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LANDFILL LEACHATE TREATMENT BY SUBMERGED-TYPE MEMBRANE BIOREACTOR

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งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาถึงการลดซีโอดี สี ไนโตรเจน และฟอสฟอรัสในน้ำชะมูลฝอยด้วยระบบถังปฏิกรณ์ชีวเคมีที่มีเมมเบรนจมตัวและทำการเปรียบเทียบประสิทธิภาพกับระบบถังปฏิกรณ์ชีวเคมีที่มีเมมเบรนจมตัวที่เติมถ่านกัมมันต์ ทำการเติมอากาศและหยุดเป็นช่วง 120-120 และ150-150 นาที

ในการทดลองนี้ระบบถังปฏิกรณ์ชีวเคมีที่มีเมมเบรนจมตัวที่เติมถ่านกัมมันต์ เติมอากาศและหยุดเป็นช่วง 150-150 นาทีสามารถกำจัดค่าต่างๆใน น้ำชะมูลฝอยได้ดีที่สุด สามารถกำจัดซีโอดีได้ 83 % สี 85% ไนโตรเจน 97% และฟอสฟอรัส 68% ถ่านกัมมันต์มีหน้าที่ช่วยในการดูดซับสารอินทรีย์ที่ย่อยยาก เพิ่มเวลาในการทำงานของจุลินทรีย์ และช่วยลดสารที่เป็นพิษ จึงทำให้ระบบถังปฏิกรณ์ชีวเคมีที่มีเมมเบรนจมตัวที่เติมถ่านกัมมันต์มีประสิทธิภาพสูงกว่าระบบถังปฏิกรณ์ชีวเคมีที่มีเมมเบรนจมตัวอย่างเดียว ถึงแม้ว่ากำจัดสารต่างๆไม่ได้หมดแต่มีประสิทธิภาพสูงที่สุดเมื่อเทียบกับการทดลองอื่นๆ

การเติมอากาศและหยุดเป็นช่วง 150-150 นาทีให้ประสิทธิภาพดีกว่า 120-120 นาที เพราะว่ามีระยะเวลาในการทำงานในแต่ละระบบยาวนานขึ้น โดยการย่อยสลายสารอินทรีย์นั้นจำเป็นต้องอาศัยสภาวะที่มีอากาศและไร้อากาศทำงานต่อเนื่องกัน ด้วยเหตุนี้จึงทำให้การเพิ่มระยะเวลาให้กับทั้งสองสภาวะ นั้นมีผลทำให้ประสิทธิภาพในการกำจัดสารต่างๆในน้ำชะมูลฝอยดีขึ้น

สหสาขา การจัดการสิ่งแวดล้อม	ลายมือชื่อนิสิต ....
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The Objectives of this research were to investigate COD, color, TKN, and TP removal from landfill leachate by using MBR and BPAC-MBR varying at intermittent aeration time of 120-120 and 150-150 minutes.

In the experimental runs, the BPAC-MBR at an intermittent aeration time of 150-150 minutes gave the best removal efficiency in terms COD at 83%, color at 85%, TKN at 97%, and Total P at 68%. The activated carbon in BPAC-MBR system also helped adsorb slowly biodegradable organic matters, increased exposure time, and reduced inhibition, which resulted in higher substrate removal than single MBR systems. Although this cycle could not completely remove substances form landfill leachate, this process could improve the removal efficiency compared to the other experimental run.

The substrates removal efficiency at an intermittent aeration time of 150-150 minutes was more than at an intermittent aeration time of 120-120 minutes. The reason might be that the microorganisms had a longer time for both aerobic and anaerobic period to treat readily biodegradable influent COD and to reduce soluble inert COD from microbial activities. The degradation mechanisms needed consecutive aerobic and anaerobic periods. Therefore, a longer intermittent aeration time could increase the efficiency for removal of substances in landfill leachate.

Inter-department Environmental Management	Student's………………………….
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LIST OF ABBREVIATIONS

AS	- Activated Sludge
AC	- Activated Carbon
ASP	- Activated Sludge Process
BOD	- Biochemical Oxygen Demand
BPAC	- Biological Powder Activated Carbon
COD	- Chemical Oxygen Demand
DO	- Dissolved Oxygen
Eff	- Effluent
HRT	- Hydraulic Retention Time
Inf	- Influent
MBR	- Membrane Bioreactor
MLSS	- Mixed Liquor Suspended Solids
NH_3-N	- Ammonia Nitrogen
NO_2-N	- Nitrite Nitrogen
NO_3-N	- Nitrate Nitrogen
PAC	- Powder Activated Carbon
SRT	- Solids Retention Time
SS	- Suspended Solids
TKN	- Total Kjedahl Nitrogen
TN	- Total Nitrogen
TP	-Total Phosphorus
VSS	-Volatile Suspended Solids

CHAPTER1

INTRODUCTION

1.1 General

Leachate is defined as liquid that has percolated through solid waste and has extracted dissolved or suspended materials. Most landfill leachate is composed of liquid that has entered the landfill from external sources, such as surface drainage, rainfall, groundwater, and water from underground springs and liquid produced from decomposition of wastes (Tchobanoglous, 1993). So, compositions of leachate are organic material, inorganic material, with odor and brown color.

Technology of wastewater treatment cannot treat color and some organic materials. The brown color is a problem for people who use water. They are often concerned that, even though it has been treated, colored water from landfill leachate may affect their health. The most popular treatment of landfill leachate in the past was anaerobic digestion or activated sludge method. These methods were known to be inadequate in handling such a difficult treatment task. In the more recent decades, the search for alternative treatment methods had focused on various sophisticated technologies. These included advanced biological, chemical and physical treatment methods, which are made up of sequencing batch reactor (SBR) method, biological activated carbon fluidized bed process, chemical oxidation, and membrane separation (Sheng , et.al., 2000).

A membrane separation system separates an influent stream into two effluent streams known as permeate and concentrate. Permeate is the portion of the fluid that has passed through semi-permeable membrane. Whereas the concentrate stream contains constituents that have been rejected by the membrane.

Membrane bioreactor (MBR) technology has been utilized in wastewater treatment as a modification of the conventional activated sludge process where separation of effluent is facilitated by membrane filtration instead of sedimentation. The MBR process has full-scale applications in a number of areas including industrial wastewater treatment, municipal wastewater treatment, landfill leachate treatment, domestic water reuse, and drinking water reclamation. The main advantages of the MBR process are the absolute control of solids and hydraulic retention time, high effluent quality, retention of all microorganisms and viruses, maintenance of high biomass concentrations, and compactness.

The objectives of this thesis are to solve problems from color, high COD, nitrogen, and phosphorus in landfill leachate by Membrane Bioreactor (MBR) and to compare it with Biological Powder Activated Carbon Membrane Bioreactor (BPAC-MBR).

1.2 Objectives of Study

1. To compare performances between MBR and BPAC-MBR in treating leachate by using Effective Microorganisms (EM).
2. To study effect of anoxic-oxic period on leachate treatment by MBR and BPAC-MBR.

1.3 Scopes of Study

1. Leachate used in the study was collected from municipal solid waste landfill in Kampangsan district, Nakonpratom province.
2. The performances of MBR with and without powder activated carbon addition for landfill leachate treatment.
3. The effects of anoxic-oxic period on MBR and BPAC-MBR performances was performed using lab-scale activated sludge reactor at 2 intermittent aeration time of 120-120 and 150-150 minutes.

CHAPTER 2

LITERATURE REVIEW

2.1 Compositions of Leachate

Leachate is defined as liquid that has percolated through solid waste and extracted dissolved or suspended material. The characteristics of leachate are reported in Tables 2-1 and 2-2.

Table 2.1 Typical data on the compositions of leachate from new and mature landfills

Constituent	New landfill (less then 2 years)		Mature landfill (greater than 10 years)
	Range	Typical	
BOD_5 (mg/l)	2,000-30,000	10,000	100-200
TOC (mg/l)	1,500-20,000	6,000	80-160
COD (mg/l)	3,000-60,000	18,000	10-150
Total suspended solids (mg/l)	200-2,000	500	100-400
Organic nitrogen (mg/l)	10-800	200	80-120
Ammonia nitrogen (mg/l)	10-800	200	20-40
Nitrate (mg/l)	5-40	25	5-10
Total phosphorus (mg/l)	5-100	30	5-10
Ortho phosphorus (mg/l)	4-80	20	4-8
Alkalinity as $CaCO_3$ (mg/l)	1,000-10,000	3,000	200-1,000
pH	4.5-7.5	6	6.6-7.5
Total hardness as $CaCO_3$ (mg/l)	300-10,000	3,500	200-500
Calcium (mg/l)	200-3,000	1,000	100-400
Magnesium (mg/l)	50-1,500	250	50-200
Potassium (mg/l)	200-1,000	300	50-400
Sodium (mg/l)	200-2,500	500	100-200
Chloride (mg/l)	200-3,000	500	100-400
Sulfate (mg/l)	50-1,000	300	20-50
Total ion (mg/l)	50-1,200	60	20-200

(Source: Tchobanoglous, 1993**)**

Table 2.2 Typical data on the compositions of landfill leachate at Kampangsan district Nakonpratom Province

Parameter	Range
pH	7.9-8.2
BOD_5 (mg/l)	420-650
COD (mg/l)	5,000-6,000
Total suspended solids (mg/l)	200-350
TKN (mg/l)	2,000-3,000
Total phosphorus (mg/l)	4.5-7.0
Color (Su.)	630-1,170

(Source: Landfill leachate at Kampangsan district Nakonpratom Province**)**

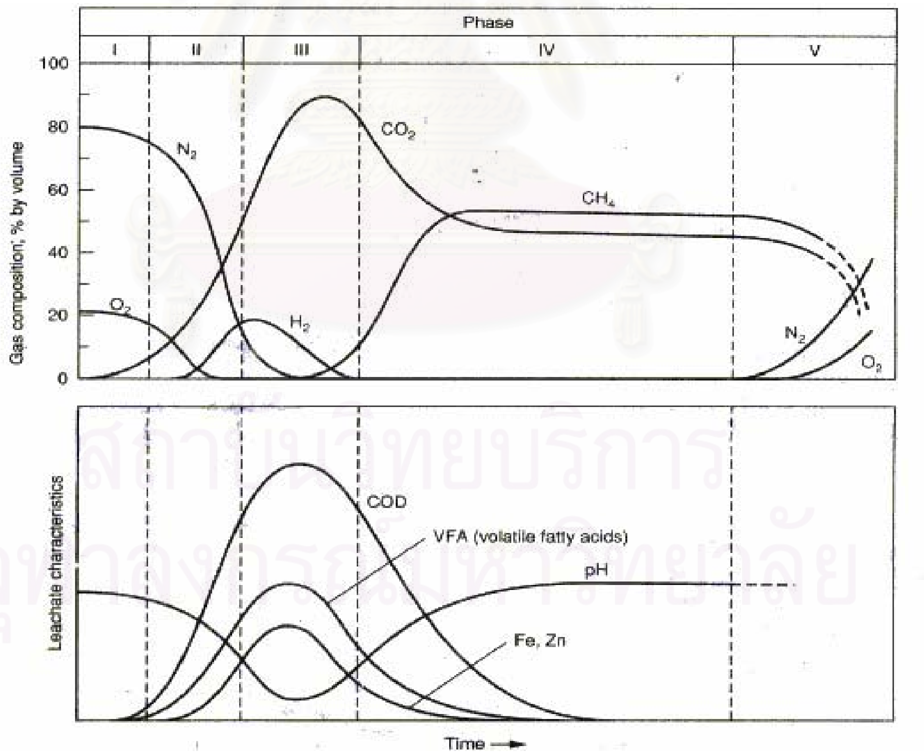

Figure 2.1 Generalized phases in the generation of landfill gas

(**Source:** Tchobanoglous, 1993)

(I= initial adjustment, II =transition phase, III= acid phase, IV= methane fermentation, and V=maturation phase)

Most landfill leachate is composed of liquid that has entered the landfill from external sources, such as surface drainage, rainfall, groundwater, and water from underground springs and the liquid produced from waste decomposition. The chemical compositions of leachate vary greatly depending on the age of the landfill and the events preceding the time of sampling. If a leachate sample is collected during the acid phase of decomposition (see Figure2.1), the pH value will be low and concentrations of BOD_5, COD, nutrients, and heavy metals will be high. If, on the other hand, a leachate sample is collected during the methane fermentation phase (see Figure2.1), the pH will be in the range of 6.5 to 7.5, and the BOD_5, COD, and nutrients concentration values will be significantly lower. Similarly the concentrations of heavy metals will be lower because most metals are less soluble at neutral pH values. The pH of the leachate depends not only on the concentration of the acids that are present but also on the partial pressure of the CO_2 in the landfill gas that is in contract with the leachate.

The biodegradability of the leachate will vary with time. Changes in the biodegradability of the leachate can be monitored by checking the BOD_5/COD ratio initially, the ratio will be in the range of 0.5 or greater. Ratios in the range of 0.4 to 0.6 are taken as an indication that the organic matter in the leachate is readily biodegradable. In mature landfills, the BOD_5/COD ratio is often in the range of 0.05 to 0.2. The ratio drops because leachate from mature landfills typically contains humic and fulvic acids, which are not readily biodegradable.

As a result of the variability in leachate characteristics, the design of leachate treatment system is complicated. For example, a treatment plant designed to treat a leachate with the characteristics reported for a new landfill would be quite different from one designed to treat the leachate from a mature landfill. The problem of interpreting the analytical results is complicated further by the fact that the leachate that is being generated at any point in time is a mixture of leachate derived from solid waste of different ages (Tchobanoglous, 1993).

2.2 Fundamental of Activated Sludge Process

The activated sludge process is one of the most typical suspended-growth biological treatment processes used in wastewater treatment. It may be defined as a system in which flocculated biological growths are continuously circulated with organic waste in the presence of oxygen. The oxygen is usually supplied though air bubbles injected into the sludge-liquid mass under turbulent conditions. The number of biological growth species and their population make up depend upon the specific wastewater being treated and the environment conditions in the reactor.

2.3 Biological Nitrification and Denitrification Processes

2.3.1 Nitrification

Nitrification is the conversion of ammonia nitrogen (NH_4^+-N) and some organic nitrogen form to nitrate nitrogen (NO_3^- -N) with nitrite (NO_2^- -N) formation as an intermediate that performed by either heterotrophic or autotrophic bacteria. However, the major nitrifying bacteria are the autotrophic species *Nitrosomonas* and *Nitrobacter*, which are common in soil and aquatic ecosystems. They derive energy for growth from the oxidation of inorganic nitrogen compounds instead of the oxidation of organic matter compounds.

The stoichiometric reaction for oxidation of ammonium to nitrite by *Nitrosomonas* is shown in Equation 2.1.

$$NH_4^+ + 1.5\, O_2 \longrightarrow NO_2^- + 2\, H^+ + H_2O \qquad (2.1)$$

The reaction for oxidation of nitrite to nitrate by *Nitrobacter* is shown in Equation 2.2

$$NO_2^- + 1.5\, O_2 \longrightarrow NO_3^- \qquad (2.2)$$

The reactions furnish energy for the growth of the nitrifying bacteria, during which some of the nitrogen is assimilated into bacterial protoplasm, carbon dioxide being the source of cell carbon. By assuming $C_5H_7O_2N$ as the empirical formulation of bacterial cell, the assimilation reaction can be written as follows,

$$5\, CO_2 + NH_4^+ + 2\, H_2O \longrightarrow C_5H_7O_2N + 5\, O_2 + H^+ \qquad (2.3)$$

The overall reactions of nitrification and assimilation become

$$55\ NH_4^+ + 5\ CO_2 + 76\ O_2 \longrightarrow C_5H_7O_2N + 54\ NO_2^- + 109\ H^+ + 52\ H_2O \quad (2.4)$$

$$400\ NO_2^- + 195\ O_2 + 5\ CO_2 + NH_4^+ + 2\ H_2O \longrightarrow C_5H_7O_2N + 400\ NO_2^- + H^+ \quad (2.5)$$

It is seen that approximately 3.22 mg O_2 will be required for each mg of NH_4^+-N oxidized to NO_2^--N, and 1.11 mg O_2 will be needed for each mg of NO_2^--N oxidized to NO_3^--N for a total of 4.33 mg O_2 of NH_4^+-N oxidized all the way to NO_3^--N.

It is generally accepted that the specific growth rate of *Nitrobacter* is higher than the growth rate of *Nitrosomonas* and hence there is no accumulation of nitrite in the process and the growth rate of *Nitrosomonas* will control the overall reaction.

2.3.2 Denitrification

Denitrificication is a biochemical reaction that involves a reduction of nitrate or nitrite, present in the water, to gaseous nitrogen compounds such as N_2, NO, and NO_2. It is carried out by facultative heterotrophic bacteria under anoxic conditions. The principal general is *Pseudomonas, Micrococcus, Achromabacter* and *Bacillus* that were reported as abundant in sewage.

Denitrification offers a mechanism of not only removing nitrogen in a non-polluting form, but also oxidizing organic matters in the process. Thus the oxygen that has been expensively supplied in nitrification can, in principle, be effectively recovered and reused in denitrification.

$$5(\text{Org-N}) + 2\ H_2O + 4\ NO_3^- \longrightarrow 2\ N_2 + 4\ OH^- + 5CO_2 \quad (2.6)$$

There are 4 conditions that are necessary for denitrification:

1. Presence of nitrate
2. Absence of dissolved oxygen
3. Bacterial mass that can accept nitrate and oxygen as electron acceptor
4. Presence of a suitable electron donor (energy source)

The presence of nitrate implies that nitrification is a prerequisite for denitrification. The absence of dissolved oxygen and bacterial mass can accept nitrate and oxygen as electron acceptor are called anoxic. The ability to denitrify is widespread among bacteria; dissimilative denitrification with end products N_2 , NO and NO_2 has been established in numerous cases. The bulk of the bacterial mass in wastewater treatment systems is facultative and a significant fraction is capable of dissimilative dentrification. Variety of carbonaceous organic substances have been investigated as energy sources for denitrification; these can be categorized as follows:

(a) Energy source not present in wastewater, i.e. an external carbonaceous energy source (e.g. methanol.)

(b) Energy source present in an influent wastewater, i.e. internal (influent) energy source.

(c) Energy source generated within a system by the release of substrates from organism death, i.e. self-generated energy source.

2.4 Membrane Bioreactor

2.4.1 Introduction

The use of biological treatment can be traced back to the late nineteenth century. By the 1930s, it was a standard method of wastewater treatment (Rittmann, 1987). Since then, both aerobic and anaerobic biological treatment methods have been commonly used to treat domestic and industrial wastewater. During the course of these processes, organic matter, mainly in soluble form, is converted into H_2O, CO_2, NH_4^+, CH_4, NO_2^-, NO_3^- and biological cells. The end products differ depending on the presence or absence of oxygen. Nevertheless, biological cells are always an end product, although their quantity varies depending on whether it is an aerobic or anaerobic process. After removal of the soluble biodegradable matter in the biological process, any biomass formed must be separated from the liquid stream to produce the required effluent quality. A secondary settling tank is used for the solid/liquid separation and this clarification is often the limiting factor in effluent quality (Benefield and Randall, 1980).

In recent years, effluent standards have become more stringent in an effort to preserve existing water resources. Recycling and reuse of wastewater for secondary purposes is on the rise due to dwindling natural resources, increasing water consumption, and the capacity limitations of existing water and wastewater conveyance systems. In both cases, achieving a high level of treatment efficiency is imperative.

The quality of the final effluent from conventional biological treatment systems is highly dependent on the hydrodynamic conditions in the sedimentation tank and the settling characteristics of the sludge. Consequently, large volume sedimentation tanks offering several hours of residence time are required to obtain adequate solid/liquid separation (Fane et al., 1978). At the same time, close control of the biological treatment unit is necessary to avoid conditions that lead to poor settle ability and/or bulking of sludge. Very often, however, economic constraints limit such options. Even with such controls, further treatment such as filtration, carbon adsorption, etc. are needed for most applications of wastewater reuse. Therefore, a solid/liquid separation method different from conventional methods is necessary.

