry basis), volatile matter, fixed carbon and ash were determined using a thermogravimetric analyzer (model Mettler Toledo, TGA/SDTA851, USA).One of the main objectives of this research is to study the effect on characteristic of mixture coal and biomass in co-gasification and compare with coal gasification or biomass gasification itself. For higher heating value, the average value is 24.5697 MJ/kg. For apparent density of the mixture, as percentage of biomass increase, the apparent density also increased but after 70% biomass, the apparent density starts to reduced. For the proximate analysis, B0 have 2 times greater weight loss compared to B100 at the same temperature. For elemental analysis, B100 contains 2 times greater oxygen compared to B0 but have greater carbon number compared to B100.Unlike coal, biomass with low ash and sulphur content, a high volatile matter yield and fixed carbon with high reactivity could potentially be attractive from the economic, environmental and social points of view that poor coal. Low density and low calorific value of biomass causes an increase in the cost of transportation and storage, hence by co-gasification of biomass with coal is more economical compared to biomass alone.

Keywords: Coal, Empty fruit bunch (EFB), co-gasification, B100, B0

ABSTRAK

Bahan api biojisim boleh terhasil oleh bahan-bahan mentah yang boleh didapati secara meluas yang dating dari pelbagai sumber dan bentuk yang berbeza. Ko-pengegasan boleh mengurangkan kos bahan mentah dan mengurangkan masalah yang berlaku dalam operasi kilang kerana pengeluaran tar (Kumabe et al., 2006). Pra-rawatan biomas, sampel yang diterima perlu dikeringkan sehingga 24 jam di bawah cahaya matahari sehingga mempunyai kurang daripada 10% berat kelembapan dan berada dalam bentuk tandan keseluruhan. TBK secara manual dicincang kepada kepingan kecil.Kemudian penggiling digunakan untuk mengurangkan saiz.Untuk analisis pertama, nilai pemanasan TBK telah dihitung dengan pembakaran sampel ditimbang dalam adiabatik kalorimeter oksigen bom (model Parr 1341, Amerika Syarikat).Ketumpatan jelas sampel TBK ditentukan dengan menggunakan piknometer gas (model Micromeritics, AccuPyc II 1340) dengan helium sebagai penyingkiran gas. Peratusan karbon, hidrogen, nitrogen, sulfur dan oksigen (oleh perbezaan) sampel TBK ditentukan selepas pembakaran lengkap sampel menggunakan CHNS / O Analyzer (model LECO TruSpec CHN, Amerika Syarikat) berikut ASTM D-5291 kaedah (Kezhong et al., 2009). Kandungan kelembapan (kering), perkara yang tidak menentu, karbon tetap dan abu ditentukan dengan penganalisis Termogravimetri (model Mettler Toledo, TGA/SDTA851, Amerika Syarikat).Bagi nilai pemanasan yang lebih tinggi, nilai purata adalah 24.5697 MJ/kg.Kepadatan jelas campuran, sebagai peratusan peningkatan biomass, ketumpatan ketara juga meningkat tetapi selepas 70% biojisim, ketumpatan ketara mula dikurangkan. Untuk analisis proksimat, B0 mempunyai 2 kali lebih besar penurunan berat badan berbanding B100 pada suhu yang sama. Untuk analisis unsur, B100 mengandungi 2 kali oksigen lebih besar berbanding dengan bilangan yang lebih besar karbon B0 tetapi mempunyai berbanding B100. Tidak seperti arang batu, biomas dengan abu yang rendah dan kandungan sulfur, hasil perkara yang tidak menentu yang tinggi dan karbon tetap dengan kereaktifan tinggi berpotensi menjadi menarik dari mata ekonomi, alam sekitar dan sosial berpendapat bahawa arang batu miskin. Ketumpatan yang rendah dan nilai kalori yang rendah biomas menyebabkan peningkatan kos pengangkutan dan penyimpanan. Oleh itu, pengegasan biomas bersama dengan arang batu adalah lebih menjimatkan berbanding dengan biomas pengegasan sahaja.

