STUDY ON FACTORS AFFECTING SEPARATION OF XYLOSE FROM GLUCOSE BY NANOFILTRATION USING COMPOSITE MEMBRANE DEVELOPED FROM TRIETHANOLAMINE (TEOA) AND TRIMETHYL CHLORIDE (TMC)

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ABSTRACT

Xylose is an abundant raw material coexists with other sugars that can be turned into useful products, such as ethanol, xylitol and 2, 3-butanediol by microorganism such as yeasts, bacteria, and mycelial fungi. However more than 80 % of the production cost come from production of xylose solely, where recovery of xylose relied on chromatographic separation alone. Nanofiltration offers more economical solution to currently in use chromatography method, by usage of composite membrane developed from economical active monomer, triethanolamine (TEOA). In this study, factors affecting the process, pressure, concentration of total sugars in solution, and composition of monosaccharides in total sugar, were investigated using two-level factorial analysis. The experiment was perform using Amicon Milipore stirred cell (Model 8200) with constant stirring speed at 300 rpm and temperature at ambient. Membrane was prepared by conventional interfacial polymerization of TEOA and tri-methyl chloride (TMC) on polyethersulfone (PES) porous membrane. The glucose and xylose concentration was quantified using high performance liquid chromatography (HPLC). In this study, it was found that the composition of xylose to glucose has affected the nanofiltration the most, at 63.56 %, followed by total sugar concentration at 19.52 %, pressure contributed the least at 0.033 %. An interaction between factor total sugar concentration and composition of xylose to glucose were also found to contribute 16.10 % on nanofiltration. The coefficient of determination (R^2) from analysis of variance (ANOVA) study was 0.9921. In a nutshell, nanofiltration using membrane developed from TEOA and TMC as monomers on PES membrane has the ability to separate xylose from glucose. Overall in this present study it can be concluded that nanofiltration has high potential to replace currently in use chromatograhic method in xylose separation.

ABSTRAK

Xylose merupakan bahan mentah yang senang diperolehi dan boleh menghasilkan produk berguna seperti etanol, xylitol dan 2, 3-butanediol melalui penapaian oleh yis, bakteria dan kulat. Walau bagaimanapun, kos pengeluaran xylose meliputi lebih 80 % daripda jumlah kos pengeluaran, di mana pemulihan xylose bergantung sepenuhnya kepada pemisahan kromatografi sahaja. Penapisan nano menawarkan penyelesaian yang lebih jimat berbanding pemisahan kromatografi demangan pengunaan membran komposit diperbuat daripada monomer aktif yang murah, triethanolamine (TEOA). Di dalam kajian ini,faktor-faktor, seperti tekanan, jumlah konsentrasi gula dalam solusi, dan komposisi gula dalam jumlah konsentrasi yang memberi impak kepada proses penapisan nano telah dikaji. Experimen telah dijalankan menggunakan sel pengaduk Amicon Milipore (model 8200) pada kelajuan 300 rpm dan suhu bilik. Membran disediakan menggunakan teknik konventional pempolimeran antara muka oleh monomer TEOA dan tri-metil klorida (TMC) atas membran berliang poliethersufon (PES). Konsentrasi glukosa dan xylose diukur menggunakan kromatografi cecair prestasi tinggi (HPLC). Dalam kajian ini , didapati bahawa komposisi antara xylose dan glukosa telah memberi kesan yang besar kepada penapisan micro, pada 63,56 %, diikuti oleh jumlah konsentrasi gula pada 19.52 %, manakala tekanan pada 0.033 %. Interaksi antara faktor jumlah konsentrasi gula dan faktor komposisi antara xylose dan glukosa boleh dilihat dan memberi kesan sebanyak 16.10 % ke atas penapisan nano. Pekali penentuan (R^2) daripada analisis varians (ANOVA) adalah 0.9921. Secara keseluruhan, penapisan nano diperbuat daripada monomer TEOA dan TMC ke atas membran PES mempunyai keupayaan untuk memisahkan xylose daripada glukosa. Kesimpulannya, penapisan nano mempunyai potensi yang tinggi untuk menggantikan kaedah kromatografi yang kini diguna pakai dalam pengasingan xylose.

