MICROCRYSTALLINE CELLULOSE FROM BIOMASS-PALM OIL FROND

MOHAMAD SALIHI BIN RAMLI

Thesis submitted in partial fulfilment of the requirements
For the award of the degree of
Bachelor of Chemical Engineering

Faculty of Chemical & Natural Resources Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2015

ABSTRACT

Malaysia, being the world's largest producer and exporter of palm oil, is currently producing about 47% of the world's supply and Indonesia is second, producing approximately 36% of world palm oil capacity. Both nations are expanding their palm oil production capacity and the market continues to grow. With the current acreage of 4.49 million hectares of Palm Oil Cultivation in Malaysia, it is estimate 26.2 million tonnes of oil palm frond are treated as biomass. Oil palm frond consist huge amount of fiber, in which it can be transform into cellulose. Fronds are taken from oil palm tree as wastes, which are normally burnt. This research is to prepare and produce the cellulose fiber from oil palm frond. Steam explosion pre-treatment was conducted to enhance the accessibility of the oil palm frond lignocellulose. The combination of temperature and time known as the Log Ro in steam explosion process were used as the main parameter in this research. It has many applications in pharmaceuticals, nutraceuticals, foods, paper and structural composites. For pharmaceutical uses, it is used as a binding agent and also as a disintegrating agent. MCC also naturally derived stabilizer, texturing agent and a fat substitute. The MCC was prepared by controlled acid hydrolysis of the isolated α-cellulose which attacked the amorphous region and was followed by the back neutralization process alkalization. The structural properties of cellulose and microcrystalline cellulose (MCC) were studied by Scanning Electron Microscope (SEM). Basically the process for producing microcrystalline cellulose (MCC) involves preparation of holocellulose and α-cellulose from oil palm frond. The steam explosion method was used to prepare holocellulose and a few parameters are involved which is pressure, temperature, retention time and severity of structural cell wall. By control the pressure it will automatically change the others parameters. The pressure is 5 bars, 10 bars and 20 bars were used and the result of the severity of structural cell was analyzed.

ABSTRAK

Malaysia, sebagai pengeluar terbesar di dunia dan pengeksport minyak sawit, kini mengeluarkan kira-kira 47% daripada bekalan dunia dan Indonesia berada di tempat kedua, menghasilkan kira-kira 36% daripada kapasiti minyak sawit dunia. Kedua-dua negara sedang mengembangkan kapasiti pengeluaran minyak sawit dan pasaran terus berkembang. Dengan keluasan semasa 4,490,000 hektar Penanaman Kelapa Sawit di Malaysia, ia adalah anggaran 26,200,000 tan pelepah kelapa sawit dianggap sebagai biojisim. Pelepah kelapa sawit terdiri sejumlah besar serat, di mana ia boleh bertukar menjadi selulosa. Pelepah yang diambil dari pokok kelapa sawit sebagai bahan buangan, yang biasanya dibakar. Kajian ini adalah untuk menyediakan dan menghasilkan serat selulosa dari pelepah kelapa sawit. Letupan wap pra-rawatan telah dijalankan untuk meningkatkan akses kepada yang lignocellulose pelepah kelapa sawit. Gabungan suhu dan masa dikenali sebagai Ro Log dalam proses letupan wap telah digunakan sebagai parameter utama dalam kajian ini. Ia mempunyai banyak aplikasi dalam farmaseutikal, nutraseutikal, makanan, kertas dan komposit struktur. Untuk kegunaan farmaseutikal, ia digunakan sebagai ejen mengikat dan juga sebagai ejen berpecah belah. Daerah juga secara semula jadi yang diperolehi penstabil, ejen Penteksturan dan pengganti lemak. MCC telah disediakan oleh dikawal hidrolisis asid terpencil α-selulosa yang menyerang rantau ini amorfus dan diikuti dengan kembali proses peneutralan pengalkalian itu. Sifat-sifat struktur selulosa dan mikrohabluran selulosa (MCC) telah dikaji oleh Mikroskop Imbasan Elektron (SEM). Pada dasarnya proses untuk menghasilkan mikrohabluran selulosa (MCC) melibatkan penyediaan holocellulose dan α-selulosa dari pelepah kelapa sawit. Kaedah letupan wap telah digunakan untuk menyediakan holocellulose dan beberapa parameter yang terlibat iaitu tekanan, suhu, masa tahanan dan keterukan dinding sel struktur. Dengan kawalan tekanan ia akan secara automatik menukar parameter lain. Tekanan 5 bar, 10 bar dan 20 bar telah digunakan dan hasil daripada tahap sel struktur dianalisis.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

k_{io}	pre-exponential factor
A	concentration of acid
m_i	exponent indicating the acid effect
E_i	activation energy
Ro	reaction Ordinate factor