Keywords: Arang, tandan buah kosong (TBK), ko-pengegasan, B100, B0

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LIST OF ABBREVIATIONS

N	Avogadro's constant
BEC	Biomass Energy Centre
C	Carbon
CO_2	Carbon dioxide
CO	Carbon Monoxide
C_EUE	Carbon Energy Utilization Efficiency
EFB	Empty Fruit Bunch
R	Gas constant
HHV	Higher Heating Value
H	Hour
H_2	Hydrogen gas
H_EUE	Hydrogen Energy Utilization Efficiency
H/C	Hydrogen to carbon ratio
IGCC	Integrated Gasification Combined Cycle
Kg	Kilogram
CH_4	Methane
MILP	Mixed Integer Linear Programming
MW	Molecular Weight
N_2	Nitrogen gas
O	Oxygen
O_EUE	Oxygen Energy Utilization Efficiency
O/C	Oxygen to carbon ratio
OECD	Organization for Economic Cooperation and Development
P_S	Pressure sample
P_{sys}	Pressure system
P_{ref}	Pressure reference
SMC	Spent Mushroom Compost
S	Sulphur
T	Temperature

TGA	Thermogravimetric Analyser
USA	United State of America
V_f	Unknown volume
V_s	Volume sample
Vs	Versus
H_2O	Water
Wt	Weight
WCI	World Coal Institute

1.0 INTRODUCTION

1.1 Background of study

One of the major renewable energy which is sustainable, environmental–friendly energy sources is biomass. Biomass is the top four among the primary energy sources such as coal, oil and natural gas and currently caters for about 14% of the world's total energy consumption (Alauddin ZABZ et al., 2010). The raw biomass can be treated thermo-chemically, biologically, or by catalytic processes. Table 1.1 displays the various biomass conversion technologies.

Table 1.1 : Biomass conversion technologies (Biomass Energy, 2009)

Technology	Type of Conversion process	Major biomass feedstock	Energy or Fuel production
Direct combustion	Thermo-chemical	Wood, agricultural waste, municipal solid waste	Heat, steam and electricity
Gasification	Thermo-chemical	Wood, agricultural waste, municipal solid waste	Producer gas
Pyrolysis	Thermo-chemical	Wood, agricultural waste, municipal solid waste	Synthethic fuel oil (bio-crude) and charcoal
Ethanol Production	Bio-chemical (aerobic)	Sugar or starch crop, wood waste	Ethanol

The increase in the global energy consumption in recent years has led to an alarming rise in emission of harmful compound into the environment that has a dominant influence on the atmosphere. Carbon dioxide emission from fossil fuel consumption has become a major problem resulting environmental pollution. According to the International Energy Outlook, world energy-related CO_2 emission will increase from 30.2 billion metric tons in 2008 to 43.2 billion metric tons in 2035 (Energy Outlook, 2011). Other than that, fossil fuel such as coal and oil also emit other compound such as NO_X and SO_x. All of this compound will lead to environmental effect like acid rain, ozone depletion, global warming and their after effects such as rising sea levels (Leila Emami et al., 2003).

Biomass fuels can be produce by widely available raw materials which is come from different sources and wide variety of forms. All of these forms can be used for fuel production purposes, however not all energy conversion technologies are suitable for all forms of biomass (Biomass Energy Centre, 2011). Based on figure 1.2, from year 2010 to 2040, the world energy consumption is expected to increase by 56% (EIA, 2013). This is due to to the economic growth and increasing population especially in the countries that is outside the Organization for Economic Cooperation and Development (OECD) known as non-OECD (EIA, 2013). In addition, the energy used in the non-OECD increase by 90% while in the OECD is about 17% only (EIA, 2013). Based on statistics provided by BP Statistical Review of World Energy 2013, 33.1% accounted by oil as world's leading fuel followed by natural gas, coal, hydroelectricity, nuclear energy and renewable. Asia Pacific region accounted the most of the global energy consumption 40% and 69.9% of global coal consumption.

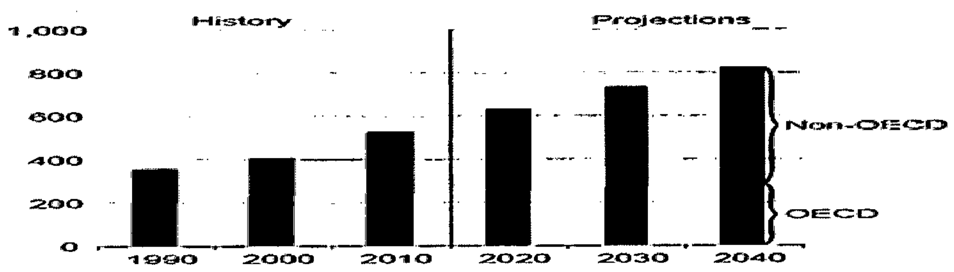

Figure 1.1: World energy consumption from 2000 to 2040 (unit in quadrillion Btu) (EIA, 2013)