Application of membrane separation (microfiltration or ultrafiltration) techniques for biosolid separation can overcome the disadvantages of the sedimentation tank and biological treatment steps. The membrane offers a complete barrier to suspended solids and yields higher quality effluent. Although the concept of an activated sludge process coupled with ultrafiltration was commercialized in the late 1960s, the application has only recently started to attract serious attention (Figure 2.2). There has been considerable development and application of membrane processes in combination with biological treatment over the last 10 years.

This emerging technology, known as a membrane bioreactor (MBR), offers several advantages over the conventional processes currently available. These include excellent quality of treated water, which can be reused for industrial processes or for many secondary household purposes, small footprint size of the treatment plant, and reduced sludge production for better process reliability. The purpose of this monograph is to provide a comprehensive review of membrane bioreactor technology. The application of membranes in different stages of biological treatment processes, the historical development of membrane bioreactors, and factors affecting the design on MBR processes performance are discussed. A number of case studies for each type of major MBR application along with some cost information on MBR processes are also presented.

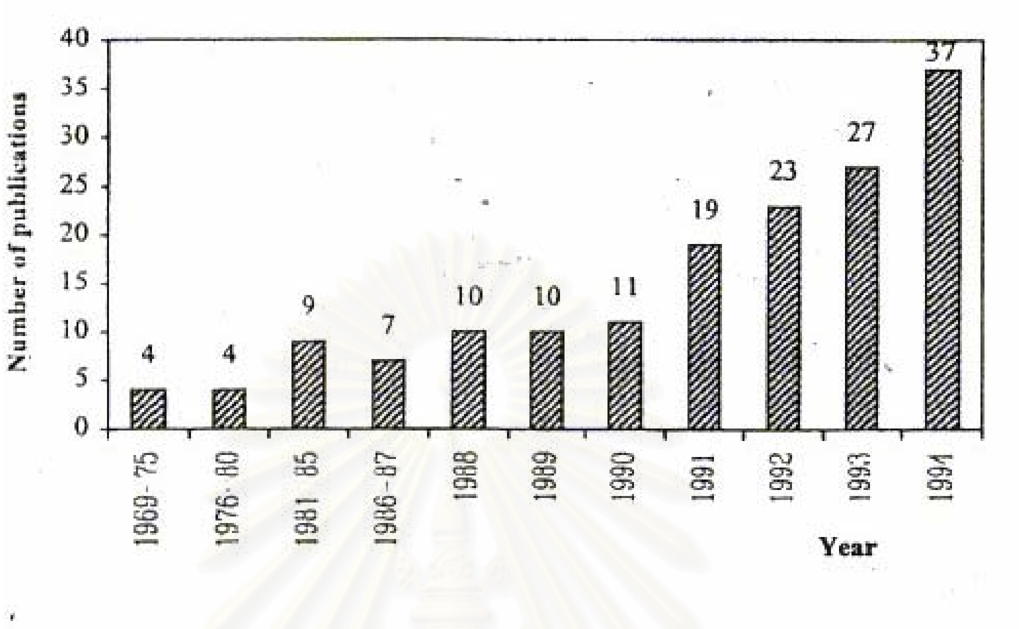

Figure 2.2 Number of studies published on MBR

2.4.2. Features of Membrane Application in Biological Wastewater Treatment

As our understanding of membrane technology grows, they are being applied to a wider range of industrial applications and are used in many new ways for wastewater treatment. Membrane applications for wastewater treatment can be grouped in three major categories (Figure 2.3): (1) biosolid separation, (2) biomass aeration, and (3) extraction of selected pollutants. Biosolid separation is, however, the most widely studied and has found full-scale applications in many countries (Table 2.3). Use of combined night-soil treatment and wastewater reclamation at plant scale operations in buildings in Japan are examples of some successful applications, and in these cases membrane-couples technology is considered a standard process (Yamamoto et al, 1989). Solid/liquid separation bioreactors employ microfiltration or ultrafiltration modules for the retention of biomass for this purpose. The membranes can be placed in the external circuit of the bioreactor or they can be submerged directly into the bioreactor (Figure 2.3a).

Asymmetric membranes consist of a very dense top layer or skin with a thickness of 0.1 to 0.5 μm, supported by a thicker sub layer. The skin can be placed either on the outside or inside of the membrane, and this layer eventually defines the characterization of membrane separation.

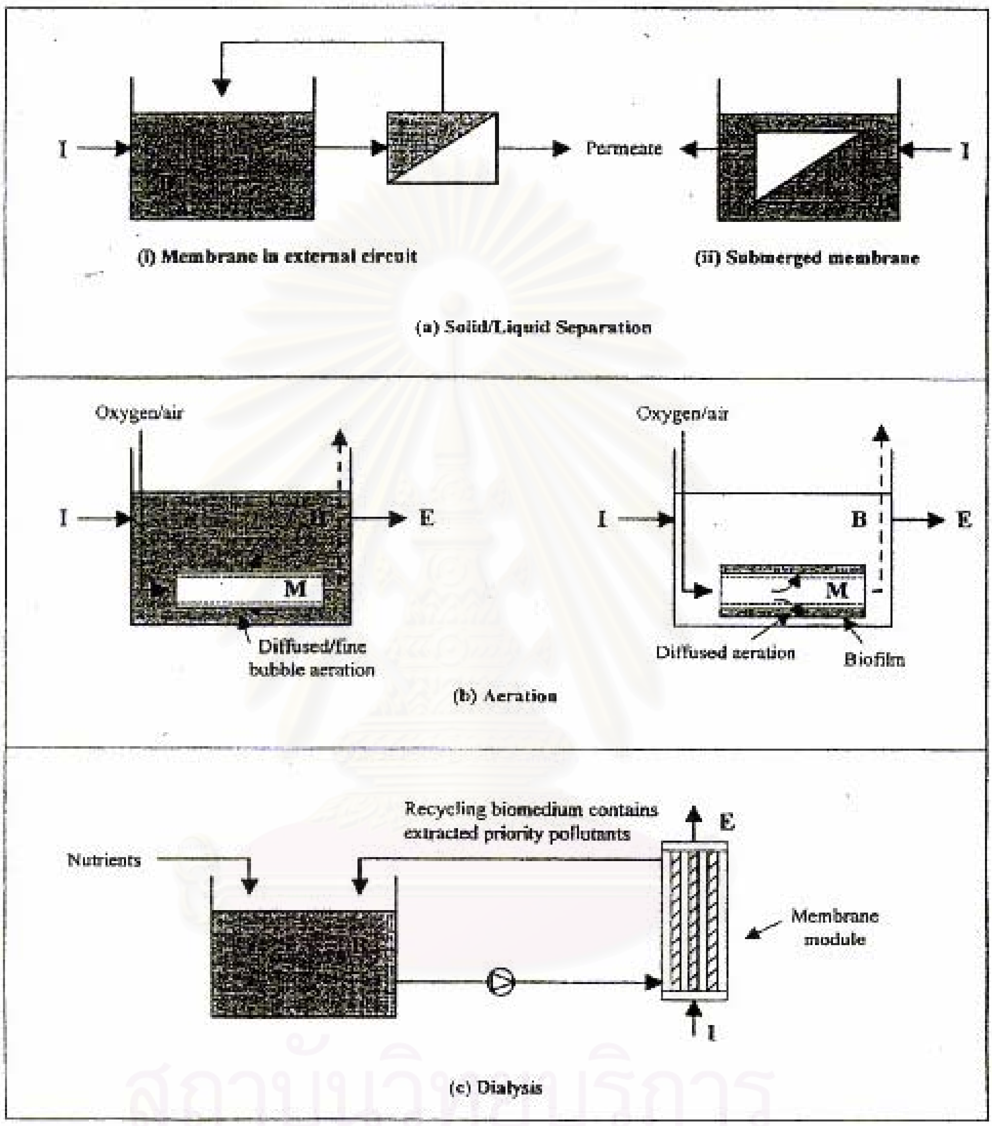

Figure 2.3 Features of membrane application in biological treatment

A submerged membrane should be outer-skinned. In general, permeate is extracted by suction or, less commonly, by pressurizing the bioreactor. In the external circuit, the membrane can be either outer- or inner-skinned, and permeate is extracted by circulating the mixed liquor at high pressure along the membrane surface. In the later case, the concentrated mixed liquor at the feed side is recycled back to the aeration tank.

Gas-permeable porous membranes can be used to aerate the mixed liquor in the aeration tank by bubble less oxygen mass transfer (Yasuda and Lamaze, 1972). At the same time, they can be used for fine bubble aeration (Semmens, 1989; Matsuoka et al., 1992). In certain cases, the membrane can act as support for biofilm

Table 2.3 Commercial Scale Solid/liquid Separation MBR Plants

Company	Commercial name	Country	Type of waste	Number of plants	Capacity (m3/d)
Rhone Poulenc-TechSep	UBIS	France	Domestic	>40	<400
Dorr Oliver	MSTS	USA	Domestic	1	13.6
Thetfort Syst	Cycle-LET	USA	Domestic	>30	<200
Kubota	Kubota	Japan	Domestic	8	10-110
	Kubota	UK	Domestic	1	96
Mitsui Petrochemical industries	ASMEX	Japan	Human excreta	>40	-
Zenon Env Inc.	Zenogem	Canada	Industrial	1	116
Dorr Oliver	MARS	USA	Industrial	1	38
Membratek	ADUF	RSA	Industrial	2	80/500
SITA/lyonnaise des Eaux	-	France	Landfill leachate	3	10-50
Membratek	-	S.Africa	Industrial	2	100-500
Grantmij	-	Germany	Landfill leachate	3	10-50
Degrement	-	France	Industrial	1	500

development, with direct oxygen transfer through the membrane wall in one direction and nutrient diffusion from the bulk liquid phases into the biofilm in the other direction (Brindle and Stephenson, 1996). Because the membranes can form bubble-free or fine-bubble mass transfer, the efficiency is very high.

Conventional membrane modules can be used in either a flow-through or dead-end mode as presented in Figure 2.3b. In the flow-through mode, the air or oxygen is continuously pumped through the hollow fibers and gas is vented to keep the partial pressure of oxygen high along the membrane. In the dead-end mode, the membrane is pressurized with air or oxygen by sealing one end of the fibers or by sending the gas from both ends. Most studies reported to date have focused on the flow-through mode, and researchers argue that the dead-end mode should be avoided because it significantly reduces performance and may result in water vapor condensation inside the membrane fibers. However, because air or oxygen is vented out in the flow-through system, part of the pumped gas is wasted, and thus the gas transfer efficiency is reduced. In addition, volatile organic compounds (VOCs) can diffuse across the membrane into the air stream (Semmens, 1989); VOCs in wastewater can be very effectively stripped and vented off to the atmosphere. Both these problems can be overcome in the dead-end mode. Also, as the total amount of air/oxygen supplied should diffuse through the membrane module, the efficiency is improved and VOCs stripped off can be minimized if not completely reduced.

An extractive membrane bioreactor was developed to extract (by dialysis) toxic organic pollutants present in industrial wastewater to a bio-medium for subsequent degradation (Livingston, 1994). In dialysis mode, organisms can be maintained in an optimal growth environment through nutrient supplementation while at the same time digesting inhibitor or recalcitrant compounds that diffuse across the membrane. Mass transfer of the pollutants across the membrane is driven by a concentration gradient, because the bio-medium passing on the membrane walls acts as a sink. Although these three applications are described separately, they are not mutually exclusive, and they may be coupled together to achieve added advantages for each process (Brindle and Stephenson, 1997).

2.4.3 Development of Membrane Bioreactors

Membranes have been finding wide application in water and wastewater treatment ever since the early 1960s when Loeb and Sourirajan invented an asymmetric cellulose acetate membrane for reverse osmosis. Many combinations of membrane solid/liquid separators in biological treatment processes have been studied. Since, the trends that let to the development of today's MBR are depicted in Figure 2.4. When the need for wastewater reuse first arose, the conventional approach was to use advanced treatment processes (Figure 2.4a). For irrigation, this treatment may be limited to filtration and disinfections, whereas for building reuse or ground water recharge it may also include reverse osmosis (RO). For example, Water Factory 21 in Orange Country uses a treatment process that consists of lime softening, air stripping, recarbonation, sand filtration, carbon adsorption, and RO for biologically treated effluent. The treated water is used to recharge the ground water. This scheme is relatively complex and produces large amounts of chemical sludge.

The progress of membrane manufacturing technology and its applications could lead to the eventual replacement of tertiary treatment steps by micro filtration or ultrafiltration and this simplified method is being evaluated at Water Factory 21 in the U.S. Parallel to this development, micro filtration or ultrafiltration was used for solid/liquid separation in the biological treatment process and the sedimentation step could also be eliminated by pumping the mixed liquor at a high pressure into the membrane unit, the permeate passes through the membrane and the concentrate is returned to the bioreactor (Hardt et al., 1970). However, higher energy costs to maintain the cross flow velocity led to the next stage of development by submerging the membranes in the reactor and withdrawing the treated water through membranes In this development, membranes were suspended in the reactor above the air diffusers. The diffusers provided the oxygen necessary for treatment to take place and scour the surface of the membrane to remove deposited solids. In a parallel attempt to save energy in membrane coupled bioreactors, the use of jet aeration in the bioreactor has been investigated (Yamagiwa et al., 1991). The main feature is that the membrane module is incorporated into the liquid recirculation line for the formation of the liquid jet such that aeration and filtration can be accomplished with only one pump. Jet aeration works on the principle that a liquid jet, after passing through a gas layer, plunges into a liquid Baht containing a considerable amount of air. The limited amount of oxygen transfer possible with this technique restricts this process to small-scale applications. However, using only one pump makes it mechanically simpler and therefore useful to small communities. The invention of air back-washing techniques for membrane declogging led to the development of using the membrane itself as both clarifier and air diffuser (Parameshwaran, 1997). In this approach, two sets of membrane modules are submerged in the aeration tank. While permeate is extracted through one set, the other is supplied with compressed air for back washing. The cycle is repeated alternatively, and there is a continuous airflow into the aeration tank, which is sufficient to aerate the mixed liquor.

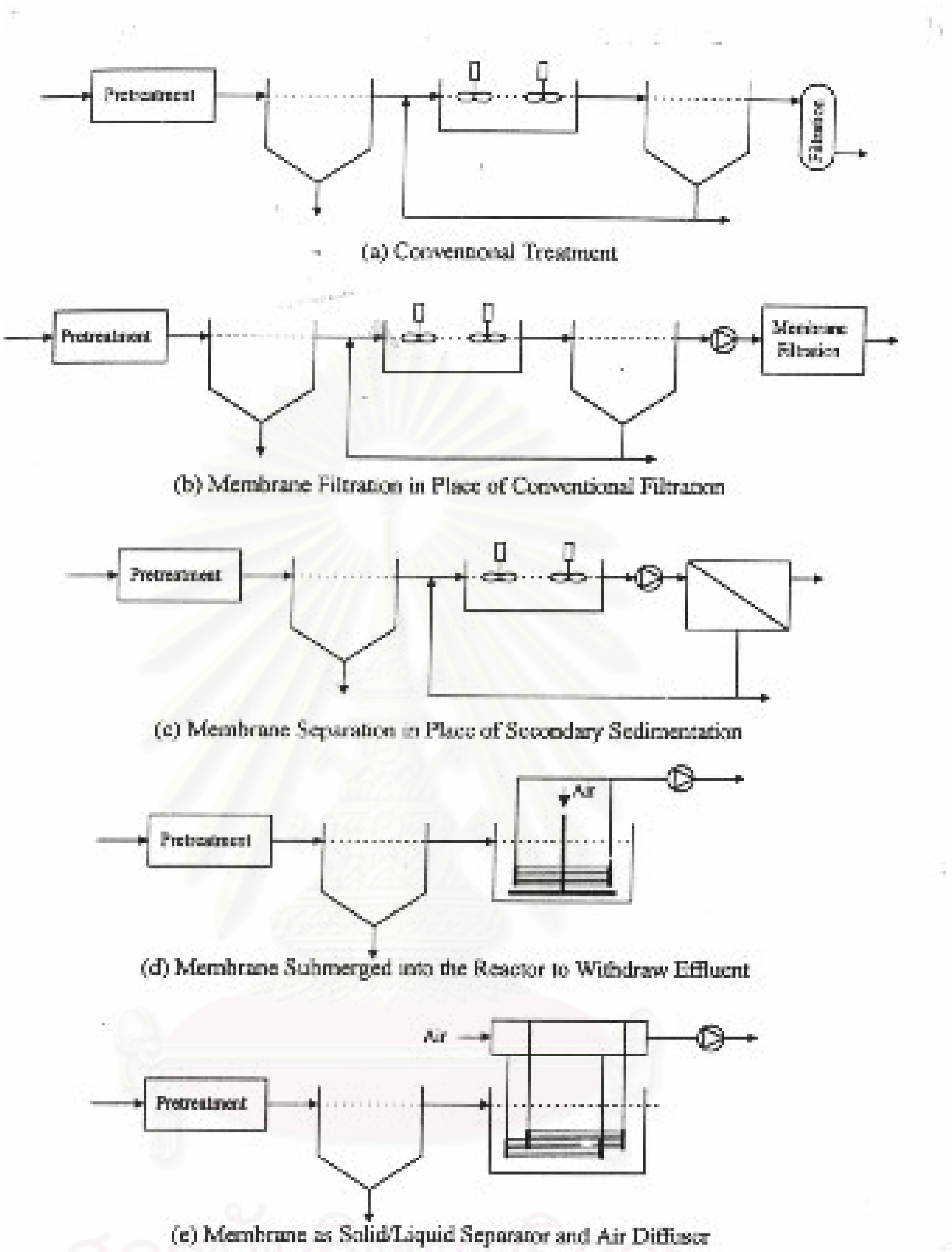

Figure 2.4 Trends in MBR development

2.4.4 Advantages of MBR

There are many advantages in using a MBR process, the prime ones being the treated water quality, the small footprint of the plant, and less sludge production and flexibility of operation.

2.4.4.1 Treated Water Quality

The major problem of conventional activated sludge processes is the settling of sludge. This is caused by poor flocculation of microfloras or the proliferation of filamentous bacteria. Because solids and colloids are totally eliminated through membrane separation, settlement has no effect on the quality of treated water. Consequently, the system is easy to operate and maintain. This is important with industrial wastewater, because a lack of nutrients leads to excessive growth of filamentous organisms resulting in poor settlement. Because the final effluent does not contain suspended matter, this enables the direct discharge of the final effluent into the surface water and the reuse of effluent for cooling, toilet flushing, lawn watering, or, with further polishing, as process water.

2.4.4.2 Flexibility in Operation

In a MBR, sludge retention time (SRT) can be controlled completely independently from hydraulic retention time (HRT). Therefore, a very long SRT can be maintained resulting in the complete retention of slow-growing microorganisms such as nitrifying or methanogenic bacteria and this results in greater flexibility of operation.

2.4.4.3 Compact Plant Size

Volumetric capacities are typically high because a high sludge concentration can be maintained independently of settling qualities. HRTs as low as 2h have been satisfactorily applied (Chaize and Huyard, 1991), and fluctuations on volumetric loading have an effect on the treated water quality (Chiemchaisri, et.al., 1993). Moreover, the higher turbulence maintained within the mixed liquor to prevent the membrane from fouling also prevents the flocculation of biosolids and keeps them highly dispersed. An analysis on the floc size distribution of MBR sludge and conventional activated sludge indicates that the floc size in the MBR (a number of samples from different MBR plants were analyzed) are smaller than 100 μm and concentrated within a small range. On the other hand, floc size from conventional activated sludge processes varies from 0.5 to 1000 μm (Zhang, et.al., 1997). The smaller flocs from MBRs could stimulate a higher oxygen and/or carbon substrates mass transfer and thus higher activity levels in the system. The beginning also found that nitrification activities in MBR processes averaged 2.28 g NH_4-N/kg MLSS.h, which was greater than in conventional processes (0.95 g NH_4-N/kg MLSS.h). Also, there is an enormous saving in space with MBRs because there is no need for secondary settling devices and post-treatment to achieve reusable quality.