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LIST OF SYMBOLS

ΔP	Applied pressure drop
Δx	Effective membrane thickness
μ	Viscosity of solution
\$	United States Dollar
a_0	Intercept value
a_i	Partial regression coefficient
A_k	Effective porosity of the membrane
$c_f(glu)$	Concentration of glucose in feed
$c_f(xyl)$	Concentration of xylose in feed
c_i	Concentration of component i
$c_p(glu)$	Concentration of glucose in permeate
$c_p(xyl)$	Concentration of xylose in permeate
$\frac{d_p}{d_x}$	Pressure gradient existing in the porous medium
J_i	Volume flux of component i
J_w	Pure water flux
K'	Coefficient reflecting the nature of the medium
r_p	Pore radius size
R^2	Coefficient of determination
$Rglu$	Observed rejection of glucose
$Rxyl$	Observed rejection of xylose
RM	Ringgit Malaysia
X_1	Factor pressure
X_2	Factor total sugar concentration
X_3	Composition of xylose:glucose in total sugar
X_i	Explanatory variable
$Xxyl$	Xylose separation factor
y	Dependent variable
y_x	Variable xylose separation factor

LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
PES	Polyethersulfone
TEOA	Triethanolamine
TMC	Tri-methyl chloride

1 INTRODUCTION

1.1 Background

Xylose is an abundant raw material coexists with other sugars that can be turned into useful products, such as ethanol, xylitol and 2, 3-butanediol by microorganism such as yeasts, bacteria, and mycelial fungi. Xylose mainly comes from hydrolysis of hemicellulose of agriculture waste, which consists around 55 % of total sugar. Another monosaccharide of interest, which is glucose, also results from the hydrolysis of hemicellulose covering around 25% of the total sugar (Flickinger and Drew, 1999). Glucose is a primary source of energy for microorganism. The presence of glucose inhibits the utilization of xylose by microorganism in producing the desired output. Microorganism tends to consume glucose for growth and metabolism and later on other monosaccharides, when supply of glucose come to an end(Kilian and Van Uden, 1988; Meinander and Hahn-Hägerdal, 1997). This has resulted a low productivity of desired products fermented from xylose.

1.2 Motivation and Statement

Separation of hemicelluloses hydrolysate is highly demand in order to separate xylose from inhibitors, for formation of desired product through microbial fermentation. da Silva and Chandel (2012) estimated the cost of production of xylitol using chemical process and found out cost of hydrogenation of xylose to xylitol was about $ 350/ton (RM 754/ton) is less than 20 % of the total cost of xylitol production. More than 80% of the total cost of xylitol production came from the cost of xylose crystal production which is about $ 2,300 - 2,500/ton (RM 7541 - 8,197/ton).

There are few reasons for the high cost of xylose crystal production. First, the composition of the non-sugar components in the hemicellulose hydrolysates is very complicated, and the purification steps required to remove these component are rather tedious. Second, the physicochemical properties of the sugar impurities are fairly similar to those of xylose and can inhibit xylose crystallization. Currently, chromatographic separation is the only method available to the industry to recover xylose. The complexity of the purification procedures and low product yield further push the cost of producing xylose production to a high level (da Silva and Chandel, 2012).

Among various method of separation currently in study, nanofiltration offers cost-effective and easy-maintenance alternative separation of xylose from glucose (Sjöman et al., 2007; Goulas et al., 2002). Nanofiltration around the world mainly applies the use of thin-film composite membranes by interfacial polymerization. Interfacial polymerization is deposition of a thin selective layer on top of a porous membrane by interfacial in situ polycondensation of diamine and diacid chloride.

Recent years saw that preparation of thin-film membrane with interfacial polymerization technique using monomers with special functional groups has been highly focused. Membrane surface charge developed with these monomers can be adjusted according to the amino groups and tertiary amino groups. A particular tertiary amino, TEOA was used in this study. TEOA is an active monomer which is environmental-friendly, economical and easy to be obtained (Tang et al., 2008). The membrane used in this study was prepared according to Tang et al. (2008) novel polyester composite nanofiltration membrane with slight modification base on study by (Abu Seman et al., 2013; Jalanni et al., 2012). Past studies on the separation of monosaccharides using nanofiltration identified four factors that affect the nanofiltration process. The factors are pressure, temperature, concentration of total sugars in solution, and composition of monosaccharides in total sugars (Sharma et al., 2003; Sjöman et al., 2008; Heikkilae et al., 2002). However effect of temperature was not selected in this study due to the equipment limitation.

1.3 Objective

This study is aim to investigate the ability of membrane developed using TEOA and TMC as monomers, on PES membrane to separate xylose from glucose.

1.4 Scope of This Study

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

i) To investigate the effect of pressure on the nanofiltration process.

ii) To investigate the effect of total sugar concentration on the nanofiltration process.

iii) To investigate the effect of composition ratio of xylose:glucose on the nanofiltration process.

iv) To analyze all the factors using two-level full factorial design.