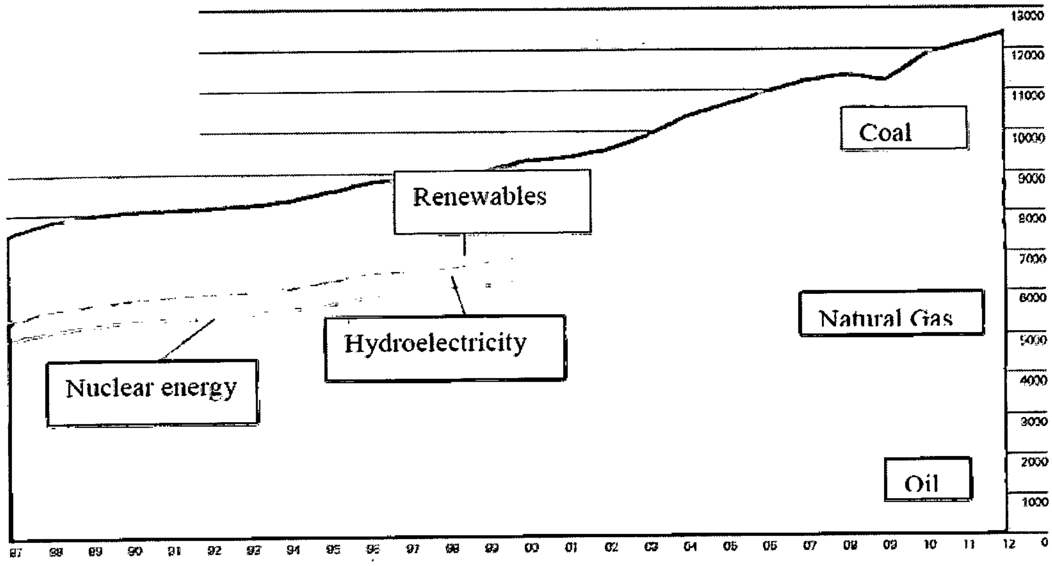

Figure 1.2: World energy consumption in term of fuels from 1987 to 2012 according to BP Statistical Review of World Energy.

They are several classes of biomass include wood and agricultural product, solid waste, landfill gas and biogas and alcohol fuels. It has been extensively studied regarding co-gasification of coal and biomass (Jhon F. et al., 2006). The use of coal could help to provide stable gasification conditions and could prevent problems due to wastes seasonal shortness (J.Fermoso, 2009). Biomass gasification itself is relatively high cost and produces large amount of tar. Therefore, co-gasification can reduce the cost of the feedstock and reduce the problems that occur in plant operation due to the production of tar (Kumabe et al., 2006). Biomass and coal are considered as potential feedstock's which supply syngas (CO and H_2) for the synthesis of liquid fuels by gasification. This is due to depletion of natural gas resources which increased the necessity for reducing the consumption of natural gas (Droege P, 2002). A reduction of green-house emission when coal and biomass are co-gasified becomes evident given the renewable character of biomass. Additional environmental benefits of co-gasification include a reduction on nitrogen oxides and sulphur emissions (Velez et al., 2008). Biomass in co-gasification could contribute to the reduction of fossil fuel dependency (Long & Wang, 2011). Tar yield from ligno-cellulosic biomass materials tend to be considerably higher than tar yield from coals. This recognise problem arise mainly from the lower temperatures and shorter residence times in gasifiers constructed for biomass processing compared to those designed for coal gasification (Fraga et al., 1991).

Unlike coal, biomass with low ash and sulphur content, a high volatile matter yield and fixed carbon with high reactivity could potentially be attractive from the economical, environmental and social points of view that poor coal would be utilized for electrical power generation (Pan et al., 1996). Increase of fluctuations in quality, availability and composition by heterogeneity of biomass and wastes cause their processes to be more complicated than of coal. In co-gasification, coal acts as buffer and a bed material to improve the quality of biomass particle. Low density and low calorific value of biomass causes an increase in the cost of transportation and storage, hence by co-gasification of biomass with coal is more economical compared to biomass alone (Hernandezz et al., 2010 & Seo et al., 2010). One of the largest producers of palm oil with a variety of empty fruit bunches waste in the world today is Malaysia. In the year 2008, Malaysia produced 17.7 million tonnes of palm oil on 4.5 million hectares of land (Malaysian Palm Oil Industry Performance, 2009). Table 1 shows the production rate of biomass for energy.

