PILOT SCALE EXPERIMENTAL INVESTIGATION OF MEMBRANE FILTRATION FOR WATER AND WASTEWATER REUSE

by

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Abstract

The increasing industrial production in Asia leads to over exploitation of water resources and discharge of significant pollution load. Water and wastewater reuse is the solution to conserve the fresh water resources of many countries. Membrane filtration is an advanced technology, which has been improving in design and decreasing in capital cost. It offers the superior quality water for reuse, than the conventional systems.

Pilot scale microfiltration membrane experiments were conducted to investigate stability and reliability of surface water and treated wastewater treatment. Bench scale chemical cleaning experiments were carried out to study on effect of chemical composition and concentration. Finally, financial analysis and reuse potential were also discussed.

These experimental results indicate that: a) Permeate flow and backwash method is the significant operating condition factors to prolong the duration time of running. b) Inorganic matters such as clay are not much effect to stability of membrane filtration, while organic matter is the significant factor for flux declined. c) Microfiltration system has a high ability to handle high turbidity and suspended solid loading but less effective for organic matters removal. Turbidity removal efficiency was 98-99 % and suspended solid removal efficiency was 100 %. In case of organic removal, COD removal efficiency for surface water and treated wastewater was 40-70 % and 65-80 %, respectively. d) The combination of caustic and oxidant is the most effective method for this particular surface water and treated wastewater. There is a threshold concentration for both chemical reagents, which the excessive concentration will not significantly improve in the flux recovery. The threshold concentration for NaClO was between 200-400 ppm for both feed water. Increase of NaOH concentration from 0.075 N to be 0.15 N was insignificant flux recovery improving for surface water but in case of treated wastewater; flux recovery improving was 20-25 %. e) This membrane filtration system was found to be an attractive economic alternative to conventional treatment process. Product water was better in quality and less in problem of disinfection-by-products and disinfection-resistant pathogens, than the conventional treatment process. The system has a potential to widely reuse in all application especially potable water and industrial activities reuse.

Table of Contents

Chapter **Title** **Page**

1 Introduction

2 Literature Review

List of Figures

List of Tables

List of Abbreviations

BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
DBPs	Disinfection By Products
DO	Dissolved Oxygen
Kwh	Kilowatt · hour
MF	Microfiltration
MWCO	Molecular Weight Cutoff
NOM	Natural Organic Matter
ppm	Part Per Million
R_{mo}	Initial Membrane Resistance
TMP	Transmembrane Pressure
TOC	Total Organic Carbons
TSS	Total Suspended Solid
UF	Ultrafiltration
US EPA	United States Environmental Protection Agency
WWTP	Wastewater Treatment Plant

Chapter 1

Introduction

1.1 General

Thailand is a newly industrialized country and growth in number and capacity of industries is constantly increasing especially in Bangkok Metropolitan Area and surrounding provinces. ESCAP (1991) reported, that the industrial sector in Thailand is a relative small user of water compared to agriculture, which uses about 30 times the amount of water per unit of GDP than industry does. The growth in industrial water use is normally expected to continue with an annual rater of about 8 to 10 percent, while the growth in agricultural water use is leveling off.

The rapid industrial growth has caused rapid population growth and urbanization, leading to increased potable water demand and consequently increasing the volume of wastewater generation. In 1996, the industrial water demand including the commerce, in Bangkok, was 421 million m^3 (McIntosh and Yniguez, 1997). The current trend of use of the freshwater resources and discharge of high-polluted wastewater to the receiving bodies are not sustainable development. Many problems of environment are multiplying in both amount of associated problems and potential for environmental destruction. Therefore, it is necessary to find proper ways to solve these problems, because it is impossible to curtail the industrial development, especially in Thailand.

Construction of additional storage such as dams can solve problem of water shortage, but costly and not a sustainable approach. So finding out a sustainable and economical method is imperative, and the reuse of wastewater reclamation is one of the ways to solve this problem.

Reuse of wastewater reclamation will reduce the potable water demand significantly and also get economic benefits because of reducing the cost of potable water and reducing the cost of disposal of sewage charges. Moreover, it will abate pollution in receiving bodies. Visvanathan and Cippe (2000) reported, that 60 to 80 percent of the industrial water demand is used for cooling processes, and it does not require high water quality such as domestic water supply. This represents a real potential for reuse and recycling of treated wastewater. So, the reuse of wastewater reclamation is the way towards the sustainable development.

The conventional approach to accomplish the reuse of wastewater is by treatment schemes such as multimedia filtration, carbon adsorption, ozonation, etc. on secondary effluents. However these conventional technologies face certain difficulties like cost, area requirement, operation problems, unstable product water quality due to load fluctuations etc. (Parameshwaran and Visvanathan, 1998). Therefore, an effective way of reuse of wastewater needs to be developed.

Membrane filtration is one of the techniques used for the solid-liquid separation and is currently gaining popularity in water and wastewater treatment (Ben Aim and Vigneswaran, 1988). As advancements in membrane filtration technology become available, many facilities are finding it profitable to recover chemicals, product, and even water from wastewater that had been previously discharged to the sewer. Improvements in design and decreasing costs of these systems have made possible a multitude of applications for this technology (Still, 1998).

Applications for membrane technology fall into three general categories: chemical process, waste treatment and water purification. Water reuse via membrane separation would generally be expected to come from waste treatment applications (Paulson and Jondahl, 2000). When membrane filtration is employed, the quality of reuse of wastewater might be near potable quality water and might apply for industrial applications such as boiler feed water.

Therefore, it is important to identify the water and wastewater reuse potentials of membrane filtration including financial analysis for the industrial sector, which will significantly help to conserve the water resource of the country.

Fouling is a major problem in all membrane operations, which affect to decrease of permeate flux over a period of time. As the concentration of foulant materials accumulates on the membrane surface, the loss of flux will continue to increase. Backwashing the membrane is the routine method for removing these materials. However, when foulants can no longer be removed from the membrane surface by backwashing, chemical cleaning is required. The cleaning of large membrane systems is an expensive and time-consuming. The current approach to cleaning membrane involves guesswork and trial-and-error, (Davis, 2000). Currently, practices of chemical cleaning are mostly based on recommendations from membrane manufacturing, which are typically recommended and some cleaner are proprietary, (Liu et al., 2000).

Different of type and concentration of fouling materials in water and wastewater have caused in different of chemical cleaning procedure. Chemical cleaning is an intregral part of membrane process operation that impact on the performance and economic of membrane processes. Hence to minimize the membrane fouling problems, chemical cleaning bench scale experiment need to be carried.

Natural Organic Matter, NOM, is a major factor of membrane fouling. As a heterogeneous mixture, NOM represents a complex solute that interacts with membrane surface and pores. The important characteristics that affect its interactions with membranes include molecular weight distribution, hydrophobic (aromatic), hydrophilic (aliphatic) character and (acidic) functional group content, (Amy and Cho, 1999), which each fractions of organic matter might influence in the different rate declining of membrane flux.

Therefore, fractionation of organic matter from water and treated wastewater is needed to analyze that which part is the most effect to flux declined and can also use this information to identify proper pretreatment and get better operating condition for membrane filtration.

1.2 Objectives of the study

1. To study the treatment efficiency, long-term reliability and stability of membrane filtration system by conducting pilot scale experiments.
2. Compare efficiency and optimum operating conditions for two types of feed water namely: surface water and treated wastewater.
3. To study effects of cleaning chemical composition and concentration for different types of feed water.
4. To make a financial analysis of membrane installation for reuse water and wastewater.

5. To investigate the potential of reuse of surface water and treated wastewater by membrane filtration in view of reuse applications for industrial process water.

1.3 Scope of the study

1. The experimental runs were conducted in two different scales:
    1.1. Bench Scale Experiments: To understand the membrane fouling mechanisms and membrane cleaning operation solution.
    1.2. Pilot Scale Experiment: To study for long-term operational stability of the system.
2. Two different feed water were used in the experimental runs:
    2.1. Surface water reuse experiment: Water as influent from AIT pond.
    2.2. Treated wastewater reuse experiment: Treated wastewater as influent from AIT wastewater treatment plant.
3. Pilot scale experiment was long-term experiment as automatic run that was run first at AIT pond for 4 months, and then at AIT WWTP for 2 months.
4. The results of bench scale experiments were used for supporting pilot scale experiment.

Chapter 2

Literature Review

2.1 Characteristic of Surface Water

The wide range of pollutants discharged to surface waters can be grouped into broad classes, as shown in Table 2.1. Domestic sewage and industrial wastes are called *point sources* because they are generally collected by a network of pipes or channels and conveyed to a single point of discharge into the receiving water. Domestic sewage consists of wastes from homes, schools, office buildings, and stores. The term municipal sewage is used to mean domestic sewage into which industrial wastes are also discharged. In general, point source pollution can be reduced or eliminated through waste minimization and proper wastewater treatment prior to discharge to a natural water body. Urban and agricultural runoff are characterized by multiple discharge points. These are called non-point sources (Davis and Cornwell, 1998). Most of the water in a lake or river comes from somewhere in the watershed. Pollutants often attach to soil and flow with runoff that drains to lakes and ponds. These pollutants include bacteria, fertilizers and other chemicals that harm water quality. The origin of non-point source pollution or polluted runoff is more difficult to pinpoint because it can originate from anywhere in the watershed. It can come from many sources including over-fertilized lawn and fields, failed septic systems, automobile oil and other pollutants on paved areas and in roadside drainages. With nearly all point source pollution eliminated, non-point source pollution presents the greatest threat to water quality. The non-point sources of contribute most of the contaminants found in surface water (DEP, 2000)

Table 2.1 Major pollutant categories and principal sources of pollutants

	Point sources		***Non-point sources***	
Pollutant Category	***Domestic Sewage***	***Industrial Wastes***	***Agricultural Runoff***	***Urban Runoff***
Oxygen-demanding material	x	x	x	x
Nutrients	x	x	x	x
Pathogens	x	x	x	x
Suspended solids/sediments	x	x	x	x
Salts		x	x	x
Toxic metals		x		x
Toxic organic chemicals		x	x	
Heat		x		

Source: Davis and Cornwell (1998)

Algae can be great nuisance in surface waters because, when conditions are right, they will rapidly reproduce and cover streams, lakes, and reservoirs in large floating colonies called blooms. Algal blooms are usually characteristic of what is called a eutrophic lake, or a lake with a high content of the compounds needed for biological growth. Because effluent from wastewater treatment plants is usually high in biological nutrients, discharge of the effluent to lakes causes enrichment and increases the rate of eutrophication. The same effects can also occur in streams.

The presence of algae affects the value of water for water supply because the often cause taste and odor problems. Algae can also alter the value of surface waters for the growth of certain kinds of fish and other aquatic life, for recreation, and for other beneficial uses.

One of the most important problems facing the environmental engineering profession in terms of water quality management is how to treat wastes of various origins so that the effluents do not encourage the growth of algae and other aquatic plants. The solution may involve the removal of carbon, the removal of various forms of nitrogen and phosphorus, and possibly the removal of some the trace elements, such as iron and cobalt (Metcalf and Eddy, 1991).

2.2 Characteristic of Wastewater

Wastewater is the flow of used water from a community. The characteristics of the wastewater discharges will vary from location to location depending upon the population and industrial sector served, land uses, groundwater levels, and degree of separation between storm water and sanitary wastes. Domestic wastewater includes typical wastes from the kitchen, bathroom, and laundry, as well as any other wastes that people may accidentally or intentionally pour down the drain. Sanitary wastewater consists of domestic wastewater as well as those discharged from commercial, institutional, and similar facilities. In general, the volume of sanitary wastewater generated is about 400 liters per capita. However, the range of flow usually varies from a minimum of about 20% to a maximum of about 400% of the average dry weather flow for small communities and about 200% for larger communities. Industrial wastes will be as varied as the industries that generate the wastes. The quantities of storm water that combines with the domestic wastewater will vary with the degree of separation that exists between the storm sewers and the sanitary sewers. Most new sewerage systems are separate, collect sanitary wastewater and storm wastes, whereas older combined systems collect both sanitary wastewater and storm water (Environmental Protection Branch of Canada, 1996).

Wastewater is characterized in terms of its physical, chemical and biological composition.

Physically, wastewater is usually characterized by a gray color, musty odor, a solids content of about 0.1%, and 99.9% water content. The solids can be suspended (about 30%) as well as dissolved (about 70%). Dissolved solids can be precipitated by chemical and biological processes. From a physical point of view the suspended solids can lead to the development of sludge deposits and anaerobic conditions when discharged into the receiving environment.

Chemically, wastewater is composed of organic and inorganic compounds as well as various gases. Organic components may consist of carbohydrates, proteins, fats and greases, surfactants, oils, pesticides, phenols, etc. Inorganic components may consist of heavy metals, nitrogen, phosphorus, pH, sulfur, chlorides, alkalinity, toxic compounds, etc. In domestic wastewater, the organic and inorganic portion is approximately 50% respectively. However, since wastewater contains a higher portion of dissolved solids than suspended, about 85 to 90% of the total inorganic component is dissolved and about 55 to 60% of the total organic component is dissolved. Gases commonly dissolved in wastewater are hydrogen sulfide, methane, ammonia, oxygen, carbon dioxide and nitrogen. The first three gases result from the decomposition of organic matter present in the wastewater.

Biologically, wastewater contains various microorganisms but the ones that are of concern are those classified as protista, plants, and animals. The category of protista includes bacteria, fungi, protozoa, and algae. Plants include ferns, mosses, seed plants and liverworts. Invertebrates and vertebrates are included in the animal category. In terms of wastewater treatment, the most important category are the protista, especially the bacteria, algae, and protozoa. Also, wastewater contains many pathogenic organisms, which generally originate from humans who are infected with disease or who are carriers of a particular disease (Environmental Protection Branch of Canada, 1996).

2.3 Characteristic of Treated Wastewater and Reclaimed Wastewater

Historically, the term “preliminary” and/or “primary” referred to physical unit operations; “secondary” referred to chemical and biological unit processes; and “advanced” or “tertiary” referred to combinations of all three. Advanced wastewater treatment is defined as the level of treatment required beyond conventional secondary treatment to remove constituents of concern including nutrients, toxic compounds, and increased amounts or organic material and suspended solids. Advanced wastewater treatment is also used in a variety of reuse applications where a high quality of water is required such as for industrial cooling water and groundwater recharge (Metcalf and Eddy, 1991).

The water quality parameters that are used to evaluate reclaimed wastewater are based on current practice in water and wastewater treatment. A summary of relevant water quality monitoring parameters is given in Table 2.2.

2.4 Situation of Water

Population growth and increased per capita demand, in the face of a relatively fixed supply of fresh water, has led to water shortages.

2.4.1 World Water

Of all the water on Earth, 97.5% is salt water, found primarily in the oceans. The remaining 2.5% is freshwater, almost all of which is stored in the ice caps of Antarctica and Greenland, and as fossil groundwater. Only about 0.01% of all water on earth is renewable freshwater and available for use on a sustainable basis. In reality, the world’s potential supply of freshwater has not decreased, but the pollution to which it is being subjected and the demands, which are placed on it, are increasing.

Between 1900 and 1995, world water use increased by a factor of six – more than double the rate of population growth during the same period. The world population is projected to increase from the current six billion or so to 8.3 billion in 2025. The result is already evident in the competition for water for agricultural, domestic and industrial purposes. Growing tensions over water resources are becoming a potentially explosive source of conflict. Many predict that wars of the next century will be over water, not oil or politics (Schonfeldt, 1999).

Table 2.2 Summary of Major Parameters Used to Characterize Treated Wastewater and Reclaimed Wastewater Quality

Parameter	***Significance in Wastewater Reclamation***	***Approximate Range in Treated Wastewater***	***Treatment Goal in Reclaimed Wastewater****
Organic indicators			
BOD_5	Organic substrate for microbial or algal growth	10-30 mg/L	< 1 to 10 mg/L
TOC	Measure of organic carbon	1-20 mg/L	< 1 to 10 mg/L
Measurement of particulate matter			
TSS	Measure of particles in wastewater can be related to microbial contamination, turbidity. Can interfere with disinfections effectiveness	< 1 to 30 mg/L	< 1 to 10 mg/L
Turbidity	Measure of particles in wastewater; can be correlated to TSS	1 to 30 NTU	0.1 to 10 NTU
Pathogenic organisms	Measure of microbial health risks due to enteric viruses, pathogenic bacteria and protozoa.	Coliform organisms: < 1 to 10^4/100 mL Other pathogens: Controlled by treatment technology	< 1 to 2,000/mL
Nutrients			
Nitrogen	Nutrient source for irrigation; can also contribute to microbial growth	10 to 30 mg/L	< 1 to 30 mg/L
Phosphorus	Nutrient source for irrigation; can also contribute to microbial growth	0.1 to 30 mg/L	< 1 to 20 mg/L

***** Treatment goal depends on specific wastewater reuse application
Source: Asano, (1998)

2.4.2 Asia Water

As a result of its population's rapid growth, Asia has now less water per capita (around 3,600 m^3 per year) than any other continent. Furthermore, there is a significant variability in the distribution of water resources among countries of Asia and the Pacific, from around 186,000 m^3 per capita per year in Papua New Guinea to just over 200 m^3 per capita per year in Singapore. Water scarcities will inevitably expand throughout Asia and the Pacific in the next 25-30 years. It is considered that water tends to become a limiting factor for socio-economic development in Asia and the Pacific, when water withdrawal exceeds 20 percent of annual total renewable water resources, in 1995 Thailand water withdrawal is 16 percent of annual total renewable water resources (Cippe and Visvanathan, 1999).

2.5 Wastewater Reclamation & Reuse

Water reclamation and reuse can become an attractive option for conserving and extending available water resources in this situation that many countries are today faced with the problem of providing adequate supplies of safe drinking water, in face of the rapid industrialization and urbanization.

Various terms related to wastewater reclamation and reuse was defined as the following

- **Wastewater reclamation** is the treatment or processing of wastewater to make reusable.

- **Wastewater reuse** is the beneficial use of the treated water.

- **Wastewater recycling** normally involves only one use or user, and the effluent from the user is captured and redirected back into that use scheme. This is applied predominantly to industrial applications such as in the steam-electric, manufacturing and minerals industries.

- **Direct use** is the use of reclaimed wastewater where there is a direct link from the treatment system to the reuse application. Direct reuse provides water for agricultural and landscape irrigation, industrial application, urban applications, and dual water systems.

- **Indirect use** including mixing, dilution, and dispersion of reclaimed wastewater by discharge in to an impoundment, receiving water, or groundwater aquifer prior to reuse such as in groundwater recharge.

- **Potable water reuse** refers to the use of highly treated reclaimed water to augment drinking water supplies. Although direct potable reuse is limited to extreme cases, it consists of incorporating reclaimed water in to a potable water system, without relinquishing control over the resource. Indirect potable water reuse includes an intermediate step in which reclaimed water is mixed with surface or groundwater sources prior to drinking water treatment.

- **Non-potable water reuse** includes all water applications other than drinking water supplies (Asano, 1998).

Following are some benefit of water reuse:

- Reduces demands on valuable ground water supplies, used for drinking water.
- Helps reduce pollutant loading to surface water.
- Postpones costly investment for development of new water sources and supplies.
- Recharge groundwater.
- Can save money and provide aesthetic value.

2.6 Wastewater Reuse Application and Water Quality Criteria

The increased implementation of wastewater reuse projects in various regions has facilitated the evaluation of new reuse alternatives. As treatment systems and applications are tested and design parameters are developed, technical barriers to reuse projects are reduced. Improvements in treatment process reliability, health risk assessment, and confidence in reuse systems coupled with increasing water demands and pollution control requirements have led to a general increase in the number of reuse projects.

Geographic, climatic, and economic factors dictate the degree and form of wastewater reclamation and reuse in different regions. In agricultural regions, irrigation is a dominant reuse application. In arid regions, such as California and Arizona in the U.S.A., groundwater recharge is a major reuse objective either to replenish existing groundwater resources or to mitigate salt-water intrusion in coastal areas. Industrial reuse of water varies with industries and locations. In contrast to the arid or semi-arid regions of the world where irrigation comprises a major beneficial use of reclaimed wastewater, wastewater reuse in Japan is dominated by non-potable urban uses such as toilet flushing, industrial use, and stream restoration and flow augmentation.

In developing countries, the water quality criteria for using reclaimed water reflect a complex balance between protection of public health and the limited financial resources available for public works and other health delivery systems. It is necessary to provide protection from exposure to pathogens by preventing direct consumption of crops irrigated with untreated wastewater. The degree of treatment required and the extent of monitoring necessary depend on the specific application (Asano, 1998). Therefore the overviews of water reuse applications and water quality requirements including health aspects of wastewater reuse are given in Table 2.3.

Table 2.3 Water Quality Required for Reuse

Category of Wastewater Reuse	***Treatment Goals***	***Example Applications***
Urban use		
Unrestricted	Secondary, filtration, disinfection BOD$_5$: ≤ 10 mg/L; Turbidity: ≤ 2 NTU; Fecal coliform: No detected/ 100 mL; Cl$_2$ residual: 1 mg/L; pH 6 to 9	Landscape irrigation: Parks, playgrounds, school yards; Fire protection; Construction;, Ornamental fountains; Impoundments; In-building uses: toilet flushing, air conditioning.
Restricted access irrigation	Secondary and disinfection BOD$_5$: ≤ 30 mg/L; TSS: ≤ 30 mg/L; Fecal coliform: ≤200/ 100 mL; Cl$_2$ residual: 1 mg/L; pH 6 to 9	Irrigation of areas where public access is infrequent and controlled. Golf courses; Cemeteries; Residential; Greenbelts.
Agricultural irrigation		
Food crops	Secondary, filtration, disinfection BOD$_5$: ≤ 10 mg/L; Turbidity: ≤ 2 NTU; Fecal coliform: No detected/ 100 mL; Cl$_2$ residual: 1 mg/L; pH 6 to 9	Crops grown for human consumption and consumed uncooked.
Non-food crops and food crops consumed after processing	Secondary and disinfection BOD$_5$: ≤ 30 mg/L; TSS: ≤ 30 mg/L; Fecal coliform: ≤200/ 100 mL; Cl$_2$ residual: 1 mg/L; pH 6 to 9	Fodder, fiber, seed crops, pastures, commercial nurseries, sod farms commercial aquaculture.
Recreational use		
Unrestricted	Secondary, filtration, disinfection BOD$_5$: ≤ 10 mg/L; Turbidity: ≤ 2 NTU; Fecal coliform: No detected/ 100 mL; Cl$_2$ residual: 1 mg/L; pH 6 to 9	No limitations on body-contact: lakes and ponds used for swimming, snowmaking.
Restricted	Secondary and disinfection BOD$_5$: ≤ 30 mg/L; TSS: ≤ 30 mg/L; Fecal coliform: ≤200/ 100 mL; Cl$_2$ residual: 1 mg/L; pH 6 to 9	Fishing, boating, and other non-contact recreational activities.
Environmental enhancement	Site-specific treatment levels comparable to unrestricted urban uses. Dissolved oxygen; pH Coliform organisms; Nutrients.	Use of reclaimed wastewater to create artificial wetlands, enhance natural wetlands and sustain stream flows.
Groundwater recharge	Site specific	Groundwater replenishment, Salt water intrusion control, Subsidence control
Industrial reuse	Secondary and disinfection BOD$_5$: ≤ 30 mg/L; TSS: ≤ 30 mg/L; Fecal coliform: ≤200/ 100 mL	Cooling system, make-up water, process waters, boiler feed water, construction activities and washdown waters
Potable reuse	Safe drinking water requirements	Blending with municipal water supply, Pipe to pipe supply

Source: Asano, (1998)

2.7 Membrane Filtration

Membrane filtration is the separation of the components of a pressurized fluid, effected by polymeric or inorganic membranes (generally man-made). The openings in the membrane material (pores) are so small that a significant fluid pressure is required to drive the liquid through them; the pressure required varies inversely with the size of the pores (basically classical orifice theory). There are now four commonly accepted categories or "classes" of membrane, defined based on the size of the material they will remove from the carrier liquid. Moving from the smallest to largest pore size, these are Reverse Osmosis (RO), Nanofiltration (NF), Ultrafiltration (UF), and Microfiltration (MF) (Cheremisinoff, 1995).

2.7.1 Type of Membrane filtration

For the application of membrane separation process to ordinary water treatment practice, there are some types. Table 2.4 indicates the size ranges of suspended matter in raw water and selected separation processes.

Table 2.4 Comparison operation pressure on membrane separation

Item	***Pore Size or Molecular Weight Cut-Off of Membrane***	***Driving Force (unit x 100 kPa)***
Microfiltration (MF)	Separation Particle Size > 0.01 μm	Suction Pressure >-0.6 Press Pressure <2
Ultrafiltration (UF)	MWCO 1000 ~ 300,000	Suction Pressure >-0.6 Press Pressure <3
Nanofiltration (NF)	MWCO Max. Hundreds	Press Pressure 2 ~ 15
Reverse Osmosis (RO)	MWCO Max Tens	Seawater Desalination 50 ~ 70 Brine water Desalination 4 ~ 40

Source: Ehara, (1998)

Microfiltration (MF): The purpose of microfiltration is to remove rather larger particles than the pore size. This membrane is used to remove turbid suspened solids, general bacteria, E.coli, etc. MF membrane may be manufactured from a variety of materials, including cellulose acetate, polysulfone, polythyren, etc.

Ultrafiltration (UF): Ultrafiltration uses membrane with pore sizes that are significantly smaller than 0.01 μm. UF is capable of removing colloids, bacteria, viruses, and high molecular weight organic compounds. The membrane are consequently susceptible to clogging. However, certain types of UF membrane can be backwashed. Materials for the membrane include polyester, polyacrylonitrile, cellulose acetate, etc.

Nanofiltration (NF): The recent development of generation Low Pressure Reverse Osmosis or nanofiltration membranes can effectively reject natural organic matter. The membrane is made from polymer organic compounds, aromatic polymide, polyvinyl alcohol, etc. The surface of membrane dose not have pores.

Reverse Osmosis (RO): This membrane was developed for desalination of seawater. The membrane by which it separates liquids and solids has not yet been explicated, but it thought that there is a chemical affinity between the molecules of constituent elements of the membrane solute and solvent (Ehara, 1998).

For this study, the microfiltration membrane, Microza USV 3003, is used and Asahi Chemical Industry Co.,Ltd. (1999) reported the advantages of this membrane as the following:

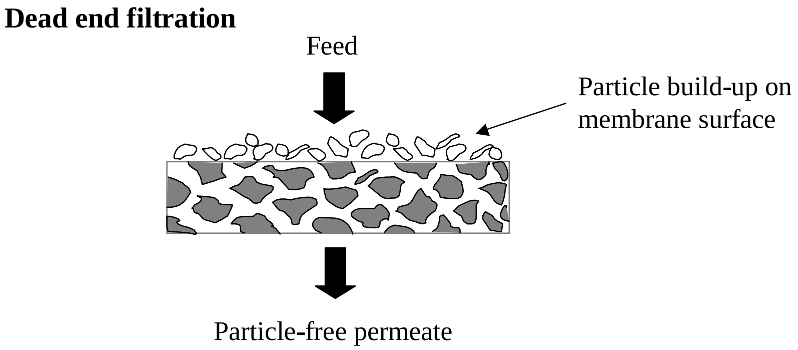
1. High Permeate Flux
    - High permeate flux membrane
    - Small installation space and high cost performance
2. Tough and reliable PVDE membrane
    - Chemical resistant membrane
    - Physical tough membrane
    - Long life of membrane
3. Sharp pore size distribution and 0.1 μm
    - Stable operation and less cleaning frequency of succeeding RO membrane

2.7.2 Dead End and Crossflow Filtration

Conventional filtration processes operate in dead-end flow. That is the familiar filtration procedure, used for filtering a precipitate with filter paper or for straining spaghetti; the flow is normal to the face of the filter. Ultrafiltration is conventionally done in cross flow, with the principal flow parallel to the surface of the filter medium, see in Figure 2.1. Microfiltration is practiced both ways. Crossflow operation is neither obvious nor difficult, and a good understanding of the reasons for its use is necessary for an understanding of membrane filtration.

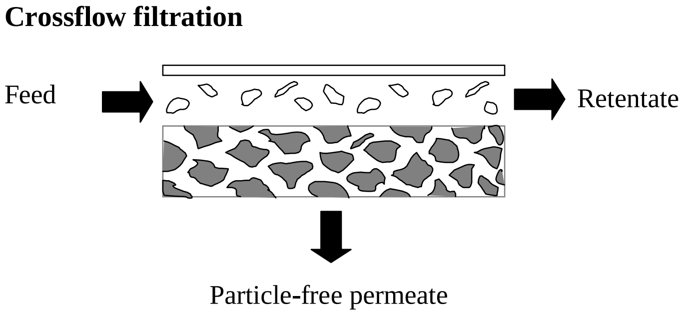
One major different in the operation of these two schemes is conversion per pass. In dead-end filtration, essentially all of the fluid entering the filter is either retained by the cake or emerges as permeate, so the conversion can approach 100%, all occurring in the first pass. For a crossflow filter, far more of the feed passes past the membrane than passes through it, and conversion per pass for a long string of filter elements in series is generally < 20%. Recycle permits the ultimate conversion to be much higher.

In crossflow, the fluid to be filtered is pumped across the membrane, parallel to its surface. Only a small fraction of the fluid actually passing across the membrane flows through it. By maintaining velocity across the membrane, material retained by the membrane is swept off its surface. Since there is little accumulation of retained material at the membrane surface, the membrane has less tendency to “blind”, and output can be maintained at a level higher than is possible for the same system operating in dead-end flow. Crossflow is advantage when the retained material is likely to plug the membrane (Noble and Stern, 1995).



Dead end filtration

(a) Dead end filtration



Crossflow filtration

(b) Crossflow filtration

Figure 2.1 Schematic of Dead end and Crossflow filtration (Noble and Stern, 1995)

2.7.3 Membrane Module

There are four major types of modules are found on the market: plate and frame, spiral wound, tubular, and hollow fiber.

Plate and Frame: These modules are made up of stacked flat-sheet membranes and support plates. Their design is derived from that of filter presses. The feed circulates between the membranes of two adjacent plates. The thickness of the liquid sheet is in the range of 0.5 to 3.0 mm. The packing density of plate-and-frame units is about 100 to 400 m^2/m^3. The plates ensure the mechanical support of the membrane and, at the same time, the drainage of the permeate. The plates may be corrugated on the feed side to improved mass transfer. Their arrangement makes it possible to bring about, in parallel and/or in series, circulation. Large unitary assemblies with a surface of up to 100 m^2 can thus be formed. Units are easily disassembled to gain access for manual cleaning or replacement of the membranes. In some of the designs, permeate is collected from individual support plates, which makes the location of faulty membranes a simple matter.

Spiral Wound: An envelope of two flat-sheet membranes enclosing a flexible porous sheet (permeate collector) is sealed on three of its edges. The open edge is connected and rolled up onto a perforated tube which carries the permeate. Several “sandwiches” are thus fastened and separated from one another by a feed-side spacer. This spacer not only maintains an open flow channel for feed flow, but also fulfills the very important function of including turbulence, thus reducing concentration polarization. The spacer may be a mesh or it may be a corrugated spacer. The feed flows parallel to the permeate tube axis.

The diameter of an element can be as much as 300 mm, and its length can be up to 1.5 m. Several elements (two to six) can be inserted into a single cylindrical pressure vessel. These are much more compact (700 to 1000 m^2/m^3) and cause a lower head loss than the plate-and-frame module. The spiral-wound module is, however, more sensitive to clogging than open-channel flat-sheet systems due to the spacer, and they cannot be used directly without pretreatment on turbid water.

Tubular: The tubular module in one form is the simplest configuration in which the membrane is cast on the inside wall of a porous support tube. These tubes have internal diameters ranging from 6 to 40 mm. Individual tubes may be placed inside stainless steel or PVC sleeves for smaller-scale units or bunched together in bundles of 3 to 151 tubes in a cylindrical housing with appropriate end plates.

In organic membranes may be formed on multichannel ceramic supports containing up to 19 parallel flow channels. Each multichannel membrane element is housed individually or in parallel sets (up to 99 elements), thus providing membrane modules with various total membrane surface areas (0.2 to 7.4 m^2).

The hydrodynamics of the flow is perfectly defined and circulation velocities up to 6 $m.s^{-1}$ are possible if a highly turbulent flow is necessary. These modules do not need fine prefiltration of the feed and are easy to clean. They are particularly well adapted to the treatment of very viscous fluids. Their main disadvantage is that they have a low packing density, thus increasing the capital cost.

Hollow Fiber: The fibers are gathered in a bundle of several thousand, even several million. Flow of the feed takes place either inside the fibers (inside-out configuration) or outside the fibers (outside-in configuration). As the packing density is inversely proportional to the diameter, these units are very compact (from 1000 m^2/m^3 in UF modules, up to 10,000 m^2/m^3 in RO modules). Operating velocities in hollow-fiber modules are normally low and modules can even be operated without recirculation (dead-end mode). Another advantages that has led to the success of UF and MF hollow fibers in water treatment is the backflushing capability resulting from the fibers being self supporting. In UF, backflush is carried out by placing the permeate under a pressure greater than the feed pressure. The change in direction of the flow through the wall of the fiber makes it possible to detach the cake of particles deposited on the surface. This cake is then transported out of the module by circulating flow through the module. During this operation it is also possible to flush the particles, which eventually block the entry of the hollow fibers. In MF, due to the larger pore dimensions, air backflush may be used (Mallevialle et al., 1996).

2.7.4 Flux

The capital and operating costs of membrane systems typically scale directly as a function of the membrane permeate flux. Where it is possible to move more water across a unit area of membrane per unit time, less membrane area will be required to provide for the design flow. This results in a lower cost for membrane modules, peripheral piping and pumps, monitoring equipment, skids, foundations, and buildings. The cost of replacing membranes as reflected in the membrane life is often the single largest component of operating cost. By reducing the amount of membrane area to be replaced, a higher permeate flux also corresponds to a lower operating cost. Thus, permeate flux and the factors that influence it are central considerations in determining membrane performance and cost.

As materials accumulate near, on, and within the membrane, they must reduce the permeability of the membrane by blocking or constricting pores and by forming a layer of additional resistance to flow across the membrane. Reductions in permeate flux over time may be substantial and represent a loss in the capacity of a membrane facility, see in Figure 2.2.

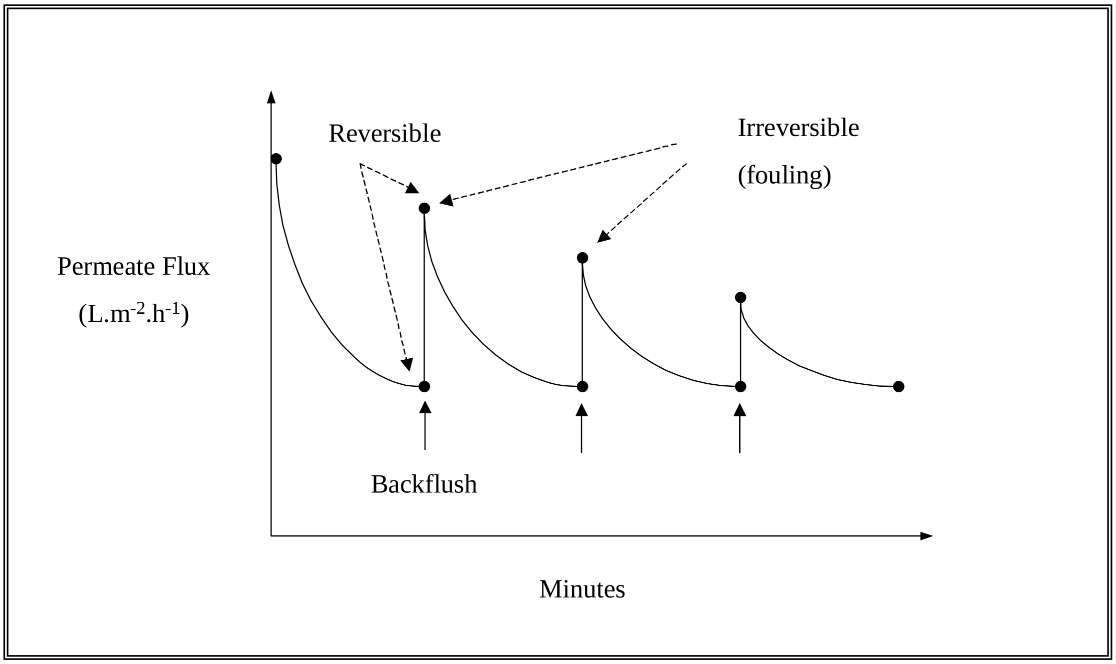


Figure 2.2 Reduction in Permeate Flux Over Time (Mallevialle et al, 1996)

2.7.5 Transmembrane Pressure

With increasing pressure the flux is increased as shown in Figure 2.3. The variation has an initial linear part, then exponential middle part and finally it becomes constant at very high pressures. For low concentrations and at modest operating pressure, the flux variation shows a linear relation with pressure. At higher operating pressure, the flux starts proportionally decreasing and finally the relationship level off. This leveling off is due to the compaction of deposit layer and densification of the membrane at higher pressure (Metcalfe et al., 1984).

Also, when particle size of a suspension is reduced, the improvement in flux obtained by raising the filtration pressure is reduced. There is a general tendency, for an equilibrium flux to establish more rapidly at lower filtration pressures. There were cases where raised filtration pressure led to increased fouling, not producing an improved filtration performance. The potential improvement to be gained by raising the pressure can be fully compensated by an increase in the flow resistance of foulants, at or near the membrane throats. When the particles in suspensions were better dispersed, the fine particles in the distribution were able to penetrate the large pores in the membrane. Because of that flux could be reduced. The results obtained with china clay of a platelet shape particles, showed that there were very little difference in the flux performance over the pressure range 0-300 kPa. This was mainly because the particles forming the cake layers were oriented in the shear field above the membrane and subsequently deposited with "faces" parallel to the membrane surface, creating a layer of low permeability (Tarleton and Wakeman, 1994).

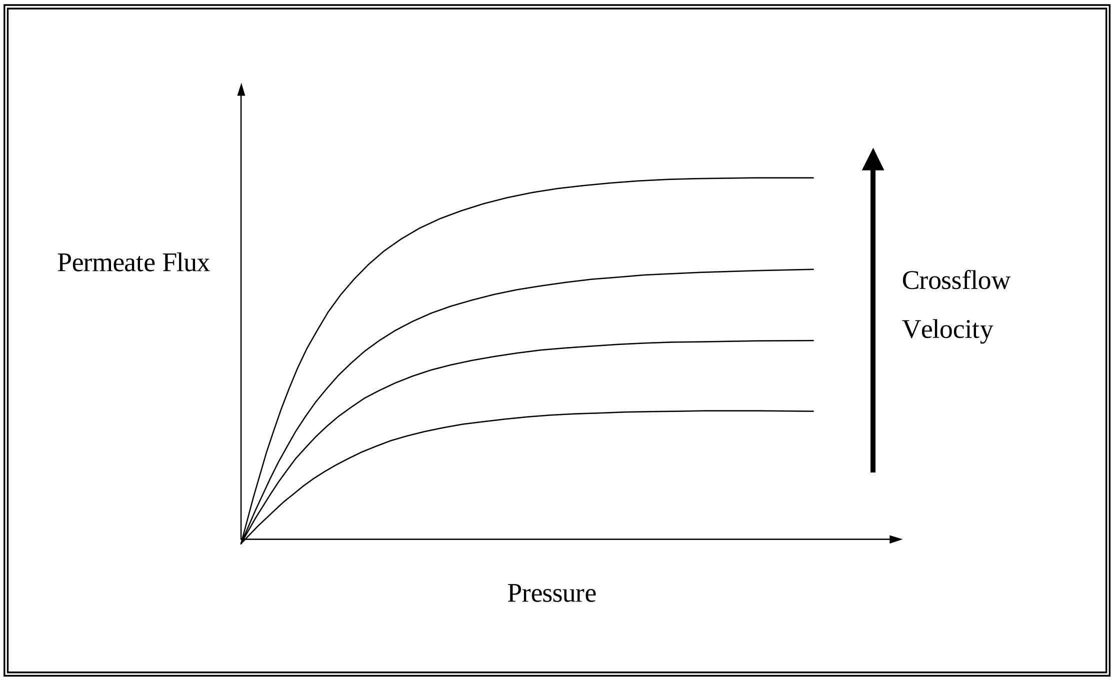


Figure 2.3 Flux-Pressure Relationship and Effect of Crossflow Velocity (Herath, 1984)

2.7.6 Type of Membrane Fouling

Fouling occurs mainly in microfiltration / ultrafiltration where porous membrane are used, which are inherently susceptible to fouling. In the case of microfiltration the flux decline can reach values of more than 90 % of the pure-water flux (Noble and Stern, 1995).

According to the type of fouling materials, four categories of membrane fouling are generally recognized. They are (a) inorganic fouling/scaling, (b) particle/colloids fouling, (c) microbial fouling, and (d) organic fouling. A brief description on the nature of fouling, relevant water quality as indicators, and control measures are summarized below for each type of membrane fouling.

Inorganic Fouling/Scaling

Inorganic fouling or scaling is caused by the accumulation of inorganic precipitates such as metal hydroxides, and "scales" on membrane surface or within pore structure. Precipitates are formed when the concentration of chemical species exceeding their saturation concentrations. Scaling is a major concern for reverse osmosis (RO) and nanofiltration (NF). RO and NF membranes reject inorganic species. Those species form a concentrated layer in the vicinity of membrane-liquid interface - a phenomenon referred to "concentration polarization". For microfiltration (MF) and ultrafiltration (UF), inorganic fouling due to concentration polarization is much less profound, but can exist most likely due to interactions between ions and other fouling materials (i.e., organic polymers) via chemical bonding. Some pretreatment processes for membrane filtration such as coagulation and oxidation, if are not designed or operated properly, may introduce metal hydroxides on membrane surface or within pore structure. Inorganic fouling/scaling can be a significant problem for make-up water of caustic solutions prepared for chemical cleaning.

Particulate/colloid Fouling

Algae, bacteria, and certain natural organic matters fall into the size range of particle and colloids. However, they are different from inert particles and colloids such as silts and clays. To distinguish the different fouling phenomena, particles and colloids here are referred to biologically inert particles and colloids that are inorganic in nature and are originated from weathering of rocks.

In most cases, particles and colloids do not really foul the membrane because the flux decline caused by their accumulation on the membrane surface is largely reversible by hydraulic cleaning measures such as backwash and air scrubbing. A rare case of irreversible fouling by particles and colloids is that they have smaller size relative to membrane pore size. Therefore, those particles and colloids can enter and be trapped within the membrane structure matrix, and not easily be cleaned by hydraulic cleaning.

Microbial/Biological Fouling

Microbial fouling is a result of formation of biofilms on membrane surfaces. Once bacteria attach to the membrane, they start to multiple and produce extracellular polymetric substances (EPS) to form a viscous, slimy, hydrated gel. EPS typically consists of heteropolysaccharides and have high negative charge density. This gel structure protects bacterial cells from hydraulic shearing and from chemical attacks of biocides such as chlorine.

Organic Fouling

Organic fouling is profound in membrane filtration with source water containing relatively high natural organic matters (NOM). Surface water (lake, river) typically contains higher NOM than ground water, with exceptions. For source water high in NOM, organic fouling is believed to be the most significant factor contributed to flux decline (Mallevialle et al., 1989; Lahoussine-Turcaud et al, 1990). Microfilters usually remove insignificant amount of organic matter, as measured by dissolve organic carbon (DOC). DOC as an indicator for organic fouling is probably neither proper nor adequate. Efforts to identify the effects of subgroups of NOM on membrane fouling have yet been able to draw definitive conclusions (Liu et al., 2000).

The effects of various operating strategies against different types of fouling are summarized in Table 2.5. As indicated in Table 2.5, chemical cleaning is an effective control strategy for all types of membrane fouling.

Table 2.5 Effects of Operating Strategies on Membrane Fouling

Type of Fouling	***Effects of Operating Strategy***			
	Hydraulic Cleaning	***Feed Concentration***	***Feed Acidification***	***Chemical Cleaning***
Inorganic	-	-	++	++
Particulate	++	-	-	++
Microbial	+	++	+*	++
Organic	-	+	-	++

Note: - No effects or have negative effects. + Some positive effects, ++ Positive effects
* in conjunction of feed chlorination

Source: Liu et al, (2000)

The mechanisms of membrane fouling are shown in Figure 2.4. Frequently, both reversible and irreversible decreases in permeate flux decline are referred to as membrane fouling, and materials in the water that produce reductions in permeated flux are collectively referred to as foulants.

The distinction between reversible and irreversible reductions in permeate flux is entirely dependent on the context in which membranes are operated and cleaned. That is to say that the process of permeate flux decline is extremely path dependent. The degree of irreversible fouling tends to reflect the “memory” of the membrane for extreme conditions it has been exposed to during operation such as the highest TMP or the worst feed water quality. A different order of addition of chemical cleaning agents (e.g., acid wash followed by base versus base followed by acid) usually produces different degrees of permeate flux recovery. Also, hydraulic-based measure to reverse permeate flux decline, such as back flushing, tend to become less effective over time, to the extent that all of the permeate flux decline would be considered irreversible by this operation. Under these conditions, chemical cleaning may be required to restore permeate flux. Thus, it is probably more practical to consider an irreversible loss in permeate flux to be the different between the permeate flux of the newly installed membrane and the permeate flux observed after applying the most rigorous cleaning procedure envisioned for a given membrane system. A loss in permeate flux that is truly irreversible, usually requiring replacement of the membrane, is sometimes termed of membrane poisoning (Mallevialle et al., 1996).

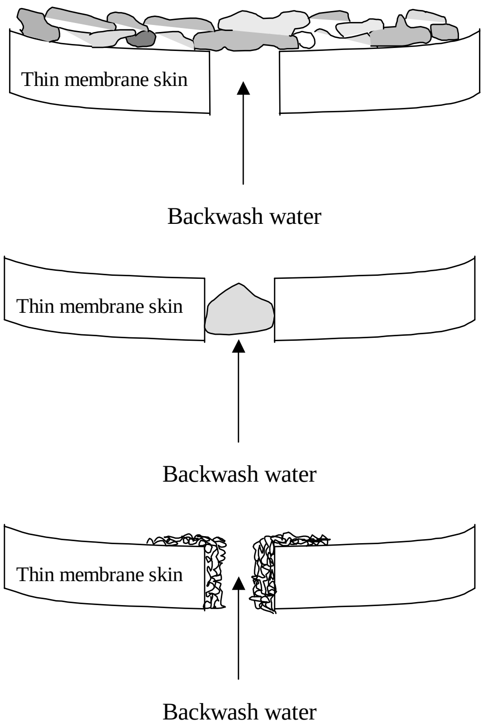


Figure 2.4 Mechanisms of membrane fouling: (a) gel/cake formation; (b) pore plugging; and (c) pore narrowing (Mallevialle et al, 1996)

2.7.7 Biofouling

Microbial growth in a water system presents two problems: it not only reduces water quality, but if left unattended, the problem can "grow" to reduce system performance and life. Biofouling can cause a decrease in product water flow rate, a decrease in driving pressure, and can contribute to corrosion of piping and housings.

It must first be understood that the presence of bacteria is inevitable, they are found in any and all water systems. Second, while they will always be present, they can be controlled. Third, a microbial contamination problem is much easier to prevent than to correct.

Biofilm Formation

If microbial levels are not controlled, they will eventually form biofilms. Established bacteria of most types found in water secrete a polysaccharide-containing slime (glycocalyx), which enhances the bacteria cell's ability to adhere to a surface, See in Figure 2.5. Bacteria grow and multiply faster when attached (sessile) than when free-floating (planktonic). Attached cells form a larger colony. The slime layer helps adhere other bacteria cells and nutrients, which float past, and also acts as a protective layer, which resists chemical penetration. This is known as a biofilm.

The size, complexity, and resistance to sanitization of the colony grows within this biofilm which is very difficult to penetrate using typical sanitizing agents. They also become a source of recontamination when sanitizing steps do not completely remove the biofilm. A single routine sanitization usually only affects the top layer of the biofilm, so viable bacteria deep in the biofilm will quickly recontaminate the system and high bacteria levels will be seen again within a few days, (Mueller and Paulson, 1997).

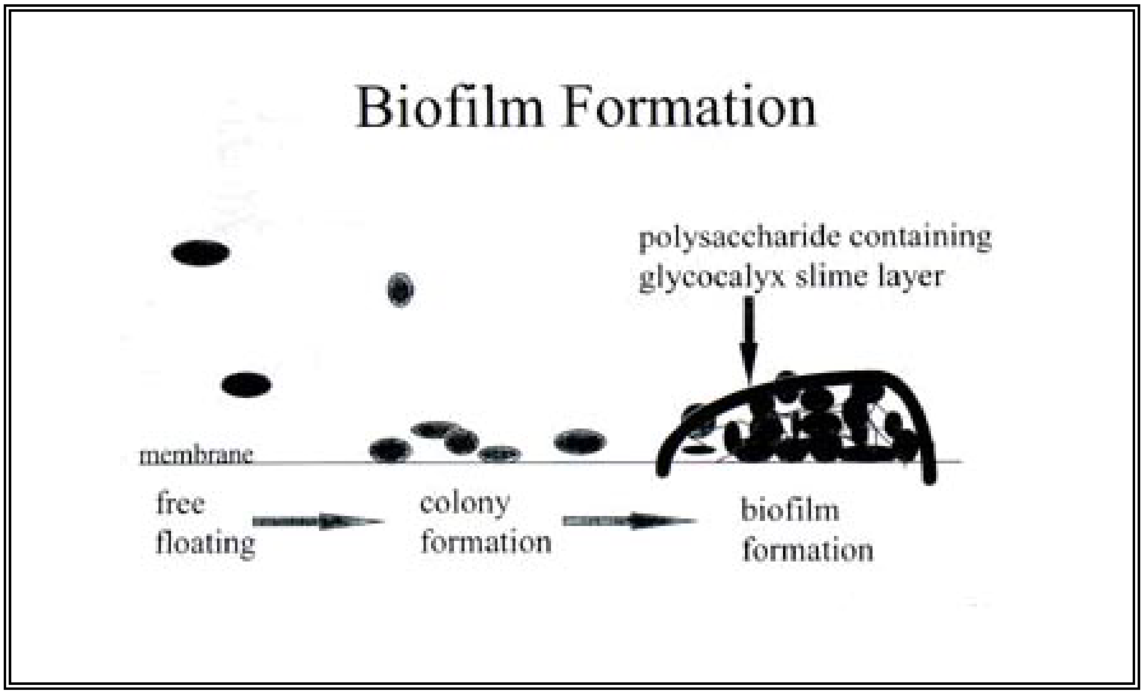


Figure 2.5 Biofilm Formations, (Mueller and Paulson, 1997).

Biofilm Removal

To destroy an established biofilm, repetitive sanitizing cycles are usually required. The first step uses a normal biocidal agent. The second step uses a high pH solution, usually sodium hydroxide, to help digest and remove the top layer of bacteria killed by the biocide. Fresh biocide is then reintroduced to the system to kill the next bacterial layer, again followed by caustic.

This biocide/caustic cycle may need to be repeated several times until the entire biofilm is removed. For a well-established biofilm, 5 or l0 cycles are commonly required.

2.7.8 Membrane Cleaning

There are two common methods for maintaining or reestablishing permeate flux after the membranes are reversibly fouled;

1. Membrane backwashing
2. Membrane chemical cleaning

2.7.8.1 Membrane Backwashing

In order to prevent the continuous accumulation of solids on the membrane surface, backwashing of the membrane is performed. Unlike conventional media filtration, the backwashing cycle takes only a few minutes. Both liquid and gas backwashing is employed with MF technology. Liquid back washing, which is usually performed for inside-out membranes, can be accomplished by two modes of operation. For most systems, backwashing is fully automatic, being initiated by either a programmable logic controller or a feedback control loop. MF systems, backwashing is performed every 30 to 60 min of operation for 1 to 3 min (Mallevialle et al., 1996). Asahi Co.,Ltd was experiment of the suspended substance removal by air scrubbing, which is shown in Figure 2.6.

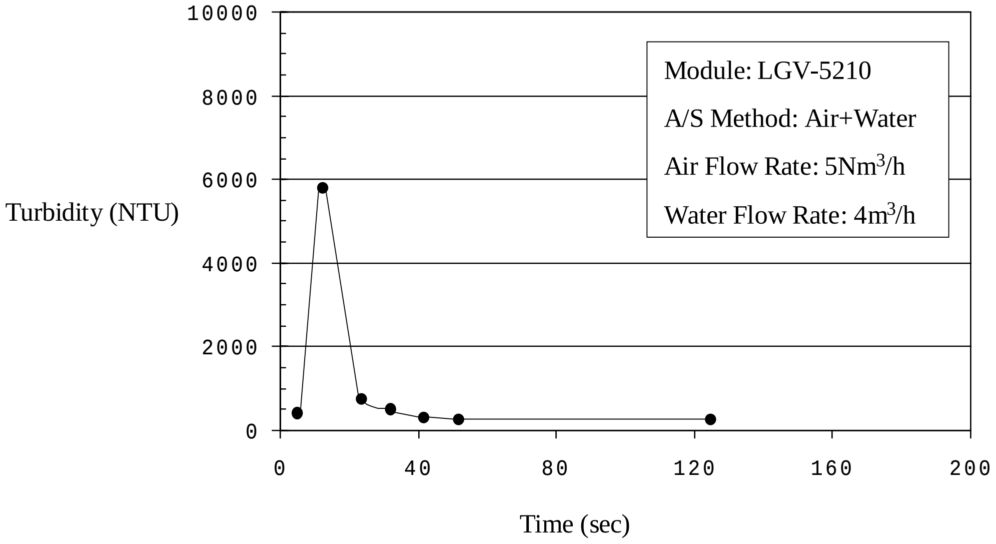


Figure 2.6 Suspended Substances Removal by Air Scrubbing (Asahi Co.,Ltd, 1999)

2.7.8.2 Membrane Chemical Cleaning

As the concentration of foulant materials accumulates on the membrane surface, the loss of transmembrane flux will continue to increase. Backwashing the membrane is the routine method for removing these materials. However, when foulants can no longer be removed from the membrane surface by backwashing, chemical cleaning is required. An example of this behavior is demonstrated schematically in Figure 2.7. After Chemical cleaning, partial or full restoration of transmembrane flux (or pressure) is achieved (Mallevialle et al., 1996).

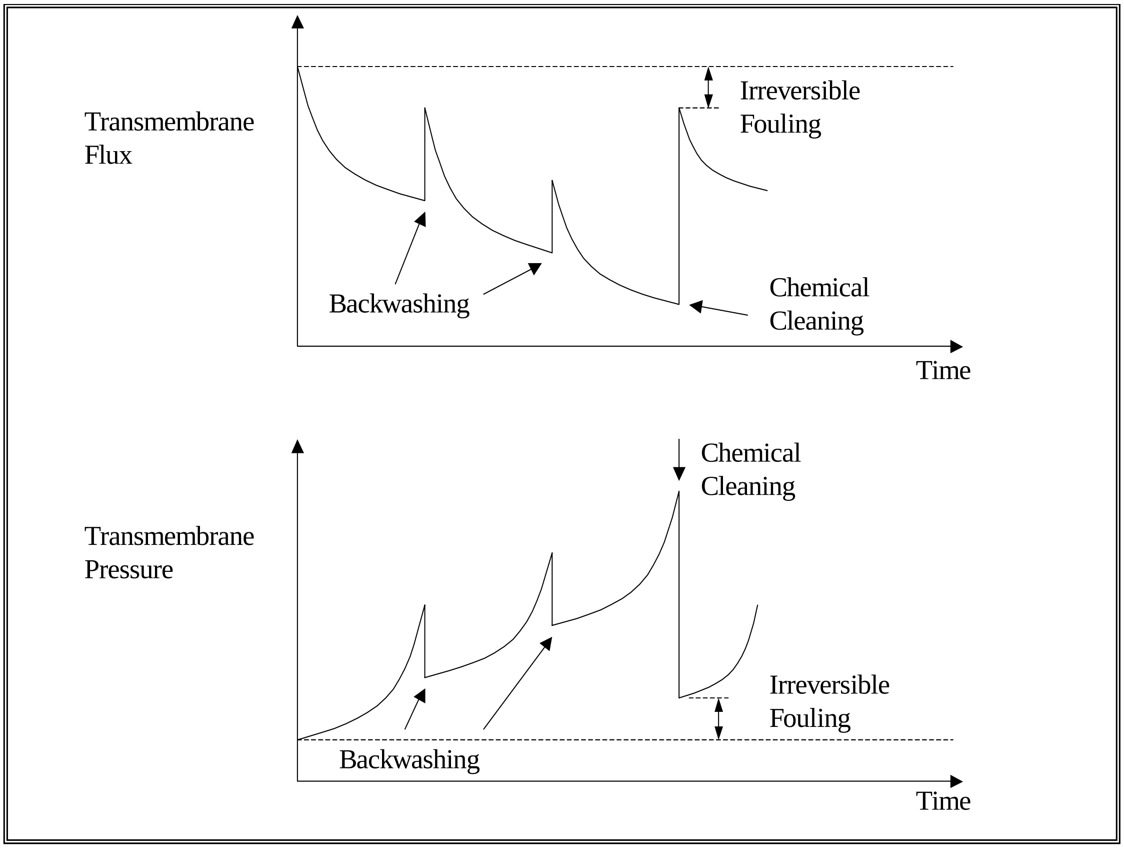


Figure 2.7 Schematic of partial restorations of transmembrane flux or pressure by chemical cleaning of MF membranes (Mallevialle et al, 1996)

2.8 Microfiltration Membrane

Microfiltration involves pressure-drive processes requiring the retention of particulates, organisms, colloids, and viruses generally in the 0.02 to 10 μm size range (greater than 300,000 molecular weight). Microfiltration membranes were developed before the advent of ultrafiltration and reverse osmosis membranes, which also operate in pressure-drive processes. Microfiltration membranes are discussed in this section with respect to types and perforamance, advantages and disadvantages, and applications (Cheremisinoff, 1995).

The market for MF membranes is increasing rapidly due to more stringent water quality regulations and scarcer water resources. As a result of market forces, many manufacturers that have focused primarily on industrial use are now placing a greater emphasis on water and wastewater applications. As shown in Figure 2.8, this membrane process is intended to replace four unit processes in conventional water treatment: rapid mix, coagulation, flocculation, and media filtration. In comparison with conventional treatment, MF is a physical process that removes contaminants primarily by sieving them from the water being treated (Mallevialle et al., 1996).

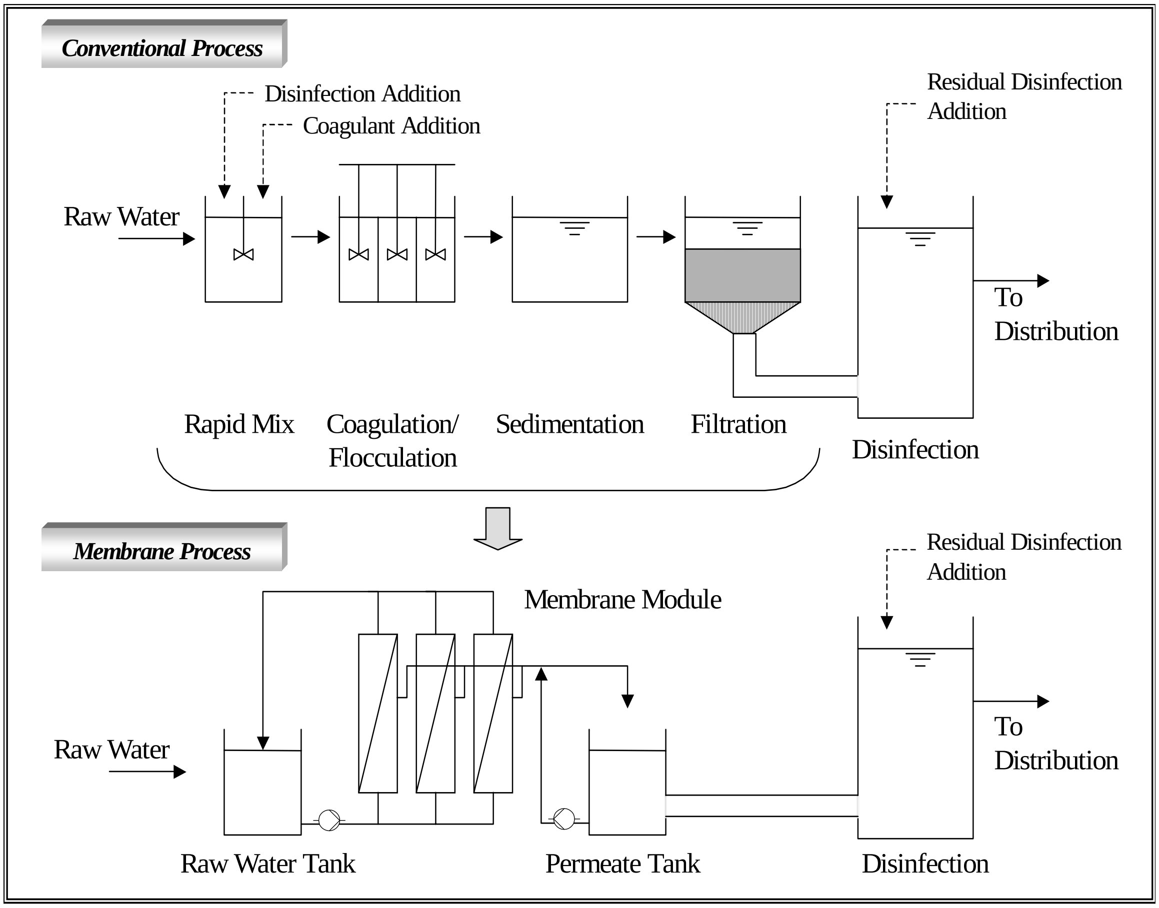


Figure 2.8 Conventional water treatment unit process replaced by MF.

2.8.1 Pretreatment & Postreatment

2.8.1.1 Pretreatment

Prefiltration: In comparison to conventional water clarification processes, where coaulants and other chemicals are added to the water before filtration, there are few pretreatment requirements for hollow-fiber systems when particles and microorganisms are the target contaminants. Prefilters are necessary to remove large particles which may plug the inlet to the fibers within the membrane module. The nominal prescreen or prefilter sizes range between 50 and 200 μm, depending on the membrane fiber inner diameter. Various types of prefilters are available such as disc filters, or for small plants, bag filters. More complex pretreatment strategies are sometimes employed either to reduce fouling or enhance the removal of viruses and dissolved organic matter (Mallevialle et al., 1996).

pH Adjustment: Adjustment of the feed water pH by chemical dosing may be required prior to membrane filtration in order to maintain the pH within the recommended operating range for the membrane material being employed. This adjustment is especially important for cellulosic derivative polymer membranes, which usually have an operating pH of 5 to 8. It should be noted that pH adjustment is not required for scaling control, since MF membranes do not remove uncomplexed dissolved ions (Mallevialle et al., 1996).

2.8.1.2 Posttreatment

MF membranes, under the most conservative conditions, appear to act as an absolute barrier to selected bacteria and protozoan cysts and oocysts. Unlike UF however, MF does not remove appreciable densities of viruses under seeding conditions. One-half to four-log removals have been observed in various studies (Coffey et al., 1993; Jacangelo and Adham, 1994). Therefore, in full-scale systems, it is necessary to complement MF with a postmembrane disinfection process.

2.8.2 Microfiltration Membrane Application

Asahi Chemical Industry Co.,Ltd. (1999) mentioned that main application fields for this MF USV are as the following:

1. Production of drinking water for public use.
2. Pretreatment of water preceding RO system in
   - Ultrapure water in semiconductor use.
   - Ultrapure water for power plant.
   - Desalination of saltwater.
3. Pretreatment of water preceding ion exchange.
4. Removal of bacteria and suspended solid in industrial water.

2.9 Case Studies of Water and Wastewater Reuse Via Membrane Technology

2.9.1 Water Treatment

Case 1: River Water Treatment for Ultrapure Water Production

The system uses an ultrafiltration membrane module and is able to treat river water in order to remove or reduce color, turbidity, permanganate consumption, and total iron below the required limits, (New Logic International, Inc, 2001). The system is presented in Figure 2.9.

2.9.2 Industrial Water Reuse

Case 1: Multi-bath Plating Rinse Water Recovery

A major West Coast wheelchair manufacturer generates a nickel and chrome plating rinse waste stream. Their manufacturing facility was located in an industrial area which had waste water discharge limitations on total dissolved solids as well as some of the particular inorganic compounds, most notably boron.

The RO machine processes the waste stream at 55 gallons per minute (gpm), returning 50 gpm of permeate (pure water) to the plant for reuse and sending 5 gpm to the evaporator for further concentration. The salt concentration in the feed to the RO unit ranges from 2,000 to 6,000 micromhos and the permeate produced for return to the plating rinse tanks ranges from 200 to 500 micromhos. Figure 2.10 is a schematic illustrating where the RO unit is located in the overall waste treatment system, (Paulson and Comb, 2001).