2.4.4.4 High Rate Decomposition

Treatment efficiency is also improved by preventing leakage of undecomposed polymer substances. If these polymer substances are biodegradable, they can be broken down with a reduction in the accumulation of substances within the treatment process. On the other hand, dissolved organic substances with low molecular weights, which cannot be eliminated by membrane separation alone, can be broken down and gasified by microorganisms or converted into polymers as constituents of bacterial cells, thereby rising the quality of the treated water. For example, permeate from microfiltration of the screened raw sewage (feed average BOD_5= 230 mg/l) had an average BOD_5 of 93mg/l. This was mainly the soluble portion of the influent BOD_5, although it showed 99% removal of suspended solids and 5.8 log removal of fecal coliforms. In contrast, most MBR studies indicate the effluent BOD_5 is below 5 mg/l (Parameshwaran and Visvanathan, 1998). Due to the high biomass concentrations and the fact that bio-oxidation is an exothermic process, temperature increase can be maintained at the maximum activity temperature level. Maximum growth rates are about five times higher than the activity commonly observed in activated sludge systems. Based on cubic meter of reactor volume, combining high activity with high biomass concentration results in conversion rates 10 to 15 times higher than conventional conversion rates (Buisson et al., 1997), an especially useful feature in cold climates.

2.4.4.5 Low Rate Sludge Production

Studies on MBR indicate that the sludge production rate is very low (Table 2.4). The treatment of domestic wastewater, sludge production is greatly reduced if the age is between 50 and 100 days. Low F/M ratio and longer sludge age in the reactor is generally used to explain this low production rate (Chaize and Huyard, 1991).

The viscosity of sludge increases with age, eventually limiting the oxygen transfer in the MBR system. It was also noted that with increased age there was greater difficulty in sludge dewater ability, which could be attributed to excess amount of cellular polymer formation.

It is also anticipated that micrological activity can be modified with increased sludge age, but little published information is available on the subject. The initial microscopic observation (Pliankarn, 1996) on microorganism population indicates that with increased sludge age, there is a reduction in filamentous bacteria in creased rotifers and nematodes.

Table 2.4 Comparison of sludge production in conventional activated sludge process (ASP) and MBR process treating domestic wastewater

Type of process	SRT (d)	Sludge Production
ASP	10-20	0.7-1kgMLSS/kg BOD_5
ASP	14	0.7 kgMLSS/kg BOD_5
ASP	33	0.6 kgMLSS/kg BOD_5
MBR	25	0.53 kgMLSS/kg BOD_5
MBR	25	0.26 kgMLSS/kg BOD_5
MBR	50	0.22 kgMLSS/kg BOD_5

2.4.4.6 Disinfection and Odor Control

In this membrane filtration process, the removal of bacteria and viruses can be achieved without any chemical addition (Pouet et al., 1994). Because all the process equipment can be tightly closed, no odor dispersion occurs. Comparison of conventional biological processes and MBR is shown in Table 2.5 and depicts the advantages discussed above.

Table 2.5 Comparison of operating data for conventional, external aeration ASP, and AS/UP treatment process

Parameters	Unit	Processes		
		ASP/UP	Conventional	Extended
System reactor volume	1	2,663	3,423	13,694
Influent BOD	mg/l	250	250	250
System MLSS	mg/l	10,000	2,500	3,500
Organic loading rate	kgBOD/kg.MLSS.d	0.12	0.2-0.7	0.1-0.15
Volumetric loading rate	kg BOD/m^3.d	1.35	0.59	0.27
Reactor DO	mg/l	1.5	1.5	1.5
SRT	d	infinite	2	11
Re-circulation ratio	%	240	25	50-100
HRT	h	5	6	12-24

With the exception of wastewater reuse, membrane separation activated sludge processes have not been widely used. Obstacles to more widespread use include:

- High capital and operating costs
- Current regulatory standards can be achieved by conventional treatment process
- Limited experience in use of membranes in these application areas
- Lack of interest by the membrane manufacturers

Membranes will only find greater application in the wastewater industry if they can achieve the required regulatory standards or better at the same cost or less compared with present processes, or if regulations were to tighten further such that conventional processes can no longer achieve the desired effluent quality.

2.4.5 Factors Affecting the MBR Process Performance

The main aim of membrane-coupled bioreactors is to improve the efficiency of the biological process step such that high-quality effluent is obtained. Because biological treatment and membrane separation are rather distinct processes, the combined MBR process is relatively complex. To optimize the MBR process, many parameters have to be considered. These include solid concentrations, sludge age, and the hydraulic retention time (HRT) in the biological step as well as the flux rate, material costs, and the energy cost of the membrane separation. The treatment and disposal of the waste sludge also needs to be considered. Comparisons made on the waste sludge properties of the conventional activated sludge process and the MBR process indicates that dewatering of MBR waste sludge is difficult compared with the conventional process. This has been attributed to higher organic matter content and excess production of extra cellular polymers (Parameshwaran, 1997). As all these parameters are interrelated, optimization is complicated. For example, an increase in sludge concentration can enhance the biological stage. However, when sludge concentration exceeds a certain limit, the permeation flux rapidly declines due to a dramatic rise in the viscosity of the sludge mixture. An increase in sludge concentration can also affect the gas transfer efficiency, and the energy requirements for the aeration therefore will increase.

Permeation flux of membrane filtration is affected by the raw materials of the membrane and its pore size as well as operational conditions such as the pressure driving force and the liquid velocity/turbulence.

2.4.6 Bioreactors with Submerged Membranes

Talat (1988) investigated hollow fiber micro filtration for solid-liquid separation from the aeration tank of an activated sludge process. The variation of three parameters of pore size (0.1, 0.2 and 0.45 μm), MLSS in the reactor (5,000, 10,000and 20,000 mg/L) and suction pressure (1.36, 2.72, and 7.5 m head of water) were conducted during a short term experiment in order to find out the suitable mode of operation for long term experiments. The short-term results show that at 10:10 intermittent operation provided the best conditions for the stable flux. In long term experiments, membrane modules were regulated at constant flux of 1.5, 2.5 and 3.5 $L/m^2.h$ and the corresponding increase in suction pressure was recorded.

Volumetric organic loading of 3 kg $COD/m^3.d$ was shown critical condition toward the separation process. However, loading of 2 kg $COD/m^3.d$ appeared to provide the most suitable condition, since the COD removal efficiency was up to 95-97%.

Nitrification and denitrification was achieved at 100% and 30-40% respectively. Under similar operating conditions, the removal efficiency was independent of the membrance pore size. The 0.45 μm membranes which operated at lower suction pressure than the 0.1 μm membrane under similar operating conditions provided the highest flux of 3.5 $L/m^2.h$ (0.084 $m^3/m^2.d$) and was similar in clogging characteristic to others. The low value of Y, k_d and F/M ratio showed very small sludge production. The 100% removal of fecal coliform can be achieved by using 0.1 and 0.45 μm membrane filters.

Series of laboratory scale experiments were carried out by Yamamoto et al. (1989) to find out the feasibility of direct membrane separation in an activated sludge aeration tank. The study was carried out with 0.1 μm pore size hollow fiber membrane. Short term experiments in substrates free water revealed high suction pressure led to rapid reduction in flux. During the long term experiments, continuous suction caused server clogging of the membrane module with an increasing pressure difference till 100 kPa. The stable flux was observed for 120 days at volumetric loading of 1.5 kg $COD/m^3.d$ using intermittent suction at low pressure of 13 kPa. COD removal of more than 90%. However nitrate removal was considerably varied above 80% and denitrification efficiency indicates the dissolved oxygen could not be depleted in a shorter non-aeration time. From the analysis of the supernatant of the reactor water and effluent shows that the membrane acts as a barrier to remove a certain amount of dissolved and colloidal COD. During the steady state F/M ratio was 0.1 d^{-1} and the critical organic loading was estimated as 3 to 4 kg COD/m^3.d to maintain both stable flux and aerobic condition. An absence of recirculation pumps led to a very low power consumption of 0.007 kWh/m^3.

Chiemchaisri (1990) investigated an activated sludge process operation using 0.1 µm hollow fiber membrane modules for solid liquid separation. This study was conducted to treat low strength wastewater from AIT domestic wastewater. Comparison of the membrane bioreactor under different operating conditions, such as non-aerated and aerated, with different initial hydraulic retention time (HRT) of 1, 3 and 6 hours which provided corresponding permeate flux of 4.17, 1.38 and 0.7 L/m^2.h was studied. The process was operated at 10:10 intermittent time. From the experiment, it can be seen that the non-aerated bioreactor has an advantage over the aerated condition at an initial HRT of 3 and 6 hours, since lower energy consumption was required while giving similar effluent quality and process stability. However, at a lower HRT of 1 hour (or higher permeate flux, 4.17 L/m^2.h) of aeration is required in order to prevent membrane clogging. This highest flux of 4.17 L/m^2.h seems to be a critical value since creating severe clogging condition.

At lower flux, no clogging was observed under non-aerated conditions. The quality of permeate in term of COD was independent of the low volumetric organic loading at the range of 0.2-2 kg COD/m^3 .d. The performance of 0.03 µm pore size with 9 m^2 surface area of hollow fiber membrane was also investigated in pilot–scale unit. Two hollow fiber membrane modules were immersed in an aeration tank that fed diurnally with AIT domestic wastewater. The suction pump was used at 10:10 minute intermittent operation to extract permeates through the membrane. The pilot scale experimental set-up is shown in Fig 2.8. For jet aeration, the effects of the jet aeration period (0.5 and 1 h) and jet aeration pattern, 15 minutes for two times a day and 30 minutes for once a day were investigated. The jet aeration flow rate used was 20 L/min.

The settling of solids to the bottom of the bioreactor and the creation of an anaerobic condition resulted in the division of the bioreactor into two zones: aerobic and anaerobic. This effect also resulted in low MLSS in the aerobic zone, which could reduce the clogging of the membrane. The mean hydraulic retention time (HRT) was determined after the permeate flux reached steady state. The average flux was found to be around 4.17 $L/m^2.h$ corresponding to an average HRT of 1 day under diurnal varied loading. Diurnal variation in loading plays a minor role in the nitrification process since more than 80% nitrification can be observed throughout the experiment.

The MLSS in the bioreactor was affected by the air flow rate, and the optimum air flow rate in this experiment was taken as 7.5 L/min., which provided sufficient oxygen for the microorganisms and maintained low MLSS in the aerobic zone.

Direct membrane separation using a hollow fiber membrane for the activated sludge process was investigated in a pilot scale study by Chiemchaisri et al. (1992). The system consists of two parts, the main bioreactor and the separation unit. The 10 l separation unit was immersed into the 62 l main bioreactor. Two hollow fiber membrane modules (0.03 and 0.1 μm pore size) 0.3 m^2 surface area were put in the separation unit. Paddles, driven by a motor, provided a cross flow of mixed liquor across the membrane surface at the speed of 290 rpm in 10 second cycles in alternating directions. By providing highly turbulent conditions within the separation zone in conjunction with jet aerating installation inside the membrane module, sludge accumulation on the membrane surface and inside the module can be reduced. Permeate flux obtained after 330 days of operation was 2.33 $L/m^2.h$ (0.2 m^3/m^2d) under intermittent suction. A high degree of organic matter reduction (more than 85%) was observed with 20.8 and 16.5 mg/L of COD in the effluent during continuous and intermittent aeration modes, respectively. The degree of nitrification and denitrification was 90% under intermittent aeration (90 minutes aeration and 90 minutes rest) at a dissolved oxygen level of 4-5 mg/L was applied. However similar interval intermittent aeration but at low dissolved oxygen level (1.5-2 mg/L) lead to a reduction in nitrification and denitrification efficiency (80%) resulting in 4.9 mg/L of total nitrogen in the effluent. The virus reduction of 4 to 6 log number also observed.

Tekasananont (2000) use MBR to treat high-rise building wastewater for removing the organic material and nitrogen in intermittent conditions. At time cycles of aeration and non-aeration 120-120 minutes performance is better than 90-90 minutes. The denitrification efficiency is 43-93% varied with COD/TKN ratio 2.1-6.2. The system can remove 99% as turbidity, 90% as COD, and 40-90% as nitrogen.

Seo et al. (2000) used a submerged membrane bioreactor (MBR) operated in 2-stage intermittent aeration for the simultaneous removal of organic matter, nitrogen and phosphorus. The system consists of two reactors with a total volume of 0.27 m^3 (1st reactor 0.09 m^3 and 2nd 0.18 m^3). The membrane used for this experiment was hollow fiber polyethylene membrane with a pore size of 0.1µ and an effective surface area of 4 m^2. SRT was maintained at 25 days, 2,700~3,400 mg/l, and HRT 16~19 hours. At 60/60 minutes intermittent, MBR could remove 98.3% as BOD 95.6% as COD, 91.6% as TN and 66% as TP.

Huang, Gui, and Qian (2000) used the submerged membrane bioreactor to treat domestic wastewater. Three experimental runs were conducted all with a hydraulic retention time of 5 hours and sludge retention times (SRTs) of 5, 10, and 20 days. The pollutant removal performance of the membrane bioreactor, the membrane effluent quality, and a kinetic model for sludge growth in the bioreactor were investigated. The process was capable of removing over 90% of both COD and NH_3-N on the average. The total removal for COD was almost independent of SRT, but for NH_3-N it was improved with increasing SRT**.** Increasing SRT caused the concentrations of suspended solids (SS) and volatile suspended solids (VSS) in the bioreactor to increase. However, the ratio of VSS/SS did not change significantly. Kinetic analysis showed that the sludge yield coefficient (kg-VSSkg-COD^{-1}) and the endogenous coefficient of microorganisms were 0.25 and 0.04d^{-1}

Brindle et al. (2000) use the submerged membrane bioreactor (MBR) pilot-plant to treat raw municipal sewage continuously for 64 days. The MBR contained one MF and two UF membrane modules, each comprised of unsupported hollow fibers with large internal diameters of 10 mm. The driving force for permeate production was the hydrostatic pressure provided by the liquid head above the membrane modules which were submerged near the bottom of the reactor vessel. During the investigation no membrane backwash was necessary to maintain a stable flux. The three membrane modules of the micro filtration module performed the best; with an average specific flux of 43 l m^{-2} h^{-1}, a turbidity removal efficiency of >99%. At an organic loading rate of 6.8 kg COD m^{-3} d^{-1}, the highest the process was subjected too, a hydraulic retention time (HRT) and an ammonia influent concentration of 35 mgNH_3-N l^{-1}, the process achieved a 93% COD removal efficiency and a nitrification efficiency of 89%.

Gaweenuntawong (1999) used the Powder Activated Carbon Ultra Filtration (PAC-UF) system to treat dye house wastewater. From the experiment results, this system had the highest performance at an operating transmembrane pressure of 2 bars. The removal efficiencies in terms of COD and TOC were higher than 80%, whit the fluxes in the range of 40-70 l/m^2-h.

Cicek et al. (1999) worked to compare performance and characteristics of a membrane bioreactor (MBR) and a conventional activated-sludge system (AS) by comparing fed wastewater containing casein and starch. Except different solids retention times (20 days for AS, 30 days for MBR), the systems were operated under identical conditions. Approximately 99.0% chemical oxygen demand and 96.9% dissolved organic carbon removal were achieved in the MBR compared to 94.5 and 92.7% in the AS. Both systems showed effective nitrification and phosphorus utilization. The MBR sludge was composed of small flocs; free-swimming bacteria; and a small number of filamentous organisms, nematodes, and ciliates.

Sang-Min et al. (2000) used the submerged membrane system in a two-phase anaerobic reactor to treat wastewater by increasing the sludge retention time (SRT) of acidogen and to enhancing the solid separation. The membrane material used was mixed esters of cellulose of 0.5 mm pore size. COD removal efficiency was 80% and the methane production showed 0.32 m^3/kg COD removed for the submerged membrane system in the anaerobic digester.

Yoshiaki et al. (2000) used nylon mesh as filter material instead of a micro filtration membrane in a membrane bioreactor. They had observed that mesh having a pore size of 100 μm effectively rejected activated sludge and that the reactor retained SS of up to 9000 mg/l with a flux of 0.5-0.76 m/day at very low pressure (5-10 mm-H_2O). The study also revealed that the sludge layer formed at the mesh surface plays an essential role in separating activated sludge. The synthetic wastewater (BOD: 200 mg/l, T-N: 50 mg/l, T-P: 5.7 mg/l) was fed to the reactor under the following conditions: HRT of 4±8 hours, continuous feeding, continuous filtration, and continuous or intermittent aeration. Under these conditions, SS and BOD of the effluent were less than 1.5 mg/l and 5.0 mg/l, respectively. Under intermittent aeration conditions T-N removal attained 80 %, although the mesh filter was clogged in 1-2 weeks. Effective T-N removal was obtained without clogging of the mesh filter for 2 months.

2.4.7 Effects of Aeration in Suction Pressure

Aeration in a submerged membrane bioreactor serves three purposes: providing the air required for the biodegradation, keeping the biomass dispersed throughout the reactor and creating a cross flow velocity in the vicinity of the membrane module. It can be anticipated that the increase in air flow rate can improve the flux rate. (Undeda et al., 1997) studied this phenomenon in a 21.4 m^3 pilot scale submerged membrane bioreactor. In this study 42 hollow fiber modules (0.1 µm pore size and 4 m^2 surface area each) were used. From this study it was concluded that cake removing efficiency of the uplifting air flow was affected by the turbulence of the flow. The cake removing efficiency was improved either by augmenting an air flow rate or by augmenting aeration intensity (an air flow rate per unit flow area) by concentrating membrane modules over a smaller floor area. It was further mentioned that an increase in the air flow rate partially stimulated the cake-removing efficiency, but there was a critical value beyond which the air flow rate increase had virtually no effect on the cake removing efficiency. The cake removing efficiency was also improved by intensifying the air flow without increasing the air flow rate. Therefore, membrane modules are to be concentrated over a smaller floor area in order to augment the aeration intensity.

2.5 Theory of Adsorption (Eckenfelder, 1989)

A solid surface in contact with a solution tends to accumulate a surface layer of solute molecules because of the unbalanced surface forces. Chemical adsorption results in the formation of a monomolecular layer of the adsorbate on the surface through forces of residual valence of the surface molecules. Physical adsorption substances of the highest molecular weight are most easily adsorbed. There is a rapid formation of an equilibrium interfacial concentration, followed by slow diffusion into the carbon particles. The overall rate of adsorption is controlled by the rate of diffusion of the solute molecules within the capillary pores of the carbon particles.

The rate varies reciprocally with the square of the particle diameter, increases with increasing concentration of solute, increases with increasing temperature, and decreases with increasing molecular weight of the solute. The rate also increases with decreasing pH because of changes in surface charges of the carbon.

The adsorptive capacity of a carbon for a solute will likewise be dependent on both the carbon and the solute.

Most wastewater is highly complex and varies widely in the adsorbability of the compounds present. Molecular structure, solubility, etc., all affect the absorbability.

2.5.1 Formulation of Adsorption

The degree to which adsorption will occur and the resulting equilibrium relationships have been correlated according to the empirical relationship of Freundlich and the theoretically derived Langmuir relationship. For practical application, the Freundlich isotherm usually provides a satisfactory correlation. The Freundlich isotherm is expressed as

$$\frac{X}{M} = kC^{1/n} \qquad (2.7)$$

Where X = weight of substance adsorbed

M = weight of adsorbent

C = Concentration remaining in solution

k and n are constants depending on temperature, the adsorbent, and the substance to be adsorbed.

The Langmuir equation is based on an equilibrium between condensation and evaporation of adsorbed molecules, considering a monomolecular adsorption layer:

$$\frac{X}{M} = \frac{abC}{1+aC} \qquad (2.8)$$

This can be expressed in linear form as

$$\frac{1}{X/M} = \frac{1}{b} + \frac{1}{ab}\,\frac{1}{C} \qquad (2.9)$$

Where b = amount adsorbed to form a complete mono layer on the surface

a = constant which increases with increasing molecular size

Since most wastewaters contain more than one substance that will be adsorbed, direct application of the Langmuir equation is not possible. Morris and Weber have developed relationships from the Langmuir equation for competitive adsorption of two substances:

$$\frac{X_A}{M} = \frac{a_A b_A C_A}{1+a_A C_A + a_B C_B} \tag{2.10}$$

$$\frac{X_B}{M} = \frac{a_B b_B C_B}{1+a_A C_A + a_B C_B} \tag{2.11}$$

More complex relationships could similarly be developed for multi component mixtures. It should be noted that although the equilibrium capacity for each individual substance adsorbed in a mixture is less than that of the substance alone, the combined adsorption is greater than that of the individuals alone. In industrial application, contact times of less than 1 h are usually used. Equilibrium is probably closely realized when high carbon dosages are employed, since the rate of adsorption increases with carbon dosage.