LIST OF ABBREVIATIONS

OPF	Oil Palm Frond
FTIR	Fourier Transform Infrared Spectroscopy
MPOB	Malaysia Palm Oil Board
SEM	Scanning Electron Microscope
EBSD	Electron Backscatter Diffraction

CHAPTER 1

INTRODUCTION

1.0 Introduction

Recycle lignocellulose waste of palm oil was a challenge to farmer and factory. Lignincellulose waste comprised 2 types, which is farm waste and factory waste. This research limited only for waste that is from palm oil estate or more specifically, palm oil frond. The oil palm industry in Malaysia started 80 years ago in a modest way. Today it is the largest in agricultural plantation sector, exceeding rubber plantation by more than double in area planted. In terms of hectare, the total area under oil palm cultivation is over 2.65 million hectares, producing over 8 million tonnes of oil annually. The oil consists of only 10% of the total biomes produced in the plantation. The remainder consists of huge amount of lignocellulosic materials such as oil palm fronds, trunks and empty fruit bunches. Utilization of waste material such as palm frond is being studied. The race for producing biodegradable products has increased tremendously. Different approaches have been attempted to use biomass as natural biopolymer for production of biodegradable plastics. It is almost 26.2 million tonnes of oil palm fronds in Malaysia according to MARDI. This biomass has been the main source cellulose fiber. This research is important because of Malaysia total net of importing cellulose is more than RM300 million per year and keep increasing.The cell walls of OPF are composed mainly of cellulose, hemicelluloses and lignins. In addition to those three main components, several percent of ash and extractives are included. Among those components, cellulose and hemicelluloses are polysaccharides, which are easily decomposed and metabolized by wood-rot fungi. In the constituent analysis of wood, when lignin is selectively removed, what is obtained is holocellulose. Holocellulose can be thought of as the total of cellulose and all hemicelluloses sources by Kozuma Yosei.

Table 1.1: Chemical Composition of Oil Palm Frond

Component	Oil Palm Frond (%)
Lignin	15.2
Holocellulose	82.2
Alpha cellulose	47.6
Ash	0.7
Polysaccharide Composition	
Arabinose	1.5
Mannose	2.2
Galactose	0.9
Glucose	66.6
Xylose	28.9

Cellulose is linear polymer of β-1, 4-D-glucopyranose units. Natural cellulose can be divided into two groups which is crystalline and amorphous. The overall structure of natural cellulose is crystallized. Cellulose is one of the most common biopolymers on the earth because it forms the primary structural component of all green plants, including vegetables. The linear cellulose chains are combining together as microfibrils. The cellulose microfibril is the basic structural component of cellulose formed during the biosynthesis. The microfibrils are composed of crystalline regions that show strong internal bonding and amorphous regions with weaker internal bonding.

We offer a new technology which is steam explosion to produce microcrystalline cellulose (MCC) and by using chemical treatment for removal other substance such as amorphous part of cellulose, hemicellulose and other substances. The all thing will remove by using acid hydrolysis method and it will remain the product is microcrystalline cellulose (MCC). Acid catalysed cellulose hydrolysis is a complex heterogeneous reaction. It involves physical factors as well as the hydrolytic chemical reaction.