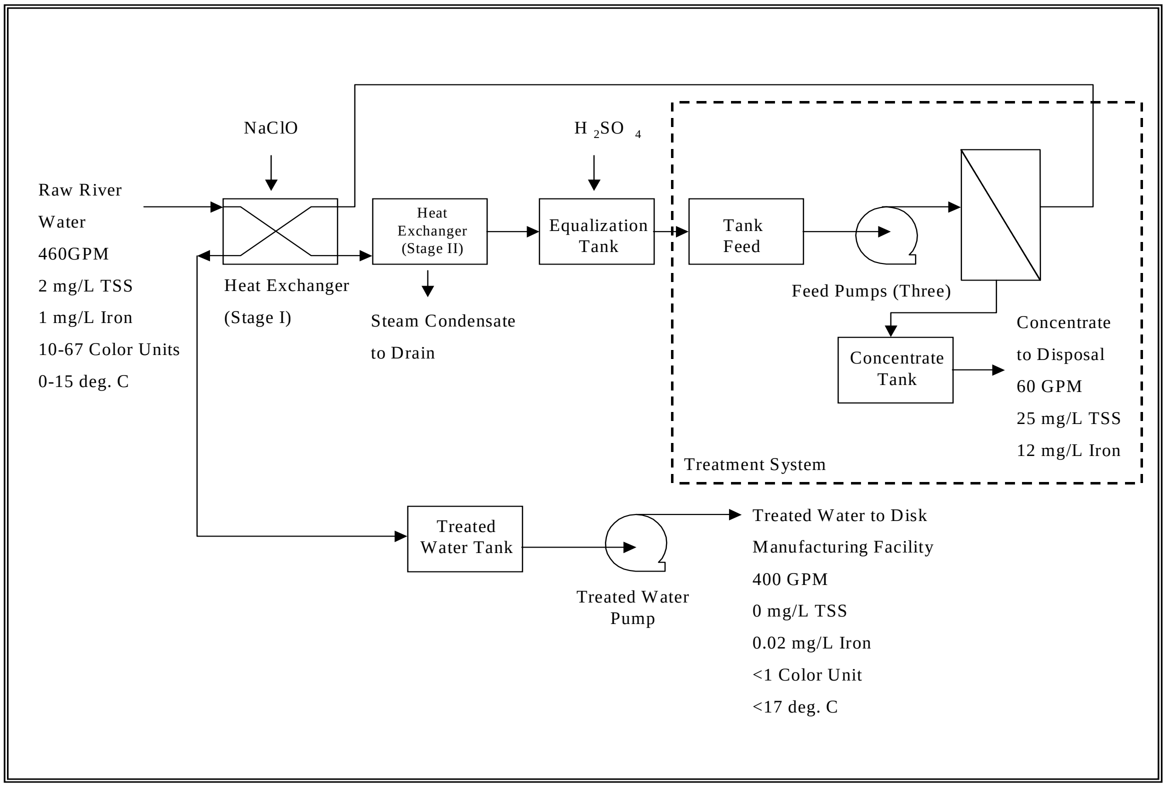


Figure 2.9 Integration of membrane filtration with Ultrapure Water Production (New Logic International, Inc, 2001)

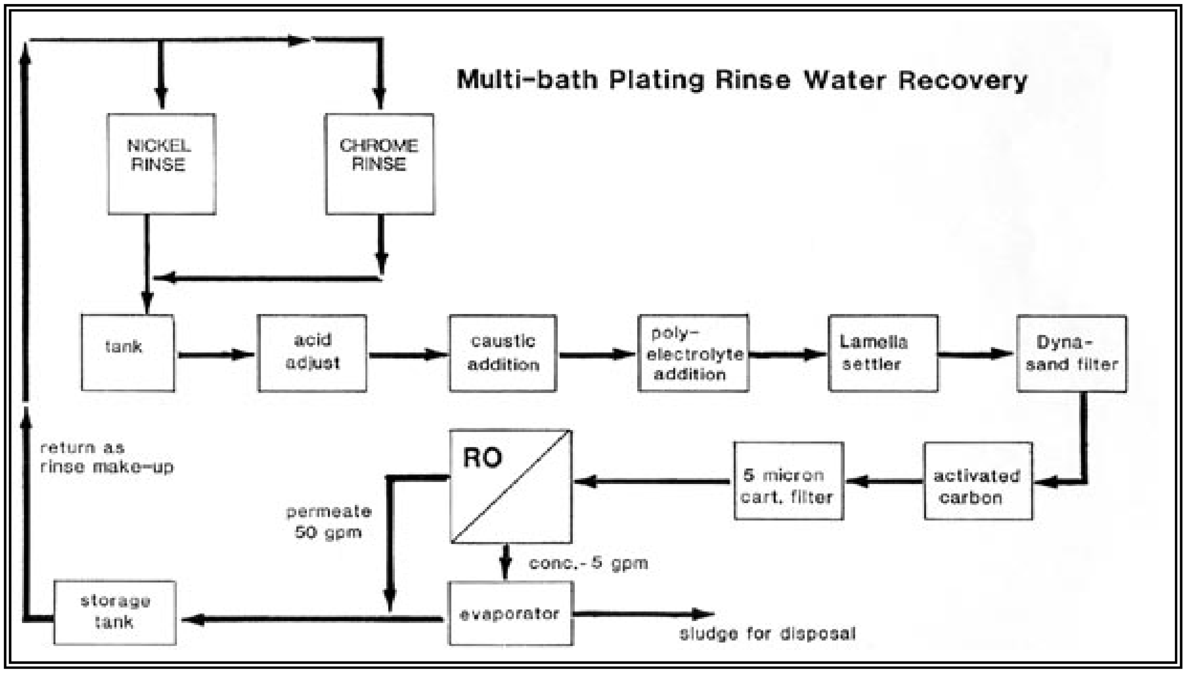


Figure 2.10 Multi-Bath Plating Rinse Water Recovery, (Paulson and Comb, 2001)

Case 2: Can Rinse Waste Water Reclaimation

The various rinsing stages that the aluminum cans must go through during the manufacturing process are major contributors to the total waste stream. This stream ends up with metal fines, cutting oils and dissolved salts, which must be dealt with as pollutants.

The waste treatment system design includes a bag filter system to remove the metal fines, followed by an ultrafiltration unit to concentrate the oily waste to a point where it can be sent to an oil stripper. Utilizing this method allows the oil to be removed from the system and recovered for use as a fuel source, aiding the overall economics of the waste water treatment system.

The permeate from the ultrafiltration unit, containing the small MW organics and dissolved salts which pass through the larger pore UF membrane, is sent to the reverse osmosis unit for concentration. The permeate from the RO unit is reused in the process as can rinse water while the concentrate is hauled away. Figure 2.11 is a system schematic showing this process, (Paulson and Comb, 2001).

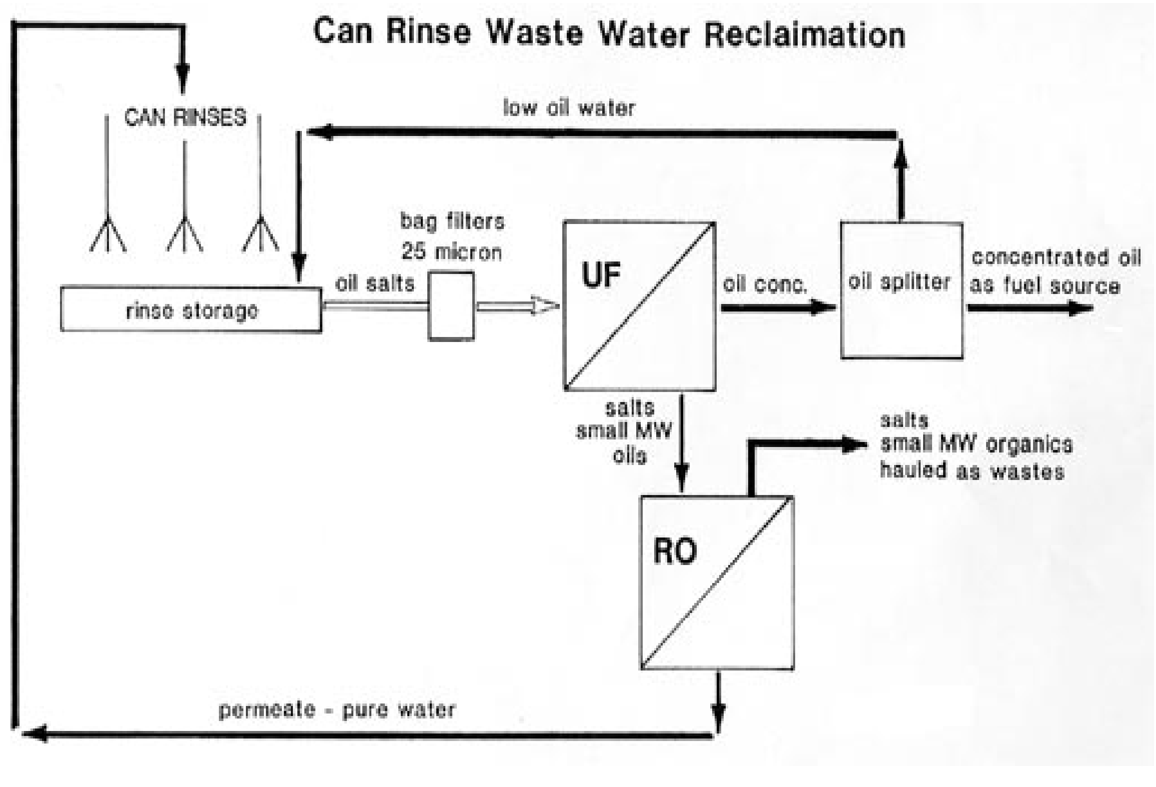


Figure 2.11 Can Rinse Waste Water Reclaimation, (Paulson and Comb, 2001)

Chapter 3

Methodology

3.1 Introduction

The concept of this experimental study is to investigate the possibility of reuse of water and wastewater by membrane filtration, which will help to conserve the water resource of the country, as presented in Figure 3.1.

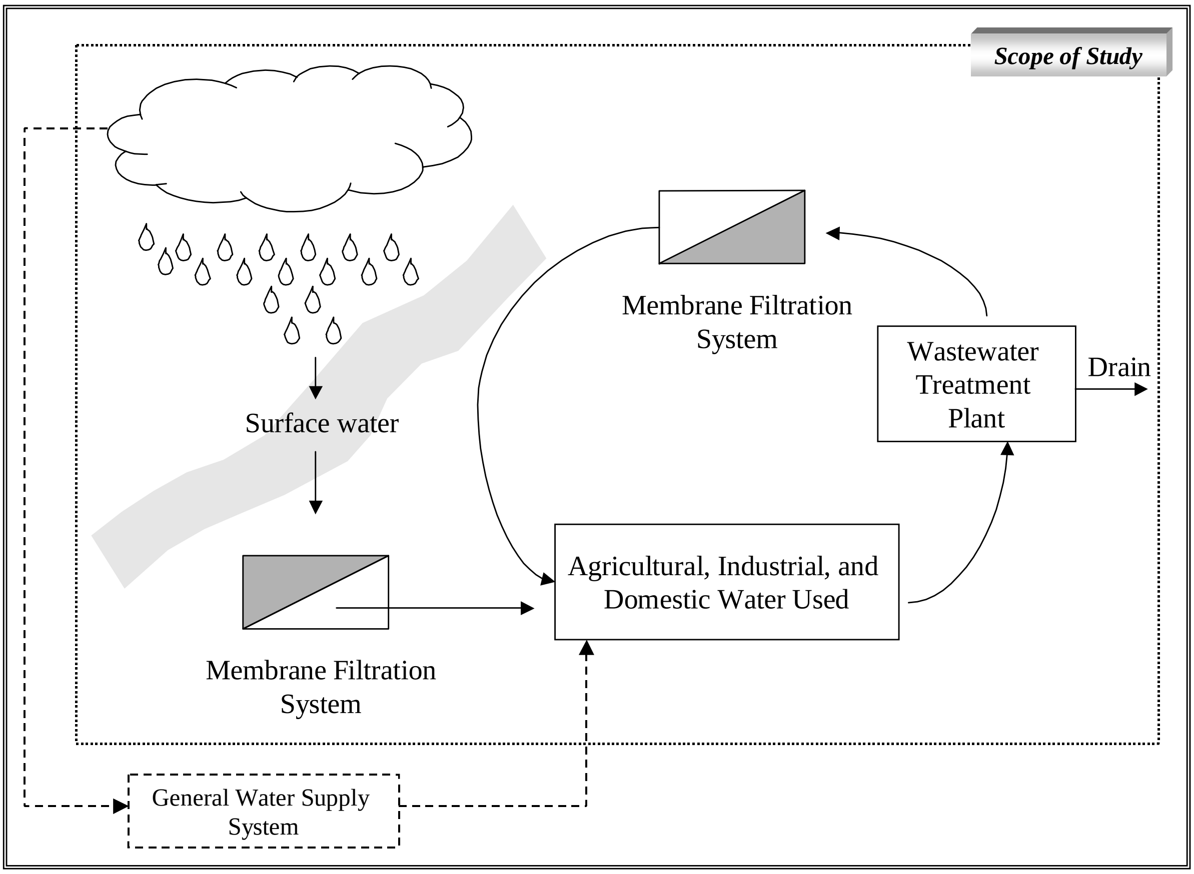


Figure 3.1 The Concept of this Experimental Study

Therefore, the pilot scale experiment was carried out for investigating the potential of reuse of water and wastewater by membrane filtration. The feed water was taken from two sources. The first source was water from AIT canal, which supposed to be water from general canals. The second source was AIT treated wastewater, which supposed to be treated wastewater from typical industries. The different feed water had different fouling and different effect to membrane system so the efficiency of membrane system was defined by significant parameters of each feed waters and methods for analysis were followed by standard method for the examination of water and wastewater of APHA-AWWA-WPCF. This experiment was run in long-term period for optimization of various operation parameters and evaluating the reliability of the membrane systems. Financial analysis was one of important factors for decision of new projects development, which was included in this research.

In this research pilot scale experiment is an application level test, which was used for studying the optimum operating condition, effect on feed water quality, and effect on permeate flux. As we known that fouling is an important factor for membrane process, hence fouling and chemical cleaning bench scale experiment, which is a fundamental level test, was also conducted to understand the membrane fouling mechanisms and membrane cleaning operation solution.

3.2 Type of Experimental Runs

The experimental runs were conducted in the different scales, which were:

1. Bench scale experiments were done to understand the membrane fouling mechanisms and membrane cleaning operation solution.
2. Pilot scale experiments were done to study for long term operational stability of the system.

The bench scale experiments were run parallel with the pilot scale experiment, which was objective to use the bench scale experiment results for supporting the pilot scale experiment. The overall experimental strategy of this research is shown in Figure 3.2.

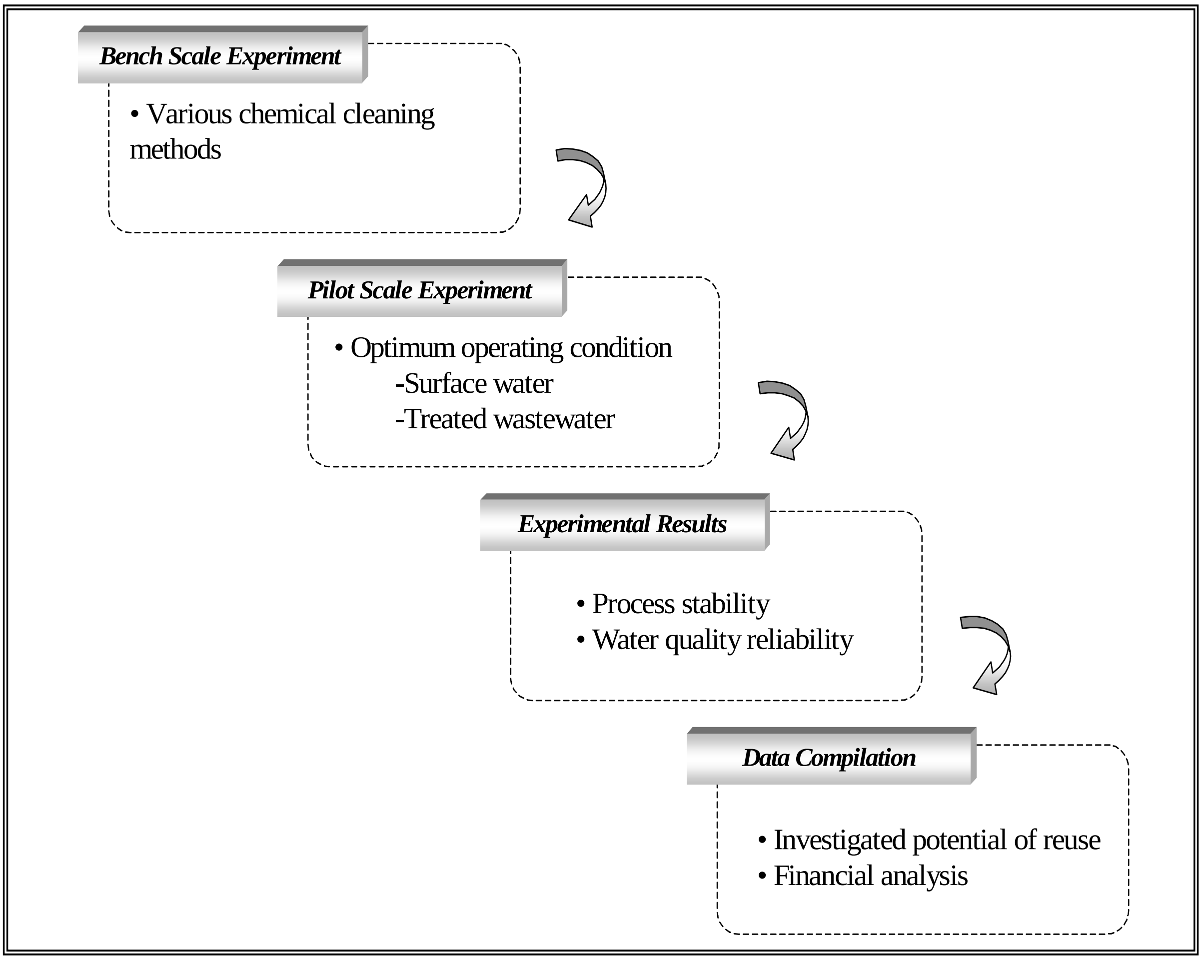


Figure 3.2 The Overall Experimental Strategy of Research

3.3 Feed Water Used

For these experimental studies, the raw water were taken from two different types as the following:

1. **AIT Canal:** Used this raw water as general canals and investigated potential for using as new source of water supply because lots of canal in Asian countries but water quality is not proper for industrial used. So if we can determine proper operation treatment system for this kind of water, we could reduce burden of expensive of water supply for industries and increase source of water for any future production expansion. See in Figure 3.3.

2. **AIT Treated Wastewater:** Used this raw water as typical treated wastewater from industries and investigated potential for reuse this reclaimed wastewater. So if we can determine proper operating conditions for this treated wastewater, it can be reused for industries. See in Figure 3.4.

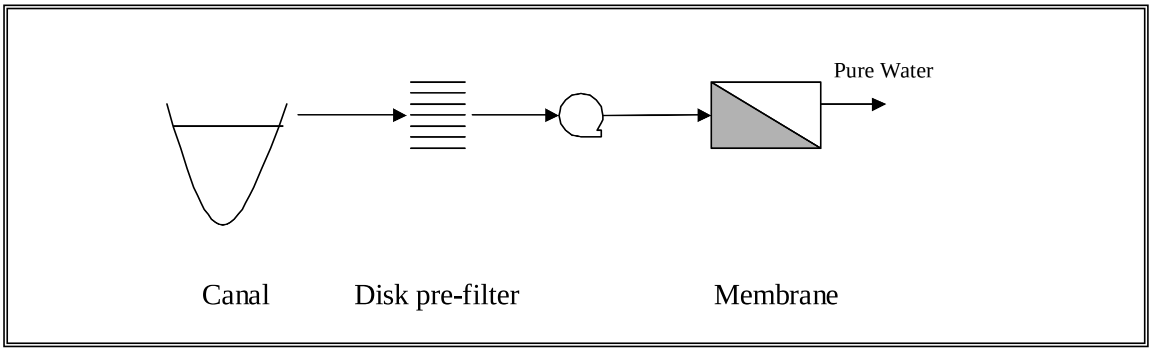


Figure 3.3 Water Reuse by Membrane Separation

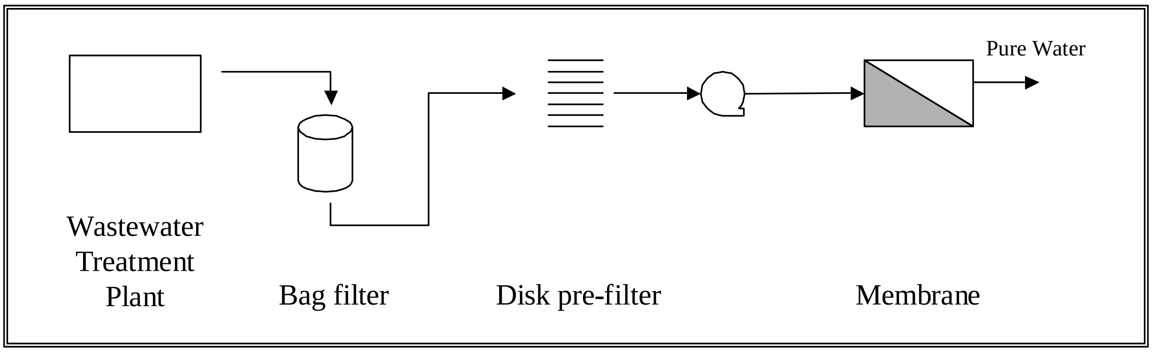


Figure 3.4 Wastewater Reuse by Membrane Separation

3.4 Pilot Scale Experiments

There were two major phases, which were categorized by types of feed water. The first phase was reuse of water experiment, which used AIT canal. The second phase was reuse of wastewater experiment, which used AIT treated wastewater. Steps of work for pilot scale experiment flow diagram is shown in Figure 3.5

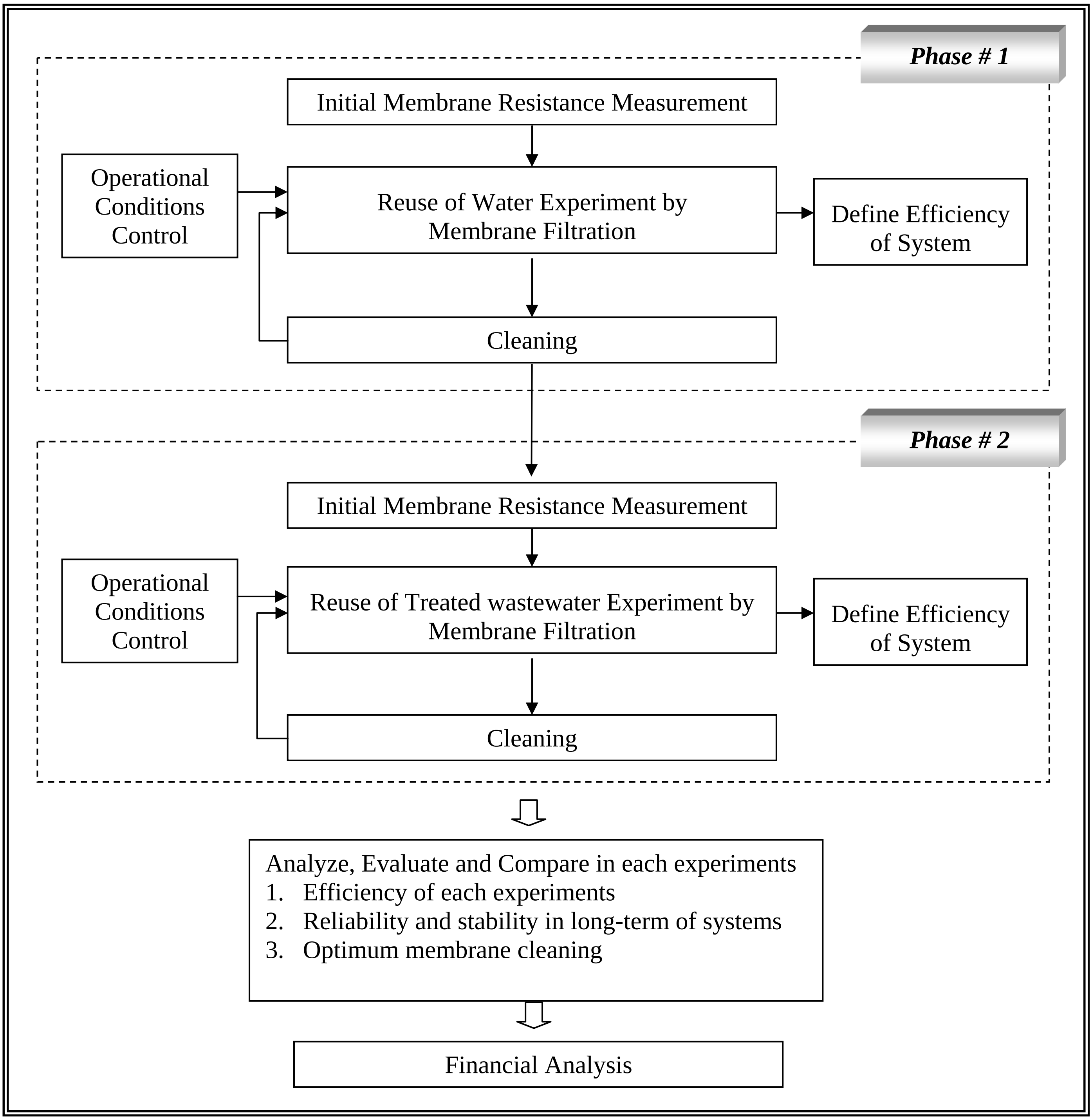


Figure 3.5 Steps of Work for Pilot Scale Experiment Flow Diagram

3.5 Membrane Filtration Modules Used in the Pilot Scale Experiments

Microfiltration membranes had an average pore sizes of 0.1 μm to a few μm, enabling the efficient and precise separation and removal of suspended substances and colloids from liquids. The hollow-fiber microfiltration module was used in this study. The membrane was manufactured by Asahi Chemical Industry Co.,Ltd in Japan and cooperated by Liquid Purification Engineering Co.,Ltd in Thailand The membrane filtration for these experiments was Microza MF, USV-3003 module. The specification of this MF module is shown in Table 3.1. The MF module structure is shown in Figure 3.6.

Table 3.1 Specifications of Microza MF, USV-3003 Module

Module Type		***USV-3003***
Filtration Mode		Outside to Inside
Dimension	Module Length	1,126 mm
	Module Diameter	89 mm
	Fiber Diameter (Inner/Outer)	0.7/1.3 mm
	Effective Surface Area (Outer)	7 m^2
Performance	Initial Water Flux	4.5 m^3/h.100kPa, 25 °C
	Nominal Pore Size	0.1 µm
Service limits	Maximum Inlet Pressure	250 kPa
	Maximum Transmembrane Pressure	250 kPa
	Maximum Temperature	40 °C
	pH Range	1 – 10
Material	Hollow Fiber	Polyvinylidenefluoride
	Module Housing	Hard PVC
	Potting Material	Epoxy Resin
	Gasket	Silicone

Source: Asahi Chemical Industry Co.,Ltd. (1999)

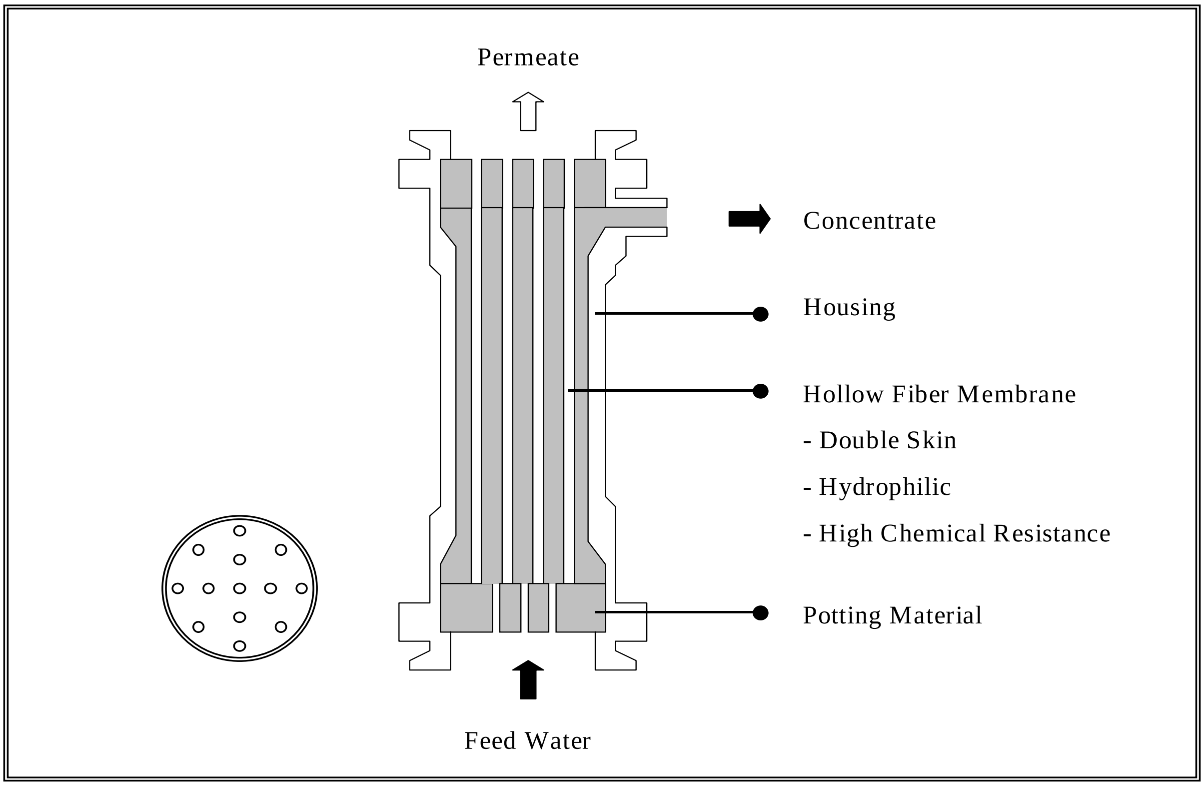


Figure 3.6 MF Module Structure

3.6 Measurement of Initial Membrane Resistance

Initial membrane resistance was conducted to find the membrane resistance of the new membrane. The pure water was withdrawn through the membrane by a suction pump and the suction pressure was measured by a pressure gauge. The experimental setup for the measurement of initial membrane resistance is shown in Figure 3.7. The following equation was used for determining membrane resistance.

$$J = \frac{\delta P}{\mu R_m}$$

Where

J	is	filtration flux (L/(m^2×h))
δP	is	transmembrane pressure (kPa)
μ	is	viscosity (kN×S/m^2)
R_m	is	apparent membrane resistance (1/m)

Since $R_m = R_{m0} + R_d$

When using ultra filtered water, $R_d = 0$

$$\begin{aligned} R_m &= R_{m0} \\ R_{m0} &= \frac{\delta P}{\mu J} \\ \delta P &= R_{m0}\mu \cdot J + \delta P_0 \end{aligned}$$

Where

R_{m0}	is	initial membrane resistance (1/m)
R_d	is	membrane resistance due to the deposition of solids (1/m)

Initial membrane resistance was conducted by following steps.

1. Filter the pure water through the membrane system.
2. Vary transmembrane pressure and record change in filtration flux.
3. Plot graph δP versus J and find out R_{m0}, which is initial membrane resistance.

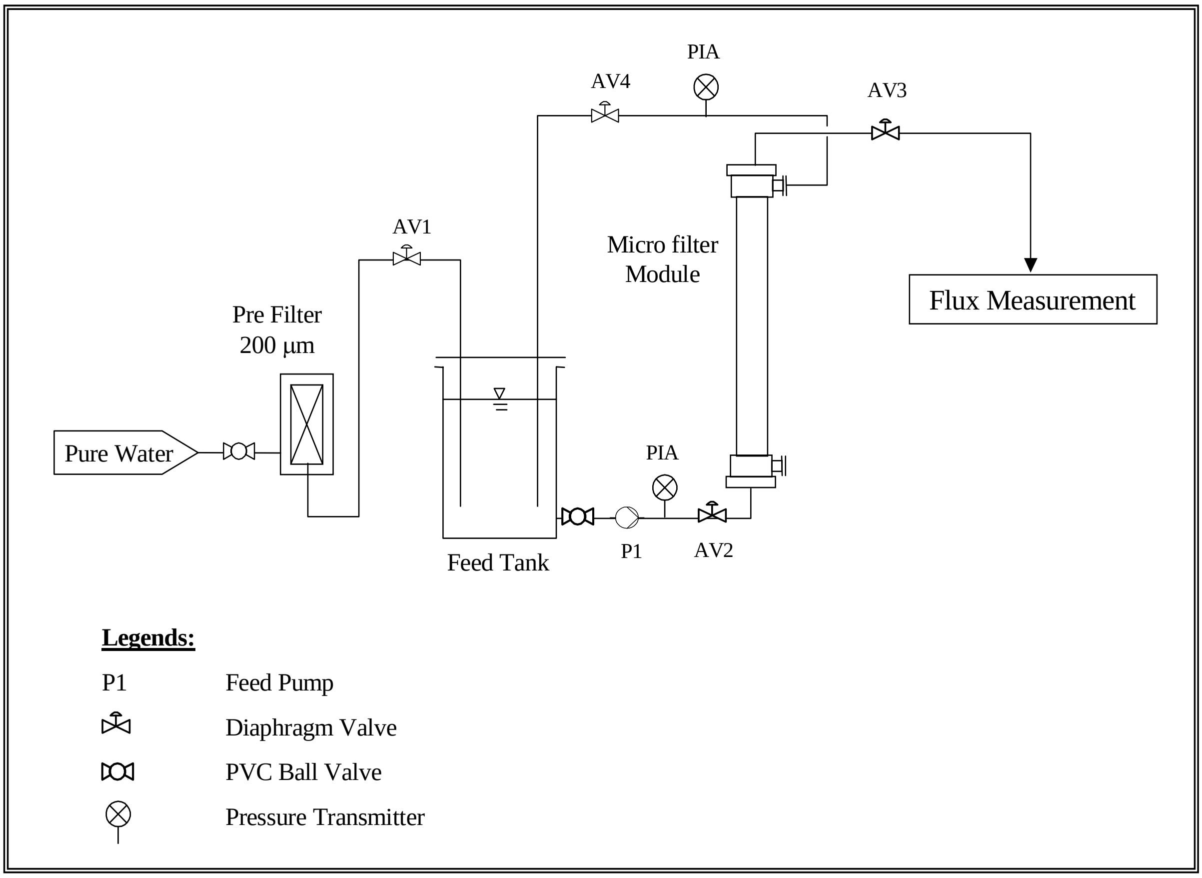


Figure 3.7 Schematic Diagram of Membrane Resistance Measurement

3.7 Long Term Experiment of Membrane Filtration Performance

As in any pilot experiment or demonstration, long-term testing was used to generate a large enough database on the treatment efficiency and operating characteristics to derive design or operation parameters.

3.7.1 Experimental Setup

The schematic diagram of the experimental setup is shown in Figure 3.8. The system consisted of feed water, pre filter, feed tank, microfiltration membrane module, chlorine tank, back wash tank, air compressor, PVC ball valve, diaphragm valve, feed pump and back wash pump. Pre filter for this pilot unit was disk pre filter with pore size 200 μm. Figure 3.9 shows the microfiltration membrane pilot unit, which was used for long-term experiment.

3.7.2 Process Operation

Membrane filtration systems are usually operated in one of two manners: at constant transmembrane water flux with variable pressure to maintain the flux or at constant transmembrane pressure with a variable transmembrane water flux.

The major obstacle to maintaining a constant rate of production was the degradation of transmembrane flux due to membrane fouling. This was due to the deposition of material on the membrane surface and/or in pores. For water from canal and wastewater from secondary treatment had different type of micro-impurities, which had a tendency to foul the membrane

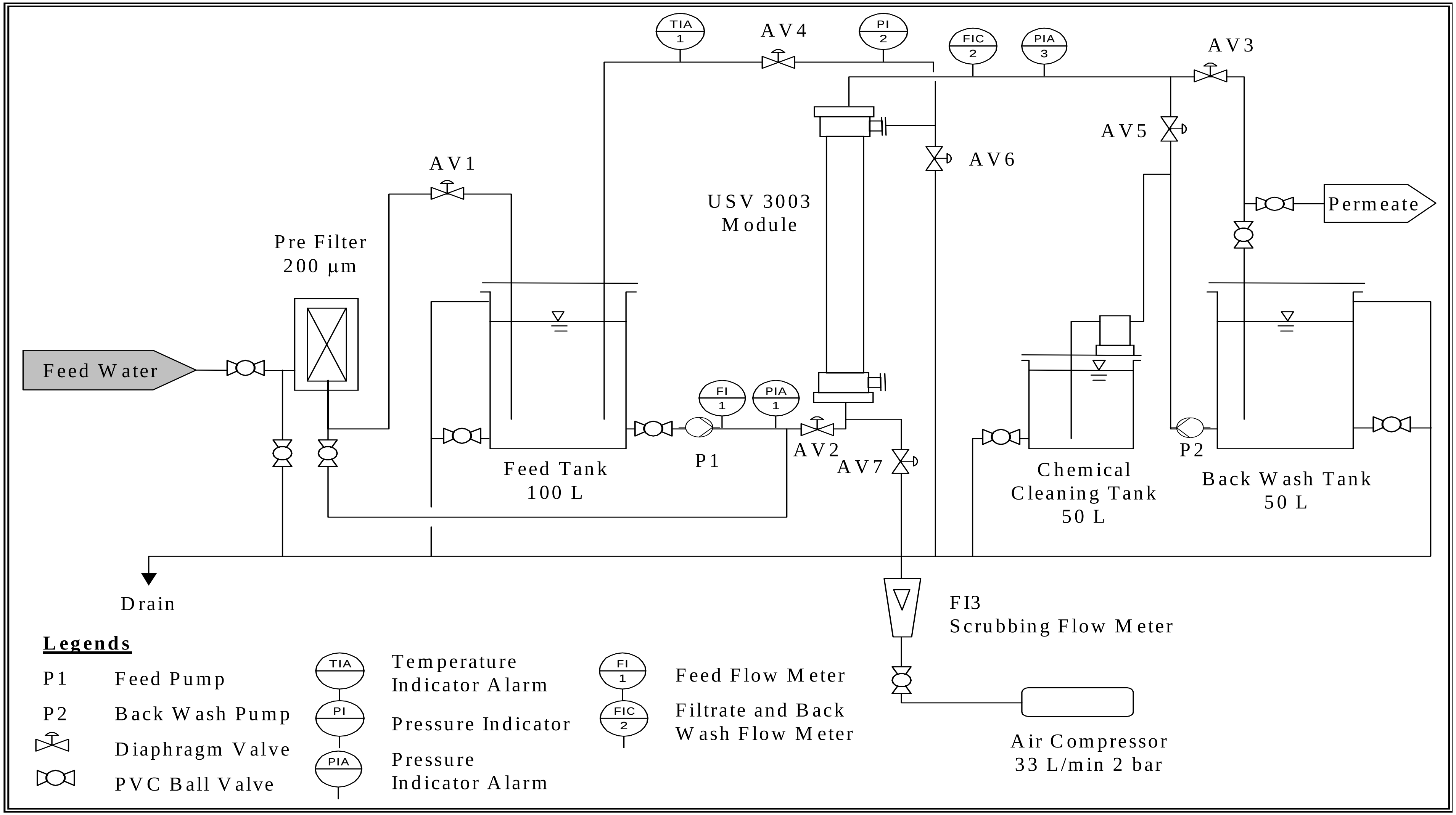


Figure 3.8 Schematic Diagram of Membrane Microfiltration Module

surface. Experiments were undertaken by fixed constant range of flux with a variable transmembrane pressure as functions of time during the period of operation.

A typical process cycle consists of a filtration period and a reverse filtration period. This cycle was controlled through diaphragm valves. These valves were automatically controlled through timers. The filtration schematic diagram is shown in Figure 3.10 and the reverse filtration schematic diagram is shown in Figure 3.11. Membrane module before and after the reverse filtration, backwashing and/or air scrubbing, is shown in Figure 3.12. The reverse filtration methods could be possible in 3 options as the following, which was find out a suitable method for this system.

1. Back washing by permeate water alone.
2. Air scrubbing plus permeate water back washing.
3. Air scrubbing plus permeate water back washing and plus chemical.

The experiments were run as long term experiments for 2 types of feed water as described in section 3.3. The experiment time period for surface water and treated wastewater were 4 months and 2 months, respectively. The standard operating condition of these experiments is shown in Table 3.2. These experiments were carried out to determine:

1. The pressure increased as a function of time.
2. Optimum cleaning control:
   2.1 Suitable reverse filtration method.
   2.2 Period of operation, which the membrane needs to be chemical cleaning.
3. Define and compare efficiency between two types of feed water.

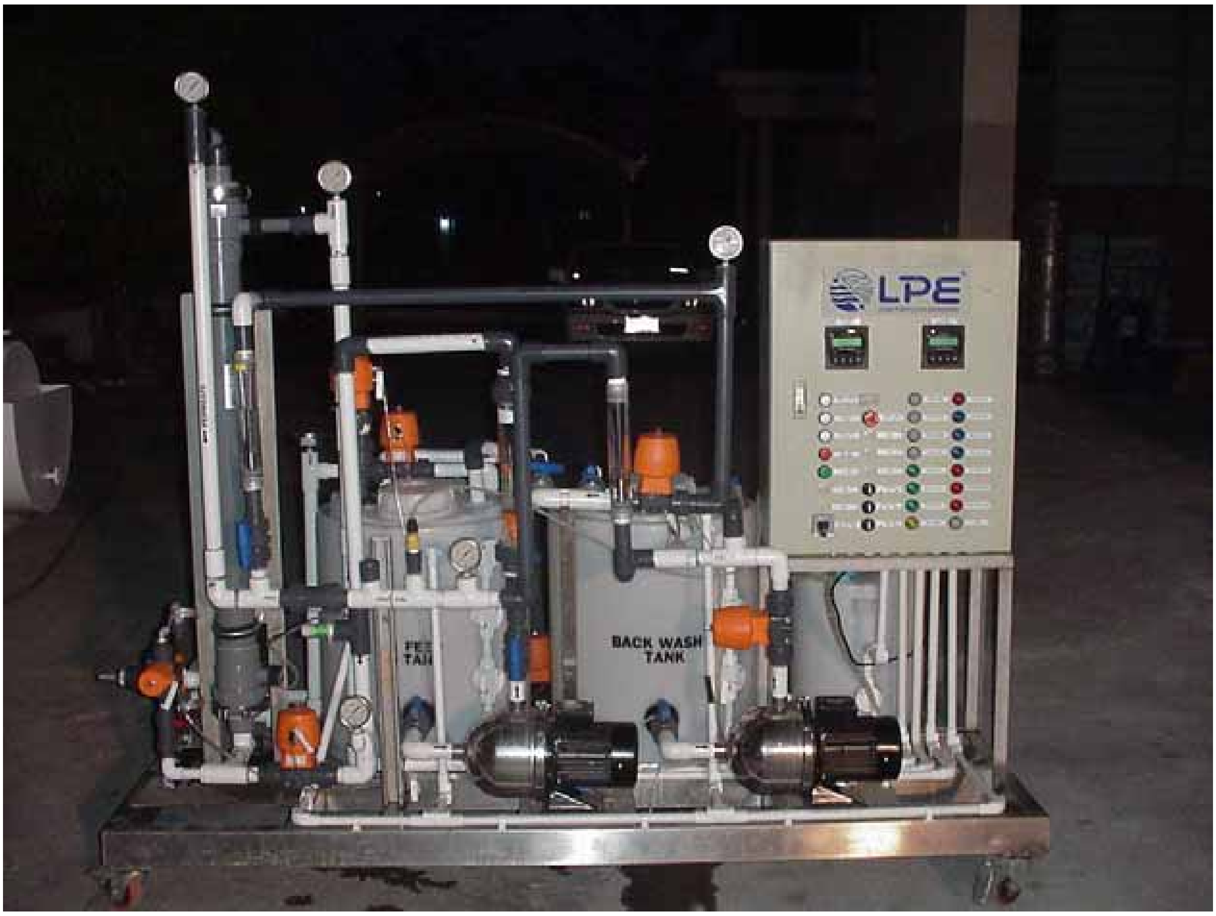


Figure 3.9 The Microfiltration Membrane Pilot Unit

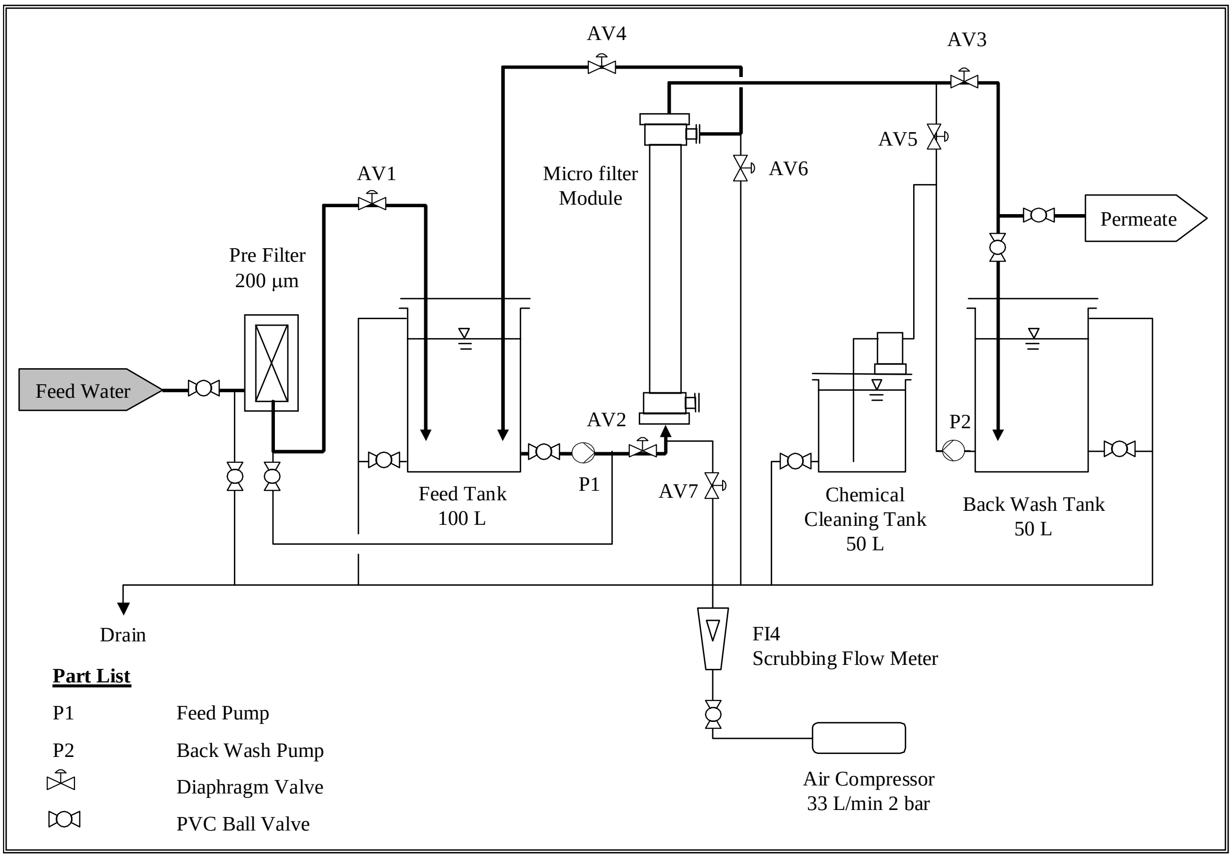


Figure 3.10 The Filtration Schematic Diagram

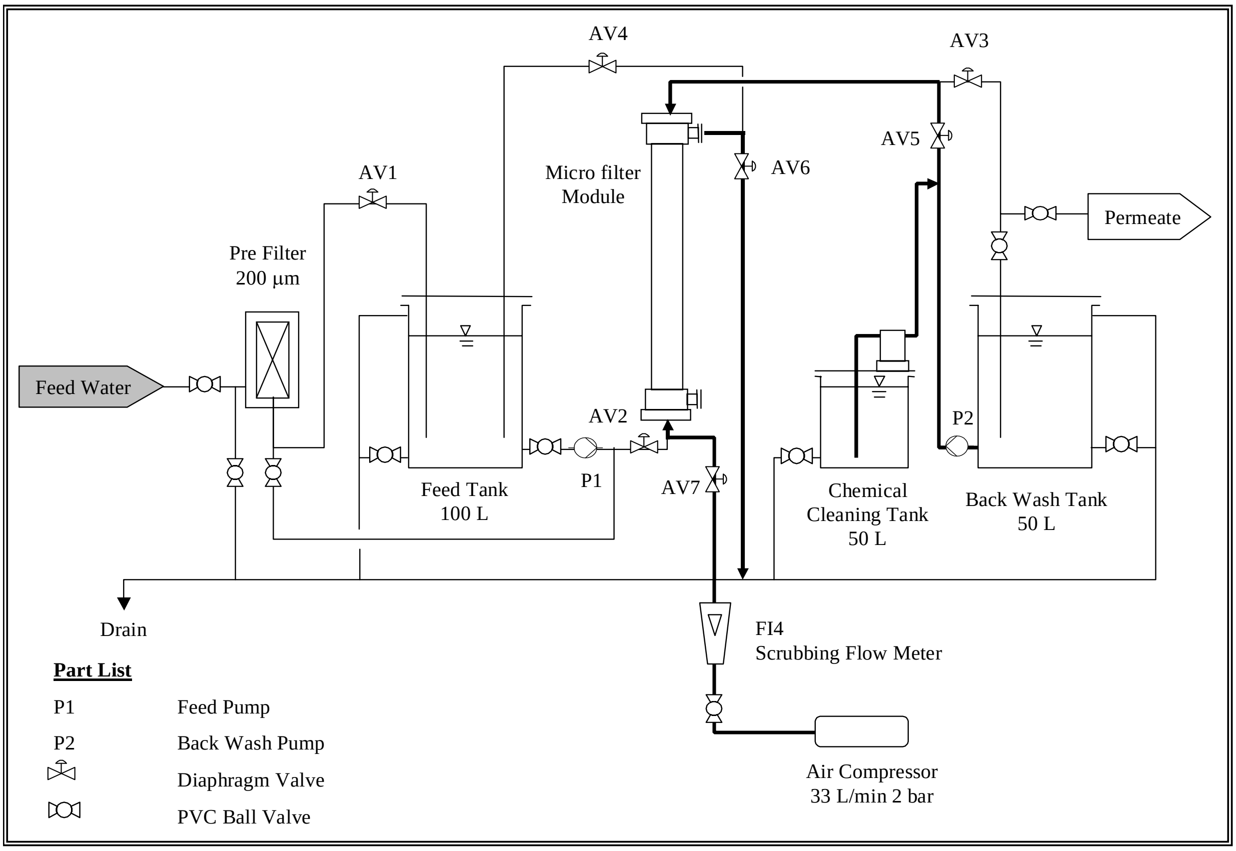


Figure 3.11 The Reverse Filtration Schematic Diagram

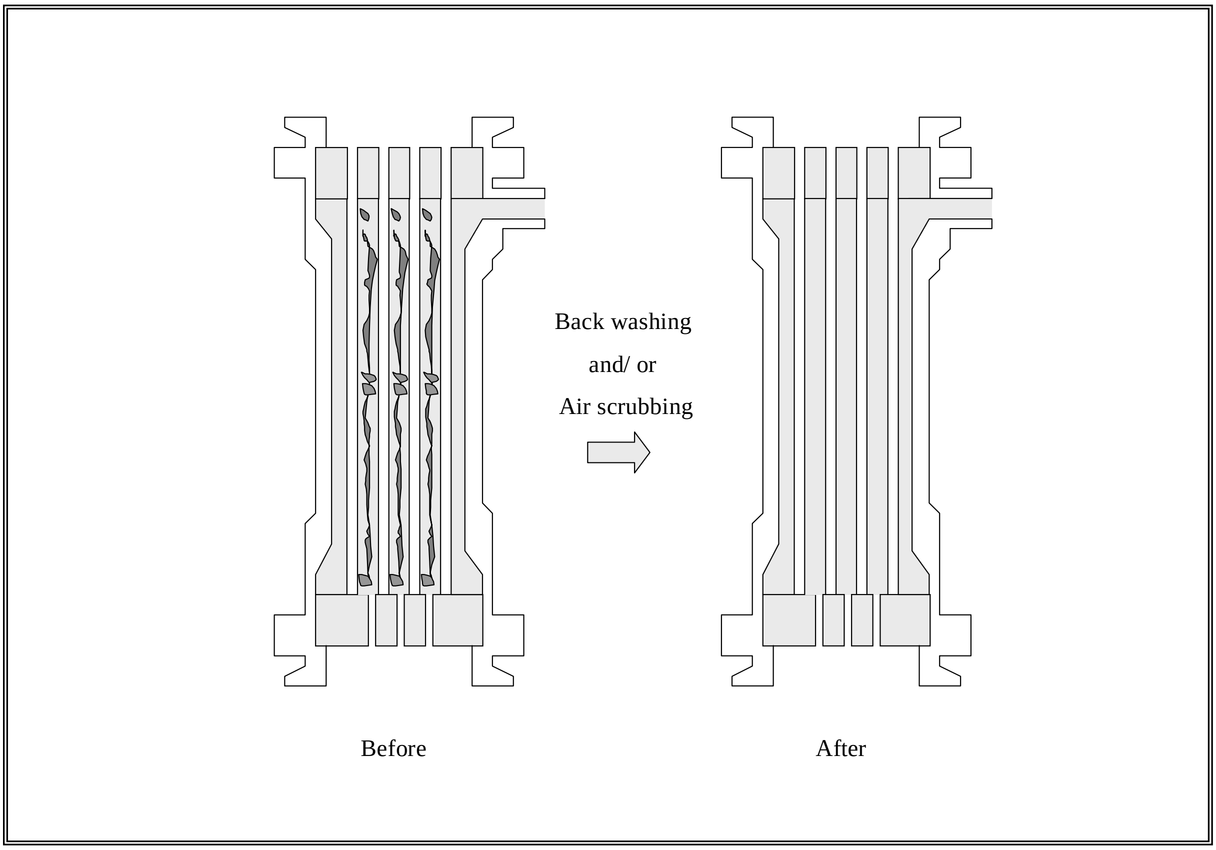


Figure 3.12 Membrane Module Before and After the Reverse Filtration

Table 3.2 Standard Operating Condition of USV-3003

Type of raw water	***Surface water***	***Sewage***
1. Feed water pretreatment	100~200 µm Filter or Screen	
2. Design Flux	0.2 ~ 1.2 m^3/h	
3. Circulation flow rate	0.2 ~ 0.5 m^3/h	
4. Filtration	15 ~ 60 min	
5. Reverse Filtration	30 ~ 90 sec	
6. Reverse Filtration Volume	5 to 10 % of permeate volume	
7. Recovery Rate	90 ~ 95 %	
8. NaClO in Rev.Filt.Water	2 ~ 5 ppm NaOCl	
9. Air Scrubbing		
9.1 Frequency & Time	Once for every 1 ~ 6 hours	Once for every 0.5 ~ 1 hours
9.2 Air Volume	2 Nm^3 / h	
9.3 Back washing pump rate	0.7 ~ 2.4 m^3 / h	
10. Temperature	Under 40 °C	
11. pH Range	2 ~ 10 (During operation)	
12. Chemical Cleaning	(1) Periodical cleaning (2) When water feed pressure reach 200 kPa	

Source: Asahi Chemical Industry Co.,Ltd. (1999)

3.7.3 Experimental Plans for Membrane Filtration

Cartwright (1994) has recommended that to operate the pilot unit on the side stream for at least 30 days. This length of time was necessary to provide sufficient information for membrane stability, long-term membrane fouling and data for engineering scale-up. The important operating condition parameters are shown in Table 3.3.

The first phase of this research was water reuse. Feed water used was AIT canal, which supposed to be general canal in Thailand. In actually different canal has a different quality of water. Therefore we also conducted experiments with higher particle concentration by adding kaolin clay to study effect on particle concentration of feed water. The second phase was wastewater reuse, which used AIT treated wastewater as feed water. Each experiment was stopped when feed pressure level reached 1.5-2.0 kg/cm^2 and chemical cleaning was required. The experiment plans could be summarized in Table 3.4.

Table 3.3 Conditions of Pilot Scale Experiments

Operating condition parameters	***Unit***	***Apparatus***	***Fixed / variable***
1. Feed water pretreatment	µm	Pre-filter	Fixed
2. Feed flow rate	m^2/h	Flow meter	Fixed
3. Permeate flux	m^3/m^2.h	Flow meter	Fixed*
4. Feed temperature	°C	Thermometer	Variable
5. Applied pressure	kPa	Pressure gauge	Variable
6. Filtration / Reverse Filtration	min/sec	Timer	Fixed*
7. Chemical cleaning period	h	Clock	Fixed

* Fixed in each experiment but was varied follow by experiment plans.

Table 3.4 Pilot Scale Experiment plans

Phase	***Feed Water***	***Feed Water***	***Permeate Flux***	***Filtration / Backwashing / Flushing***
Phase 1	Surface water	Experiment 1	480 L/h	30 min/30 sec/30 sec
		Experiment 2	600 L/h	30 min/30 sec/30 sec
		Experiment 3	720 L/h	30 min/30 sec/30 sec
	Surface water plus Kaolin Clay	Experiment 4	480 L/h	30 min/30 sec/30 sec
		Experiment 5	600 L/h	30 min/30 sec/30 sec
		Experiment 6	720 L/h	30 min/30 sec/30 sec
Phase 2	Treated wastewater	Experiment 1	480 L/h	30 min/30 sec/30 sec
		Experiment 2	600 L/h	30 min/30 sec/30 sec
		Experiment 3	720 L/h	30 min/30 sec/30 sec
		Experiment 4	600 L/h	15 min/30 sec/30 sec
		Experiment 5	720 L/h	15 min/30 sec/30 sec

3.7.4 Membrane Chemical Cleaning for Pilot Scale Experiment

As the concentration of foulant materials accumulated on the membrane surface, the loss of transmembrane flux was continuing to increase. Backwashing the membrane was the routine method for removing these materials. However, when foulants could do no longer be removed from the membrane surface by backwashing, chemical cleaning was required. When the transmembrane pressure reaches a certain level, chemical cleaning was started in order to reduce the pressure needed to maintain a specified transmembrane water flux rate. Typical chemical cleaning procedure for USV module was required when the module inlet pressure level reached 1.5-2.0 kg/cm^2.

The chemical-cleaning agents were varied with contaminants in feed water as shown in Table 3.5. The chemical cleaning schematic diagram is shown in Figure 3.13. The chemical cleaning of these experiments was Clean In Place (CIP) by manual, which was suggested from Asahi Co.,Ltd as the following steps:

1. Selection of proper chemical cleaning agents from contaminants in feed water, which 3,000 ppm–Cl (NaClO) plus 1% NaOH for four hours was typical recommended.
2. Filled the chemical agent that was selected into the feed tank.
3. The chemical cleaning agent was filtered through the membrane for proper duration time.
4. Measured membrane resistance with procedure that described in section 3.5.
5. If this chemical cleaning could not restore membrane performance, other chemical cleaning reagent, which 2% Oxalic acid for an hour was typical recommended, was used and followed the step 2 to 4 again, and so on.

Table 3.5 Selection of cleaning agent (USV)

Contaminants	***Cleaning agent***	***Concentration***
Bacteria Organic	NaClO	Up to 5,000 ppm
Organics Colloidal Silica	NaOH	Up to 4 %
Inorganic Colloid	Nitric Acid Hydrochloric Acid Oxalic Acid Citric Acid EDTA	5 to 10 % 5 to 10 % Up to 2 % Up to 10 % Up to 0.4 %
Sterilization	NaClO Hydrogen Peroxide	10 to 100 ppm Up to 1 %

Source: Asahi Chemical Industry Co.,Ltd. (1999)

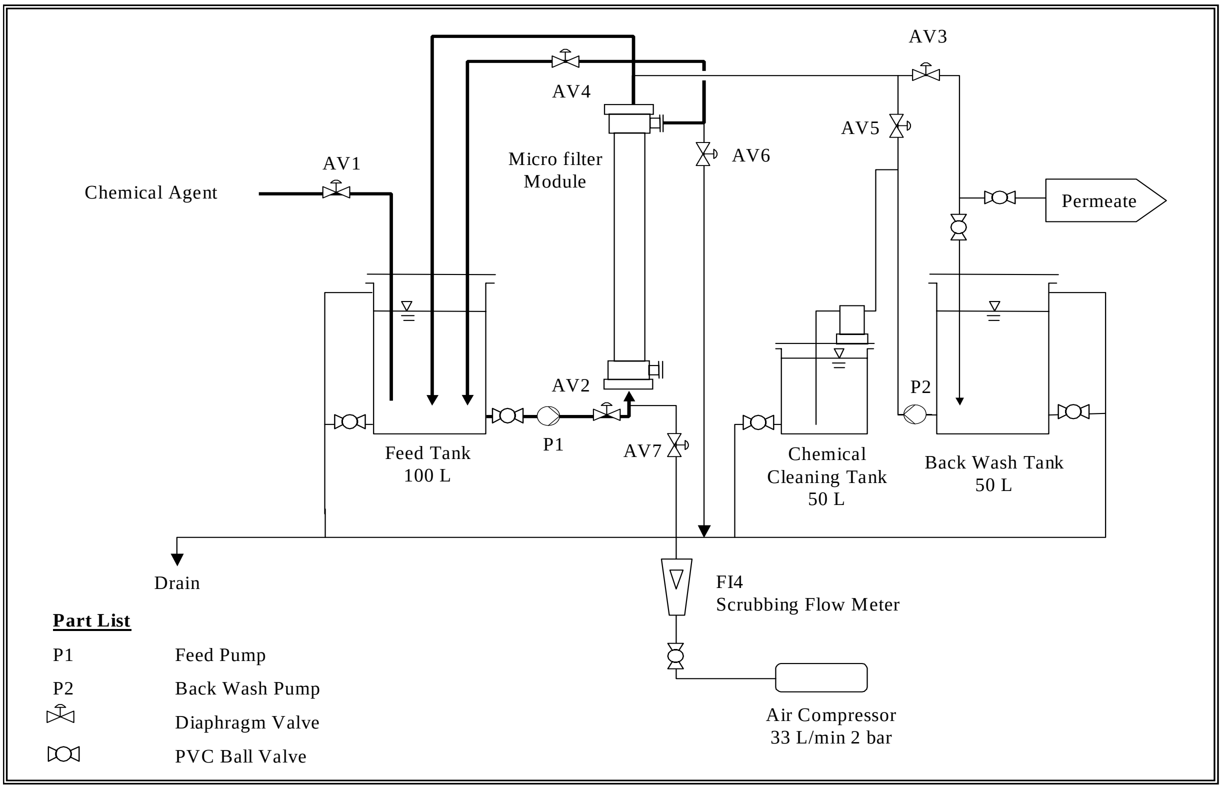


Figure 3.13 The Chemical Cleaning Schematic Diagram

3.7.5 Operation Control of the System

Typical membrane failures result from chemical attack such as chlorine, system design such as permeate back pressure, improper operation such as excessive concentrate pressure drop, or fouling, (Davis, 2000). Daily operational control is indispensable to prevent troubles. The operational control data sheet is shown in Table 3.6.

Table 3.6 The Operational Control Data Sheet

Frequency	***Control items***	***Unit***	***Indicator***
Forth a day	1. Feed water pressure	kg/cm^2	PIA-1
	2. Circulation water pressure	kg/cm^2	PI-2
	3. Permeate water pressure	kg/cm^2	PIA-3
	4. Feed water flow rate	L/min	FI-1
	5. Permeate water flow rate	L/min	FIC-2
	6. Back wash water pressure	kg/cm^2	PIA-3
	7. Back wash water flow rate	L/min	FIC-2
Twice a day	1. Feed and permeate water temperature	°C	Thermometer
	2. Feed and permeate pH	-	pPH meter
	3. Air scrubbing flow rate	Nm^3/h	FI-3

Adapted from Asahi Chemical Industry Co.,Ltd. (1999)

3.7.6 Monitoring of Membrane Filtration and Analytical Methods

From the discussion in section 3.4, the experiments were divided in two phases depend on feed water used because of different significant parameter in each feed water. For surface water or canal water, the frequency of analysis, sampling point and analytic methods are presented in Table 3.7. For treated wastewater, the frequency of analysis, sampling point and analytic methods are presented in Table 3.8.

Table 3.7 Frequency, sampling points and analytical methods of parameter analysis for surface water.

Parameters	*Frequency of analysis*	*Sampling points*	*Expected Interference of Examinations*	*Apparatus / Methods*
pH	Everyday	FW / FT	-	pH meter
Turbidity	Everyday	FW / FT/ Eff	-	Turbidity meter
SS	Everyday	FW / FT/ Eff	High mineral salt	Dry at 103-105 °C
Color	Weekly	FW / FT/ Eff	Suspend Solid	Spectrometer with centrifuge
Phytoplankton	Weekly	FW / FT/ Eff	-	Plant pigments: Chlorophylls
COD	Weekly	FW / FT/ Eff	Nitrate, Chloride	Closed reflux method
TOC	Weekly	FW / FT/ Eff	Acids, Alkalis, Salts	TOC Analyzer, Model TOC-5000A
BOD_5	Twice in experiment	FW / FT/ Eff	Chloride, heavy metals, toxic materials	5 day incubation at 20 °C
Total Fe	Twice in experiment	FW / FT/ Eff	Oxidizing agents, PO^{-}_{4} heavy metals, Nitrite	Atomic Absorption Spectrometer
Total Mn	Twice in experiment	FW / FT/ Eff	Chloride, Organic matters	Atomic Absorption Spectrometer
Total Hardness	Twice in experiment	FW / FT/ Eff	Metal ion	Titration with EDTA
Fecal Coliform	Twice in experiment	FW / FT/ Eff	-	Membrane Filtration Technique

- Examinations base on Standard Methods for the Examination of Water and Wastewater, APHA-AWWA-WPCF, 1995.
- FW: Feed water
- FT : Feed tank before membrane filtration
- Eff : Effluent from membrane filtration

Table 3.8 Frequency, sampling points and analytical methods of parameter analysis for treated wastewater.

Parameters	***Frequency of analysis***	***Sampling points***	***Expected Interference of Examinations***	***Apparatus / Methods***
pH	Everyday	FW / FT	-	pH meter
Turbidity	Everyday	FW / FT/ Eff	-	Turbidity meter
SS	Everyday	FW / FT/ Eff	High mineral salt	Dry at 103-105 °C
Color	Weekly	FW / FT/ Eff	Suspend Solid	Spectrometer with centrifuge
Phytoplankton	Weekly	FW / FT/ Eff	-	Plant pigments: Chlorophylls
COD	Weekly	FW / FT/ Eff	Nitrate, Chloride	Closed reflux method
TOC	Weekly	FW / FT/ Eff	Acids, Alkalis, Salts	TOC Analyzer TOC 500-A
BOD_5	Twice in experiment	FW / FT/ Eff	Chloride, heavy metals, toxic materials	5 day incubation at 20 °C
Total Fe	Twice in experiment	FW / FT/ Eff	Oxidizing agents, PO^-_4 heavy metals, Nitrite	Atomic Absorption Spectrometer
Total Mn	Twice in experiment	FW / FT/ Eff	Chloride, Organic matters	Atomic Absorption Spectrometer
Total Hardness	Twice in experiment	FW / FT/ Eff	Metal ion	Titration with EDTA
Fecal Coliform	Twice in experiment	FW / FT/ Eff	-	Membrane Filtration Technique

- Examinations base on Standard Methods for the Examination of Water and Wastewater, APHA-AWWA-WPCF, 1995.
- FW: Feed water
- FT : Feed tank before membrane filtration
- Eff : Effluent from membrane filtration

3.8 Comparison of the Results

The comparison in this research could be divided in two categories as the following.

1. The comparison between the effluents quality of each experiments from microfiltration membrane and criteria of reclaimed water quality whether the potential of reuse by this system was proper for which kind of reuse application. The different feed water had the different potential of reuse application. The permeate water quality comparison with tap water was also done.
2. The comparison of the results between two types of feed water was also done. The comparison was concerned about reliability, stability, optimum membrane cleaning, which the parameters for comparison are listed in Table 3.9.

Table 3.9 Parameters for comparison of surface water and treated wastewater for membrane filtration.

Parameter	Unit
1. Reliability	
1.1 Efficiency of treatment	%
2. Stability	
2.1 Transmembrane pressure profile	-
2.2 The duration time	h / run
3. Operating conditions	
3.1 Frequency of chemical cleaning	h / time
3.2 Operating costs	Baht / m^3 of water production

3.9 Bench Scale Experiments

Bench scale experiments were performed on flat sheet membrane for studying in fundamental things, which were difficult to study in pilot scale experiment.

The cleaning of large membrane systems is an expensive and time-consuming. The current approach to cleaning membrane involves guesswork and trial-and-error, (Davis, 2000). Therefore, the membrane fouling determination in bench scale experiment was needed in this research to find out suitable cleaning agents for each feed water and properly used in long-term experiment.

The schematic diagram of membrane fouling determination in bench scale experiment is shown in Figure 3.14. The plate and frame membrane was used in this bench scale experiment. The water was fed through the membrane by a feed pump and the applied pressure was measured by pressure gauge. When the permeate flux was reduced more than 80%, the membrane was removed for chemical cleaning test.

Bench scale experiments were conducted to investigate:

1. Effects of chemical cleaning composition;
2. Effects of chemical cleaning concentration.

To investigate the effect of different composition of cleaning solution, potential of various chemical-cleaning reagents for membrane recovery experiment step was conducted in flat sheet membrane. The experimental steps were carried out as the following,

1. Initial membrane resistance measurement.
2. Filtrated plate and frame membrane by raw water for 12 hours.
3. Chemical cleaning with selected reagent for an hour.
4. Membrane resistance measurement.
5. Repeat the step 2-4 with other options of chemical reagents.