1.5 Main Contribution of This Study

Many useful products can be produced from utilization of xylose as raw material either by chemical or biological processes. This make xylose a highly demanded sugar in the industry. However more than 80 % of the production cost come from production of xylose solely, where recovery of xylose relied on chromatographic separation alone. This study was intended to look in the possibility of alternative separation xylose from glucose using nanofiltration to reduce the cost of xylose production. Membrane developed by interfacial techique using economical monomer, TEOA can further reduce the xylose production cost. This cost reduction will have a huge impact on the industry, where cheaper end products such as ethanol, xylitol, and 2, 3-butanediol can be made available on the market by lowering the overall cost. Besides, separation of xylose from glucose offers new potential use of xylose as raw material in microbial fermentation where in the past restricted by the high cost of xylose.

1.6 Organization of This Thesis

This thesis was divided into five chapters. Following this introductory chapter was Chapter 2, which presented the reviews of important information of the study.

Chapter 2 was segregated into 9 sections; xylose, glucose, xylose and glucose in plant residue, separation of hemicelluloses hydrolysate, nanofiltration, composite membrane, factors affecting nanofiltration, design of experiment and calculation for separation evaluation. The first two sections described the use and properties of xylose and glucose, respectively. In the next section, sources of xylose and glucose were presented. Past studies on separation of xylose from hemicelluloses hydrolysate were summarized in the following section. Next, the nanofiltration process were reviewed followed by composite membrane in the following section. After that, the effect and selection of factors to be studied on nanofiltration were explained. The use of two-level full factorial design in analysis were covered in the succeeding section. Lastly, calculation involved in evaluating separation performance were presented.

Chapter 3 was one of the essential elements in this study where brief procedures and techniques were shown. This chapter was separated into six sections. The first section covered the source of materials for this study. The second section covered the preparation of composite membrane. Next, the characterization of membrane using water permeability test were covered. After that the experimental design using software Design-Expert version 7.0.0 (Statease Inc., USA) were covered. The next section covered the setup of

experiment for this study. The last section briefly showed the method of analysis for sample.

Chapter 4 was focused on the major findings of this study with relevant discussion. This chapter was divided into three sections. The first section discussed the characterization of membrane developed in thisstudy using water permeability test. Next, the standard curve for xylose and glucose were presented. Lastly, the findings from analysis of factors were shown and discussed.

In the last chapter, the conclusions of the objective and some recommendation for future study were revealed. These conclusion were based on the objective of the study and according to the findings in Chapter 4. Based on the conclusion, recommendations for future work were suggested.

2 LITERATURE REVIEW

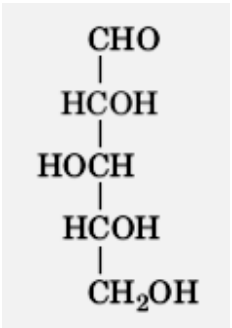
2.1 Overview

In this chapter, the important information on this study was summarized. This chapter contains few sections that begin by discussing the monosaccharides involved in this study. Next, the separation process is reviewed and the factors affecting the nanofitlration is discussed. The use of design of experiment in this study is briefly explained after that. Lastly, calculation for evaluating the nanofiltration is stated.

2.2 Xylose

Xylose belongs to the group of aldopentose type monosaccharide. Xylose is normally found in plants because xylose is the main building block for hemicellulose xylan. Xylose is a abundant raw material coexist with other sugars that can be turned into useful products, such as ethanol, xylitol and 2,3-butanediol. Properties of xylose are summarized in Table 2.1.

Table 2.1: Properties of xylose (Haynes et al., 2012; Qi et al., 2011)

Molecular formula	$C_5H_{10}O_5$
Molecular structure	
Molecular weight	150.13 g/mol
Difusion coefficient at 25 °C	$7.5 \times 10^{-6} cm^2/s$
Stokes diameter	0.64 nm
Dissociation constant (pKa)	12.14 (18 °C)

Recently, ethanol is the most studied metabolic product from xylose by fermentation as it has the potential to substitute the petrol fuel, in coming years. Xylose can be converted to ethanol by microorganism such as yeasts, bacteria, and mycelial fungi. Ethanol

provides energy security and diversity, improves global competitiveness, and promotes energy independence. Ethanol also improves the air quality and reduces the threat of global warming (Bruinenberg et al., 1984).

Yeasts are facultative organisms that have the ability to produce energy on their own under either aerobic or anaerobic conditions. Under aerobic, sugars are metabolized to carbon dioxide and water for the production of energy and cell constituents. Under anaerobic conditions, most sugars are metabolized to ethanol by a process called alcohol fermentation. Ethanol fermentation by yeast from xylose can be divided into four distinctive steps (Laplace et al., 1991; Flickinger and Drew, 1999).

The first step is the reduction of xylose to xylitol mediated by NADPH/NADH-linked xylose reductase. This followed by the oxidation of xylitol to xylulose by NAD-linked xylitol xylose dehydrogenase. Phophorylation of xylulose by xylulose kinase turn xylulose to xlylulose-5-phosphate. Further metabolism of xylulose-5-phosphate is carried out in the pentose phosphate pathway ending up with ethanol as product (Flickinger and Drew, 1999). The process is illustrated in Figure 2.1.

