DILUTE ACID HYDROLYSIS OF OIL PALM EMPTY FRUIT BUNCHES, RICE HUSKS, RICE STRAWS AND OIL PALM TRUNKS TO PRODUCE GLUCOSE AND XYLOSE

By

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Thesis submitted in fulfillment of the requirements for the degree of Master of Science

May 2013

ACKNOWLEDGEMENT

First and foremost, I thank God for allowing me to have this opportunity to be part of this research project in USM. Secondly, I would like to express my high gratitude to my main supervisor, Emeritus Professor Dr. Lim Koon Ong and co-supervisor, Professor Dr. Teng Tjoon Tow. This project can be successfully carried out because of the tremendous efforts they put in supervising me throughout the whole period of this project. Their support, suggestions, assistance as well as love and patience are very much contributed in realizing this thesis.

A special appreciation goes to Bean Bee Rice Mill Sdn Bhd at Arau, Perlis and MALPOM at Nibong Tebal, Penang in providing the biomass raw materials. My appreciation also extended to the Ministry of Higher Education, Malaysia in funding this project (Fundamental Research Grant Scheme FRGS, No. 203/PFIZIK/671164).

Last but not the least, I would like to thank all the co-workers that have directly or indirectly helped me in this project. Special thanks to Miss Sia Char Ling, who unselfishly shared a lot of knowledge with me and worked together with me. My gratitude also goes to Mr. Illias Budin, the Lab Assistant of Energy Study Laboratory, School of Physics and Mr. Maarof, the Lab Assistant of Food Technology Laboratory, School of Technology Industry. Their assistance and help in parts acquisition have been very much contributed in the experiments I carried out. Thank you very much.

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M_1	Original concentration of a solution	% (v/v)
M_2	New concentration of a solution after dilution	% (v/v)
V_1	Original volume of a solution	mL
V_2	New volume of a solution after dilution	mL
W_1	Mass of sample used	g
W_2	Mass of samples after heating	g
X	Raw material size after sieving	µm

LIST OF ABRREVIATIONS

ABS	Absorbance
ASTM	American Society for Testing and Materials
Ca-EDTA	Calcium ethylenediamine tetra-acetic acid
CASH	Canada America Sweden Hydrolysis
DOA	Department of Agriculture Malaysia
ED	Electrodialysis
EDTA	Ethylenediamine tetra-acetic acid
EFB	Empty fruit bunches
FiT	Feed-in Tarrif
GC	Gas Chromatography
GE	Glucose Enzymatic
H_2SO_4	Sulphuric acid
HPLC	High Performance Liquid Chromatography
IEA	International Energy Agency
MALPOM	Malaysia Pail Oil Manufacturing Industries Sdn. Bhd.
MPOB	Malaysian Palm Oil Board
MS	Mass Spectrometer
MSW	Municipal Solid Waste
OECD	Organization for European Economic Co-operation
OPF	Oil palm Fronds
OPS	Oil palm shells

OPT	Oil palm trunks
PPF	Pressed fruit fibers
RF	Response factor
RI	Refractive index
R/P	Reserves-to-production
WEO	World Energy Outlook

HIDROLISIS ASID CAIR KE ATAS TANDAN KOSONG KELAPA SAWIT, SEKAM PADI, BATANG PADI DAN BATANG POHON KELAPA SAWIT BAGI PENGHASILAN GLUKOSA DAN XILOSA

ABSTRAK

Biojisim berlignocelulosa adalah sumber boleh diperbaharui yang berpotensi untuk menghasilkan bahan api bio yang mungkin dapat menggantikan bahan api fosil yang tidak boleh diperbaharui. Tandan kosong kelapa sawit (EFB), batang pohon kelapa sawit (OPT), sekam padi dan batang padi telah dipilih untuk digunakan dalam penghasilan gula fermentasi melalui hidrolisis asid. Kaedah *glucose enzymatic* diuji dan dipastikan bahawa kaedah ini dijejas oleh warna hidrolisat manakala analisis *High Performance Liquid Chromatography* (HPLC) didapati tidak dijejas oleh warna hidrolisat semasa penentuan kepekatan glukosa dan xilosa. Empat jenis biojisim yang dipilih dihidrolisiskan dengan menggunakan satu kaedah hidrolisis asid dua peringkat yang mudah untuk mendapat gula fermentasi. Tiga parameter hidrolisis iaitu tempoh hidrolisis, kepekatan asid hidrolisis dan nisbah asid pekat kepada berat bahan mentah telah dikaji dan dioptimumkan bagi setiap biojisim. Keputusan ditafsir melalui hasil glukosa dan xilosa dengan menggunakan HPLC. Kaedah hidrolisis asid dua peringkat yang mudah ini didapati dapat menghasilkan jumlah hasil glukosa dan xilosa yang baik. Dalam bahagian pengoptimuman bagi parameter-parameter, tempoh hidrolisis 4 jam didapati paling sesuai untuk kesemua empat jenis biojisim. Bagi dua parameter yang lain pula, kepekatan asid hidrolisis yang paling sesuai untuk keempat-empat biomass adalah 4.5 % (v/v) manakala nisbah asid pekat kepada berat bahan mentah yang paling sesuai bagi kesemua empat jenis biojisim adalah 4:1 (w/w). Dengan menggunakan hidrolisis asid dua peringkat yang mudah serta parameter-parameter yang telah

dioptimumkan, jumlah hasil glukosa dan xilosa yang dapat dihasilkan oleh EFB, OPT, sekam padi dan batang padi adalah 30.71 % (w/w), 29.41 % (w/w), 29.31 % (w/w) dan 35.16 % (w/w).