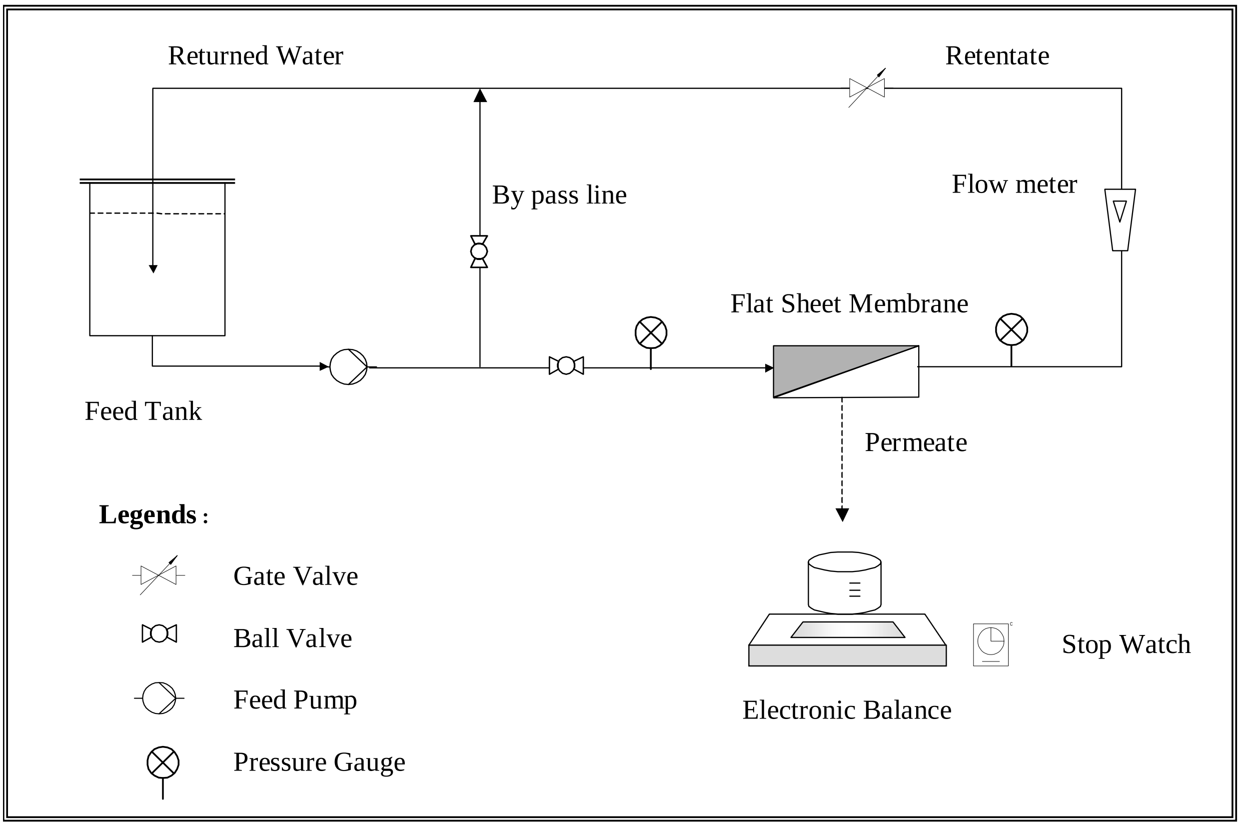


Figure 3.14 : Schematic Diagram of Membrane Fouling Bench Scale Experiment

3.10 Financial Analysis for a Full-Scale Membrane Filtration

The financial analysis was done in two major steps. The first step was the comparison between each experiment for getting optimum conditions of each feed water. The second step was the financial analysis of the full-scale, which was made based on the optimum conditions that were got from these experiments. The total cost for the industries was analyzed by two main categories that were membrane system capital costs and operating costs such as maintenance costs, labor costs, water lost in back washing cost, energy cost. The power consumption was got by installation watt meter, which was converted to be the energy cost. The total cost for this system was compared with conventional systems. The total benefit for the industries were analyzed by the current price of water supply costs that will be safe from reuse system.

Chapter 4

Results and Discussions

4.1 Introduction

Microfiltration pilot unit experiments were run with two different sources of feed water. The first source of water was surface water, where AIT canal was chosen. This feed water was supposed to be a general canal in Thailand. In the AIT canal experiments were run from end of January 2001 to mid of April 2001. In order to investigate the effects of higher suspended solids in the surface water, Kaolin clay was added to the feed water which was filtered through the pilot unit from mid of April 2001 to end of May 2001. The second water source was AIT effluent from the wastewater treatment ponds, which was used from end of May to early July 2001. Chemical cleaning bench scale experiments were run in parallel with the pilot scale experiment as a fundamental study, which supported for a better application study. This section of report presents the results of experiments and offers the discussion of the results.

4.2 Initial Membrane Resistance for Microfiltration Membrane Pilot Unit

Tap water was used for this initial membrane resistance measurement (R_{mo}). Before using microfiltration membrane modules, the initial membrane resistance was measured. The purpose of initial membrane resistance value is to evaluate the effectiveness of membrane chemical cleaning. Feed flow was 1,700 L/h. Figure 4.1 shows the variation of permeate flux of clean water with pressure.

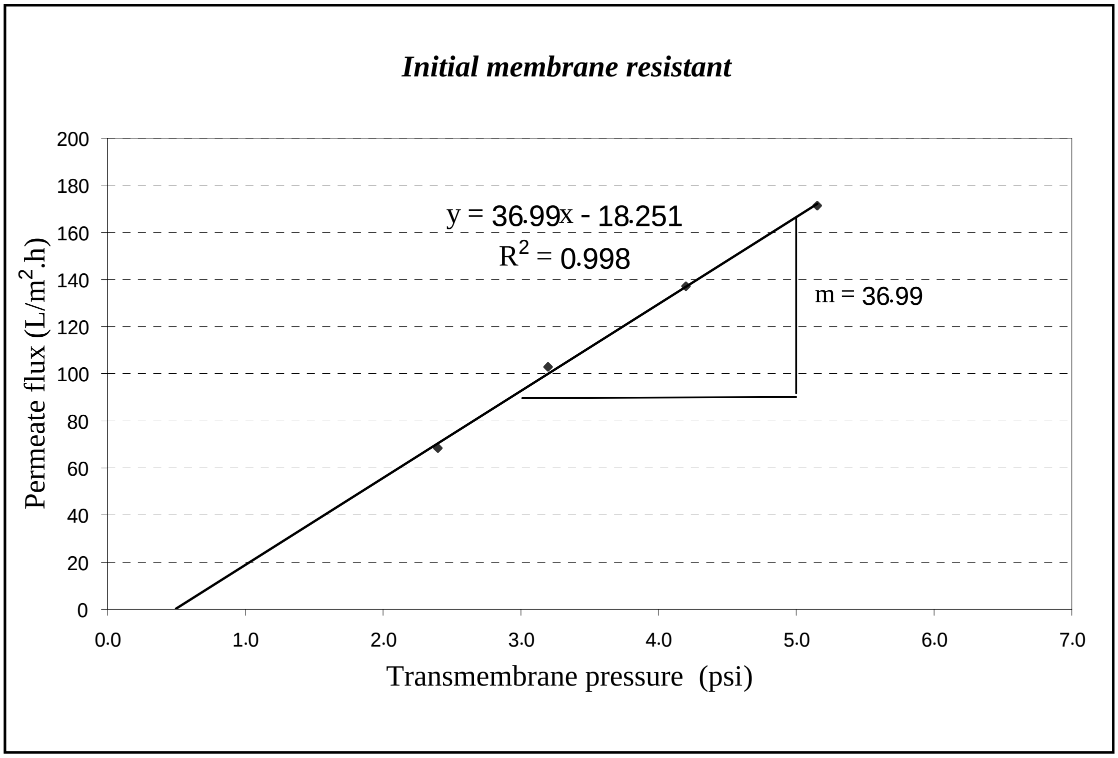


Figure 4.1 Variation of Permeate Flux of Clean Water with Pressure

The flux J of very clean water pass through a membrane without materials deposited on its surface or inside its pores is often described by Darcy's law, (Mallevialle et al., 1996), which is shown in equation 4.1.

$J = \delta P / \mu R_m$ Eq. 4.1

$\mu = 0.8352 \text{ N.s/m}^2$: at 28 °C

$Rm = 8.04 \times 10^8 \text{ m}^{-1}$: at 28 °C

$J = 36.99\, \delta P - 18.251$

Where ΔP: psi
J: $L/m^2.h$

Initial water flux from the experiment was 518.10 $L/m^2.h$ .14.5 psi, 28 °C. Surface area of this membrane module was 7 m^2. Therefore, the initial water flow rate from the experiment was 3.63 m^3/h. 100 kPa, 28 °C

Specific flow = [Flow (m^3/h)] / [TMP (kPa)] x [Temperature correction factor]

= 3.68 m^3/h. 100 kPa x (0.8532/0.8933)

= 3.47 m^3/h. 100 kPa, 25 °C

Initial water flow from the experiment was **<u>3.47 m^3/h. 100 kPa, 25 °C</u>**

Design water flow from Asahi Co.,Ltd was **<u>4.50 m^3/h. 100 kPa, 25 °C</u>**

Remark: Coefficient of water viscosity (η)

$\eta = A \exp[(1+BT) / (CT + DT^2)]$

where T: Temperature (K)
A: 1.257187×10^{-2}
B: -5.806436×10^{-3}
C: 1.130911×10^{-3}
D: -5.723952×10^{-6}

Temperature correction factor (ft)

$ft = \eta t / \eta$

where ηt: coefficient of water viscosity at t °C
η: coefficient of water viscosity at 25 °C

4.3 Short-Term Experiment for Appropriate Backwash Method

The primary goals of these experiments were to investigate and establish the appropriate backwash method for this system by using the following options:

1. Back washing only with permeate water.
2. Air scrubbing along with permeate water back washing.
3. Air scrubbing and permeate water back washing and with chemical.

Two set of experiments were conducted to investigate the suitable backwash method. The first sets of experiments were run by fixed transmembrane pressure at 0.5 bar and backwashed by water alone. The operating conditions of these experimental runs are presented in Table 4.1 and the result of experiment is shown in Figure 4.2. The second sets of experiments were run by fixed permeate flow at 480 L/h and with different backwash methods. The operating conditions of these experiments are shown in Table 4.2 and the results of experiment is shown in Figure 4.3.

Experiment 1: Fixed transmembrane pressure at 0.5 bar

Table 4.1 Operating Conditions of Short-Term Experiment 1: Fixed Transmembrane pressure

Description	***Operating conditions***
1. Membrane module	USV-3003
2. Raw water	Surface water
3. Feed flow rate	1,500 L/h
4. Transmembrane pressure	0.5 bar
5. Filtration / Reverse filtration	Filtrate 30 min / Backwash by water 30 sec / Flushing 30 sec

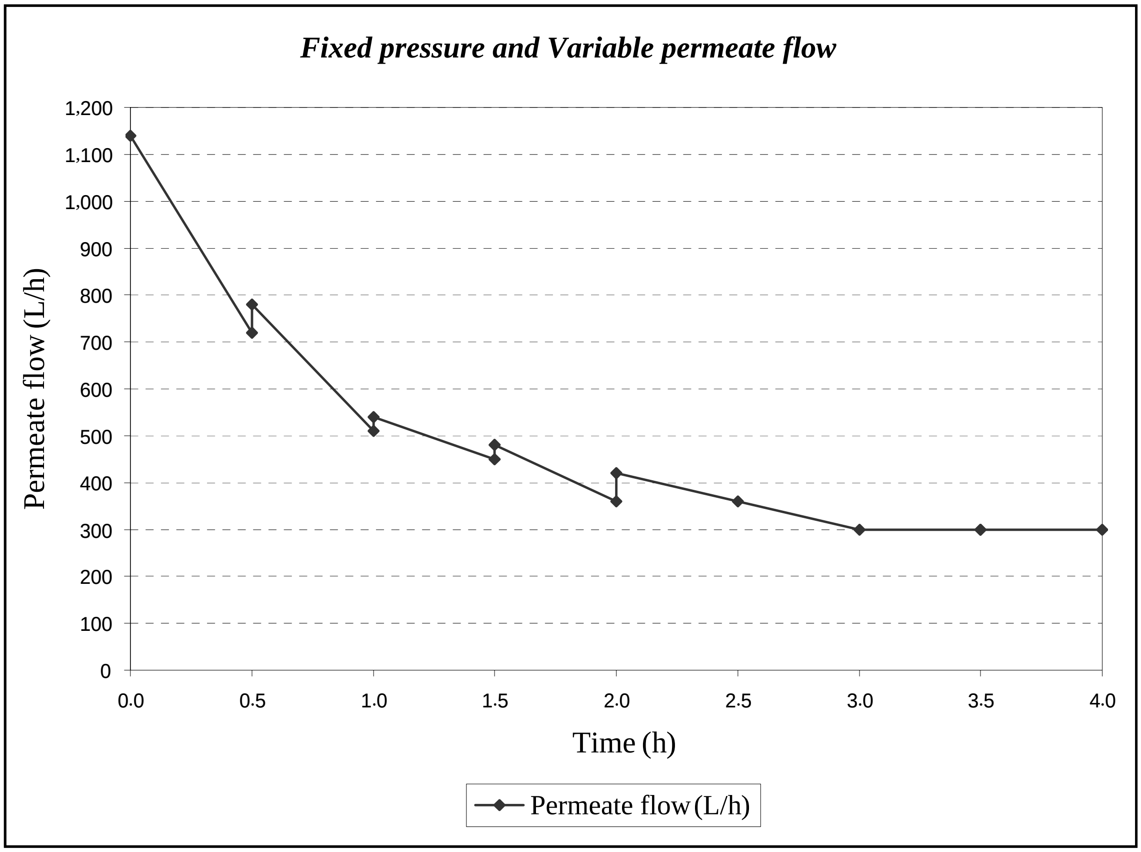


Figure4.2 Variable permeate flow with time at transmembrane pressure 0.5 bar

Microfiltration systems are usually operated in one of the following methods: constant transmembrane water flux with variable pressure to maintain the flux or at constant transmembrane pressure with a variable transmembrane water flux rate. This short-term experiment or the initial operation period was established to investigate the permeate flux declining with time by the fixed feed pressure, at 0.5 bar.

As depicted in Figure 4.2, the initial flow obtained at the start of the experiment was 1,140 L/h or 0.16 $m^3/m^2.h$ at 28 °C. The investigation time was four hours. The permeate flow declined to 300 L/h or 73.7 % within four hours by fixed feed pressure at 0.5 bar and backwash by water alone without adding any chlorine or air scrubbing. It indicates that the selected backwashing arrangement is not adequate remove the internal pore clogging.

Experiment 2: Fixed permeate flow at 480 L/h

Table 4.2 Operating Conditions of Short-Term Experiment 2: Fixed Permeate Flow

Description	***Operating conditions***		
	Backwash by water	***Backwash by water & air***	***Backwash by water& air& NaClO 3 ppm***
1. Membrane module	USV-3003		
2. Raw water	Surface water		
3. Feed flow rate	1,500 L/h		
4. Permeate flow rate	480 L/h		
5. Filtration / Reverse filtration	Filtrate 30 min / Backwash 30 sec / Flushing 30 sec	Filtrate 30 min / Backwash 60 sec / Flushing 30 sec	Filtrate 30 min / Backwash 30 sec / Flushing 30 sec

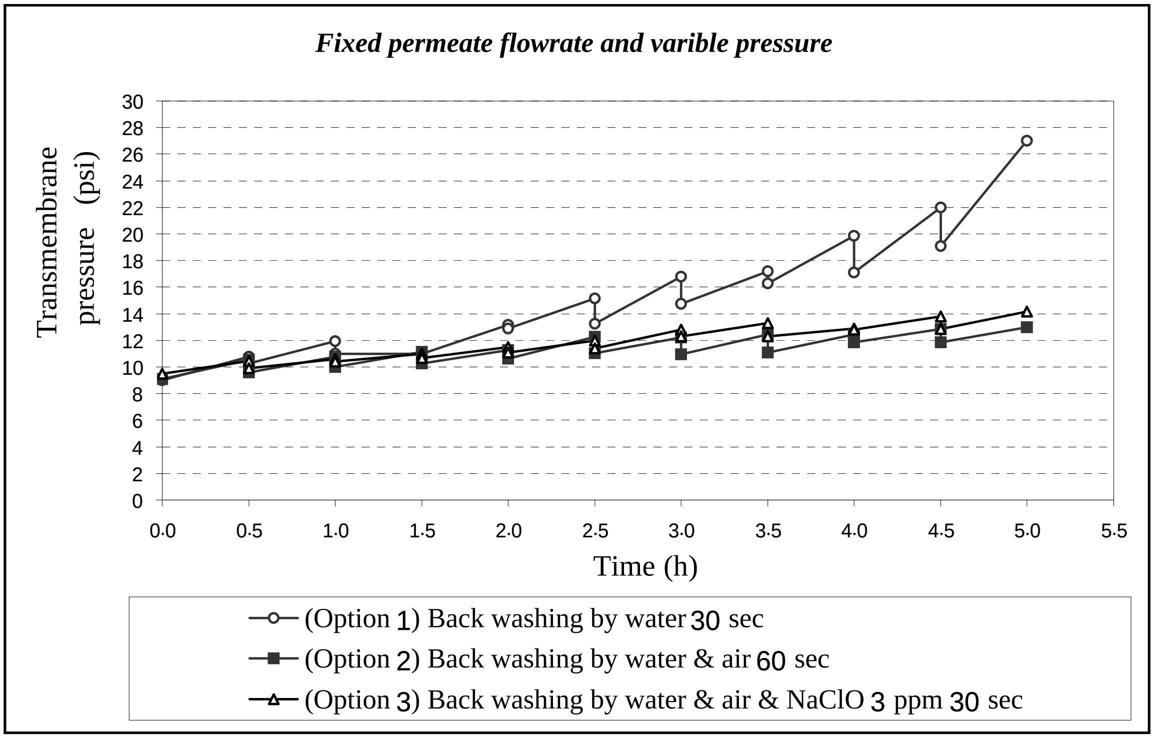


Figure 4.3 Variable transmembrane pressure with time by fixed permeate flow at 480 L/h

Three backwash options were investigated, which the first option was to backwash by water for 30 seconds, the second option was to backwash by water & air scrubbing for 60 seconds and the last option was to backwash by water with adding NaClO 3 ppm & air scrubbing for 30 seconds. The backwash period was done every 30 minutes of filtration which was followed the backwash step by 15 seconds water flushing for two times. Figure 4.3 presents a graph of comparison of transmembrane pressure (TMP) increasing with time, which was investigated for five hours. The initial TMP of three options were almost the same, which was 9.0-9.5 psi. After the system had run for two hours, TMP of backwash by water alone for 30 seconds was observed to be higher than others. At five hours running, TMP of the first option was 27 psi, which was considered bad. The increase in TMP may be due to the accumulation of particles on the membrane surface. The backwash with only water was not effective to remove the particle material from the membrane, which caused fast increasing of TMP. In the second and third options, the TMP increased for five hours, which was low and had a small difference in both of them, which were 13.0 psi and 14.2 psi respectively. It seems that these two backwash methods were appropriate for this feed water quality. Percent feed water recovery of backwash for 30 seconds with NaClO was 98 % and 96 % for 60 sec backwash without NaClO, which the calculation is shown in Appendix A. Therefore air scrubbing and water backwash with NaClO, 3 ppm was the economical and effective method for this system.

4.4 Long Term Experiment of Microfiltration Pilot Unit

The primary goal of the long-term experiment is to study stability and reliability of the system. The experiments were conducted in order to study the effect of the feed water quality and the effect of permeate flux rate. Filtration and backwash period is one of the important factors for membrane microfiltraion system, which was also studied. The secondary goal is to study the efficiency of water treatment, which can be used for investigation of water and wastewater reuse potential. The following parts are the results and discussion of 12 experiments, which were compared between related categories.

4.4.1 Comparison of Permeate Flow: Surface Water

AIT Canal was used as surface water. In the filtration and reverse filtration system, filtration was 30 minutes, backwash was 30 seconds and flushing was 30 seconds. The operating conditions for four surface water experiments are shown in Table 4.3. The increasing transmembrane pressure with time is presented in Figure 4.4 to 4.7.

Each experiments were run by fixing permeate flow constant. As the concentration of foulant materials accumulated on the membrane surface, the permeate flow was continuing to decrease. For maintaining the permeate flow constant, the valves adjustment was required. In these experiments, the different of transmembrane pressure before and after backwashing step was investigated. The records of TMP were done every six hours by adjusting the valves to maintain permeate flow constant before and after backwashing step. This microfiltration pilot unit was automatically cut off when the feed pressure was equal or higher than 28 psi for preventing membrane failure. As depicted in Figure 4.4, 4.5 and 4.6, TMP was the “Zig-Zag” curve at the beginning because the feed pressure before backwashing step was less than 28 psi, which could be adjusted and recorded. When the feed pressure before backwashing step was higher than 28 psi, the valve adjustment could be done and recorded the TMP only after backwashing step.

Table 4.3 Operating Conditions of Long Term Experiment for Surface Water

Description	***Operating conditions***			
	Experiment 1	***Experiment 2***	***Experiment 3***	***Experiment 4***
1. Membrane module	USV-3003			
2. Raw water	Surface water			
3. Feed flow rate	1,500 L/h			
4. Permeate flow rate	480 L/h		600 L/h	720 L/h
5. Filtration / Reverse filtration	Filtrate 30 min / Backwash 30 sec / Flushing 30 sec			
6. Backwashing method	Water & NaClO 3 ppm & air 0.3 bar (1,000 L/h)	Water & NaClO 3 ppm & air 0.75 bar (1,600 L/h)	Water & NaClO 3 ppm & air 1.5 bar (2,000 L/h)	Water & NaClO 3 ppm & air 1.5 bar (2,000 L/h)

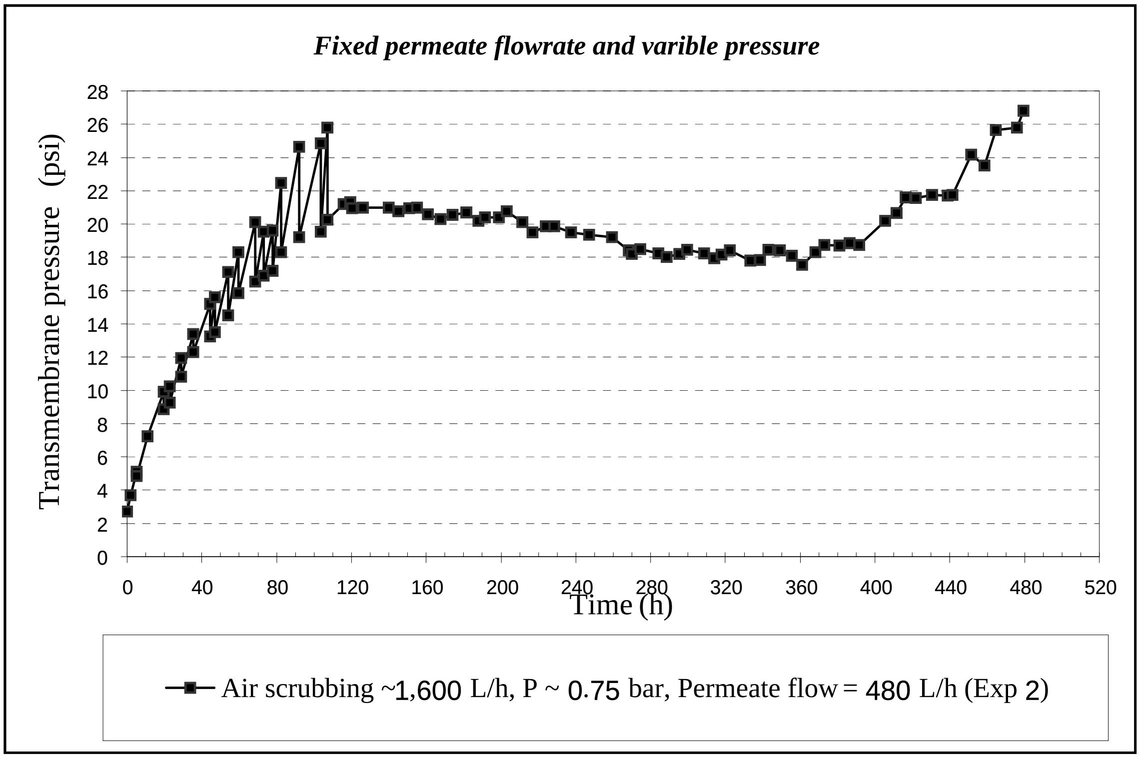


Figure 4.4 Variable transmembrane pressure with time by fixed permeate flow at 480 L/h of long term experiment for surface water (Adjust permeate flow before and after backwashing)

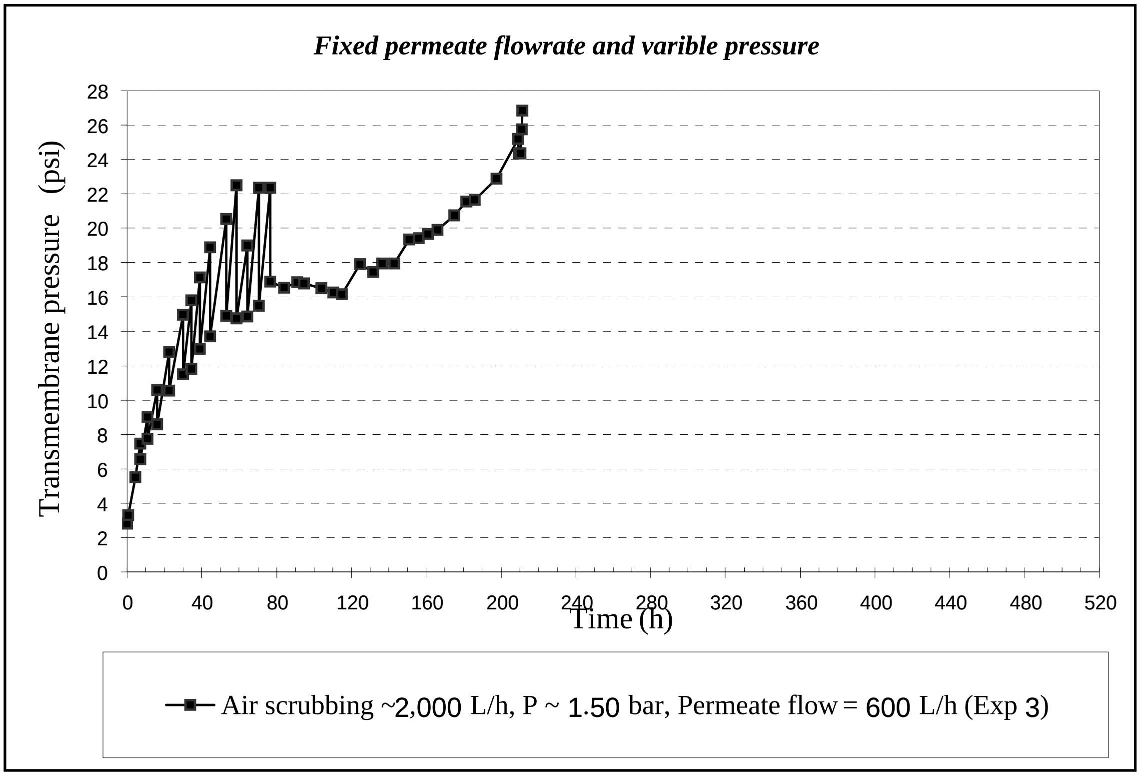


Figure 4.5 Variable transmembrane pressure with time by fixed permeate flow at 600 L/h of long term experiment for surface water (Adjust permeate flow before and after backwashing)

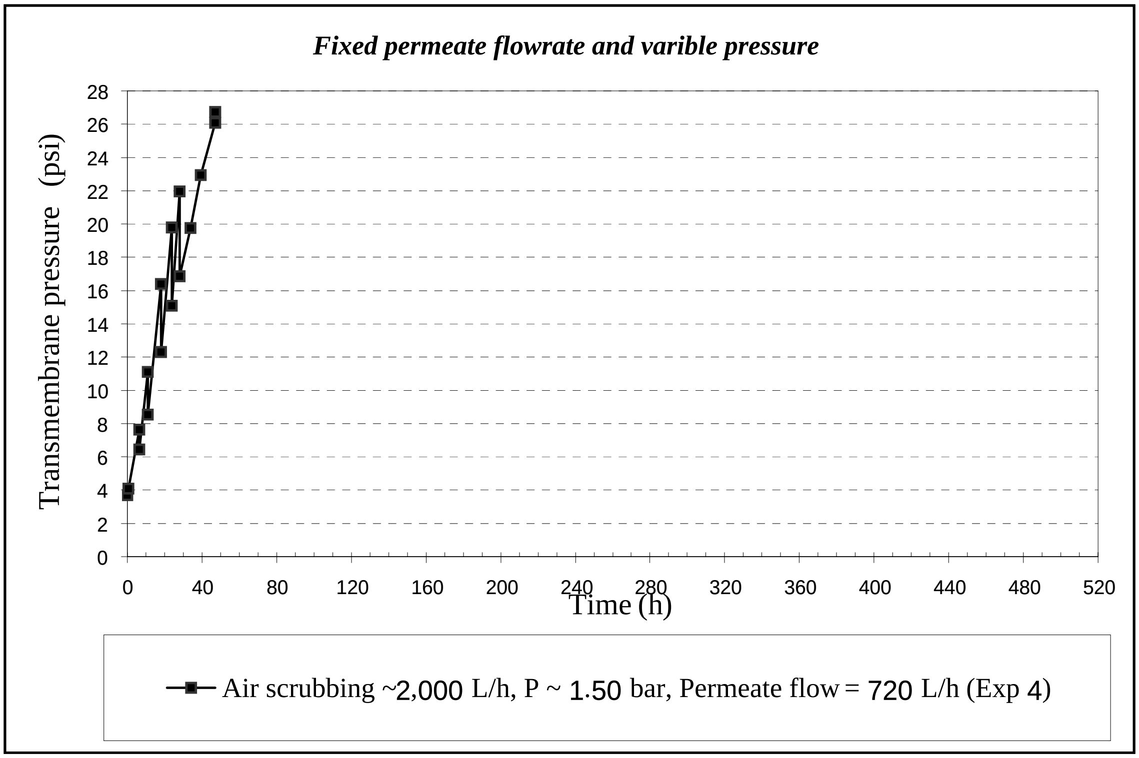


Figure 4.6 Variable transmembrane pressure with time by fixed permeate flow at 720 L/h of long term experiment for surface water (Adjust permeate flow before and after backwashing)

From Figure 4.4, 4.5 and 4.6 show the difference of TMP before and after backwashing, which was increased with time in all the permeate flow rate. For example, permeate flow of 480 L/h, the difference at three hour running was 0.25 psi but at 106 hour running it was 5.55 psi. The reason is that some of the material fouling could not be removed completely from the membrane by backwashing and accumulation over a period of time, which caused increasing transmembrane pressure along with time. At the certain value of TMP, which was 28 psi for this system, the chemical cleaning was required.

As depicted in Figure 4.7, different parameter in experiment 1 and 2 was air-scrubbing volume, which were 1,000 L/h and 1,600 L/h respectively. The trend of increasing transmembrane pressure of experiment 1 was higher than experiment 2 even though the initial TMP were almost the same. As a comparison, at 60 hours of running, TMP of experiment1 was around 20 psi but TMP of experiment 2 was only 16 psi. In the other way of comparison, experiment 2 could be run for 470 hours, where TMP increased to 26 psi but experiment1 could be run only for 60 hours. The possible reasons are the accumulation of rejected materials on the membrane surface which often leads to a decline in the permeate flux or increasing of TMP with over time. Backwashing is a mechanical cleaning, which is used to remove these materials. It was found from these experiments that, higher the scrubbing volume and fouling removal, lower the increasing TMP.

Experiment 2, 3 and 4 were used to compare the effects of permeate flow rate. These experiments were stopped running when TMP reached to 28 psi. The running hours of this system were 479.5, 210.5 and 47.5 h for permeate flow 480 L/h, 600 L/h, and 720 L/h respectively. In comparison between experiment 3 and 4, only the permeate flow was different, while the other factors were the same. It was found that, when the permeate flow increased to 20 % the running time decreased to 77.4 % shows that the permeate flow is one of the most important factor, which influences to the membrane fouling.

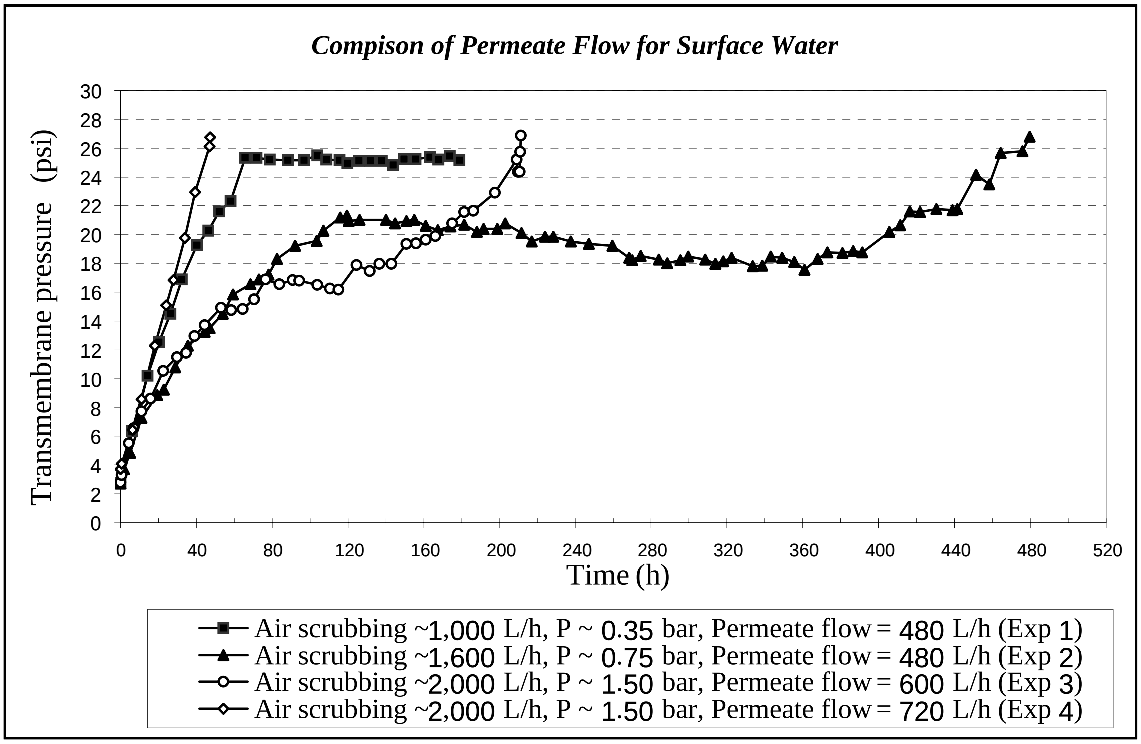
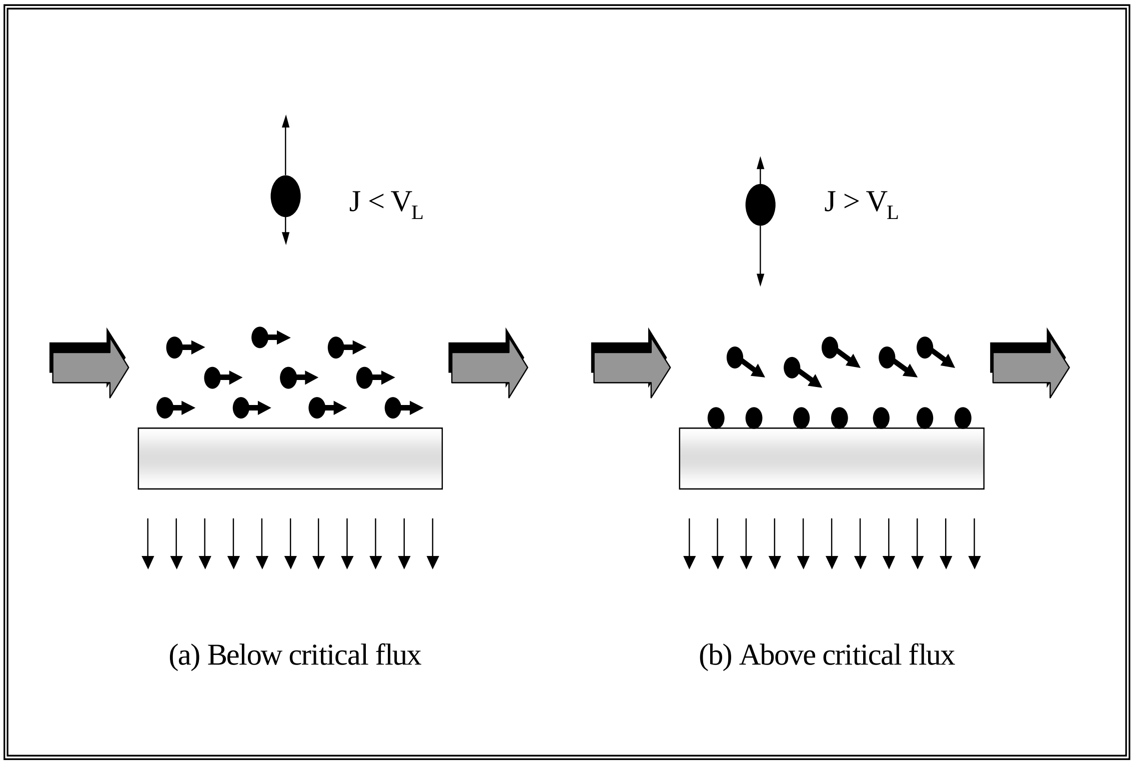


Figure 4.7 Variable transmembrane pressure with time by fixed permeate flow of long term experiment for surface water

Two concepts, which explaines about fouling and critical flux are described below. First concept, which was propsed by Belfort (1980) is when the lift velocity (V_L) at the colloidal cake surface equals or exceeds the oppositely-directed membrane permeation velocity (J), fouling would not be expected to occur. Based on this theory, if J is less than V_L, particles will not deposit on the membrane surface, which is shown in Figure 4.8 (a). This situation is below critical flux. On the other hand, as shown in Figure 4.8 (b), the deposition of particles occurs when J exceeds V_L. The latter can be assumed as above critical flux conditions. Thus, critical flux is a permeation flux over which the particles start to deposit on the membrane surface; but below this value, deposition of particles does not occur. This value of critical flux is equivalent to the lift velocity; $V_L = J$.

The other concept, which was stated by Field et at (1995) shows that, there exists a flux below which a decline of flux with time does not occur; but above this flux, the fouling is observed. According to this definition, the decline of flux with time is the criteria for the critical flux. Although higher permeation velocity (J) (higher than the lift velocity (V_L)) forces the particles to deposit on the membrane surface, according to this definition, this flux can be assumed below the critical flux if the deposit layer does not interfere with the flux, which is show in Figure 4.9 (b). At this condition, the flux is equal to the clean water flux (with the same TMP). Figure 4.9 (c) presents the case, where the flux is above the critical value. Here, the particles deposit on the surface or into the pores of the membrane, causing a flux decline. This flux decline can be due to reversible effects such as cake and gel layers, or due to irreversible effects such as adsorption, pore clogging and membrane compactness.



(a) Below critical flux

(b) Above critical flux

Figure 4.8 Different circumstance of CFMF: below and above critical flux (Kwon and Vigneswaran, 1998)

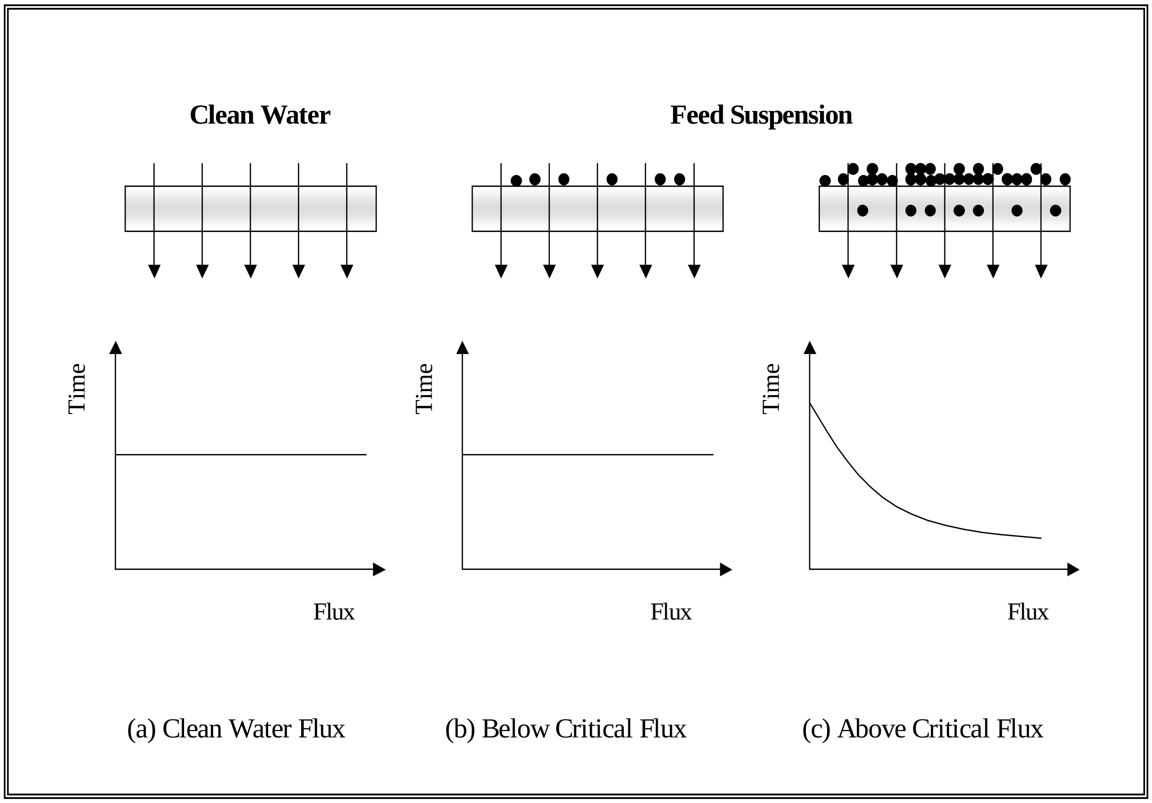


Figure 4.9 Comparison of the flux with clean water flux, below and above critical flux (Kwon and Vigneswaran, 1998)

These definitions of critical flux and deposition of fouling on membrane surface, can also be used to explain the effect of permeate flux rate for the next two feed water types, which were surface water where Kaolin clay was added and treated wastewater. The results of these experiments are shown in the next section.

4.4.2 Comparison of Permeate Flow: Surface Water with Kaolin Clay

Kaolin clay is an inorganic material, in which the particle size range between 0.1-4.0 μm. The surface water, which was AIT canal, was added by Kaolin clay to investigate the effect of higher suspended solid. The relation of Kaolin clay concentration and turbidity is shown in Appendix B. The operating conditions of the three surface water and Kaolin clay experiments are shown in Table 4.4. The increasing transmembrane pressure with time is presented in Figure 4.10. It shows that the difference of TMP before and after backwashing, which was increased with time in all the permeate flow rate. For example, in permeate flow of 480 L/h, the difference at five hour running was 0.4 psi but at 271 hour running it was 8.85 psi. The initial of TMP for all the permeate flow were almost the same. The TMP of permeate flow 480 L/h was gradually increasing and stopped at 500.5 hours of running. For permeate flow 600 L/h and 720 L/h, the running hours were 127 and 19.5 hours, respectively. The possible reasons have been described in section 4.4.1.

Table 4.4 Operating Conditions of Long Term Experiment for Surface Water and Kaolin Clay

Description	***Operating conditions***		
	Experiment 1	***Experiment 2***	***Experiment 3***
1. Membrane module	USV-3003		
2. Raw water	Surface Water plus Kaolin Clay		
3. Feed flow rate	1,500 L/h		
4. Permeate flow rate	480 L/h	600 L/h	720 L/h
5. Filtration / Reverse filtration	Filtrate 30 min / Backwash 30 sec / Flushing 30 sec		
6. Backwashing method	Water & NaClO, 3 ppm & air 1.5 bar (2,000 L/h)		

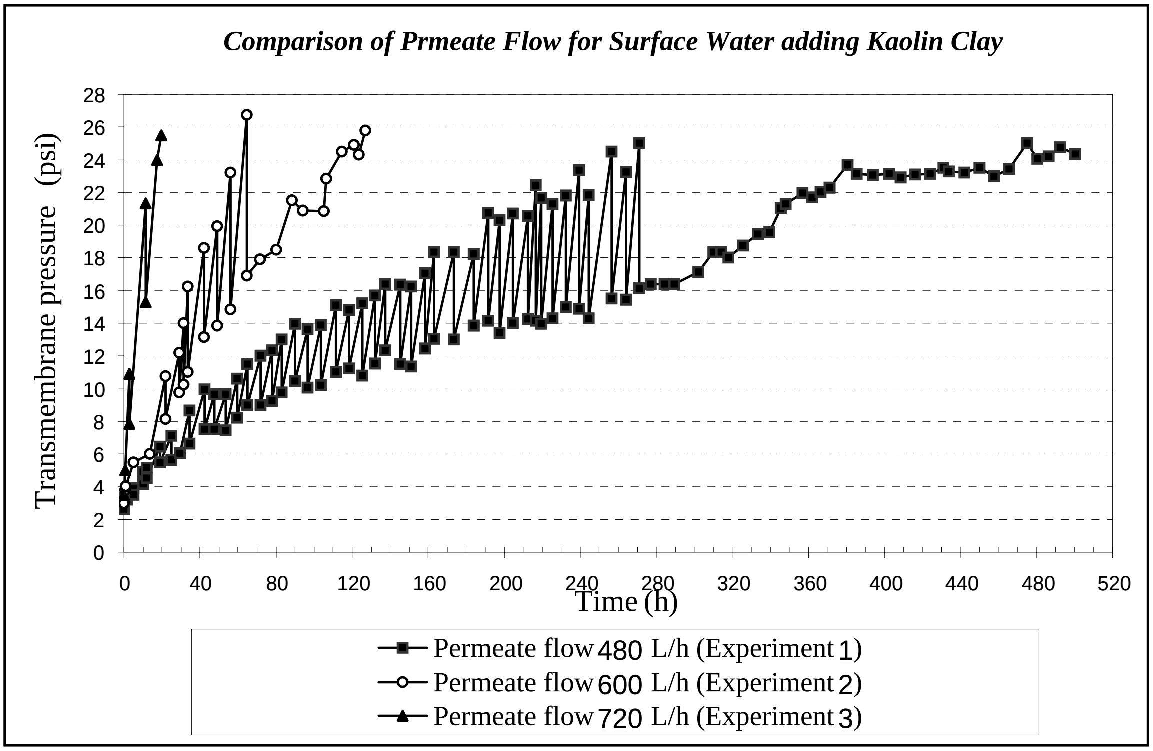


Figure 4.10 Variable transmembrane pressure with time by fixed permeate flow of long term experiment for surface water plus kaolin clay (Adjust permeate flow before and after backwashing)

4.4.3 Comparison of Permeate Flow: Treated Wastewater

Treated wastewater for three experiments was brought from effluent of AIT treatment pond. When comparing with surface water, it is higher in both organic matter and suspended solids. Biofouling is one of the main problems of this type of water to membrane. In this case, we dosed NaClO 5 mg/L as Cl on pipe before storing in the storage tank and filtered through membrane. The water characteristics are shown in the section 4.5.7. The operating conditions for three treated wastewater experiments are shown in Table 4.5. The increasing transmembrane pressure with time is presented in Figure 4.11. It shows that the difference of TMP before and after backwashing, which was increased with time in all the permeate flow rate. For example, in permeate flow of 480 L/h, the difference at two hour running was 3.1 psi but at 46.5 hour running it was 15.35 psi. The initial of TMP for all the permeate flow were almost the same. The TMP of permeate flow 480 L/h was gradually increasing and stopped at 301 hours of running. For permeate flow 600 L/h and 720 L/h, the TMP was highly increasing and the running hours were 127 and 19.5 hours, respectively. The possible reasons have been described in section 4.4.1.

Table 4.5 Operating Conditions of Long Term Experiment for treated wastewater

Description	***Operating conditions***		
	Experiment 1	***Experiment 2***	***Experiment 3***
1. Membrane module	USV-3003		
2. Raw water	Treated Wastewater		
3. Feed flow rate	1,500 L/h		
4. Permeate flow rate	480 L/h	600 L/h	720 L/h
5. Filtration / Reverse filtration	Filtrate 30 min / Backwash 30 sec / Flushing 30 sec		
6. Backwashing method	Water & NaClO, 3 ppm & air 1.5 bar (2,000 L/h)		

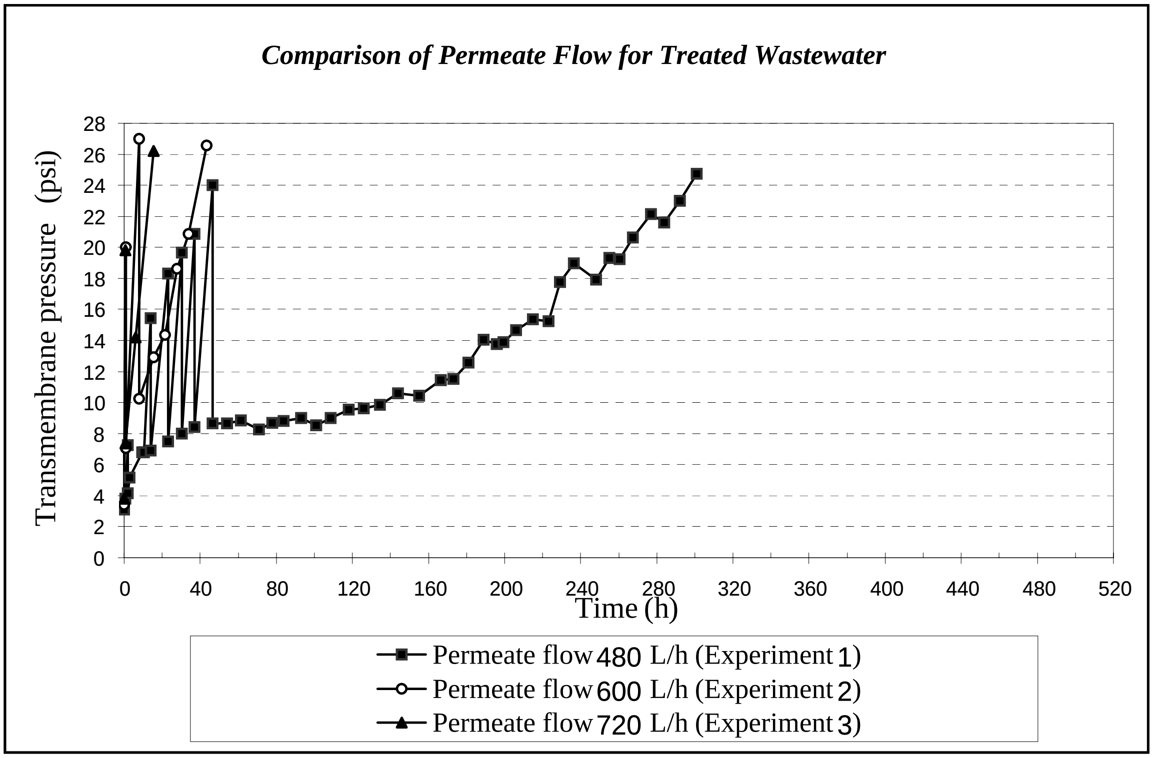


Figure 4.11 Variable transmembrane pressure with time by fixed permeate of treated wastewater long-term experiment (Adjust permeate flow before and after backwashing)

4.4.4 Permeate Flux Reducing with Time in a Cycle of Filtration: Various Permeate Flow Comparison

The objective of these experiments is to investigate the permeate flow reducing with time in a cycle of filtration, which was 30 minutes. The initial permeate flow, which were used in these experiments were 480 L/h, 600 L/h and 720 L/h.

Figure 4.12 and 4.13 shows the permeate flow reduction with time, in a cycle of filtration of surface water and surface water adding Kaolin clay. Flow decreasing in all permeates flow of surface water and surface water adding Kaolin clay were 18-20 % and 22-26 % respectively, which had a small difference in all of them. The possible reasons were as follows:

1. Surface water was low in organic content and suspended solids. The rejected material when compared to the three permeate flow were not so different. That caused a small difference of flow decreasing in a cycle between all the permeate flow.

2. When Kaolin clay was added to surface water, it had a smaller effect on permeate flow, which declined compared to natural organic matter. Mallevialle et al, (1996) had stated that humic acids and other naturally occurring organic materials can have a much greater effect on permeate flux than clays or other inorganic colloids, even at lower mass concentrations.

But, why the running hours, which could be run in all various permeate flow were different?

3. The reason was that running hours in all the permeate flow from the both feed water types were different while flow reduction in a cycle of filtration had a small difference, which is described below. Fouling could be mainly divided in to two types, which namely internal and external clogging. Higher permeate flow could influence to be internal clogging, which is difficult to remove by reverse filtration and become increased faster in TMP.

As depicted in Figure 4.14, we can observe a difference in flow decrease between various permeate flow. Treated wastewater was high in both organic material and suspended solid, which had a fast decrease in the permeate flow when the cycle just started of filtration and kept decreasing because accumulation of fouling was near, on and in membrane. The accumulation of fouling also caused in transmembrane pressure increase. Figure 4.15 shows the initial TMP of three permeate flow were almost the same, which was 16.5-17.1 psi. After the system had run, it could be obviously observed a difference in TMP increase between various permeate flow. Higher permeate flow caused high flux decrease and high TMP increase because of high amount of materials that retain in the system. Therefore proper operating conditions for this kind of feed water should be adopted at low permeate flow as a critical flux concept or a shorter filtration time.

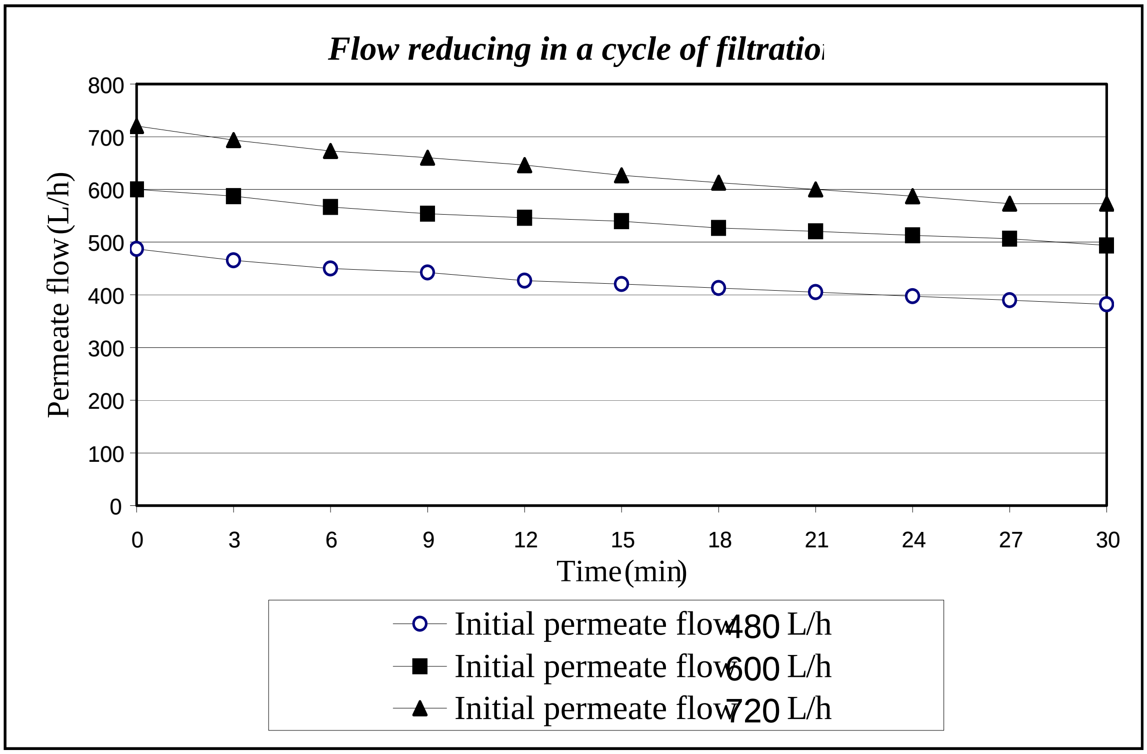


Figure 4.12 Permeate flow reducing with time in a cycle of filtration of Surface Water

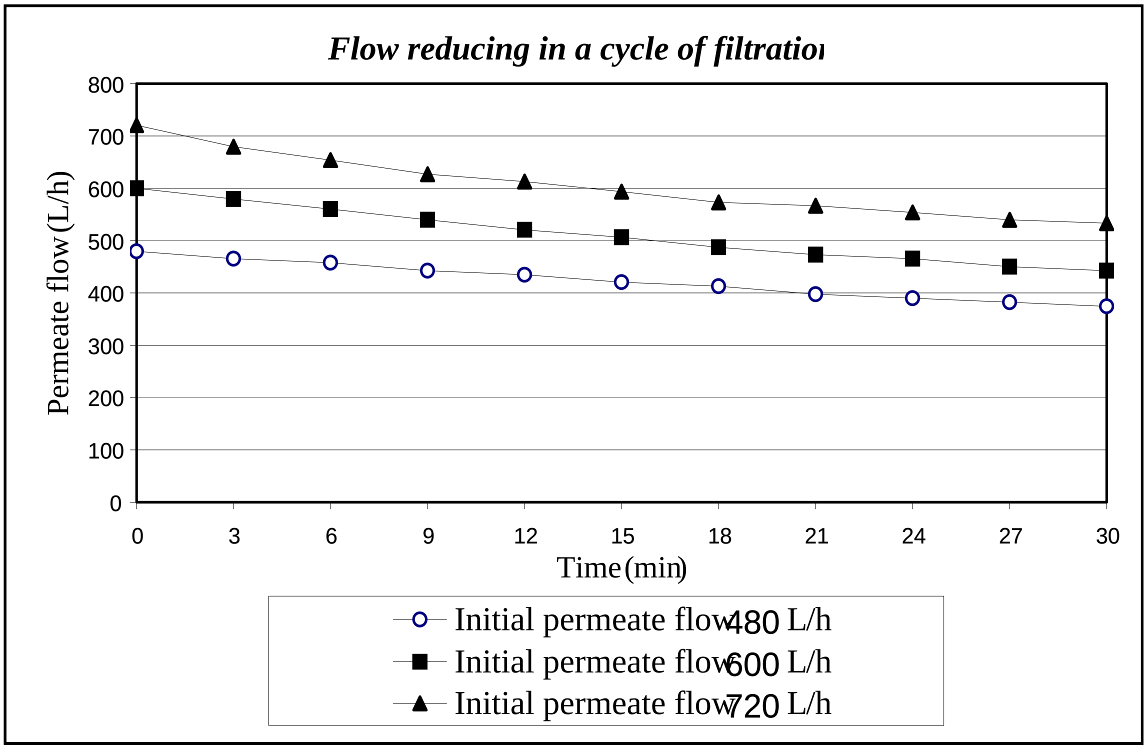


Figure 4.13 Permeate flow reducing with time in a cycle of filtration of Surface Water Plus Kaolin Clay

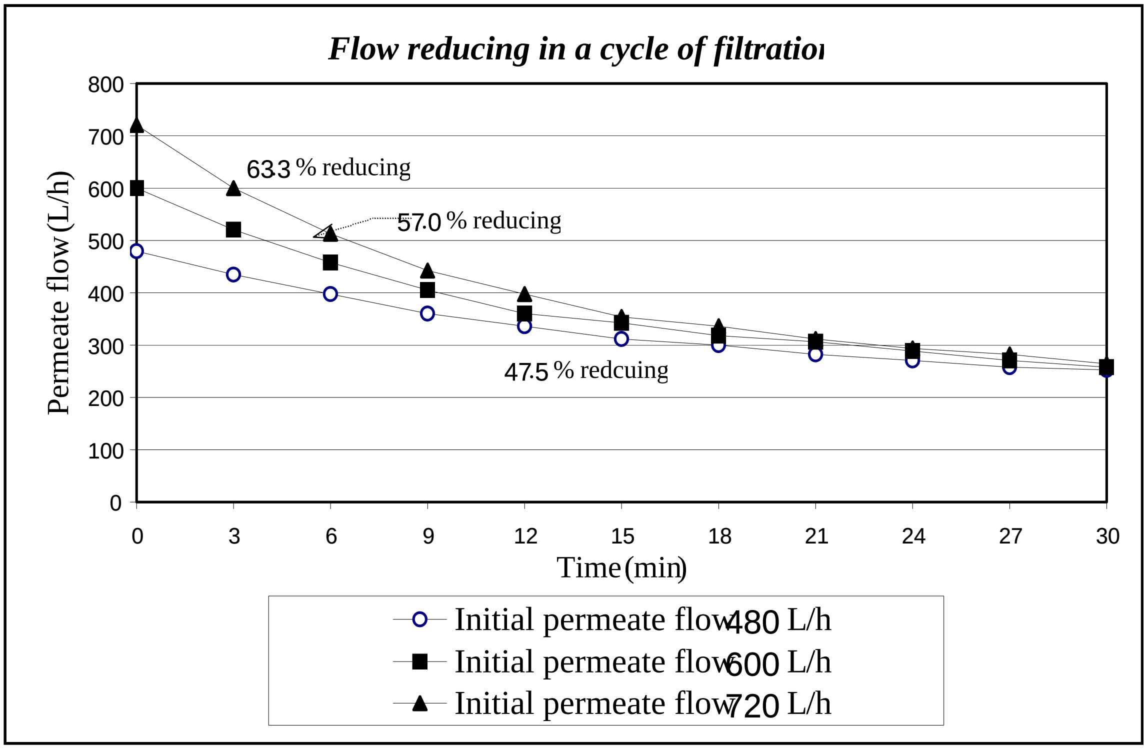


Figure 4.14: Permeate flux reducing with time in a cycle of filtration of Treated Wastewater

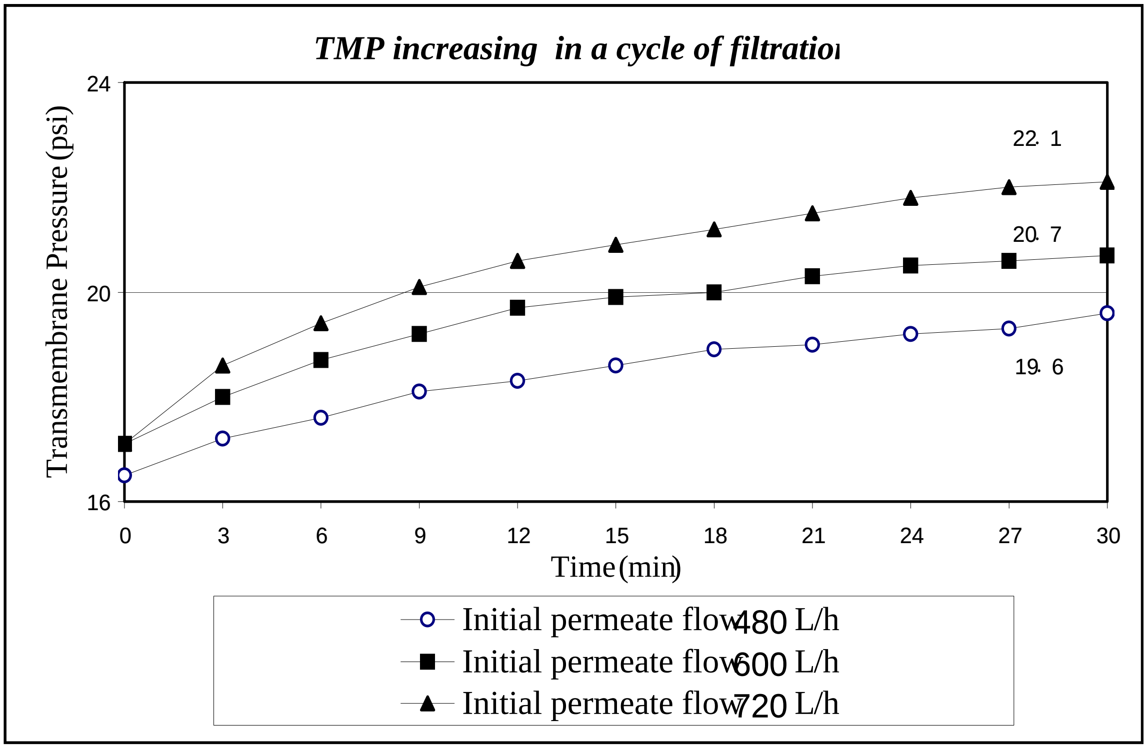


Figure 4.15 Transmembrane pressure with time in a cycle of filtration of Treated Wastewater

4.4.5 Comparison Between Different Types of Feed Water

Different feed water have different water characteristics, which is shown in the section 4.5.7. One expected that different water quality of feed water, effect to the stability of membrane operation. Therefore the comparison between surface water, surface water adding Kaolin clay, and treated wastewater were done in three permeate flow rate, which were 480 L/h, 600 L/h and 720 L/h. The operating conditions of experiments are shown in Table 4.6, 4.7 and 4.8. Variable transmembrane pressure with time, which was recorded before and after backwashing are shown in Figure 4.16, 4.17, and 4.18.

From Figure 4.16, 4.17 and 4.18, we observed that the difference of transmembrane pressure before and after backwashing of treated wastewater was the highest. For surface water adding Kaolin clay, the difference of TMP was little higher than surface water. For example, at permeate flow 480 L/h and 23 hours running, the difference of TMP of surface water, surface water adding Kaolin clay and treated wastewater were 1.0, 1.5 and 10.8 psi respectively. It was found that treated wastewater was high in both organic matter and suspended solids, which caused high in cake formation and adsorptive fouling. So the running hours was the lowest of all the permeate flow. Surface water adding Kaolin clay had higher suspended solids than surface water alone but organic matters were the same, which was not caused much in adsorptive fouling or internal clogging. Cake formation was high but this kind of fouling could be removed by mechanical cleaning which was water backwashing or air scrubbing. As shown in Figure 4.16, surface water adding Kaolin clay, which was very high in suspended solids could be run longer than surface water alone because of higher volume of air scrubbing, which was used in surface water adding Kaolin clay experiment. Therefore, low organic matters, high-suspended solid or high inorganic matter were not much effect to stability of membrane filtration but required higher volume of air scrubbing or longer time of water backwashing.