Table 1.2: Recoverable production of biomass for energy (Tester et al.,2004)

Region	Forest (EJ/yr)	Crop (EJ/yr)	Dung (EJ/yr)
US and Canada	1.7	3.8	0.4
Europe	1.3	2.0	0.5
Japan	0.1	0.2	-
Africa	0.7	1.2	0.7
China	1.9	0.9	0.6
World Total	12.5	13.7	5.1

Coal has the largest reservoir in the world compared to the other energy sources like oil and gas according to the BP statistics review of the world's energy (BP, 2011). Top five producers of coal are China, US, India, Australia and South Africa (WCI, 2013). They are highly dependent on coal resources for their energy needs. Japan and Korea are the examples of country which need to import coal. Since industrial era in the 18th and 19th coal has been used and have higher demand. Global coal consumption and production grew by 2.5% and 2.0% in 2012 respectively (BP, 2013). Coal production has increase fastest in Asia and the global coal production is expected to reach billion tonnes in 2030 where China accounting half of the production. Steam coal production is use in Asia for electricity, coking coal for cement manufacturing and steel production. Due to the common availability of coal and its cost feasibility, most of the developed countries use coal as a fossil fuel for power generation. However if some countries have a deficit in coal resources then they mainly import from the coal enriched countries. Although, there is a large scientific knowledge on separate gasification of both coal and biomass, the application of this technology to coal mixed with wastes is still under development (Filomena et al., 2003).

Gasification is a clean technology that converts different carbonaceous feed stocks such as natural gas, coal, petroleum, coke, biomass and municipal solid wastes in a limited supply of air to gaseous products such as hydrogen and carbon monoxide (syngas), carbon dioxide, water as well as gaseous hydrocarbons at high temperatures (Leila Emami et al., 2012). It also produces solids such as char, ash and condensable products like tars and oils. Gaseous products can be used to produce electricity, hydrogen, chemicals and liquid transportation fuels. Gasification process is one of the promising technologies that has been widely studied to exploit energy using several kind of feedstock, as coal, biomass or mixtures (Maria P.Aznar, 2006). Sewage sludge and municipal solid wastes have been also used in this process (Mohd Asadullah, 2013).

This process begin with pyrolysis which is endothermic process where small part of carbon-based feedstock is burned to provide heat that is needed to remove moisture and volatiles in the absence or poor presence of oxygen. After pyrolysis, more heat is needed to thermally crack the volatiles to break the long hydrocarbon chains into lighter gases as well as to gasify the remaining carbon left in the feedstock into synthesis gases (Henry et al., 2011).

1.2 *Problem Statement & Motivation*

The use of biomass as renewable energy is important to alleviate global warming (McKendry, 2002). Greenhouse gas emissions by fossil fuels burning can be reduced by renewable energy (Babu, 2006). Renewable energy resources like biomass have high potential in produce zero net carbon dioxide emissions (Tijmensen et al.,2002). It can be converted into gas or liquid fuels by processes called bio-chemical or thermochemical (Darvell, 2006). Gasification of biomass is one of the few technologies that can potentially produce carbon negative energy with pollution-free power and also change the agricultural gas into energy (Li et al., 2004). Biomass contain excessive amount of moisture content that must be remove preferably prior to entry in the gasifier. This excessive amount of moisture content will reduce the thermal efficiency of the gasification system (Asadullah, 2013). Water content during first stage of combustion system must be removed, requiring energy, and thus reducing overall system efficiency and potentially reducing combustion temperature below the optimum. Temperature below the optimum may cause incomplete combustion which will giving rise to emission of tars. Other than that, moisture content in biomass can cause impact on storage and transport (Biomass Energy Centre, 2011). There are several step to remove moisture content in biomass such as sun drying at the origin where the biomass is produced or drying using heat at the plant where it would be converted to energy. Sun drying is time consuming and generally the cheapest drying to reach the equilibrium moisture content (Asadullah, 2013).