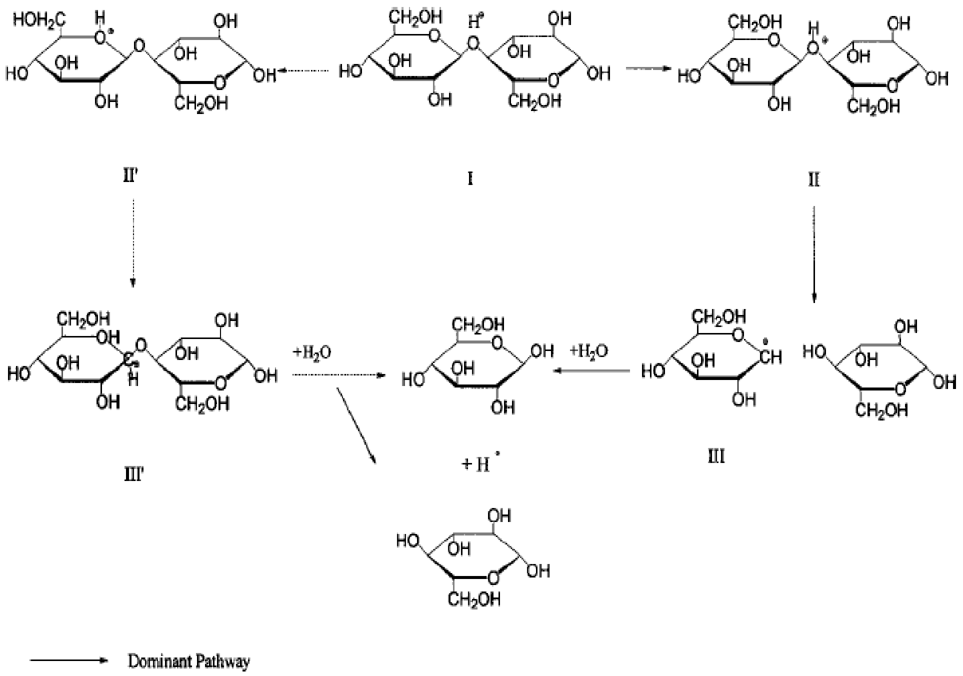


Figure 1.1: Mechanism of acid catalyzed hydrolysis of β-1-4 glucan
(Fengel and Wegener (1984))

The molecular mechanism of acid catalysed hydrolysis of cellulose (cleavage of β-1-4-glycosidic bond) follows the pattern outlined in Fig. 1.1 [Fengel and Wegener (1984)]. Acid hydrolysis proceeds in three steps. The reaction starts with a proton from acid interacting rapidly with the glycosidic oxygen linking two sugar units, forming a conjugate acid. The cleavage of the C-O bond and breakdown of the conjugate acid to the cyclic carbonium ion then takes place, which adopts a half-chair conformation. After a rapid addition of water, free sugar and a proton are liberated it is proof by journal Shafizadeh, F. (1963), Timell, T. E. (1964) and Harris, J. F. (1975). The formation of the intermediate carbonium ion takes place more rapidly at the end than in the middle of the polysaccharide chain. In accordance with this, the yield of monosaccharides after partial hydrolysis is higher than that calculated on the basis of a random bond cleavage [Fengel and Wegener (1984)].

The global kinetics of acid hydrolysis was first described by Saeman (1945) as two pseudo-homogeneous consecutive first-order reactions. Hydrolysis of glycosidic bonds also follows a first-order reaction shown by Springer (1966), Daruwalla, E. H. and Shet, R. T. (1962)].

The first-order kinetic equation generally applies to reactions in homogeneous phase. Therefore, first-order reaction is justifiable for hydrolysis of oligosaccharides that are soluble in the hydrolysing medium. In actual hydrolysis with dilute acids, a heterogeneous reaction takes place, yielding “hydrocellulose,” a product with reduced degree of polymerization (DP) but higher crystallinity. The rate of hydrolysis of cellulose in crystalline form is one to two orders of magnitude lower than that of homogeneous hydrolysis of soluble model compounds. The hydrolysis of cellulose is strongly influenced by the degree of crystallinity and the swelling state of cellulose .The reactivity of cellulose is also affected by mechanical disintegration and recrystallization procedures sources by Millett, Effland *et all* (1979).

It is quite obvious that acid catalysed cellulose hydrolysis is a heterogeneous reaction in which the no reaction factors (e.g., crystallinity, diffusion barrier, physical conformation) represent a major part of the overall resistance proof by Torget, Kim, J. *et all* (2000). The present investigation was undertaken to verify the nature of the no reaction resistances in cellulose hydrolysis and to provide further understanding of the heterogeneous aspects of this reaction.

1.1 Research background

Oil palm frond (OPF) from oil plantation are considered biomass waste that can be fully utilized as pharmaceuticals, nutraceuticals, foods, paper, structural composites and other. In Malaysia, the oil palm industry has contributed a lot to country's economic development. In fact, crude palm oil (CPO) production has increased from only 1.3 million tonnes in 1975 to approximately 18.6 million tonnes in 2013 and continuously increased. Meanwhile, the total oil palm planted area in Malaysia has increased to 4.85 hectares' in 2010 and surely keep increased. On the other hand, with the significantly large plantation area in Malaysia, large amount of oil palm frond (OPF) are pruned regularly during the harvesting of fresh fruit bunches (FFB). It was estimated that for every tonne of crude palm oil (CPO) processed from fresh fruit bunches (FFB), around 6 tonne of oil palm frond (OPF) is produced.

