A REMOVAL OF IMPURITIES USING HYBRID MEMBRANE FROM POME (PALM OIL MILL EFFLUENT)

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A thesis submitted in fulfillment for the award of the Degree of Bachelor in Chemical Engineering (Gas Technology)

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NOVEMBER 2010

ABSTRACT

Malaysia is the largest producer and exporter of the palm oil covering 49% of world production and 58% of total world exports. Unfortunately, this important economic activity generates an enormous amount of liquid effluent or palm oil mill effluent (POME). The palm oil mill effluent can gives detrimental effects on the environment since the aerobic digestion by natural decay of POME using ponding technique can release a large amount of greenhouse gas such as methane and carbon dioxide. This conventional technique by ponding is not feasible anymore because of the limited space. New techniques of treating the POME using membrane have been developing. This research will discuss on removing the gas contains in POME using hybrid membrane, remove the impurities including COD, BOD and suspended solid contains in POME (Palm oil Mill effluent) using hybrid membrane process. Several pretreatment procedures applied before using membrane treatment such as centrifuge and vacuum pump to remove most of the suspended solid in POME. This study includes analysis on COD, BOD, ph and turbidity. The results shows that the COD, BOD and the turbidity of the POME sample is reduce after each membrane and the percentage removal of impurities is by each membrane is calculated.

ABSTRAK

Malaysia adalah pengeluar dan pengeksport minyak kelapa sawit terbesar meliputi 49% penghasilan dalam dunia dan 58% jumlah keseluruhan eksport dunia. Malangnya, aktiviti ekonomi yang penting ini menghasilkan jumlah sisa buangan cecair atau sisa buangan kilang kelapa sawit yang sangat besar. Sisa buangan kilang kelapa sawit ini boleh menyebabkan kesan yang akan menjejaskan alam sekitar memandangkan penguraian dengan udara melalui pereputan semulajadi sisa buangan kilang kelapa sawit ini yang menggunakan kaedah kolam akan membebaskan gas rumah hijau yang banyak seperti gas metana dan karbon dioksida. Kaedah konvensional yang mengguna pakai kolam ini tidak lagi munasabah kerana ruang yang terhad. Kaedah terbaru yang sedang membangun bagi merawat sisa buangan kilang kelapa sawit ini adalah menggunakan membran. Penyelidikkan ini membincangkan tentang penyisihan gas yang terkandung dalam sisa buangan kilang kelapa sawit menggunakan membran hibrid dan penyisihan bendasing termasuk COD, BOD dan pepejal terampai yang terdapat dalam sisa buangan kilang kelapa sawit menggunakan sistem hibrid. Beberapa kaedah pra rawatan telah digunakan sebelum menggunakan rawatan membran seperti centrifuse dan pam vakum untuk menyisih kebanyakkan pepejal terampai dalam sisa buangan kilang kelapa sawit. Penyilidikkan ini juga termasuk analisis terhadap COD, BOD, pH dan kekeruhan. Keputusan menunjukkan COD, BOD dan kekeruhan sisa buangan kilang kelapa sawit dapat dikurangkan selepas setiap rawatan menggunakan membran dan peratusan penyisihan bendasing oleh setiap membran juga dikira.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

POME	Palm Oil Mill Effluent
COD	Chemical Oxygen Demand
BOD	Biochemical Oxygen demand
MF	Microfiltration
UF	Ultrafiltration
NF	Nanofiltration
RO	Reverse Osmosis
GHG	Greenhouse Gas
CPO	Crude Palm Oil
MPOB	Malaysian Palm Oil Board
DOE	Department of Environment
DOM	Dissolve Organic Matter
TFC	Thin Film Composite
MWCO	Molecular Weight Cut Off
N_2	Nitrogen
CO_2	Carbon Dioxide
CO	Carbon Monoxide
CH_4	Methane

CHAPTER 1

INTRODUCTION

1.1 Background of study

Palm oil production is one of the major industries in Malaysia and rapidly growing and quickly becoming an important agriculture-based industry in Malaysia. Malaysia ranks one of the largest productions in the world where the total production of crude palm oil in 2008 was 17,734,441 tonnes (Wu et.al, 2010). However, the large amount of the production of this palm oil resulting even larger amount of palm oil mill effluent (POME). In year of 2008, 44 million tones of POME were generated in Malaysia (Wu et.al, 2010) .The palm oil industry in Malaysia had identified that, the major factor that contributing towards the greenhouse gas is from palm oil mill wastewater treatment system. The main practice of treating POME is by using ponding and or open digesting tank systems (Yacob et.al, 2005). This system allowing the greenhouse gas such as CO_2 and CH_4 contained in POME freely being released into the atmosphere and causing a detrimental effects to the environment. The end products of the anaerobic digestion of POME are a mixture of biogas, 65% CH_4, 35% CO_2 and small traces of H_2S. CH4 and CO2 are classified as major contributor in greenhouse gases issue.