Empty fruit bunch (EFB) is type of agricultural biomass that is not easy to feed in the gasification unit. The heterogeneity and low bulk density of the biomass can be overcome by densification process called pelletisation. EFB can be converted into a value added fuel with homogenous properties, shapes and sizes. Pelletisation provides advantages in terms of handling, storage, transportation and feeding properties. Pelletisation of material is performed by applying pressure, shear or combination of both (Changkook et al., 2007). Size, shape and structure of biomass the rate of gasification. For maximum rate of gasification and better controlling temperature, small size of biomass is preferable (Leila Emami et al., 2013). The composition and impurities of the syngas produced in the gasification depends on biomass feedstock, gasifier design, gasifying agent and gasification condition (Asadullah, 2013). Besides producing syngas, gasification process produced other contaminants that can be removed by gas cleaning. They are two different type of gas cleaning which is cold and hot cleaning system (Ruiz et al., 2012). Tar is unpleasant by-product of gasification. Compared to coal gasification itself, tar is produced in greater quantity during pyrolysis zone (Leila Emami et al., 2013). As the syngas cools downstream of the reactor, vaporised tars will condense either onto cool surfaces or as aerosols or small liquid droplets, which could lead to blockages in the downstream syngas pipe work. Hence tar removal is critical in systems where the syngas is compressed prior to use, such as gas turbines. Wet scrubbers have been used widely in the removal of tars from gas streams in coal processing plants. Catalytic tar destruction techniques are also being developed, which retain the energy value of the tar compounds in the syngas.

1.3 Objective of the research

The objective of the research is characterisation of coal and untapped biomass which is palm empty fruit bunch (EFB) for co-gasification.

1.4 *Scope of study*

In order to fulfill the research objective, the following scopes of research has been outlined:

i) To produce untapped biomass palm empty fruit bunch (EFB) with low moisture content and high density for easier mixing with coal before gasification process

ii) To demonstrate the effectiveness of biomass and coal being gasified together; so that co-gasification can be developed into a cost-effective and environmentally friendly

iii) To study the factor effecting the co-gasification process (type of biomass, proportion of biomass in coal-biomass mixture, ash content, air-steam flow rate, gasifier temperature, catalyst, downstream processing, particulate matter removal or gas cleaning, alkali removal, tar removal, environmental benefit).

iv) To study the effect on characteristic of mixture coal and biomass in co-gasification and compare with coal gasification or biomass gasification itself. (moisture content, fixed carbon content, element composition C,H,O,N,S).

v) Examine potential issues related to the chemistry during biomass and coal gasification and their impact to the syngas.

1.5 Chapter Organisation

Chapter 2 provides a description of the problems, background, pre-treatment of coal and biomass, coal gasification, biomass gasifications and co-gasification of coal and biomass mixture. This chapter also provides a brief discussion effect co- gasification process using different ratio of biomass and compare the coal gasification and biomass gasification itself.

Chapter 3 gives a review on the procedures and detailed about the analysis of biomass and coal mixture. Brief explanation regarding the description of process equipment that will be used in this research also presented. Besides that, the full sequence about this research also presented along with the step required to run the experiment.

Chapter 4 is about the results that have been obtained from the analysis of biomass by using different ratios regarding this research along with brief discussion by comparing it with previous study. Besides that, expected results for this research, also will be discusses and briefly explain based on results that have been obtained.

Chapter 5 is about the conclusion regarding experiment. Besides that, in this chapter also provides a brief recommendation that can be suggested to improve this research.

2.0 LITERATURE REVIEW

2.1 *Biomass collection*

Biomass is considered as a big challenge that negatively impact the profitability and further development of biomass based energy due to collection and delivery of biomass to the energy conversion plant that is cost intensive (Asadullah, 2013). Difficulties of biomass collection system are cause by the unstable market of biomass due to lack of fully established biomass energy conversion technology (Ruiz et al., 2013). Cost related to biomass feedstock can be reducing by optimized collection, storage and transportation along with appropriate selection of the power plant location. Over the last few years based on regional biomass, a comprehensive research both in modelling and practical field has been conducted to estimate the available biomass and to establish a suitable collection method (Leila Emami et al., 2013). One of the cost effective ways to collect distributed agricultural biomass is the satellite storage and delivery. Harvesting and collection cost of biomass depends on the type of biomass and economic status of the country. Even the economic status for almost all Europe country is the same, but the cost of biomass still varies across the Europe countries. The highest cost have been found to be in Italy where \$39.8 t^{-1} for agricultural and \$88.8 t^{-1} for forest residue. Different cost is depends on difficulties of ways of collection (Asadullah, 2013).