2.5.2 Properties of Activated Carbon

Activated carbons are made from a variety of materials including wood, lignin, bituminous coal, lignite, and petroleum residues. Granular carbons produced from medium volatile bituminous coal or lignite have been most widely applied to the treatment of wastewater. Activated carbons have specific properties depending on the material source and the mode of activation. Property standards are helpful in specifying carbons for a specific application. In general, granular carbons from bituminous coal have a small pore size, a large surface area, and the highest bulk density. Lignite carbon has the largest size, least surface area, and the lowest bulk density. Adsorptive capacity is the effectiveness of the carbon in removing desired constituents such as COD, color, phenol, etc., from the wastewater. Several tests have been employed to characterize adsorptive capacity. The phenol number is used as an index of a carbon’s ability of activated carbon to adsorb low-molecular-weight substances (micro pores having an effective radius of less than 2 μm) while the molasses number relates to the carbon's ability to adsorb high-molecular-weight substances (pores ranging from 1 to 50 μm). In general, high iodine numbers will be most effective on wastewaters with predominantly low-molecular-weight organics, while high molasses numbers will be most effective for wastewaters with a dominance of high-molecular-weight organics.

2.5.3 The PACT® Process

Recently, powder activated carbon (PAC) has been added to the activated sludge process for enhanced performance (the PACT® process). The addition of PAC has several process advantages, namely, decreasing variability in effluent quality and removal by adsorption of non-degradable organics-principally, color, reduction of inhibition in industrial wastewater treatment, and removal of refractory priority pollutants. PAC offers the advantage of being able to be integrated into existing biological-treatment facilities at minimum capital cost. Since the addition of PAC enhances sludge settle ability, conventional secondary clarifiers will usually be adequate, even with high carbon dosages. In some industrial waste applications, nitrification is inhibited by the presence of toxic organics. The application of PAC has been shown to reduce or eliminate this inhibition. Batch isotherm screening tests are used on the biological effluent in order to select the optimal carbon.

The PAC dosage and the PAC mixed liquor solids concentration are related to the sludge age:

$$X_p = \frac{X_i \theta_c}{t} \qquad (2.12)$$

in which X_p = equilibrium PAC MLSS content, mg/l

X_i = PAC dosage, mg/l

t = hydraulic retention time, d

θ_c = Solids retention time, d

The sludge age affects the PAC efficiency with higher sludge ages enhancing the organic removal per unit of carbon; affects the molecular configuration of the adsorbate based on varying biological uptake patterns and end products; and establishes the equilibrium biological solids level in the aeration basin. There is some evidence the attached biomass degrades some of the low-molecular-weight compounds that are adsorbed, as demonstrated by superior TOC removal rates for PAC when added to an aeration basin as opposed to isotherm predictions of adsorption capacity. The mechanisms felt to be responsible for this phenomena include:

1. Additional biodegradation of organics due to decreased biological toxicity or inhibition via activated carbon.
2. Degradation of normally non-degradable substances due to increased exposure time to the biomass through adsorption on the carbon. The carbon with adsorbed material remains in the system for one sludge age, typically 10 to 30 d, while without carbon the substances would remain in the system for only one hydraulic retention time, typically 6 to 36 h.
3. Substitution/adsorption phenomena, replacement of low molecular weight compounds with high-molecular-weight compounds, resulting in improved adsorption efficiency and lower toxicity.

CHAPTER 3

METHODOLOGY

3.1 Membrane Bioreactor (MBR)

3.1.1 Sampling and Preparation

Landfill leachate from municipal solid waste landfill in Kampangsan district Nakonpatom province was used as raw water in both systems. It was diluted with tap water to COD ~1,000mg/l before being fed to the reactor. The seed microorganisms used in this experiment was obtained from Techno Green (Thailand) Co., Ltd.

3.1.2 Experiment Set-up

The main schematic diagram of the experiment set up is shown Figure3.1 The rectangular reactor (25 cm x 30 cm x 60 cm) was made of transparent acrylic plastic sheet with a working volume of 40L. The membrane module was immersed in the reactor of the activated sludge system. It was manufactured by Mitsubishi Rayon Co., Ltd. and properties are pore size 0.1 μm, and surface area 0.3 m^2. It was connected to the suction pump and used a submerged pump to provide mixing in the reactor during non-aeration time. A floating valve was used to control the water level, keeping the volume constant. Air compressor with air flow rate 38 l/min and pressure 0.015 MPa operated to maintain DO at 5 to 6 mg/l.

3.1.3 Experiment Operation

At the beginning, the reactor was seeded with microorganisms from Techno Green (Thailand) Co., Ltd. The experiment started after a seeding period of three months to ensure the stable performance of the microorganisms.

The effects of cycle time of aeration and non-aeration on performance were studied as shown in Table 3.1. Solids Retention Time (SRT) in the reactor was infinity since there was no sludge wastage (except a sample for analysis) throughout the period.

The effluent sample was pumped for 10 minutes with flow rate 40 ml/min and stopped for 10 minutes (or 30 l/d including time operating and non- operating). Submerged pump with flow rate 2,000 l/h and head 2.5 m operated at the same time of suction pump for protection from membrane clogging.

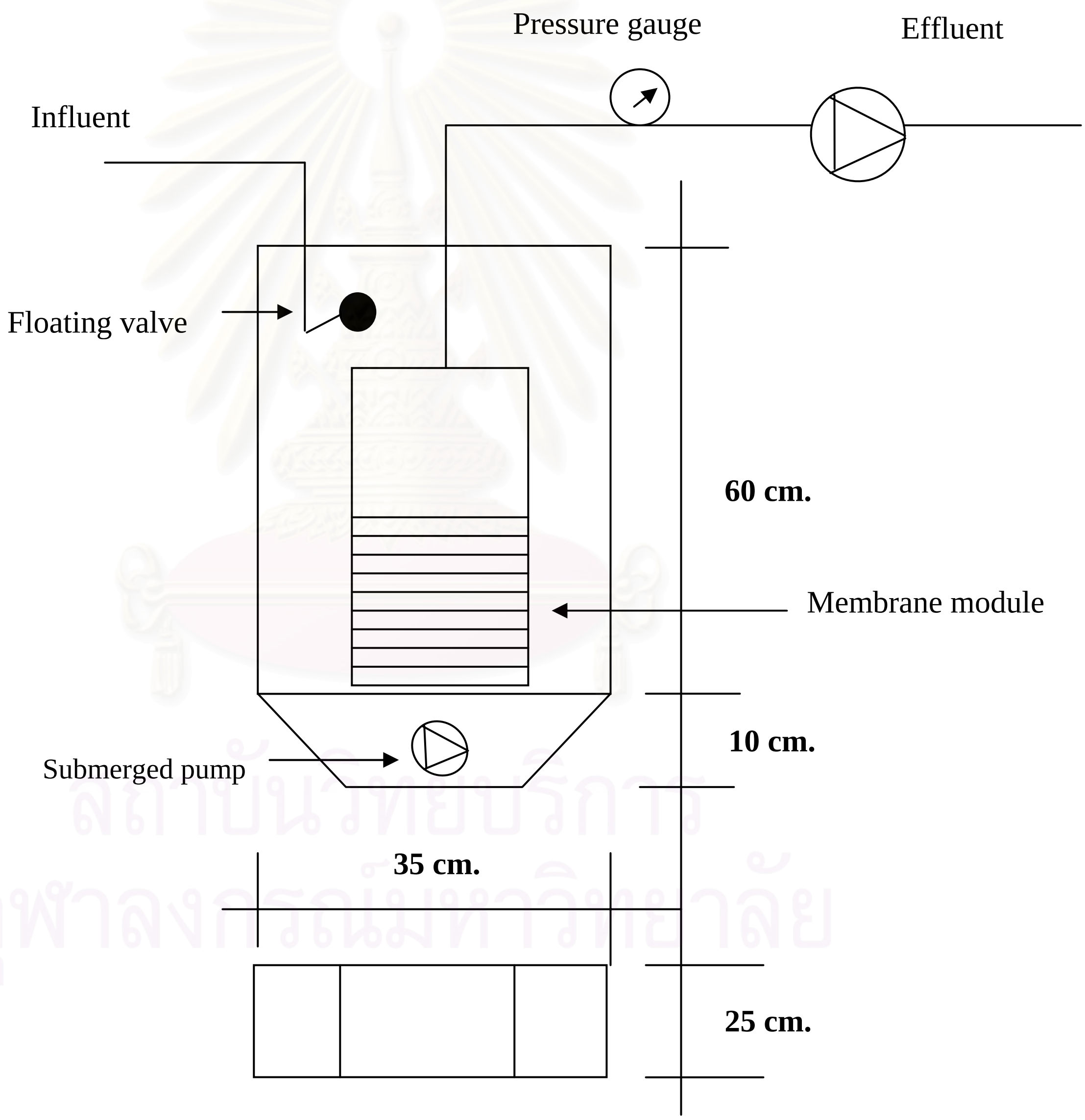

Figure 3.1 Experimental Set-up

3.2 Biological Powder Activated Carbon Membrane Bioreactor (BPAC-MBR)

3.2.1 Sampling and Preparation

The sampling and preparation in this experiment was similar to those under 3.1.1

3.2.2 Experiment Set-up

The experiment set-up in this experiment was similar to those under 3.1.2

3.2.3 Experiment Operation

3.2.3.1 Choosing an Optimum Dose of Activated Carbon

An activated carbon dose was chosen by conducting a batch adsorption experiment. Landfill leachate was diluted to COD concentration at around 1,000 mg/l. Varying activated carbon type CGC200c at 1,000, 2,000, 5,000, 10,000, 15,000, and 20,000 mg/l shook with landfill leachate at 200 rpm until it reached equilibrium of adsorption. After stopping, water was sampled for analyses COD and color, and a dose was chosen optimum to be used in BPAC-MBR.

3.2.3.2 Experiment Operation

The experiment operation in this experiment was similar to those under 3.1.3 and added activated carbon that was chosen from content 3.2.3.1

Table 3.1 The systems and operating at an intermittent aeration time

Run	System	Intermittent aeration time (minutes)
1	MBR	120-120
2	MBR	150-150
3	BPAC-MBR	120-120
4	BPAC-MBR	150-150

Table 3.2 The parameters to be analyzed, sampling point and frequency of analysis

Parameters	Frequency	Sampling points	Analytical methods
COD	Daily	Inf/Eff	Dicromate closed reflux method
Color	Daily	Inf/Eff	Su method
MLSS	Daily	Reactor	Gravimetric method
TKN	Daily	Inf/Eff	Macro-Kjeldahl method
Total phosphate	Daily	Inf/Eff	Micro-kjeldahl and calorimetric
pH	Daily	Reactor	pH meter

<u>Remark</u>: Inf = Influent ; Eff = Effluent

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Choosing an Optimum Dose of Activated Carbon

This experiment used removal efficiencies in terms of COD and color for choosing an optimum dose of activated carbon. The relationship between COD, color and dosing of activated carbon are shown in Figures 4.1, 4.2, 4.3, and 4.4. The laboratory data are shown in Table 4.1.

Table 4.1 The laboratory data for choosing an optimum dose of activated carbon

Dose of activated carbon (mg/l)	COD residual (mg/l)	Color residual (Su.)	X/M (mg COD/ mg PAC)	X/M (Su. Color/ mg PAC)	COD removal efficiency (%)	Color removal efficiency (%)
0	1028.5	136.3	-	-	0	0
100	874.3	127.7	1.542	0.086	14.99	6.31
500	754.5	120.4	0.548	0.0318	26.64	11.66
1,000	675.6	108.4	0.3529	0.0279	34.31	20.47
2,000	570.2	97.5	0.22915	0.0194	44.56	28.47
5,000	260.9	47.4	0.15352	0.01778	74.63	65.22
10,000	134.9	19.6	0.08936	0.01167	86.88	85.62
15,000	103.3	12.2	0.06168	0.008273	89.96	91.05
20,000	90.6	10.3	0.046895	0.0063	91.19	92.44

From Figures 4.1 and 4.2, it was found that Freundlich isotherm could explain the adsorption characteristics for PAC very well. From Freundlich isotherm equation; $X/M = k\,C^{1/n}$ the obtained values are as follows

Case of COD k = 3.6, n = 0.83

Case of color k = 2.9, n = 1.43

From Figures 4.3, and 4.4 show. It was found that increasing activated carbon up to 20,000 mg/l lead to increase slightly in the COD and color removal percentages. The dose of 20,000 mg/l was selected to achieve removal percentage of both COD and color higher than 90%. This dose was used further in run 3 and 4.

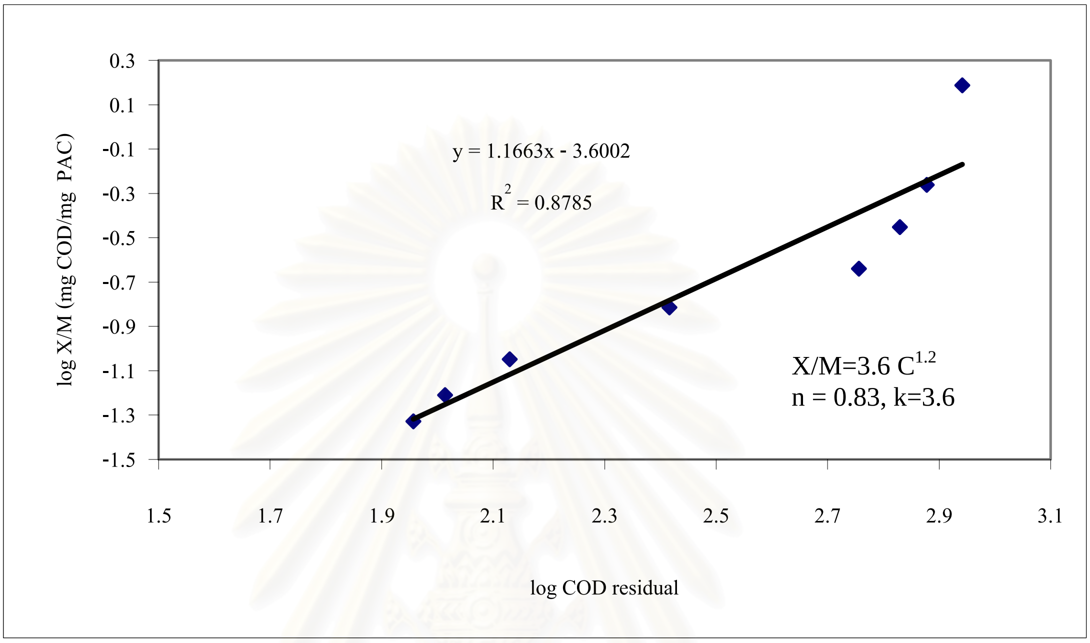

Figure 4.1 Relationship between log X/M (mg COD/ mg AC) and log COD residual

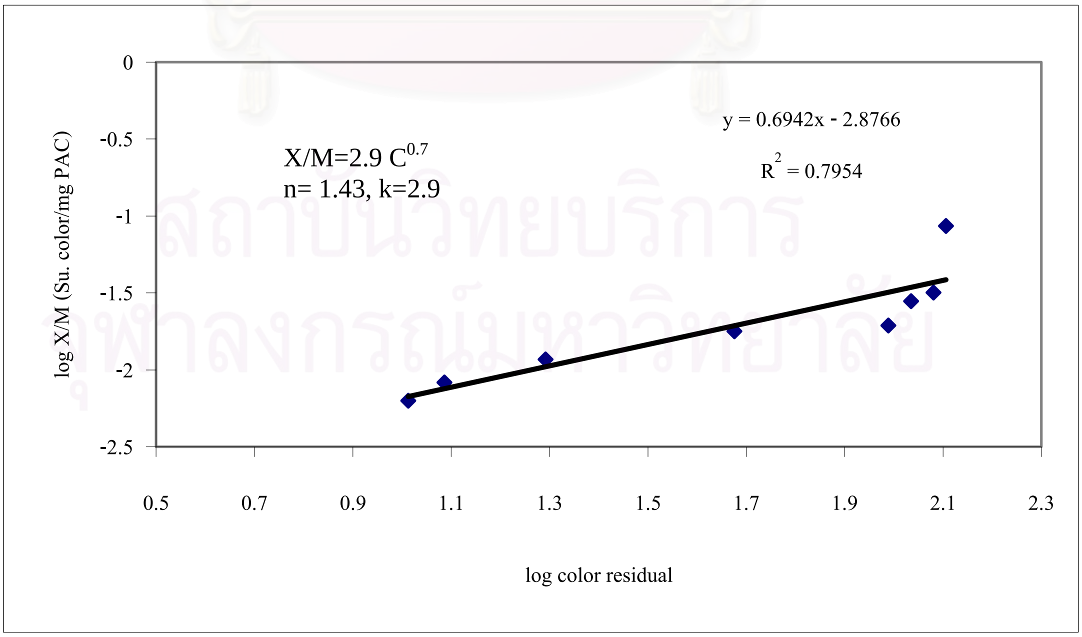

Figure 4.2 Relationship between log X/M (Su. color/ mg AC) and log color residual

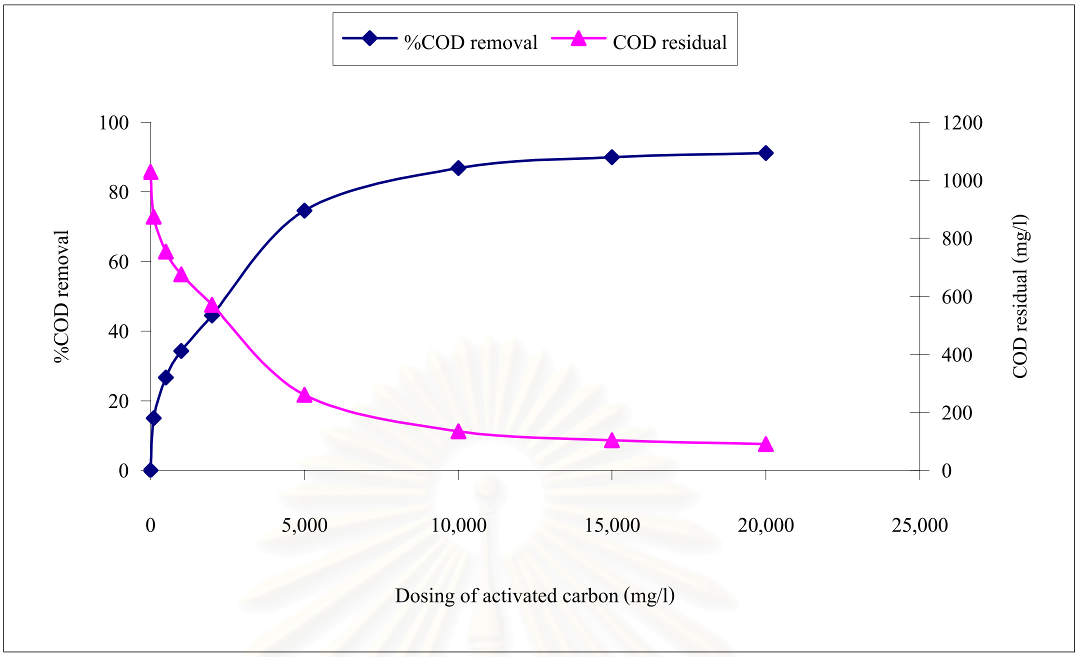

Figure 4.3 Relationship between COD and dosing of activated carbon

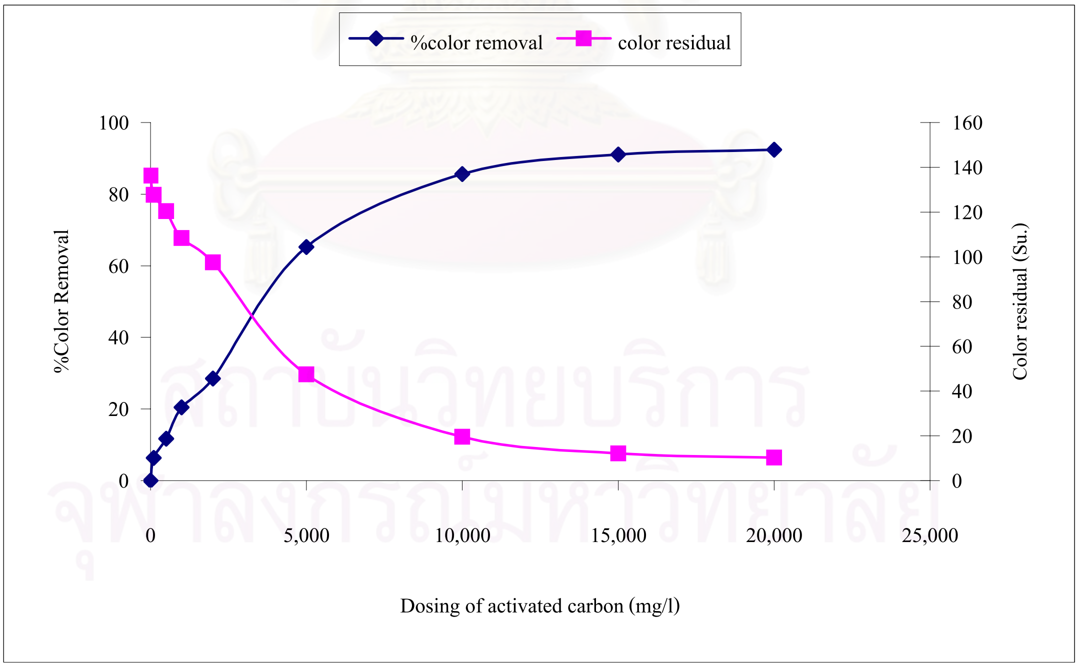

Figure 4.4 Relationship between color and dosing of activated carbon

4.2 MBR at an Intermittent Aeration Time of 120-120 minutes

4.2.1 COD Removal

Figure 4.5 shows the influent and effluent COD with a MBR intermittent time of 120-120 minutes. The influent COD was maintained at 1,000 mg/l. The removal efficiency in this run, at the beginning fluctuated in a range of 60-70% and at the steady state after 30 days the removal efficiency was stable at around 70% and the effluent COD was 300 mg/l.