Many techniques had been used to remove gas such as N_2, CO_2, CO, NO_X, SO_2, H_2S and C_XH_Y. They include scrubbers, bio-filters, incinerators, absorbers, and ozonation processes. Several dissolved gases concern the water treatment industry. The most common are oxygen, carbon dioxide and hydrogen sulfide. These gases exist naturally in many water supplies. Removing, adding or controlling the dissolved concentration of these gases depend on the water treatment user's pure water requirements. Removing these gases prior to, or during ion exchange demineralization, can have a significant impact on operating performance and efficiency.

Nowadays, Membrane separation process used in water treatment minimizes waste and pollution unlike coagulation-clarification and ion exchange. It is becoming the technology of choice for making potable water around the world desalination, reuse of municipal water, wastewater reclaim and recycle as well as for pollution control treatment and zero discharge.(Rajindar,2006). Membrane separation in wastewater treatment has been widely used and has successfully proven its efficiency in various types of industries and successfully reduced the COD value to 90% using an organic ultra filtration (UF) membrane for olive mill washing water and RO to treat vegetable oil industry effluent with a resulting high rejection of TDS (99.4%), COD (98.2%) and also complete rejection of color and BOD (Ahmad et. al,2005).

Due to membranes high performance of treating wastewater, it is essential to refine flue gases from palm oil mill effluent which is one of the major industrial polluting effluents in Malaysia. This research introduces hybrid membrane as a way to separate flue gases from palm oil mill effluent because hybrid systems represent a promising class of materials because they can potentially be used to control and obtain the appropriate ratio between hydrophilic and hydrophobic domains in order to have sufficient proton conductivity, mechanical strength and morphological stability simultaneously (Ahmad et al, 2010). Hybrid membrane systems also reduce operating costs and environmental pollution, and make the overall process becoming more efficient. (Rajindar,2006)

1.2 Problem Statement

Effluent discharge from palm oil industries currently causing a lot of greenhouse gas such as CH_4 and CO_2 emit into the atmosphere and causes harmful effect to the environment. CH_4 and CO_2 are known to be the main contributor to global warming. Furthermore, CH_4 is reported to be 23 times more harmful than CO_2 as greenhouse gas. Majority of flue gases contains in Palm oil mill effluent (POME) is CO_2 and CH_4. Palm Oil Mill Effluent is not only contains a high amount of green house gases but also contains a high amount of impurities which can harm the environment especially the ecosystem of river where it being discharged. So, the efficient treatment of impurities such as COD, BOD, and suspended solid in POME is very crucial before it being release into the river course.

Another problem faced by the palm oil industries is the limitation space for treatment facilities. Conventional technique for POME treatment is by ponding where it needs a lot of pond considering of the high production of palm oil will produced high amount of POME. Series of anaerobic and facultative ponds is use until it meets the required standards. This conventional ponding process has been an effective method to reduce the biological and chemical constituents of POME. This method, even though simple, reliable, required less energy and cheaper but it can generate large amounts of sludge, required longer time and takes up large land areas. So, in near future this type of treat process for treating POME can no longer applicable and economical because of the space constraints. Since, membrane technology can be considered as an efficient, energy saving and can provide a high performance of treating wastewater, hybrid membrane is introduce to remove most of the impurities like Chemical oxygen demand, Biochemical oxygen demand, turbidity, suspended solid and CO_2 gas in palm oil mill effluent. By using hybrid membrane system, it can increase the overall process efficiency; reduce operating costs and environmental pollution.