2.2 *Biomass transportation*

Transportation of biomass from the origin where it is available to the power generation unit is one of the challenges of biomass based power generation. There are several problems in effective transportation that can be solved: (1) excessive moisture content and (2) low bulk density (except wood log) (Kezhong et al., 2010). These two problems increase the biomass transportation cost as well as increase the cost of bio energy as a whole. To ensure the consistent supply of biomass to the power plant and reduce transportation cost as well, the transportation network and medium of transportation as part of logistic support can be optimized (Abdullah., 2011). A comprehensive research in mathematical modelling has been proposed in developing an optimized logistic system. For cotton stalk transportation from the field to warehouses, a linear programming model was proposed. This linear programming initially developed for designing a delivery for herbaceous biomass as well as for solving the day to day tactical planning problems. A conceptual mixed integer programming (MILP) model was used to identify the key cost component is biomass logistic, where transportation was one of the major factors that give rises to the biomass price. To minimize the delivery cost, a linear programming model is proposed for switch grass transportation by scheduling shipments from the various on-farm storage locations to meet the demand of feedstock supply (Asadullah, 2013).

2.3 *Pre-treatment of coal and biomass for co–gasification*

Biomass is very difficult to be transport and use as feedstock. It is not easily to pulverized or slurries like coal, so continuous feeding tends to be an issue. Biomass has a highly fibrous, sinewy structure, making it hard to tear up and easily to get stuck in most machine usually between gears and in conveyor belt drives. To solve this issue, a few step have been taken through several technologies. Due to easily pulverized or slurries like coal continuous feeding of biomass can be a problem. Biomass physically has a highly fibrous, sinewy structure making its hard to tear up and easily get stucked in most machines, especially between gears and in conveyor belt drives. Flash pyrolysis and torrefaction are technologies which can reduced this problem. First phase of the overall gasification process.

2.3.1 *Drying*

Before coal and biomass can be fed into gasifier, it must be reduction in moisture content and size for easy co-gasification process. To achieve moisture content suitable for this operations, drying is required. They are several benefits using dry biomass for combustion such as increased boiler efficiency, lower fuel gas emissions and improved boiler operations compared to fuels with high moisture (Hanning et al., 2012). They are three types of drying biomass such as rotary dryers, flash dryers and superheated steam dryers. The most common dryers use is rotary dryers because of its least sensitive to material size and greatest fire hazard (Wade, 1998). For freshly cut wood, the typical ranges moisture content is from 30% to 60% and may be exceed 90% in some types of biomass. The most preferable moisture content for gasification process is 10% to 15% (Ruiz et al, 2012).

High moisture content will cause temperature of the gasification process reduced thus will result to incomplete combustion. Forest residues or wood has a fiber saturation point at 30% to 31% moisture content. To reduce the moisture content below saturation point, compressive and shear strength should be increased. This will push the cell wall closer to one another and bind more tightly. In the gasification zone, a high level of moisture usually fed in form of steam to favour water-gas shift reaction that will increase hydrogen concentration in the resulting gas (Brar et al., 2011). Moisture will generate steam which act as gasifying agent that react with volatiles and char to convert them to product gas as well as taking part in water-gas shift reaction to increase hydrogen gas production (Lv et al., 2007 & Yan et al., 2010). Moisture content which is higher than 40% will reduces the thermal efficiency of the gasification system. This is because the heat absorbed by the unreacted steam in three steps, including heating of moisture content more than 100°C, latent heat of vaporization and heating of steam to gasification temperature is totally lost from the system, and thus increase the thermal cost. In additional, during gasification process, further addition of water is needed to balance the hydrogen content in the product gas. This complete drying of biomass is cost intensive. The moisture content in raw biomass usually above 50 wt% such as palm empty fruit bunch (EFB) is the abundantly available agricultural biomass in Malaysia and Indonesia (Ma & Basiron, 2005). The utilization of this kind of biomass for energy production is a real challenge. There are several crucial factors severely affecting the constant supply of this biomass and the most severe challenge is drying. There may be two options to reduce the moisture content to a desired range whether by sun drying at the origin where the biomass is produced or it may be drying using heat at the plant where it would be converted to energy. Eventhough, the sun drying process is less costly it takes longer time to reach the equilibrium moisture content (Acharjee et al., 2011). It also depends on the atmospheric humidity. The challenge in this slow drying process is that the biomass gets molds and biologically degrades. On the other hand, the drying at the processing plant is costly because of using costly drying equipment as well as supplying heat for drying.