Beside yeasts, bacteria and mycelial fungi also convert xylose to ethanol. A wide range of bacterial species utilizes xylose as carbon and energy sources. Bacteria direct isomerizes xylose to xylulose before further metabolism to become ethanol. Most of these bacteria belong to the species of *Klebsiellae* and *Erwinia*, and *Escherichia coli*. Research on this field revolves around the improvement of such bacteria through genetic recombination. Fungi also have the ability to metabolize xylose to produce ethanol. However, the slow rate of ethanol production from xylose by fungi is undesirable (Tolan and Finn, 1987; Ohta et al., 1990; Ueng and Gong, 1982).

Xylitol occurs naturally in small quantities in many fruits and vegetable. Xylitol is a five-carbon sugar alcohol and the only second-generation polyol sweetener. Sadly, xylitol is one of the most expensive polyol sweeteners due to its low availability and high cost of production. Commercially, xylitol is produced through chemical reduction of xylose obtained from hemicellulosic hydrolysate. The most common substrate is birch hydrolysate. The production through chemical process is expensive because of the usage of high temperature and high pressure in hydrogenation of xylose. Furthermore, extensive steps for separation and purification add to the cost (Winkelhausen et al., 1996).

Another alternative approach is currently studied has been considered for the production of xylitol using yeasts.Xylose is converted into xylitol either by NADPH-denpendent aldehyde reductase, or from xylulose by NADH-dependent xylitol dehydrogenase. However, the substrate for xylitol production, xylose, is expensive. Thus, many studies have

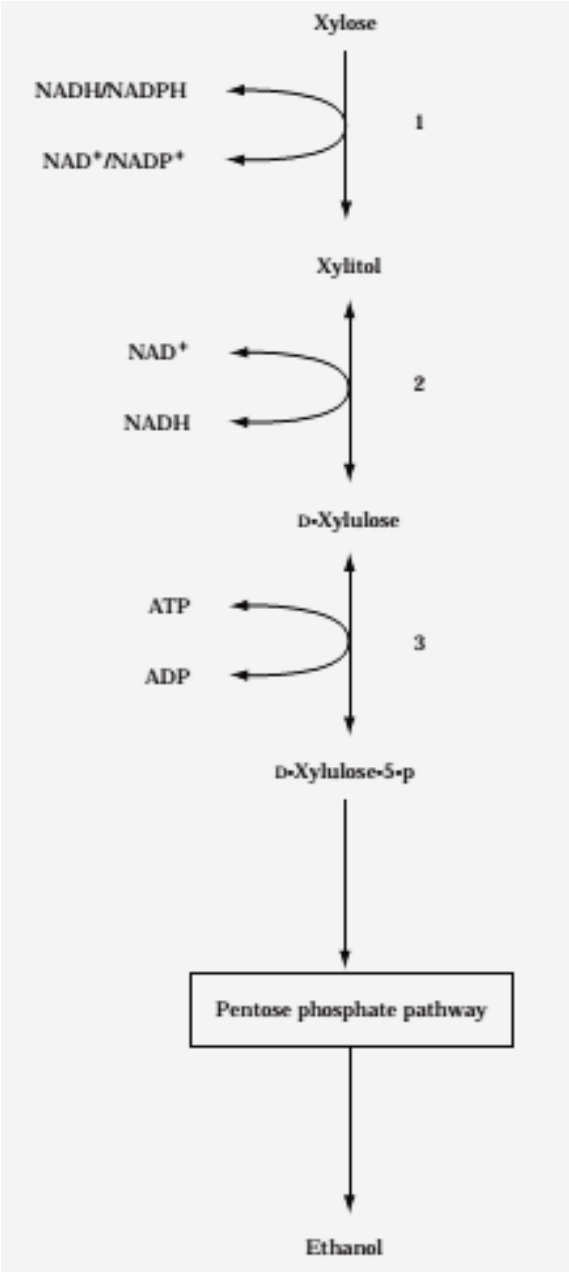


Figure 2.1: Pathway of conversion of xylose to ethanol by yeast. (1) Xylose reductase; (2) Xylitol dehydrogenase; (3) Xylulokinase (Flickinger and Drew, 1999)

been conducted in utilization of xylose fraction in hemicellulose portion of agriculture residues. Purification of xylose from hemicellulose hydrolysate is greatly demanded (Lu et al., 1995; Kim et al., 1997).