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ABSTRACT

Lignocellulose biomass are potential renewable sources to produce biofuels that may replace the non-renewable fossil fuels. Oil palm empty fruit bunches (EFB), oil palm trunks (OPT), rice husks and rice straws were used to produce fermentable sugars via acid hydrolysis. Glucose enzymatic assay was tested and shown to be affected by the colour of the hydrolysate while High Performance Liquid Chromatography (HPLC) analysis was shown to be no problem with the colour of the hydrolysate in determining glucose and xylose concentrations. Four types of biomass chosen were hydrolyzed using a simple two-stage acid hydrolysis method to obtain fermentable sugars. Three hydrolysis parameters i.e. hydrolysis duration, hydrolyzing acid concentration and the concentrated acid to raw material weight ratio were studied and optimized for every biomass. The results were interpreted via the sugar yields of glucose and xylose by HPLC. The simple two-stage acid hydrolysis method was shown to achieve good total glucose and xylose yields. In the parameters optimization, the most suitable hydrolysis duration for all the four types of biomass used was 4 hours. As for the other two parameters, 4.5 % (v/v) was found to be the most suitable hydrolyzing acid concentration while the ratio of 4:1 (w/w) was found to be the most suitable concentrated acid to raw material weight ratio for all the four types of biomass. By using the simple two-stage acid hydrolysis and the optimized parameters, the total glucose and xylose yields achieved for EFB, OPT, rice husks and rice straws were 30.71 % (w/w), 29.41 % (w/w), 29.31 % (w/w) and 35.16 % (w/w) respectively.

CHAPTER ONE

INTRODUCTION

1.1 The world energy scenario

In our global society today, the primary energy source is fossil fuels. The three kinds of fossil fuels that the world mostly depended on for energy needs, from electricity to fuel for automobiles and mass transportation are coal, oil and natural gas. These fossil fuels are non-renewable and will be depleted one day in the future. The data of world energy consumption in 2010 is shown in Figure 1.1 where oil remains the dominant fuel follow by coal and natural gas.

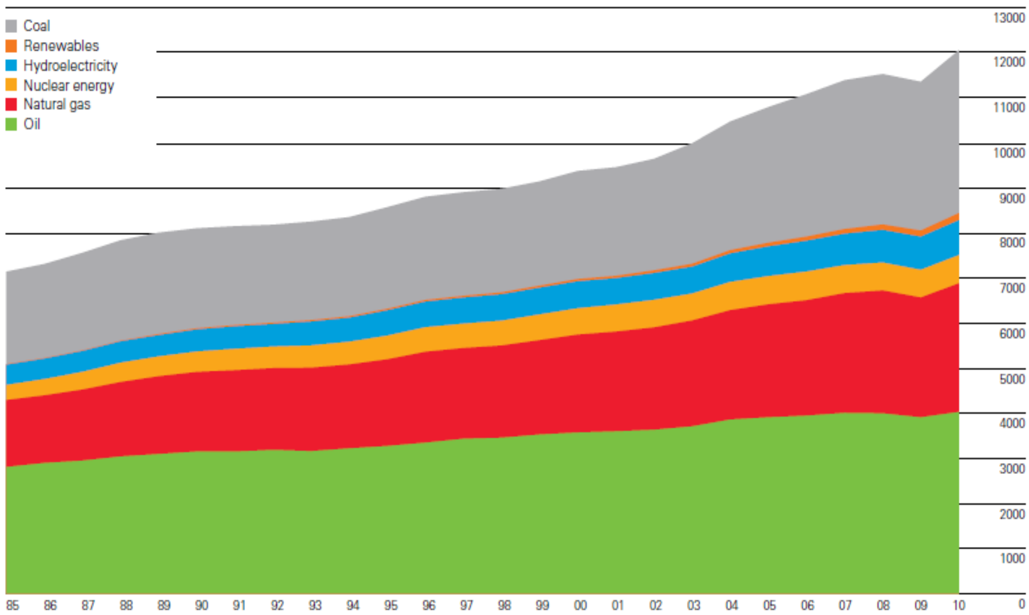

Figure 1.1: World energy consumption (Million tones of oil equivalent) (BP, 2011)

The oil sources were estimated to be depleted by year 2050 (Goyal et al., 2008). However, because of the continuously increasing demand for energy as a result of urbanization and industrialization, the exhaustion of oil sources might come sooner than we thought. Hence, renewable energy sources are deemed to be able to replace fossil fuels in daily usage. Unfortunately, despite the promise of renewable energy, currently they provide only about 7 % of the world's energy needs (Mclamb, 2011).