1.3 Objective of study

The objective of this study is to remove the impurities including COD, BOD, turbidity and CO_2 gases contains in POME (Palm oil Mill effluent) using hybrid membrane process, casting the asymmetric polyamide membrane use for the separation process and study the performance of the membranes use by analyzing the percentage removal of COD, BOD and turbidity of the sample water and observe the pH change.

1.4 Scope of study

The scopes which need to be focused in order to meet the objective are:

1) Develop the water treatment unit for the hybrid membrane treatment process.

2) Casting the asymmetric polyamide membranes.

3) Study on the performance of the hybrid membrane by analyzing and calculating the percentage removal of the COD, BOD, pH, Turbidity of the water sample and study the removal of CO_2 gas.

1.5 Significance of the study

The rationale of this research is to remove the impurities consist in POME such as suspended solid, COD, BOD, turbidity and reduce the emission of greenhouse gas (GHG) emit by POME into the atmosphere such CO_2 gas which can cause a lot more effect on the environment. Beside that, it is important to ensure the wastewater can be disposed safely in an environmentally acceptable manner because water is one of the important elements of human daily life usage in which can avoid from harmful effect towards human. The current technique to treat POME used by the Palm Oil industry in Malaysia is by using ponding technique where it will consume more spaces due to the high capacity of POME discharge from each tones production of Palm Oil. So, a clean, fast and efficient treatment technique for POME is needed near future to ensure that the space constraints can no longer be a problem and the POME can be discharge and dispose to the river safely according to the Malaysian water quality standard.

CHAPTER 2

LITERATURE REVIEW

2.1 Palm Oil Mill Effluent (POME)

The Palm Oil industry in Malaysia currently become one of the largest industrial fields and expected to be continuously increasing its production from year to year. It is good on the economic side but there are some disadvantages base on the environmentally issues. Each year, the palm oil industry contributed about 44 million tones of POME which are contains lignocellulosic wastes with a mixture of carbohydrates and oil. It is expected to be continuously increased corresponding to the increasing of the production of palm oil. It has been reported that for every tonnes of crude palm oil produced, about 2.5-3.5 tonnes of POME is generated. (Ahmad et.al, 2003)

Based on the study made by the MPOB (Malaysia Palm Oil Board) on the projection of Malaysia Palm Oil Production from 2003 to 2020, the results from the below table show an increasing of palm oil production every year. That means the POME that would be discharge from the Palm Oil Industry would also increase. Significant increases are expected in the next 10 years. On 2020, it is expected the CPO (crude palm oil) production to decrease due to the fact that total planted area is likely to increase at a slower rate too due to the constraint in land available for oil palm planting in future. As a result, new planting is expected to decrease from 258 572 ha in 2002 to 1000 ha in 2020. (MPOB, 2003)

Table 2.1 Palm Oil production projection 2003-2020

Year	Total planted areas	New planting (ha)	Immature areas (ha)	Mature areas (ha)	Crude palm oil production (t)
2000	3 376 664	110 883	434 873	2 941 791	10 842 095
2001	3 499 012	122 346	493 745	3 005 267	11 803 788
2002	3 670 242	258 572	481 935	3 188 307	11 909 298
Forecast					
2003	3 792 000	113 000	503 000	3 290 000	12 220 000
2004	4 034 000	142 000	573 000	3 462 000	13 157 000
2005	4 170 000	135 000	578 000	3 592 000	14 362 000
2010	4 522 000	46 000	130 000	4 389 000	16 964 000
2015	4 907 000	63 000	291 000	4 616 000	17 739 000
2020	4 915 000	1 000	74 000	4 841 000	1 791 900

Source: MPOB, 2003

The Palm Oil Mill Effluent (POME) is a brownish colloidal suspension, characterized by high organic content, and high temperature (70–80 °C) and it is a non-toxic compounds because no chemicals are added during the oil extraction process. (Abdurahman et.al, 2010). Based on Wah et.al, 2002, the data value of the crude oil production in May 2001 which is 985,063 tonnes of crude palm oil will med a total value of 1,477,595 m^3 of water and releases approximately 738,797 m^3 amount of Palm Oil Mill Effluent (POME) in that month alone. Fresh POME containing 95-96% water, 0.6--0.7% oil and 4- 5% total solids including 2-4% suspended solids that are mainly debris from palm fruit mesocarp generated from three main sources sterilizer condensate, separator sludge and hydro cyclone. (Ahmad et.al, 2003). The diagram below shows the typical palm oil milling process.