4.2.2 Color Removal

Figure 4.6 shows the influent and effluent color with a MBR intermittent time of 120-120 minutes. The influent color was maintained in a range of 95-110 Su. The removal efficiency in this run, at the beginning fluctuated in a range of 37-40 % and at the steady state after 30 days the removal efficiency was stable at around 40% and the effluent color was 63 Su.

4.2.3 TKN Removal

Figure 4.7 shows the influent and effluent TKN with a MBR intermittent time of 120-120 minutes. The influent TKN was maintained in a range of 500-590 mg/l. The removal efficiency in this run, at the beginning fluctuated in a range of 88-90% and at the steady state after 30 days the removal efficiency was stable at around 90% and the effluent TKN was 52 mg/l.

4.2.4 TP Removal

Figure 4.8 shows the influent and effluent TP with a MBR intermittent time of 120-120 minutes. The influent TP was maintained in a range of 14-16 mg/l. The removal efficiency in this run, at the beginning fluctuated in a range of 43-48% and at the steady state after 30 days the removal efficiency was stable at around 48% and the effluent TP was 8.3 mg/l.

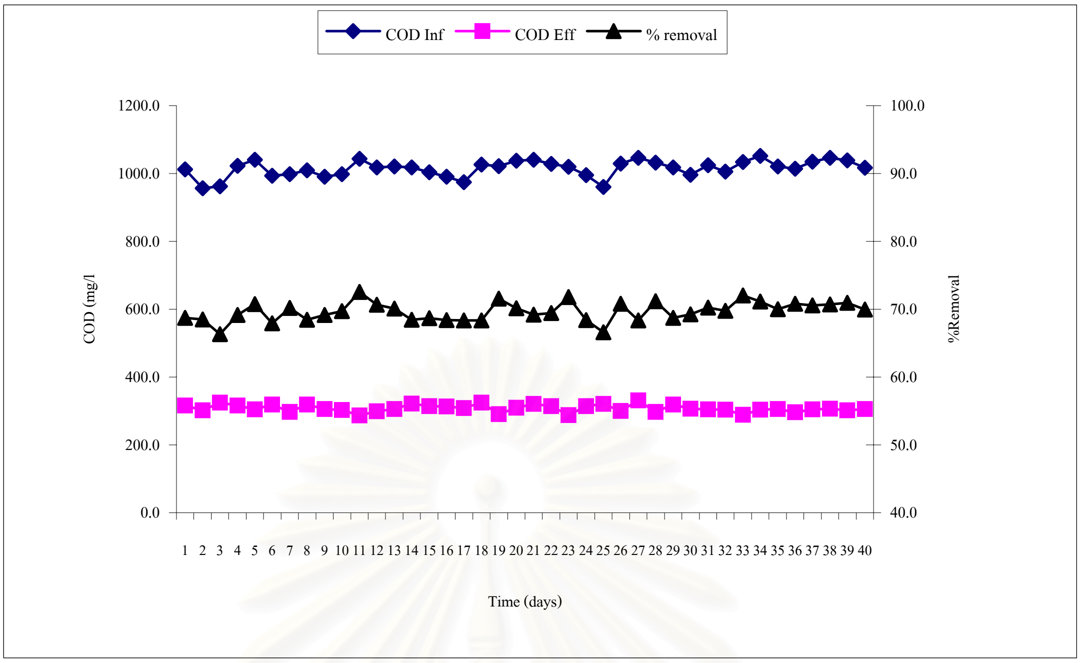

Figure 4.5 Variation of COD removal with time in MBR at an intermittent aeration time of 120-120 minutes

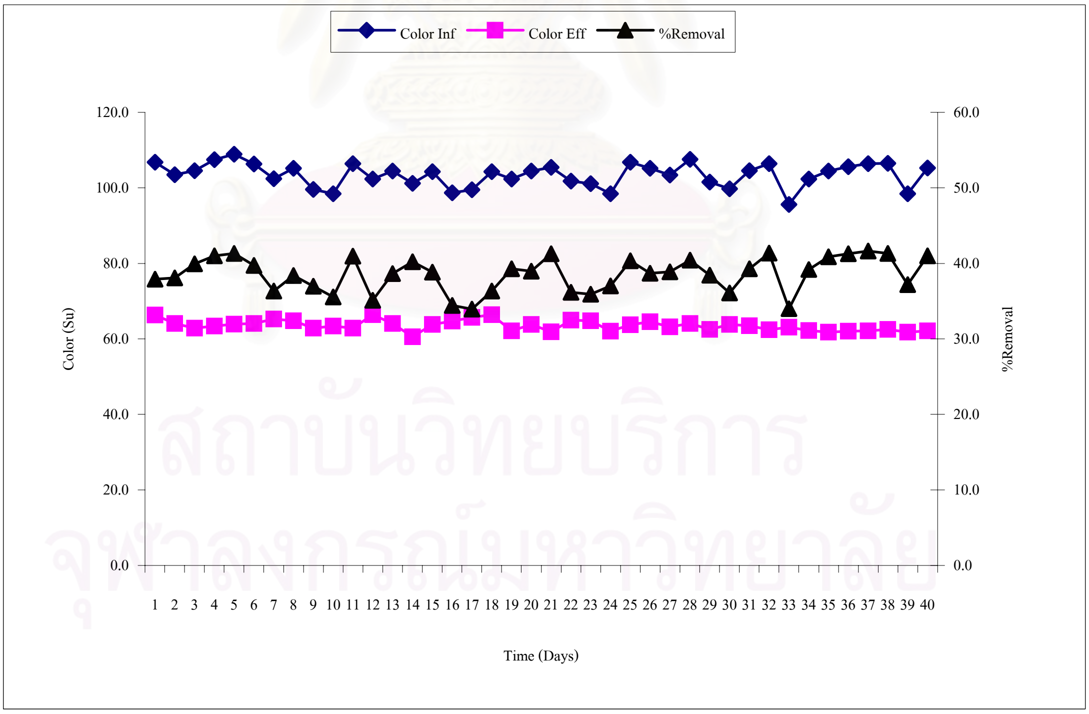

Figure 4.6 Variation of color removal with time in MBR at an intermittent aeration time of 120-120 minutes

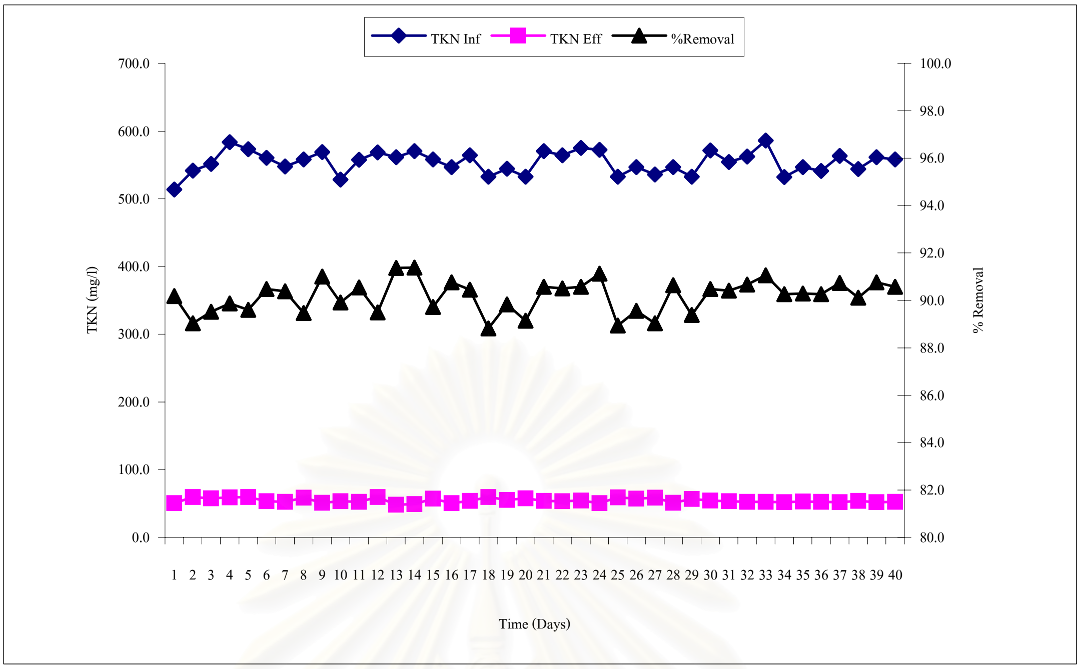

Figure 4.7 Variation of TKN removal with time in MBR at an intermittent aeration time of 120-120 minutes

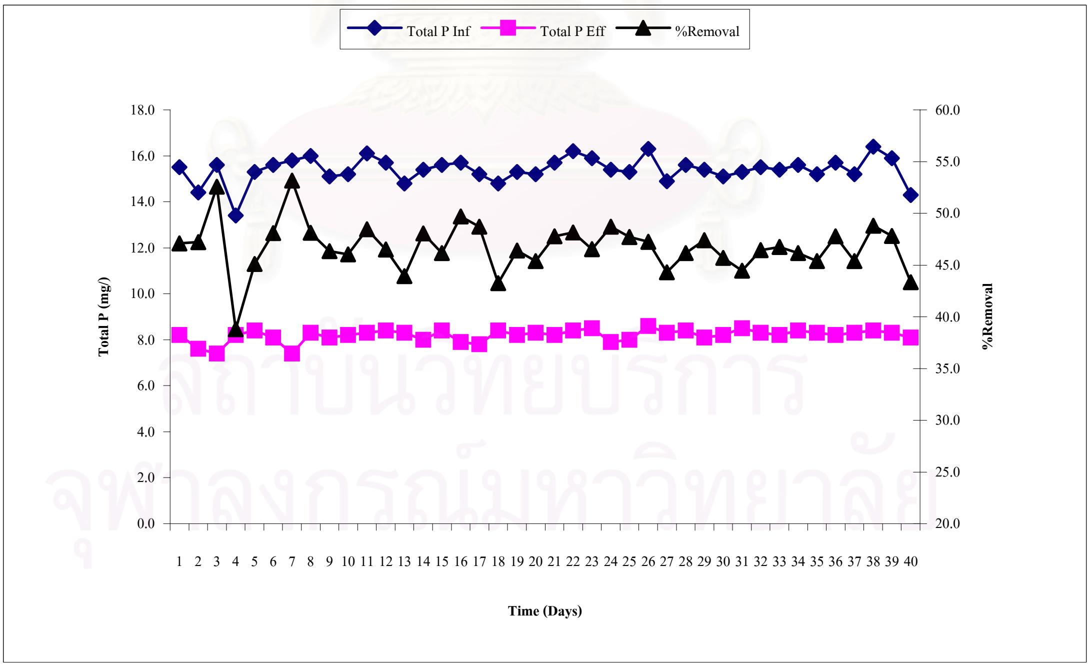

Figure 4.8 Variation of TP removal with time in MBR at an intermittent aeration time of 120-120 minutes

4.2.5 MLSS

Figure 4.9 shows the variation of biomass concentrations, at the beginning it fluctuated in a range of 3,600-4,400 mg/l, and at the steady state after 30 days MLSS stable at around 4,500 mg/l.

4.2.6 Flux and Suction Pressure

Figure 4.10 shows Flux and suction pressure. This system used flux at 0.07 m^3/m^2min with suction pressure stable at around 4.6 KPa. The suction pump operated for 10 minutes and stopped for 10 minutes. The submerged pump operated at the same time as suction pump. The submerged pump forced air across the membrane to prevent sludge from sticking to its surface.

4.2.7 Temperature and pH

Figure 4.11 shows temperature and pH. Temperature varied between at 30-35 c° because the submerged pump raised the temperature in the reactor. The pH was maintained in the range of 7.0-8.0 follow characteristic of landfill leachate.

4.2.8 DO

Figure 4.12 shows variation of DO and time at intermittent time of 120-120minutes. DO increased slowly from the time after aeration was started until 50 minutes, its value was stable at around 5.6 mg/l after 120 minutes. DO was decreased after aeration was stop. DO was equal to 0 mg/l at after 150 minutes. It shows that the oxic reaction started after aerated for 50 minutes and stopped after aerated for 120 minutes. A cycle of anoxic reaction started at 150 minutes and stopped at 240 minutes.

4.2.9 Discussions

The total soluble COD concentration of feed leachate was equal to the sum of the initially present inert soluble COD, which bypass the treatment system without any change and the readily biodegradable soluble COD. The effluent soluble COD of membrane bioreactor included the remaining readily biodegradable influent soluble COD, initial soluble inert COD in influent, and soluble inert COD from microbial activities. An intermittent aeration time was appropriated for reducing readily biodegradable together with inert COD from microbial activities.

An intermittent aeration time could improve the quality of landfill leachate. Anaerobic process involved the break down of high molecular compounds to the suitable form of molecule for using as a source of energy in aerobic process. Since an intermittent aeration time of 120-120 minutes could differentiate microorganisms in substrates from landfill leachate. The microorganisms must have a carbon source as energy for synthesis of new cellular material. Under aerobic conditions, with a DO 5.6 mg/l, the microorganisms can use free oxygen from the aerator. While under anoxic conditions, with a DO of nearly zero, these microorganisms use nitrite and nitrate as electron accepters. Concurrently, COD, TKN, and TP must be used for new cells production. COD, TKN and TP were removed from wastewater at the appropriate an intermittent aeration time. At the end of the process, treated water was discharged while the microorganisms should be maintained in the process by using a membrane for separating. The TP removal was lower efficiency than 50% because the MBR operated without sludge wastage. Moreover, the color in leachate, which represented substrates concentration, was also removed as COD was reduced. The percent removal of this experiment depended on the MLSS. During aeration period, nitrifying bacteria oxidized ammonia nitrogen to nitrite and finally nitrate. The amount of TKN lost mainly depends on the nitrifying bacteria growth and the denitrification process changed nitrate to nitrogen gases in during non-aeration. The simultaneous nitrification-dinitrification process should be the main procedure for such high levels of TKN reduction in the effluent, and as the result more than 90% of TKN could be removed. On the other hand, conventional activated sludge could partially remove TKN.

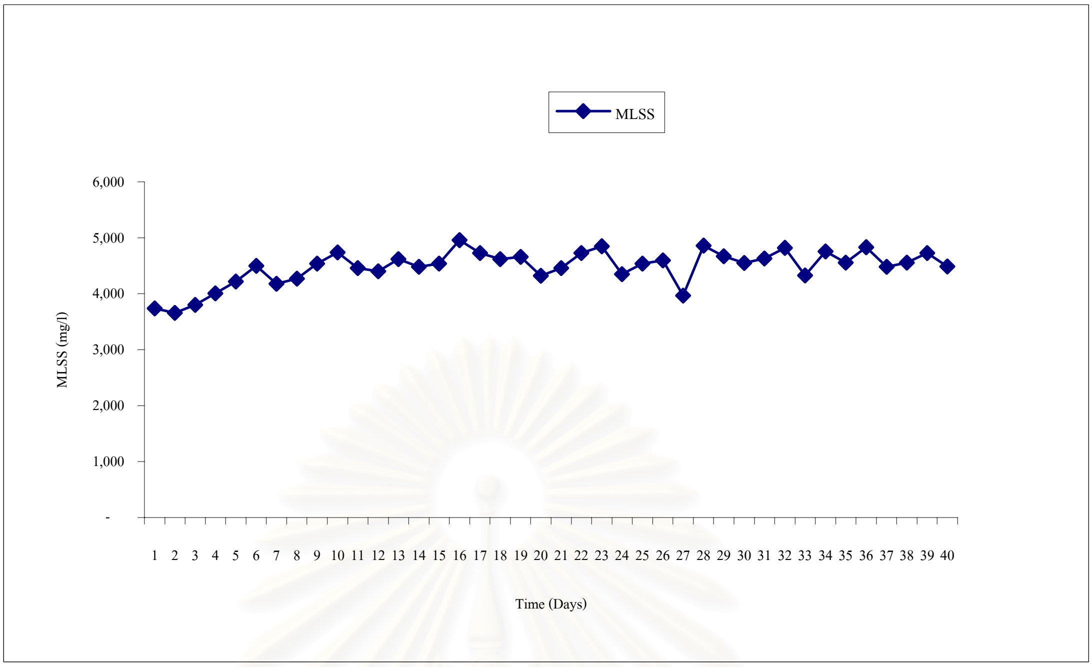

Figure 4.9 Variation of MLSS with time in MBR at an intermittent aeration time of 120-120 minutes

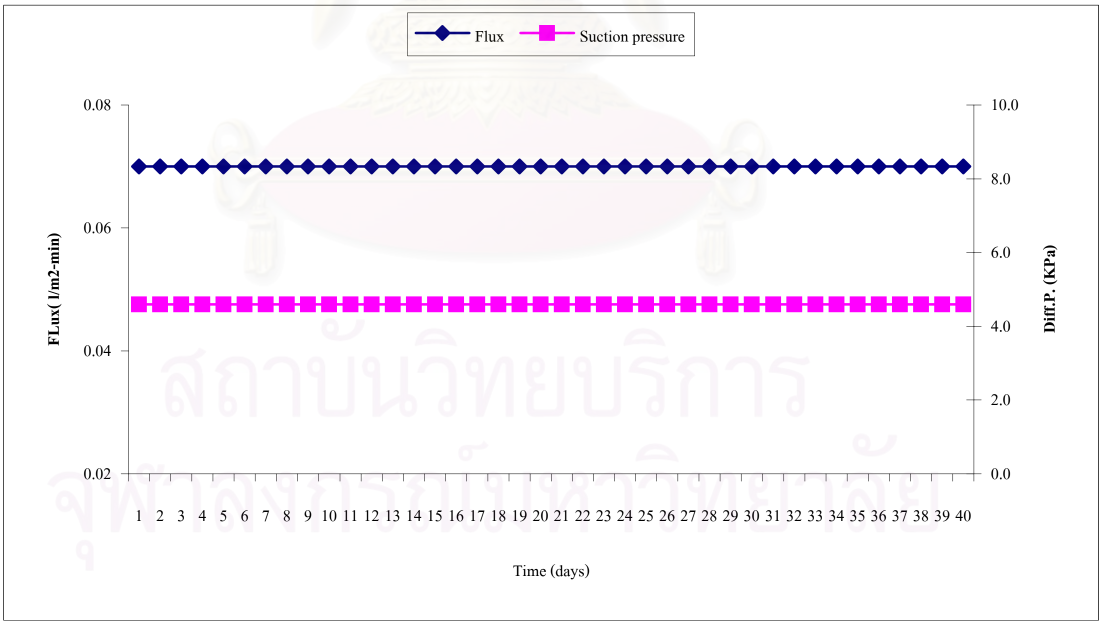

Figure 4.10 Variation of Flux and suction pressure in MBR at an intermittent aeration time of 120-120 minutes