The reserves-to-production (R/P) ratios of 2010 for coal, oil and natural gas are shown in Figures 1.2, 1.3 and 1.4. The R/P ratio is a measure of the reserves remaining at the end of a year divided by the production in that year. The world proved reserves of coal in 2010 were sufficient to meet 118 years of global production. The R/P ratio of coal also, by far, the largest among fossil fuels. On the other hand, the world proved reserves of oil and natural gas in 2010 were only sufficient to meet 46.2 years and 58.6 years respectively. The R/P ratio of oil in 2010 was slightly lower than 2009 R/P ratio but the R/P ratio of natural gas declined for each region, driven by rising production (BP, 2011).

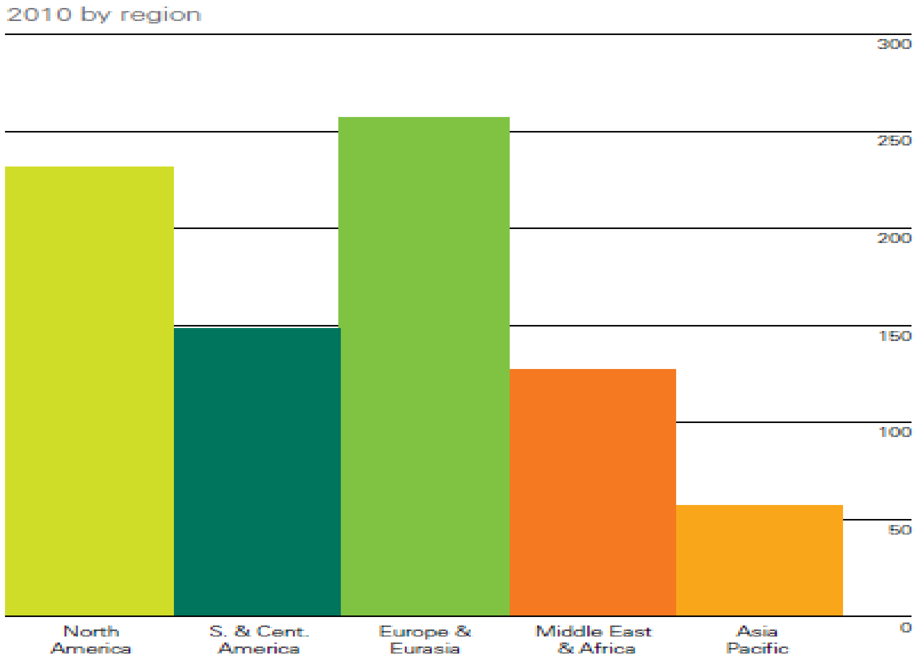

Figure 1.2: Coal reserves-to-production (R/P) ratios of 2010 by region (BP, 2011)

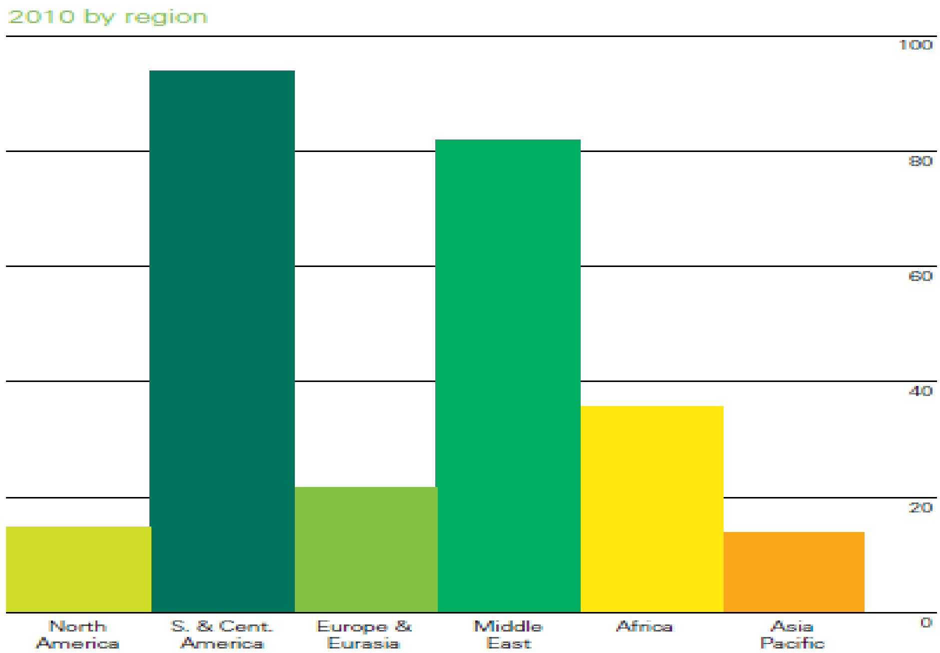

Figure 1.3: Oil reserves-to-production (R/P) ratios of 2010 by region (BP, 2011)