Table 4.6 Operating Conditions of Long Term Experiment: 480 L/h Permeate Flow

Description	***Operating conditions***		
	Experiment 1	***Experiment 2***	***Experiment 3***
1. Membrane module	USV-3003		
2. Raw water	Surface water	Surface water plus kaolin	Treated wastewater
3. Feed flow rate	1,500 L/h		
4. Permeate flow rate	480 L/h		
5. Filtration / Reverse filtration	Filtrate 30 min / Backwash 30 sec / Flushing 30 sec		
6. Backwashing method	Water & NaClO 3 ppm & air 0.75 bar (1,600 L/h)	Water & NaClO 3 ppm & air 1.5 bar (2,000 L/h)	Water & NaClO 3 ppm & air 1.5 bar (2,000 L/h)

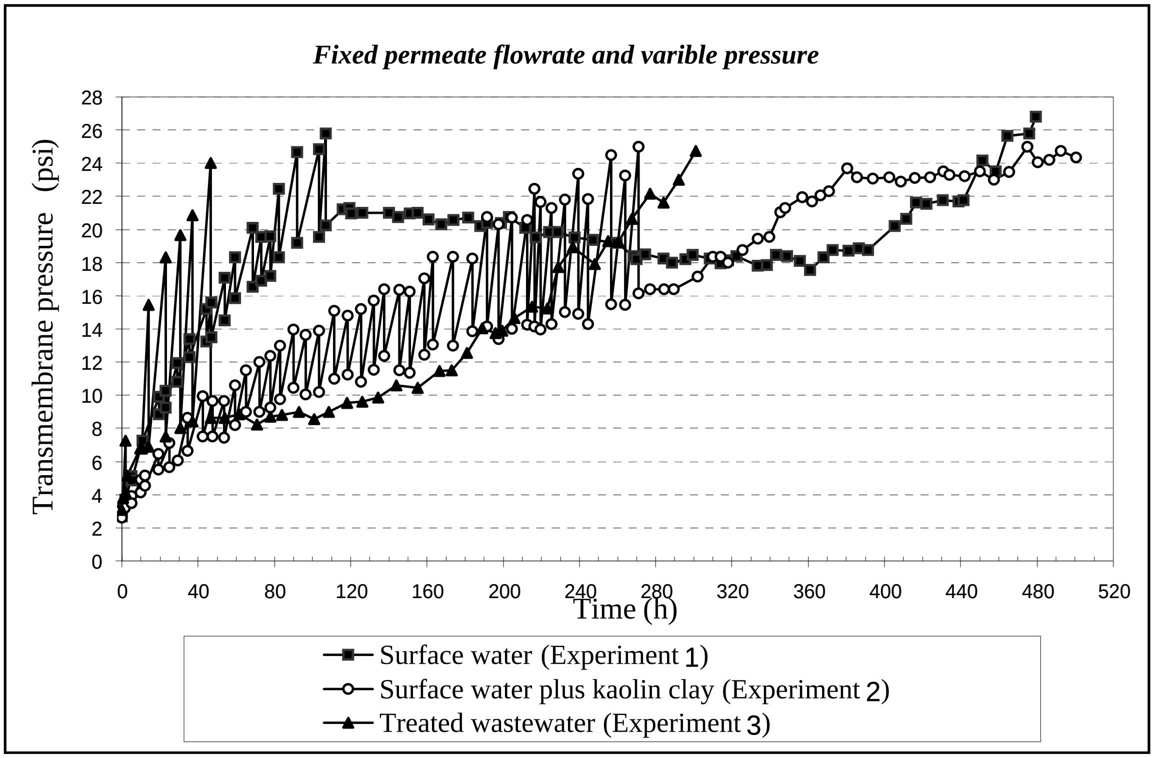


Figure 4.16 Variable transmembrane pressure with time by fixed permeate at 480 L/h of long term experiment (Adjust permeate flow before and after backwashing)

Table 4.7 Operating Conditions of Long Term Experiment: 600 L/h Permeate Flow

Description	***Operating conditions***		
	Experiment 1	***Experiment 2***	***Experiment 3***
1. Membrane module	USV-3003		
2. Raw water	Surface water	Surface water plus kaolin	Treated wastewater
3. Feed flow rate	1,500 L/h		
4. Permeate flow rate	600 L/h		
5. Filtration / Reverse filtration	Filtrate 30 min / Backwash 30 sec / Flushing 30 sec		
6. Backwashing method	Water & NaClO, 3 ppm & air 1.5 bar (2,000 L/h)		

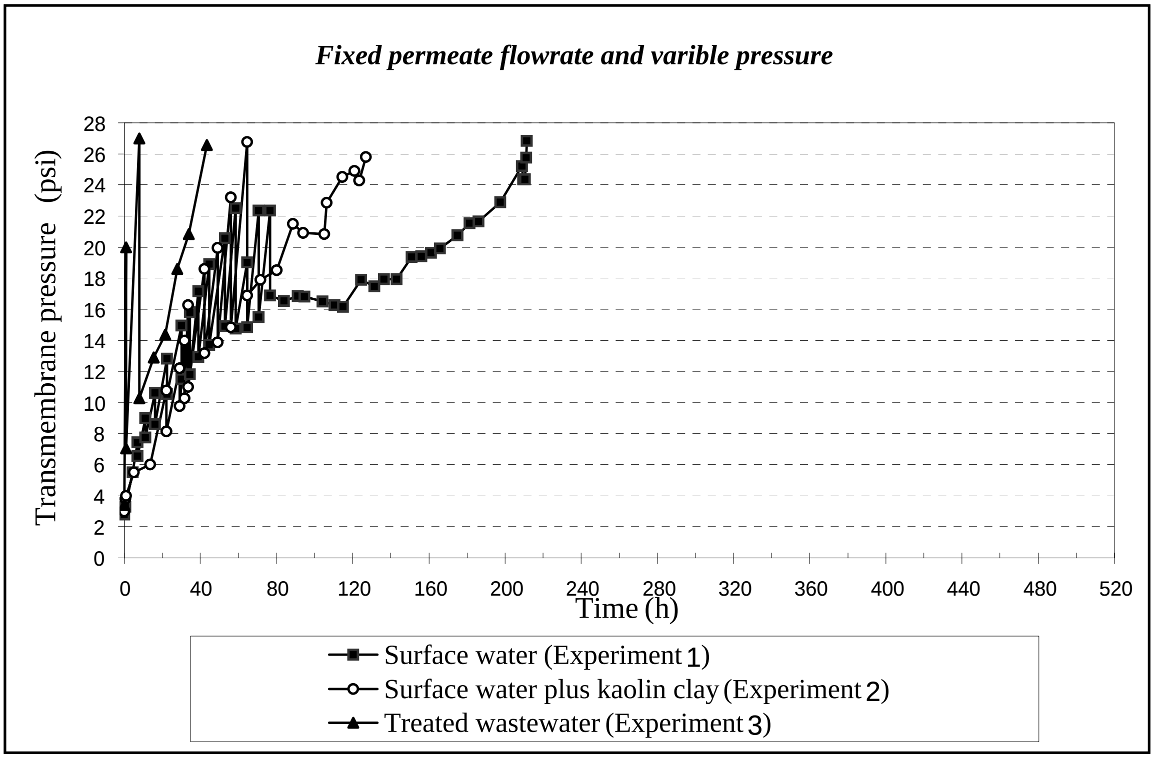


Figure 4.17 Variable transmembrane pressure with time by fixed permeate at 600 L/h of long term experiment (Adjust permeate flow before and after backwashing)

Table 4.8 Operating Conditions of Long Term Experiment: 720 L/h Permeate Flow

Description	***Operating conditions***		
	Experiment 1	***Experiment 2***	***Experiment 3***
1. Membrane module	USV-3003		
2. Raw water	Surface water	Surface water plus kaolin	Treated wastewater
3. Feed flow rate	1,500 L/h		
4. Permeate flow rate	720 L/h		
5. Filtration / Reverse filtration	Filtrate 30 min / Backwash 30 sec / Flushing 30 sec		
6. Backwashing method	Water & NaClO 3 ppm & air 1.5 bar (2,000 L/h)	Water & NaClO 3 ppm & air 1.5 bar (2,000 L/h)	Water & NaClO 3 ppm & air 1.5 bar (2,000 L/h)

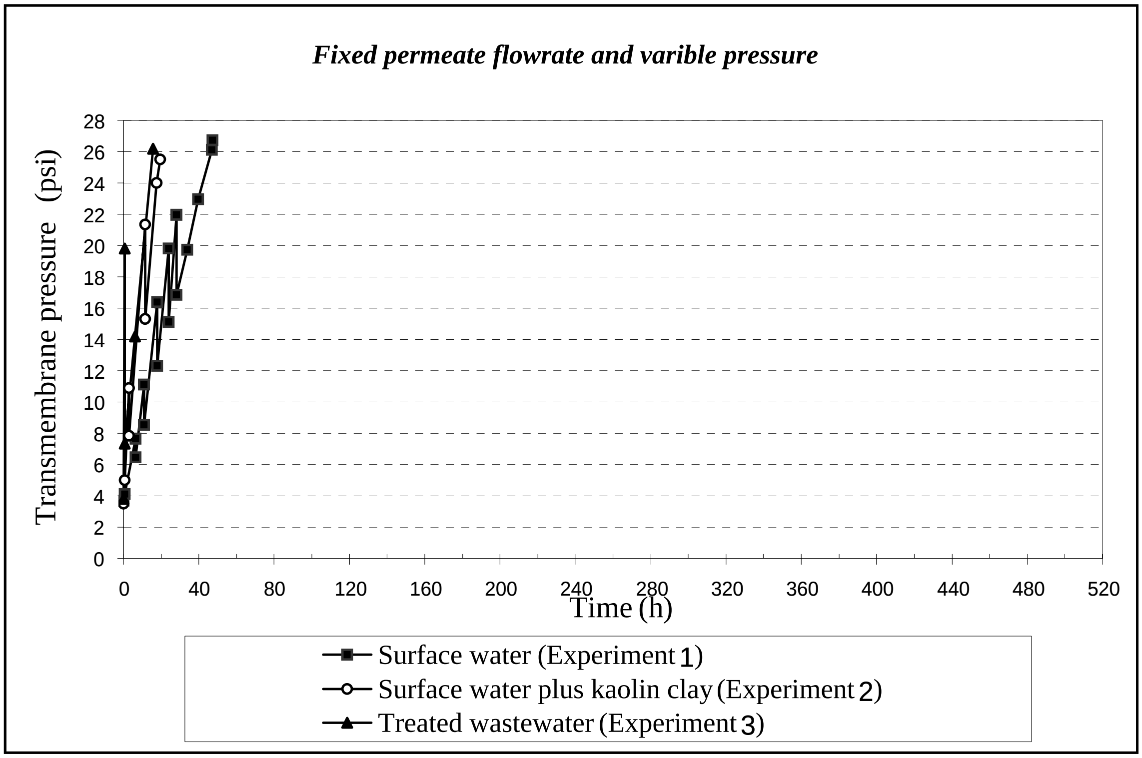


Figure 4.18 Variable transmembrane pressure with time by fixed permeate at 720 L/h of long term experiment (Adjust permeate flow before and after backwashing)

4.4.6 Permeate Flow Reduction within a Filtration Cycle: Various type of Feed Water

Mechanically reversible fouling is due to accumulation of particles, precipitates and/ or organic matter at the water membrane interface. In MF and UF processes, this material is removed from the membrane by either flushing or backwashing. It is important to evaluate the period at which the mechanical cleaning should be performed in order to know the down periods and water losses (Mallevialle et al., 1996). Therefore, permeate flow reduction with time in a cycle of filtration were done and compared between three types of feed water to study how flux declined between each feed water. As shown in Figure 4.19, 4.20, and 4.21, it was found that, flow reduction in surface water and surface water adding Kaolin clay had a small difference but the big difference was observed in treated wastewater. The reason has been already explained in section 4.4.5. From these experiments we found that the treated wastewater should be run in shorter time of filtration to prolong running hours and reduce water losses of the system. Hence, the shorter filtration experiments of treated wastewater were done and the result is shown in the next section.

From the above experiments we can summarize the total running hours in Figure 4.22. The relation of various permeate flux and running hours was not an increasing linear curve. It meant that we cannot expect to get higher water production by increasing permeate flow rate because of high fouling occurred and high pressure driven through the membrane. The other point to be noted is the irreversible fouling, which might be occurred and damage the membrane in the long-term running by using higher permeate flow rate running.

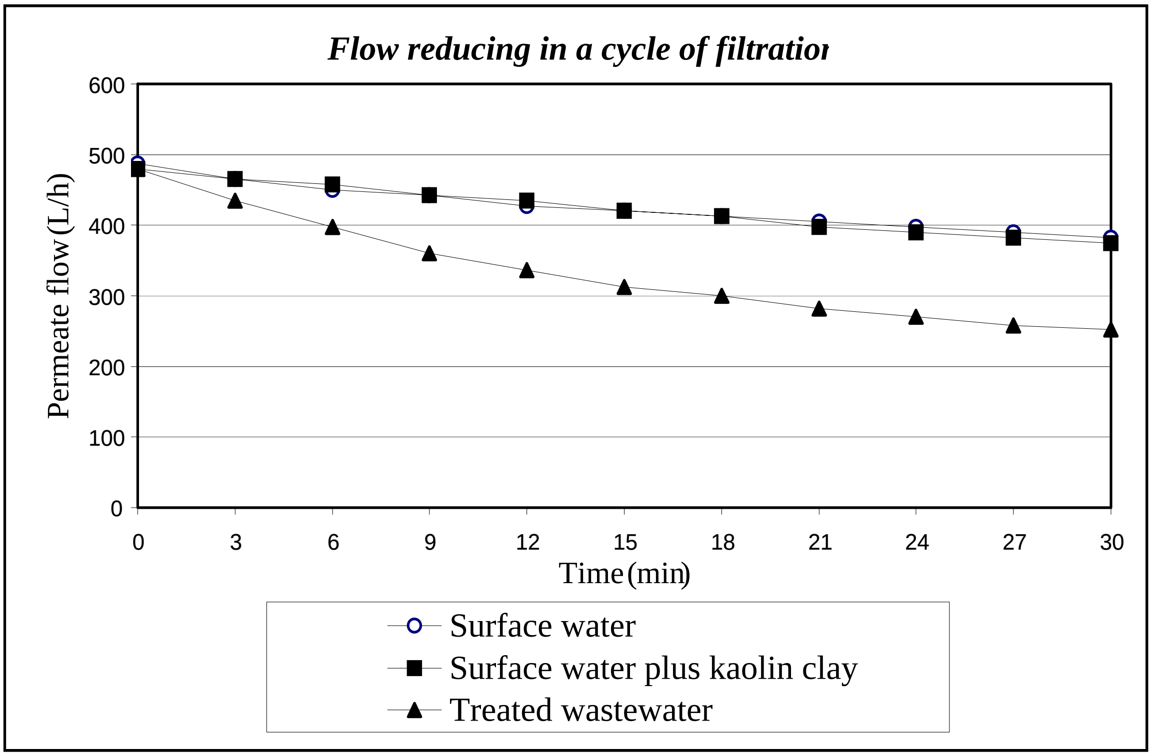


Figure 4.19 Permeate flow reducing with time in a cycle of filtration at 480 L/h

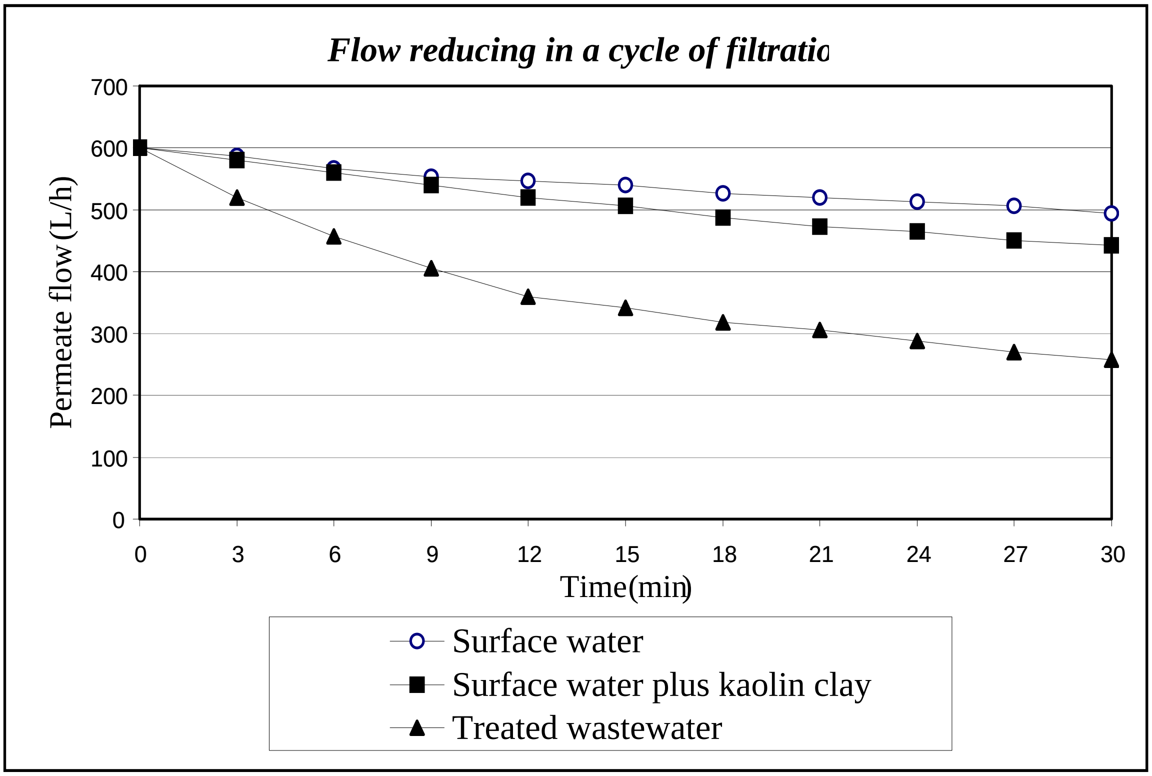


Figure 4.20 Permeate flow reducing with time in a cycle of filtration at 600 L/h

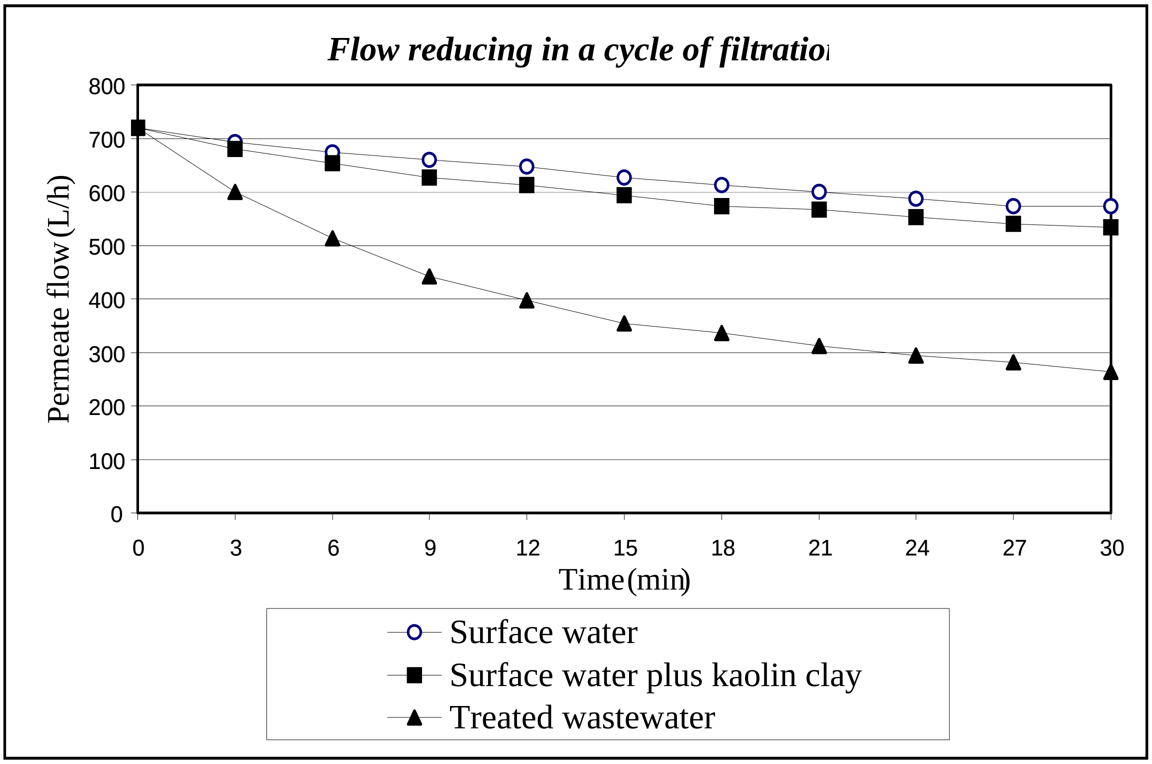


Figure 4.21 Permeate flow reducing with time in a cycle of filtration at 720 L/h

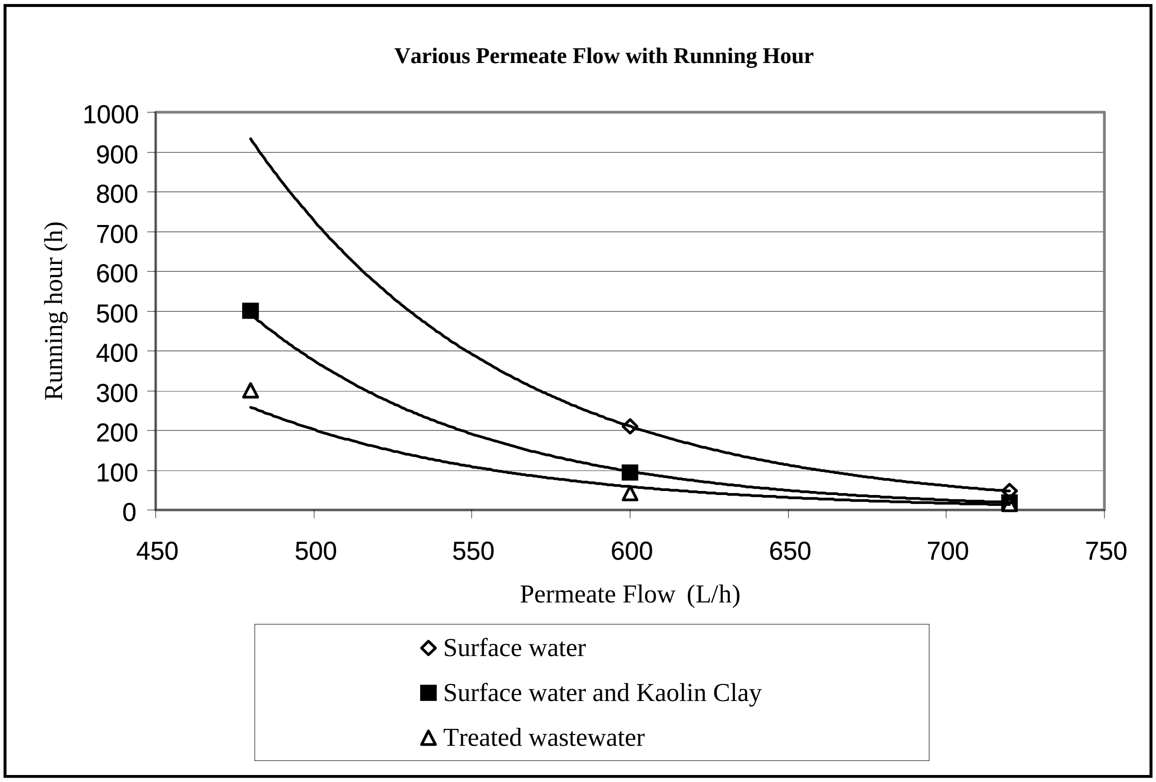


Figure 4.22 Relation of permeate flow with running hour in different feed water

4.4.7 Effect of Filtration Time: Treated Wastewater

The results of permeate flow, which reduces with time in a filtration cycle has been presented in section 4.4.4 and 4.4.6. For the treated wastewater, there was a rapid decrease in a permeate flow when compared to surface water and surface water with Kaolin clay. The treated wastewater is high in both organic matters and suspended solids, which leads to high fouling problem, rapid flow reduction. In addition, inappropriate process such as longer filtration time, shorter reverse filtration time and smaller in volume of air scrubbing, could increase the mechanical and chemical fouling tendency. Therefore, these experiments were conducted to investigate the effect of filtration time.

The operating conditions of different filtration time of treated wastewater are shown in Table 4.9 and 4.10. Figure 4.23 and 4.25 show the difference of transmembrane pressure before and after backwashing. It could be observed that the difference of TMP before and after backwashing of 15 minutes filtration time was lower than 30 minutes filtration time. For example at around 8 hours running, the difference of TMP of 15 minutes filtration time was 3.55 psi but for 30 minutes filtration time was 10.75 psi. The reason is that the materials fouling accumulated on the membrane are decreased permeate flux over a period of time. To control the permeate flux constant, increased feed pressure must be supplied. It meant that the less filtration time, the less material fouling retained in the membrane filtration system and the less TMP required to control the permeate flux constant.

As presented in Figure 4.24 and 4.26, the initial TMP was almost the same in all the experiments. For a permeate flow of 600 L/h, with the running hours of 15 minutes and 30 minutes, the filtration time were 48.5 hours and 74 hours respectively. For a permeate flow of 720 L/h, with the running hours of 15 minutes and 30 minutes, the filtration time were 15.5 hours and 27 hours respectively. Running hours improved when the filtration time was reduced to 15 minutes. The improved percentage of 600 L/h and 720 L/h were 70.1 % and 74.2 % respectively.

Since the mechanical cleaning was done more often, the product water that was used for backwashing had high losses. Therefore, compared to the higher production water got from longer running hours, and the higher production water loss from often of backwashing, it is found that the total volume of water recovery from 15 minute filtration was higher than 30 minute filtration. The results are shown in Section 4.7.1, Table 4.11. For a permeate flow of 600 L/h, production water from experiment of 15 minutes and 30 minutes filtration time were 26.1 m^3 and 44.4 m^3, while water loss was 0.7 m^3 and 2.4 m^3 respectively. For permeate flow of 720 L/h, production water from experiment of 15 minutes and 30 minutes filtration time was 11.2 m^3 and 19.4 m^3, while water losing were 0.3 m^3 and 0.9 m^3 respectively. It meant that we could increase in the totally permeate water production 65 % and 72 % by reducing the filtration time from 30 minutes to be 15 minutes when permeate flow were 600 L/h and 720 L/h respectively.

Table 4.9 Operating Conditions of Long Term Experiment: Effects of Filtration Time of 600 L/h

Description	***Operating conditions***	
	Experiment 1	***Experiment 2***
1. Membrane module	USV-3003	
2. Raw water	Treated Wastewater	
3. Feed flow rate	1,500 L/h	
4. Permeate flow rate	600 L/h	
5. Filtration / Reverse filtration	Filtrate 30 min / Backwash 30 sec / Flushing 30 sec	Filtrate 15 min / Backwash 30 sec / Flushing 30 sec
6. Backwashing method	Water & NaClO 3 ppm & air 1.5 bar (2,000 L/h)	

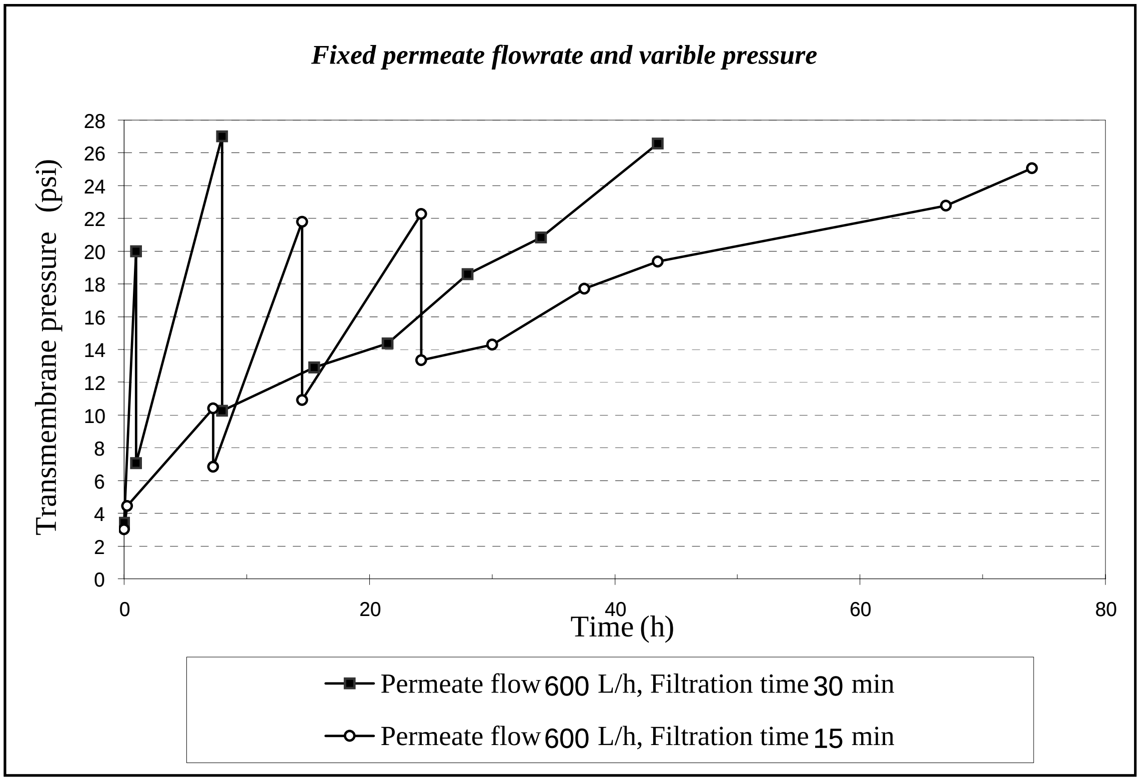


Figure 4.23 Variable transmembrane pressure with time by fixed permeate flow at 600 L/h of treated wastewater long-term experiment: comparing by filtration time (Adjust permeate flow before and after backwashing)

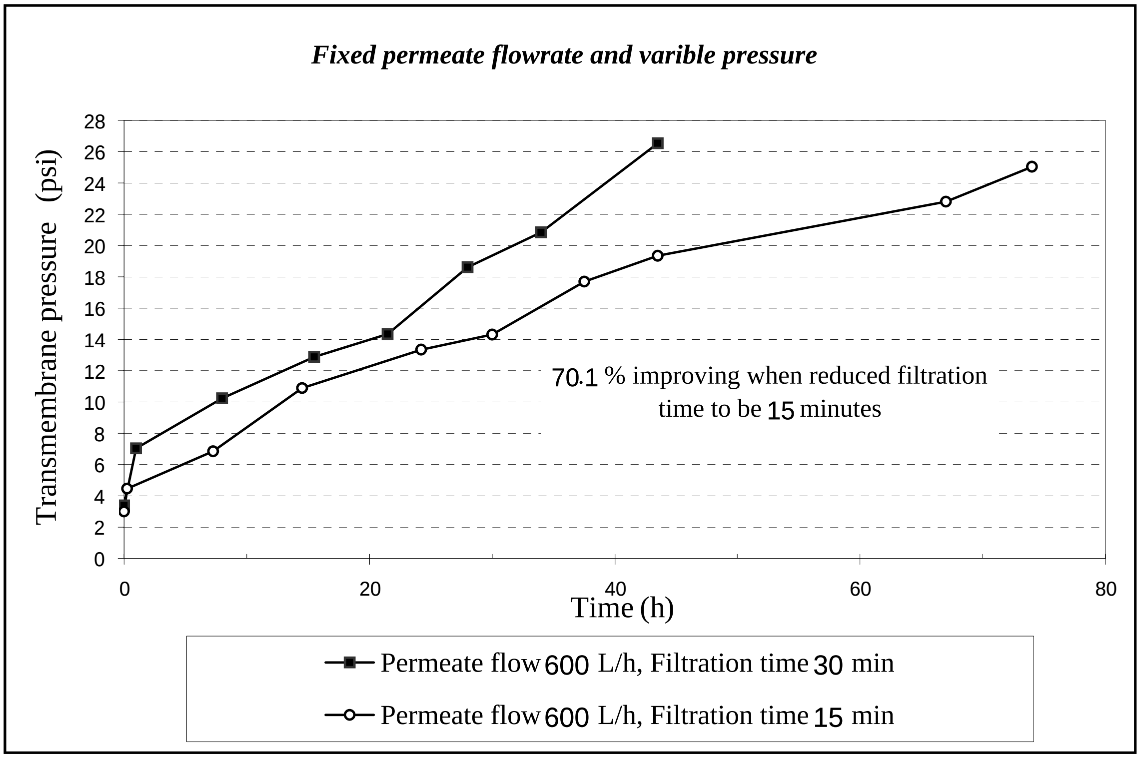


Figure 4.24 Variable transmembrane pressure with time by fixed permeate flow at 600 L/h of treated wastewater long-term experiment: comparing by filtration time (Adjust permeate flow after backwashing)

Table 4.10 Operating Conditions of Long Term Experiment: Effects of Filtration Time of 720 L/h

Description	***Operating conditions***	
	Experiment 1	***Experiment 2***
1. Membrane module	USV-3003	
2. Raw water	Treated Wastewater	
3. Feed flow rate	1,500 L/h	
4. Permeate flow rate	720 L/h	
5. Filtration / Reverse filtration	Filtrate 30 min / Backwash 30 sec / Flushing 30 sec	Filtrate 15 min / Backwash 30 sec / Flushing 30 sec
6. Backwashing method	Water & NaClO 3 ppm & air 1.5 bar (2,000 L/h)	

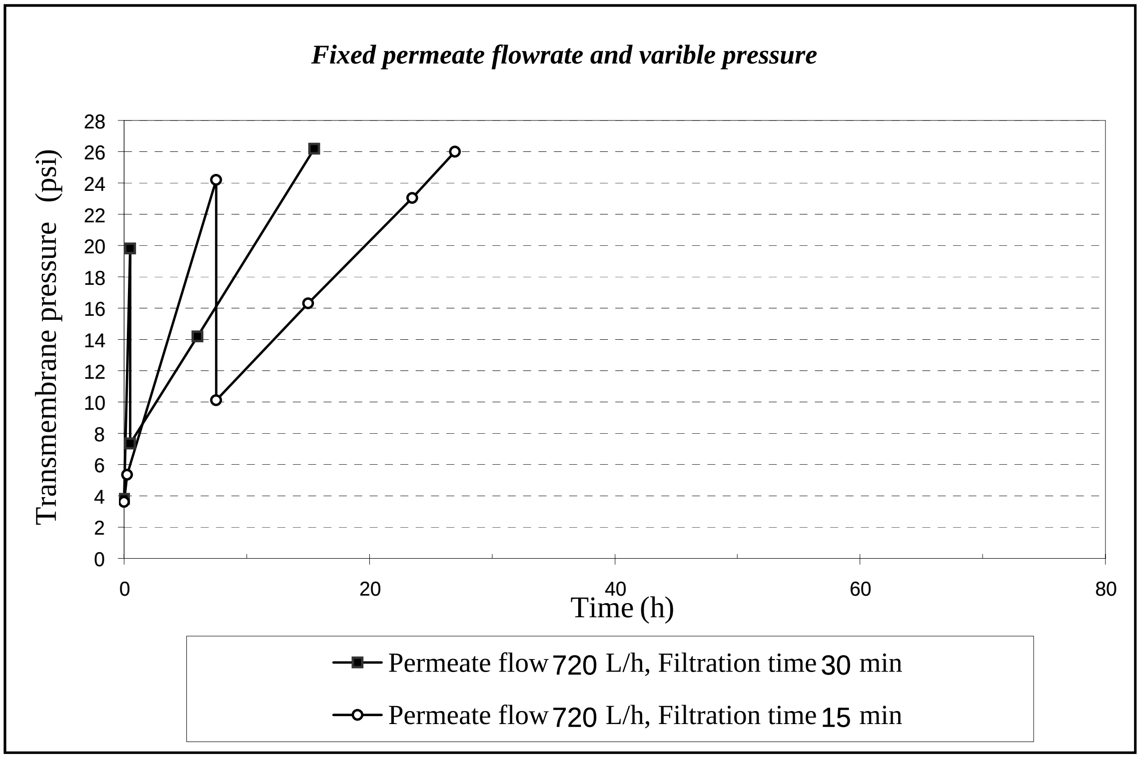


Figure 4.25 Variable transmembrane pressure with time by fixed permeate flow at 720 L/h of treated wastewater long-term experiment: comparing by filtration time (Adjust permeate flow before and after backwashing)

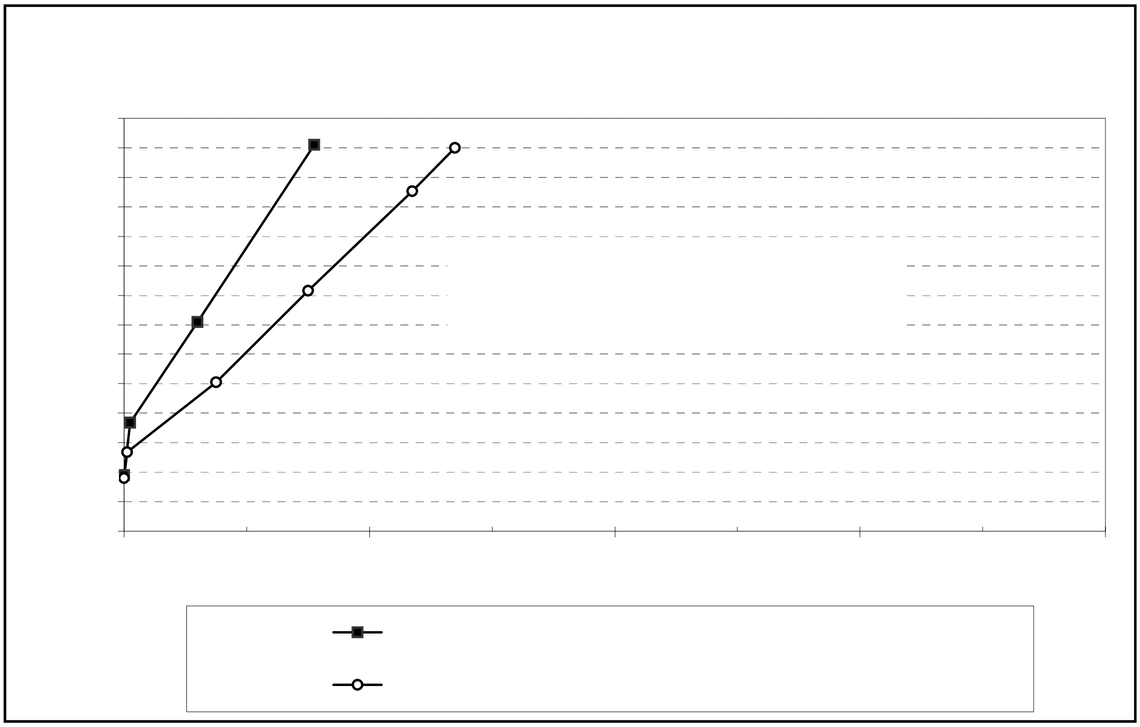


Figure 4.26 Variable transmembrane pressure with time by fixed permeate flow at 720 L/h of treated wastewater long-term experiment: comparing by filtration time (Adjust permeate flow after backwashing)

4.5 Water Quality Monitoring

Long-term evaluation of membrane performance is used to generate a large enough database on the treatment efficiency to investigate the reliability of the system. Turbidity and suspended solid are the most commonly used method for measuring the performance of filtration systems. Organic matter is the significant factor, which effected to the membrane performance that was weekly examined by COD and TOC parameters. In surface water, which was pond or canal and treated wastewater, algae are high in amount. Hence, algae and color was also analyzed in long-term experiment. pH and temperature were measured twice a day because they are the operation control parameters, which are indispensable to prevent troubles to membrane material. Other characteristics, which were Fe, Mn, hardness, BOD, and fecal coliform, were evaluated to compare the water quality and derive the removal efficiency of membrane filtration system between two different sources of feed water. Figure 4.27 shows the visual observation of water quality. The permeate water was obviously more clear than the raw water, which was treated wastewater.

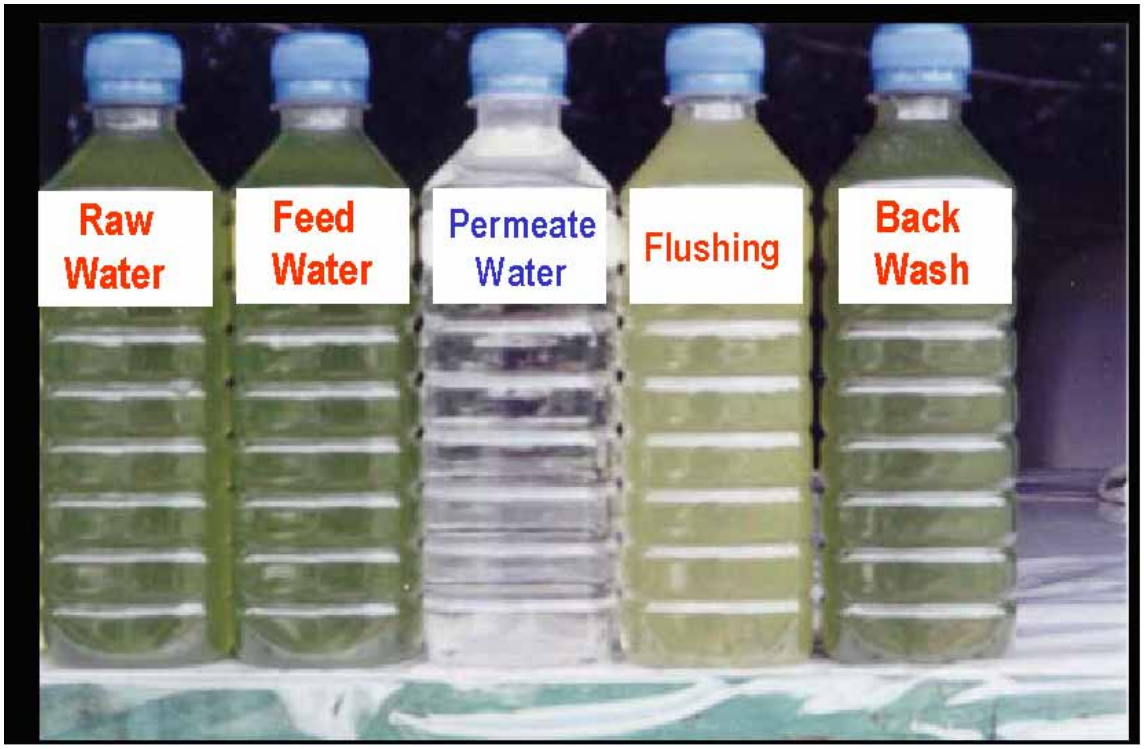


Figure 4.27 Water Quality in Case of Secondary Treated Wastewater as the Raw Water

4.5.1 pH

From the standard operating condition of this membrane filtration system, pH range should be 2-10 during the operation. The pH results of this long-term experiment varied in a small range. The pH of influent and effluent of surface water and treated wastewater were 7.7-8.2 and 8.0-8.4 respectively, which were in range of standard operating conditions. These results made us to ensure that membrane was not damaged by high intensity of acid and alkaline.

4.5.2 Temperature

From the standard operating condition of this membrane filtration system, temperature range should be less than 40 °C during the operation. The temperature results of this long-term experiment varied in a small range. The temperature of influent and effluent of surface water and treated wastewater were 28.0-30.5 and 30.0-32.0 respectively, which were in range of standard operating conditions. These results made us to ensure that membrane was not damaged due to high temperature.

4.5.3 Turbidity and Suspended Solid

Membrane filtration is a solid-liquid separation. Microfiltration is used to remove turbid suspended solids, general bacteria, which are micron-size particle. Turbidity and suspended solid are the main parameters to monitor the performance of filtration system.

Results of testing for turbidity and suspended solid in raw water, feed water and product water were examined. The turbidity and suspended solid result of surface water, surface water adding Kaolin clay and treated wastewater at various permeate flow experiments are shown in Figure 4.28 to 4.33.

Surface water turbidity and suspended solid varied between 7-25 NTU and 3-35 mg/L. For surface water adding Kaolin clay, turbidity and suspended solid varied between 40-90 NTU and 30-110 mg/L, and for treated wastewater, it varied between 15-25 NTU and 15-50 mg/L. Due to wide vary of turbidity and suspended solid of feed water, the permeate turbidity was still very low throughout the duration of all experiments, which was 0.05-0.45 NTU. The permeate suspended results were also related to turbidity results, which could not detect any suspended solid from permeate water because this microfiltration pore size was 0.1 μm while filter paper for SS method pore size was 0.45 μm. These results show that the system has a high ability to handle high turbidity and suspended solids loading without any effect to permeate water quality.

4.5.4 COD and TOC

COD and TOC investigation of long-term experiment are shown in Figure 4.34 and 4.35. COD of surface water was 15-50 mg/L while TOC was 4.1-7.7 mg/L. For treated wastewater, COD was 70-135 mg/L while TOC was 18-27 mg/L. As depicted in Figure 4.34 and 4.35, the permeate COD and TOC were maintained at 7-30 mg/L and 3.8-10.6 mg/L, even at high organic matter of treated wastewater. Some organic matter, which was in dissolved material form could not be removed by microfiltration. Hence, microfiltration alone was shown to be effective removal of particles, but ineffective for removal of organic materials.

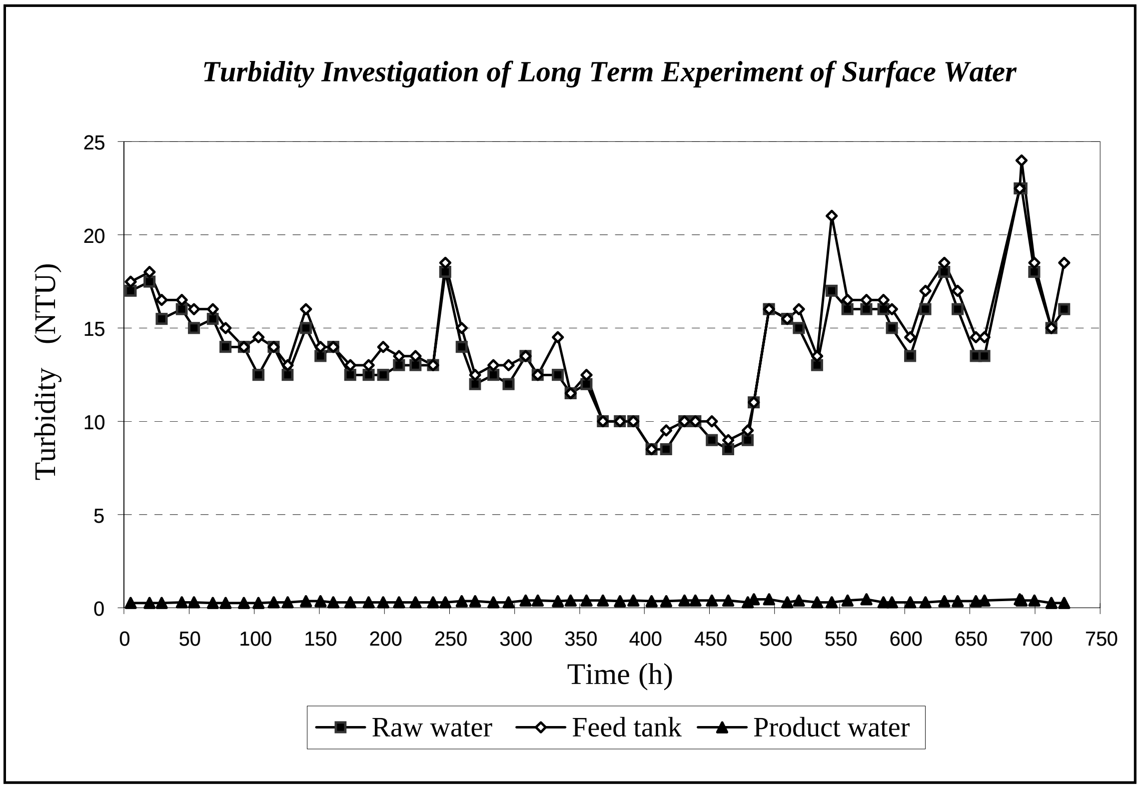


Figure 4.28 Turbidity result of surface water

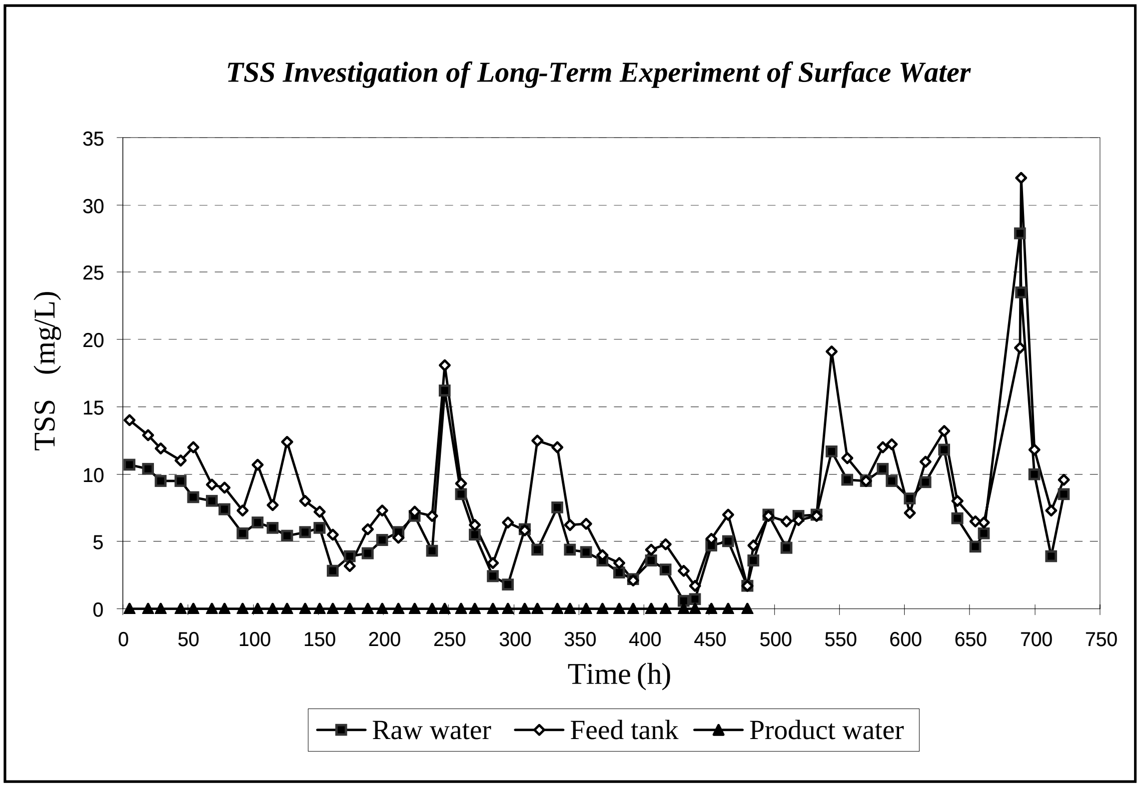


Figure 4.29 TSS result of surface water

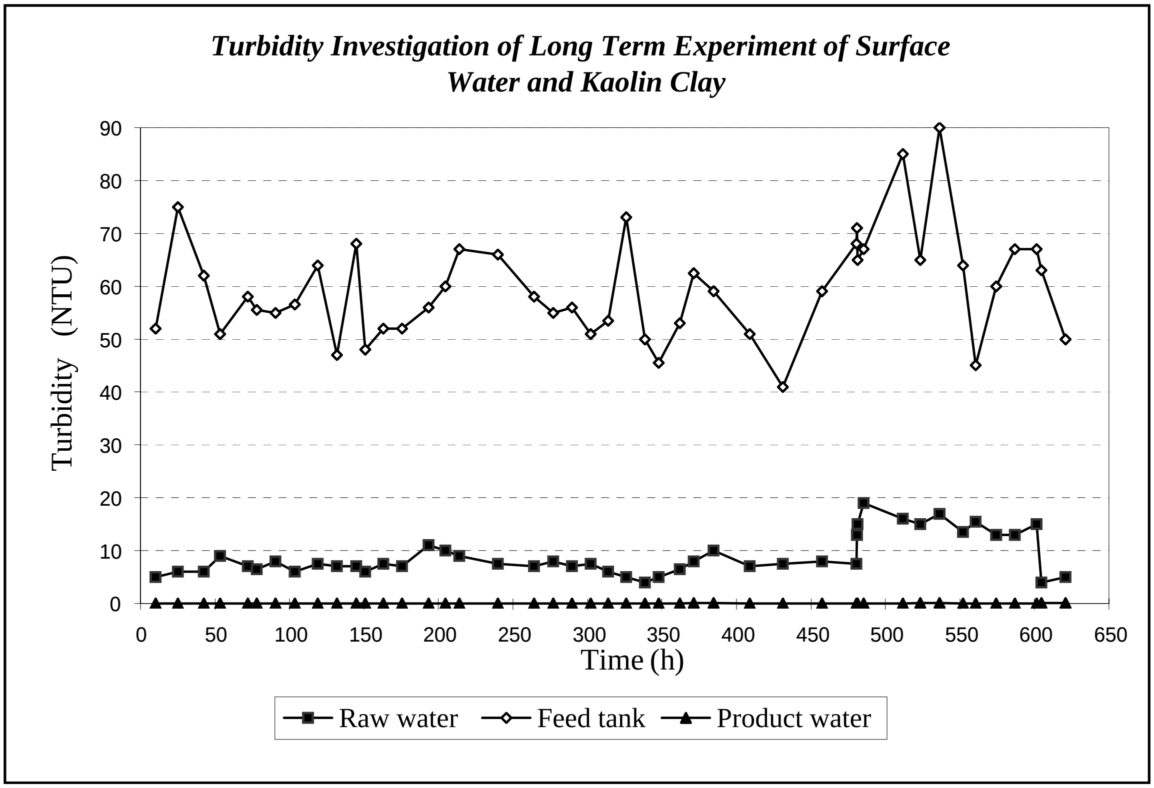


Figure 4.30 Turbidity result of surface water and kaolin clay

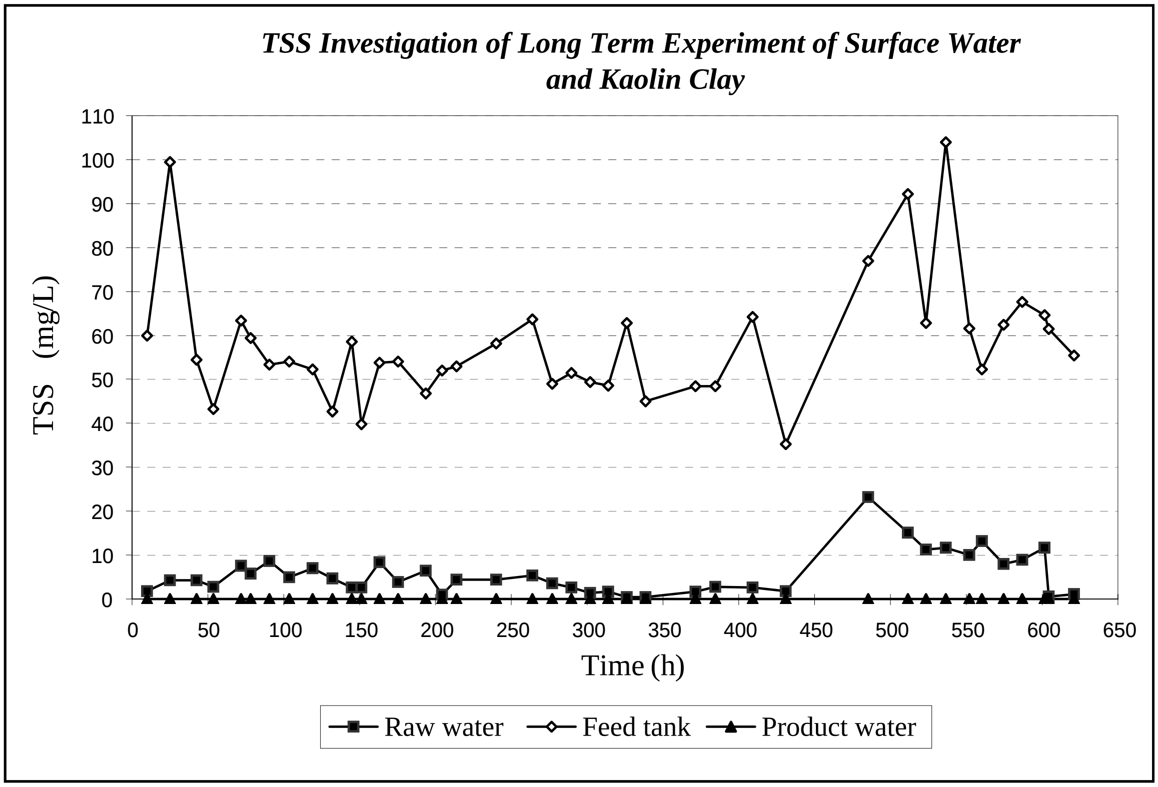


Figure 4.31 TSS result of surface water and kaolin clay

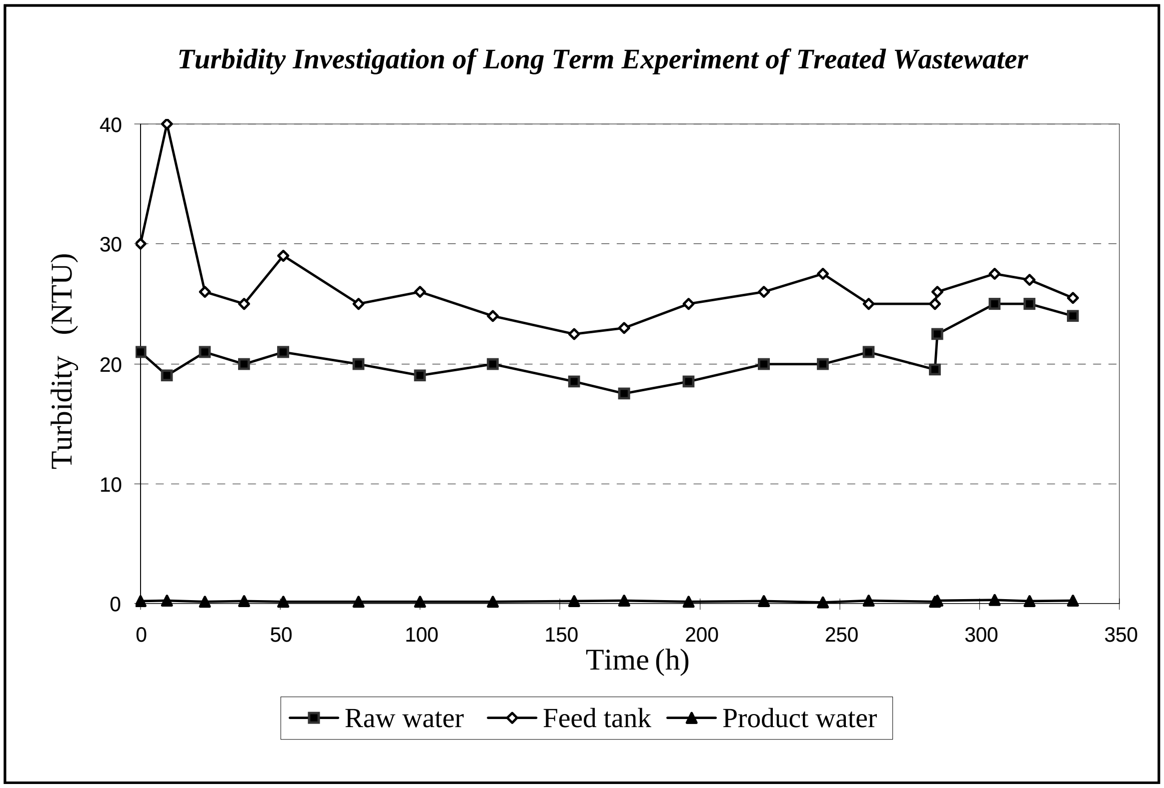


Figure 4.32 Turbidity result of Treated Wastewater

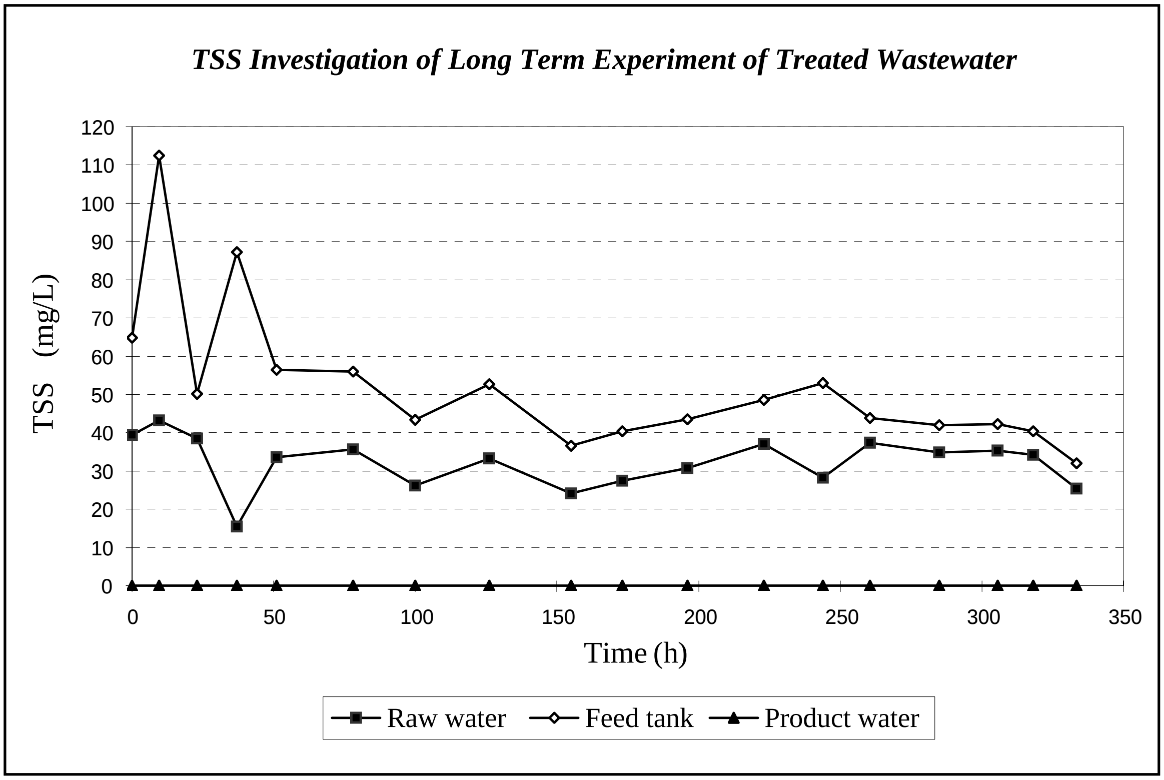


Figure 4.33 TSS result of Treated Wastewater

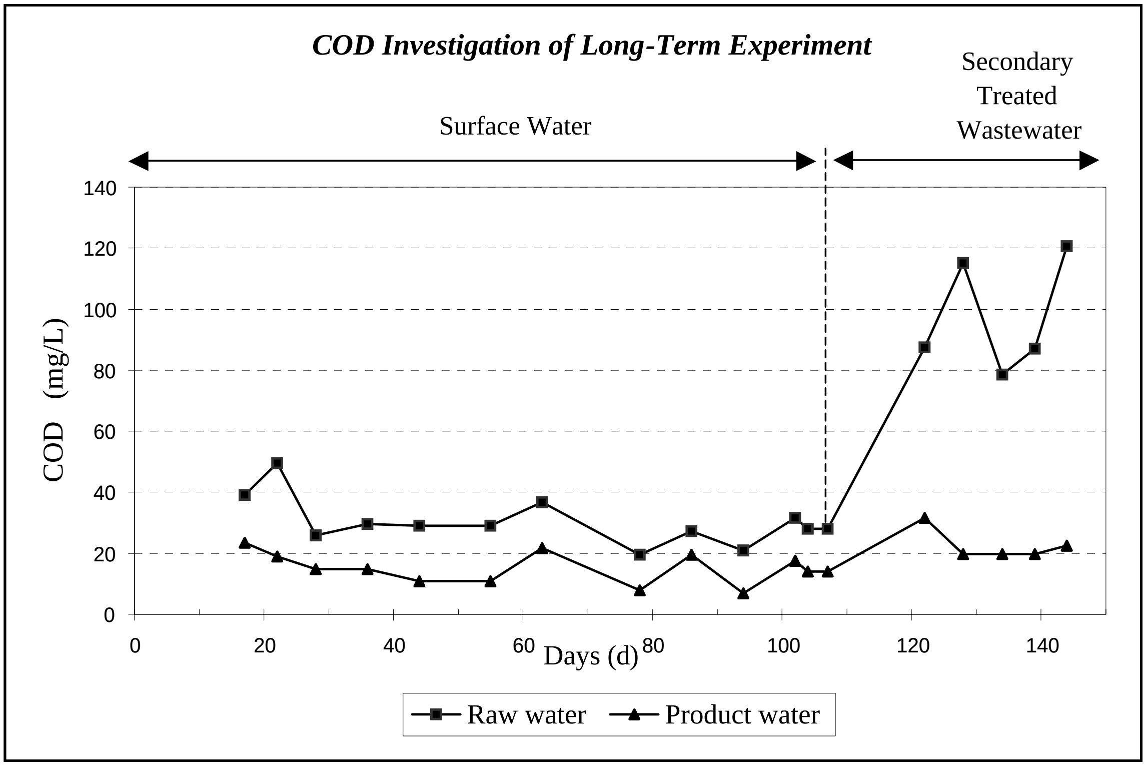


Figure 4.34 COD Results of Surface Water and Treated Wastewater

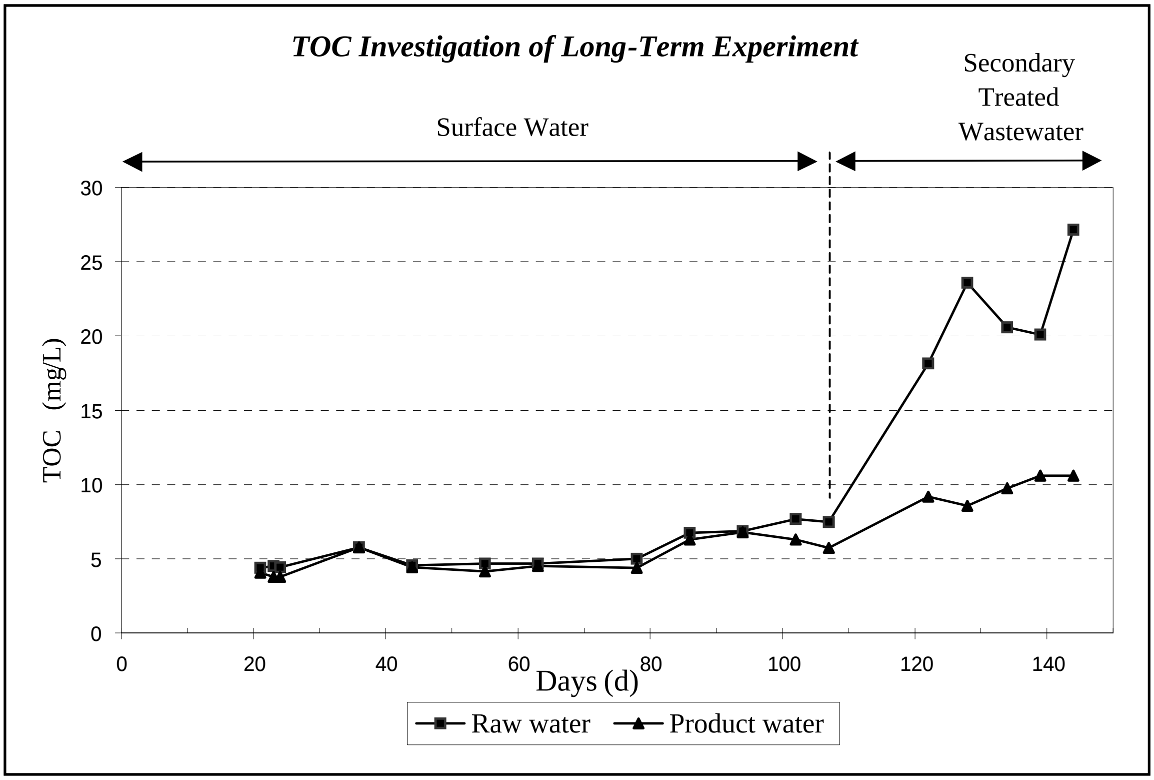


Figure 4.35 TOC Results of Surface Water and Treated Wastewater

4.5.5 Color

Surface water may appear highly colored, because of colored suspended matter, but in reality they are not (Sawyer et al, 1994), which related to our results. The color of surface water was less than 4 units. Treated wastewater from pond contained high turbidity and algae, which effect to be higher color than in surface water. Color result of surface water and treated wastewater are shown in Figure 4.36. Product water was generally less than 4 units, even at high color of treated wastewater. High color values were associated with high turbidities. When the filtered turbidity was low, then the filtered color was also low (Furry et al, 2000).