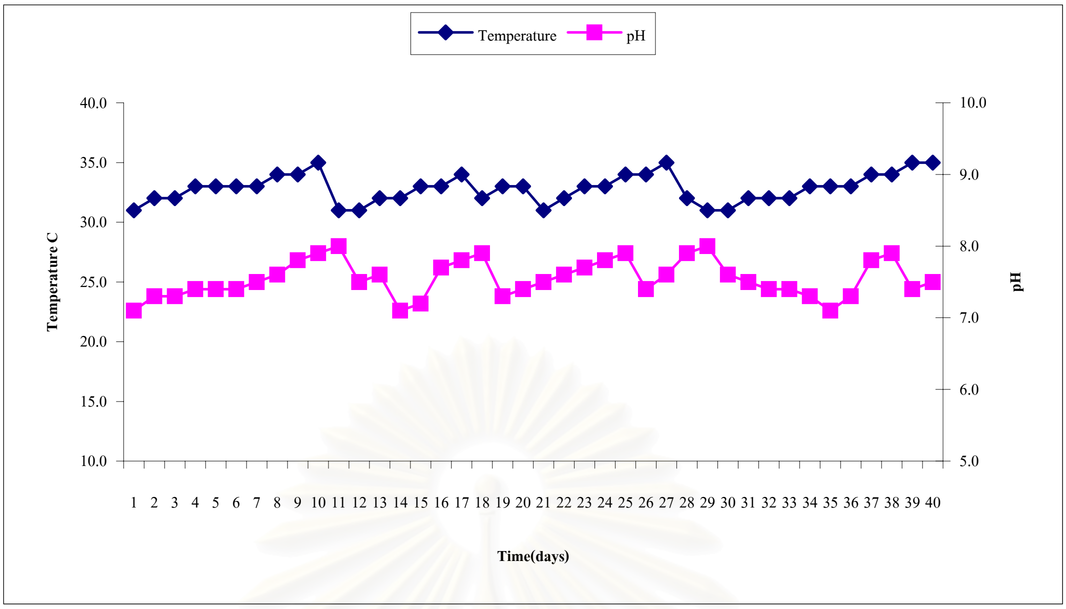

Figure 4.11 Variation of temperature and pH in MBR at an intermittent aeration time of 120-120 minutes

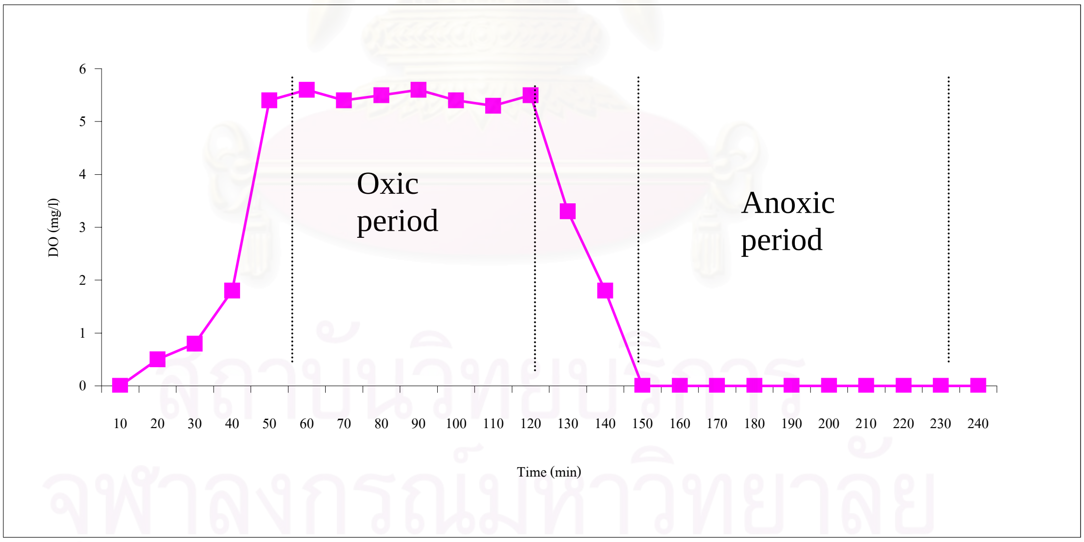

Figure 4.12 Relationship between DO and intermittent aeration time of 120-120 minutes

4.3 MBR at an Intermittent Aeration Time of 150-150 minutes

4.3.1 COD Removal

Figure 4.13 shows the influent and effluent COD with a MBR intermittent time of 150-150 minutes. The influent COD was maintained at 1,000 mg/l. The removal efficiency in this run, at the beginning fluctuated in a range of 74-76% and at the steady state after 30 days the removal efficiency was stable at around 76% and the effluent COD was 240 mg/l.

4.3.2 Color Removal

Figure 4.14 shows the influent and effluent color with a MBR intermittent time of 150-150 minutes. The influent color was maintained in a range of 104-106 Su. The removal efficiency in this run, at the beginning fluctuated in a range of 56-60 % and at the steady state after 30 days the removal efficiency was stable at around 60% and the effluent color was 42 Su.

4.3.3 TKN Removal

Figure 4.15 shows the influent and effluent TKN with a MBR intermittent time of 150-150 minutes. The influent TKN was maintained in a range of 530-550 mg/l. The removal efficiency in this run, at the beginning fluctuated in a range of 92-94% and at the steady state after 30 days the removal efficiency was stable at around 94% and the effluent TKN was 33 mg/l.

4.3.4 TP Removal

Figure 4.16 shows the influent and effluent TP with a MBR intermittent time of 150-150 minutes. The influent TP was maintained in a range of 12-16 mg/l. The removal efficiency in this run, at the beginning fluctuated in the range of 53-60% and at the steady state after 30 days the removal efficiency was stable at around 60% and the effluent TP was 6.3 mg/l.

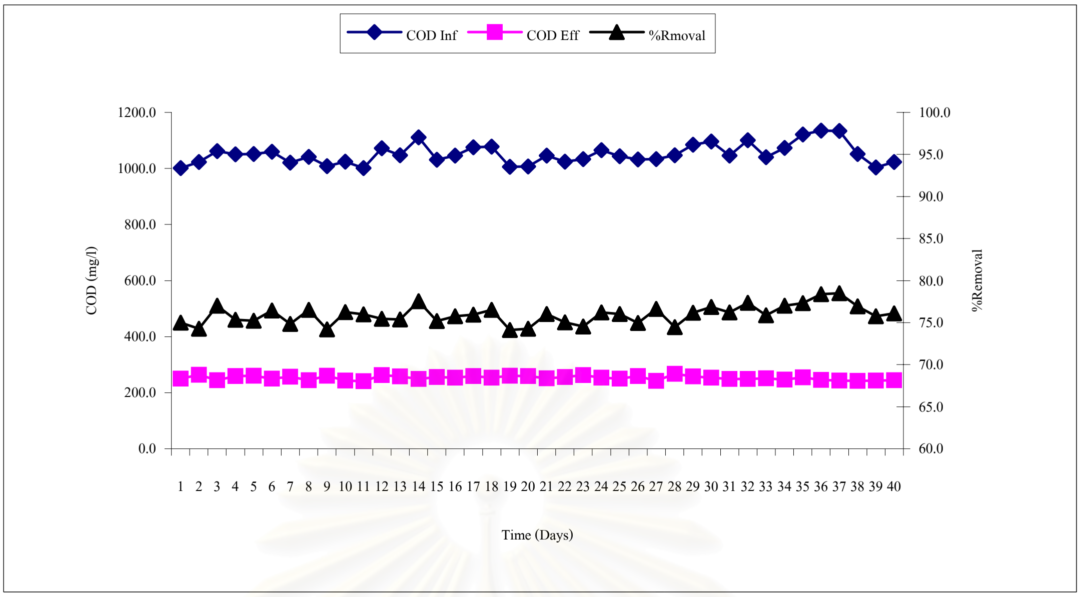

Figure 4.13 Variation of COD removal with time in MBR at an intermittent aeration time of 150-150 minutes

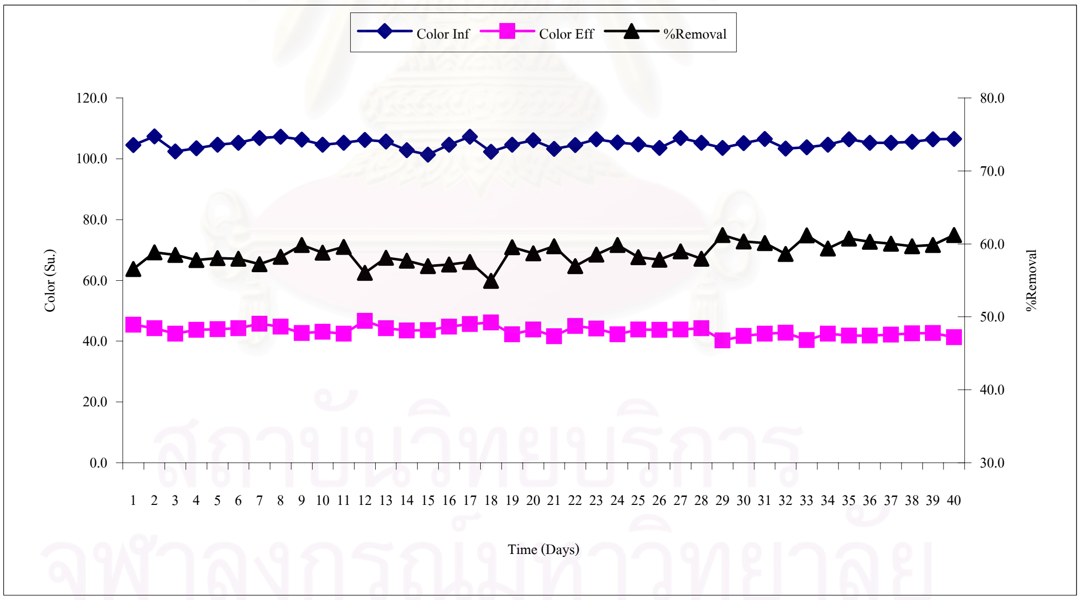

Figure 4.14 Variation of color removal with time in MBR at an intermittent aeration time of 150-150 minutes

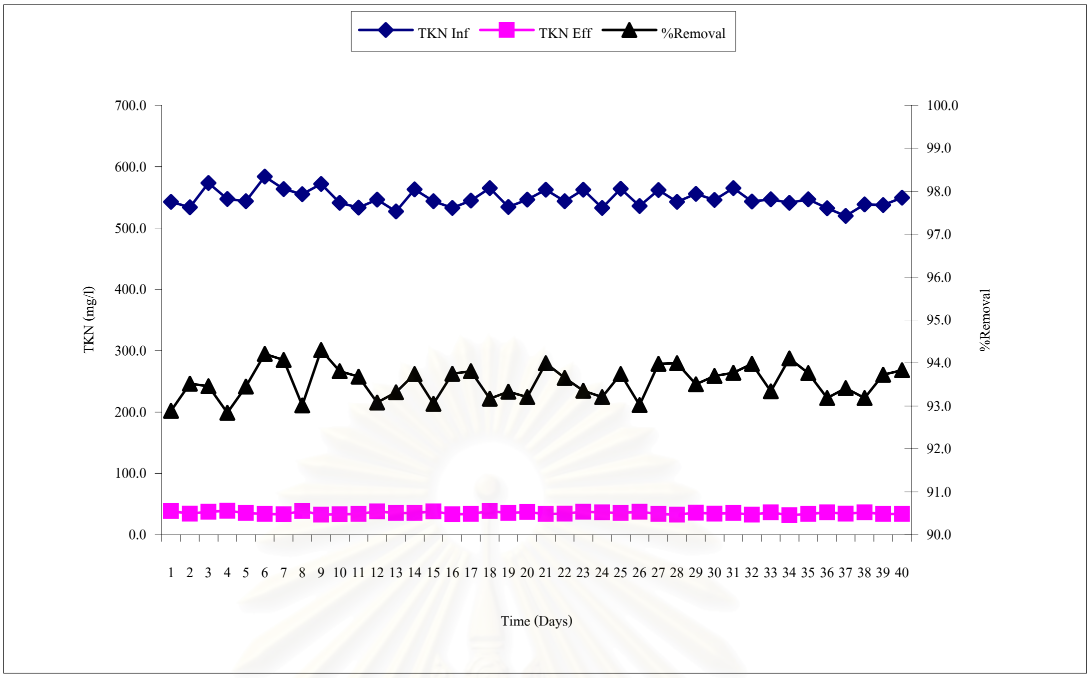

Figure 4.15 TKN removal with time in MBR at an intermittent aeration time of 150-150 minutes

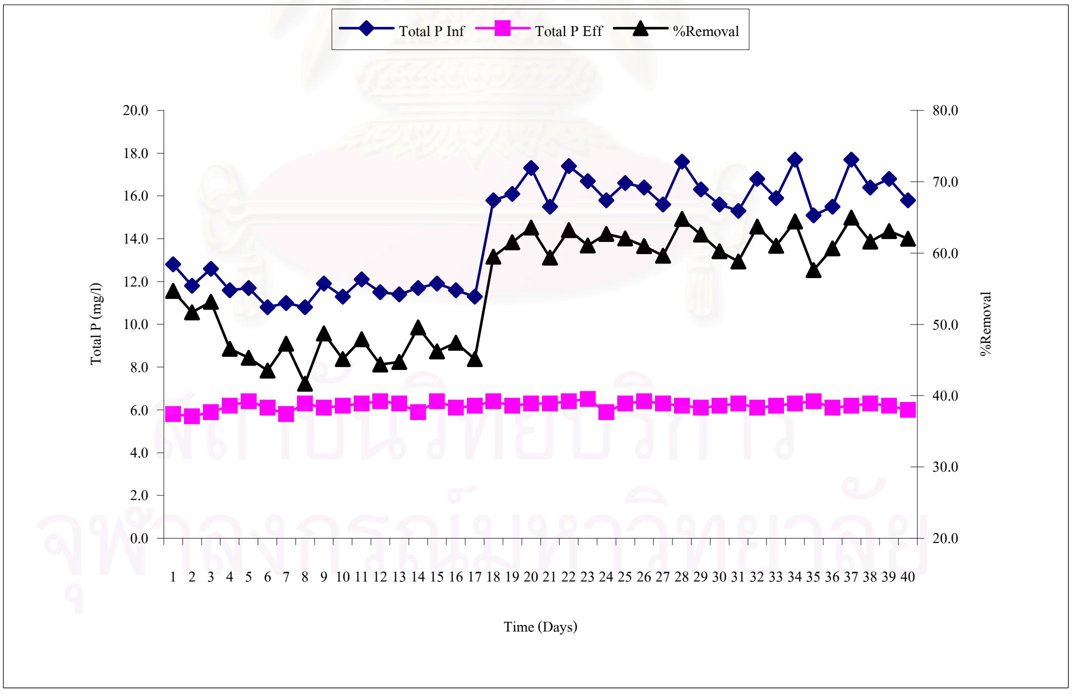

Figure 4.16 Variation of TP removal with time in MBR at an intermittent aeration time of 150-150 minutes

4.3.5 MLSS

Figure 4.17 shows the variation of biomass concentrations, at the beginning it fluctuated in a range of 4,800-5,000 mg/l, and at the steady state after 30 days MLSS stable at around 5,000 mg/l.

4.3.6 Flux and Suction Pressure

Figure 4.18 shows Flux and suction pressure. This system used flux at 0.07 m^3/m^2min with suction pressure stable at around 4.9 KPa. The suction pump operated for 10 minutes and stopped for 10 minutes. The submerged pump operated at the same time as suction pump. The submerged pump forced air across the membrane to prevent sludge from sticking to its surface.

4.3.7 Temperature and pH

Figure 4.19 shows temperature and pH. Temperature varied between at 30-35 c° because the submerged pump raised the temperature in the reactor. The pH was maintained in the range of 7.0-8.0 follow characteristic of landfill leachate.

4.3.8 DO

Figure 4.20 shows variation of DO and time at intermittent time of 150-150minutes. DO increased slowly from the time after aeration was started until 50 minutes, its value was stable at around 5.6 mg/l after 150 minutes. DO was decreased after aeration was stop. DO was equal to 0 mg/l at after 180 minutes. It shows that the oxic reaction started after aerated for 50 minutes and stopped after aerated for 150 minutes. A cycle of anoxic reaction started at 180 minutes and stopped at 300 minutes.

4.3.9 Discussions

The comparison of an intermittent aeration time of 150-150 minutes and 120-120 minutes, the percent removal of substrates at an intermittent aeration time 150-150 minutes was more than 120-120 minutes.

The microorganisms had a longer intermittent aeration time for using more substrates than in a short intermittent aeration time. The reason might be that the microorganisms had a longer time for both aerobic and anaerobic period to treat readily biodegradable influent COD and to reduce soluble inert COD by microbial activities. The degradation mechanisms needed consecutive aerobic and anaerobic periods. Anaerobic process involved the break down of high molecular compounds to the suitable form of molecule for using as a source of energy in aerobic process. The longer intermittent aeration time not only resulted in the selection of the microorganisms but also led the microorganisms to be tolerated and provided better utilization. This can be explained by the fact that there were more microorganisms in MBR at an intermittent aeration time of 150-150 minutes and resulted in reduction of more substrates.