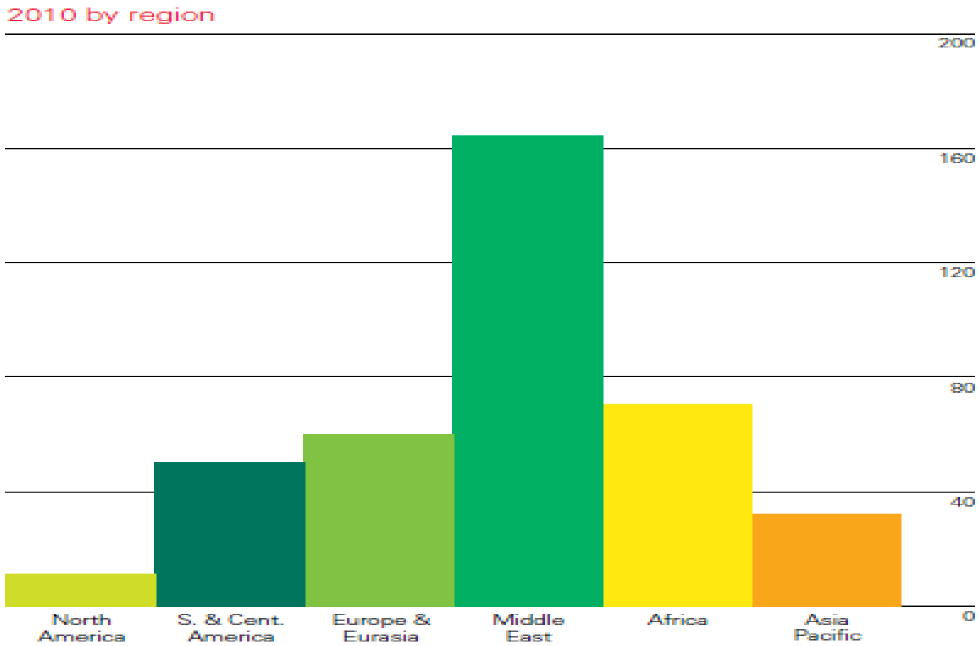

Figure 1.4: Natural gas reserves-to-production (R/P) ratios of 2010 by region (BP, 2011)

Figure 1.5 shows R/P ratios of coal, oil and natural gas at the end of 2010 in one chart. From the statistic shown, oil and natural gas will be depleted by the middle of 21st century. One must be mindful that if production continues to increase while no new reserves are found, the R/P ratios may drop significantly and these fossil fuels may be depleted even sooner.

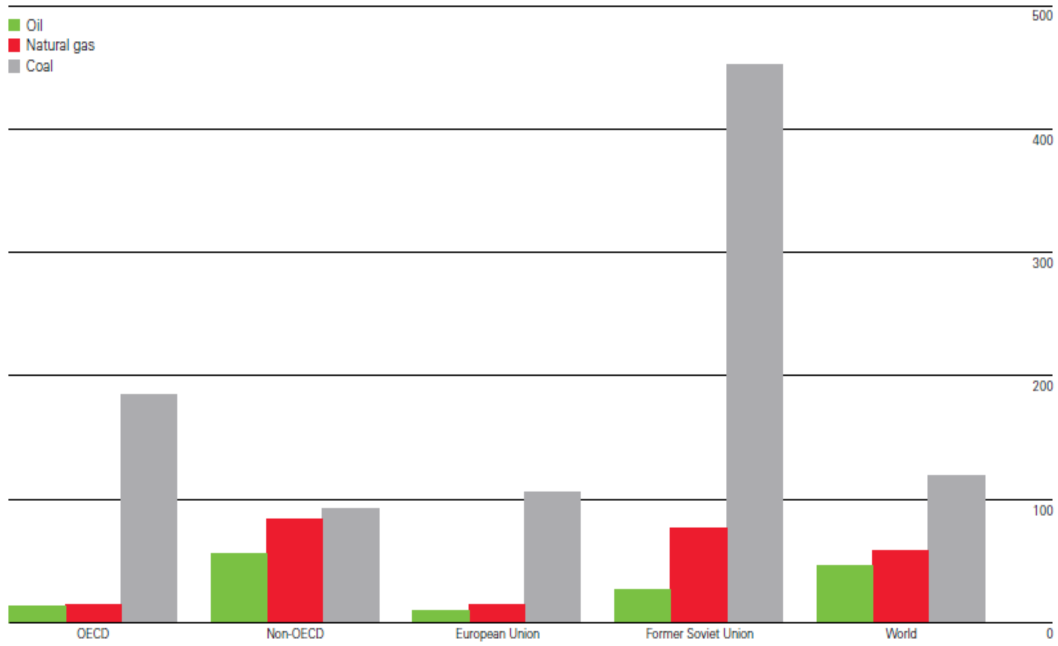

Figure 1.5: Fossil fuel reserves-to-production (R/P) ratios at end of 2010 (BP, 2011)

The International Energy Agency (IEA) publishes a remarkable document "World Energy Outlook" (WEO) every year, showing the latest data, policy developments and the experience of another year to provide a robust analysis of current global energy markets. WEO 2010 estimated that the OECD (Organization for European Economic Co-operation) governments support for electricity from renewables and for biofuels cost $57 billion in 2009, an increase from $44 billion in 2008 and $41 billion in 2007. This support is predicted to grow to $205 billion by 2035 in the New Policies Scenario, where cautious implementation of national pledge to reduce greenhouse-gas emissions by 2020 and to reform fossil-fuel subsidies are assumed (IEA, 2010). Although the realization towards the importance of renewables was increasing especially among the OECD countries, the estimated accomplishments stated in WEO 2010 can only be achieved with large scales of government support. There are still risks in investments and serious problems in dispatching with increasing cost of supply and costs to consumers (Khatib, 2011).