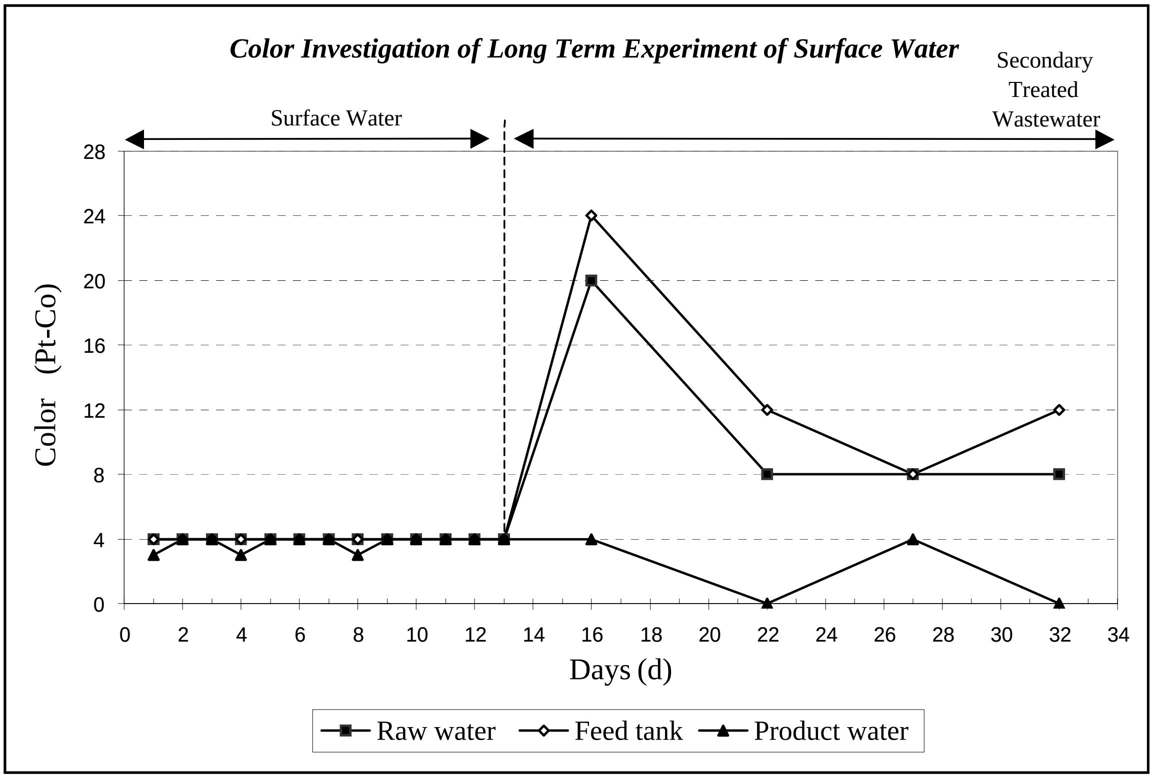


Figure 4.36 Color Result of Surface Water and Treated Wastewater

4.5.6 Chlorophyll a

Chlorophyll a is a parameter used to evaluate algae in water. As depicted in Figure 4.37, the chlorophyll a of product water was very low, which is less than 0.35 μg/L. The reason is that the algae size is bigger than 1.0 μm while this microfiltration pore size is 0.1 μm. Therefore most of the algae should be rejected from the permeate water.

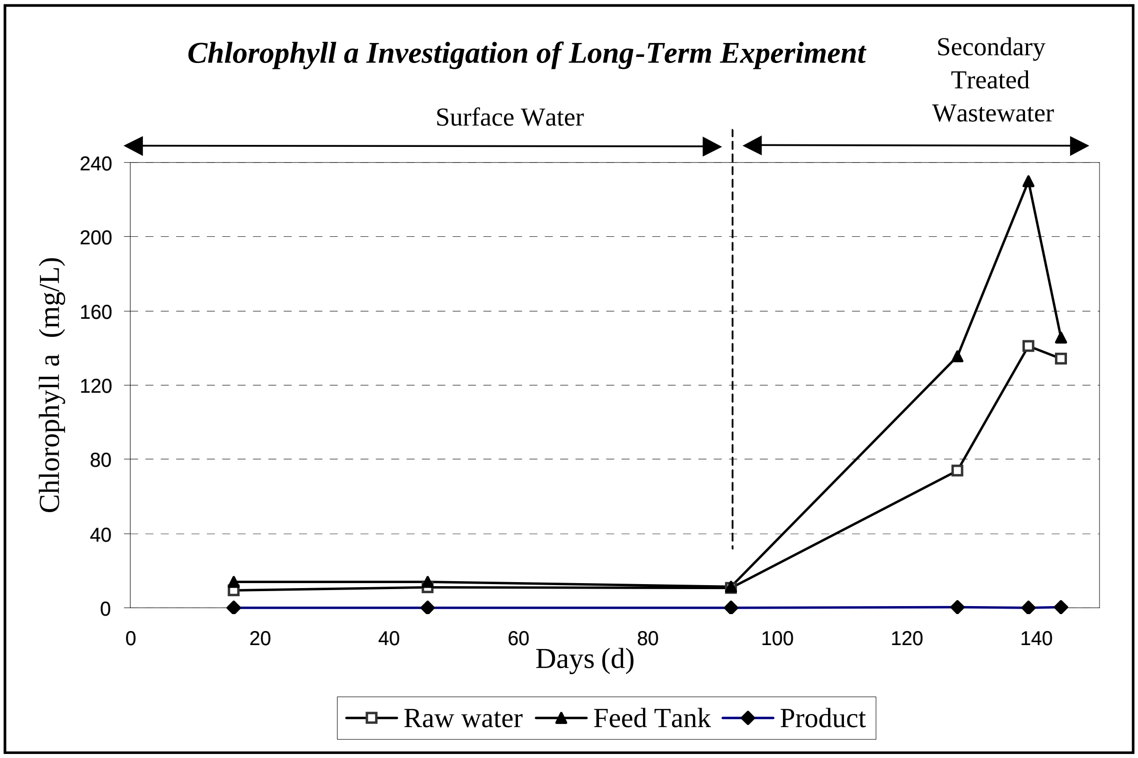


Figure 4.37 Chlorophyll a Results of Surface Water and Treated Wastewater

4.5.7 Water and Wastewater Characteristics and Removal Efficiency

Table 4.11 shows the water and wastewater characteristics and percentage removal of each types of feed water. The influent characteristics of treated wastewater were higher than surface water in all of parameters.

Removal percentage of turbidity, suspended solid and chlorophyll a were higher than 98 %, which were very effective. Organic matter removal was not much effective, which were shown by COD and TOC removal. Removal of metals, Fe and Mn, depended on whether the metals were precipitated or dissolved before reaching the microfilter. Hardness removal was 0 % because Mg^{2+} and Ca^{2+} could not be retained by microfiltraion.

Fecal coliform were not detected in product water of both the feed water because the bacteria size is greater than 0.1 μm, which was this microfiltration pore size.

Table 4.11 Water and Wastewater Characteristics

Parameter	***Unit***	***Surface Water***			***Treated Wastewater***		
		Inf	Eff	% Removal	Inf	Eff	% Removal
1. pH	-	7.8-8.2	7.7-8.1	-	8.1-8.4	8.0-8.3	-
2. Temperature	°C	28-30	28.5-30.5	-	30-31.5	30.5-32.0	-
3. Turbidity	NTU	7-25	0.04-0.45	98-99	16-25	0.05-0.45	98-99
4. TSS	mg/L	15-20	Nil	100	20-45	Nil	100
5. Color	Pt-Co	3-5	4	0	8-20	4	50-80
6. COD	mg/L	15-50	7-23	40-70	70-135	20-32	65-80
7. BOD	mg/L	<6	<2	60	20-40	<2	80-90
8. TOC	mg/L	4.1-7.7	3.8-6.8	5-20	18-27	8.6-10.6	50-65
9. Hardness	mg/L	80-100	80-100	0	110-130	110-130	0
10. Chlorophyll a	µg/L	10-12	0.02-0.35	98-99	80-135	0.02-0.35	99
11. Fe	mg/L	0.02-0.09	0	100	0.02-0.13	0-0.05	60-100
12. Mn	mg/L	0.07-0.15	0.01-0.08	60-85	0.09-0.23	0.02-0.19	20-80
13. Fecal Coliform	CFU/ ml	15	0	100	8	0	100
14. Chlorine residual	mg/L	-	<0.1	-	-	<0.8	-

4.6 Bench Scale Chemical Cleaning Experiment

Chemical cleaning is an integral part of membrane process operation that impact on the performance and economic of membrane process. Chemical cleaning process removes certain foulants, which could not be removed by mechanical cleaning such as water backwashing or air scrubbing. Currently, chemical cleaning solutions are mostly used based on the recommendations from membrane manufactures. In this part, two set of experiments were carried out to study effects on chemical cleaning, namely:

1. Effects of chemical cleaning composition;
2. Effects of chemical cleaning concentration.

To investigate the effect of different composition of cleaning solution, the experiments were conducted in the flat sheet membrane. The feed water was surface water and treated wastewater. The operating conditions of bench scale experiment are shown in Table 4.12. Before measuring the initial membrane resistant, flat sheet membranes were pre-cleaned by NaOH 0.075 plus NaClO 200 ppm for two hours. Some possibility that the membrane had been polluted by microorganism due to the long-term preservation. The distilled water used for measuring membrane resistant. First, initial membrane resistant was measured. Then membrane flat sheet module was filtered by feed water for 12 hours, which the flux declined over a period of time is shown in Appendix C.

Table 4.12 Operating Conditions of Bench Scale Experiment

Description	***Operating conditions***
1. Membrane module	Flat sheet ultrafiltration
2. Membrane material	Polysulfone
3. Molecular Weight Cut Off	200,000
4. Surface area	56.87×10^{-4} m^2
5. Feed flow rate	1.3 L/min
6. Transmembrane pressure	2.0 bar
7. Filtration duration	12 h.

4.6.1 Effects of chemical cleaning composition

Different of type and concentration of fouling materials in water and wastewater demands different of chemical cleaning procedure. The feed water characteristics have been presented in Table 4.11. Chemical cleaning time was one and a half hour. The results of membrane before and after chemical cleaning are shown in Appendix D. The comparison of membrane resistant between different chemical cleaning composition for surface water and treated wastewater is summarized in Figure 4.38 and 4.39, respectively. The initial membrane resistant of the membrane flat sheet was around 2.0×10^8 m^{-1}. NaClO 200 ppm plus NaOH 00.075 N was the most effective for both feed water, which could bring membrane resistant back to the initial level. H_2O_2 was the least effective for both feed water.

The percentage of membrane recovery after chemical cleaning of surface water and treated wastewater is shown in Figure 4.40 and 4.41, respectively. The combination of NaClO and NaOH could recovery or increase flux by 95% of both feed water. The possible reasons are describe as the following. Characteristics of both feed water contain in organic, particulate, and microbial fouling. Chlorine is an oxidant, which the oxidation of organic polymers generates more oxygen containing functional groups such as carboxylic acids. The increase in abundance of carboxylic groups on aromatic rings increase negative charges of natural organic matter at alkaline pH condition due to the dissociation of these acid. A function of caustic is to increase negative charged of humic substance. As a result, the negative charges on organic molecules increase to a great extent, so does their solubility. Therefore, they are easier to be removed from membranes. Hence, oxidant alone, which was NaClO or H_2O_2, was not effective because of the above reason. Oxalic acid and HNO_3 are primarily used for removing inorganic matter, which was less in amount on both feed water when compared with organic matter. So the percentage of recovery was very low, which were approximate 10% for surface water and 25-45% for treated wastewater. Asahi Chemical Industry Co.,Ltd, which manufactured this MF pilot, are also recommend NaClO mixing with NaOH.

Figure 4.42 shows the visual observation of membrane flat sheets, which were the new membrane, the filtrated membrane and the cleaned membrane in case of NaOH and NaClO was used for chemical cleaning.

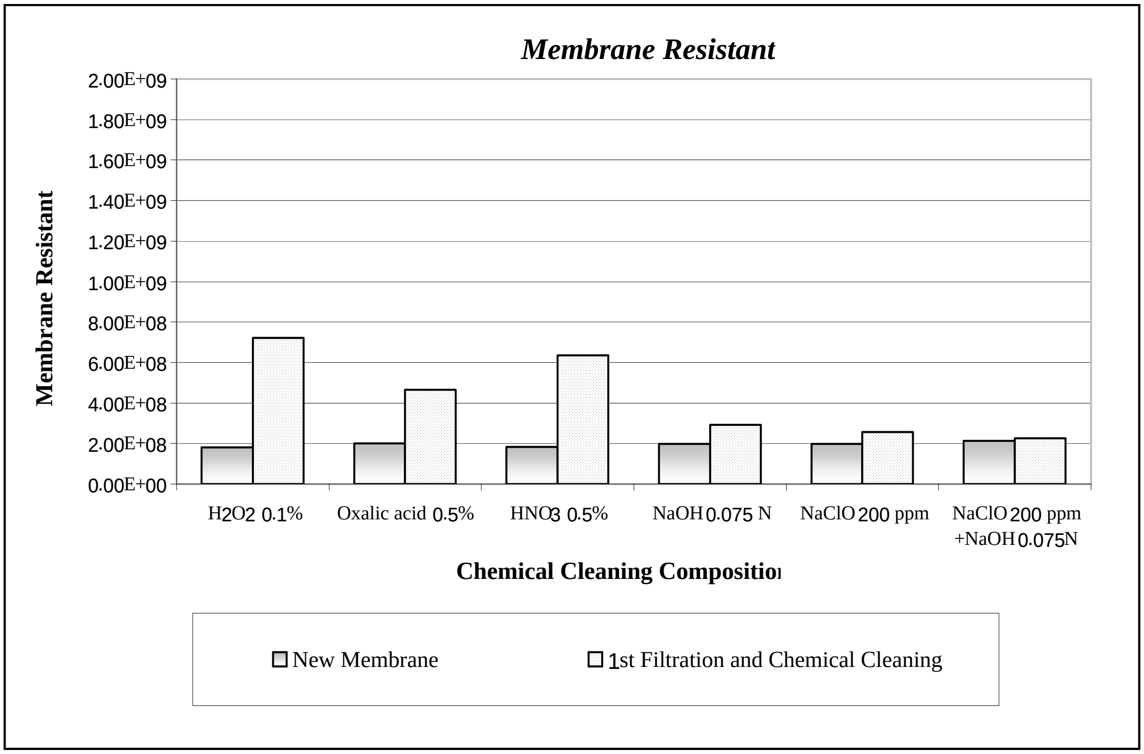


Figure 4.38 The comparison Membrane Resistant between Different Chemical Cleaning Composition for Surface Water

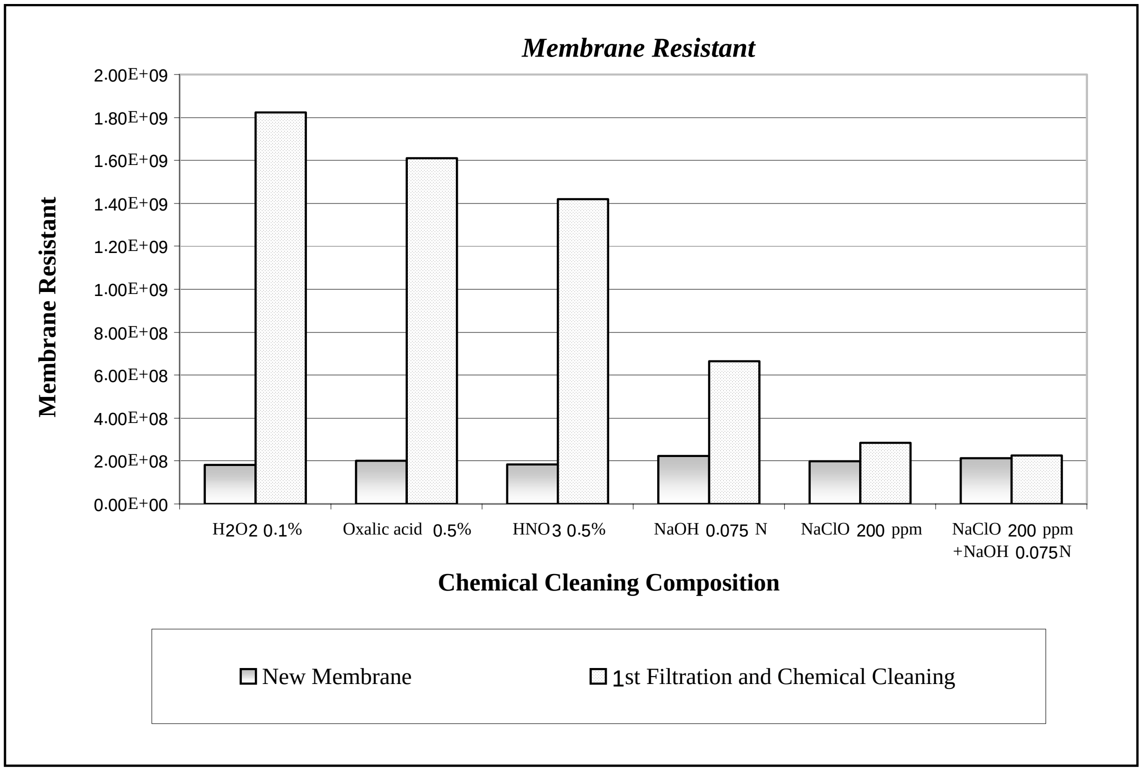


Figure 4.39 The comparison Membrane Resistant between Different Chemical Cleaning Composition for Treated Wastewater

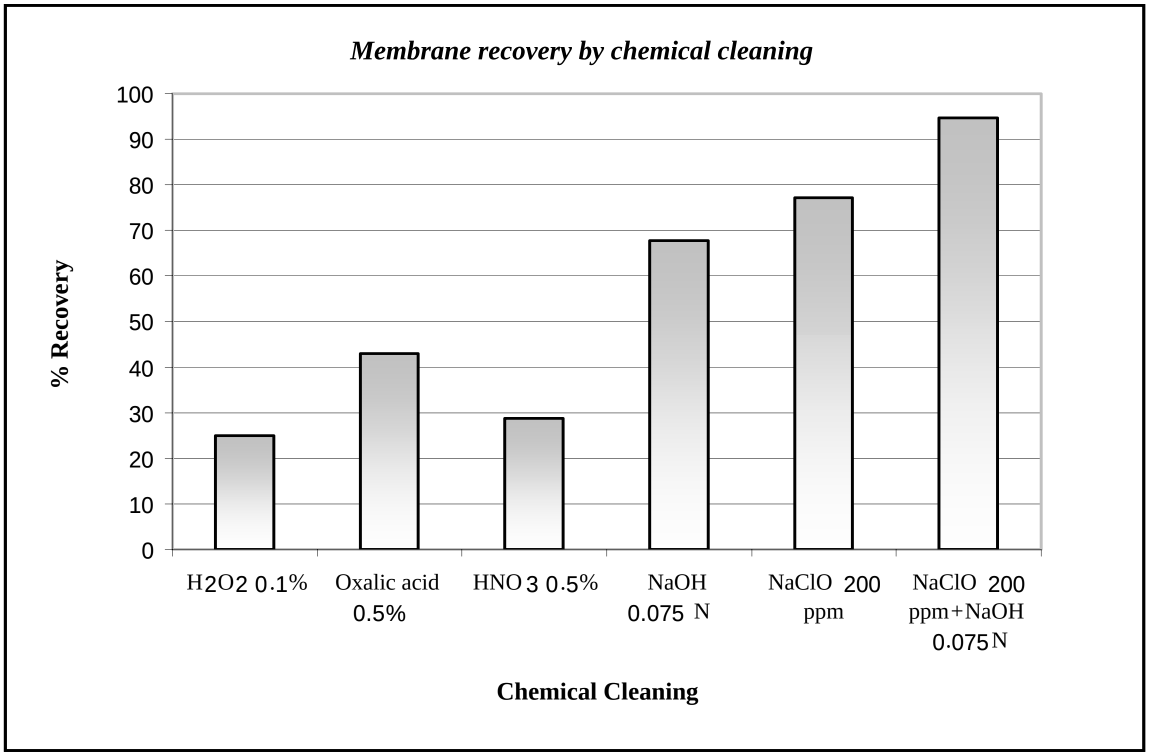


Figure 4.40 Percentage of Membrane Recovery After Chemical Cleaning of Surface Water

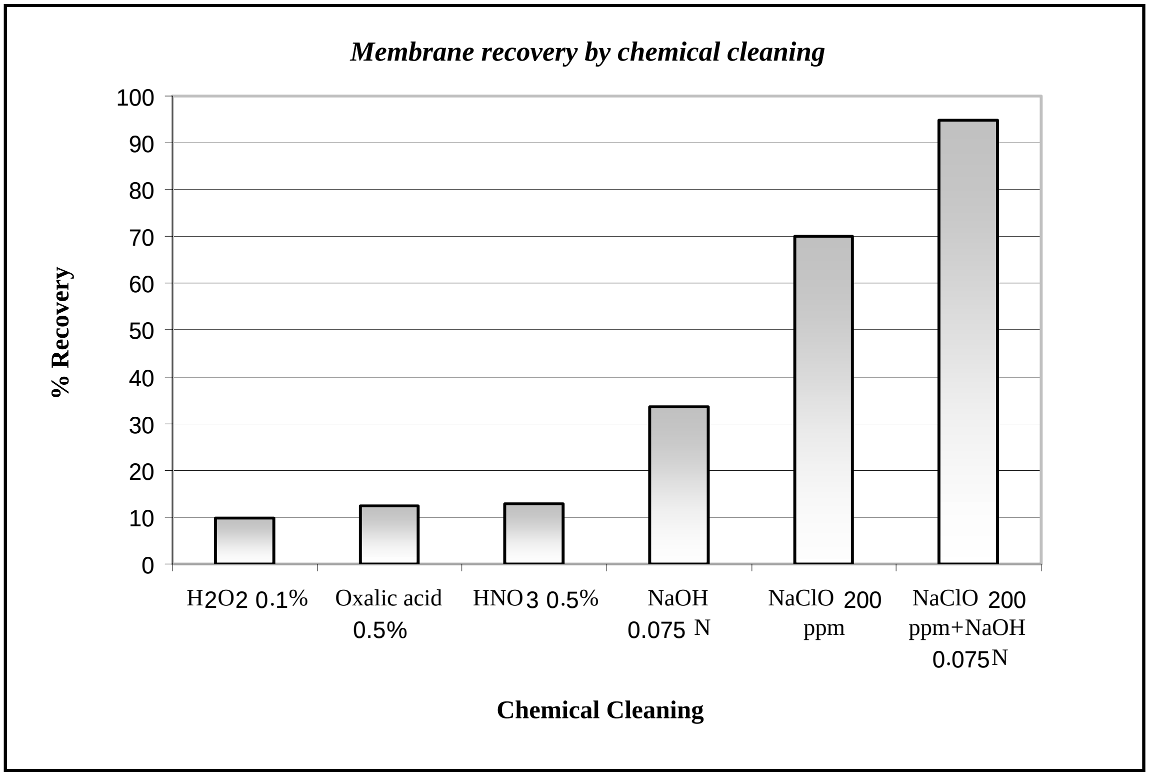


Figure 4.41 Percentage of Membrane Recovery After Chemical Cleaning of Treated Wastewater

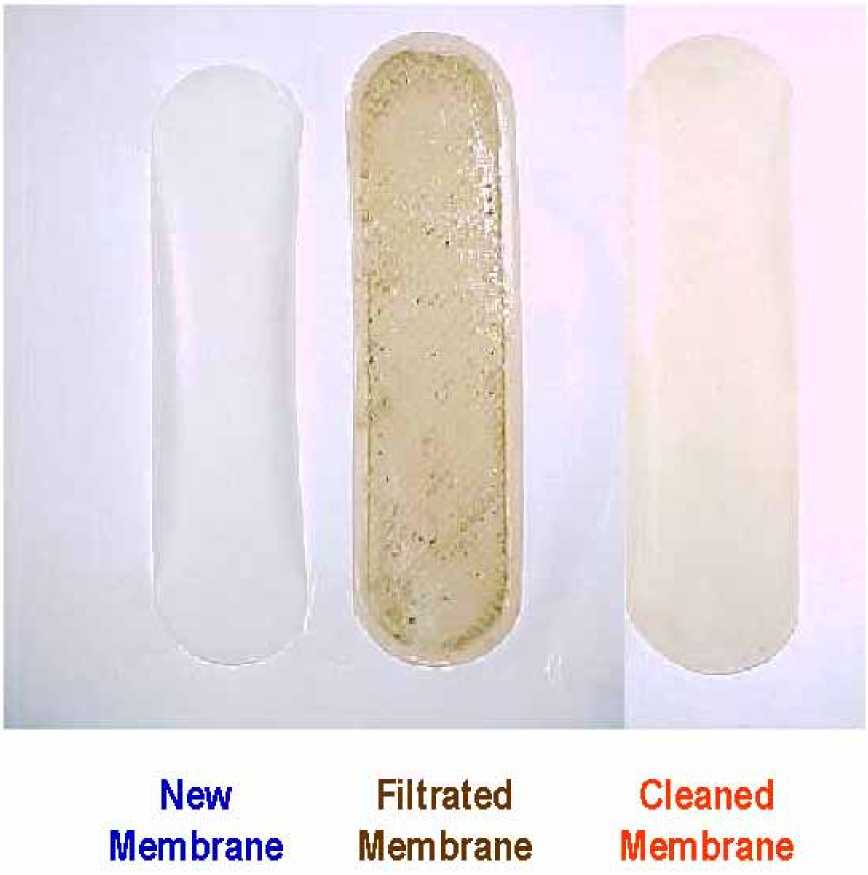


Figure 4.42 Membrane Flat Sheet

4.6.2 Effects of chemical cleaning concentration

As discussed in the previous section, the combination of caustic and oxidant was the most effective cleaning. Surface water and treated wastewater mainly contain organic matter and particulate matter but different in amount. Optimum concentration of the best reagent should be identified to balance in chemical cleaning cost and flux recovery effectiveness.

Chemical cleaning time was an hour. Figure 4.43 and 4.44 show the effect of NaOH and NaClO concentration on membrane cleaning for surface water and treated wastewater, respectively. Surface water was low in organic matter. Increase of NaOH from 0.075 N to be 0.15 N was insignificant. 0.075 N NaOH was seemed to be the optimum concentration for this surface water. For treated wastewater, Increase of NaOH from 0.075 N to be 0.15 N, the difference of recovery percentage was observed because of high in amount of organic matter. In both feed water, the flux recovery percentage increased when the concentration of NaClO increased because the oxidation reduced the adhesion of fouling materials on membrane. After 200 ppm NaClO, the effectiveness of cleaning had a small increase. It seems that a threshold concentration for NaClO was between 200 to 400 ppm, which was enough for removing organic matters. Excessive this concentration, the flux recovery did not significant improve.

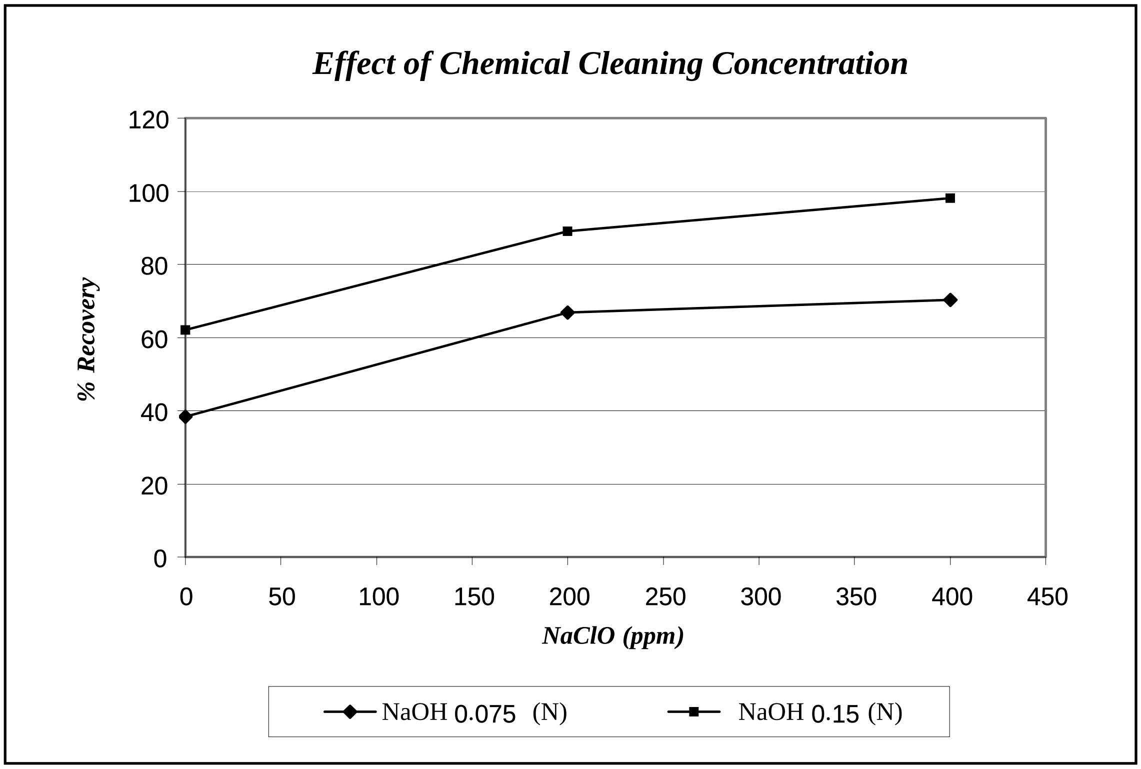


Figure 4.43 Effect of Chemical Cleaning Concentration for Treated Wastewater

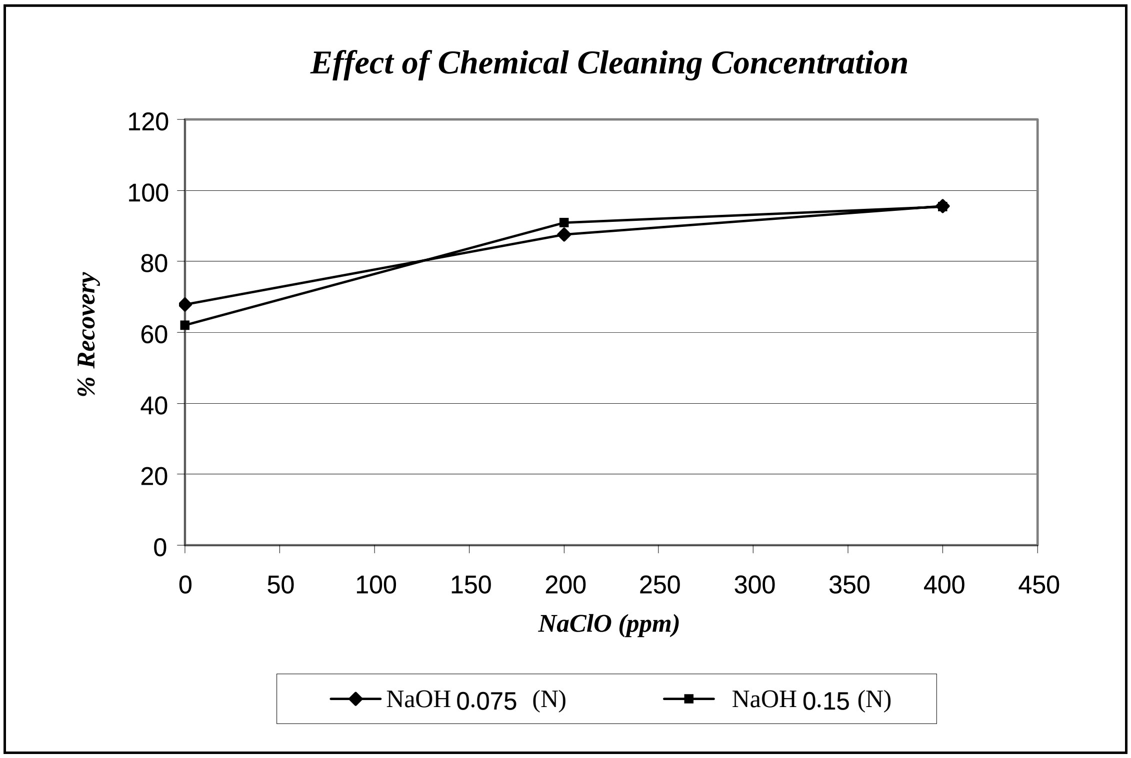


Figure 4.44 Effect of Chemical Cleaning Concentration for Surface Water

4.7 Financial Analysis

The membrane process has been normally thought to be very expensive, which is the important obstacle to promote this technology. As advancement in membrane filtration technology become available, improvements in the design and decreasing costs of these systems have made possible in a multitude of applications for this technology. Therefore, both technical and economical analyses are significance issues for studying. Cost will vary if the system is operated at different flux rates. In this section, quantitative factors are compared between all of permeate flux in both feed water types, which were water quantity, power supply requirement, and chemical requirement. Optimum flux rate in both feed water types are used to compare in capital cost, operating & maintenance cost and land requirement with conventional process treatment.

4.7.1 Water quantity

Various operating conditions lead to different filtration cycle duration and also water production, which is the basic information to calculate cost-benefit of the system. All of experiment operating conditions, which were done in this research, is summarized in Table 4.13 and 4.15 for easy understanding and referring. Comparison of water production from all operating condition was carried out, which are shown in Table 4.14 for surface water and in Table 4.16 for treated wastewater.

Table 4.13 Summarized Operating Conditions of All Experiments of Surface Water

Description	***Operating conditions***						
	Exp 1	***Exp 2***	***Exp 3***	**Exp4**	***Exp 5***	***Exp 6***	***Exp 7***
1. Feed water	Surface water				Surface water adding Kaolin clay		
2. Feed flow rate	1,500 L/h						
3. Permeate flow rate	480 L/h	480 L/h	600 L/h	720 L/h	480 L/h	600 L/h	720 L/h
4. Backwash flow rate	600 L./h		960 L/h				
5. Filtration / Reverse filtration	Filtrate 30 min / Backwash 30 sec / Flushing 30 sec						
6. Backwashing method	Water & NaClO 3 ppm & air 0.3 bar (1,000 L/h)	Water & NaClO 3 ppm & air 0.75 bar (1,600 L/h)	Water & NaClO 3 ppm & air 1.5 bar (2,000 L/h)				

Table 4.14 Water Quantity Comparison of Surface Water (a)

Descriptions	**Unit**	**Exp 1**	**Exp 2**	**Exp 3**	***Exp4***	**Exp 5**	**Exp 6**	**Exp 7**
1. Time of running	h	178.8	479.5	211.3	47.3	500.5	127.0	19.5
2. Permeate flow rate	L/h	480	480	600	720	480	600	720
3. Volume of permeate water production	m^3	85.8	230.2	126.8	34.0	**240.2**	76.2	14.0
4. Total backwashing time	h	2.98	7.99	3.52	0.8	8.34	2.11	0.3
5. Backwashing flow rate	L/h	600	600	960	960	960	960	960
6. Volume of backwashing water lost	m^3	1.8	4.8	3.4	0.8	8.0	2.0	0.3
7. Volume of water recovery	m^3	84	225.4	123.4	33.2	**232.2**	74.2	13.7
8. % of water recovery	%	97.9	97.9	97.3	97.6	96.7	97.4	97.9

(a) Sample of calculation is shown in Appendix D

Table 4.15 Summarized Operating Conditions of All Experiments of Treated Wastewater

Description	***Operating conditions***				
	Exp 8	**Exp 9**	**Exp 10**	***Exp 11***	**Exp 12**
1. Feed water	Treated wastewater				
2. Feed flow rate	1,500 L/h				
3. Permeate flow rate	480 L/h	600 L/h	720 L/h	600 L/h	720 L/h
4. Backwash flow rate	960 L/h				
5. Filtration / Reverse filtration	Filtrate 30 min / Backwash 30 sec / Flushing 30 sec			Filtrate 15 min / Backwash 30 sec / Flushing 30 sec	
6. Backwashing method	Water & NaClO 3 ppm & air 1.5 bar (2,000 L/h)				

Table 4.16 Water Quantity Comparison of Treated Wastewater [(a)]

Descriptions	**Unit**	**Exp 8**	***Exp 9***	**Exp 10**	**Exp 11**	**Exp 12**
1. Time of running	h	301.0	43.5	15.5	74.0	27.0
2. Permeate flow rate	L/h	480	600	720	600	720
3. Volume of permeate water production	m^3	**144.5**	26.1	11.2	44.4	19.4
4. Total backwashing time	h	5.0	0.7	0.3	1.2	0.5
5. Backwashing flow rate	L/h	960	960	960	960	960
6. Volume of backwashing water lost	m^3	4.8	0.7	0.3	2.4	0.9
7. Volume of water recovery	m^3	**139.7**	25.4	10.9	42.0	18.5
8. % of water recovery	%	96.7	97.3	97.3	94.6	95.4

(a) Sample of calculation is shown in Appendix D

As the results are presented in Table 4.14 and 4.16, the experiment 5 was the best option for surface water and the experiment 8 was the best option for treated wastewater. In cases of treated wastewater, the experiment 8 was run at 30 minutes of filtration time. It was proved that we would get longer running hours if reduced filtration time to be 15 minutes. But, for this financial analysis we will use results of the experiment 8 as the base information for the optimum condition of treated wastewater.

4.7.2 Power Supply Requirement

The pilot unit was operated with 380 volts, three phases. Total power consumption was determined by reading from the watt-hour meter. Power supply requirement comparison are summarized in Table 4.17 and 4.18. The power consumption was related as a linear curve to the duration time of running, which is shown in Figure 4.45. The cost of power per unit was referred from Metropolitan Electricity Authority of Thailand. In this case, the rate for medium and big enterprises was used, which was approximately 2 Baht per unit. As the results shown, the average of power cost per water production was 0.2-0.3 Baht/m^3

Table 4.17 Power Supply Requirement Comparison of Surface Water

Descriptions	**Unit**	**Experiments**						
		1	**2**	**3**	**4**	**5**	**6**	**12**
1. Time of running	h	178.8	479.5	211.3	47.3	500.5	127.0	19.5
2. Volume of water recovery	m^3	84	225.4	123.4	33.2	232.2	74.2	13.7
3. Power consumption	Kwh	12.2	30.7	13.7	3.0	39.2	7.5	1.2
4. Total Power cost	Baht	24.4	71.4	27.4	6.0	78.4	15.0	2.4
5. Power cost per water production	Baht/ m^3	0.3	0.3	0.2	0.2	0.3	0.2	0.2

Table 4.18 Power Supply Requirement Comparison of Treated Wastewater

Descriptions	**Unit**	**Experiments**				
		7	**8**	**9**	**10**	**12**
1. Time of running	h	301.0	43.5	15.5	74.0	27.0
2. Volume of water recovery	m^3	139.7	25.4	10.9	43.2	18.9
3. Power consumption	Kwh	16.9	2.6	0.9	4.4	1.4
4. Total Power cost	Baht	33.8	5.2	1.8	8.8	2.8
5. Power cost per water production	Baht/ m^3	0.2	0.2	0.2	0.2	0.2

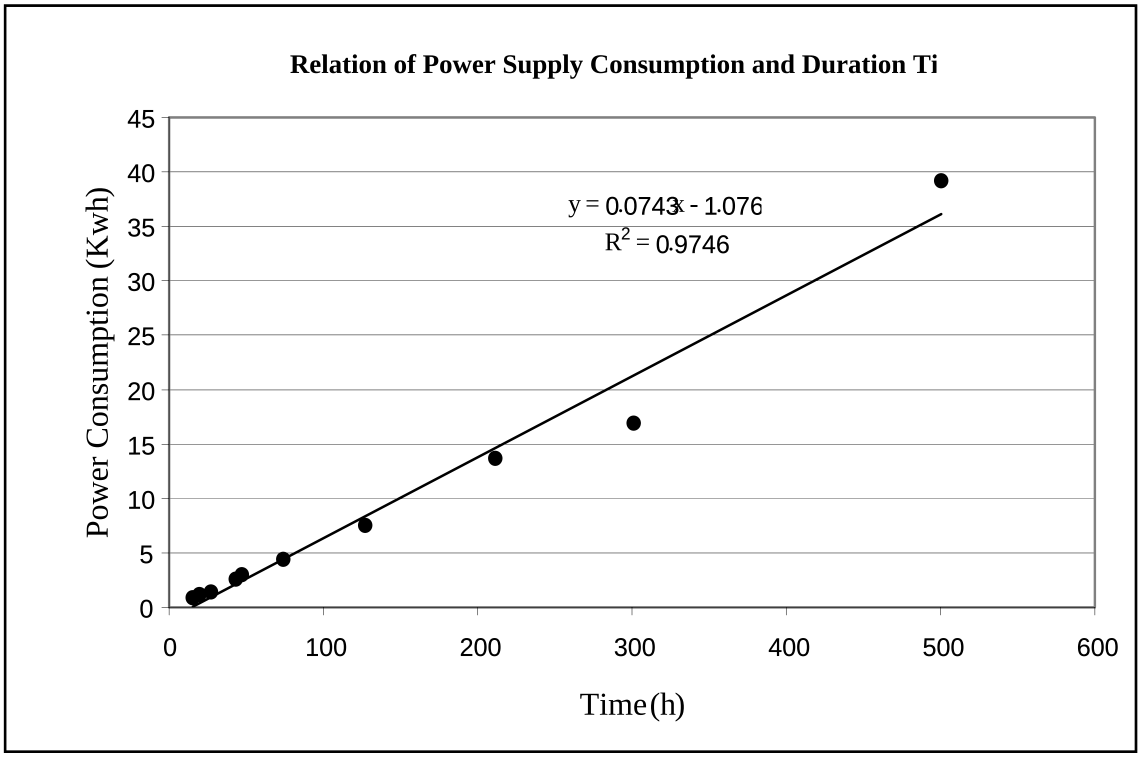


Figure 4.45 Relation of Power Supply Consumption and Duration Time

4.7.3 Chemical Requirement

In this system, chemical reagent was used in three tasks, which are below:

1. Sodium Hypo chlorite, which was added with water backwashing.
2. Sodium Hypo chlorite, Sodium Hydroxide and oxalic acid, which were used in chemical cleaning step.
3. Sodium Hypo chlorite dosing before filtered through membrane, which was used in case of treated wastewater to prevent biofouling problem.

The detail of chemical cost calculation is shown in Appendix E. The results of chemical cost were calculated from the optimum operating conditions of both feed water. Chemical cost, which was used with water backwashing, was 0.05 Baht/m^3. Chemical dosing before filtered through membrane in case of treated wastewater was 3.11 Baht/m^3. Chemical cost for cleaning step was 944.12 Baht/time, which meant that chemical cleaning cost for surface water was 4.07 Baht/m^3 and for treated wastewater was 6.76 Baht/m^3.

4.7.4 Cost-Benefit Analysis from the Optimum Operating Condition

The total cost, which was considered in this study, were calculated from the capital costs of investment, annual O&M costs, and land requirement cost. The depreciation cost was not included in this analysis. The membrane lifetime was approximate 5 years. The benefit was analyzed from local water supply cost, which could be saved by use this water and wastewater reuse technique.

4.7.4.1 Capital Cost

Appendix F summarizes equipment, instrumentation and controls cost. The MF module cost was 180,000 Baht/unit, while other equipment cost was 570,000 Baht. These experiments were conducted in the pilot scale. In the full scale or the practical case, we could install more MF modules parallel in one unit. It meant that we could increase water production, which the main increasing costs are MF module while other equipments cost are little increased. Feed pressure and flow rate, which were the main points for MF, was control by the feed pump. From the feed pump technical data in this case, we could install one more MF module while has little changing in other equipments. Therefore, the total equipment cost will be 930,000 Baht. The water production, which was calculated from optimum condition, was 23 m^3/day. The standard factors, which referred from US EPA, were used to estimate the capital costs are listed in Table 4.19.

Table 4.19 Capital Cost

Descriptions	***Factor***	***Cost (Baht)***
• Equipment and controls	Technology-Specific Cost	930,000
• Installation	25 percent of Equipment Cost	232,500
• Piping	35 percent of Equipment Cost	325,500
Total Construction Cost	Equipment and Controls + Installation + Piping	***1,488,000***
• Engineering	15 percent of Total Construction Cost	223,200
• Contingency	15 percent of Total Construction Cost	223,200
Total Indirect Cost	Engineering + Contingency	***446,400***
Total Capital Cost		***1,934,400***

Adapted from US EPA, 1998.

4.7.4.2 Operation and Maintenance Cost

The annual O&M costs represent the costs of maintenance, labor, electricity and chemical. The total water production was based on 23 m^3/day in both surface water and treated wastewater. The standard factors, which referred from US EPA, were used to estimate the annual O&M costs are listed in Table 4.20.

4.7.4.3 Land Requirement Cost

One of the most significance advantages for membrane filtration technology is small land requirement, which is very effective in urban area or in the high cost area. Only 1 x 2 meters was required for this unit to provide 23 m^3/day. Cost of land requirement depends on local condition.

Table 4.20 Operation and Maintenance Cost

Descriptions	***Factor***	***Cost (Baht / year)***	
		Surface water	Treated wastewater
• Maintenace	4 percent of Total Capital Cost	77,400	77,400
• Labor	4,000 Baht per man-month or 5.80 Baht per m^3	48,000	48,000
• Electricity	0.30 Baht per m^3	2,500	2,500
• Chemical			
Backwashing	0.05 Baht per m^3	400	400
Cleaning	4.07 Baht per m^3 for surface water 6.76 Baht per m^3 for treated wastewater	34,200	56,800
Prevent biofouling	3.11 Baht per m^3	0	26,100
Annual O&M Cost		***162,500***	***211,200***

Adapted from US EPA, 1998.

4.7.4.4 Water Saving Benefit

From this water and wastewater reuse by membrane filtration technique, we could save of using fresh water supply. Tap water cost per unit, which referred from Provincial Water Authority, was 19.25 Baht/m^3 for industries. From Table 4.21, surface water operating cost was 10.71 Baht/m^3 and treated wastewater was 16.51 Baht/m^3. The maintenance cost was 9.22 Baht/m^3. The total O&M cost was 19.33 and 25.73 Baht/m^3, which more expensive than PWA tap water cost. The reason is this microfiltration cost was calculated base on pilot unit. If calculate in full scale, the cost per unit production water will be reduced, than this value. PWA cost trends to be increased the cost every year, while membrane filtration trends to be reduced.

4.7.5 Conventional Process Cost

Conventional process, which was used to compare with this microfiltration membrane, was chemical precipitation and followed by clarifier. The calculation for this conventional process was referred from US EPA. The resulting total capital cost, O&M cost and land requirement cost for the chemical precipitation are calculated from equation 4.2, 4.3 and 4.4. The resulting total capital cost, O&M cost and land requirement cost for the clarifier are calculated from equation 4.5, 4.6 and 4.7. The total cost of conventional process is summarized in Table 4.21.

- **Chemical Precipitation Process**

Capital Cost $\ln(Y1) = 14.019 + 0.481\ln(X) - 0.0307(\ln(X))^2$ Eq. 4.2

O&M Cost $\ln(Y2) = 15.3086 + 1.08349\ln(X) + 0.04891(\ln(X))^2$ Eq. 4.3

Land Requirement $\ln(Y3) = -1.019 + 0.299\ln(X) + 0.015(\ln(X))^2$ Eq. 4.4

- **Clarifier Process**

Capital Cost $\ln(Y1) = 11.552 + 0.409\ln(X) + 0.020(\ln(X))^2$ Eq. 4.5

O&M Cost $\ln (Y2) = 10.673 + 0.238\ln (X) + 0.013(\ln (X))^2$ Eq. 4.6

Land Requirement $\ln (Y3) = -1.773 + 0.513\ln (X) + 0.046(\ln (X))^2$ Eq. 4.7

Where:

X = Flow Rate (MGD)
Y1 = Capital Cost ($)
Y2 = O&M Cost ($)
Y3 = Land Requirement (Acres)

Table 4.21 The Cost of Conventional Process

Descriptions	***Unit***	***Convention Process***		
		Chemical Precipitation	***Clarifier***	***Total***
Capital Cost	Million Baht (a)	1.93	0.89	2.82
O&M Cost	Million Baht/year (a)	2.56	0.74	3.30
Land Requirement	m^2 (b)	470	170	640

(a) 1$ = 41 Baht
(b) 1 Acres = 4,047.40 m^2

4.7.7 Comparison between Microfiltration Membrane and Conventional Process

Thailand is newly industrialized country and growth in number and capacity of industries is constantly increasing. The rapid industrial growth has caused rapid population growth and urbanization, leading to increase for potable water demand and consequently increasing in volume of wastewater. Reuse of wastewater reclamation will reduce the potable water demand significantly and also get economic benefits. The conventional approach to accomplish the reuse of wastewater is by treatment schemes such as chemical precipitate and clarifier. However these conventional technologies face certain difficulties like cost, area requirement, operation problems, unstable product water quality due to load fluctuations etc. Microfiltration membrane is the new way to solve problems but three aspects, which were cost, safety and water quality aspect, should be compared. The detail are described as the following:

4.7.7.1 Cost Aspect

As presented in Table 4.22, it was found that microfiltration process for surface water and treated wastewater treatment was found to be an attractive economic alternative to conventional process in both capital cost and O&M cost. Land requirement for membrane process was required very small when compared with the conventional process.

Table 4.22 Microfiltration Membrane and Conventional Process Comparison

Descriptions	***Unit***	***Conventional Process***	***MF for Surface Water***	***MF for treated WW***
Capital Cost	Million Baht	2.82	1.93	1.93
O&M Cost	Million Baht/year	3.30	0.16	0.21
Land Requirement	m^2	640	2	2

4.7.7.2 Safety Aspect

The conventional process required primary disinfection and coagulation addition for *Giardia and Cryptosporidium* removal or inactivation, (Mallevialle, 1996). MF treatment goal is to remove particles and microorganism, which is physical process. By removing microorganisms with this technology, less primary disinfectant would be required, thus lowering the concentration of DBPs formed through treatment process. Therefore, microfiltion membrane is also provided more safety to human life than conventional process.

4.7.7.3 Water Quality Aspect

With chemical precipitation and clarification process, it is possible to remove 80 to 90 percent of the suspended solids, 50 to 80 percent of the BOD_5, and 80 to 90 percent of the bacteria, (Metcalf & Eddy, 1991). For these experiments, microfiltration membrane could remove 100 percent of the suspended solids, 60 to 90 percent of the BOD_5, and 100 percent of the bacteria. From above results, the water quality from microfiltration membrane was better in all of parameters when compared with conventional process.

4.8 Water and Wastewater Reuse Potential by Microfiltration Membrane

Permeate water quality of microfiltration membrane has been shown in Table 4.11. Water quality required for reuse has been shown in Table 2.3. Six parameters, which concerned for reuse, were pH, BOD_5, Turbidity, Fecal coliform and Cl_2 residual. Chlorophylla is another important parameter, which was concerned. This parameter is one indicator of the biological productivity of a lake. The lake is required to be free-from algal blooms, which a primary component of chlorophyll a. In general, an oligotropic condition is associated with a chlorophyll a concentration of less than 2 μg/L, while eutrophic conditions are associated with concentration greater than 10 μg/L, (Rasmussen et al., 1998). The chlorophyll a of product water from MF was very low, which was 0.02-0.35 μg/L in both surface water and treated wastewater. This is another good point of microfiltration treatment, which the effluent water has little effect of algal blooms. Comparisons of MF permeate water quality and water quality required for reuse are shown in Table 4.23.

Table 4.23 Comparisons of MF permeate water quality and water quality required for reuse

Parameters	***Unit***	***Water Quality Requirement for Reuse***	***MF Permeate of***	
			Surface Water	***Treated Wastewater***
1. pH	-	6-9	7.7-8.1	8.0-8.3
2. BOD_5	mg/L	<10	<2	<2
3. Turbidity	NTU	<2	0.05-0.45	0.05-0.45
4. TSS	mg/L	<30	Nil	Nil
5. Fecal Coliform	CFU/ml	0	0	0
6. Cl_2 residual	mg/L	<1	<0.1	<0.8
7. Chlorophyll a	μg/L	Not specific	0.02-0.35	0.02-0.35

As the results shown in Table 4.23, it meant that product water from microfiltration membrane could be reused for all of categories, which are summarized in Table 4.24. These water quality required for reuse might be also success by the conventional process. The valuable advantage of membrane process is, getting higher water quality than the conventional process, which objective to reuse in high water quality categories that the conventional process could not provide. The possible areas for reuse by this microfiltration membrane are described as the following.

Table 4.24 Categories of Water and Wastewater Reuse

Category of Wastewater Reuse	***Example Applications***
Urban use	
Unrestricted	Landscape irrigation: Parks, playgrounds, school yards; Fire protection; Construction;, Ornamental fountains; Impoundments; In-building uses: toilet flushing, air conditioning.
Restricted access irrigation	Irrigation of areas where public access is infrequent and controlled. Golf courses; Cemeteries; Residential; Greenbelts.
Agricultural irrigation	
Food crops	Crops grown for human consumption and consumed uncooked.
Non-food crops and food crops consumed after processing	Fodder, fiber, seed crops, pastures, commercial nurseries, sod farms commercial aquaculture.
Recreational use	
Unrestricted	No limitations on body-contact: lakes and ponds used for swimming, snowmaking.
Restricted	Fishing, boating, and other non-contact recreational activities.
Environmental enhancement	Use of reclaimed wastewater to create artificial wetlands, enhance natural wetlands and sustain stream flows.
Groundwater recharge	Groundwater replenishment, Salt water intrusion control, Subsidence control
Industrial reuse	Cooling system, make-up water, process waters, boiler feed water, construction activities and wash down waters

Adapt from Asano, (1998)

4.8.1 Potable Water Reuse

Surface water is a natural source, which is an unpolluted freshwater source. Potential for potable water reuse is possible. Asano (1998) has stated that direct potable reuse, where reclaimed water is piped directly into potable water distribution system, is not practiced anywhere in the U.S. Indirect potable reuse, where treated wastewater is discharged into a water course, a raw water reservoir, or an underground aquifer and withdrawn downstream or down gradient at a later time for treatment and subsequent distribution as drinking water, is being practiced. The drinking water standard is referred from Pollution Control Department of Thailand 1997. In case of surface water treatment by microfiltration membrane, physical and bacteria properties could meet the drinking water standard. Hence, the permeate water of MF, which feed water was surface water has a potential to reuse as indirect potable water but some other chemical properties such as Arsenic (As), Barium (Ba), etc, must be identified. Treated wastewater was come from polluted source, which should not reuse as potable water.

4.8.2 High Quality Industrial Water Reuse

About 25 % of worldwide water demand is related to industrial application (Crook et al. 1994). This MF pilot unit experiments was conducted to study the potential of water and wastewater reuse for industries. The application concept of water and wastewater reuse by MF for industries is summarized in Figure 4.46. As shown in this figure, there are three possible sources of water reuse by MF. Surface water and reclaimed municipal wastewater can be used as the external source for industrial application. As advancements of membrane technology, which can provide high water quality, the possible reuse of wastewater within an industry is possible in wide area of application. The industrial water and wastewater can be reused in three following processes:

- Cooling water
- Boiler feed water
- Process water

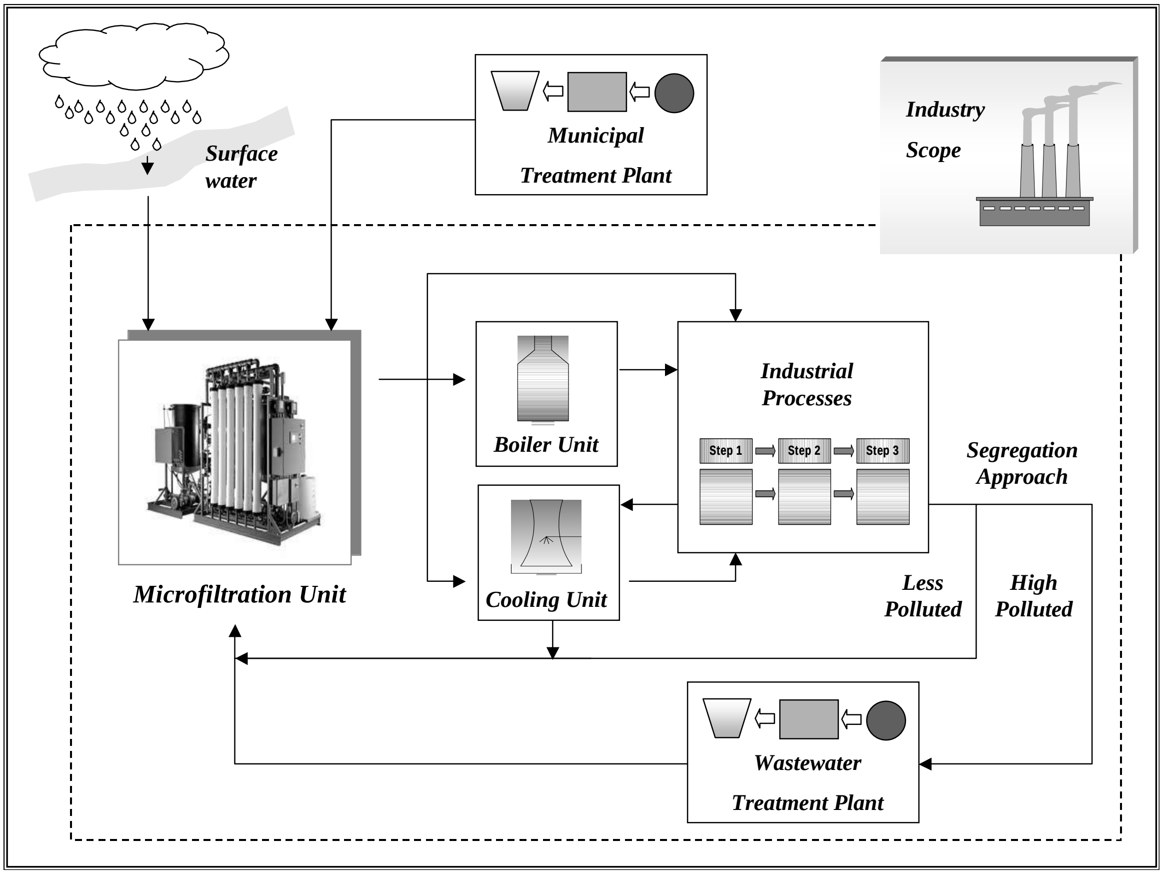


Figure 4.46 The application concept of water and wastewater reuse by MF for industry

4.7.2.1 Cooling Water

There are two types of cooling. The first type is one-through cooling system, which water quality required for this cooling system is generally not restrictive. The second type is recirculating cooling system, which some specifications of water quality are required. The most frequent water quality problems in cooling water system are scaling, corrosion, biological growth and fouling. The principal causes of scaling are calcium and magnesium, which hardness of both feed water used in these experiments were lower than the criteria, (US

EPA, 1992). Permeate pH value were 7.7 – 8.3, which will not cause in corrosion. Permeate BOD_5 were very low and permeate fecal coliform could not be detected, so the biological growth problem will not be formed. Fouling problem is controlled by preventing the formation and settling of particulate matter, which the permeate water from MF was very low in particulate matter. Therefore, both surface water and treated wastewater can reuse for cooling water of industries.

4.7.2.2 Boiler-Feed Water

Quality requirement for boiler-feed make-up water are dependent upon the pressure, which hardness is the main factor. MF was not effective to remove hardness but from feed water quality of these surface water and treated wastewater, hardness was less than 130 mg/L, which could reuse as low pressure boiler feed water, (US EPA, 1992).

4.7.2.3 Industrial Process Water

Industrial process water has required high water quality. Membrane filtration is an advancement treatment, which can provide high water quality. The suitability of reclaimed water for reuse in industrial process depends on the particular use. For example, the electronics industry requires water of almost distilled quality for washing circuit boards and other electronic components. On the other hand, the tanning industry can use relatively low-quality water. Requirements for textiles, pulp and paper, and metal fabricating are intermediate, (US EPA, 1992). Industrial process water quality requirements are shown in Appendix I. As presented in the industrial process water quality requirements, physical water quality of MF permeate water could supply for all kinds of industry but some other specific requirements should be determined before desired to reuse such as silica, copper, etc.

Chapter 5

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Conclusions and Recommendations

5.1 Conclusions

The pilot scale experiments were conducted to investigate stability, reliability, treatment efficiency, financial analysis and potential for reuse. The bench scale experiments were conducted to study the appropriate chemical cleaning solution. The conclusions were summarized follow by the objectives of this study.

1. The first and the second objectives were reached from the pilot scale experiments. The objectives were to study treatment efficiencies, stability and reliability in long-term, and to compare treatment efficiency and optimum conditions for surface water and treated wastewater. The conclusions of these objectives were as the following:

    1.1 The system has a high ability to handle high turbidity and suspended solids loading without any effect to permeate water quality but less effective for removal of organic materials. Turbidity removal was 98-99 % and Suspended solid removal was 100 %. COD removal was approximate 55-70 %. The microfiltration system with its 0.1 μm was a barrier to remove microorganisms. Less primary disinfectant would be required, thus lowering the concentration of Disinfection- By- Prodcuts (DBPs) formed through treatment process, which safe for human life. Fecal coliform removal was 100 %. In case of hardness removal, the efficiency was 0 % because microfiltration could not remove Ca^{2+} and Mg^{2+}, which cause of hardness.

    1.2 The backwash with only water was not effective to remove the particle material from the membrane, which caused fast increasing of TMP. Air scrubbing and water backwash with 3 ppm of NaClO was the economical and effective method for this system.

    1.3 Low organic matters, high-suspended solid or high inorganic matter such as Kaolin clay, were not much affected to stability of membrane filtration because it was not caused much in adsorptive fouling or internal clogging. Particle deposition was high but this kind of fouling could be removed by mechanical cleaning, which required high volume of air scrubbing or longer time of water backwashing.

    1.4 Secondary treated wastewater was high in both organic material and suspended solid, which had a fast decrease in the permeate flow when the cycle just started of filtration and kept decreasing because accumulation of fouling was near, on and in membrane. Higher permeate flow caused high flux decrease because of high materials that retain in the system. Running hours improved when the filtration time was reduced from 30 minutes to be 15 minutes. The improved percentage of 600 L/h and 720 L/h permeate flow were 70.1 % and 74.2 % respectively.

    1.5 The permeate flux is one of the most important factor, which influences to the membrane fouling. Higher permeate flow could influence to be internal clogging, which is difficult to remove by reverse filtration and become increased faster in TMP.

1.6 The relation of various permeate flux and running hours was not an increasing linear curve, which we cannot expect to get higher water production by increasing permeate flow rate because of high fouling occurred and high pressure driven through the membrane.

1.7 The system could be run in long-term without effects on water quality. The duration time of running for surface water and treated wastewater was 500 h and 300 h, respectively. The operating conditions, which were used for this duration time, were filtration 30 minutes with 480 L/h permeate flow and backwashing 30 seconds with the combination of water, NaClO 3 ppm and 2,000 L/h air scrubbing. The system duration time could be improved to be longer by decrease the permeate flow because of the critical flux reason.

2. The third objective was reached from the bench scale experiments, which was to study the effect of chemical cleaning composition and concentration. The conclusions of this objective were as the following:

2.1 The combination of NaClO and NaOH was the most effective solution for these both feed water, which contain in organic, particulate, and microbial foulant.

2.2 The flux recovery increased when increased the concentration of NaClO but a threshold concentration was between 200 to 400 ppm for both feed water. Excessive this concentration, the flux recovery did not significantly improve.

2.3 Increase of NaOH from 0.075N to be 0.15N was significant of flux recovery for treated wastewater but insignificant for surface water because of lower organic content in surface water, which 0.075 N NaOH was enough for chemical cleaning.

3. The forth and fifth objectives were reached by analyzing data that getting from the pilot scale experiment. The objectives were to make a financial analysis and investigate the potential of reuse. The conclusions of these objectives were as the following:

3.1 This microfiltration system was found to be an attractive economic alternative to conventional process, especially land requirement, which was required very small.

3.2 The permeate water of MF, which feed water was surface water has a potential to reuse as indirect potable water. Treated wastewater was come from polluted source, which should not reuse as potable water. High Quality Industrial Water Reuse could be supply by MF. Both surface water and treated wastewater can reuse for cooling water of industries. In case of industrial process, physical water quality of MF permeate water could supply for all kinds of industry. MF was not effective to remove hardness, which required for boiler unit but in this case, feed water quality of these surface water and treated wastewater, hardness was less than 130 mg/L, which could reuse as low-pressure boiler feed water.

5.2 Recommendations for further study

From these experimental studies, the recommendations for further studies were as the following:

1. Organic fouling is profound in membrane filtration with source water containing high Natural Organic Matter (NOM). For source water high in NOM, organic fouling is believed to be the most significant factor contributed to flux decline. Therefore, fractionation of organic matter should be carried out to study fraction of hydrophobic / hydrophilic in water. The schematic diagram of dissolved organic matter fractionation is shown in Figure 5.1. Effect of flux declined from each fraction should also be determined whether which part is the most effective to flux declined. So, the proper treatment is able to be identified and get better operating condition for membrane filtration.

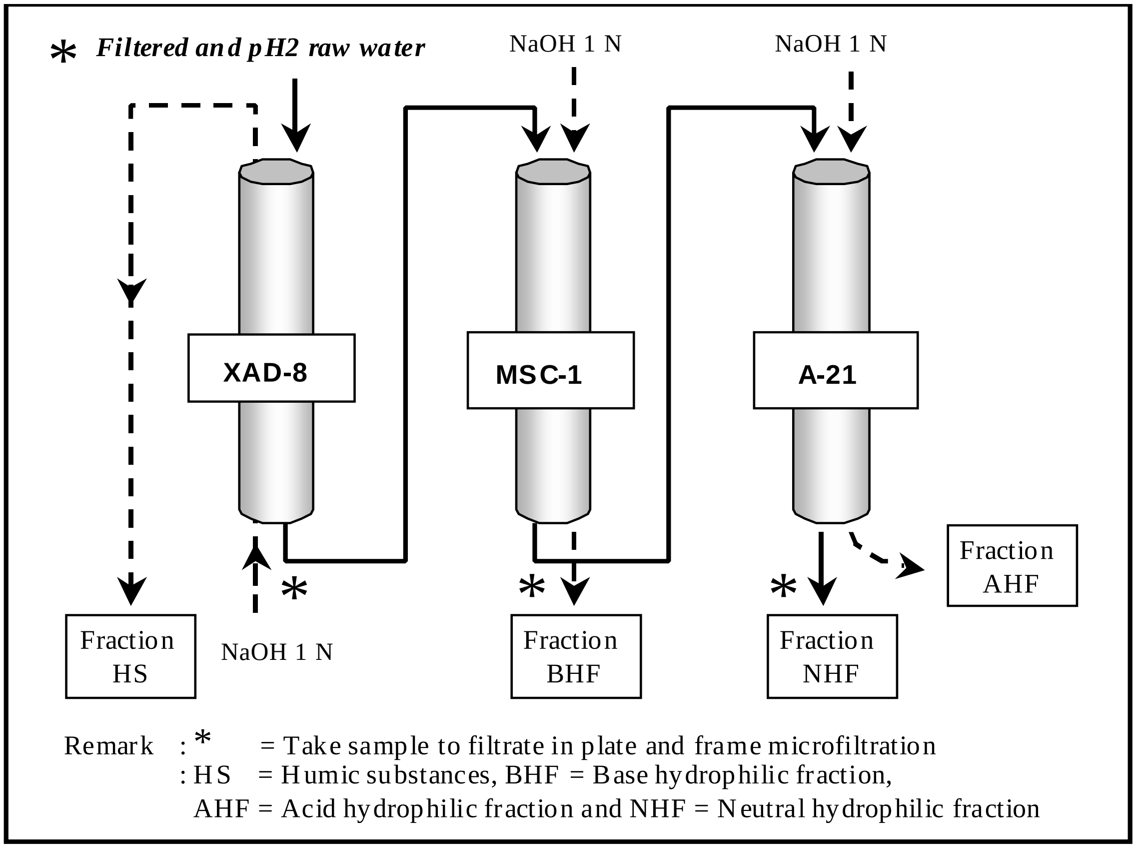

Figure 5.1 Schematic Diagram of Dissolved Organic Matter Fractionation (Adapted from Namour and Muller, 1998)

2. The standard factor of capital and O&M cost in this study was referred from US EPA. It could show the relationship of each cost and compare between the conventional process and microfiltration. In case of actual cost for Thailand, the appropriate factor and cost estimation should be further derived.