Figure 1.2: Abundance of oil palm fronds

Open burning or simply abandon the waste away a great loss that shown on the figure 1.2 above. In this study, an attempt has been made to convert oil palm frond (OPF) into microcrystalline cellulose for a lot of uses as mention at earlier by using explosion steam method.

1.2 Problem statement

The oil palm frond (OPF) are pruned regularly and left on the ground for natural decomposition which is slow and uneconomical process. Open burning or simply abandon the waste away also a great loss. In this study, an attempt has been made to convert oil palm frond (OPF) into microcrystalline cellulose for a lot of uses in our daily life such as pharmaceuticals, nutraceuticals, foods, paper and structural composites. For pharmaceutical uses, it is used as a binding agent and also as a disintegrating agent. MCC also naturally derived stabilizer, texturing agent and a fat substitute.

Meanwhile, the cost for the microcrystalline cellulose from oversea is high and the demand keep increasing year by year. Based on research by Rosnah Mat Soom (2009), microcrystalline cellulose was produce by preparation of holocelluse from frond by using a few types of chemical and economically it is very high in term of cos producing of MCC. The method steam explosion was used for the preparation of holocellulose by using different pressure and the severity of structure cell wall was recorded.

1.3 Objective of research

The objectives of this research are:

1.3.1 To produce microcrystalline cellulose from oil palm frond using explosion steam method.

1.3.2 To determine the accurate pressure in steam explosion tank.

1.3.3 To determine the severity of the structural cell wall of cellulose.

1.4 Scope of research

In order to achieve the objective, the following scopes have been identified and to be applied:

1.4.1 Palm oil frond is used as raw material for the reaction.

1.4.2 The pressure will use in range of 5-20 bar.

1.4.3 Scanning Electron Microscope (SEM) is used.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the finding of related articles from MPOB website and I-portal is needed in order to do literature review. The literature review is research done in the past by other people and it is needed to support our research objectives.

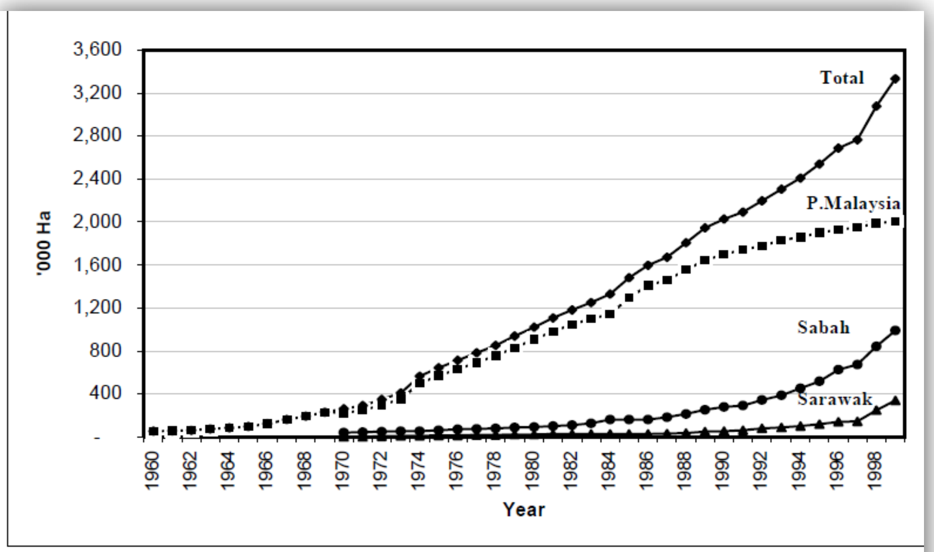
2.2 History, habitat, tree and industrial development of oil palm

The oil palm or *Elaeis guineesis Jac* is a tropical palm tree. The oil palm tree is tropical palm tree under the family of *Palmae* originally come from Guinea; West Africa sorced from Yusof, (2000) is originally illustrate by Nicholaas Jacquin in year of 1763. Oil palm was introduced to Malaysia in 1910 by Scotsman William Sime. Sime Darby and Boustead who are the first plantations British plantation owner were established and operated in Malaysia.

Furthermore, the most suitable culture for oil palm is soil must be free from drained with low pH, but does not thrive at very high pH which is greater than 7.5.Oil palm culture is done in low altitude less than 500m above sea level with 15 ˚ from the equator in humid tropics. The soil is properly drained with evenly distributed rainfall of 1,800 to 2,000 mm/year, but will tolerate rainfall up to 5,000 mm/year. If there are more than three consecutive months with less than 100 mm rainfall per month, potential yield will be reduced and oil palm is sensitive to poor drainage and drought.