1.2 Energy scenario in Malaysia

Malaysia is highly depended on oil and gas as the major energy source. By 2010, the largest commercial energy demand in Malaysia is from petroleum (61.9%) followed by electricity (18.9%) and natural gas (15.8%) in 2010. The energy demand by source and the percentage contributed by each source is shown in Table 1.1.

Table 1.1: Final Commercial Energy by Source (2000 – 2010) (Ninth Malaysia Plan 2006 – 2010)

Source	**Petajoules (PJ)**			**Percentage of total (%)**		
	2000	2005	2010	2000	2005	2010
Petroleum products	820.0	1023.1	1372.9	65.9	62.7	61.9
Natural gas	161.8	246.6	350.0	13.0	15.1	15.8
Electricity	220.4	310.0	420.0	17.7	19.0	18.9
Coal and coke	41.5	52.0	75.0	3.4	3.2	3.4
Total	1243.7	1631.7	2217.9	100.0	100.0	100.0

As for the energy supply in the country, the total supply of energy increased from 2003 PJ in 2005 to 3128 PJ in 2010 with the main sources of supply being still crude oil and petroleum products as well as natural gas. The share of coal and coke increased from 5.2 % in year 2005 to 11.2 % in year 2010 which indicates that the dependence on oil and gas source of supply is being reduced. The primary commercial energy supply by source and the percentage contributed by each source is shown in Table 1.2.

Table 1.2: Primary Commercial Energy Supply by Source (2000 – 2010)
(Ninth Malaysia Plan 2006 – 2010)

Source	**Petajoules (PJ)**			**Percentage of total (%)**		
	2000	2005	2010	2000	2005	2010
Crude oil and petroleum products	988.1	1181.2	1400.0	49.3	46.8	44.7
Natural gas	845.6	1043.9	1300.0	42.2	41.3	41.6
Coal and coke	104.1	230.0	350.0	5.2	9.1	11.2
Hydro	65.3	71.0	77.7	3.3	2.8	2.5
Total	2003.1	2526.1	3127.7	100.0	100.0	100.0

1.3 Biomass as an alternative energy source in Malaysia

There are multiple sources of biomass in Malaysia. When the trend of the world energy scenario is heading towards replacing fossil fuels with renewable energy, Malaysia is blessed because of the large amounts of biomass that can be converted into alternative energy. These biomass include oil palm biomass, mill residues, municipal waste, rice husk, solar/thermal, hydro, solar PV, forest residues and landfill gas (Jaafar et al., 2003).

Biomass is introduced to replace fossil fuel not only because of the limited stock of fossil fuel and the uncertainty in the price of fossil fuel but also the concern on the environmental pollution of greenhouse emissions. Although a lot of initiatives have been done by the Malaysian government to develop the renewable energy industry, yet the approach has not achieved as founding outcomes.

Huge amounts of oil palm empty fruit bunches (EFB), oil palm trunks (OPT), rice husks and rice straws are produced in Malaysia every year. In fact, the most abundant agriculture waste in Malaysia comes from oil palm fields (Misson et al., 2009; Ahmad, 2001). Among the biomass produced from oil palm fields, EFB is the greatest contributor (Sumathi et al., 2008), producing a quantity of 18.022 ktons in year 2007 (MPOB, 2009), while oil palm trunks produced in year 2007 was 10,827 ktons (Goh et al., 2010) Beside oil palm wastes being the largest contributor to the agriculture biomass, rice husks and rice straws are also significant agriculture wastes produced in Malaysia. In year 2007, the amount of rice husks and rice straws produced were 484 and 880 ktons respectively (Abdel-Mohdy et al., 2009; DOA, 2009). With appropriate treatments and processes, all these biomass can be used as an alternative energy source.

1.4 Biomass and biofuel

Biomass is any organic material from living organisms including plants and animals. Biomass contains solar energy stored from the sun. Plants absorb solar energy by the photosynthesis process and convert the solar energy into chemical energy in the form of sugars. The chemical energy in plants gets passed on to animals or human beings that eat them.

Biomass is a renewable energy source because the biomass is derived from the sun and natural processes that are replenished constantly. Biomass as an energy source can be used directly such as burning or converted into other usable forms of energy such as methane gas, ethanol and biodiesel. Biomass also includes plants or animals matter for production of fibers and chemicals. The organic material that has been transformed by geological processes into other substances such as coal or petroleum is not included in the biomass category.

Biomass available today can be categorized into four major groups (Keller, 1996):

- **Wood, wood waste and energy crops**: This group of biomass includes wood and other products such as bark and sawdust which had no chemical treatments or finishes applied. The wood can be obtained from forestry or from co-products of the wood processing industry. Most of them are used to generate electricity. This category covers purpose-grown energy crops also, a multitude of wood materials generated by industrial process or provided from forestry and agriculture as well as other wood wastes.

- **Agricultural residues**: Covers a wide variety of types and the appropriate energy conversion technologies vary from type to type. The most significant division of these residues is between those that are predominant dry (such as straw and husk) and those that are wet (such as animal slurry). Many of such residues are presently widely used for soil nutrient recycling and soil improvement purposes.

- **Municipal solid waste**: Municipal waste comprises wastes produced by the residential and public services sectors. Trash can be converted into usable form of energy. Garbage is not all biodegradable material; perhaps half of its energy content comes from plastics and other synthetic materials. The renewable energy portion is defined by the energy value of combusted biodegradable materials only.