Butaniediol is another product derived from xylose through microorganisms. Butanediol (butylene glycol), a colorless and odorless liquid with a high boiling point (180-184 °C) and low freezing point (60 °C). Butanediol has a wide range of usage in industry as polymeric feed stock in addition to its use for manufacturing butadiene or antifreeze. In the other hand, butanediol can be dehydrated into methyl ethyl ketone (MEK) and used as octane booster for gasoline or as high-grade aviation fuel. MEK can be further dehydrated to 1,3 butadiene and dimerized to styrene, a raw material for production of polystyrene plastics and resin (Garg and Jain, 1995)

There are few isomers of butanediol such as 1,2-butanediol, 1,3-butanediol, 1,4-butanediol, and 2,3-butanediol. However, microorganism only can produce 2,3 butanediol out of those isomers of butanediol. Bacterial species of *Klebsielleae* metabolize hexoses and pentoses to produce 2,3 butanediol, acetoin, and ethanol. Enterobateria such as *Erwinia* also produced 2,3 butanediol and mixed acid from hemicellulose-derived carbohydrates. Butanediol-producing bacteria has three enzyme that responsible to accumulate 1 mole of butanediol from 2 moles of pyruvate. The enzymes are α-acetolactace synthesis (ALS), α-acetolactace decarboxylase (ALDC), and acetoin reductase (AR) (Garg and Jain, 1995; Jansen and Tsao, 1983; Mayer et al., 1995; Flickinger and Drew, 1999). The metabolic pathway leading to butanediol is shown in Figure 2.2.

2.3 Glucose

Glucose is another type of monosaccharide belonging to the group aldohexoses. Glucose is one of the main products of photosynthesis. Glucose also the primary source of energy for cells in cellular respiration uses. Properties of glucose are summarized in Table 2.2. Microorganism acquire and utilize energy they need to carry out their various functions through metabolism. A major pathway of metabolism is cellular respiration, in which the sugar glucose are broken down in the presence of oxygen to carbon dioxide and water (Reece et al., 2011; Voet and Voet, 2011). The overall reaction for cellular respiration is shown in Figure 2.3. Glucose is an important sugar for cell activity and growth of microorganism. However when it comes to producing desired product, such as ethanol, from utilization of xylose, glucose became the hindrance. Various studies had reported that glucose inhibiting the xylose uptake in yeasts (Kilian and Van Uden, 1988; Meinander and Hahn-Hägerdal, 1997). The main reason behind the inhibition of glucose is that the

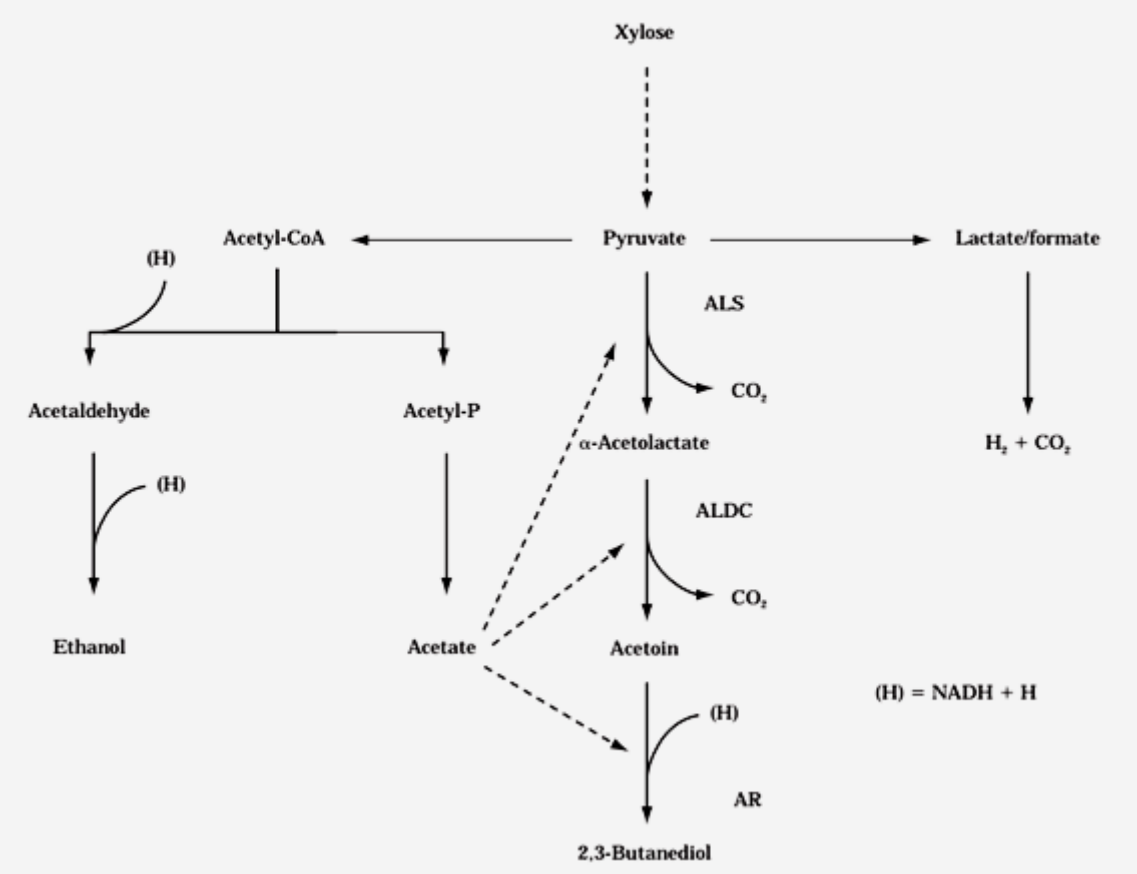
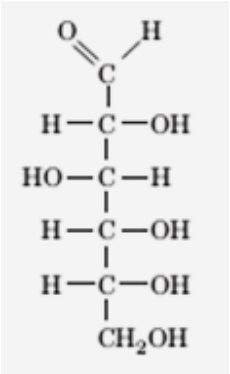