Oil palm tree consist of three main which are trunks, fruit bunches and fronds. The height of oil palm tree usually with an un-branched tree from 20 m to 30 m and its trunk is formed after 3 years old when the apex has reached its full diameter in form of an inverted cone after intermodal elongation take place. Weight of bunches of fruit is about 10 kg to 25 kg and sometime might be up to 50 kg. Moreover, the most suitable time to harvest ripe fruits is 5 to 6 month after flowering. A bunch of fruit can produce 500 until 4000 number of fruit. The fruit is reddish with ovoid type shaped, have 2 cm to 5 cm measurement of length and weight scale from 3 g to 30 g. Each of the fruit contains a single seed surrounded by a soft oily pulp. The palm oil produces two type of main vegetable oil. The examples of vegetable oil are palm oil extracted from mesocarp of the fruit and palm kernel oil extracted from seed.

Besides that, according to MPOB (2012), Malaysia had 5 Million hectares of palm oil areas in year of 2011.In Malaysia, oil palm area plated was 2,096,856 hectares being in Peninsular Malaysia, 1,027,329 hectares in Sabah and 374,828 hectares in Sarawak in 2001 and as reported by Teoh (2002). Malaysia planting of oil palm commercially began in 1917 and then, growth of the industry in terms of planted area has been very rapid. Figure 2.1 shows the oil palm planted area in Malaysia from year 1960 to 1998.



.Malaysia: Peninsular Malaysia
Source: MPOB (data from www.mpob.gov.my)

Figure 2.1: Oil palm planted area in Malaysia from 1960 – 1998
(Qian Xing, Y.Y. Lee (2003)

2.3 Characteristics of palm oil frond

Oil palm frond (OPF) consists primarily of celluloses, hemicelluloses and lignin, and lesser amounts of protein, oil and ash that make up the remaining fraction of the lignocelluloses biomass. The toughness of the native cellulose fibre results because it is embedded in lignin. The hemicelluloses provide the link between lignin and cellulose. This lignin coating, when intact in the plant, reduces the accessibility of the cellulose for digestion by chemical and/or biochemical means for the production of fermentable sugars and liquid fuels. Pretreatments of the lignocellulosic materials before subjecting them to fermentable sugar production via enzymatic hydrolysis can resolve this problem. Various pretreatment processes, i.e. physical, chemical and biochemical are commonly used to remove barriers to cellulose hydrolysis. Chemically, the frond strands are rich in holocellulose (83.5%) and also high in α-cellulose (49.8%) as illustrated in table 2.1 and table 2.2, both of which are important parameters in determining the suitability of a raw material for papermaking. The lignin content (20.5%) is lower than normally found in common hardwood, for example aspen of 18.1% and eucalyptus of 22% , which is not surprising since oil palm trees are non-woody and the requirement for structural support is lower compared to that of trees. The functional significance of lignin has long been associated with mechanical support for a plant organ that enables increased growth in height it’s lacking will no longer allow plants to be upright.

Figure 2.2: Oil palm Fronds

Table 2.1: Proximate analysis of biomass of oil palm biomass (%, dry weight)
[Rosnah, Ku Halim *et all* (2002)]

	Oil palm trunk	Oil palm fronds	Empty fruit bunch
Lignin	18.1	18.3	21.2
Hemicellulose	25.3	33.9	24.0
α-cellulose	45.9	46.6	41.0
Holocellulose	76.3	80.5	65.5

Table 2.2: Estimated availability of oil palm fronds (metric tonnes, dry matter basis) in Malaysia
[Malaysian Palm Oil Board(2009)]

Year	Oil palm fronds production		Total
	Replanting	Pruning	
1990	0.25	16.92	18.49
1992	0.64	17.64	21.67
1994	0.88	17.89	22.37
1996	0.83	19.09	24.28
1998	1.42	18.18	27.08
2000	1.34	17.85	26.21

2.4 Structure and properties of Microcrystalline Cellulose

Cellulose is linear polymer of β-1, 4-D-glucopyranose units. Natural cellulose can be divided into two groups which is crystalline and amorphous. The overall structure of natural cellulose is crystallized. Cellulose is one of the most common biopolymers on the earth because it forms the primary structural component of all green plants, including vegetables. The linear cellulose chains are combining together as microfibrils. The cellulose microfibril is the basic structural component of cellulose formed during the biosynthesis. The microfibrils are composed of crystalline regions that show strong internal bonding and amorphous regions with weaker internal bonding. Vegetable oils are determined by their fatty acid composition. A high content of linoleic or linolenic acid decreases thermal oxidative stability sources by Abdulazia, Rosnah *et all* (1989).