- **Landfill gas**: Landfill gas is the biogas that contains methane produced via the decomposition of the organic waste by the bacteria that lives in landfills. Methane is energy-rich same as natural gas. Landfill gas can be used to produced heat and power.

The demand of biomass as a renewable energy source is increasing widely as a substitute for the non-renewable fossil fuels. Bioenergy is not only renewable, it is also generally more environmental friendly, although burning biomass may result in air pollution depending on the type of biomass and the types of energy sources that it replaces.

Biofuels are transportation fuels that are made from biomass materials. These fuels such as ethanol and biodiesel are usually blended with the gasoline and diesel fuels. Biofuels may be considered to be carbon neutral because the plants that are used to produce biofuels absorb carbon dioxide as they grow and may offset the carbon dioxide produced when biofuels are produced and burned. Thus, biofuels can reduce the greenhouse gas and will not contribute towards global warming. Although the variety of feedstocks and sources of the biomass makes it difficult to identify indicative values of the energy input and emissions of the biofuels, it is no doubt that biofuels give a significant contribution to the reduction of carbon dioxide emission.

1.5 Biomass from oil palm industry

Malaysia is currently the second largest producer of palm oil after Indonesia. Oil palm cultivation covers 14 % of the total land area of Malaysia, having a growth from less than 1 million ha in the 1970s to 4.98 million ha in 2011 (MPOB, 2011). Most of the oil palm cultivation used to take place in Peninsular Malaysia. However, as the available suitable land in Peninsular Malaysia runs out, oil palm cultivation was expanded to the states of Sabah and Sarawak (Teoh, 2000, 2002) with Sabah now being the largest palm oil producing state in Malaysia, accounting for 29 % of the national output from 1.4 million ha of oil palm (MPOB, 2011).

The productive lifetime of an oil palm tree is about 25 years. During this period of time, crude palm oil and crude palm kernel oil are produced from the fruit and the kernel respectively. The oil palm industry produces a substantial amount of biomass as well as solid by-products every year. These by-products include oil palm fronds (OPF), empty fruit bunches (EFB), pressed fruit fibers (PFF), oil palm shells (OPS) and oil palm trunks (OPT). The latter are from felled trees aged approximately 25 years or older where their productivity decreases.

It was reported that the extraction of crude palm oil and palm kernel oil comprises only about 10 % of the total dry matter of the industry. The other 90 % of the matter (OPF, EFB, PFF, OPS, OPT and palm oil mill effluent) are discarded as waste (Yusoff, 2006). These plentiful amounts of biomass are disposed off through various ways such as being burned in the field or left on the ground to decompose naturally. As oil palm cultivation has been expanding for the past years and is expected to expand further in the coming years, more development and research are essential in managing and best utilizing the solid oil palm wastes.

1.6 Biomass from rice milling industry

There has been a long history of rice planting in Malaysia in rain-fed areas located along the flood plains of rivers. The country is rich in water sources mainly due to the Southwest and Northeast monsoons. Rice cultivation covers a total land area of 673745 ha in Malaysia (DOA, 2011).

Although the rice industry is not as large as the oil palm industry in Malaysia, still large quantity of wastes, mainly husks and straws are produced from the cultivation and milling of rice every year. It was reported that for every kilogram of rice grain harvested, 1 – 1.5 kilograms of rice straw (Maiorella, 1985) and rice husks are produced thus giving an annual biomass generation rate of approximately 0.5 million tonnes (Rozainee et al., 2009).

The options for the disposal of rice straw are limited due to their slow degradation in soil and their high mineral content. Field burning is the major practice to get rid of rice straw, but this method is certainly environmental unfriendly as it leads to air pollution and consequently affects public health. The same goes to rice husk where field dumping and open burning are the disposal methods being practiced currently.

Although there is a power plant in the state of Perlis that uses rice husk as the main source of fuel (Cogen 3, 2004), there are still a lag of research and development on utilizing rice wastes as a large scale energy source. Thus, better technologies with cheaper costs and also environmental friendly are needed to make the rice wastes useful.

1.7 Renewable energy in Malaysia

In the Ninth Malaysia Plan (2006 – 2010), the biomass based development was planned to be expanded in the plan period. Efforts to promote the development of biofuel using palm oil as a renewable source of energy were undertaken during the plan period, in line with the initiative to make the country a world leader and hub for palm oil. Designated pump stations, mainly in Klang Valley were expected to supply diesel blended with 5 % of palm olein in 2006. In the plan period, efforts were also intensified in the area of energy efficiency where the supply and use of alternative renewable energy was expected to increase so that the dependence on petroleum products can be reduced. By 2010, renewable energy was expected to contribute 350 MW to total energy supply (Ninth Malaysia Plan 2006 – 2010).

However, despite rigorous initiatives, the target set under the Ninth Malaysia Plan period was not achieved (Tenth Malaysia Plan 2011 – 2015). In the Tenth Malaysia Plan, several new initiatives anchored upon the renewable energy policy and action plans are to be undertaken to achieve a renewable energy target of 985 MW by 2015, and contributing 5.5 % to Malaysia's total electricity generation mix. A Feed-in Tariff (FiT) was introduced where 1 % to be incorporated into the electricity tariffs of consumers to support the development of renewable energy in the Tenth Malaysia Plan. As such, there will also be an establishment of a Renewable Energy Fund from the FiT, administered by a special agency, the Sustainable Energy Development Authority, under the Ministry of Energy, Green Technology and Water (KeTTHA) to support the development of renewable energy.