Figure 2.2: The metabolic pathway of xylose to butanediol by butanediol-producing bacteria (Flickinger and Drew, 1999)

Table 2.2: Properties of glucose (Haynes et al., 2012; Qi et al., 2011)

Molecular formula	$C_6H_{10}O_6$
Molecular structure	
Molecular weight	180.16 g/mol
Difusion coefficient at 25 °C	$6.7 \times 10^{-6} cm^2/s$
Stokes diameter	0.73 nm
Dissociation constant (pKa)	12.46 (18 °C)

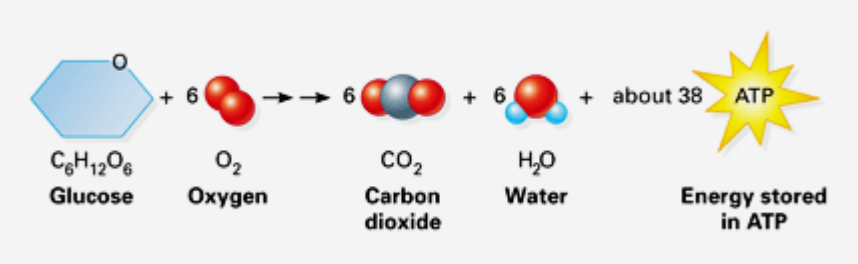


Figure 2.3: Overall reaction of cellular respiration (Voet and Voet, 2011)

affinity for glucose is approximately 200 times higher than that for xylose (Kötter and Ciriacy, 1993). The high affinity implies that when glucose concentration is low, only then the xylose will be transported into the cell (Erdei et al., 2013) resulting competition between xylose and glucose for metabolism. The presence of glucose is all over the potential raw materials derived from agriculture residues.

2.4 Xylose and Glucose in Plant Residue

Plant cell wall rigidity and flexibility are closely associated with polysaccharide localized mostly in cell wall middle lamella, called hemicellulose. Hemicelluloses are heteropolysaccharides that are composed of various hexoses, pentoses, uronic acids, acetic acids, and other minor sugars. Hydrolysis of the hemicellulose in annual plants, agricultural wastes, and hardwood yields glucose, xylose, and other minor sugars (Flickinger and Drew, 1999). Monosaccharides from hydrolyzed hemicellulose of agriculture residues are shown in Table 2.3. From the tables below, monosaccharides of interest, glucose and xylose are highly concentrated in most of the materials and plant residues.

2.5 Separation of Hemicelluloses Hydrolysate

Past researches investigated various methods to separate hemicelluloses hydrolysate. The methods are membrane filtration processes such as microfiltration, ultrafiltration and nanofiltration, liquid-liquid extraction, ion exchange resins, and adsorption using silica adsorbent. Separation of hemicelluloses hydrolysate is important, typically separation of xylose from glucose for the use in commercial xylitol production. Summary on the past research in separation of hemicelluloses hydrolysate can be referred in Table 2.4. Nanofiltration was found to be a great advantage because it offers a more cost-effective and eases of maintenance separation of hemicelluloses hydrolysate compared to other techniques (Tang et al., 2008; Sjöman et al., 2007)

Table 2.3: Monosaccharides from hydrolyzed hemicelluloses of agricultural waste (Flickinger and Drew, 1999)