3. Physical characteristic of microfiltration has a potential to reuse as the potable water and industrial processes. Some other specific chemical characteristics for each application should be determined to ensure before deciding to reuse.

4. In case of surface water, the optimum concentration of NaOH should be futher determined because lower chemical used, lower problem occurred to the enviroment.

5. Chemical cleaning is the disadvantage of membrane filtration because of cost requirement and not environmental friendly process. The minimization of chemical cleaning process should be studied.

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Appendix A: Percent Feed Water Recovery

The percent feed water recovery of the membrane filtration system was calculated by comparing the net production to the total water filtered.

Refer to Table 4.3, the operating conditions of both experiments were

- Permeate flow rate = 480 L/h
- Average backwash flow rate = 600 L/h
- Filtration time = 30 min
- Running hours = 5h
- Total water filtered = 480 L/h x 5 h
  = 2,400 L

Option 2: Backwash by water & air 60 sec.

- Total backwash water used = 60sec/time x 2times/h x5h x600L/h x 1/3600 h/sec

  = 100 L

- % Feed water recovery = $\frac{\text{Total water filtered – Total backwash water used}}{\text{Total water filtered}}$

  = (2,400 – 100)/ 2,400 x 100

  = 95.8 %

Option 3: Backwash by water & air & NaClO 30 sec.

- Total backwash water used = 30sec/time x 2times/h x5h x600L/h x 1/3600 h/sec

  = 50 L

- % Feed water recovery = $\frac{\text{Total water filtered – Total backwash water used}}{\text{Total water filtered}}$

  = (2,400 – 50)/ 2,400 x 100

  = 97.9 %

Appendix B: Kaolin Clay Concentration and Turbidity Relation

Kaolin clay is used to add in surface water to evaluate effect of suspended solid or turbidity to membrane filtration system. Before running surface water adding Kaolin clay experiments, the relation of its concentration and turbidity was tested. The result is shown in Figure B1. Kaolin clay concentration at 300 mg/L was used for long- term experiments and need to be stirred to maintain required turbidity.

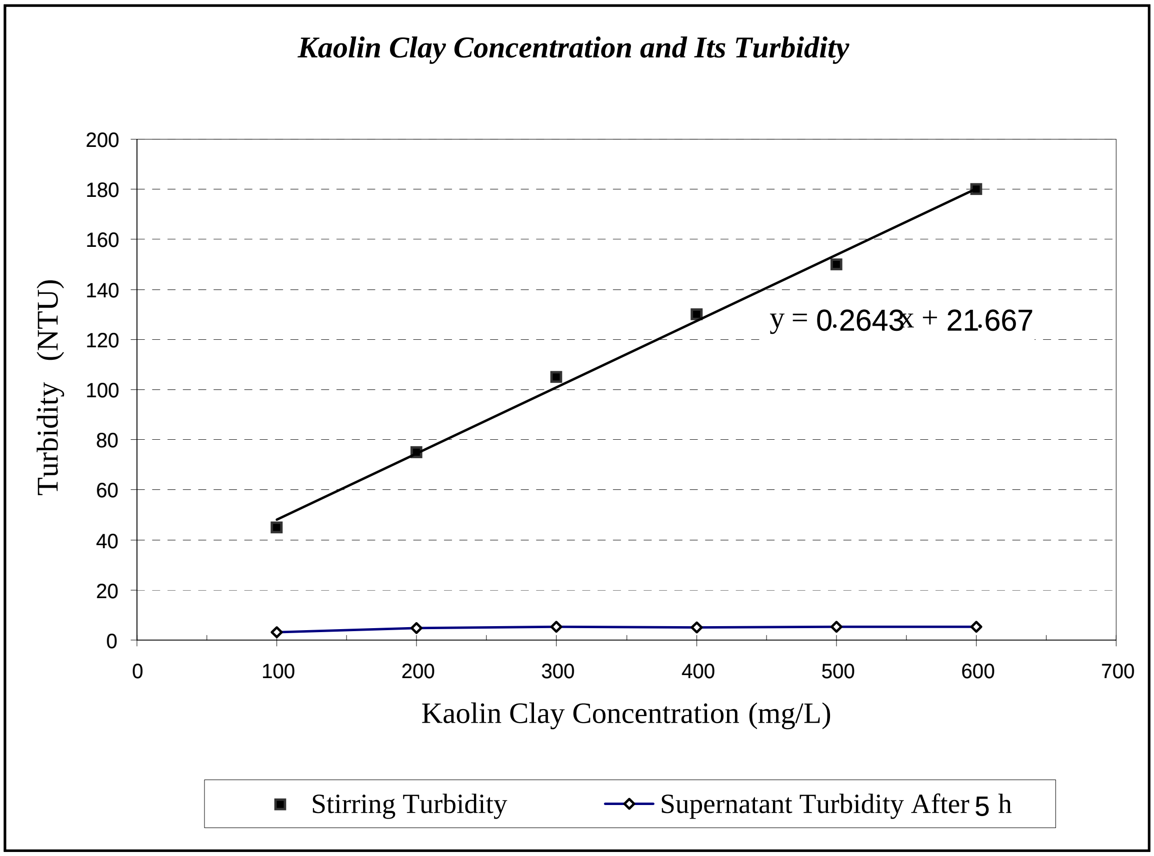


Figure B1 Variation of Turbidity with Kaolin Clay Concentration

Appendix C: The flux declined over a period of time

1. Treated wastewater

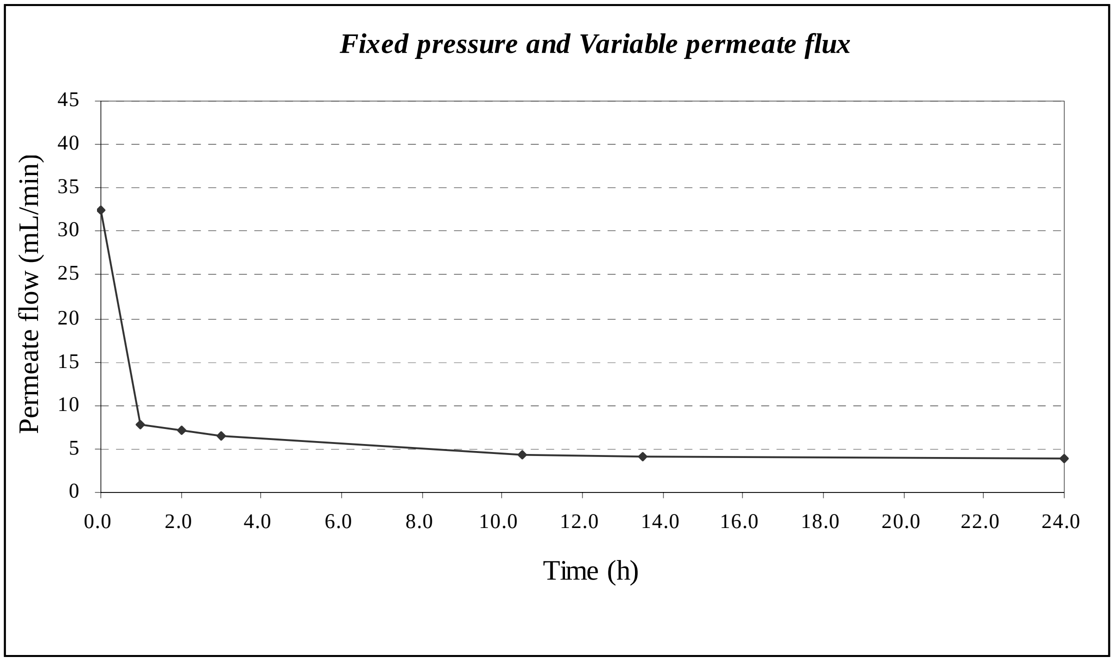


Figure C1 Variable Permeate Flow with Time at Feed Pressure 2.0 bar for Treated Wastewater

2. Surface water

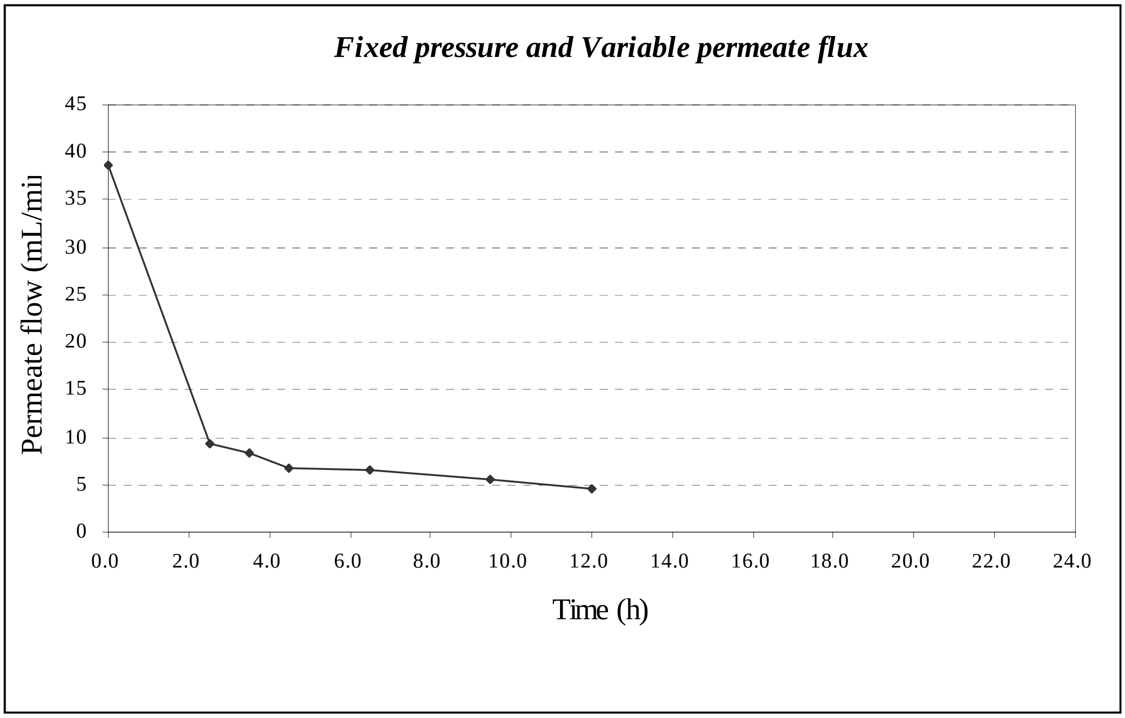


Figure C2 Variable Permeate Flow with Time at Feed Pressure 2.0 bar for Surface Water

Appendix D: Bench Scale Chemical Cleaning Experiment Results

1. Results of effect of chemical cleaning reagents for treated wastewater

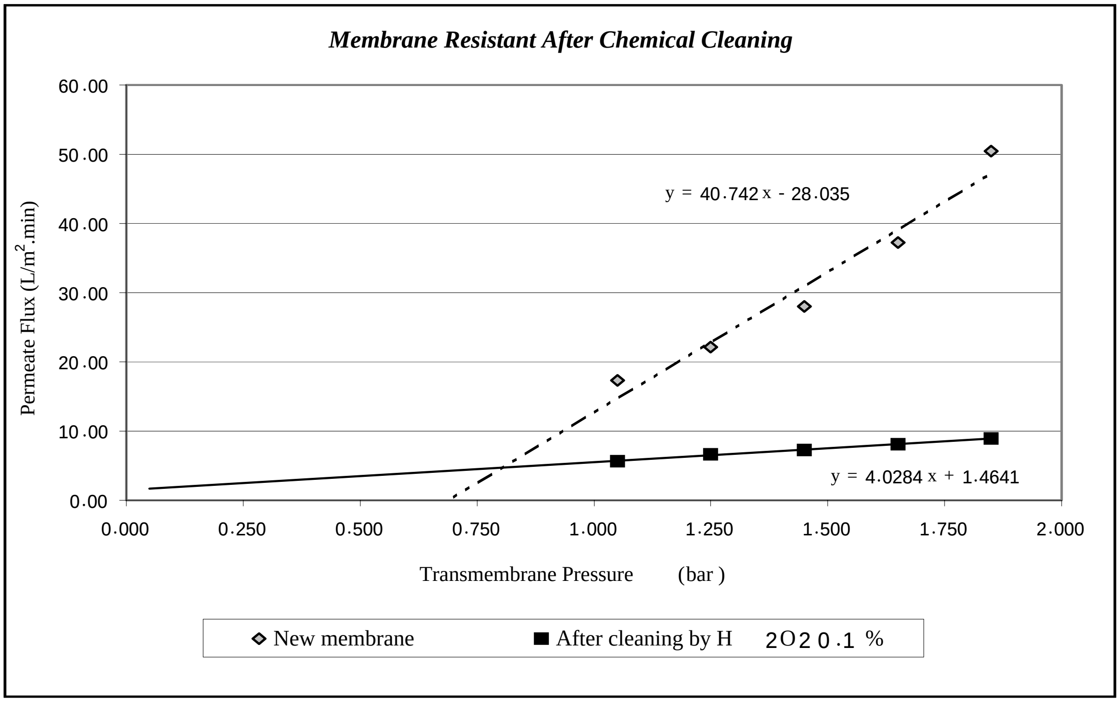


Figure D1 Membrane Resistant after Filtration with AIT Treated Wastewater and Chemical Cleaning by H_2O_2

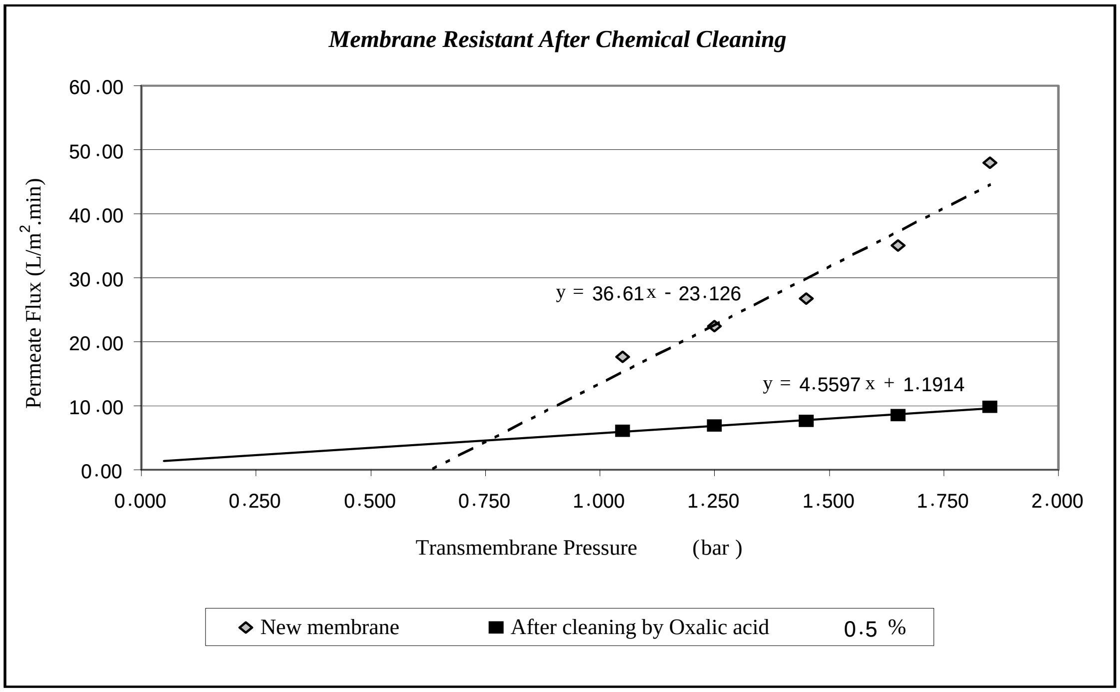
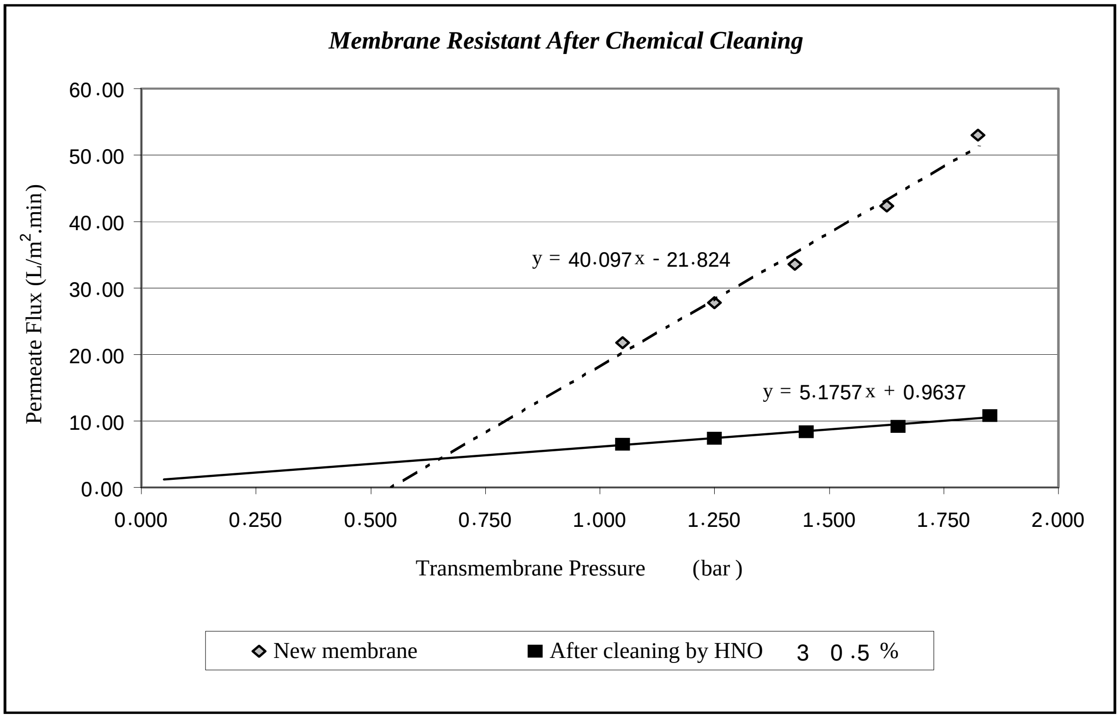


Figure D2 Membrane Resistant after Filtration with AIT Treated Wastewater and Chemical Cleaning by Oxalic Acid



FigureD3 Membrane Resistant after Filtration with AIT Treated Wastewater and Chemical Cleaning by HNO_3

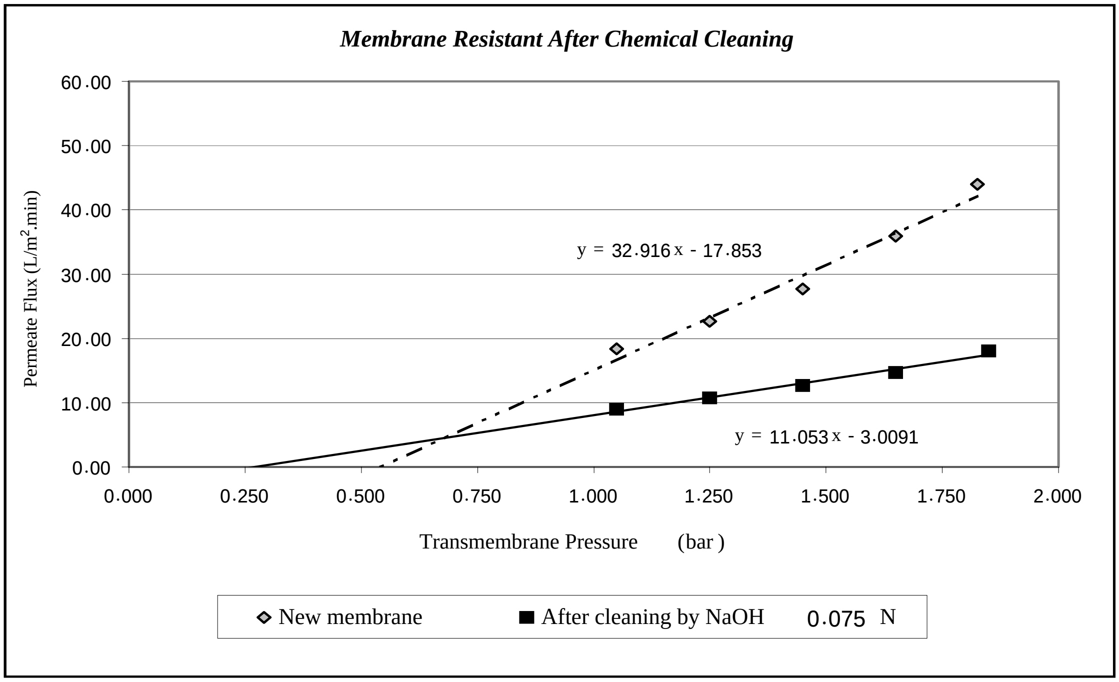


Figure D4 Membrane Resistant after Filtration with AIT Treated Wastewater and Chemical Cleaning by NaOH

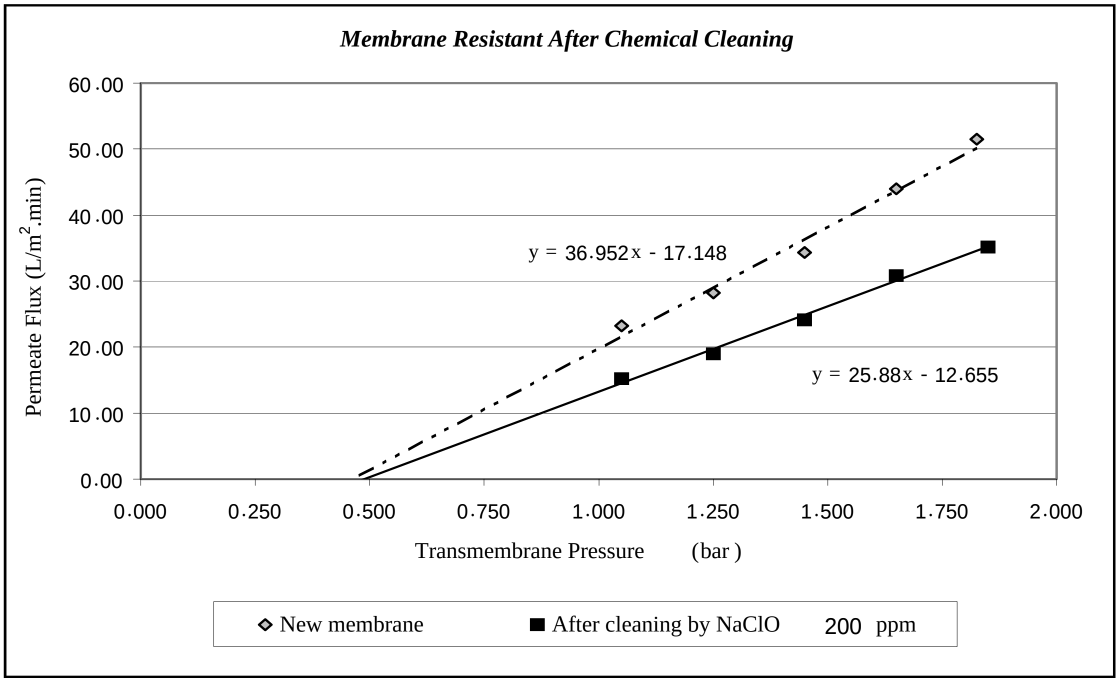


Figure D5 Membrane Resistant after Filtration with AIT Treated Wastewater and Chemical Cleaning NaClO

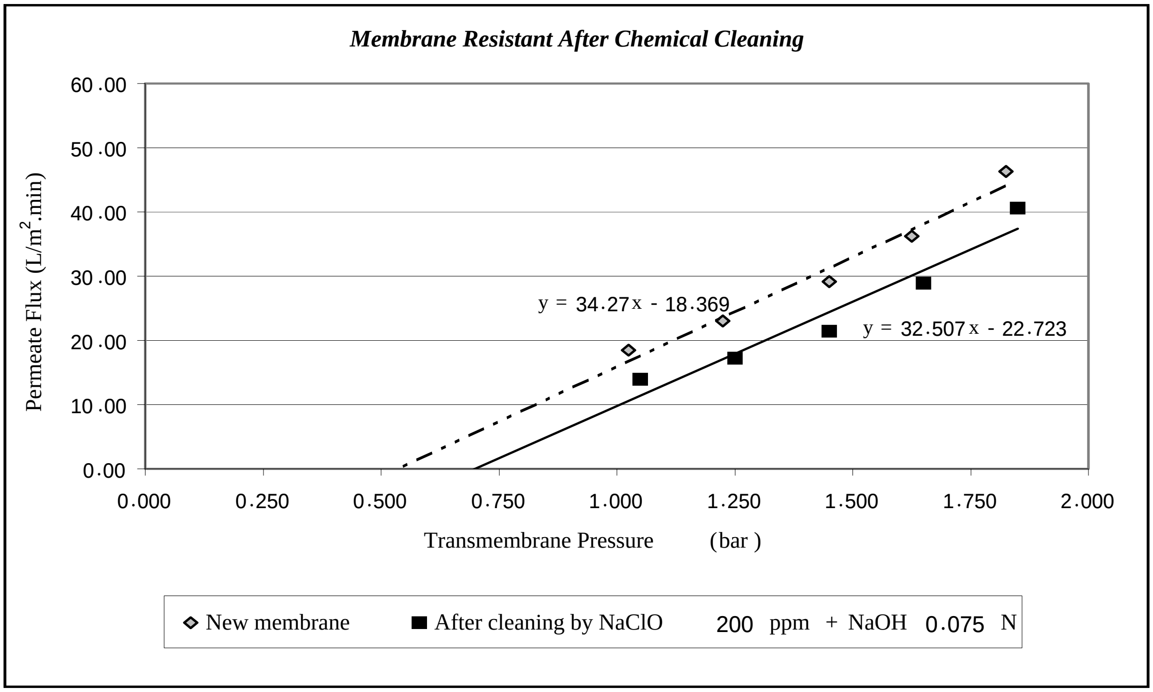


Figure D6 Membrane Resistant after Filtration with AIT treated wastewater and Chemical Cleaning by NaClO & NaOH

1. Results of effect of chemical cleaning reagents for surface water

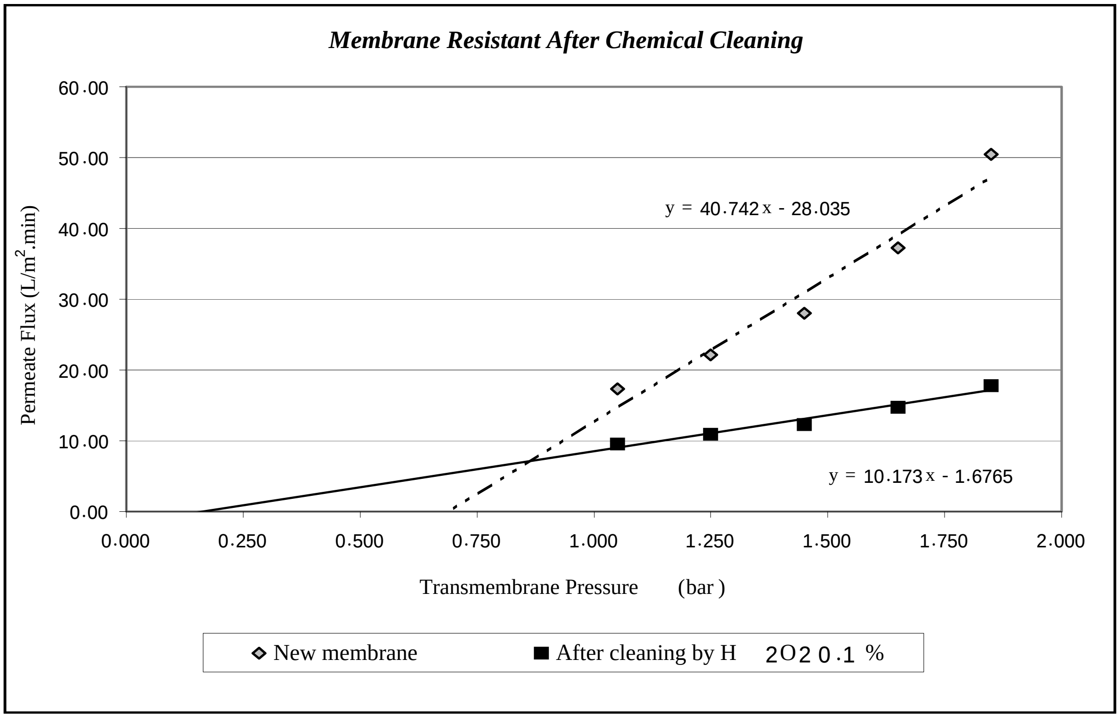


Figure D7 Membrane Resistant after Filtration with AIT Surface Water and Chemical Cleaning by H_2O_2

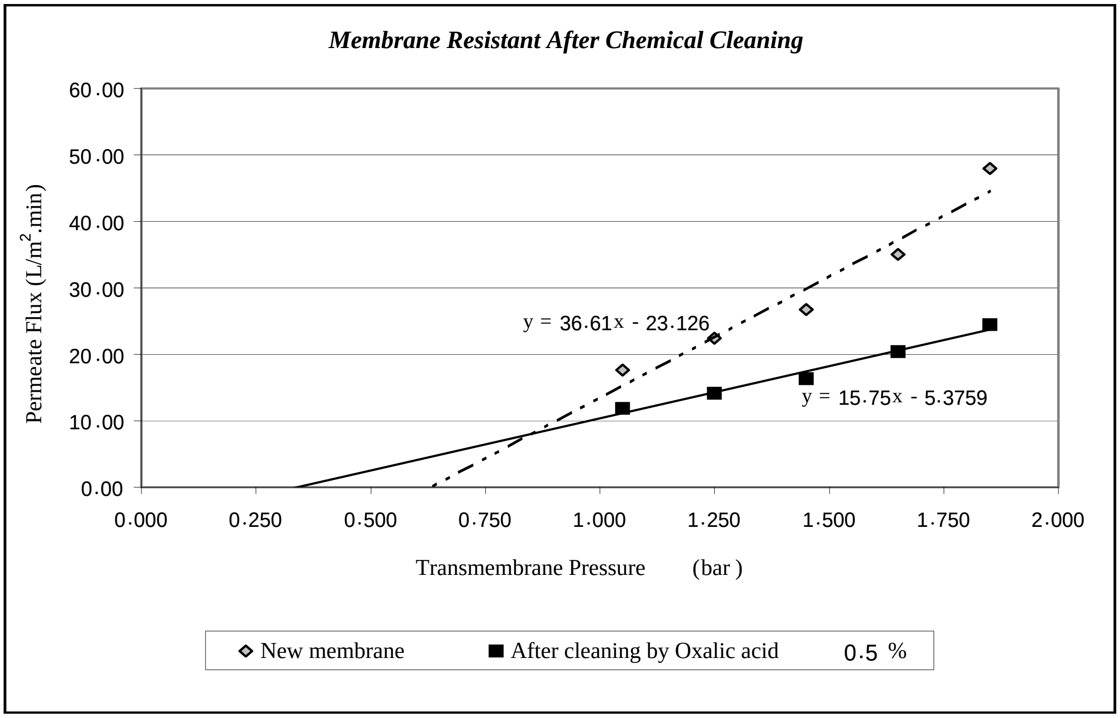


Figure D8 Membrane Resistant after Filtration with AIT Surface Water and Chemical Cleaning by Oxalic Acid

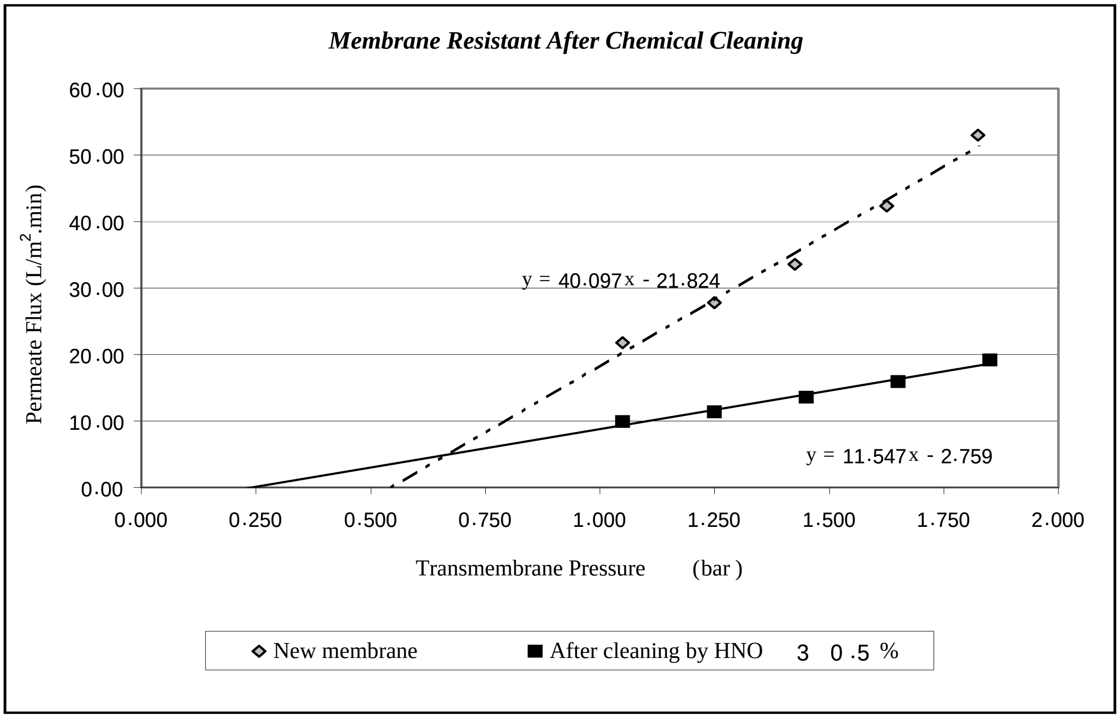


Figure D9 Membrane Resistant after Filtration with AIT Surface Water and Chemical Cleaning by HNO_3

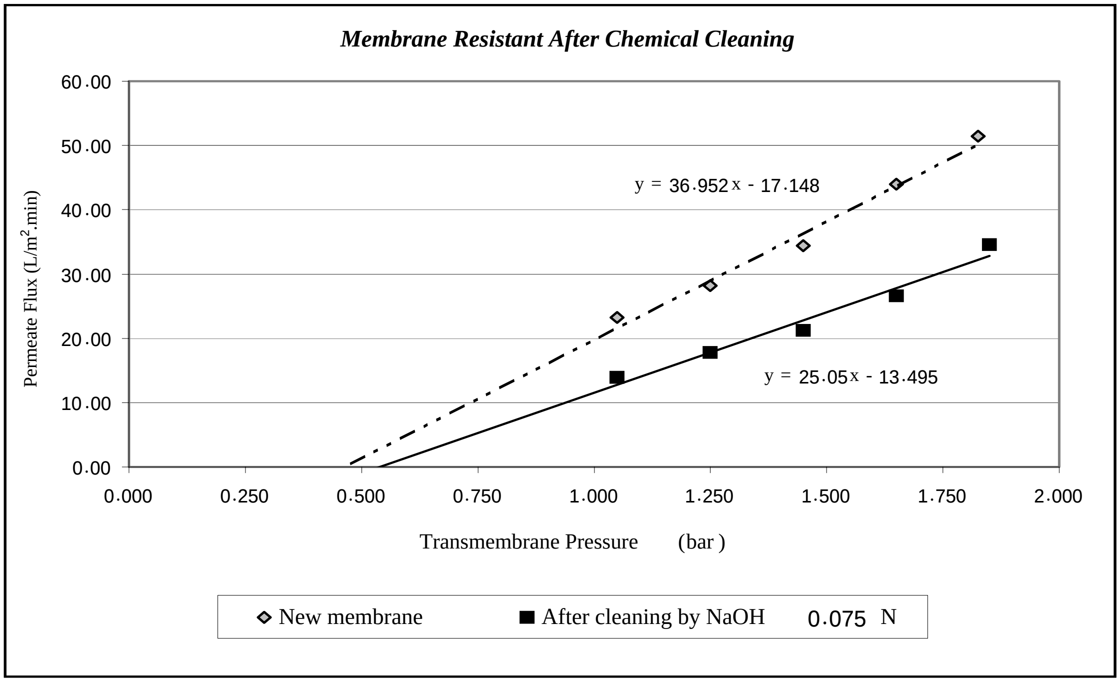


Figure D10 Membrane Resistant after Filtration with AIT Surface Water and Chemical Cleaning by NaOH

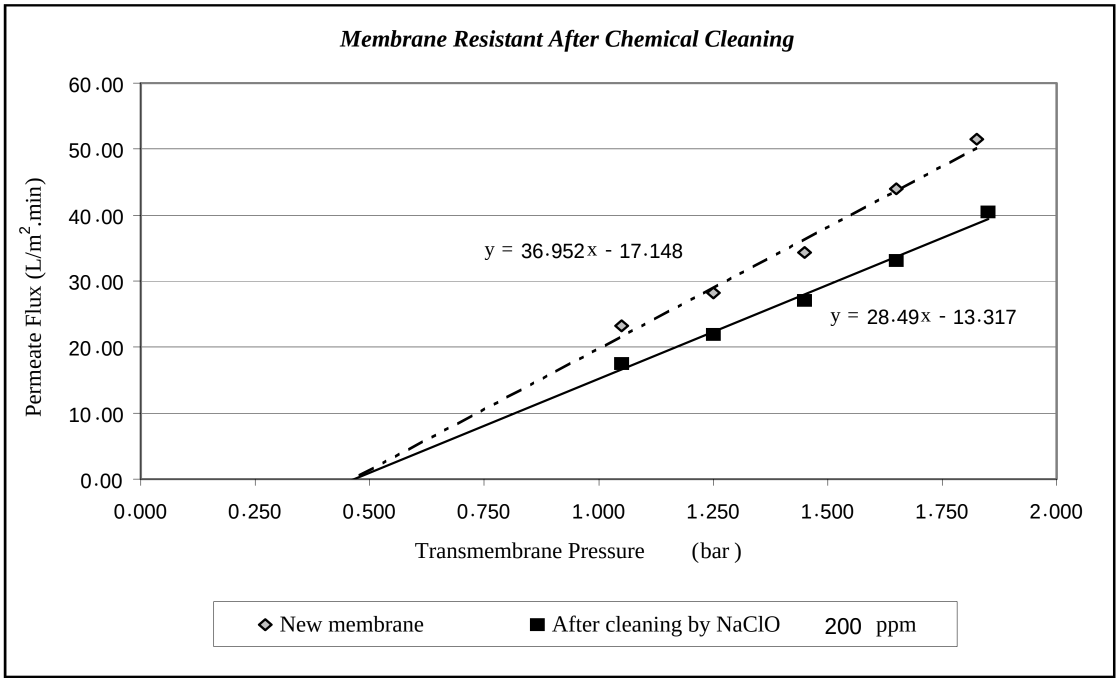


Figure D11 Membrane Resistant after Filtration with AIT Surface Water and Chemical Cleaning by NaClO

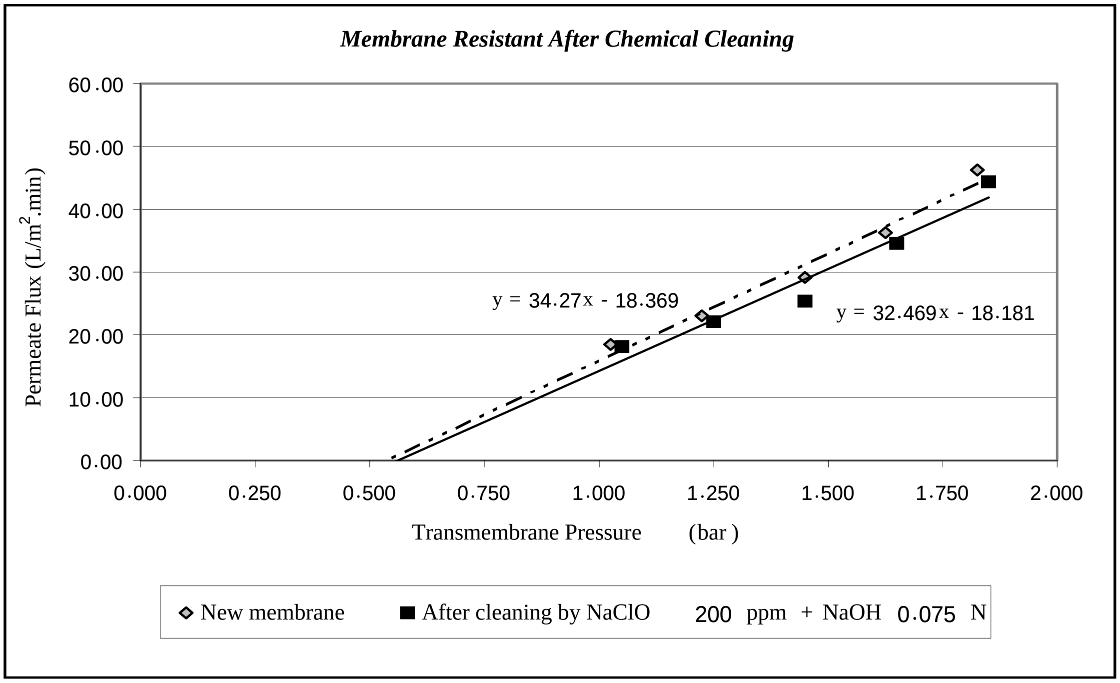


Figure D12 Membrane Resistant after Filtration with AIT Surface Water and Chemical Cleaning by NaClO & NaOH

3. Results of effect of chemical cleaning concentration for treated wastewater

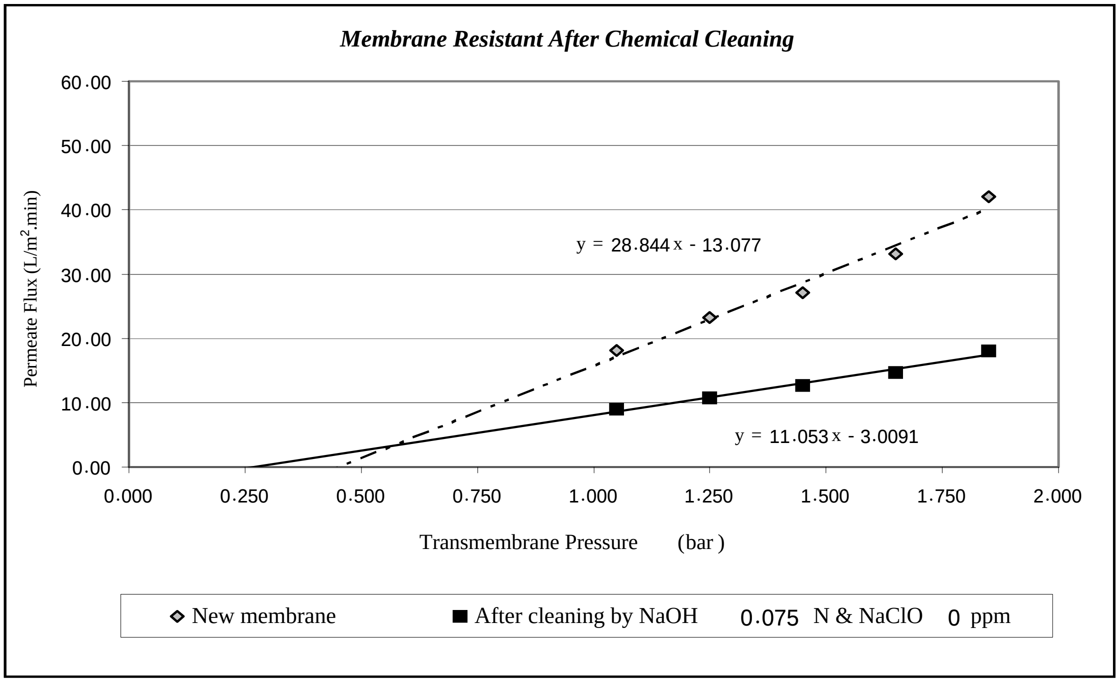


Figure D13 Membrane Resistant after Filtration with AIT Treated Wastewater and Chemical Cleaning by NaOH 0.075 N & NaClO 0 ppm

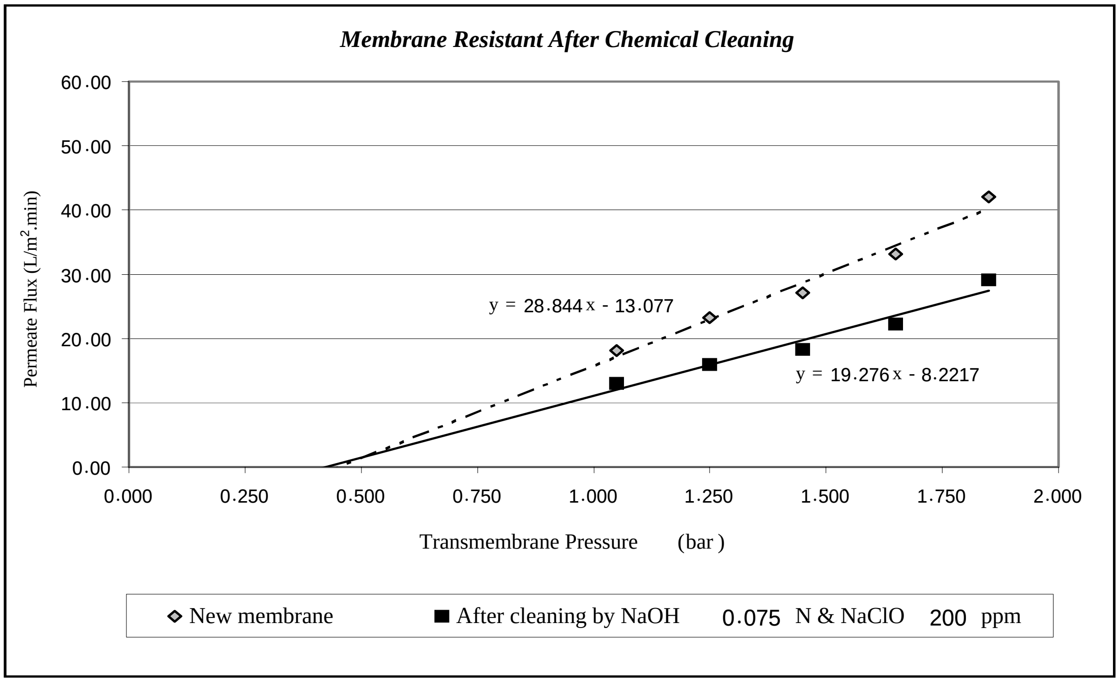


Figure D14 Membrane Resistant after Filtration with AIT Treated Wastewater and Chemical Cleaning by NaOH 0.075 N & NaClO 200 ppm

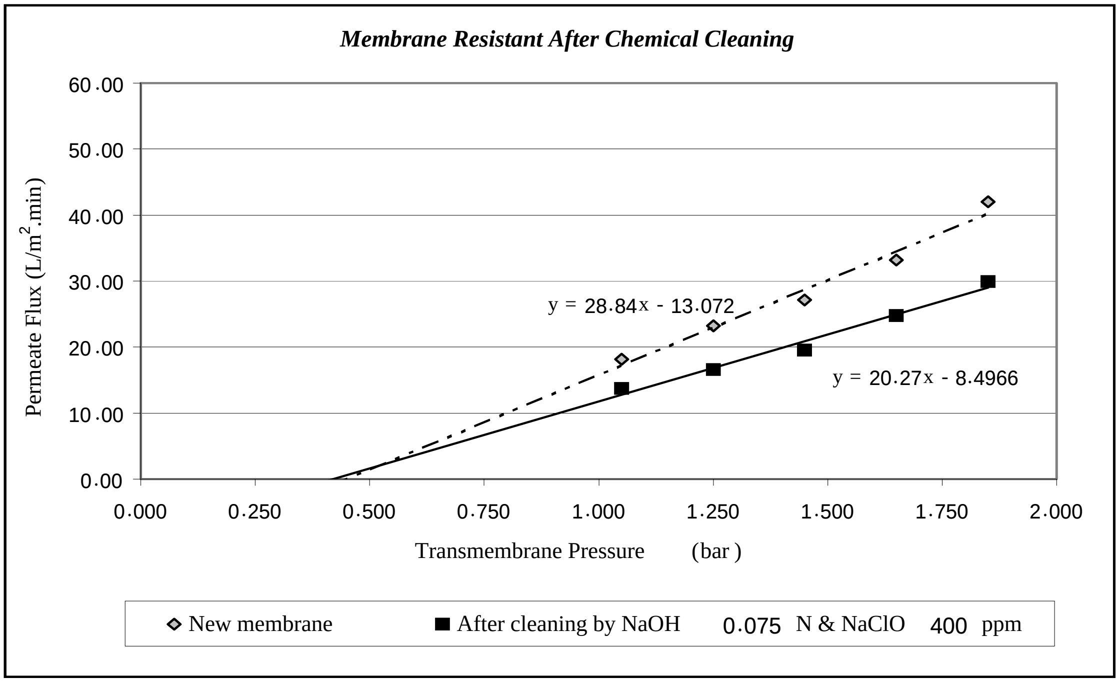


Figure D15 Membrane Resistant after Filtration with AIT Treated Wastewater and Chemical Cleaning by NaOH 0.075 N & NaClO 400 ppm

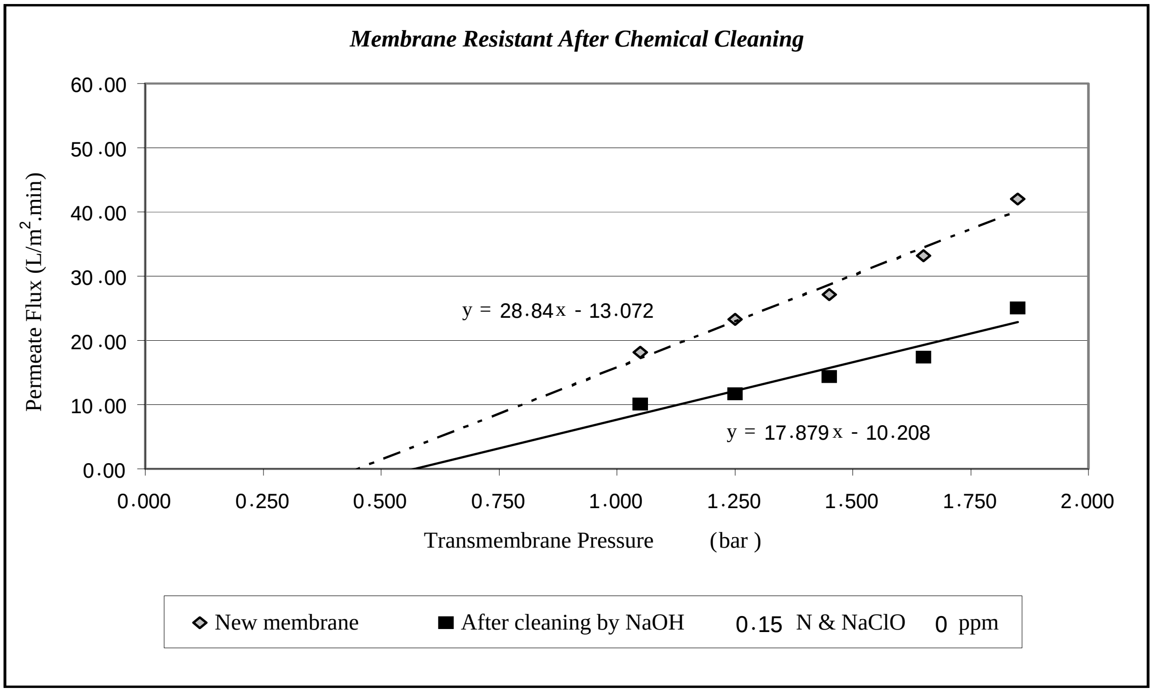


Figure D16 Membrane Resistant after Filtration with AIT Treated Wastewater and Chemical Cleaning by NaOH 0.15 N & NaClO 0 ppm

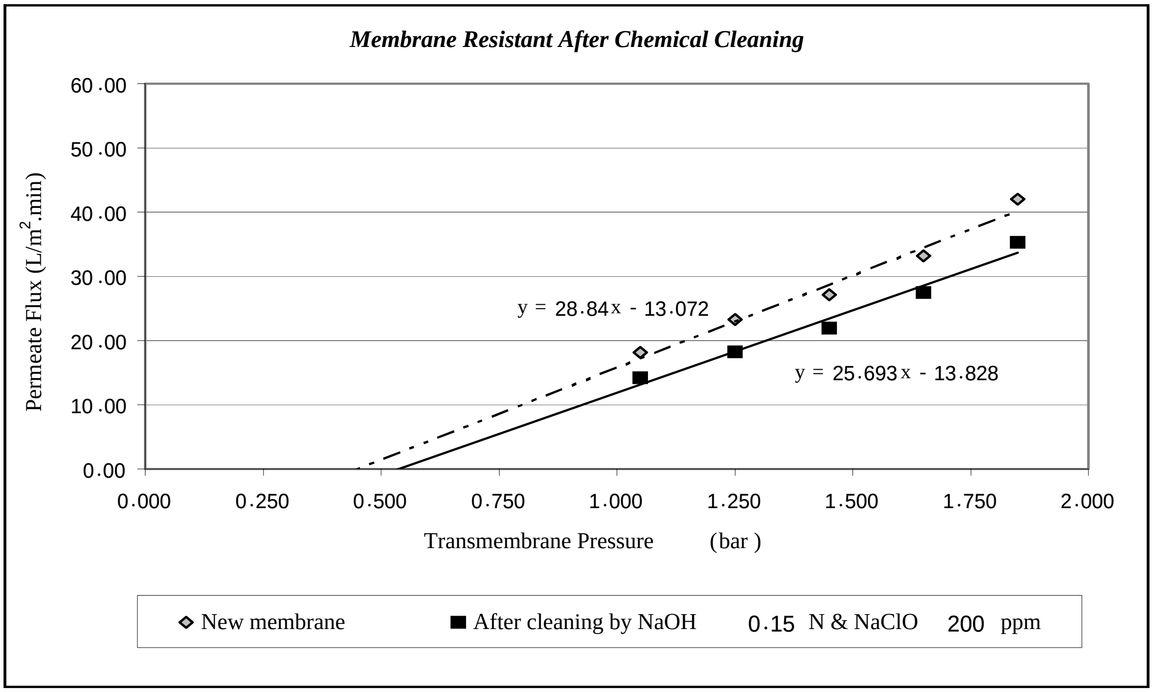


Figure D17 Membrane Resistant after Filtration with AIT Treated Wastewater and Chemical Cleaning by NaOH 0.15 N & NaClO 200 ppm

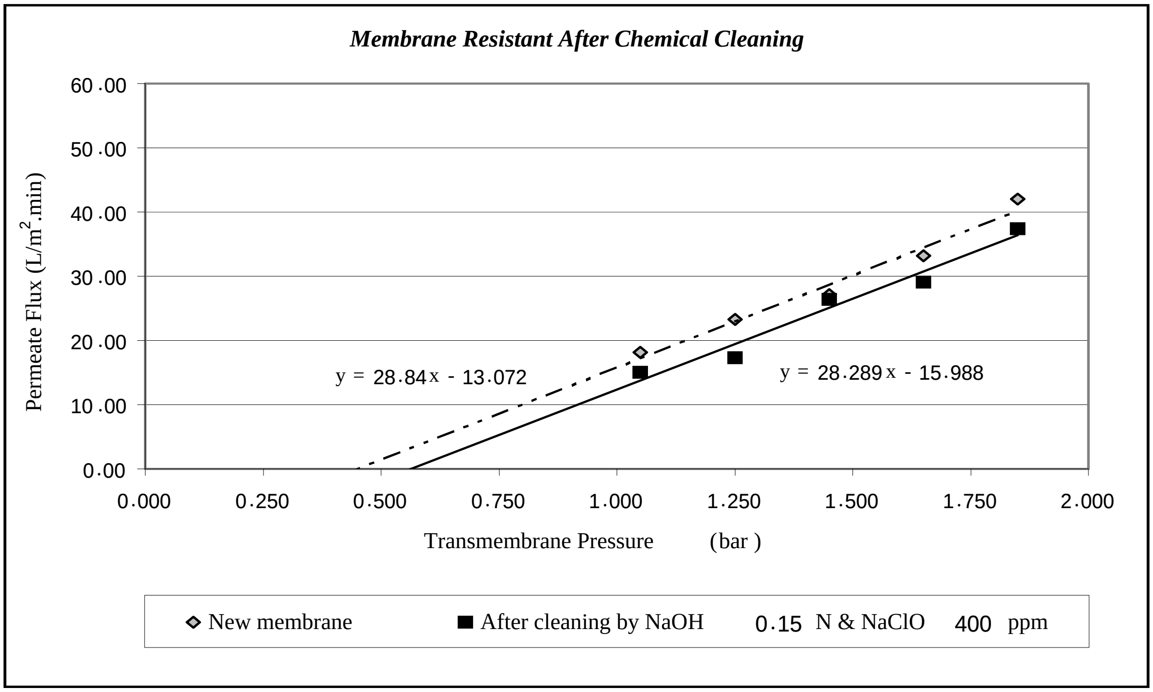


Figure D18 Membrane Resistant after Filtration with AIT Treated Wastewater and Chemical Cleaning by NaOH 0.15 N & NaClO 400 ppm

4. Results of effect of chemical cleaning concentration for surface water

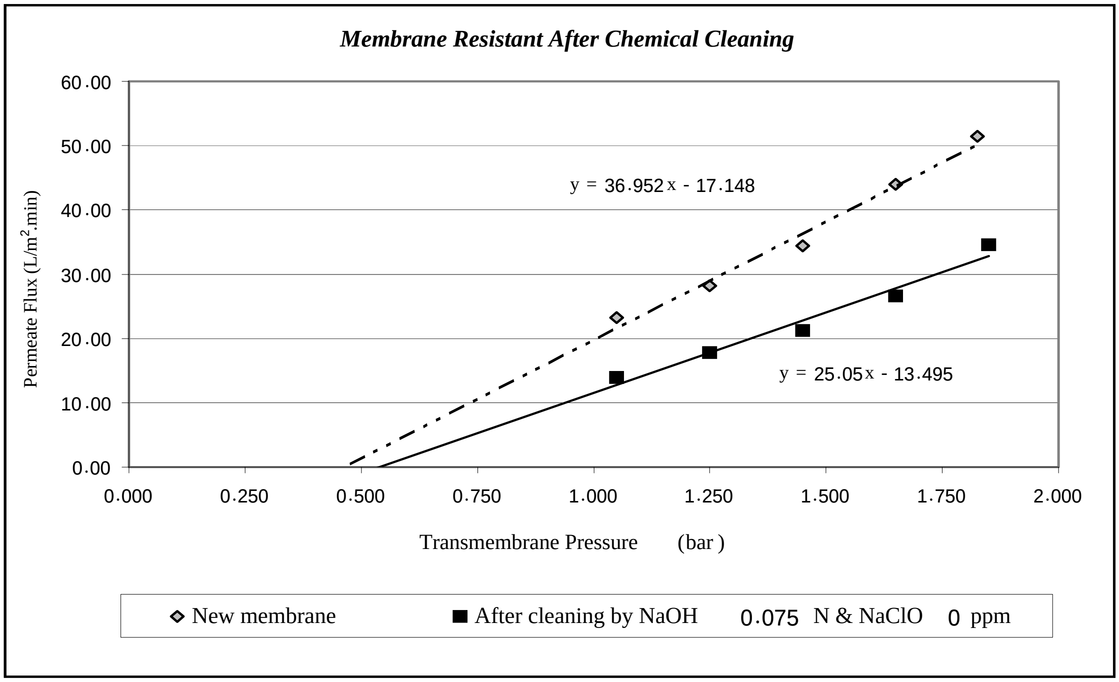


Figure D19 Membrane Resistant after Filtration with AIT Surface Water and Chemical Cleaning by NaOH 0.075 N & NaClO 0 ppm

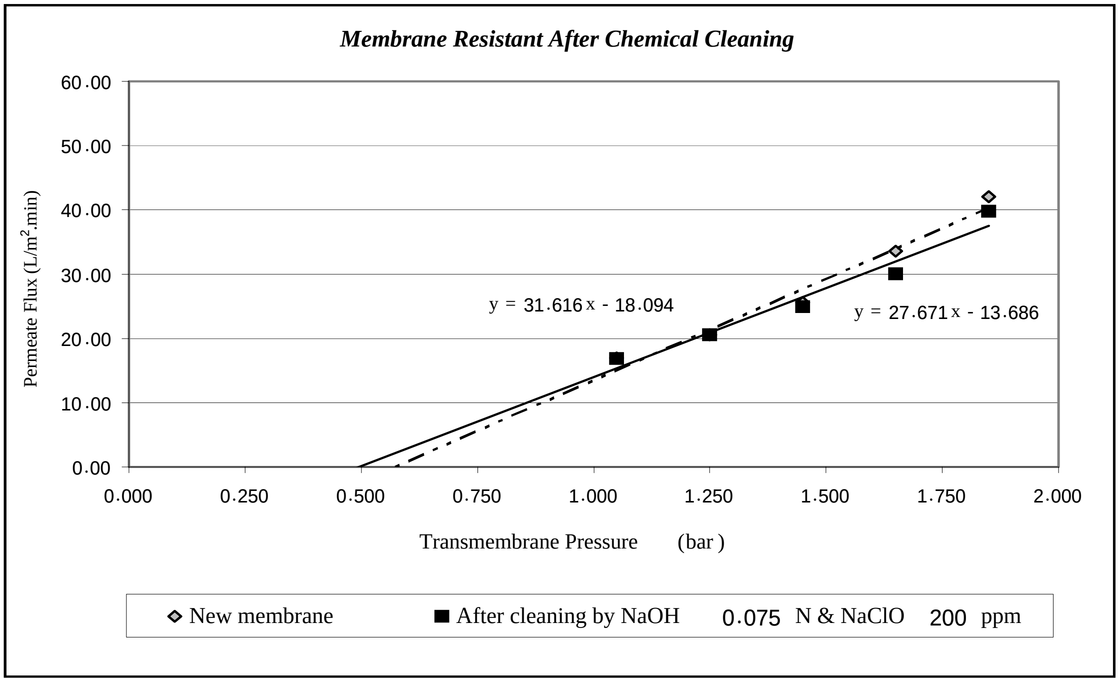


Figure D20 Membrane Resistant after Filtration with AIT Surface Water Chemical Cleaning by NaOH 0.075 N & NaClO 200 ppm

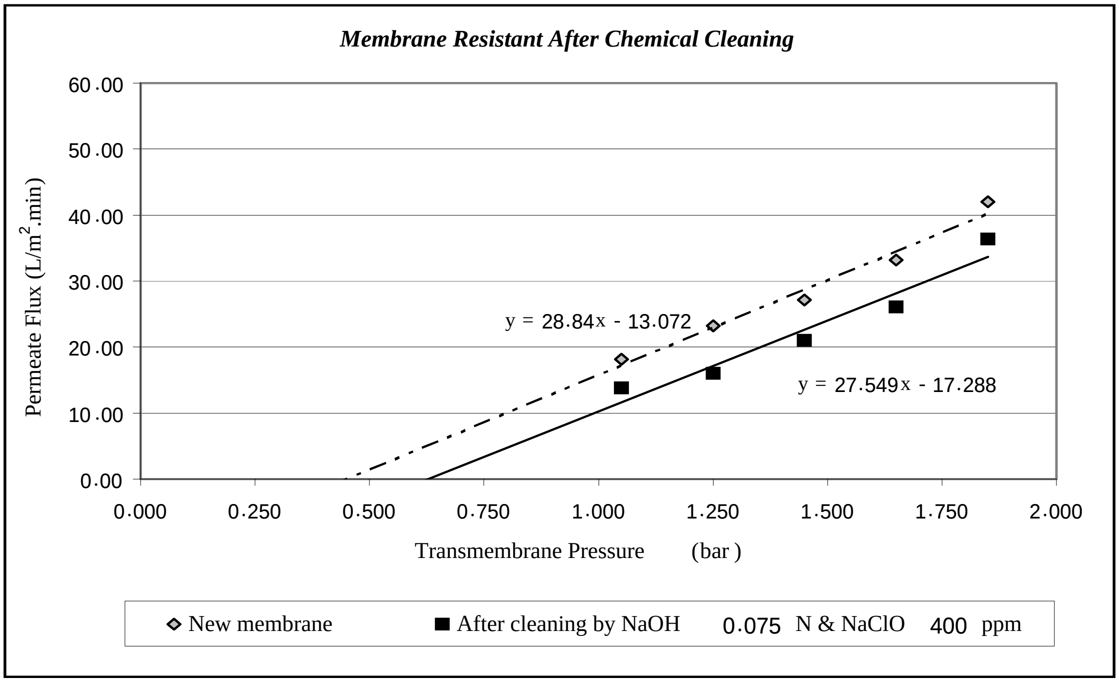


Figure D21 Membrane Resistant after Filtration with AIT Surface Water and Chemical Cleaning by NaOH 0.075 N & NaClO 400 ppm

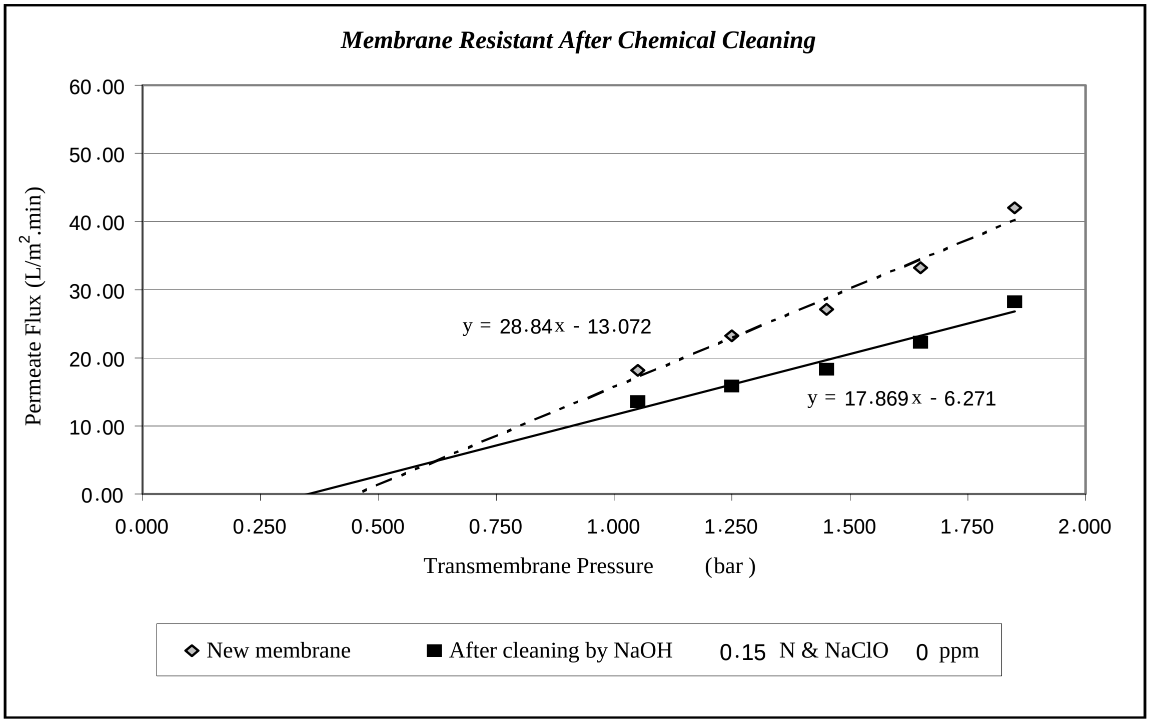


Figure D22 Membrane Resistant after Filtration with AIT Surface Water and Chemical Cleaning by NaOH 0.15 N & NaClO 0 ppm

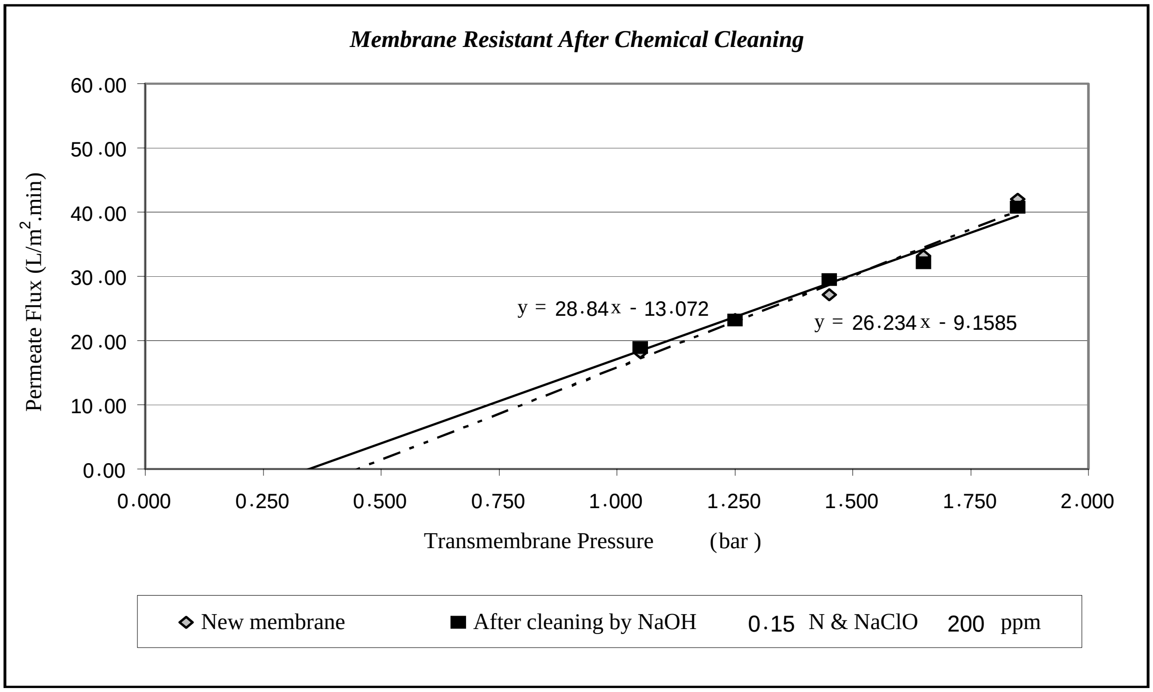


Figure D23 Membrane Resistant after Filtration with AIT Surface Water and Chemical Cleaning by NaOH 0.15 N & NaClO 200 ppm

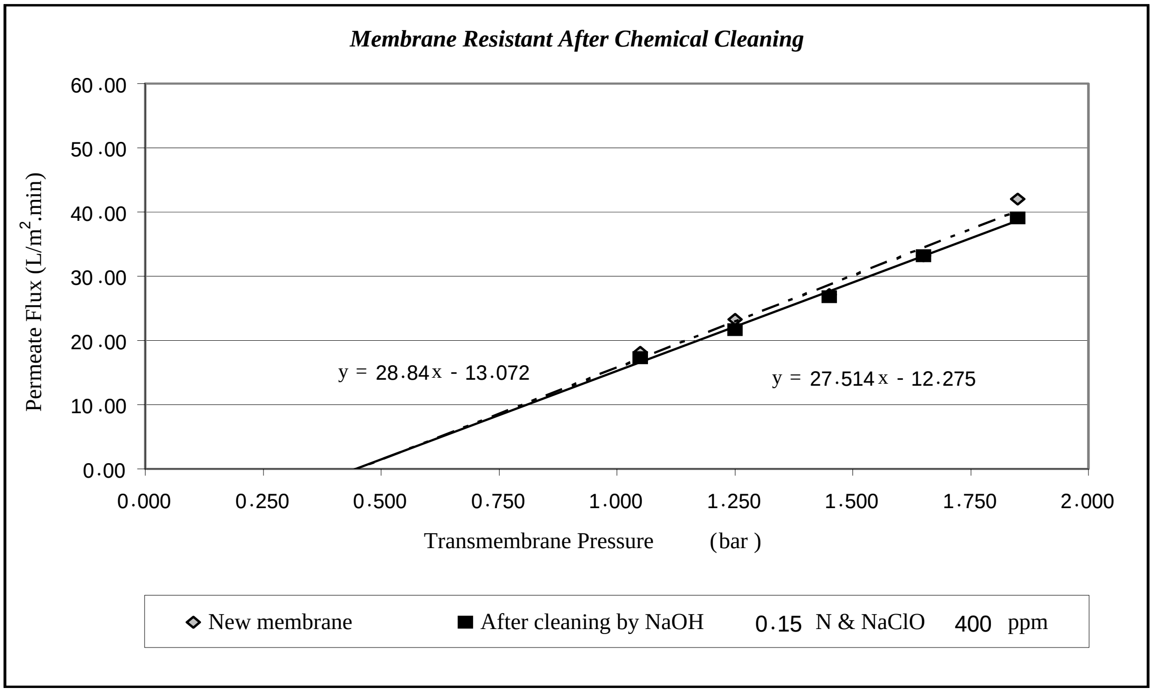


Figure D24 Membrane Resistant after Filtration with AIT Surface Water and Chemical Cleaning by NaOH 0.15 N & NaClO 400 ppm

Appendix E: Water Quantity Calculation

The following calculation is sample calculation of water quantity, which experiment 5 is done.