2.5 Process for production of Microcrystalline Cellulose from Oil Palm Frond

The microcrystalline cellulose can be obtained from oil palm fronds (OPF). The MMC are produce by using steam explosion to remove lignin and hemicellulose from the frond. The remaining of the holocellulose will go to the next process is hydrolysis. The hydrolysis of cellulose is strongly influenced by the degree of crystallinity and the swelling state of cellulose. The reactivity of cellulose is also affected by mechanical disintegration and recrystallization procedures from Millett, Caulfield *et all.* (1979).

It is quite obvious that acid-catalysed cellulose hydrolysis is a heterogeneous reaction in which the no reaction factors (e.g., crystallinity, diffusion barrier, physical conformation) represent a major part of the overall resistance .The present investigation was undertaken to verify the nature of the no reaction resistances in cellulose hydrolysis and to provide further understanding of the heterogeneous aspects of this reaction.

An expected outcome from this research on the production of microcrystalline cellulose are based on Figure 2.4.1 presents the hydrolysis profiles of cellulose pretreated with concentrated H_2SO_4. When pretreatment was done with 60% or less H_2SO_4, the hydrolysis of cellulose was extremely slow, basically at the same level as untreated cellulose. However, when α-cellulose was pretreated with 65% H_2SO_4 or higher, most of the cellulose was dissolved. When it was diluted with water, part of the dissolved cellulose was precipitated. The hydrolysis rate of the precipitated cellulose was two orders of magnitude higher than that of untreated α-cellulose. Beyond 65% H_2SO_4, the increase in hydrolysis rate was again gradual with respect to acid concentration. The precipitated cellulose was hydrolysed at about the same rate as cornstarch under the identical hydrolysis condition. It is therefore reaffirmed that the hydrolysis reaction is indeed strongly influenced by the physical state of the cellulose. The acid hydrolysis as a rate process has two different types of resistance: reaction and physical. If so, the physical resistance is two orders of magnitude greater than the reaction resistance.

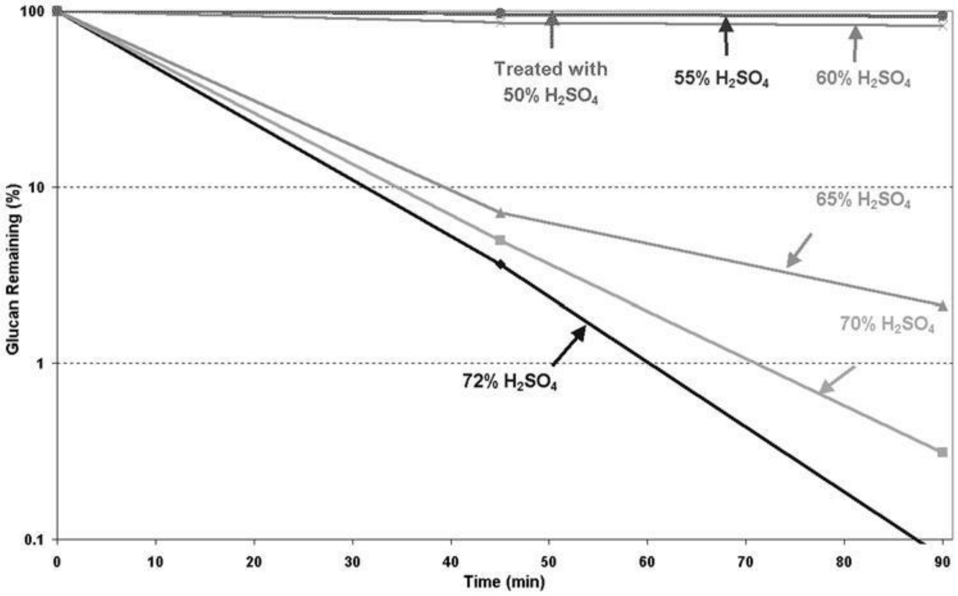


Figure 2.3.1 Structure of untreated cellulose.

(Qian Xing, Y.Y. Lee (2003)

X-ray diffractograms were taken for the cellulose and reprecipitated cellulose. As shown in Fig. 2.4.2, the highly crystalline structure of untreated cellulose was totally disrupted and a completely different diffraction pat-tern with near zero crystallinity appeared after dissolution into 65% H_2SO_4 and reprecipitation. SEM photographs were taken for untreated α-cellulose and those treated with 55, 60, and 65% H_2SO_4.Untreated α-cellulose.