2.3.2 Pelletisation

Biomass such as forest slash and construction waste usually irregular in shape, low in energy density, high moisture content and difficult to transport and store. Lignocellulosic biomass which is biomass from plants usually have a relatively low bulk density of 30 kg/m^3 and a moisture content between 10% to 70% (wb). Pelleting increases specific density (gravity) of biomass to more than 1000 kg/m^3(Lehtikangas, 2001; Mani et al., 2004). Approximately about 10 to 15 percent of energy density of biomass increase by densification thus more heat is produced per unit of pellets burned than raw biomass. Compared to raw biomass feedstock, biomass pellet are superior fuel. Pellets are not only more energy dense, they are also easy to handle and used in automated feed systems. Cylindrical shape of pellet having diameter 6 to 8 millimeters and a length of not more than 38 millimetres . Diameter of pellets more than 25 millimetres is also manufactured but they are usually referred to as "briquettes" (Mani et al., 2006). To improve density and material flow in the feeder areas, pelletization is one the best method of densification process. Quality of the pellet is depends on several factor which is in terms of moisture content, biomass type, particle size. Pelletiser type, binding agent and operating conditions is factor to be considered for best quality management of the manufacturing process (Gilbert et al., 2009). Binding agent or stabilizing agents are used to reduce the pellet springiness and to increase the pellet density and durability. The most commonly binders use in pelletisation process of animal feeds are calcium lignosulfonate, colloids, bentonite, starches, proteins and calcium hydroxide (Pfost, 1964; Tabil and Sokhansanj, 1996). Spent mushroom compost (SMC) and coal tailings are type of pellets that is suitable in chain grate furnances, industrial gasifiers or conventional pulverised fuel-based power stations where it also can be fed into the mills. Lime in SMC help to reduce sulphur emission from coal combustion (Changkook et al., 2007). Research at the Swedish University of Agricultural Sciences has tested 9 different sources of pellets (Lehtikangas et al., 2001). The pellets from bark had the highest durability whereas the conventional sawdust pellets had the least. Pellet density was found to have no effect on durability. In a similar pilot study to the above, the same nine pellet samples were stored for five months in plastic bags in an unheated barn to examine the changes in moisture content, heating value and ash content (Lehtikangas et al., 2000). The research concluded that storage of the pellets led to a negative effect on durability, especially on pellets made from fresh materials. In general, the changes in pellet quality during storage in large bags were not large, but notable. Even there is a lot of variation between pelletisers, the common method for mass production is to use a die and a press roller (Alankangas et al., 2009). Pelletisers are often more simplistic for laboratory-based small-scale work. It is consist of modified hydraulic presses, where ease of pellet manufacture, time scale or costs would not be an issue (Li et al., 2000).

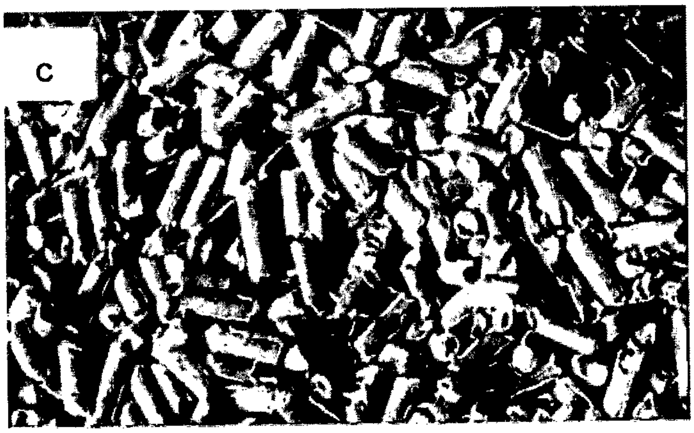

Figure 2.1: Densified biomass in the form of pellet