- Time of running = 500.5 h
- Permeate flow rate = 480 L/h
- Volume of permeate water production = Time of running x Permeate flow rate

  = 500.5 h x 480 L/h

  = 240.2 m^3 (1)
- Backwashing flow rate = 960 L/h
- Filtration/Backwash/Flushing = 30 min/ 30 sec / 30 sec
- Total Backwashing time = 500.5h x 2 time/h x 30 sec/time x 1h/3,600sec

  = 8.34 h
- Volume of backwashing water lost = 960 L/h x 8.34 h

  = 8.0 m^3 (2)
- Volume of water recovery = (1) – (2)

  = 240.2 - 8.0

  = 232.2 m^3 (3)
- % of water recovery = (1) / (3)

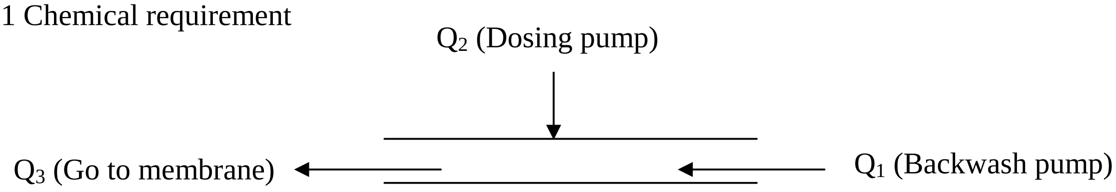
  = 232.2 / 240.2

  = 96.7 %

Appendix F: Chemical Requirement Calculation

1. Sodium Hypo chlorite, which was added with water backwashing.

1.1 Chemical requirement



Q1C1 + Q2C2 = Q3C3
(960L/h x 0) + (1.16L/h x C2) = 961.16 L/h x 3 ppm as Cl
C2 = 2,485.76 ppm as Cl
So, concentration in chemical tank = 2,485.76 ppm as Cl
Commercial NaClO = 10 % as NaClO or 4.77 % as Cl

C1V1 = C2V2
4.77 % as Cl x V1 = 2,485.76 ppm as Cl x 25 L x 1%/10^4 ppm
V1 = 1,304.15 mL

So, NaClO 10 % 1,304.15 mL was added and then added water up to 25 L. The water backwashing will be concentrated at 3 ppm as Cl.

1.2 Chemical Cost

The experiment 5 condition is used to be a sample calculation
Time of running = 500.5 h
Volume of water recovery = 232.2 m^3
Chlorine dosing flow rate = 1.16 L/h
Filtration/Backwash/Flushing = 30 min/ 30 sec / 30 sec
Chlorine used per time = 1.16 L/h x 30 sec x 1h/3600 sec
= 0.0967 L/time
Chlorine used per run = 0.0967 x 500.5 x 2
= 9.67 L
Required NaClO 10 % = 9.67 x 1,304.15 / 25
= 0.5 L
Commercial NaClO 10% cost was 500 Baht / 20 L
So, 0.5 L NaClO cost = 12.5 Baht / 232.2 m^3
Or = 0.05 Baht / m^3

2. Sodium Hypo chlorite, Sodium Hydroxide and Oxalic acid, which were used in chemical cleaning step.

2.1 Chemical requirement

- The first step of cleaning was 1% NaOH plus 3,000 ppm NaClO

- *1% NaOH by weight*

Specific gravity = 2.13 g/mL
Or 1g = 0.47 mL
NaOH 1% is 1 g in solution = 99.47 mL

So, Solution 70 L required NaOH = 703.73 g
NaOH pure 99 %, total required = 710.84 g

- *3,000 ppm NaClO as Cl*

C1V1 = C2V2
4.77 % as Cl x V1 = 3,000 ppm as Cl x 70 L x 1%/10^4 ppm
V1 = 4.41L

So, NaOH 710.84 g and NaClO 10 % 4.41 L was added and then added water up to 70L.

-The second step of cleaning was 1% NaOH plus 3,000 ppm NaClO

- *2 % Oxalic acid*

Specific gravity = 1.65 g/mL
Or 2g = 0.61 mL
Oxalic acid 2% is 2 g in solution = 99.21 mL
So, Solution 70 L required NaOH = 1,411.15 g
NaOH pure 99 %, total required = 1,418.24 g

So, Oxalic acid 1,418.24 g was added and then added water up to 70L.

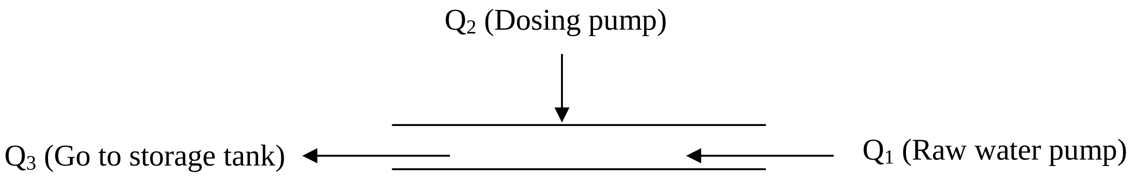
2.2 Chemical cost

Commercial NaClO 10% cost was 500 Baht / 20 L
Lab grade NaOH cost was 375 Baht / 1000 g
Lab grade Oxalic acid cost was 600 Baht / 500 g (but can use 3 times)
Optimum volume of water recovery for surface water was 232.2 m3/ run
Optimum volume of water recovery for treated wastewater was 139.7 m3/ run

Chemical cost required per time
- NaClO cost = 110.25 Baht / time
- NaOH cost = 266.57 Baht / time
- Oxalic acid = 567.30 Baht / time
Total cost = 944.12 Baht / time
Chemical per water production of surface water was 4.07 Baht/m^3
Chemical per water production of treated wastewater was 6.76 Baht/m^3

3. Sodium Hypo chlorite dosing before filtered through membrane, which was used in case of treated wastewater to prevent biofouling problem.

3.1 Chemical requirement



Q1C1 + Q2C2 = Q3C3
(6.0 m^3/h x 0) + (0.042 m^3/h x C2) = 6.042 m^3/h L/h x 5 mg/L as Cl
C2 = 719.29 mg/L as Cl

C1V1 = C2V2
4.77 % as Cl x V1 =719.29 mg/L as Cl x 100L x 1%/10^4 ppm
V1 = 1.51 L
So, NaClO 10 % 1.51 L was added and then added water up to 100 L.

3.2 Cheimcal cost

Raw water used (drain out 15 %) = 480x1.15x301h
= 166.2 m3
Dosing hour = 27.5 h
Chlorine dosing = 1.15 m3
Total chlorine used = 1.15 x 1.51
= 1.74 L
Commercial NaClO 10% cost was 500 Baht / 20 L
So, 17.4 L NaClO cos = 435 Baht / 139.7 m^3
Or = 3.11 Baht / m^3

Pilot Scale Experimental Investigation of Membrane Filtration for Water and Wastewater Reuse

Miss Suwanna Kitpati

Examination Committee

- Prof. C. Visvanathan (Chairperson)
- Dr. Ajit P. Annachhatre
- Dr. Preeda Parkpian
- Dr. Seung-Hwan Lee

LPE Co.,Ltd

- Mr. Prapan Ariyamethee

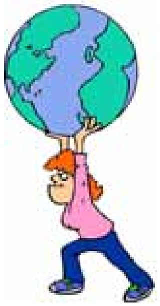
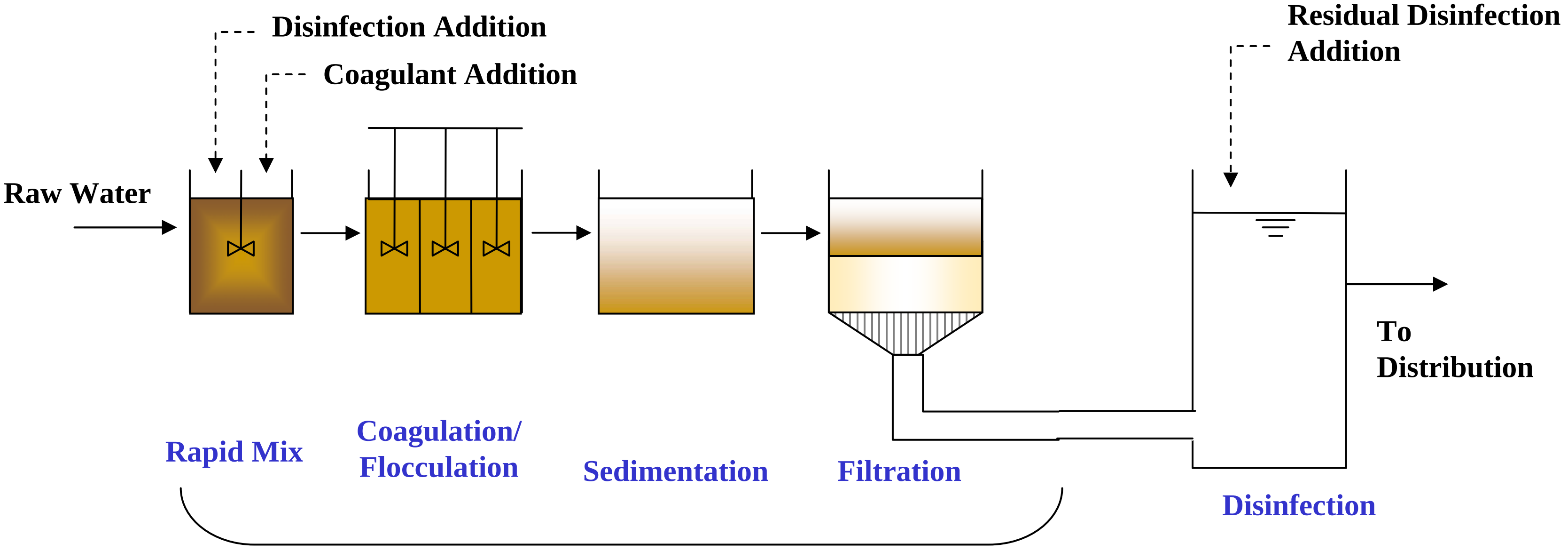


Table of Contents

- Brief of Literature Review
- Objectives and Scopes
- Methodology with Results & Discussion
- Conclusion & Recommendation

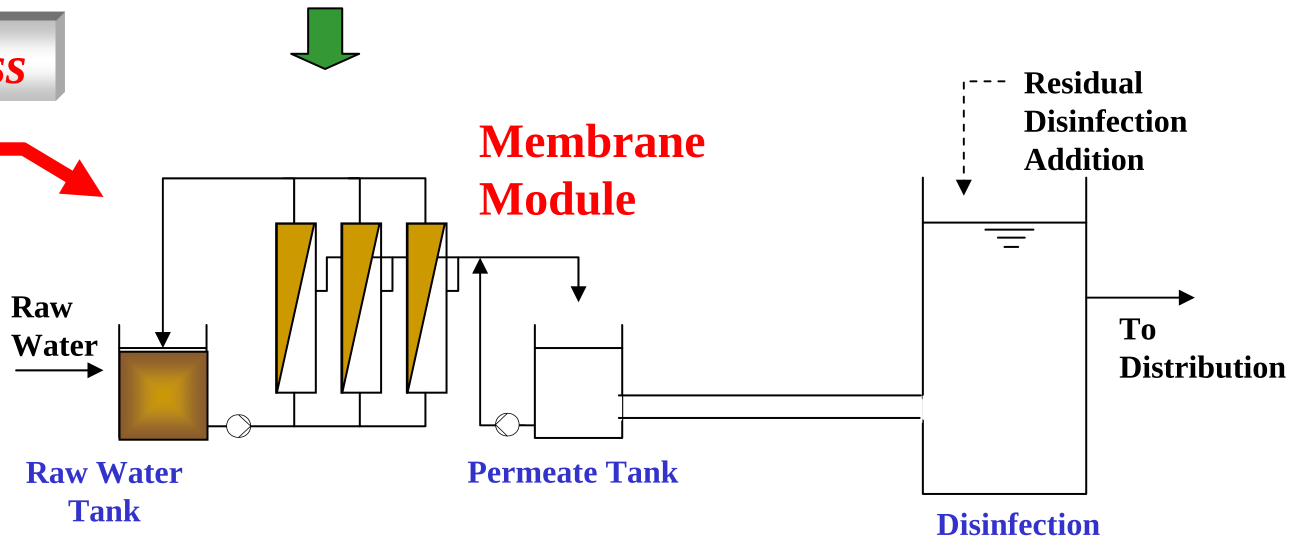
Conventional Process



Membrane Process

Small Area

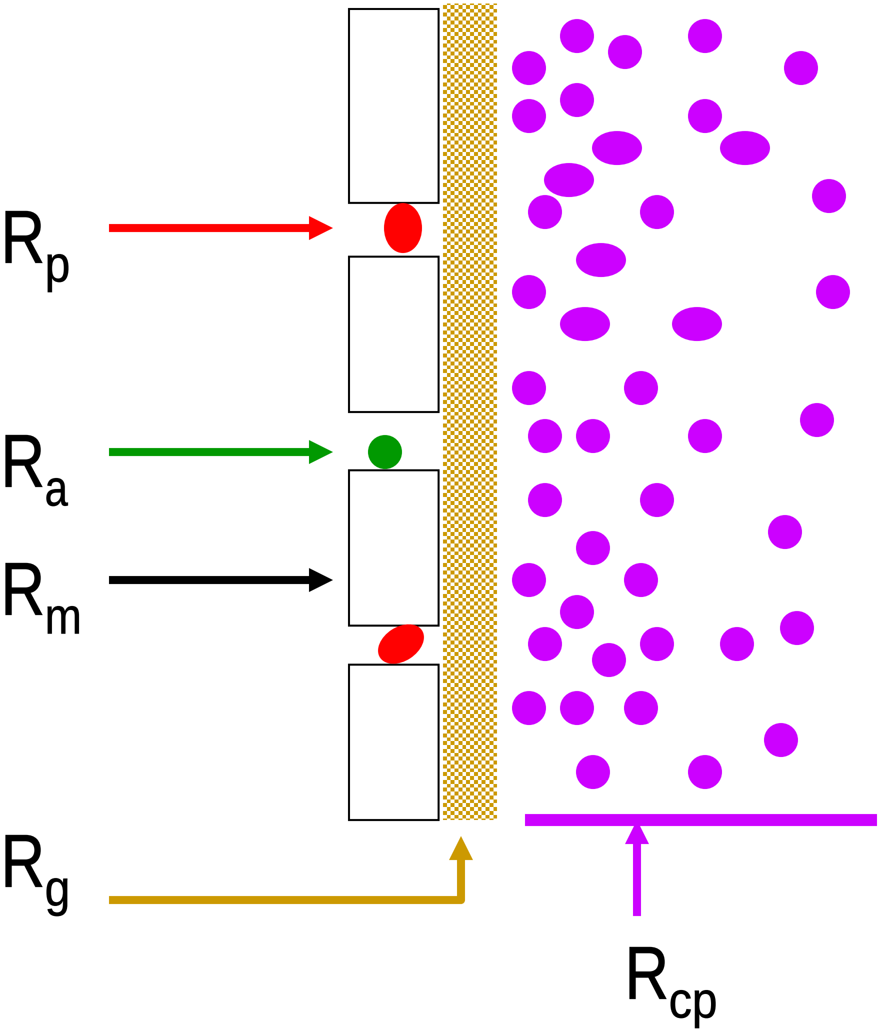
Easy to Operate



Conventional water treatment unit process replaced by MF

Membrane Stability Effect

- Fouling



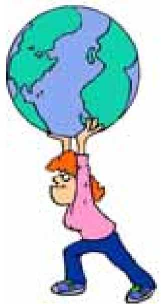
Rp : pore-blocking

Ra : adsorption

Rm : membrane

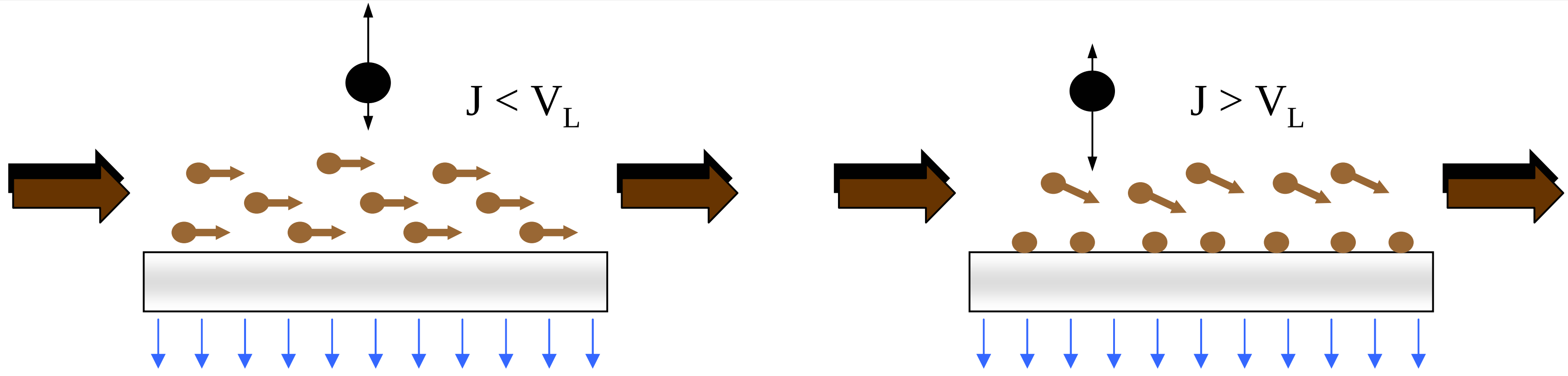
Rg : gel layer formation

Rcp : concentration polarization



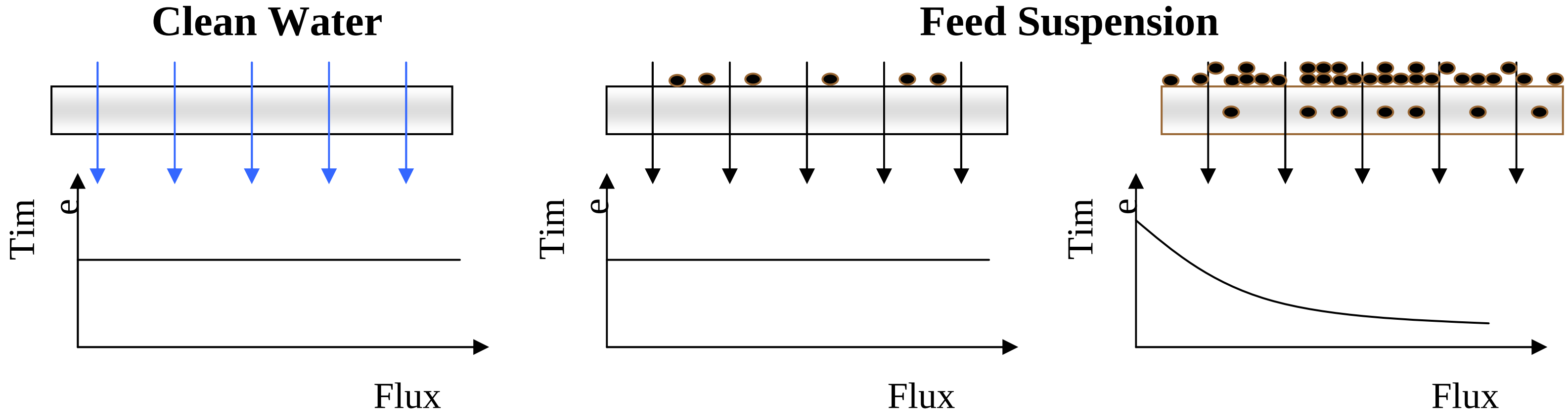
Membrane Stability Effect

- Permeate Flux



(a) Below critical flux **(b) Above critical flux**

Different circumstance of CFMF(Belfort, 1980)



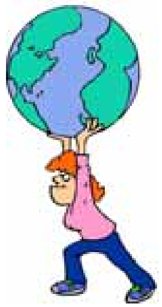
(a) Clean Water Flux **(b) Below Critical Flux** **(c) Above Critical Flux**

Comparison of the flux with clean water flux (Field,1995)

- Contaminant

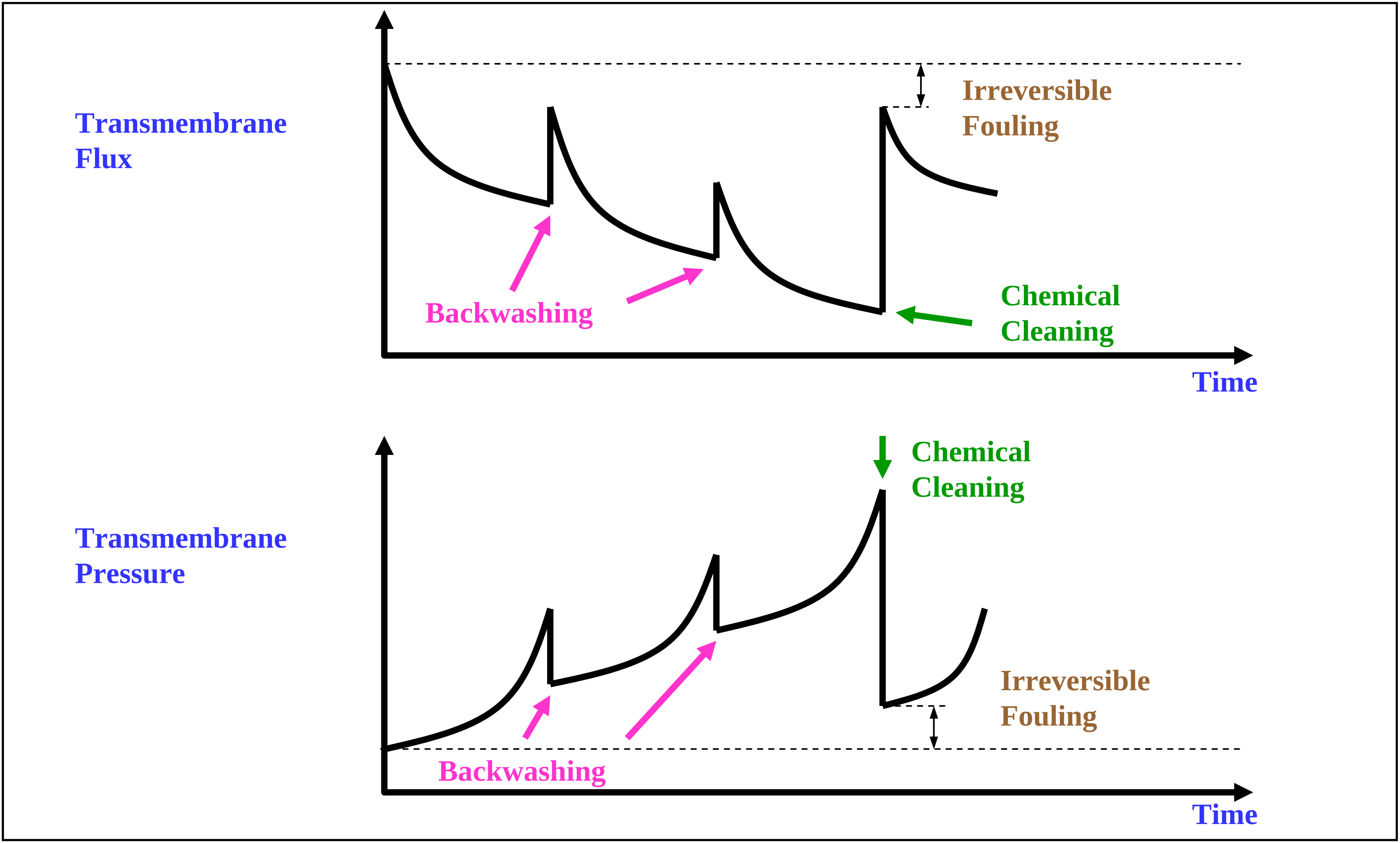
Membrane Stability Effect

1. Organic Fouling
   - NOM (Surface water : lake, river)
2. Inorganic Fouling
   - Metal oxides, Kaolin clay
3. Particulate Fouling
   - Algae, bacteria, Suspended solid
4. Biological Fouling
   - Biofilms



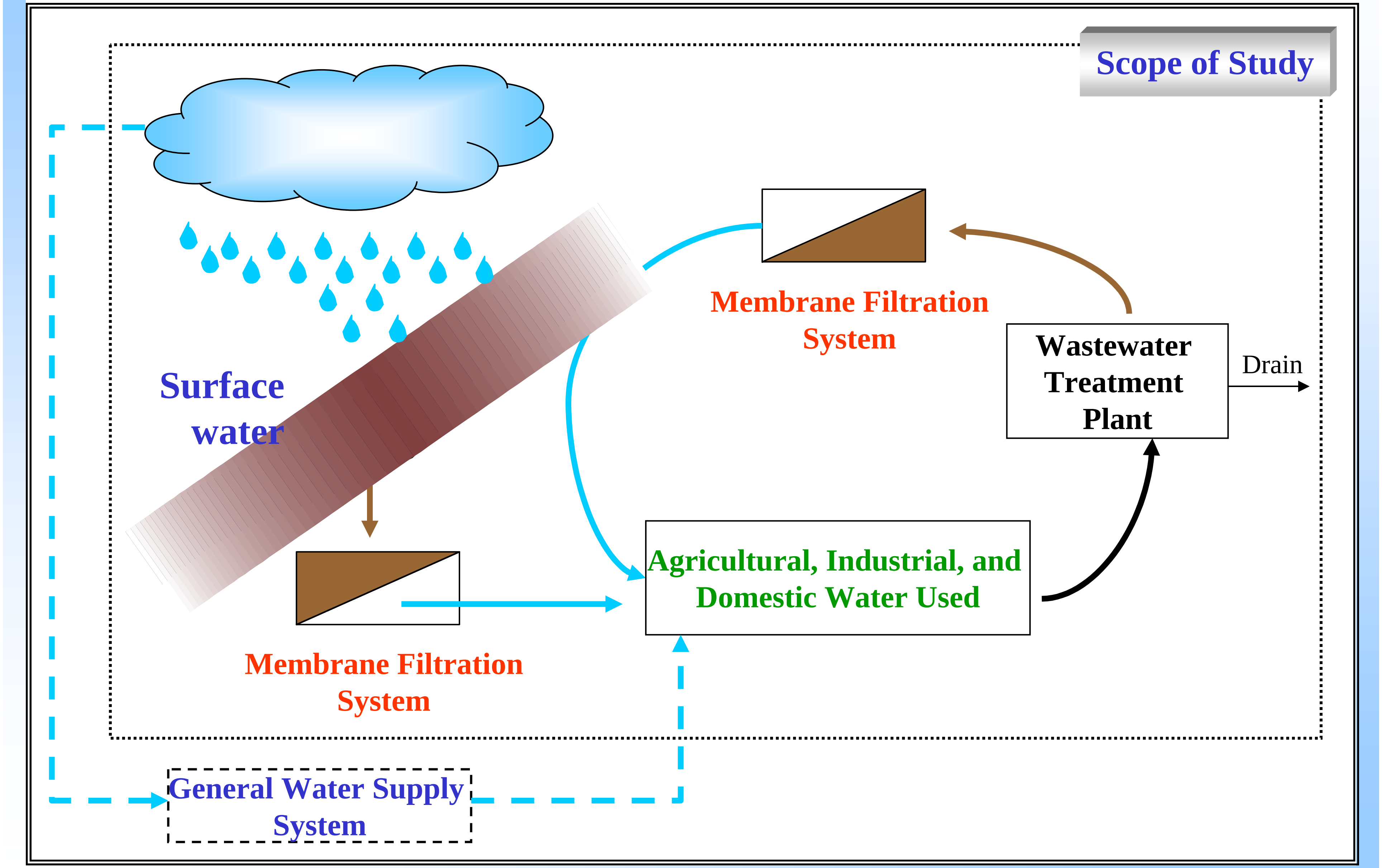
- Cleaning

Membrane Stability Effect



Backwashing & Chemical Cleaning (Mallevialle et al, 1996)

Concept of Study



Scope of Study

Surface water

Membrane Filtration System

Wastewater Treatment Plant

Drain

Agricultural, Industrial, and Domestic Water Used

Membrane Filtration System

General Water Supply System

Objectives

1. To study reliability and stability in long term experiment.
2. To study treatment efficiency.
3. To study chemical concentration and composition effect
4. To make a financial analysis.
5. To investigate the potential of reuse of surface water and treated wastewater.

Scopes

1. Pilot scale experiment : Long term stability and reliability
2. Bench scale experiment : Chemical cleaning solutions
3. Feed water : AIT Pond (surface water)
   : AIT Treated wastewater

Methodology

Bench Scale Experiment

- Effect of compostition
- Effect of concentration

Pilot Scale Experiment

- Optimum operating condition
  - -Surface water
  - -Treated wastewater

Experimental Results

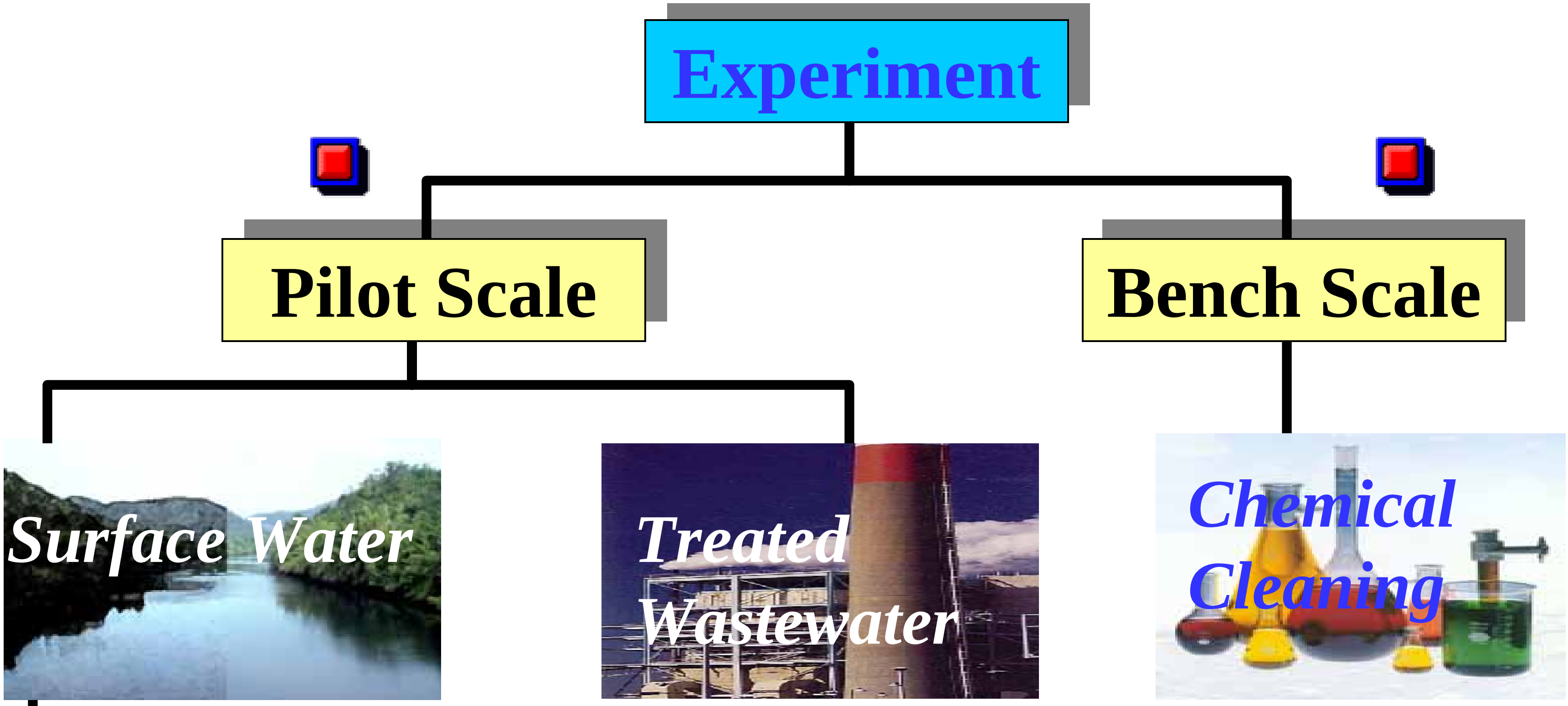
- Process stability
- Water quality reliability

Data Compilation

- Investigated potential of reuse
- Financial analysis

Overall Experimental Strategy of Research

Overall of Experiment



Experiment

Pilot Scale

Bench Scale

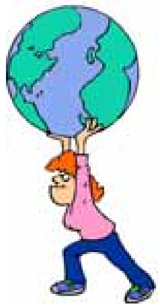
Surface Water

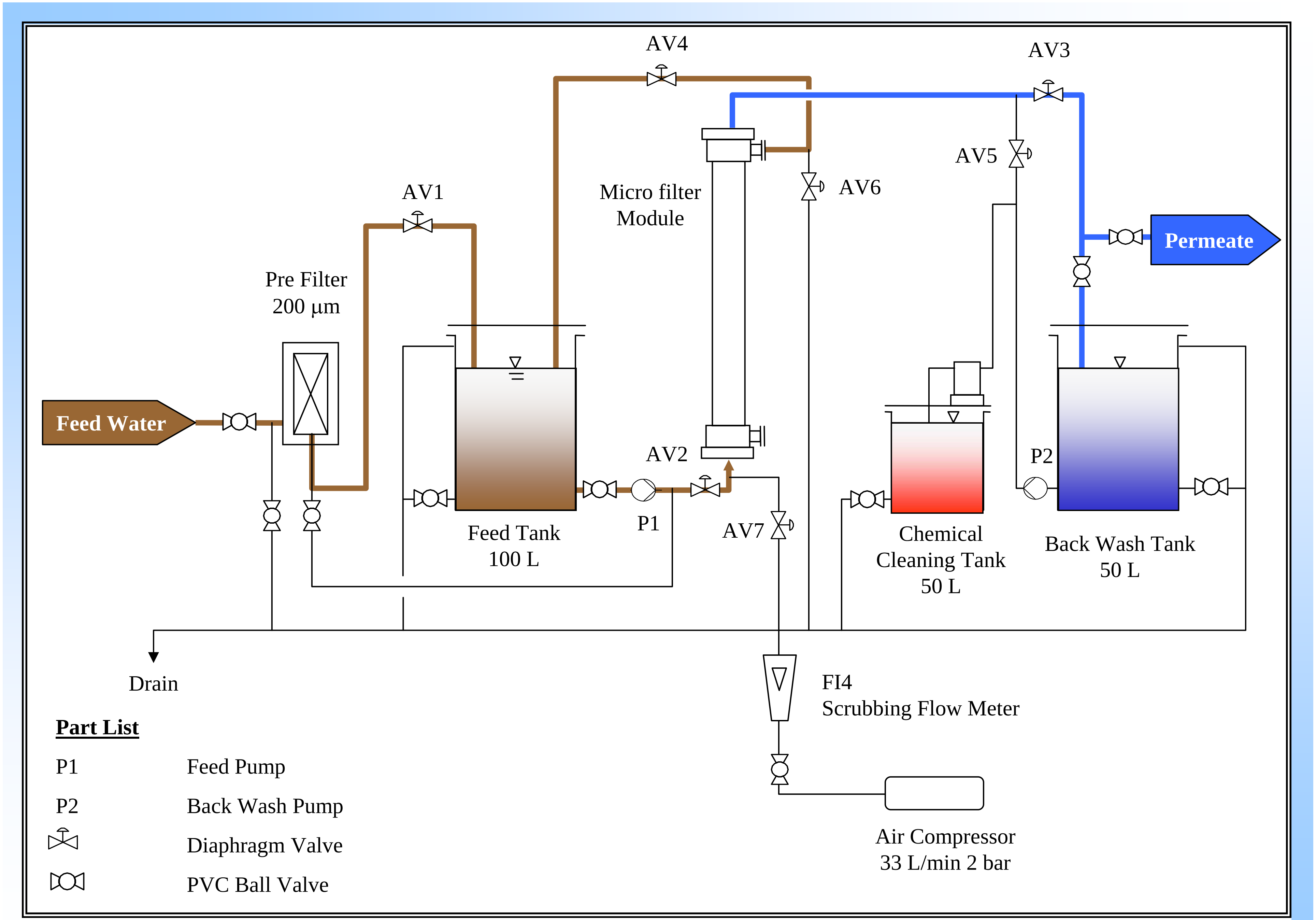
Treated Wastewater

Chemical Cleaning

Surface Water

Kaolin Clay





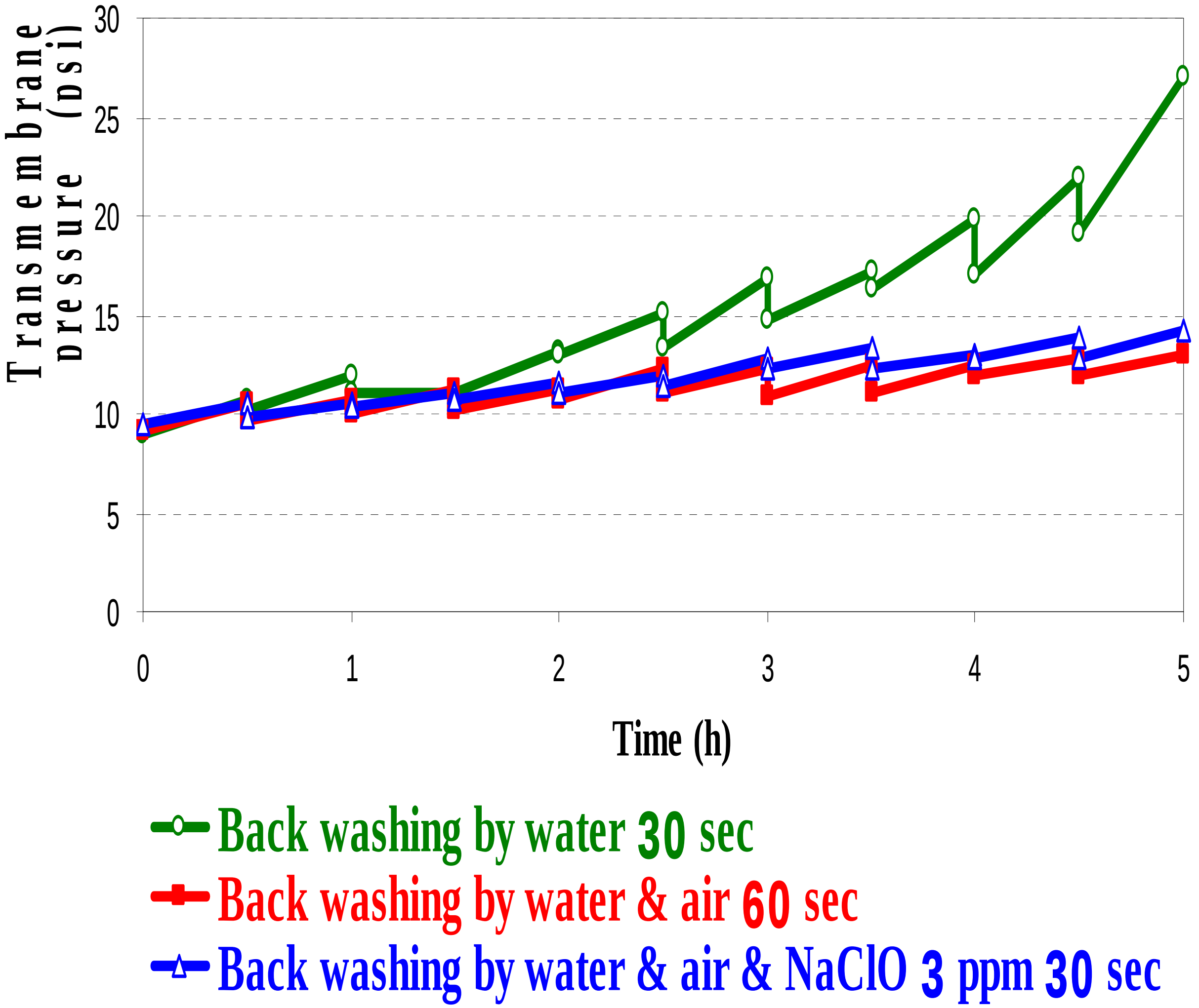
Part List

P1	Feed Pump
P2	Back Wash Pump
⋈	Diaphragm Valve
⋈	PVC Ball Valve

The Filtration Schematic Diagram of Pilot Scale


LPE
PRE FILTER
FEED TANK

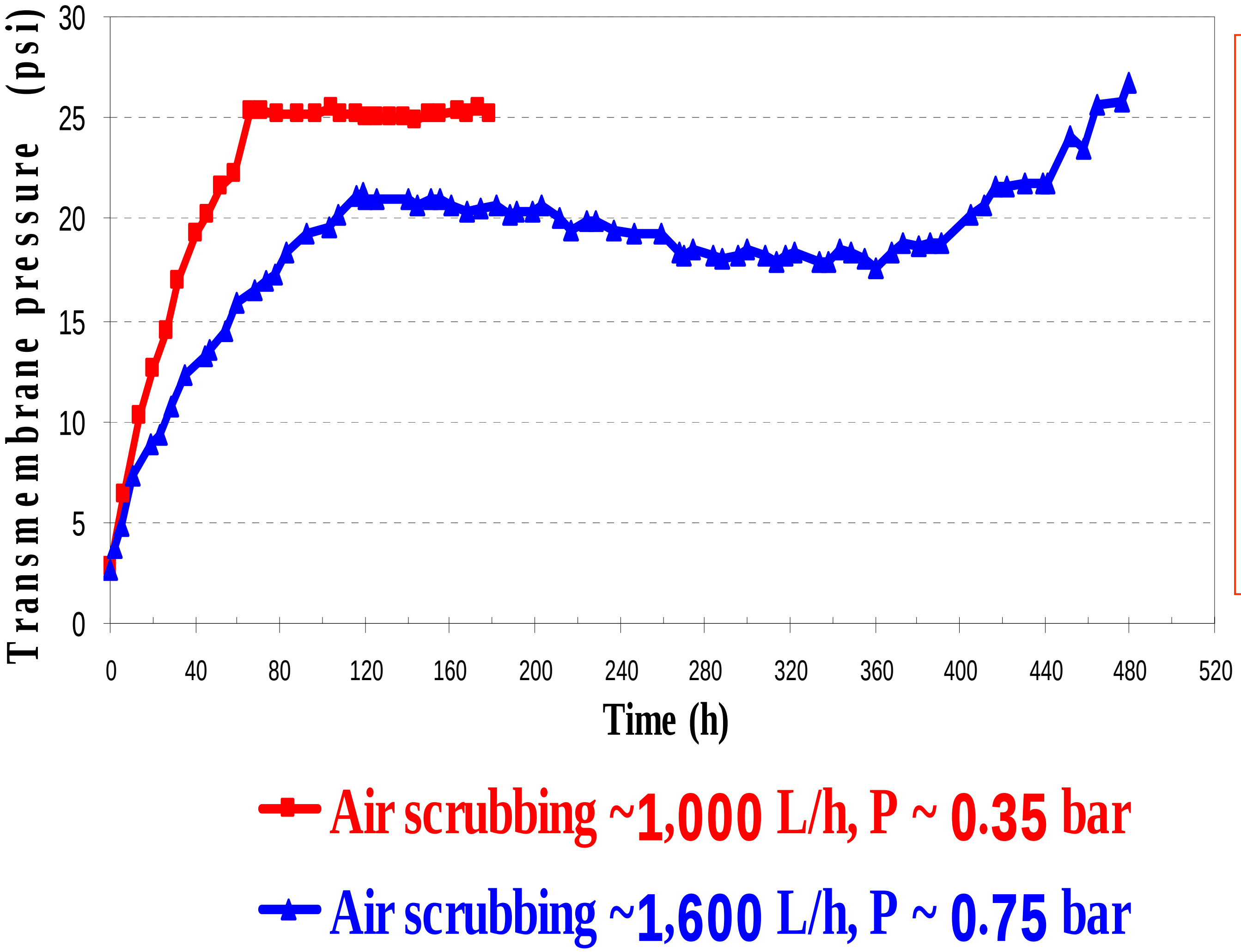
Backwash Effect



- Backwash time is significant.
- Adding chemical could reduce backwash time
- % water recovery for 60 sec = 96 %

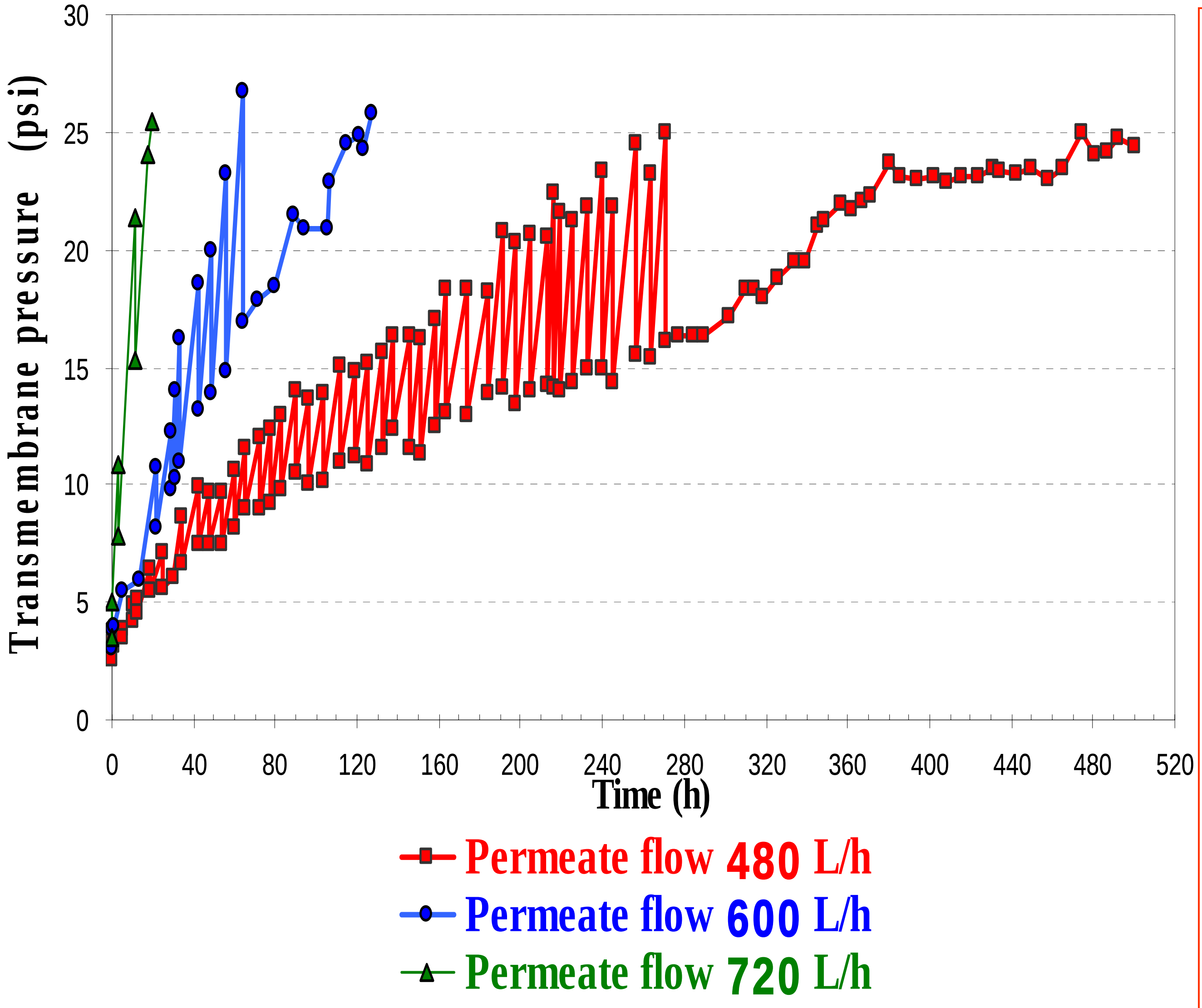
  for 30 sec = 98 %
- The economical and effective method was backwash with NaClO, 3 ppm, 30 sec

Backwash Effect



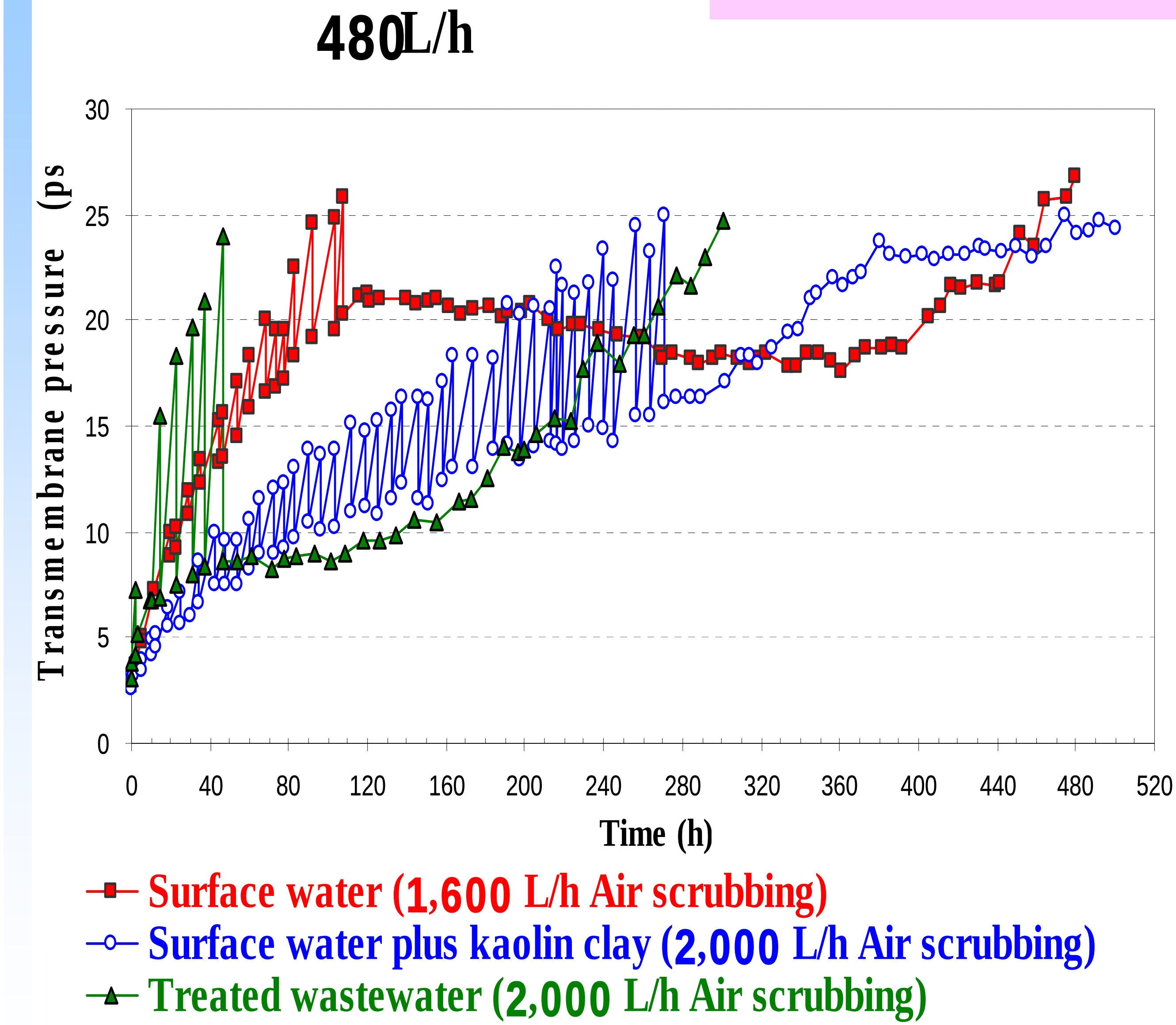
- Air scrubbing volume was very important to prolong running hour.

Permeate Flux Effect



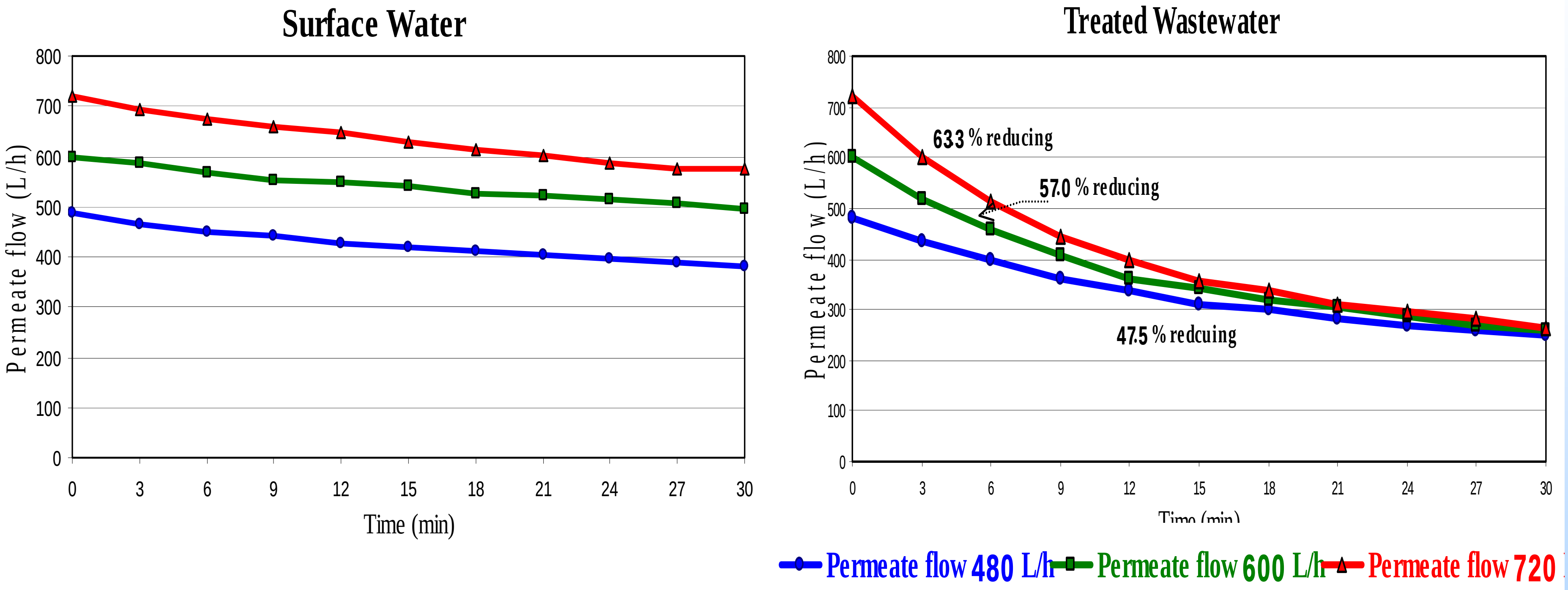
- The different TMP before and after backwash was increased with time: accumulated particle
- 480 L/h was the longest running : Critical flux reason

Feed Water Type Effect



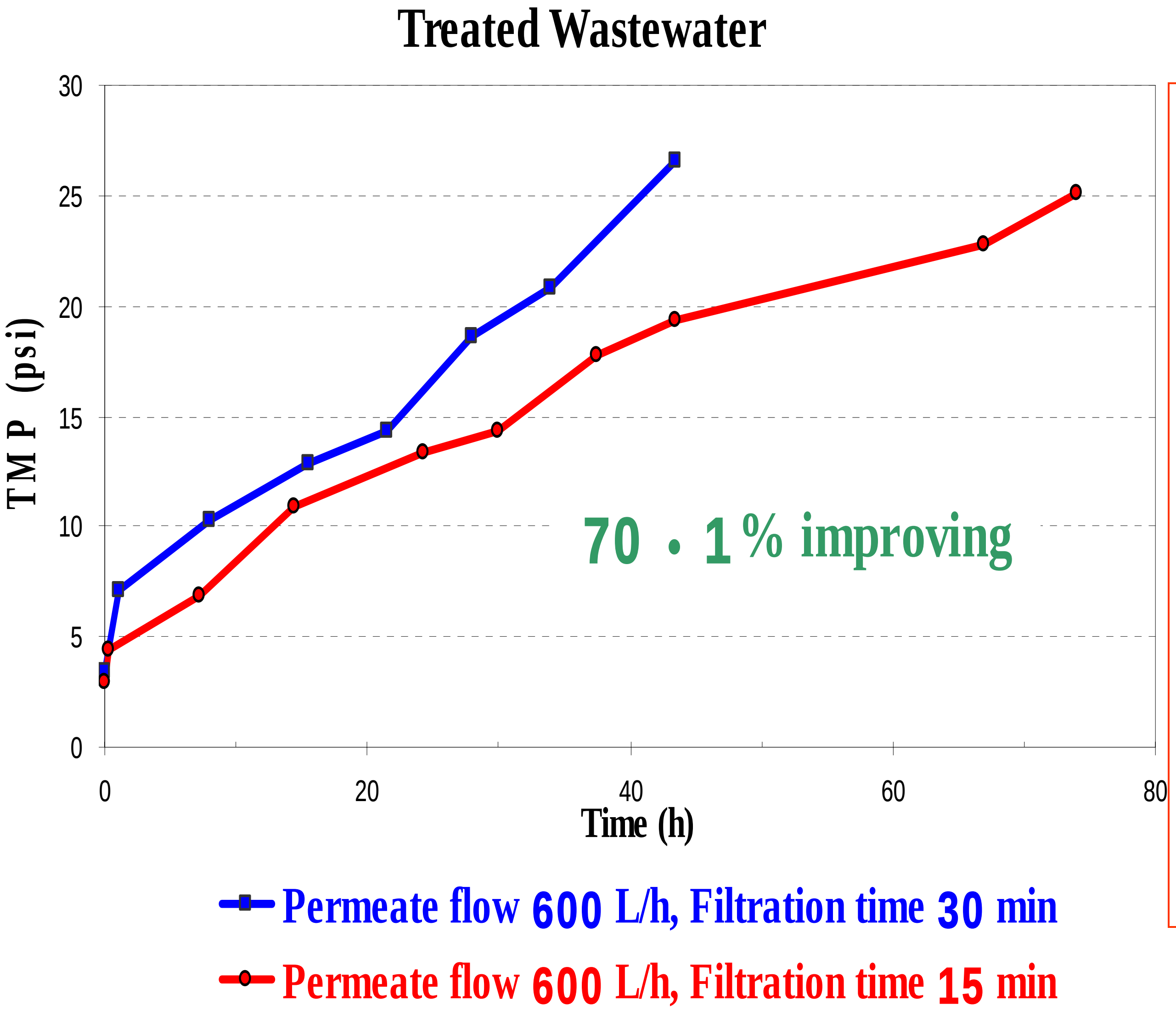
- ΔP of Treated wastewater was the highest: high organic & SS
- Air scrubbing volume help much in prolong running, even high of inorganic clay.

Flux Decline in a Filtration Cycle



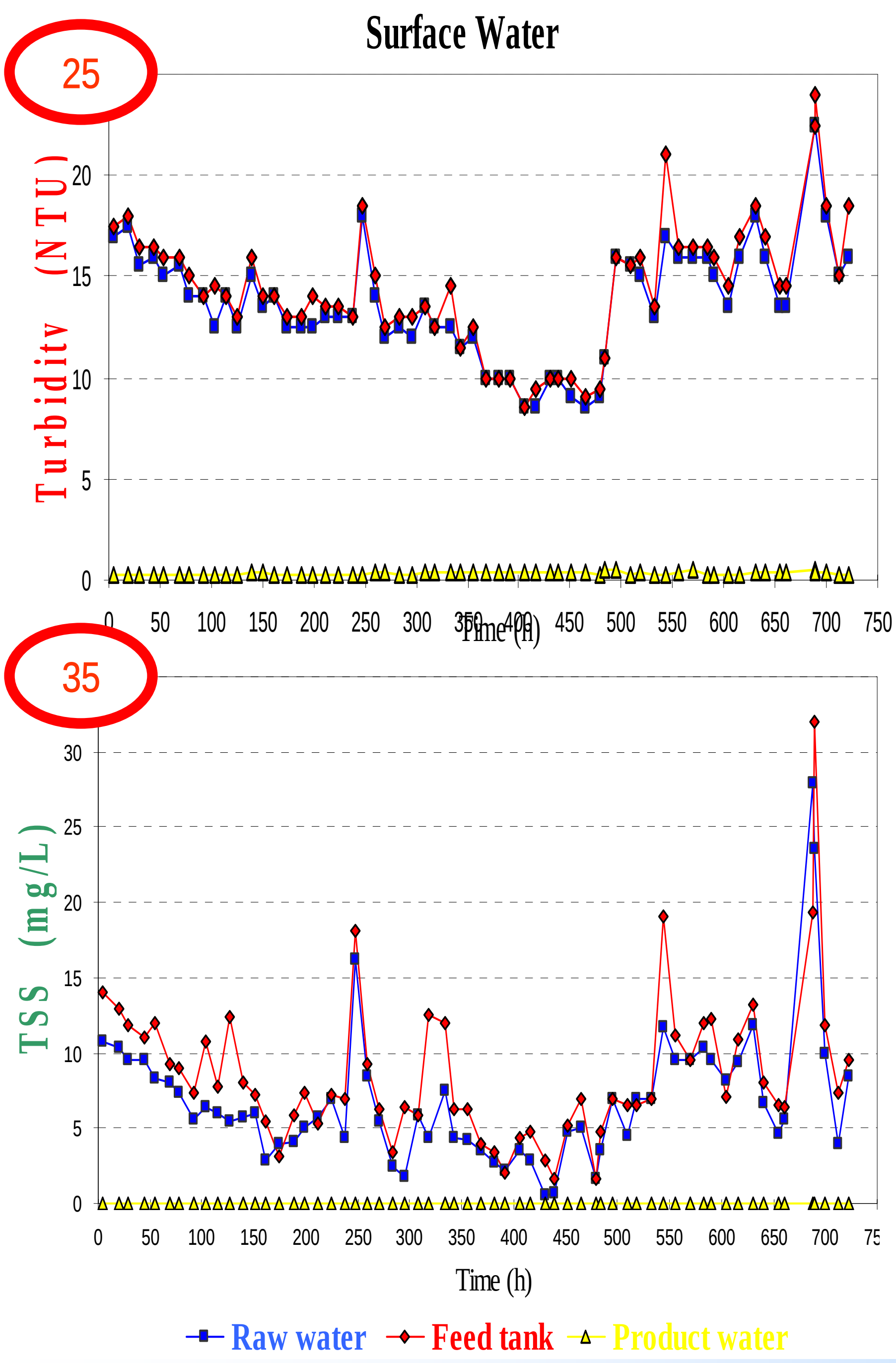
- % flux reducing of surface water had a small different between different permeate flow.
- 720 L/h permeate flow had the highest % flux reducing for treated wastewater.
- Treated wastewater caused higher % flux reducing than surface water.