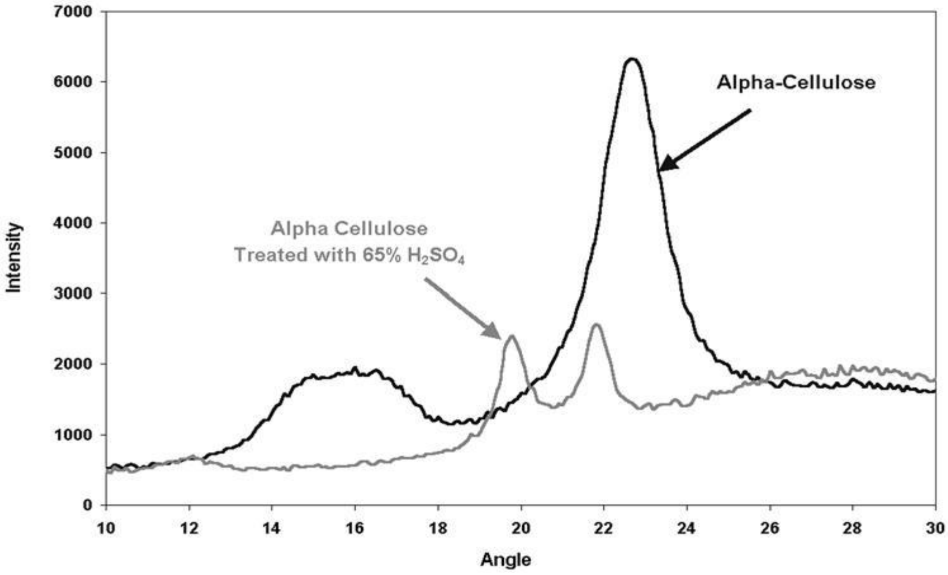
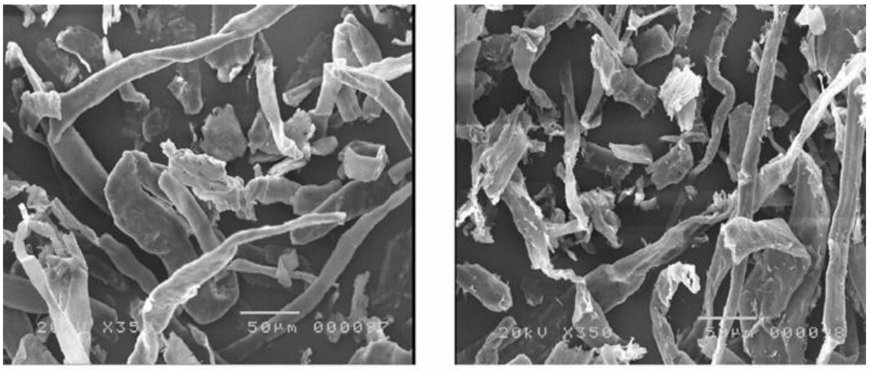
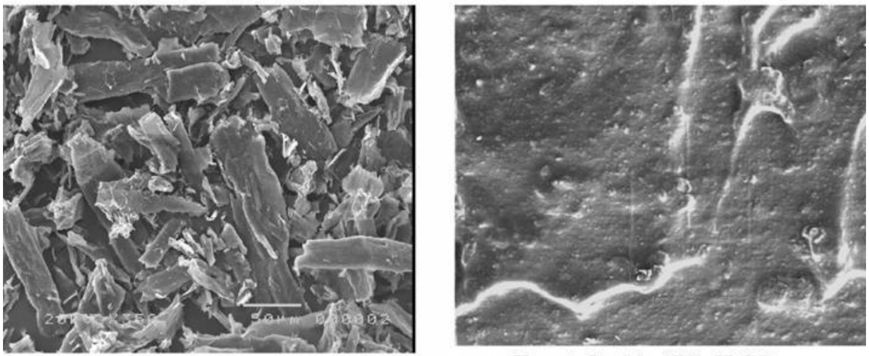