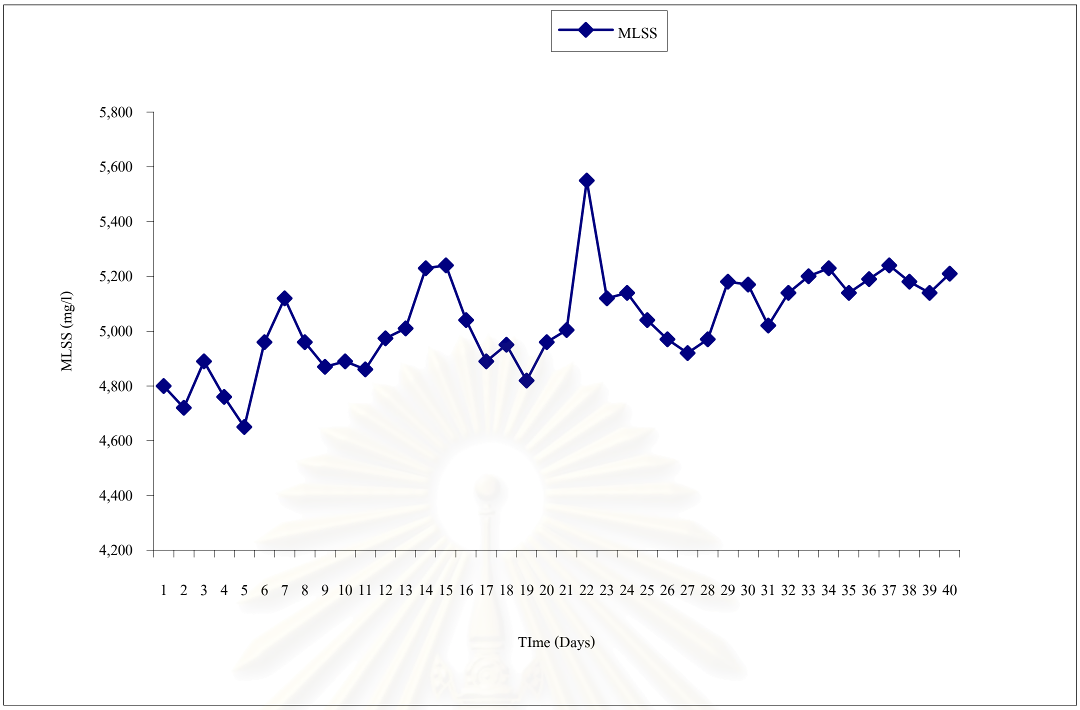

Figure 4.17 Variation of MLSS with time in MBR at an intermittent aeration time of 150-150 minutes

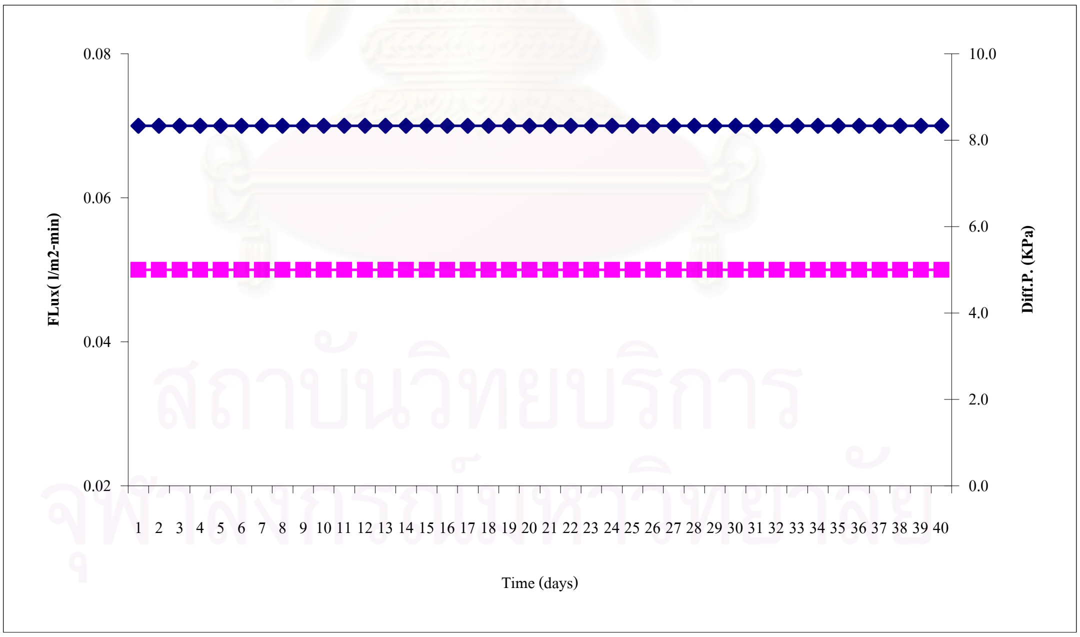

Figure 4.18 Variation of Flux and suction pressure in MBR at an intermittent aeration time of 150-150 minutes

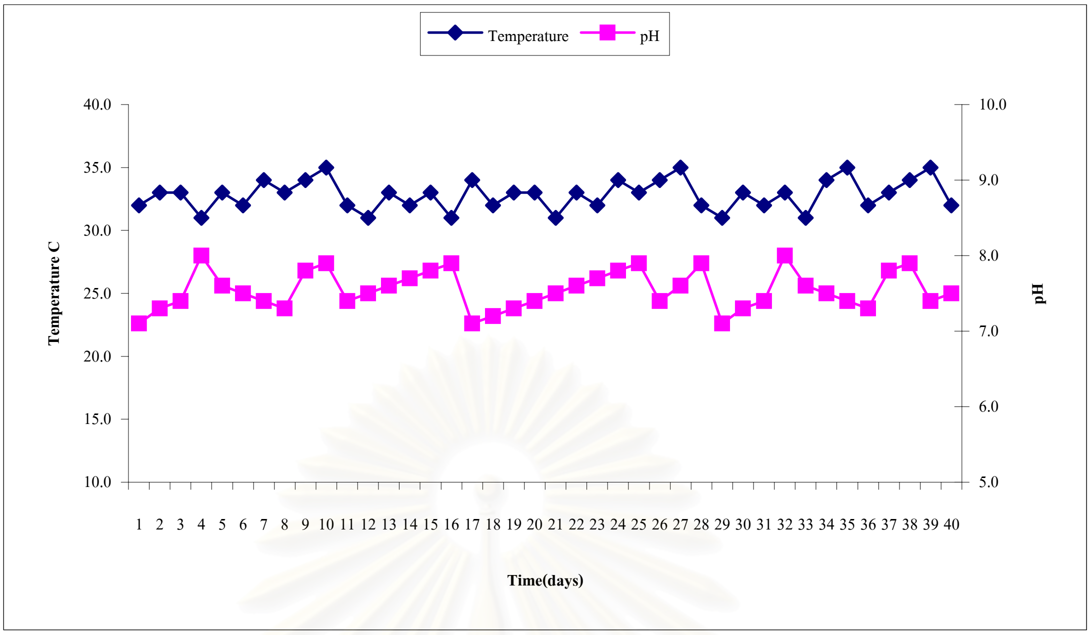

Figure 4.19 Variation of temperature and pH in MBR at an intermittent aeration time of 150-150 minutes

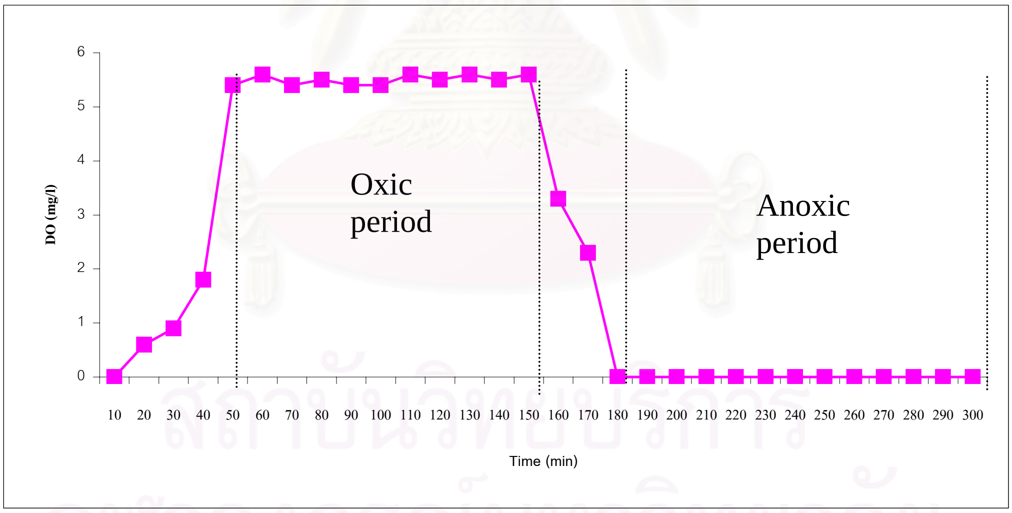

Figure 4.20 Relationship between DO and intermittent aeration time of 150-150 minutes

4.4 BPAC-MBR at an Intermittent Aeration Time of 120-120 minutes

4.4.1 COD Removal

Figure 4.21 shows the influent and effluent COD with a BPAC-MBR intermittent time of 120-120 minutes. The influent COD was maintained at 1,000 mg/l. The removal efficiency in this run, at the beginning fluctuated in a range of 77-80% and at the steady state after 30 days the removal efficiency was stable at around 80% and the effluent COD was 203 mg/l.

4.4.2 Color Removal

Figure 4.22 shows the influent and effluent color with a BPAC-MBR intermittent time of 120-120 minutes. The influent color was maintained in a range of 98-106 Su. The removal efficiency in this run, at the beginning fluctuated in a range of 68-70 % and at the steady state after 30 days the removal efficiency was stable at around 70% and the effluent color was 30 Su.

4.4.3 TKN Removal

Figure 4.23 shows the influent and effluent TKN with a BPAC-MBR intermittent time of 120-120 minutes. The influent TKN was maintained in a range of 500-570 mg/l. The removal efficiency in this run, at the beginning fluctuated in a range of 95-96% and at the steady state after 30 days the removal efficiency was stable at around 96% and the effluent TKN was 20 mg/l.

4.4.4 TP Removal

Figure 4.24 shows the influent and effluent TP with a BPAC-MBR intermittent time of 120-120 minutes. The influent TP was maintained in a range of 12-16 mg/l. The removal efficiency in this run, at the beginning fluctuated in a range of 53-60% and at the steady state after 30 days the removal efficiency was stable at around 60% and the effluent TP was 6.3 mg/l.

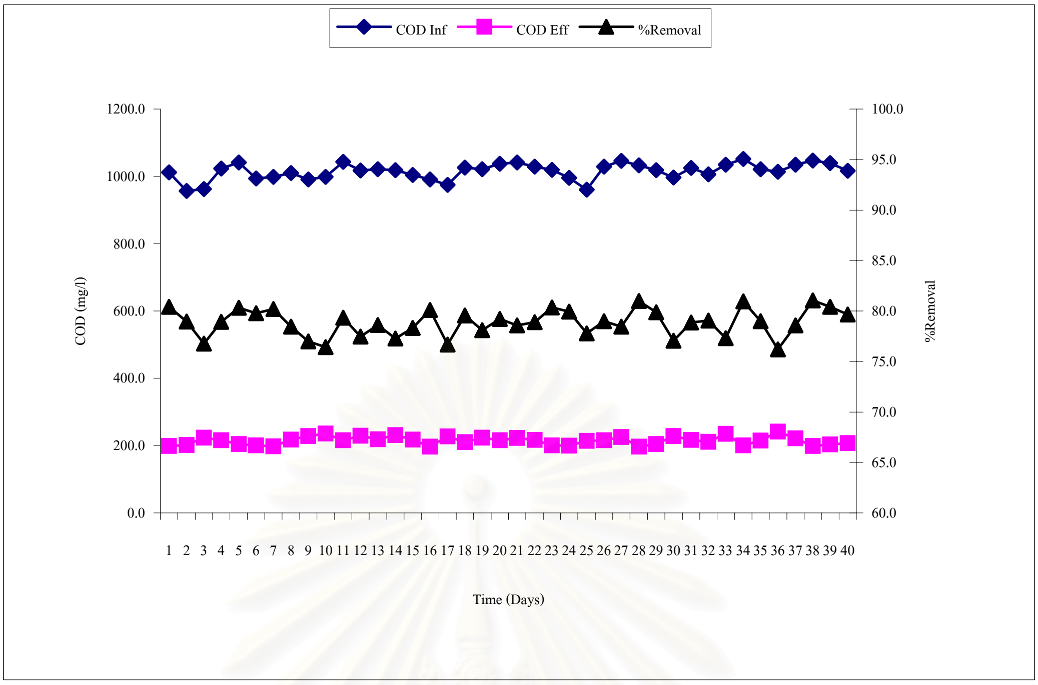

Figure 4.21 Variation of COD removal with time in BPAC-MBR at an intermittent aeration time of 120-120 minutes

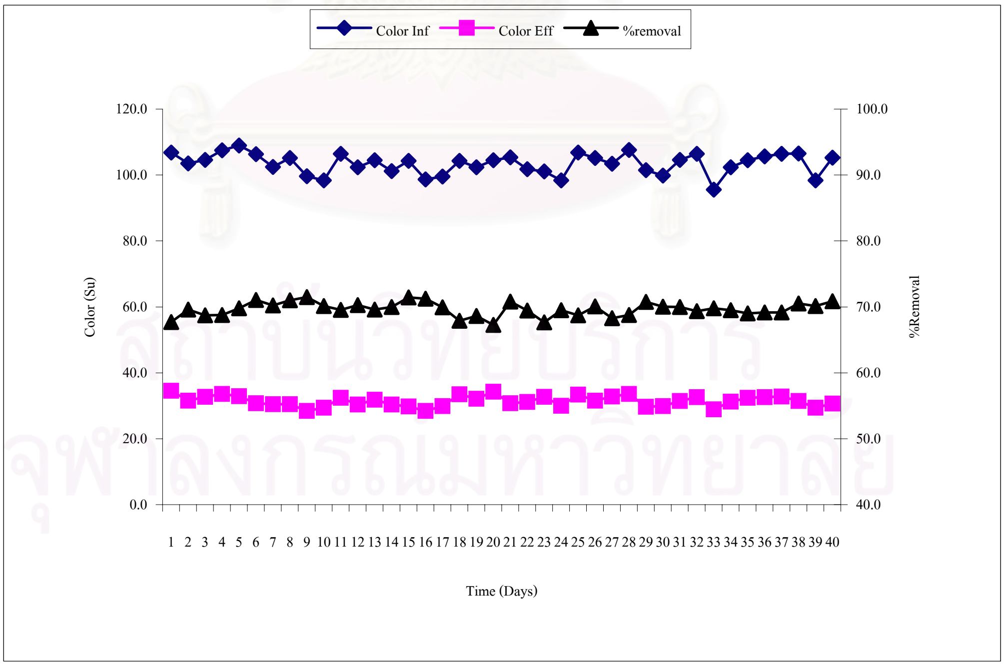

Figure 4.22 Variation of color removal with time in BPAC-MBR at an intermittent aeration time of 120-120 minutes

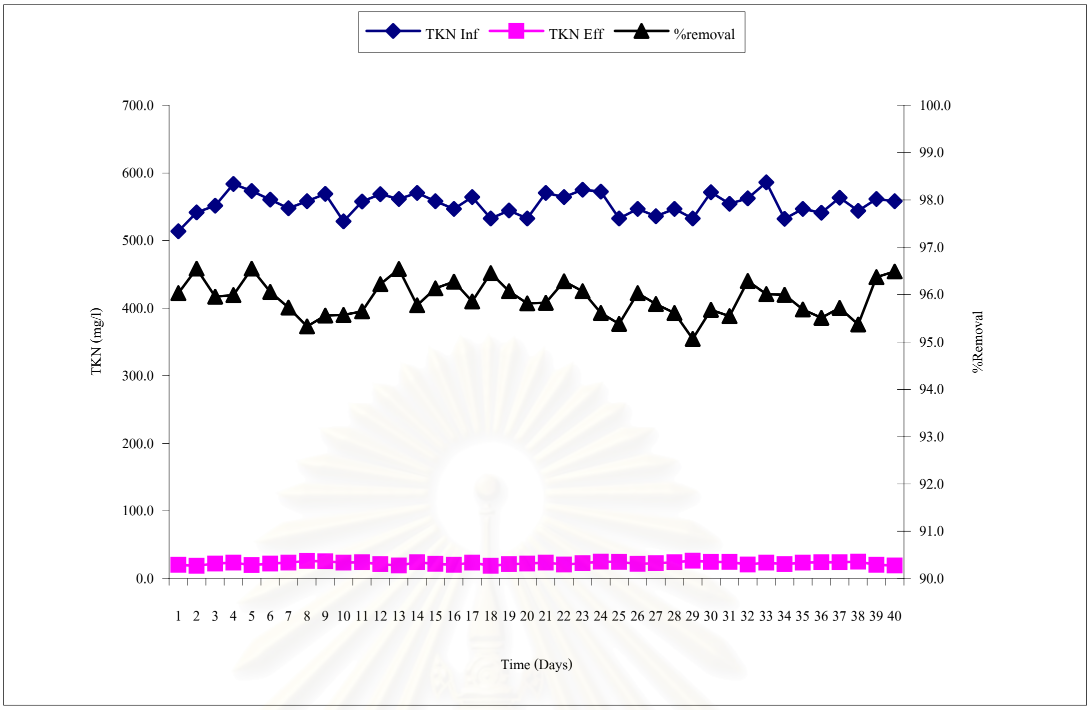

Figure 4.23 Variation of TKN removal with time in BPAC-MBR at an intermittent aeration time of 120-120 minutes

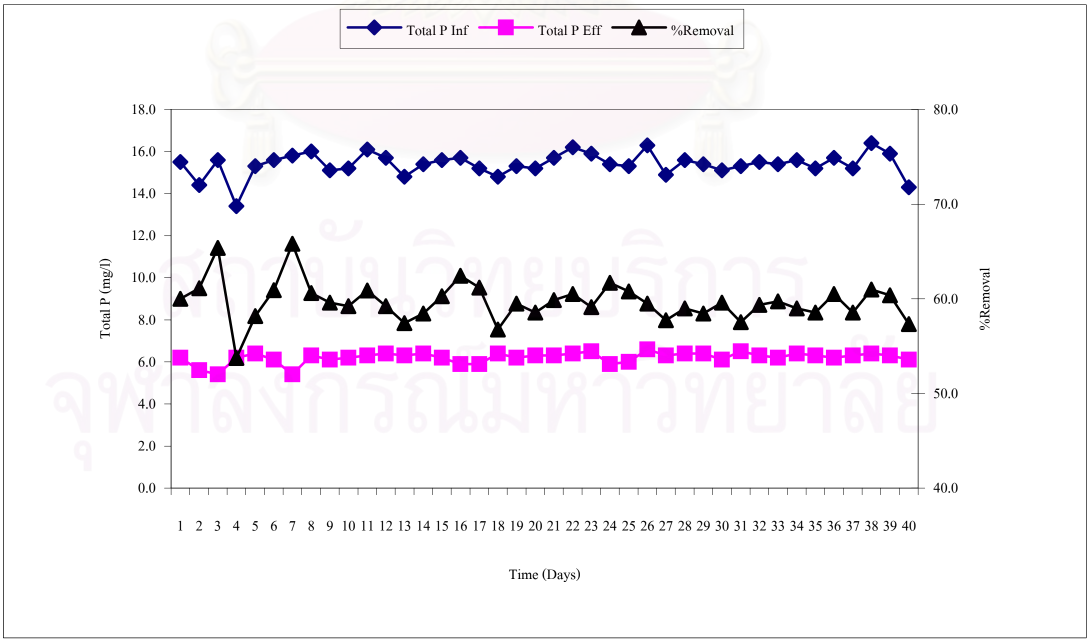

Figure 4.24 Variation of TP removal with time in BPAC-MBR at an intermittent aeration time of 120-120 minutes

4.4.5 MLSS

Figure 4.25 shows the variation of biomass concentrations, at the beginning it fluctuated in a range of 18,600-19,600 mg/l, and at the steady state after 30 days MLSS stable at around 19,600 mg/l.

4.4.6 Flux and Suction Pressure

Figure 4.26 shows Flux and suction pressure. This system used flux at 0.07 m^3/m^2min with suction pressure stable at around 5.0 kPa. The suction pump operated for 10 minutes and stopped for 10 minutes. The submerged pump operated at the same time as suction pump. The submerged pump forced air across the membrane to prevent sludge from sticking to its surface.

4.4.7 Temperature and pH

Figure 4.27 shows temperature and pH. Temperature varied between at 30-35 c° because the submerged pump raised the temperature in the reactor. The pH was maintained in the range of 7.0-8.0 follow characteristic of landfill leachate.

4.4.8 DO

Figure 4.28 shows variation of DO and time at intermittent time of 120-120minutes. DO increased slowly from the time after aeration was started until 50 minutes, its value was stable at around 5.0 mg/l after 120 minutes. DO was decreased after aeration was stop. DO was equal to 0 mg/l at after 150 minutes. It shows that the oxic reaction started after aerated for 50 minutes and stopped after aerated for 120 minutes. A cycle of anoxic reaction started at 150 minutes and stopped at 240 minutes.

4.4.9 Discussions

The comparison of the MBR and BPAC-MBR at an intermittent aeration time of 120-120 minutes, the percent removal of substrates of BPAC-MBR was more than MBR.

The activated carbon in BPAC-MBR system also helped adsorb soluble inert COD and high molecular weight in influent landfill leachate. The degradation of normally non-degradable substances in landfill leachate was due to an increase in exposure time and minimization of inhibition by adsorption process using activated carbon, while an intermittent aeration time could remove readily biodegradable influent soluble COD and soluble inert COD from microbial activities by anaerobic process involved the break down of high molecular compounds to the suitable form of molecule for using as a source of energy in aerobic process. COD, TKN, and TP must be used for new cells production. The amount of TKN lost mainly depended on the nitrifying bacteria growth in during aeration and the denitrification process changed nitrate to nitrogen gases in during non-aeration. The color in leachate was removed by activated carbon and the process of substrates removal. The resulted to BPAC-MBR system was higher substrates removal efficiency than single MBR system.