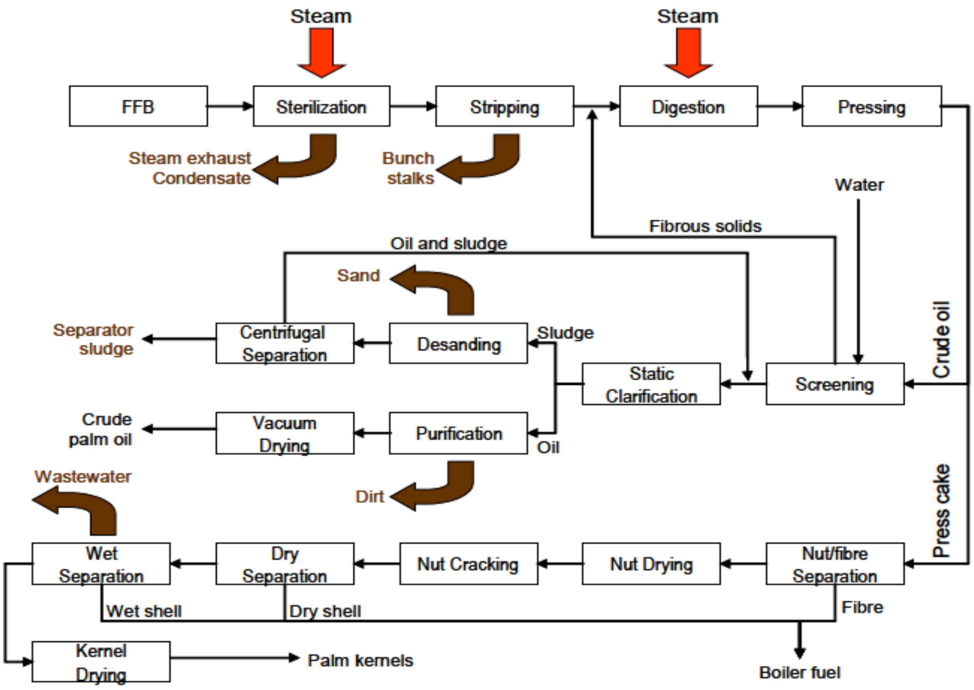

Figure 2.1: Typical Palm Oil Milling Process

Source: MPOB, 2000

Table 2.2: Characteristic of Palm Oil Mill Effluent

Parameter*	Amount
pH	4.7
Oil and grease (O&G)	4 000
Biological oxygen demand (BOD_3)	25 000
Chemical oxygen demand (COD)	50 000
Total solids (TS)	40 500
Suspended solids (SS)	18 000
Total volatile solids (TVS)	34 000
Ammoniacal nitrogen (AN)	35
Total nitrogen (TN)	750

Notes:
*All parameters in mg/l except pH
BOD_3 – after incubation for 3 days at 30 °C

Source: Shazrin and Premjit

The composition of POME in term of its chemical oxygen demand (COD) and biochemical oxygen demand (BOD) are very high. The COD values are greater than 80,000 mg/l and the acidic pH values between (3.8 and 4.5) are frequently reported. The incomplete extraction of palm oil from the palm nut can increase COD values substantially. (Abdurahman et.al, 2010). In Malaysia, there are various system for treating POME of which ponding is the most commonly practiced. In this system, the effluent is progressively degraded in a series of anaerobic and facultative ponds until it meets the required standards set by the Malaysian Department of Environment (DOE) under the Environment Quality Act (1974). It can then be discharge into the river course.

Palm oil mill effluent (POME) is an important source of inland water pollution when it is released into local rivers or lakes without treatment. So, the treatment of POME before being released into the river is crucial.