Despite the failure of the "Envo Diesel", a mixture of 95 % petroleum diesel and 5 % of processed palm oil introduced in late 2006 (Lim and Teong, 2010), the Malaysian government proceeded to introduce the biodiesel B5 in 2011 (Singh, 2011). B5 is a mixture of 95 % petroleum diesel and 5 % palm methyl ester. The Malaysian government has put aside RM 200 million to set up blending facilities nationwide to blend diesel with palm methyl ester as the green fuel to reduce its carbon intensity by up to 40 % after five years of delay (Singh, 2011). Besides, it was reported that the B5 blend could reduce the volume of diesel import by 500000 tonnes, saving an estimated US $380 million a year (Lim and Teong, 2010).

Although the B5 blend diesel contributes to saving almost 12.4 million litres of fossil diesel a year in Kuala Lumpur, a government subsidy of RM 23.65 million is needed for B5 blend diesel in the central region alone (Wong, 2011). Hence, the obstacle of replacing fossil fuel with green fuel is not only the blending facility, but to make the production economically viable. As such, more appropriate technologies need to be developed in order for the abundant biomass in Malaysia be best utilized.

1.8 Statement of problems and research objectives

The rice husks and rice straws produced in the country are usually disposed of by burning though a small quantity of the rice wastes is used for power generation. Oil palm wastes on the other hand are getting much more attention. Various attempts have been made to add value to EFB and OPT fibers such as the production of biodegradable food container and medium density fiber board.

Presently, more and more attention is given to these renewable energy sources that potentially are able to replace non-renewable energy sources. Biofuels is one of the products that people are looking forward to replace fossil fuels. However, these biomass in their original form are not suitable to be used as fuels as they are bulky, uneven in character and they have low energy densities. Due to technological and cost constrains, present processes are still unable to fully utilize the available biomass to produce biofuels on a large scale.

This research project aims to contribute towards the technology of converting four types of biomass available in Malaysia to biofuel. A laboratory-scale study was carried out in the Energy Laboratory of the School of Physics, Universiti Sains Malaysia to study the viability of converting EFB, OPT, rice husks and rice straws to fuel ethanol. The approach of this project is to initially obtain glucose and xylose via dilute acid hydrolysis of the biomass and the sugars can then be fermented into usable ethanol. Therefore, the objectives of the present study are:

i. To test on the feasibility of adopting a single two stage acid hydrolysis.

There are a lot of methods used by other researchers all over the world in the acid hydrolysis of lignocellulosic biomass. In this project, the feasibility of a simple laboratory-scale two-stage dilute acid hydrolysis was investigated with attempts to control as little parameters as possible but yet achieve an acceptable outcome.

ii. To determine the parameters that will optimize the glucose and xylose yield.

Three parameters i.e. the hydrolysis time, the hydrolyzing acid concentration and the concentrated acid to raw material weight ratio were examined using all the four types of biomass chosen in this project.

iii. To determine how the raw materials affect the sugar yields.

Different raw materials will result in different sugar yields after acid hydrolysis, mainly depends on the chemical composition of the raw materials. Experiments were done to study the effects of different raw materials on sugar yields and determine whether the raw materials used were suitable to produce sugars with acceptable yields.

The benefits of this research project will contribute in the study of converting biomass to fuel ethanol. The data obtained can be referred to when the same method as that used in this project is employed on a larger commercial scale.

CHAPTER TWO

LIGNOCELLULOSIC BIOMASS

2.1 Introduction

Lignocellulosic biomass is biomass that is principally made up of lignin, hemicellulose and cellulose. These three polymers are bonded together strongly (Zaldivar et al., 2001). This category of biomass includes woods, wood wastes, agricultural wastes, organic municipal wastes and various organic industrial wastes.

The composition of lignocellulosic biomass is made up of about 10 – 25 per cent of lignin, 35 – 50 per cent of cellulose and 20 – 35 per cent of hemicellulose. The remaining fraction comprises insoluble phenylpropene polymer attached to the hemicellulose, a small amount of ash, soluble phenolics and fatty acid termed extractives and other minor components (Wyman, 1996).

Although lignocellulosic biomass is the most abundant organic material on earth, some lignocellulosics are cultivated to be the source for renewable energy. The cost and the quantity of lignocellulosic biomass available are the key factors to the possibility of using lignocellulosic biomass as a renewable energy source.

2.2 Cellulose

Cellulose is a long chain of glucose molecules joined together in a crystalline structure. It is the primary component in the cell wall of green plants. The hydrogen covalent bond between the glucose molecules strongly bonded the molecules to allow the plants to grow straight up high (Thomas, 1981).