Plant Residues	**% of total sugars**			
	Xylose	Glucose	Arabinose	Others
Corn residues				
Cobs	65.1	25.3	9.6	-
Leaves	59	29.7	9.4	2.5
Stalks	70.5	14.5	9.0	5.9
Husks	53.5	32.6	12.3	1.6
Pith	71.5	26.8	9.8	3
Fibers	63.8	26.8	6.6	2.8
Wheat straw	57.9	28.1	9.1	5
Soybean				
Stalks and leaves	59.9	6.1	6.6	27.4
Hulls	26.6	21	12.7	39.7
Sunflower				
Stalks	60.6	32.6	2.2	4.6
Pith	10.7	63.5	11.8	14
Flax straw	64.6	1.2	12.8	21.4
Sweet clover hays	49.3	8.9	21.9	9.9
Peanut hulls	46.3	46.6	5	2.1
Sugarcane bagasse	59.5	26	14.5	-

Table 2.4: Summary on past research related to separation of hemicelluloses hydrolysate

Past research	**Remarks**
(Canilha et al., 2004)	Purification using ion-exchange resins and adsorption techniques
(Vegas et al., 2006)	Purification using ultrafiltration and nanofiltration
(Egüés et al., 2012)	Purification using liquid-liquid extraction

2.5.1 Separation using Ion-exchange Resins

Ion exchange is a separation process where reversible exchange of ions between a liquid phase and a solid phase which is not accompanied by any radical change in the solid structure. The solid phase in the ion exchange process is the ion-exchange resin. Ion exchange resin is divided in to a few groups, mainly cation and anion exchange resins. Cation exchange resins bear fixed negative charges that retain cations. Anion exchange resins bear positive charges that retain anions (Coulson et al., 2002; Rousseau, 1987).

The kinetics of ion exchange may be divided into five steps. The first step is diffusion of counter-ions through the bulk solution to the surface of the ion-exchange resin. The second step is diffusion of the counter-ions within the solid phase. Follow by chemical reaction between the counter-ions and the ion-exchange resin. After that, diffusion of the

displaced ions out of the ion-exchange resin. Lastly, diffusion of the displaced ions from the ion-exchange resin surface into the bulk solution (Rousseau, 1987).

Canilha et al. (2004) investigate the use of ion-exchange resins in improving the production of xylitol from xylose. Improvement can be seen by the removal of inhibitors such as acetic acid, furfural and hydroxymethyl-furfural.

2.5.2 Separation using Adsorption Techniques

Beside ion-exchange, Canilha et al. (2004) also investigated the adsorption technique using activated carbon in removal of inhibitors. However, these separation is targeted during the fermentation. Inhibitors are not separated after hydrolysis of hemicellulose biomass in this study may inhibit the growth of other types microorganism. Adsorption process occurs when the selective concentration (adsorption) of one or more components (adsorbates) of either a gas or a liquid at the surface of a microporous solid (adsorbent). The forces that let adsorbates attracted to adsorbents are weaker than chemical bonds such that adsorbates can desorbed by increase of temperature or reducing adsorbates' partial pressure (or concentration in a liquid) (Rousseau, 1987).

Bi et al. (2010) investigated the use of silica-confined ionic liquid stationary phase replacing conventional NH_3 column in separating xylose and glucose. This study employ liquid chromatography using ion-exchange resins as stationary phase. The outcome of the study showed xylose and glucose are able to be separated using adsorption techniques in chromatography. Lei et al. (2009) investigated adsorption equilibrium of glucose, xylose and arabinose on different resins using static method. The capacity of the adsorbents with respect ro individual monosaccharides decreased in order of arabinose > xylose > glucose in the study. Xylose tend to bind with resins compared to glucose due to different in molecular size where glucose is larger. Commercially, xylose is separated from hemicellulose hydrolysate by chromatography which contribute substantial cost in production of xylitol (Sjöman et al., 2008).

2.5.3 Separation using Membrane (Microfiltration, Ultrafiltration and Nanofiltration)

Membrane is defined generally as a selective barrier between two phases. Membrane is made of a thin, typically planar structure or material that separates two environments or phases and has a finite volume. Most membrane used in the industries has an asymmetric structure. Asymmetric structure consists of two layers: top with thin dense layer (also called top "skin" layer) and the bottom with thick porous later (Matsuura, 1993; Mulder,

1996; Khulbe et al., 2007). A schematic representation of the cross-section of an asymmetric membrane is shown in Figure 2.4. An electron micro-graph of a section of an asymmetric ultrafiltration membrane showing finely porous "skin" layer on more openly porous supporting matrix is shown in Figure 2.5.