Table 2.3: POME treatment process comparison

PROCESS / DESCRIPTION	PONDING	ANAEROBIC CONTACT & AERATION	ANAEROBIC TANK & LAND APPLICATION	EVAPORATION	**MEMBRANE TECHNOLOGY**
Acreage & Facilities	Large land area	Large land area	Large land area	Modular but complicated	**Modular**
Controllability & Susceptibility to Environmental Changes	Difficult and depend on MOs	Difficult and depend on MOs	Difficult and depend on MOs	Good & None	**Good & None**
Organic Loading	Small, 0.2-0.35kg/m^3.d BOD	Small, 0.8-1.0kg/m^3.d BOD	High, 4.8kg/m^3.d VS	Moderate	**Moderate**
Sludge Generation	Large	Large	Large	None	**Little, but can cause fouling**
Energy Requirement	Minimal	High	High	High	**Moderate**
Requirement of Further Treatment	Yes	Yes	Yes	Yes	**No**
Possibilities of Resource Recovery	No	No	No	Yes	**Yes**
Operating Cost & Maintenance	Cheap & Intensive	Cheap & Intensive	Cheap & Intensive	Cheap & Moderate	**Moderate & Expertise requires**

Source: Shazrin and Premjit

Currently, various treatment processes had been design in order to achieve an efficient treatment system for this POME such as anaerobic digestion and membrane separation. Some common types of processes comparison is summarize in the table above. In this research membrane technology is highlighted as the most efficient, clean and fast technique for POME treatment.

2.2 Membrane

The word membrane is derived from a Latin word, *membrana* which means skin. There are various definitions about membrane. In general, membrane can be defined as a selective barrier between two phases, a thin barrier that permits selective mass transport or a phase that acts as a barrier to prevent mass movement but allows restricted and/or regulated passage of one or more species. So the function of membrane can be simplified as a barrier.

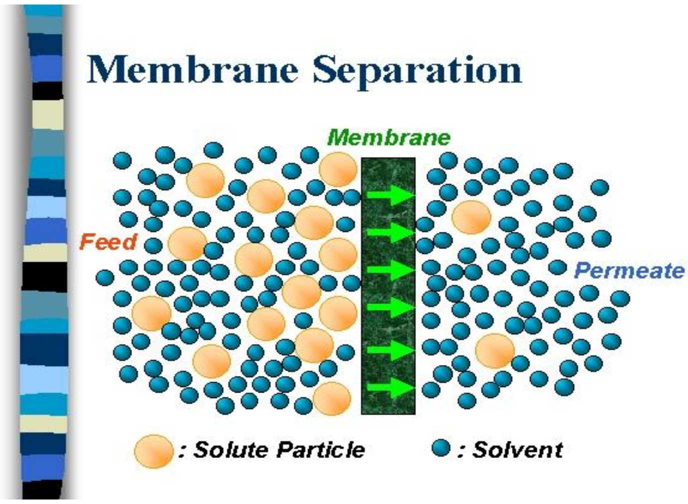

Figure 2.2: Fundamental of membrane separation

Membrane processes offer a number of advantages over conventional water and waste water treatment processes including higher standards, reduced environmental impact of effluents, reduced land requirements and the potential for mobile treatment units. Potential application areas range from sludge dewatering, waste water disinfection, suspended solids and pathogen removal from supply waters to reverse osmosis desalination. (Owen et.al, 1995)

Microfiltration (MF), ultrafiltration (UF) and nanofiltration (NF) in potable water production have increased rapidly over the past decade. MF and UF are employed to remove micro particles and macromolecules, which generally include inorganic particles, organic colloids and dissolved organic matter (DOM).

Table 2.4: Membrane Characteristic for water treatment

Membrane materials	Configuration	Pore size
Sulfonated PES	Flat sheet (cross flow)	0.7 nm
Polyslphone	Plate and frame (cross flow)	10 kDa
Polysulfone	Flat sheet (cross flow)	10 kDa
Polypropylene	Hollow fibre (dead end)	0.2 µm
PES	Flat sheet (dead end)	100 kDa
Regenerated cellulose	Flat sheet (dead end)	100 kDa
PVDF	Flat sheet (dead end)	0.22 µm
Cellulose ester	Flat sheet (dead end)	0.22 µm
PAN	Hollow fibre (cross flow)	50 kDa
Metal	Plate and frame (submerged)	0.2 µm
Composite (PA+PS)	Flat sheet (cross flow)	0.65 nm
Polypiperazine	Flat sheet (spiral wound)	360 g/mol
PES	Flat sheet (spiral wound)	2000 g/mol
Polyethylene	Hollow fibre (submerged)	0.1 µm
PAN	Flat sheet (cross flow)	110 kDa
Polypropylene	Flat sheet (dead end)	0.2 µm
Polysulphone	Hollow fibre (cross flow)	0.01 µm
Sulfonated PES	Flat sheet (cross flow)	20 kDa
PVDF	Flat sheet (dead end)	0.22 µm
Regenerated cellulose	Flat sheet (cross flow)	3 kDa
Polyamide TFC	Flat sheet (cross flow)	8 kDa
Polypiperazine	Flat sheet (cross flow)	290 Da
Polypropylene	Hollow fibre (dead end)	0.2 µm
Polysulphone	Capillary (cross flow)	40 kDa
Polysulphone	Hollow fibre (cross flow)	100 kDa
PES	Flat sheet (dead end)	0.16 µm
Cellulosic	Hollow fibre (cross flow)	100 kDa
Acrylic	Hollow fibre (cross flow)	50 kDa
Polyethylene	Hollow fibre (dead end)	0.1 µm