Figure 2.3.2: X-ray diffractograms of α-cellulose



α-Cellulose, Untreated, *350X* Treated with 55% H_2SO_4



Treated with 60% H_2SO_4 Treated with 65% H_2SO_4

Figure 2.3.3: SEM photographs of α-cellulose
(Qian Xing, Y.Y. Lee *et all*.(2003)

and samples treated with 55 and 60% acid are seen to retain the original fibrous structure although the fibers were broken into smaller fragments by acid treatment (Fig. 2.5.3). However, the sample treated with 65% acid shows a completely different picture. The original fibrous form of cellulose disap-peared and changed into a gel-like substance. When the cellulose fibers are dissolved into concentrated acid, the bundles of glucan chains are sepa-rated into multiple single chains. As the acid is diluted, the dissolved glucan chains reassociate. When this happens, the glucan chains do not go back to the original orderly structured 14ehaviour14 form but form an irregular bundle. We note that the change in cellulose structure owing to acid treatment is gradual to a certain point (60% acid in this case) and then undergoes a drastic change beyond that point. At higher temperature, it requires less concentrated acid to undergo this drastic change. For example, at 70°C, it requires only 50% H_2SO_4. We mentioned earlier a similar behaviour with respect to temperature: a drastic increase in hydrolysis rate at a certain temperature. We have confirmed that these sudden changes in kinetic 14ehaviour and crystallinity are owing to structural changes in the cellulose.

The cellulose structure is closely related with the hydrogen bonding exist-ing inside the cellulose chains. The existence of hydrogen bonds in cellulose molecule is well documented (Fengel and Wegener (1984). The hydrogen bonding exists within a single chain of glucan (intramolecular hydrogen bonding) and between the adjacent glucan chains (intermolecular hydrogen bonding). The inter-molecular hydrogen bonds are believed to be the primary factor holding the cellulose chains together forming the fibrous structure. The state of hydrogen bonding in cellulose also determines other physical properties of cellulose, such as the extent of crystallinity.

Among all possible nonreaction factors (e.g., physical conformation, diffusion, crystallinity, chemical composition), the state of hydrogen bond-ing stands out as the primary factor controlling the main resistance in acid hydrolysis of cellulose. There is yet another support for this contention. Of all the physical factors, only hydrogen bonding can undergo such an abrupt change in reaction rate and structure in response to temperature and con-centration of acid as seen in our experiments.

The state of hydrogen bonding is the primary factor determining the molecular level structure of cellulose. Kinetics of acid hydrolysis of cellulose is therefore strongly dependent on the state of hydrogen bonding. A better understanding of hydrogen bonding as to how it relates to the molecular structure of cellulose and finding an effective means to disrupt the hydrogen bonding may prove to be a fruitful way to establish acid hydrolysis as a viable biomass scarification process.

Another expected outcome from this research is the production of microcrystalline cellulose from oil palm fronds. Oil palm fronds (OPF) are determined by using Fourier Transform Infrared Spectroscopy (FTIR). Detail properties of MCC are shown in Table.

Table 2.3: Properties of microcrystalline cellulose from oil palm fronds
(Rosnah Mat Soom, 2009)

Characteristic	White, odourless and tasteless, insoluble in water, acetone, ethanol and toluene
Water-soluble substances	0.1%-0.4%
pH	6.5-7.3
yield	18%-24% (dry weight)

2.6 Application of microcrystalline cellulose

Microcrystalline cellulose (MCC) is a compound with high value and can be exploited for the benefit of the palm oil industry. It has many applications in pharmaceuticals, nutraceuticals, foods, paper and structural composites. For pharmaceutical uses, it is used as a binding agent and also as a disintegrating agent. MCC also naturally derived stabilizer, texturing agent and a fat substitute Cellulose for industrial use is mainly obtained from wood pulp and cotton. The kraft process is used to separate cellulose from lignin, another major component of plant matter.

- Paper products: Cellulose is the major constituent of paper, paperboard, and card stock.
- Fibers: Cellulose is the main ingredient of textiles made from cotton, linen, and other plant fibers. It can be turned into rayon, an important fiber that has been used for textiles since the beginning of the 20th century. Both cellophane and rayon are known as "regenerated cellulose fibers"; they are identical to cellulose in chemical structure and are usually made from dissolving pulp via viscose. A more recent and environmentally friendly method to produce a form of rayon is the Lyocell process.
- Consumables: Microcrystalline cellulose (E460i) and powdered cellulose (E460ii) are used as inactive fillers in drug tablets[30] and as thickeners and stabilizers in processed foods. Cellulose powder is, for example, used in Kraft's Parmesan cheese to prevent caking inside-of the package.
- Science: Cellulose is used in the laboratory as a stationary phase for thin layer chromatography. Cellulose fibers are also used in liquid filtration, sometimes in