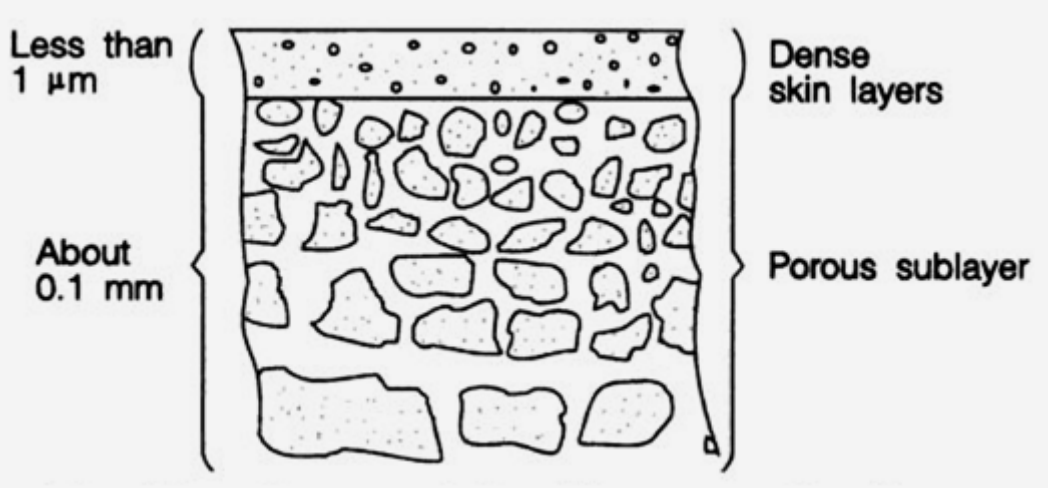


Figure 2.4: Schematic representation of the cross-section of an asymmetric membrane (Matsuura, 1993)

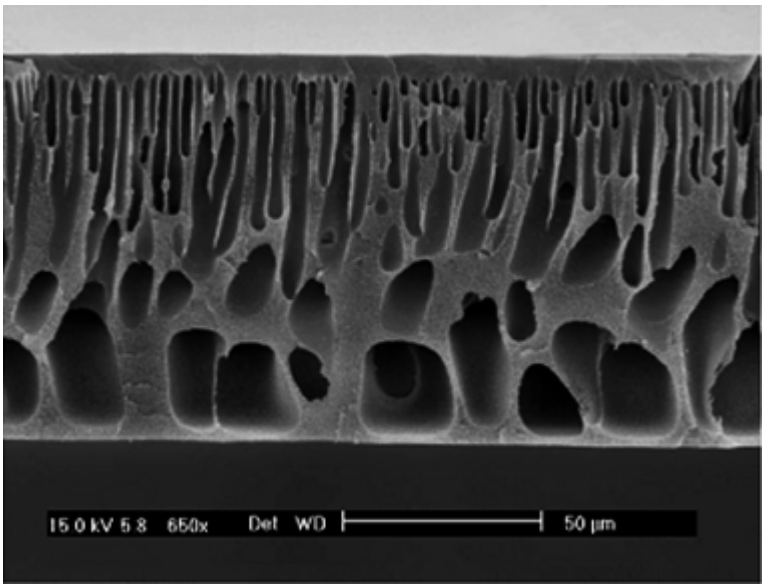


Figure 2.5: Schematic representation of the cross-section of an asymmetric membrane (Coulson et al., 2002)

Industrial membranes separation processes can be classified into few groups according to the driving force that causes the flow of permeate through the membrane (Matsuura, 1993). Following Table 2.5 classified each process in respective groups based on its driving force. Membrane with pressure difference across the membrane can be further divided

Table 2.5: Separation process using membrane in respective driving force groups

Type of driving force	**Separation process**
Pressure difference across the membrane	• Reverse osmosis • Ultrafiltration • Microfiltration • Membrane gas and vapor separation • Pervaporation
Temperature difference across the membrane	• Membrane distillation
Concentration difference across	• Dialysis • Membrane exoractitn
Electric potential difference	• Electrodialysis

into classes according to the pore sizes. There are microfiltration, ultrafiltration, nanofiltration, and reverse osmosis. The classification of membrane groups according to pore size is illustrated in Figure 2.6.

Vegas et al. (2006)investigated the feasibility of low molecular cut-off ultrafiltration and nanofiltration membrane in fractionation and purification process for oligosccharide mixture containing monosaccharides obtaine after rice husk autohydrolysis. Results of the study show that ultrafiltration and nanofiltration membrane is feasible with recovery of xylooligosaccharides as high as 99% with the lowest at 70%. More recent study by Sjöman et al. (2007) showed that nanofiltration can separate xylose from glucose is possible to a limited extent. Further review of nanofiltration is discussed in Section2.6.

2.6 Nanofiltration

Nanofiltration is a filtration process employing size exclusion membranes with pore size of 1-10 nm. Nanofiltration has advantage of low operation pressure, and high permeates flux. Nanofiltration is capable of separation of charged and uncharged substance. In this study, glucose and xylose are uncharged substance. Separation of uncharged substances mainly based on the differences in molecular sizes and diffusivities (Boussu et al., 2008).