Source: Zularisam et al.2006

Membrane separation in wastewater treatment has been widely used and has successfully proven its efficiency in various types of industries. A membrane can be homogenous or heterogeneous, symmetric or asymmetric in structure, solid or liquid can carry a positive or negative charge or be neutral or bipolar. Transport through a membrane can be affected by convection or by diffusion of individual molecules, induced by an electric field or concentration, pressure or temperature gradient. The membrane thickness may vary from as small as 100 rnicron to several mms. A membrane separation system separates an influent stream into two effluent streams known as permeate and the concentrate. Permeation is the portion of the fluid that has passed through the semi-permeable membrane while the other is the gas concentrated flow out the reject steam.

Membrane separation has numerous industrial applications with the following advantages: (Srikanth, 2008)

- Appreciable energy savings
- Environmentally benign
- Clean technology with operational ease
- Replaces the conventional processes like filtration, distillation, ion-exchange and chemical treatment systems
- Produces high quality products
- Greater flexibility in designing systems

Table 2.5: Status of membrane process

Category	Process	Status
Developed industrial membrane separation technologies	Microfiltration, ultrafiltration, reverse osmosis, electrodialysis	Well-established unit operations. No major breakthroughs seem imminent.
Developing industrial membrane separation technologies	Gas separation, pervaporation	A number of plants have been installed. Market size and number of applications served are expanding.
To-be-developed industrial membrane separation technologies	Carrier facilitated transport membranes, piezodialysis	Major problems remain to be solved before industrial systems will be installed on a large scale

Source: M.T. Ravanchi et.al, 2009

2.2.1 Type of Membrane

1. Artificial membrane

An artificial membrane is also known as a synthetic membrane that usually use for separation tasks in laboratory and industry. The active part of the membrane which permits selective transport of material usually made of from polymers or ceramics, seldom glass or metals.

The driving force of the material transport is given by concentration, pressure, electrical or chemical gradient across the membrane. Membranes can be prepared in the form of flat sheets, tubes, capillaries and hollow fibers. Membranes are built in membrane systems like plate and frame, spiral-wound module, hollow fiber module, tube-in-shell module. Some of the most common artificial membranes are polymeric membranes. Under some conditions ceramic membranes can be utilized with advantage.

Such membranes are employed in a wide range of membrane operations, such as microfiltration, ultrafiltration, reverse osmosis, pervaporation, gas separation, dialysis or chromatography. The applications depend on the type of functionality incorporated in the membrane, which can be based on size-exclusion, chemical affinity or electrostatics. (Mulder,1996)

2. Polymeric Membrane

Polymeric membranes are membranes that take the form of polymeric interphases, which can selectively transfer certain chemical species over others. There are several mechanisms that could be deployed in their functioning. Knudsen diffusion and solution diffusion are prominent mechanisms. Polymeric membranes are of particular importance in gas separation applications. (Mulder,1996)

3. Semi permeable Membrane

A semi permeable membrane is a membrane that will allow certain molecules or ions to pass through it by diffusion and occasionally specialized "facilitated diffusion." It is also termed as selectively-permeable membrane, a partially-permeable membrane or a differentially-permeable membrane. The rate of passage depends on the pressure, concentration, and temperature of the molecules or solutes on either side, as well as the permeability of the membrane to each solute. Depending on the membrane and the solute, permeability may depend on solute size, solubility, properties, or chemistry. An example of a semi-permeable membrane is a lipid bilayer, on which is based the plasma membrane that surrounds all biological cells. (Mulder,1996)

2.2.2 Structure of Membrane

Membranes (solid synthetic membranes) can be classified from its structure. The membrane structures are important to determine the separation mechanism and the application. Membrane structure can be divided into two groups that are symmetric membrane and asymmetric membrane.