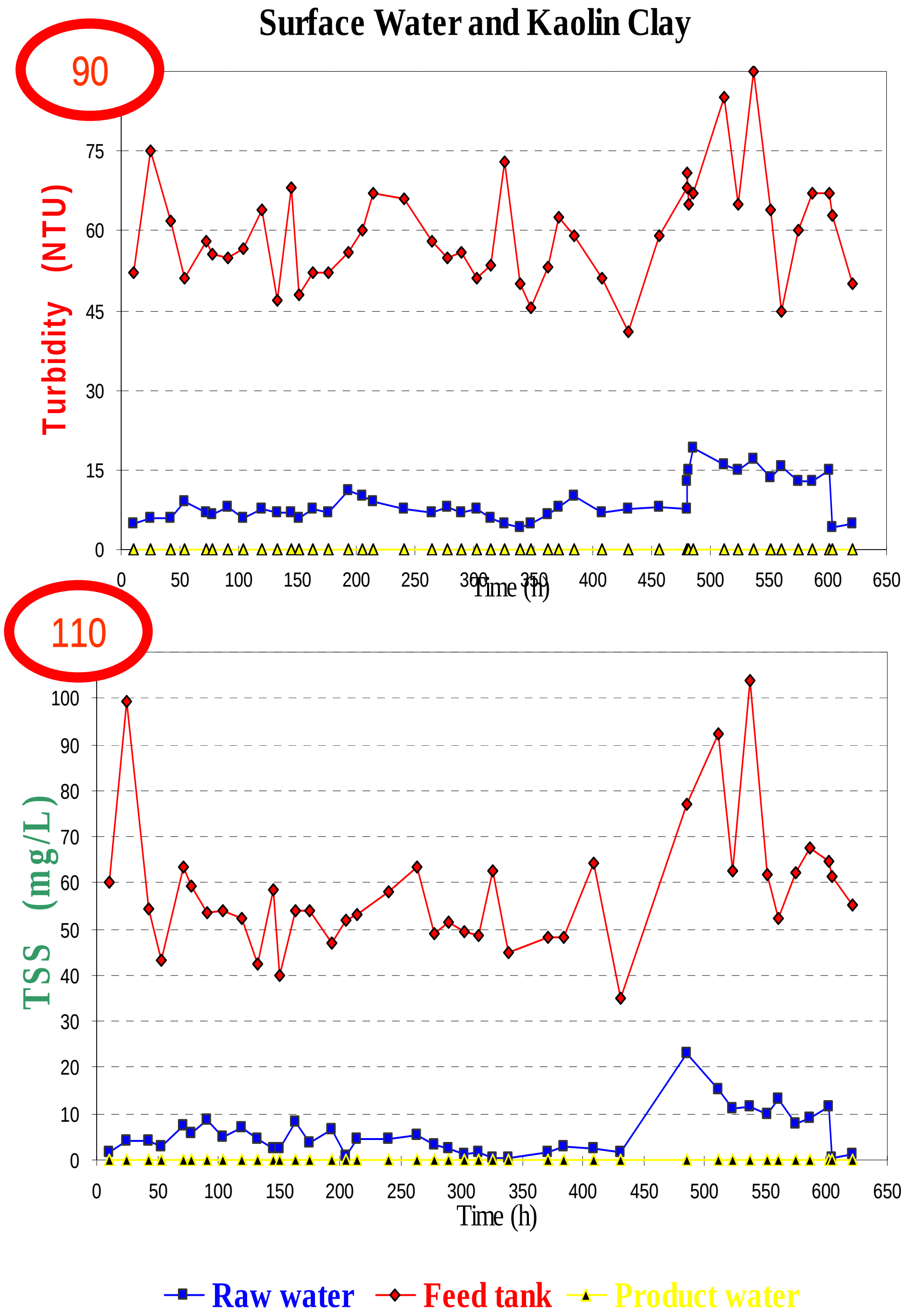
Filtration Time Effect



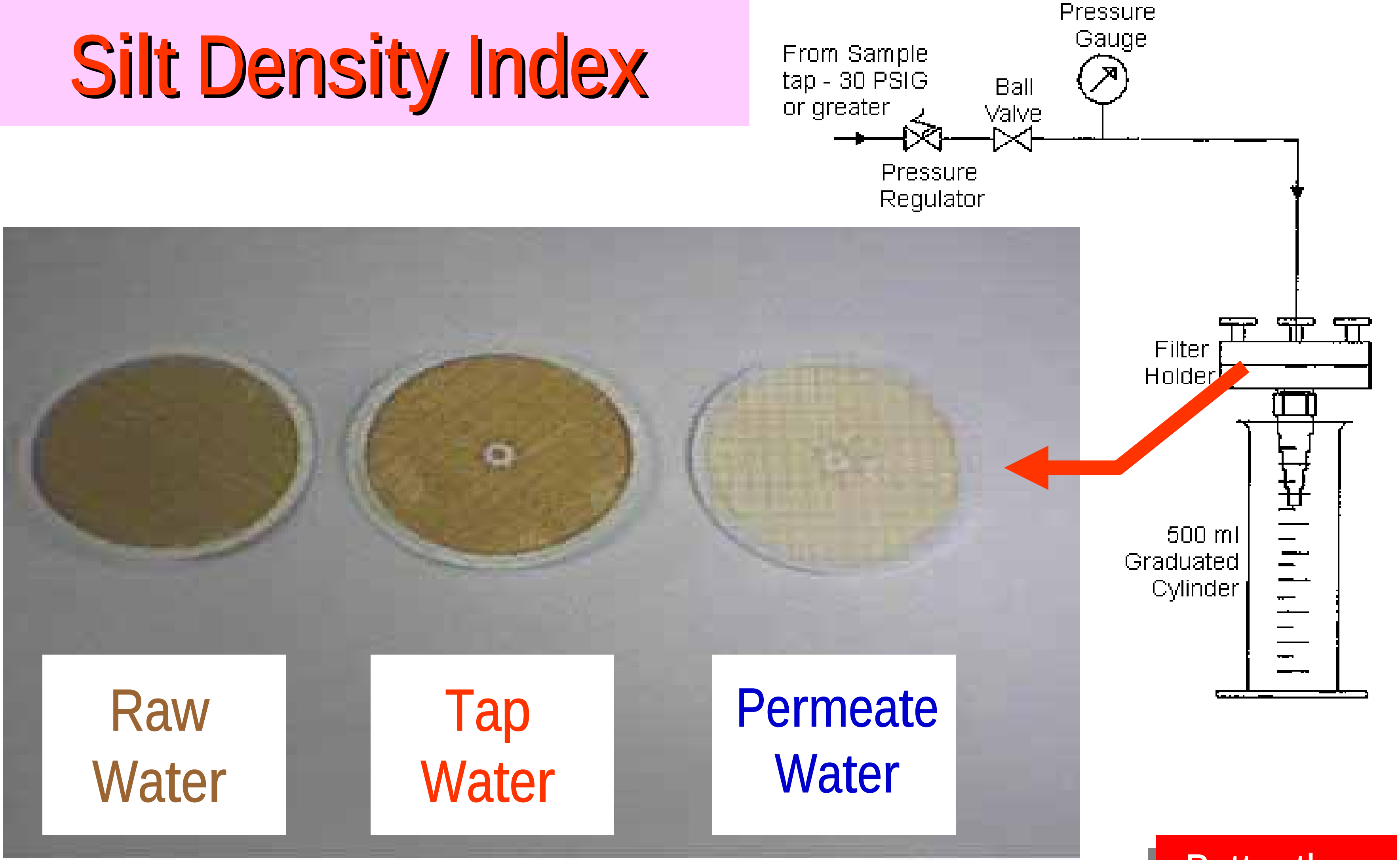
- The less filtration time, the more running hour.
- 70.1 % running hours improving
- 65 % water production improving

Water Quality


Surface Water
25
Turbidity (NTU)
0
5
10
15
20
0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750
Time (h)
35
TSS (mg/L)
0
5
10
15
20
25
30
0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 75
Time (h)
Raw water
Feed tank
Product water


Surface Water and Kaolin Clay
90
Turbidity (NTU)
0
15
30
45
60
75
0 50 100 150 200 250 300 350 400 450 500 550 600 650
Time (h)
110
TSS (mg/L)
0
10
20
30
40
50
60
70
80
90
100
0 50 100 150 200 250 300 350 400 450 500 550 600 650
Time (h)
Raw water
Feed tank
Product water

Silt Density Index

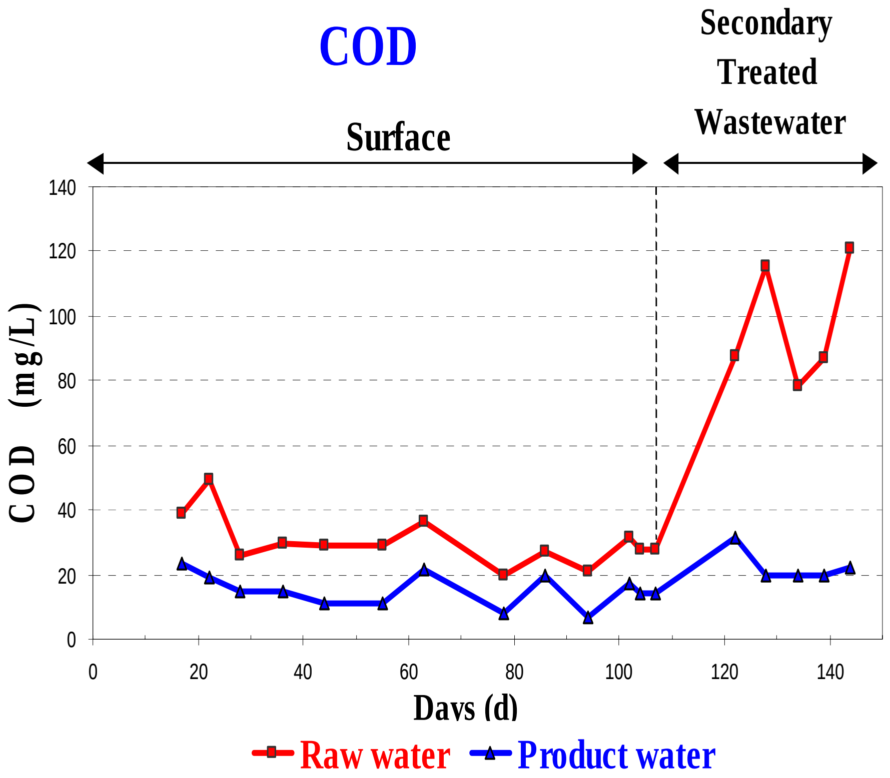


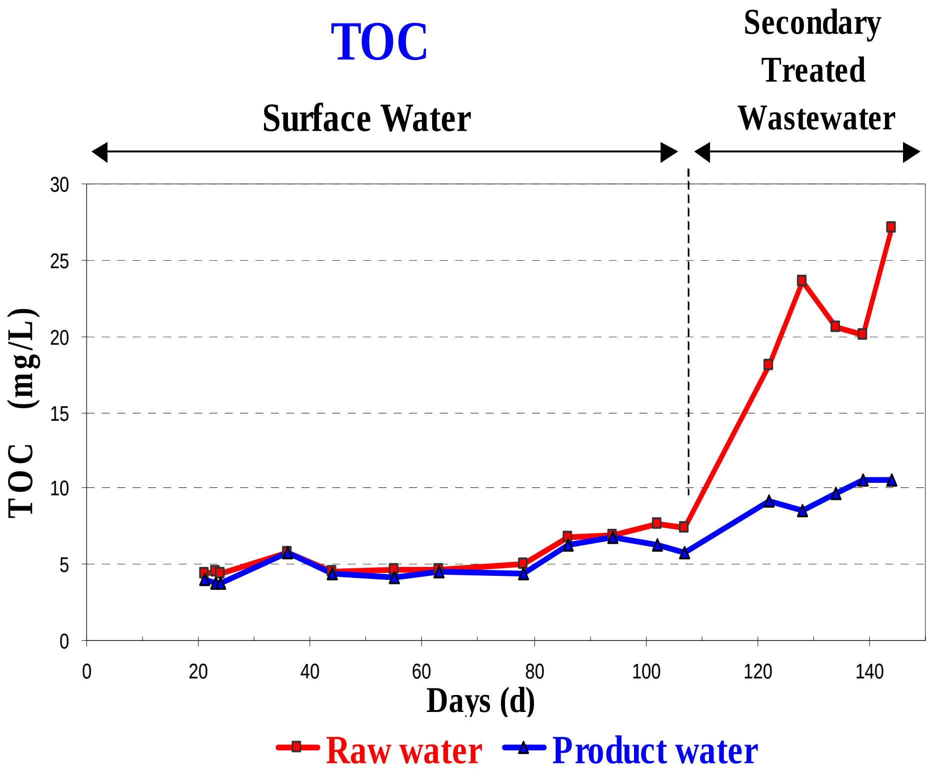
SDI : Tap water = 1.8 - 3.0

SDI : Permeate water = 1.0 - 1.3

Better than Tap Water

COD & TOC

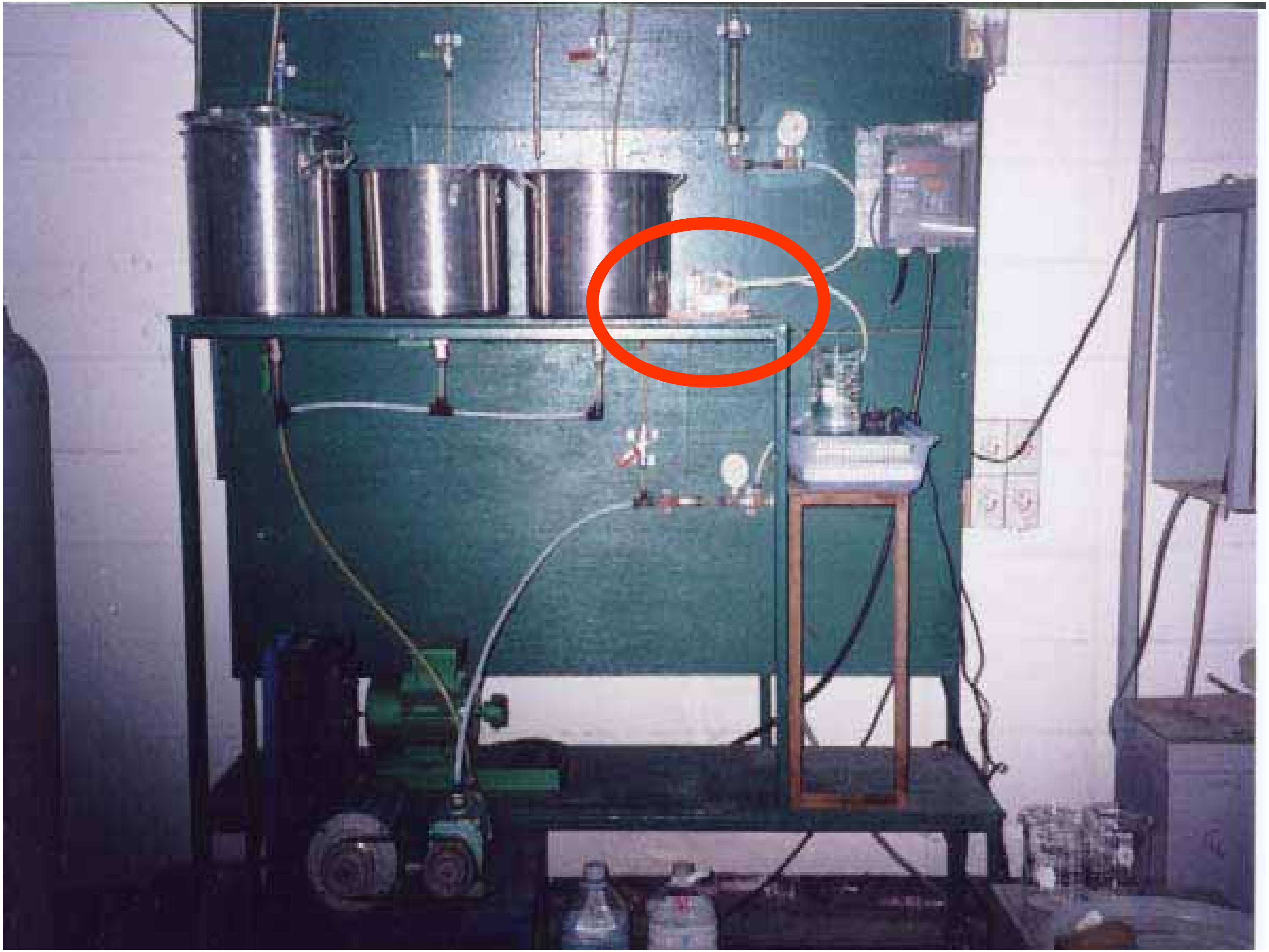




- Dissolved organic matter could not be removed by microfiltration.

Overall Removal Efficiency

Parameter	*Unit*	**Surface Water**			**Treated Wastewater**		
		Inf	**Eff**	**% Removal**	**Inf**	**Eff**	**% Removal**
1. Turbidity	**NTU**	**7-25**	**0.04-0.45**	**98-99**	**16-25**	**0.05-0.45**	**98-99**
2. TSS	**mg/L**	**15-20**	**Nil**	**100**	**20-45**	**Nil**	**100**
3. Color	**Pt-Co**	**3-5**	**4**	**0**	**8-20**	**4**	**50-80**
4. COD	**mg/L**	**15-50**	**7-23**	**40-70**	**70-135**	**20-32**	**65-80**
5. BOD	**mg/L**	**<6**	**<2**	**60**	**20-40**	**<2**	**80-90**
6. TOC	**mg/L**	**4.1-7.7**	**3.8-6.8**	**5-20**	**18-27**	**8.6-10.6**	**50-65**
7. Hardness	**mg/L**	**80-100**	**80-100**	**0**	**110-130**	**110-130**	**0**
8. Chlorophyll a	µg/L	**10-12**	**0.02-0.3**	**98-99**	**80-135**	**0.02-0.3**	**99**
9. Fe	**mg/L**	**0.02-0.09**	**0**	**100**	**0.02-0.13**	**0-0.05**	**60-100**
10. Mn	**mg/L**	**0.07-0.15**	**0.01-0.08**	**60-85**	**0.09-0.23**	**0.02-0.19**	**20-80**
11. Fecal	**CFU/ml**	**15**	**0**	**100**	**8**	**0**	**100**
12. Cl2 residual	**mg/L**	**-**	**<0.1**	**-**	**-**	**<0.8**	**-**

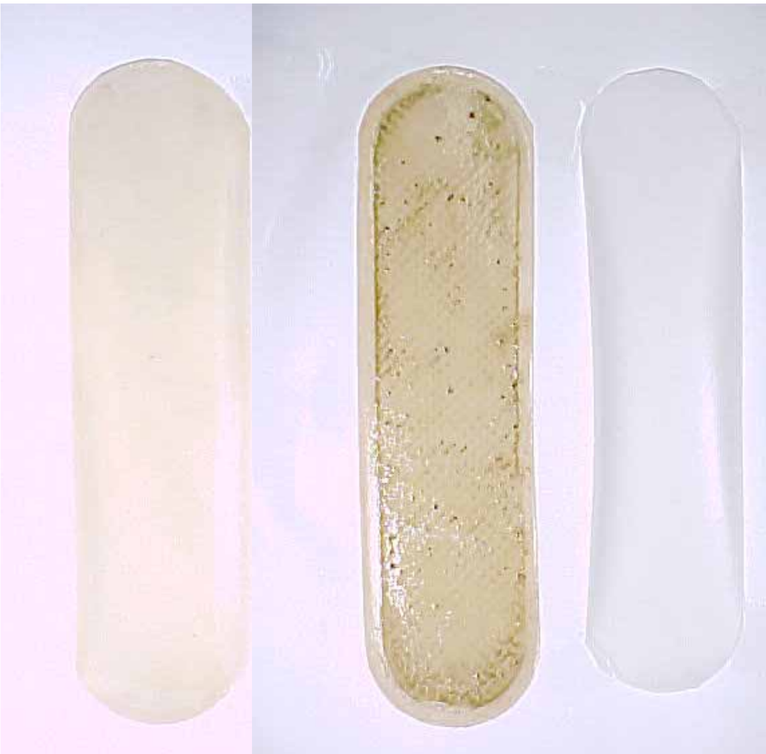


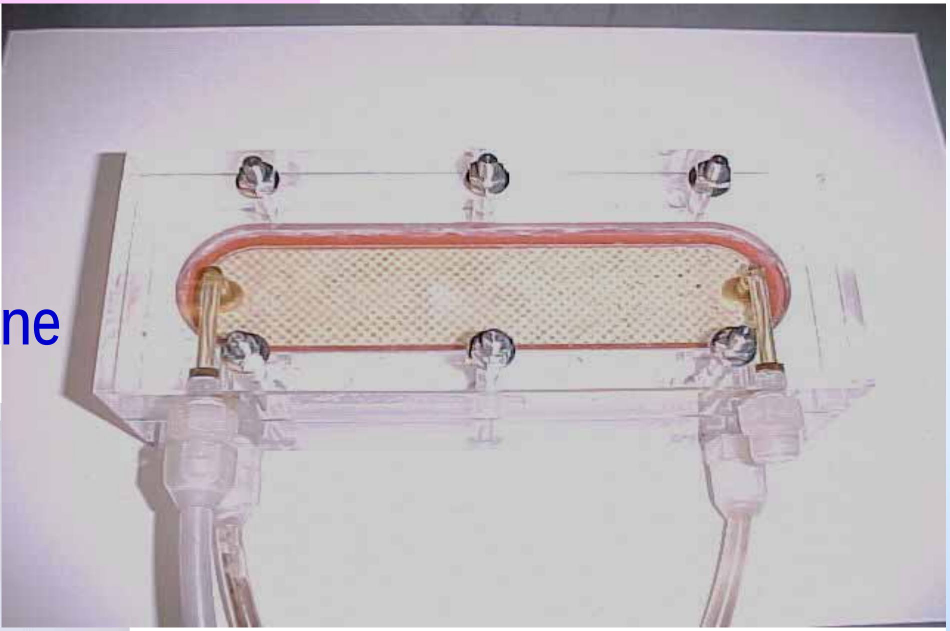
Bench Scale Experiment

Cleaned
Membrane

Filtrated
Membrane

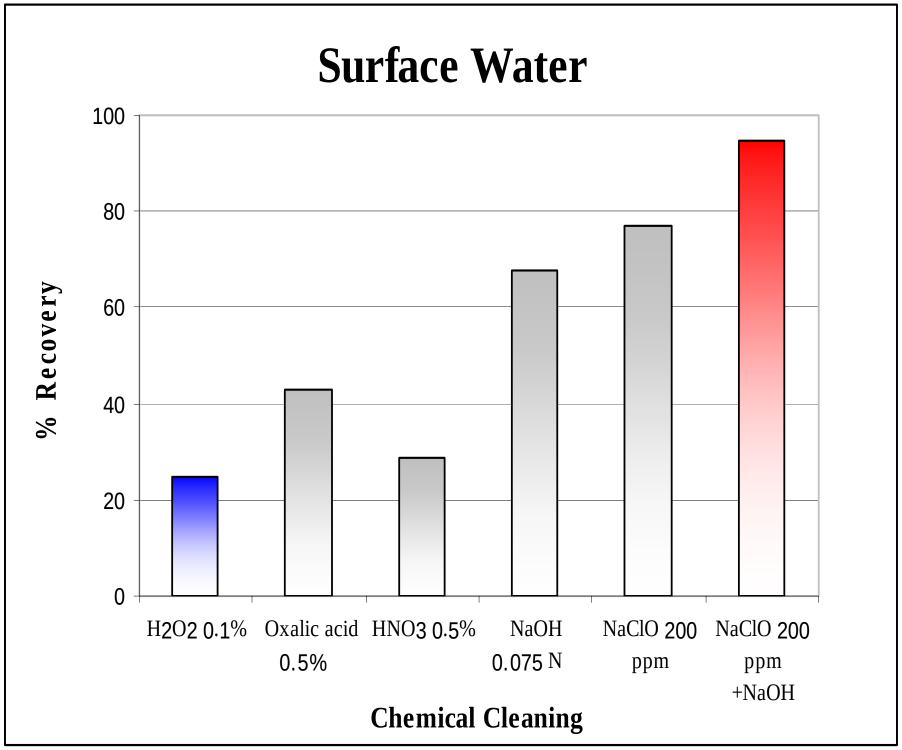
New
Membrane

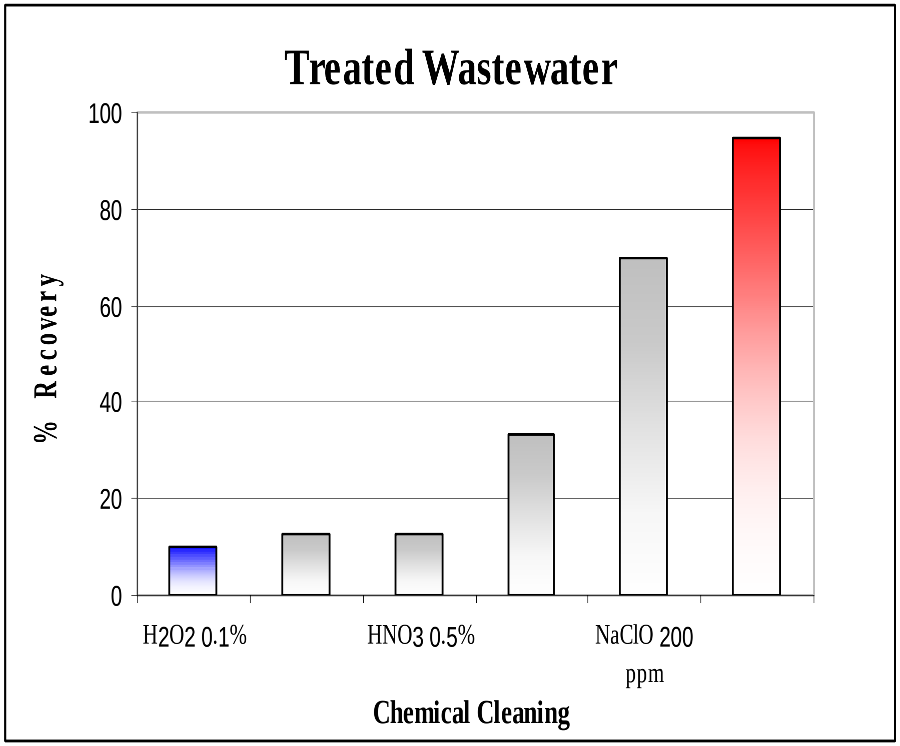




Membrane Module

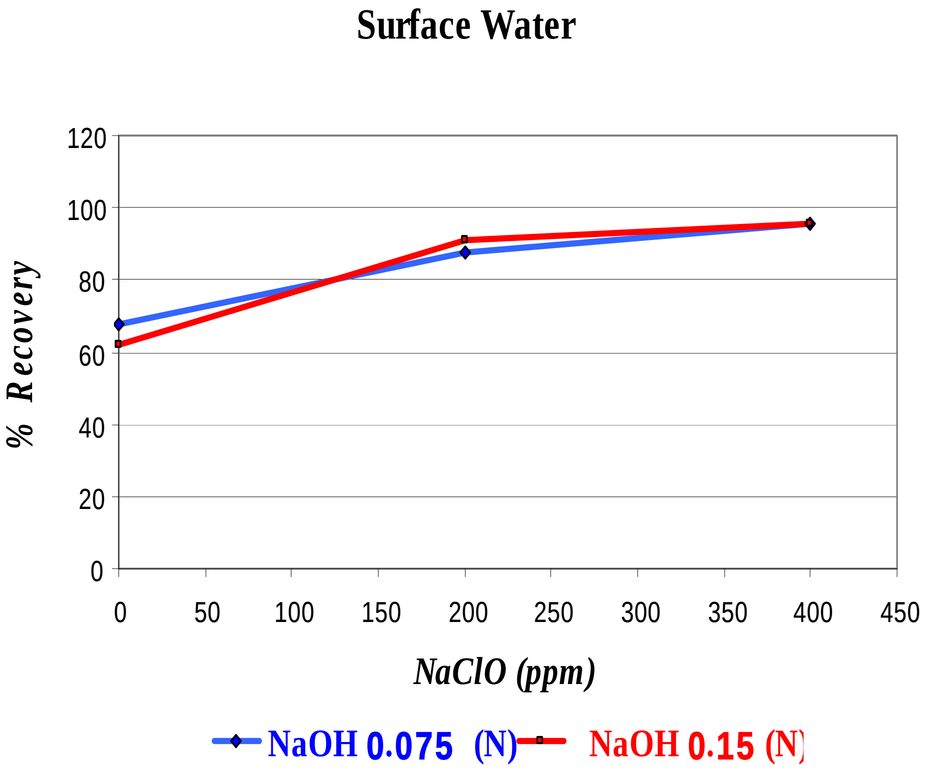
Effect of Chemical Composition

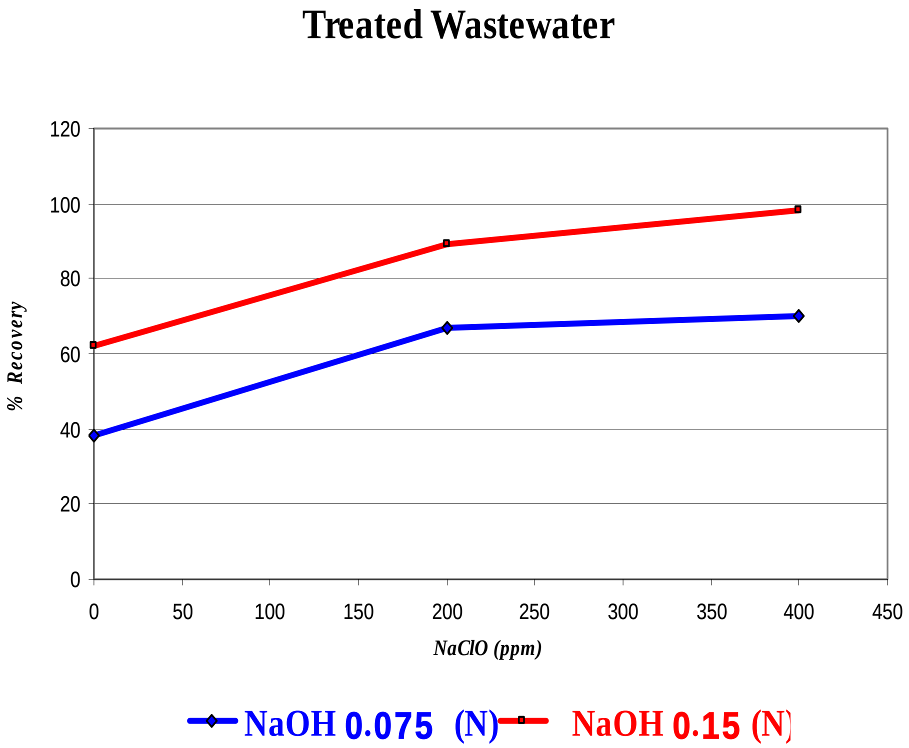




- Organic & microbial fouling
- NaClO combined with NaOH was the most effective.
- Acid reagents was not proper for these particular feed water.

Effect of Chemical Concentration



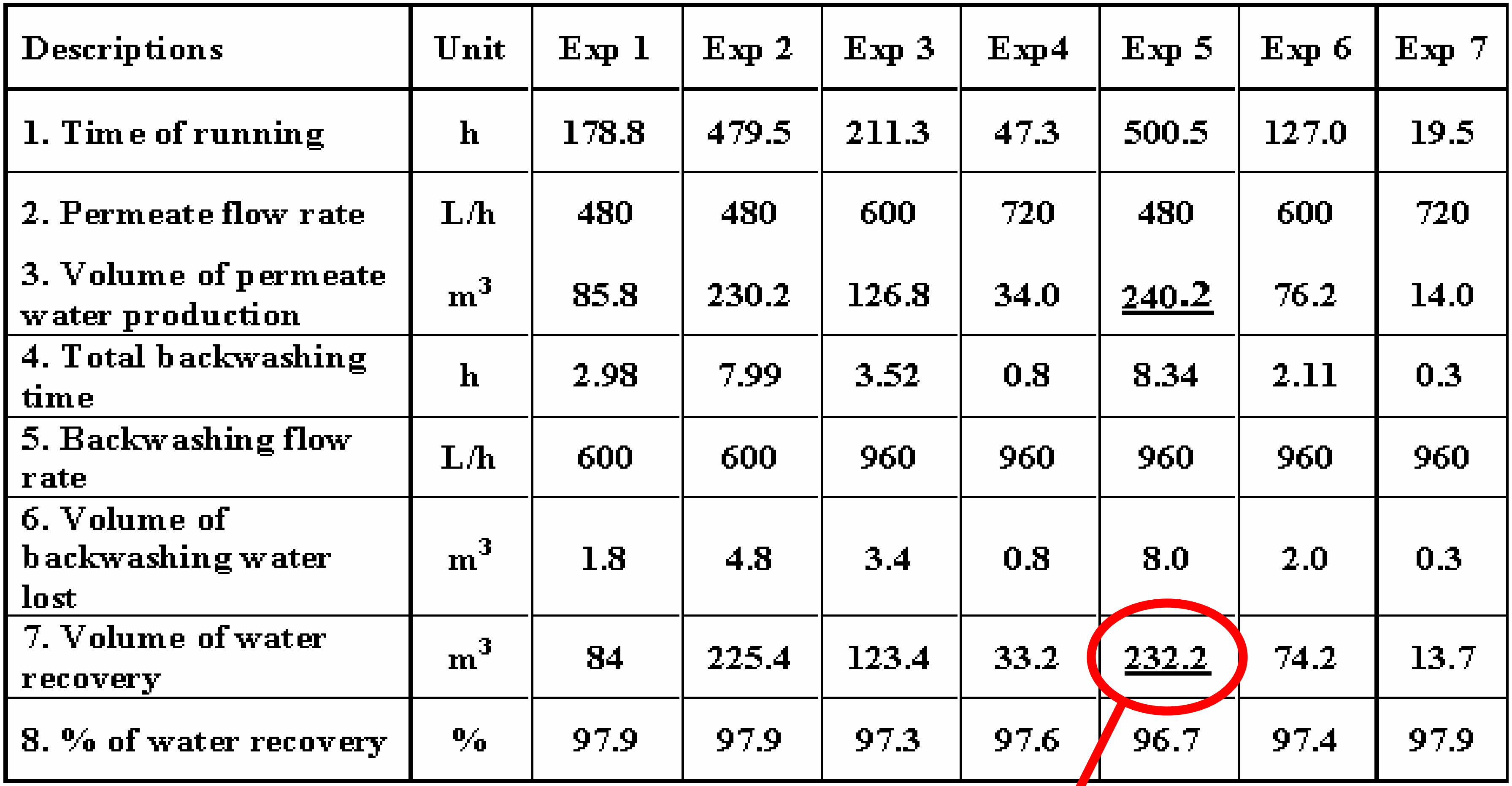


- Increase NaOH from 0.075 to be 0.15 N was significance to treated wastewater , but was not for surface water: Caustic : increase -

- NaClO threshold was 200 - 400 ppm.

Financial Analysis

- Water Quantity



Descriptions	Unit	Exp 1	Exp 2	Exp 3	Exp4	Exp 5	Exp 6	Exp 7
1. Time of running	h	178.8	479.5	211.3	47.3	500.5	127.0	19.5
2. Permeate flow rate	L/h	480	480	600	720	480	600	720
3. Volume of permeate water production	m^3	85.8	230.2	126.8	34.0	240.2	76.2	14.0
4. Total backwashing time	h	2.98	7.99	3.52	0.8	8.34	2.11	0.3
5. Backwashing flow rate	L/h	600	600	960	960	960	960	960
6. Volume of backwashing water lost	m^3	1.8	4.8	3.4	0.8	8.0	2.0	0.3
7. Volume of water recovery	m^3	84	225.4	123.4	33.2	232.2	74.2	13.7
8. % of water recovery	%	97.9	97.9	97.3	97.6	96.7	97.4	97.9

Surface Water: 480 L/ h Permeate Flow

Filtration / Backwashing/ Flushing = 30 min/ 30 sec/ 30 sec

Financial Analysis

- Water Quantity

Descriptions	Unit	Exp 8	Exp 9	Exp 10	Exp 11	Exp 12
1. Time of running	h	301.0	43.5	15.5	74.0	27.0
2. Permeate flow rate	L/h	480	600	720	600	720
3. Volume of permeate water production	m^3	144.5	26.1	**11.2**	44.4	19.4
4. Total backwashing time	h	5.0	0.7	0.3	1.2	0.5
5. Backwashing flow rate	L/h	960	960	960	960	960
6. Volume of backwashing water lost	m^3	4.8	0.7	0.3	2.4	0.9
7. Volume of water recovery	m^3	139.7	25.4	10.9	42.0	18.5
8. % of water recovery	%	96.7	97.3	97.3	94.6	95.4

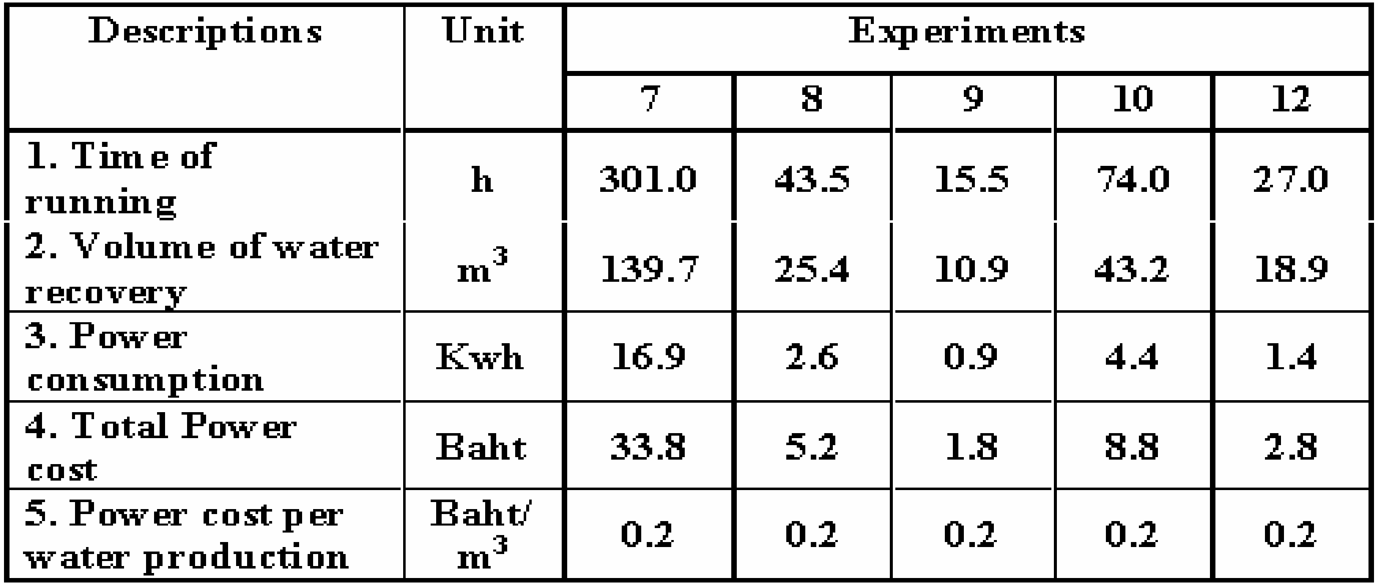
Treated Wastewater : 480 L/ h Permeate Flow

Filtration / Backwashing/ Flushing = 30 min/ 30 sec/ 30 sec

Financial Analysis

- Power Supply

Descriptions	Unit	Experiments						
		1	2	3	4	5	6	12
1. Time of running	h	178.8	479.5	211.3	47.3	500.5	127.0	19.5
2. Volume of water recovery	m^3	84	225.4	123.4	33.2	232.2	74.2	13.7
3. Power consumption	Kwh	12.2	30.7	13.7	3.0	39.2	7.5	1.2
4. Total Power cost	Baht	24.4	71.4	27.4	6.0	78.4	15.0	2.4
5. Power cost per water production	Baht/ m^3	0.3	0.3	0.2	0.2	0.3	0.2	0.2



Descriptions	Unit	Experiments				
		7	8	9	10	12
1. Time of running	h	301.0	43.5	15.5	74.0	27.0
2. Volume of water recovery	m^3	139.7	25.4	10.9	43.2	18.9
3. Power consumption	Kwh	16.9	2.6	0.9	4.4	1.4
4. Total Power cost	Baht	33.8	5.2	1.8	8.8	2.8
5. Power cost per water production	Baht/ m^3	0.2	0.2	0.2	0.2	0.2

= 0.2-0.3

Baht / m^3

Financial Analysis

- Chemical Required

Three Tasks

1. Backwashing (NaClO)

   : 0.5 Baht / m^3

2. Chemical Cleaning (NaClO, NaOH, Oxalic acid)

   : 4.07 Baht / m^3 in case Surface Water

   : 6.76 Baht / m^3 in case Treated wasteWater

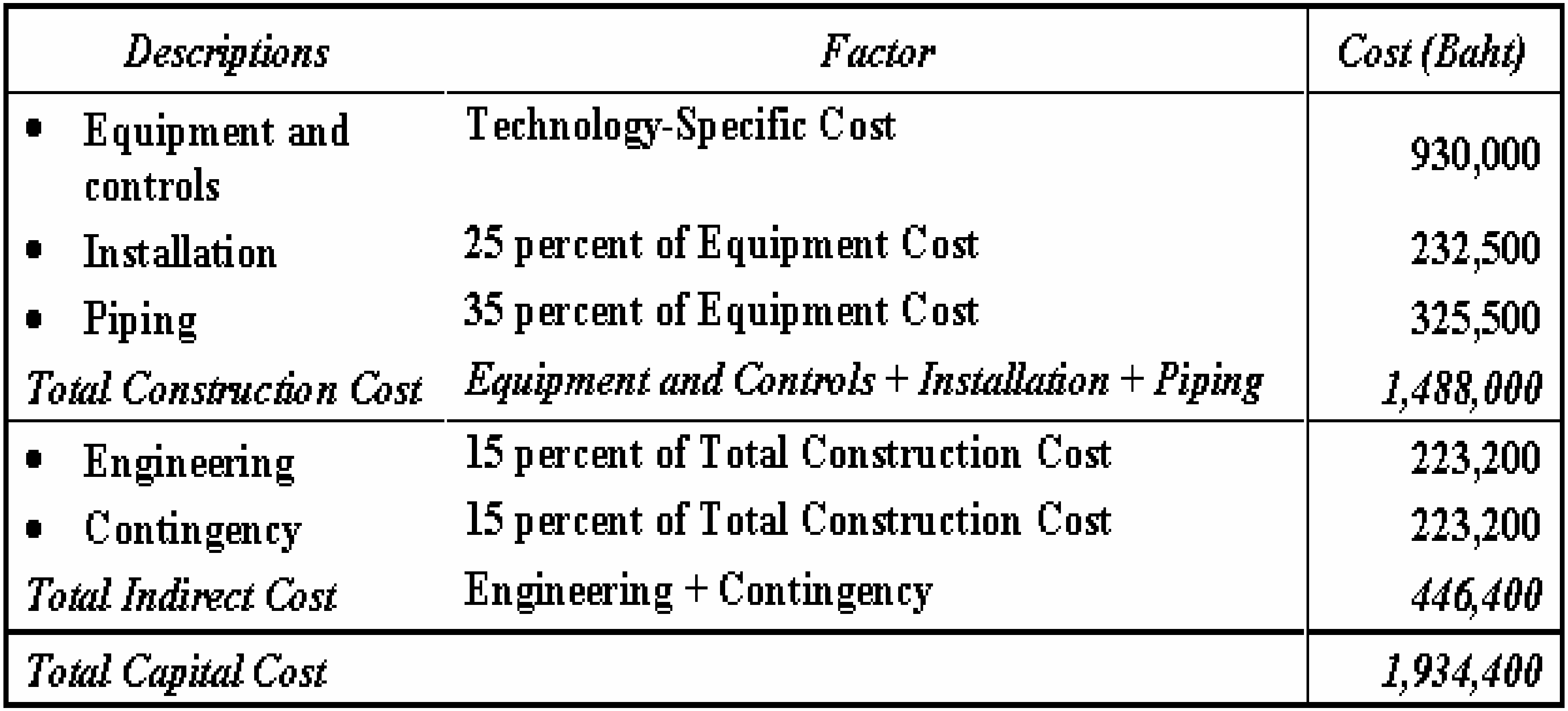
3. Prevent biofouling problems (NaClO)

   : 3.11 Baht / m^3

Financial Analysis

- Cost – Benefit

Capital Cost : To provide 23 m^3 / day



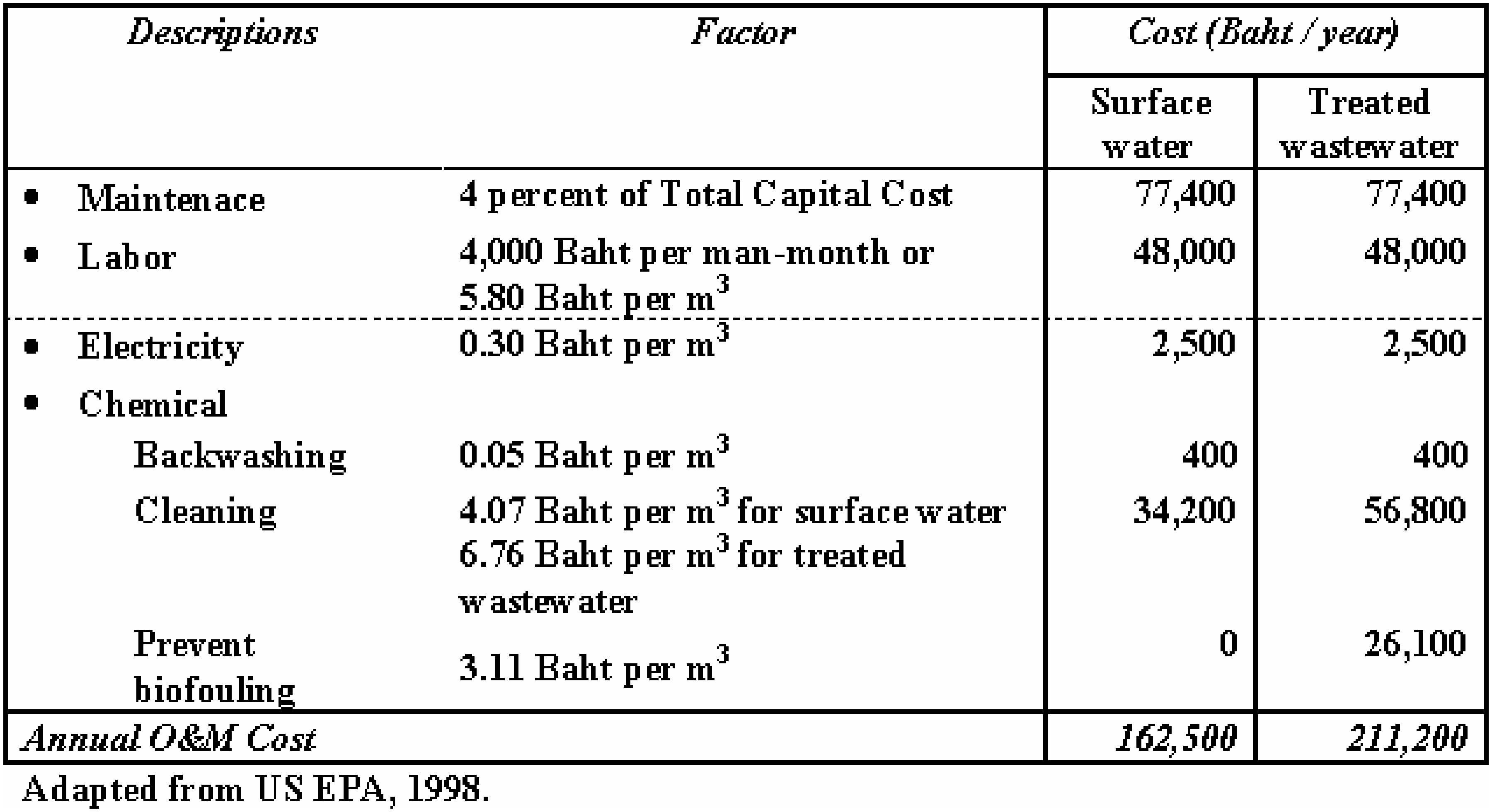
Descriptions	*Factor*	*Cost (Baht)*
• Equipment and controls	Technology-Specific Cost	930,000
• Installation	25 percent of Equipment Cost	232,500
• Piping	35 percent of Equipment Cost	325,500
Total Construction Cost	*Equipment and Controls + Installation + Piping*	*1,488,000*
• Engineering	15 percent of Total Construction Cost	223,200
• Contingency	15 percent of Total Construction Cost	223,200
Total Indirect Cost	Engineering + Contingency	*446,400*
Total Capital Cost		*1,934,400*

Adapted from US EPA, 1998.

Financial Analysis

- Cost – Benefit

O & M Cost : To provide 23 m^3 / day



Descriptions	*Factor*	*Cost (Baht / year)*	
		Surface water	Treated wastewater
• Maintenace	4 percent of Total Capital Cost	77,400	77,400
• Labor	4,000 Baht per man-month or 5.80 Baht per m^3	48,000	48,000
• Electricity	0.30 Baht per m^3	2,500	2,500
• Chemical			
Backwashing	0.05 Baht per m^3	400	400
Cleaning	4.07 Baht per m^3 for surface water 6.76 Baht per m^3 for treated wastewater	34,200	56,800
Prevent biofouling	3.11 Baht per m^3	0	26,100
Annual O&M Cost		*162,500*	*211,200*

Adapted from US EPA, 1998.

Financial Analysis

- Cost – Benefit

Land Requirement Cost

- Area Required ~ 2 m^3
- Land cost depends on local condition.

Benefit : Safe Fresh Source Water

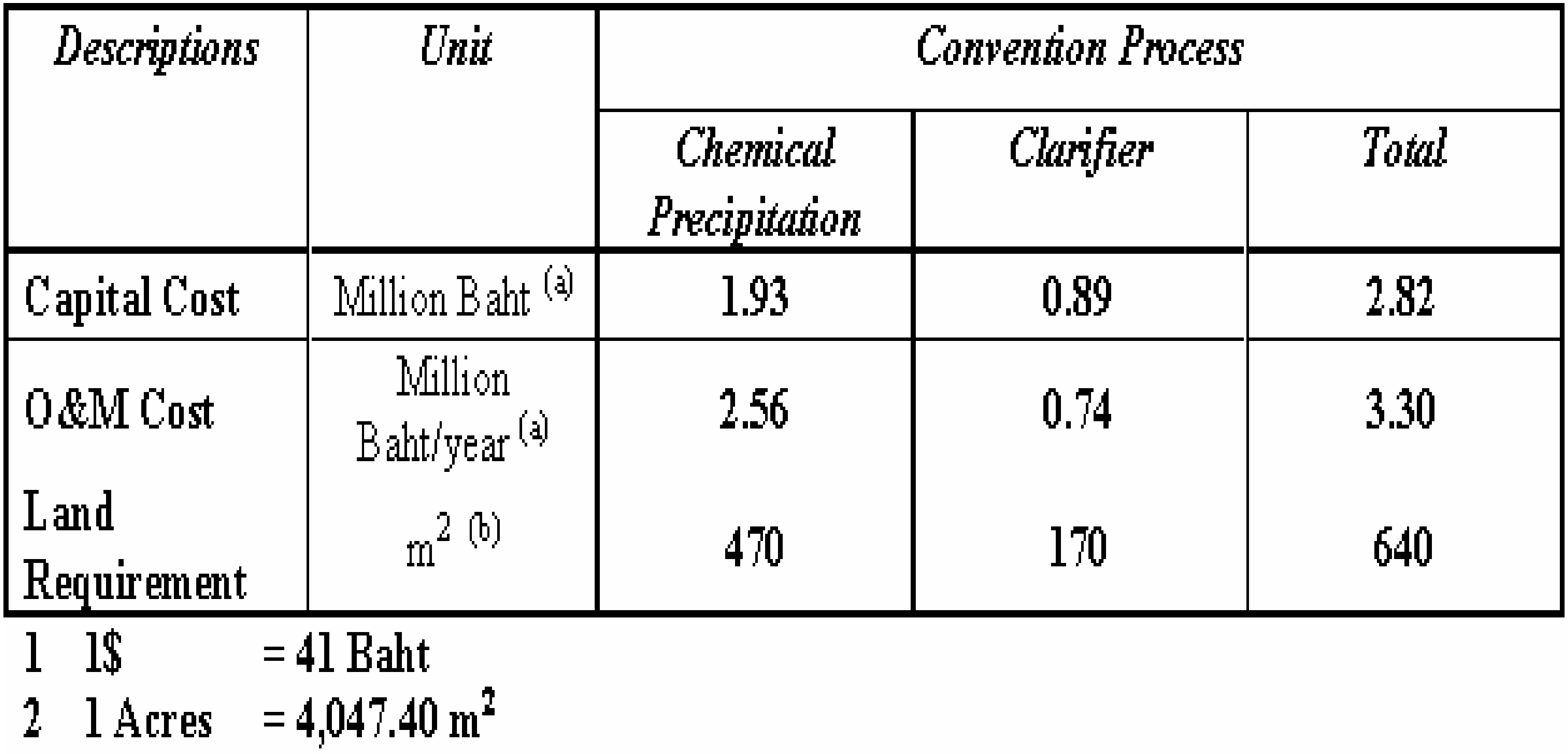
- PWA Tap water cost = 19.25 Baht / m^3
- Total O & M cost (MF) = 19.33 – 25.73 Baht / m^3

- But PWA Tap water cost trend to be increased, While MF cost trend to be reduced.
- Based on Pilot Unit

Financial Analysis

- Conventional Cost

Conventional Process: To provide 23 m^3 / day



Descriptions	*Unit*	*Convention Process*		
		Chemical Precipitation	*Clarifier*	*Total*
Capital Cost	Million Baht (a)	1.93	0.89	2.82
O&M Cost	Million Baht/year (a)	2.56	0.74	3.30
Land Requirement	m^2 (b)	470	170	640

1 1$ = 41 Baht

2 1 Acres = 4,047.40 m^2

- ✓ Cost Aspect

Comparison

Descriptions	*Unit*	*Conventional Process*	*MF for Surface Water*	*MF for treated WW*
Capital Cost	Million Baht	2.82	1.93	1.93
O&M Cost	Million Baht/year	3.30	0.16	0.21
Land Requirement	m^2	640	2	2

MF is cheaper than Conventional process

Comparison

✓ Safety Aspect

- Less required primary disinfection
- Lower DBPs (Disinfection by Products)

✓ Water Quality Aspect

Parameter	% Removal	
	Convention	MF
Suspended Solid	80-90	100
BOD_5	50-80	60-90
Bacteria	80-90	100

Reuse Potential

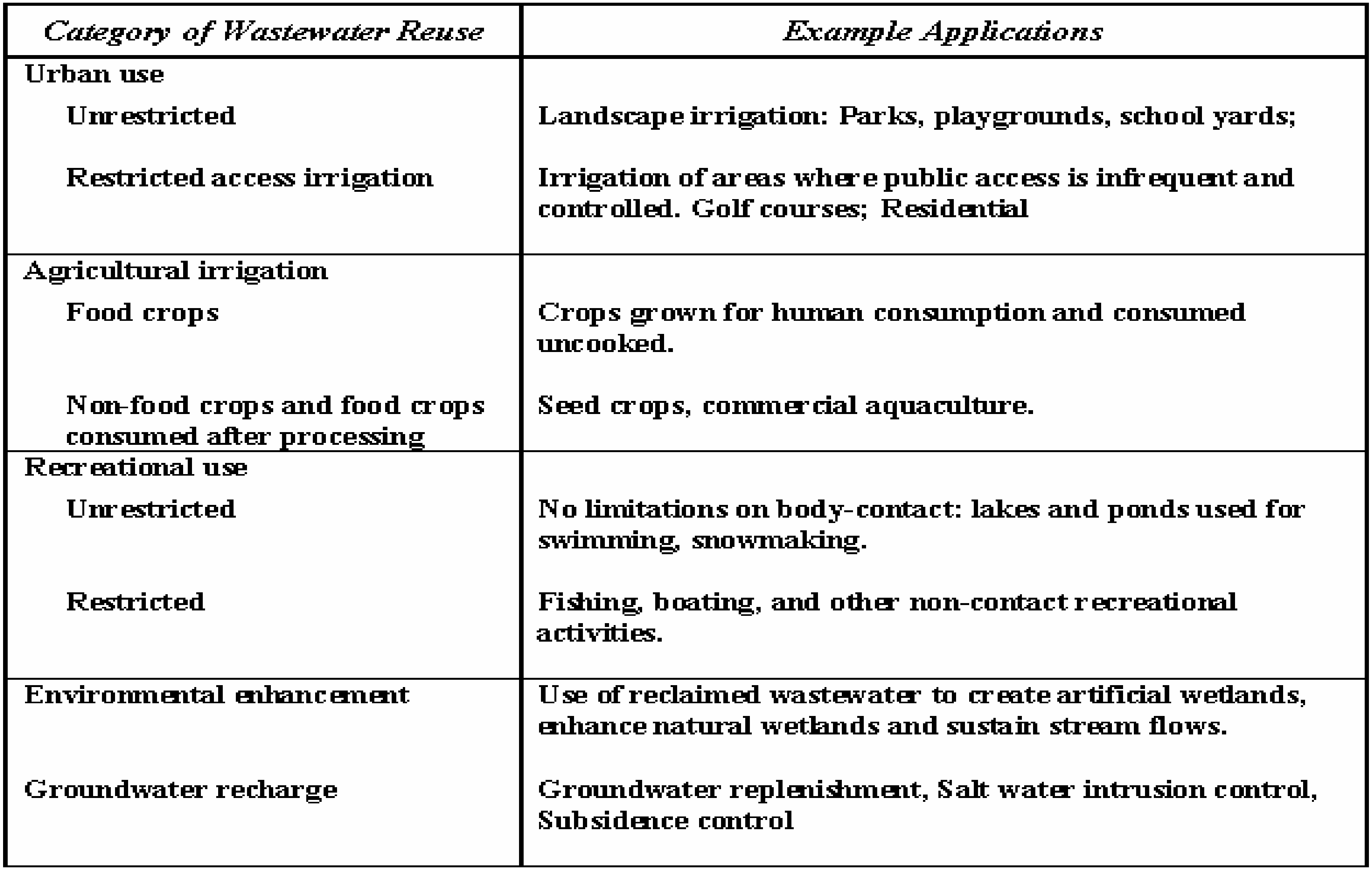
✓ Water Quality Required for Reuse

Parameters	*Unit*	*Water Quality Requirement for Reuse*	*MF Permeate of*	
			Surface Water	*Treated Wastewater*
1. pH	-	6-9	7.7-8.1	8.0-8.3
2. BOD_5	mg/L	<10	<2	<2
3. Turbidity	NTU	<2	0.05-0.45	0.05-0.45
4. TSS	mg/L	<30	Nil	Nil
5. Fecal Coliform	CFU/ml	0	0	0
6. Cl_2 residual	mg/L	<1	<0.1	<0.8

Meet Criteria All Parameters

Reuse Potential

✓ General Reuse



Category of Wastewater Reuse	*Example Applications*
Urban use	
Unrestricted	Landscape irrigation: Parks, playgrounds, school yards;
Restricted access irrigation	Irrigation of areas where public access is infrequent and controlled. Golf courses; Residential
Agricultural irrigation	
Food crops	Crops grown for human consumption and consumed uncooked.
Non-food crops and food crops consumed after processing	Seed crops, commercial aquaculture.
Recreational use	
Unrestricted	No limitations on body-contact: lakes and ponds used for swimming, snowmaking.
Restricted	Fishing, boating, and other non-contact recreational activities.
Environmental enhancement	Use of reclaimed wastewater to create artificial wetlands, enhance natural wetlands and sustain stream flows.
Groundwater recharge	Groundwater replenishment, Salt water intrusion control, Subsidence control

Reuse Potential

✓ **Potable Water**

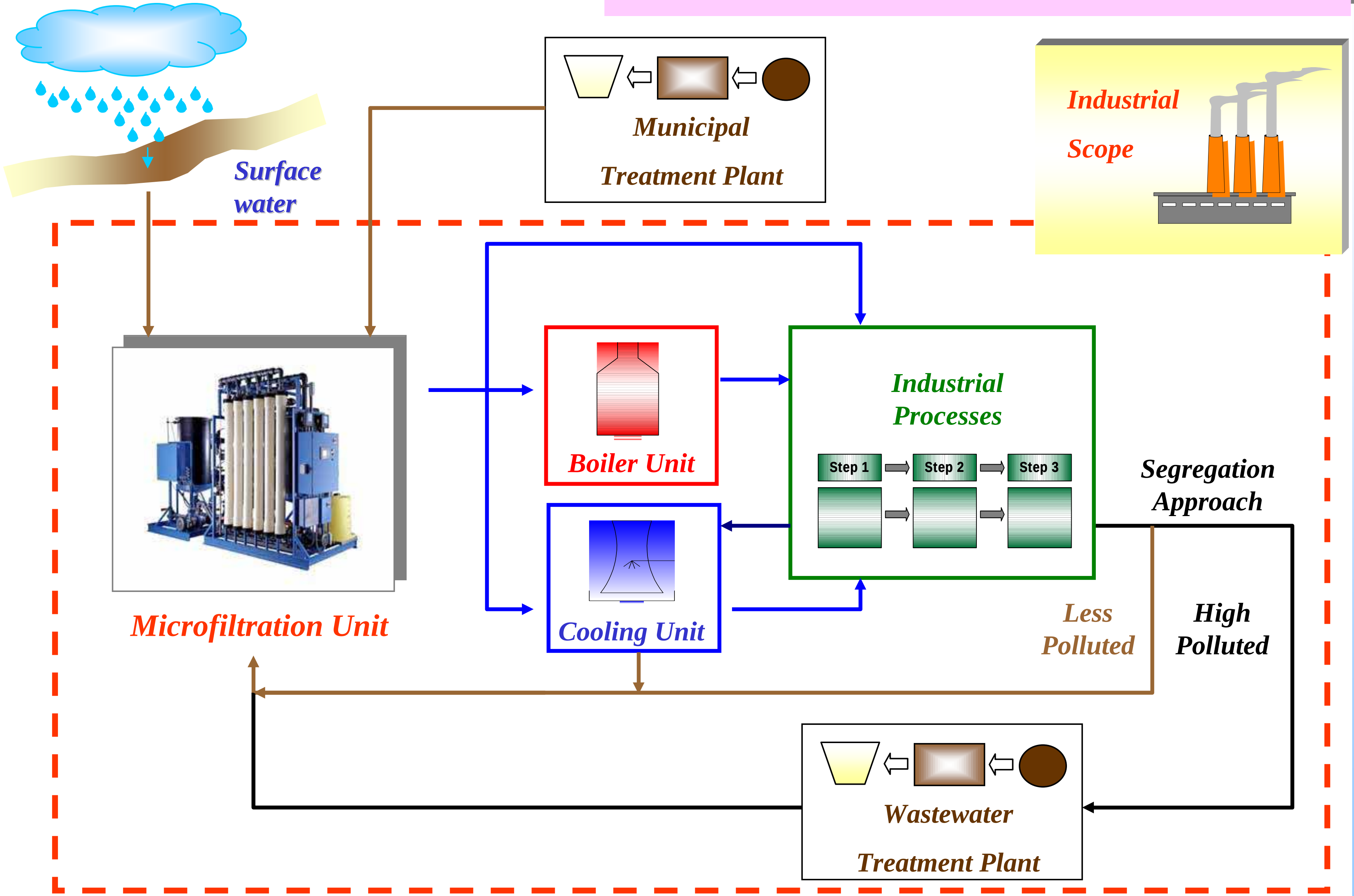
- Surface Water:
  - Indirect Potable Water Reuse
- Treated Wastewater:
  - Should not use for Potable Water Reuse

✓ **Industrial Application**

- Cooling Water
- Boiler Water
- Industrial Processes

✓ Industrial Reuse

Reuse Potential



Conclusions: Followed by Objectives

Conclusions: Objective 1

1. It could run in long-term without effect on water quality.

   Surface water : 500 h

   Treated wastewater : 300 h

2. Backwash method and Permeate flux was the significance factor for stability
3. When reduced the filtration time from 30 min to 15 min, duration time of running improved 70-74 %

4. Inorganic clay do not play important role for stability.

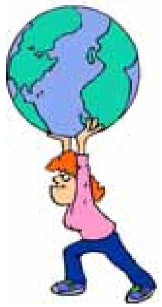
Conclusions: Objective 2

1. High ability to remove particle matter and bacteria
   - Turbidity : 99 %
   - Suspended Solids : 100 %
   - Chlorophyll a : 100 %
   - Fecal coliform : 100 %
2. Less effective to remove organic matter and hardness
   - TOC : 5-65 %
   - Hardness : 0 %

Conclusions: Objective 3

1. Composition Effect
   - NaClO with NaOH : the most effective solution.
   - Acid reagents : less effective
   - Because : high organic, less inorganic

2. Concentration Effect
   - NaClO Threshold : 200 – 400 ppm
   - Increase NaOH from 0.075 to 0.15N, not much effect to Surface water but effect to Treated wastewater



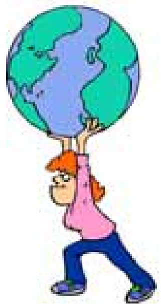
Conclusions: Objective 4 , 5

1. Microfiltration is attractive economic alternative to Conventional process

   - Capital cost
   - O & M cost
   - Land requirement cost
2. Various categories reuse
3. Indirect potable reuse
4. Industrial application reuse

Recommendations

1. Natural Organic Matter (NOM) play significant role for flux declined, which should be further study.
2. Thai Cost Factor should be further derived.
3. Specific Chemical Characteristic should be determined.



Conclusions: Thesis

Publishability

- Discuss with Membrane Manufacturing
- Microfiltration in Long Term Study

Academic Contribution

- Effects of Stability on Membrane
- Bench Scale Unit: Fouling & Cleaning

Practical Value

- Pilot Scale Unit: Optimum Conditions
- Reliability and Stability in Long Term

Thank you very much