The cellulose chains are bond together by hydrogens bonds to form microfibrils. These chains are the primary structural component responsible for the mechanical strength of the microfibrils. These high tensile strength crystalline microfibrils are bonded by a gel matrix composed of hemicellulose, lignin and other carbohydrate polymers to form biocomposites (Wiiiam et al., 2005). The cellulose microfibrils represent about 10 – 20 per cent of dry weight cell wall material, occupying about 15 per cent of cell wall volume. In those cell walls that have secondary cells, the proportion of cellulose may reach 40 – 50 per cent of the wall biomass. Harder wood generally contains more cellulose than softer wood (Laureano et al., 2005).

2.2.1 Molecular structure of cellulose

Cellulose, a linear molecule, consists of repeating cellobiose units held together by β-1,4 glycosidic linkages (Duff and Murray, 1996). The basic structural diagram of cellulose is shown in Figure 2.1. The β-linked glucopyranose residues stabilizes the chain structure of cellulose but this minimizes its flexibility.

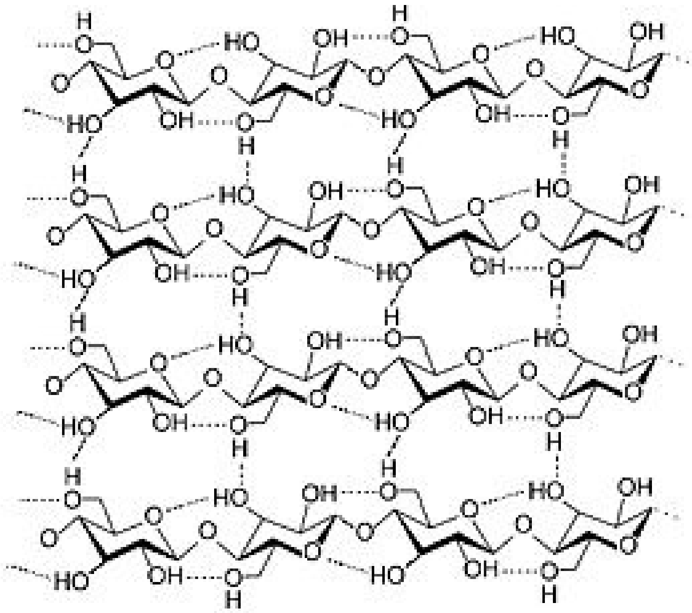

Figure 2.1: Structure diagram of cellulose (Bailey, 1988)

Cellulose is more homogeneous than hemicellulose but it is also highly crystalline and highly resistant to depolymerisation. Cellulose which is of insoluble molecules form crystals where the intra-molecular and intra-strand hydrogen bonds hold the molecular network flat allowing the hydrophobic ribbon faces to stack. This tendency to form crystals, utilizing extensive hydrophobic interactions in addition to the intra- and intermolecular hydrogen bonds, makes cellulose completely insoluble in normal aqueous solutions (Lindman et al., 2010). Nevertheless, cellulose is soluble in more exotic solvents such as near-supercritical water (Deguchi et al., 2006).

As cellulose is formed by long chains of glucose molecules, when treated with exotic solvents, the cellulose can be broken up into individual glucose molecules. One of the methods of breaking the cellulose chains is to hydrolyze the cellulose using acid to form glucose (Dadi et al., 2006).

2.2.2 The functionality of cellulose

Presently, cellulose is usually used as an anticake agent, stabilizer, emulsifier, dispersing agent, thickener and gelling agent. All these usages are generally based on the important cellulose use of holding on to water. Water cannot penetrate the crystalline cellulose but dry amorphous cellulose absorbs water becoming soft and flexible.

The water absorbed by cellulose is simply trapped. The water holding ability correlates well with its amorphous and void fraction. As a result, the water stored is protected against ice damage. Cellulose can give improved volume and texture particularly to sauces and dressings but its insolubility will cause the products to be cloudy (Lindman et al., 2010).

Swelled bacterial cellulose, a cellulose type with much smaller fibrils than from plants is another cellulose type that is being used in the area of microbiology. The viscosity of the bacterial cellulose is not lost at high temperatures and low shear rates so the cellulose can retain its structure. Bacterial cells may be removed by hot alkali and the clean wet cellulose can be used as a substrate to immobilize biomolecules (Chaplin et al., 1989) or to cover wounds (Czaja et al, 2006).

Most of the world's production of purified cellulose is used as the base material for a number of water-soluble derivatives with pre-designed and wide ranging properties dependent on the groups involved and the degree of derivations (Clasen and Kulicke, 2001). The orderly crystallized hydrogen bonding in the derivatives of cellulose are interfered so that even hydrophobic derivatives may increase its apparent solubility in water.

Cellulose is also a good source for paper pulping and for renewable energy. The cellulose in lignocellulosic biomass can be hydrolyzed to form glucose. The glucose can then be further fermented into ethanol to be used as biofuel.

2.2.3 The bioconversion of cellulose

There are several reactions of cellulose that can result in cellulose derivatives. These degradations of cellulose are soluble in common solvents thus capable of extrusion to form filaments or other structures. The bioconversion of cellulose, that is the topic in this project, is the degradation by acid of cellulose into glucose which can potentially be converted further into ethanol.

The influence of physical and biochemical factors in the biodegradation of cellulose whether by fungal or bacterial enzymatic methods are significant (Verstraete and Top, 1992). Wide areas of research works have also been carried out regarding the optimization of the parameters of degradation in order to maximize the efficiency of these biotechnological processes (Alexander, 1996).