1) Symmetric Membrane

The thickness of symmetric membranes, whether it is porous or nonporous are in range of roughly from 10 to 200 µm. The resistance to mass transfer was determined by the total membrane thickness. A decrease in membrane thickness results in an increase permeation rate.

2) Porous Membrane

A porous membrane is when the particle permeate through membrane and particle separation by membrane are considered, the size of the hole, which acts as a passage for the moving particles, becomes one of the indices and a membrane with many holes bored through of about 0.005 – 1 µm in diameter.

3) Non porous membrane

Non –porous membrane has hole smaller than 0.001 µm in diameter. However, it cannot be called a hole; it is a gap between particles based on thermal vibration of the polymer which constitutes the membrane.

4) Asymmetric Membrane

An asymmetric membrane comprises a very thin (0.1-1.0 micron) skin layer on a highly porous (100-200 microns) thick substructure. The thin skin acts as the selective membrane. Its separation characteristics are determined by the nature of membrane material or pore size, and the mass transport rate is determined mainly by the skin thickness. Porous sub-layer acts as a support for the thin, fragile skin and has little effect on the separation characteristics. These membranes combine the high selectivity of a dense membrane with the high permeation rate of a very thin membrane (Mulder,1996)

5) Composites Membrane

A membrane composed of more than one kind of material is called a composite membrane. There are three group of composite membrane that is laminate membrane, coated membrane and plasma membrane. Laminate membranes are membrane that laminated with more than two kinds of membranes. A coated membrane is made by evaporating a solvent after coating the heterogeneous polymeric solution on a membrane surface. A plasma membrane is made by chemically combining heterogeneous organic substances using plasma.

2.2.3 Membrane Module

Large membrane areas are normally required in order to apply membranes on a technical scale. A module is defined as the smallest unit into which the membrane area is packed. At certain flow rate and composition, a feed is enters the module. Both the feed composition and flow rate inside the module will change as a function of distance. This is due to the ability of membrane which able to transport one component more readily than other. There are five major types of modules normally used in membrane separation processes which are plate and frame, capillary, spiral wound, hollow fiber module and tubular. (Mulder,1996)

1) Plate and Frame

This structure is a simple and can be replacing easily. The sets of two membranes are placed in a sandwich- like fashion with their feed sides facing each other. In each compartment; feed and permeate, the suitable spacer- membrane-support plates are stacked alternately.

2) Capillary

This membrane serves as a selective barrier which is sufficiently strong to resist filtration pressure. Because of this characteristics, the flow through capillary membranes can be both inside out and outside in. Its diameter is smaller compared to tubular module in the range of 0.5 to 5 mm. The chance of plugging is much higher with a capillary tube. Other benefit of capillary tubes is the packing density is much greater.

3) Spiral Wound

Spiral wound membrane module is formed using a flat sheet membrane. Spiral membranes consist of two layers of membrane, placed onto a permeate collector fabric. This membrane envelope is wrapped around a centrally placed permeate drain. This causes the packing density of the membranes to be higher. The feed channel is placed at moderate height, to prevent plugging of the membrane unit. Spiral membranes are only used for nanofiltration and Reverse Osmosis (RO) applications.

4) Hollow Fiber

Hollow fiber membrane has diameter below 0.1 µm which mean the chances of plugging is very high. The membranes can only be use for the treatment of water with low suspended solids content. The packing density of a hollow fiber membrane is very high. Hollow fiber membranes are nearly always used merely for nanofiltration and Reverse Osmosis (RO).

5) Tubular

Tubular membranes are not self supporting membrane. It is made of special kind of material and they are located on the inside of a tube. This module acts as the supporting layer for the membrane. The flow a tubular membrane is usually inside out due to the location of tubular membranes is inside a tube. This happen because the attachment of the membrane to the supporting layer is very weak. Tubular membranes have a diameter of about 5 to 15 mm. Because of this size of the membrane surface, plugging of tubular membranes is not likely to occur. A drawback of tubular membranes is that the packing density is low, which results in high prices per module.