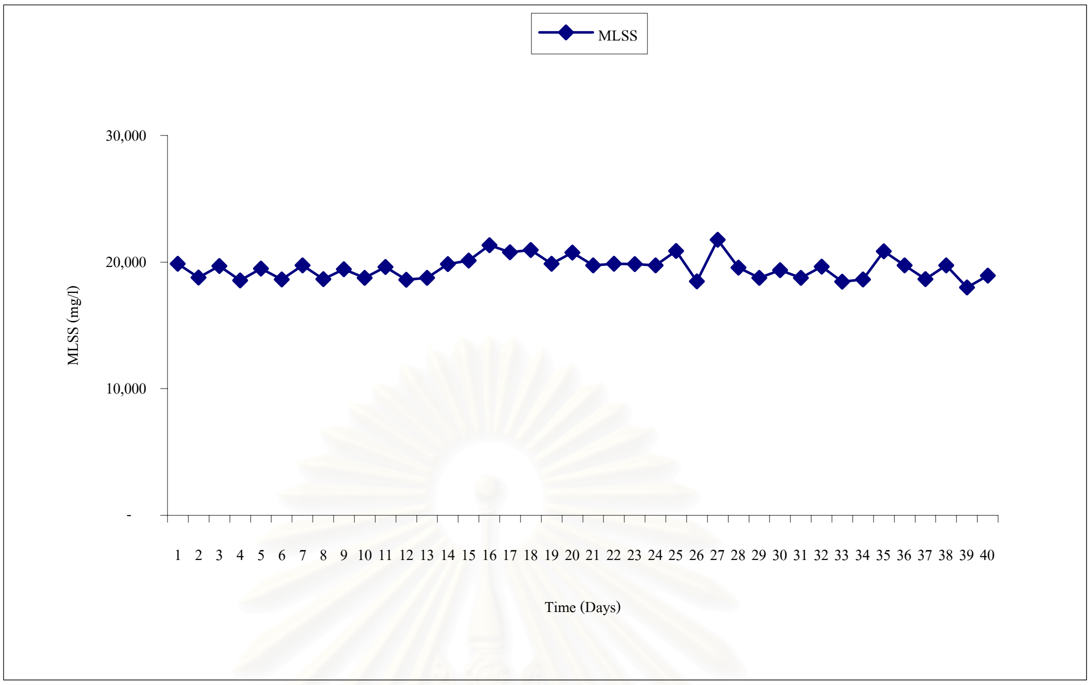

Figure 4.25 Variation of MLSS with time in BPAC-MBR at an intermittent aeration time of 120-120 minutes

Figure 4.26 Variation of Flux and suction pressure in BPAC-MBR at an intermittent aeration time of 120-120 minutes

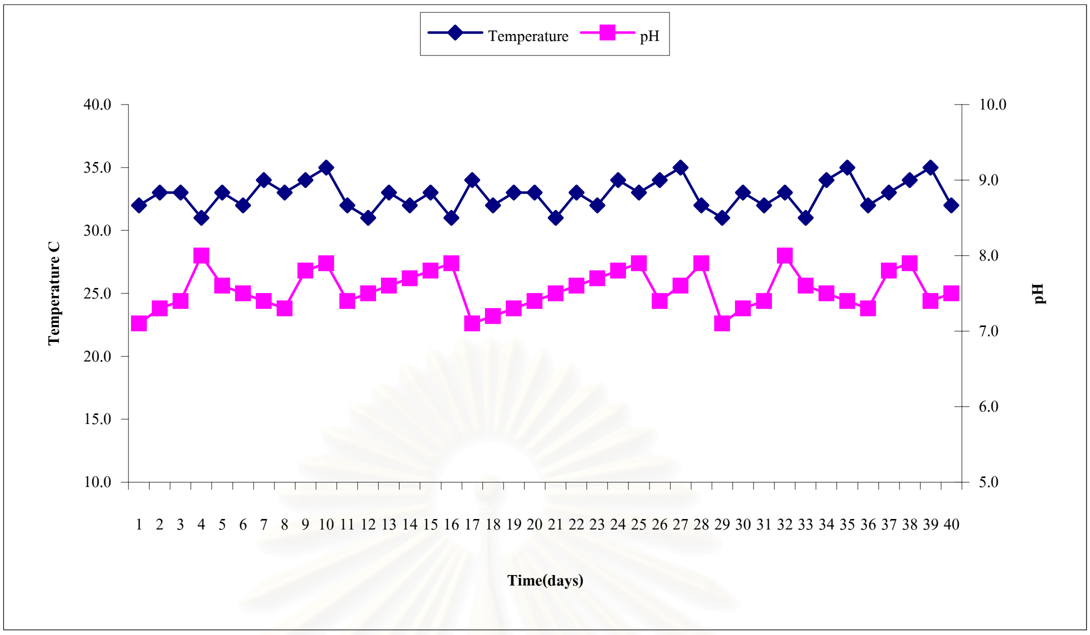

Figure 4.27 Variation of temperature and pH in BPAC-MBR at an intermittent aeration time of 120-120 minutes

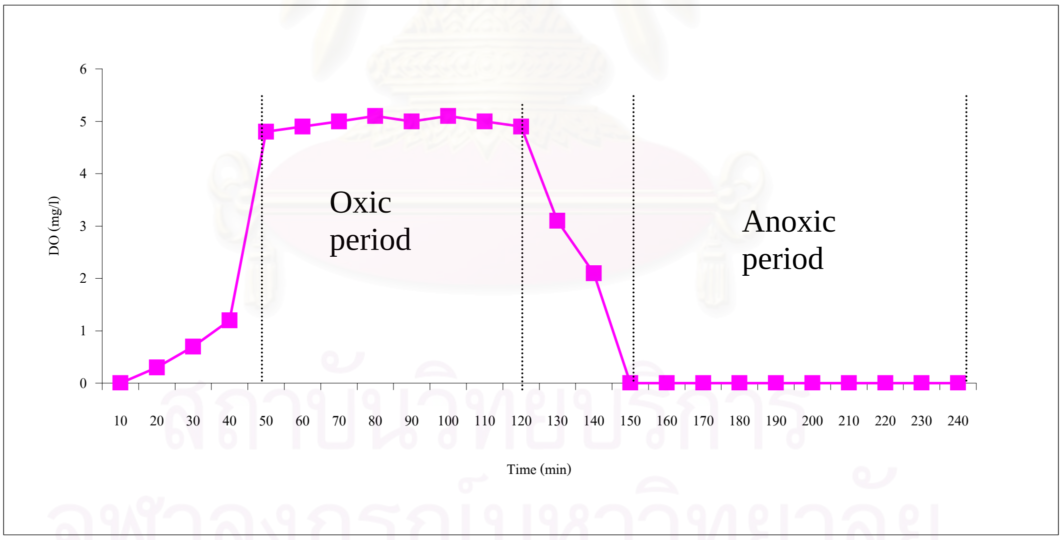

Figure 4.28 Relationship between DO and intermittent aeration time of 120-120 minutes

4.5 BPAC-MBR at an Intermittent Aeration Time of 150-150 minutes

4.5.1 COD Removal

Figure 4.29 shows the influent and effluent COD with a BPAC-MBR intermittent time of 150-150 minutes. The influent COD was maintained at 1,000 mg/l. The removal efficiency in this run, at the beginning fluctuated in a range of 81-83% and at the steady state after 30 days the removal efficiency was stable at around 83% and the effluent COD was 174 mg/l.

4.5.2 Color Removal

Figure 4.30 shows the influent and effluent color with a BPAC-MBR intermittent time of 150-150 minutes. The influent color was maintained in a range of 101-106 Su. The removal efficiency in this run, at the beginning fluctuated in a range of 83-85 % and at the steady state after 30 days the removal efficiency was stable at around 85% and the effluent color was 16 Su.

4.5.3 TKN Removal

Figure 4.31 shows the influent and effluent TKN with a BPAC-MBR intermittent time of 120-120 minutes. The influent TKN was maintained in a range of 540-570 mg/l. The removal efficiency in this run, at the beginning fluctuated in a range of 96-97% and at the steady state after 30 days the removal efficiency was stable at around 97% and the effluent TKN was 13 mg/l.

4.5.4 TP Removal

Figure 4.32 shows the influent and effluent TP with a BPAC-MBR intermittent time of 150-150 minutes. The influent TP was maintained in a range of 12-16 mg/l. The removal efficiency in this run, at the beginning fluctuated in a range of 59-70% and at the steady state after 30 days the removal efficiency was stable at around 70% and the effluent TP was 4.6 mg/l.

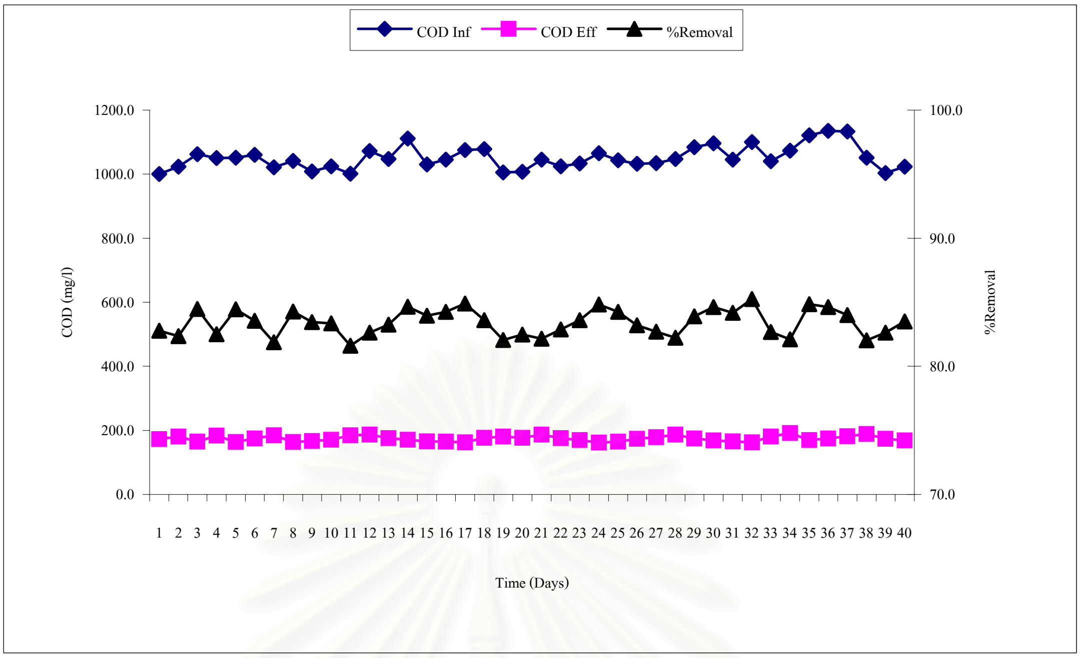

Figure 4.29 Variation of COD removal with time in BPAC-MBR at an intermittent aeration time of 150-150 minutes

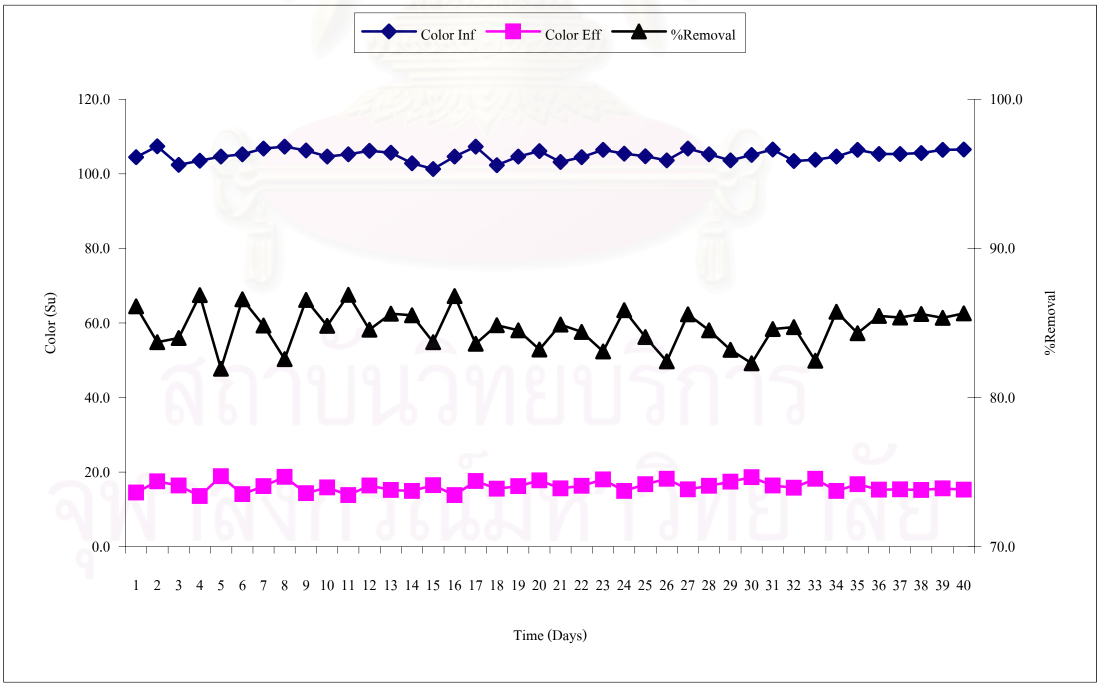

Figure 4.30 Variation of color removal with time in BPAC-MBR at an intermittent aeration time of 150-150 minutes

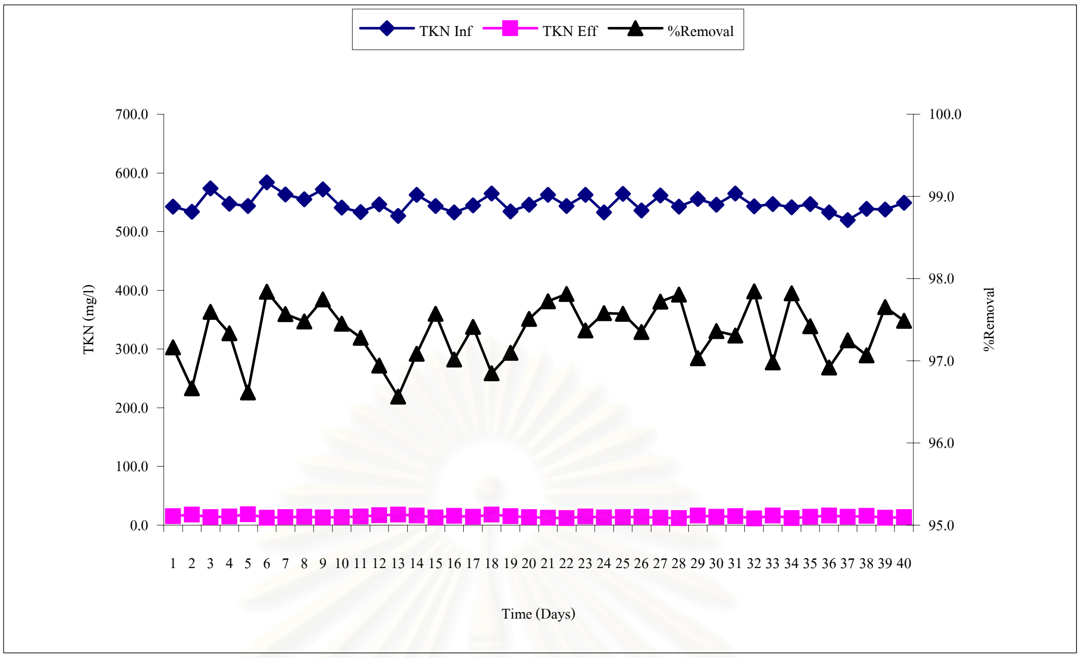

Figure 4.31 Variation of TKN removal with time in BPAC-MBR at an intermittent aeration time of 150-150 minutes

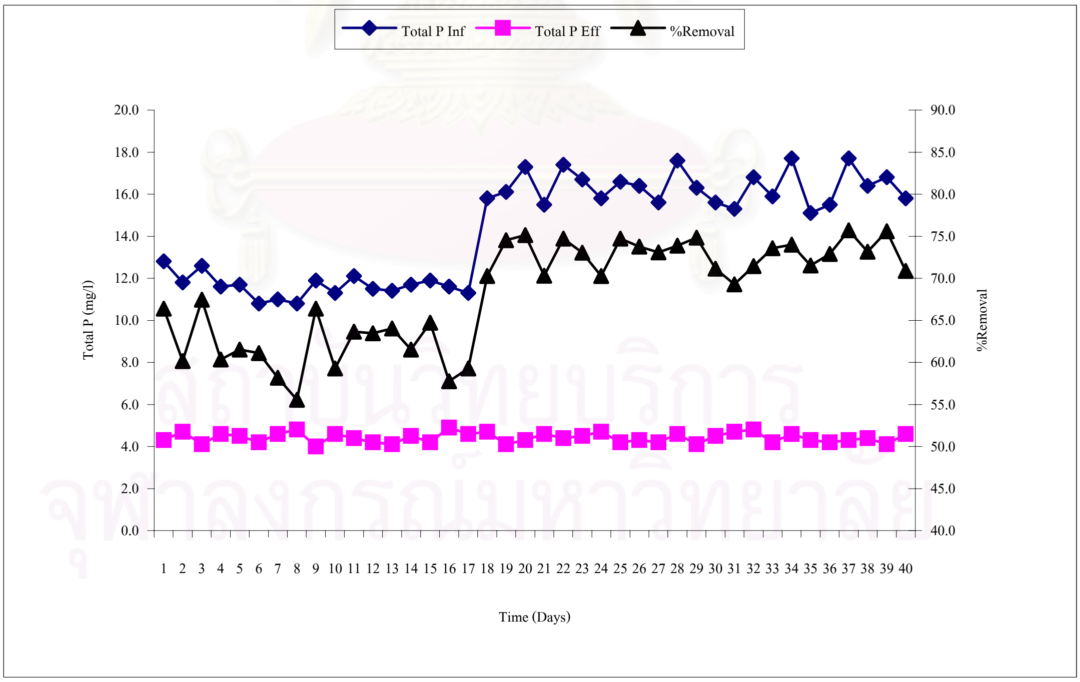

Figure 4.32 Variation of TP removal with time in BPAC-MBR at an intermittent aeration time of 150-150 minutes

4.5.5 MLSS

Figure 4.33 shows the variation of biomass concentrations, at the beginning it fluctuated in a range of 20,000-23,000 mg/l, and at the steady state after 30 days MLSS stable at around 23,000 mg/l.

4.5.6 Flux and Suction Pressure

Figure 4.34 shows Flux and suction pressure. This system used flux at 0.07 m^3/m^2min with suction pressure stable at around 5.2 KPa. The suction pump operated for 10 minutes and stopped for 10 minutes. The submerged pump operated at the same time as suction pump. The submerged pump forced air across the membrane to prevent sludge from sticking to its surface. This process had suction pressure more than intermittent aeration time of 120-120 minutes because it had higher MLSS. The high MLSS had chanced to stick on membrane.

4.5.7 Temperature and pH

Figure 4.35 shows temperature and pH. Temperature varied between at 30-35 c° because the submerged pump raised the temperature in the reactor. The pH was maintained in the range of 7.0-8.0 follow characteristic of landfill leachate.

4.5.8 DO

Figure 4.36 shows variation of DO and time at intermittent time of 150-150minutes. DO increased slowly from the time after aeration was started until 50 minutes, its value was stable at around 5.0 mg/l after 150 minutes. DO was decreased after aeration was stop. DO was equal to 0 mg/l at after 180 minutes. It shows that the oxic reaction started after aerated for 50 minutes and stopped after aerated for 150 minutes. A cycle of anoxic reaction started at 180 minutes and stopped at 300 minutes.

4.5.9 Discussions

The comparison of the MBR with BPAC-MBR at an intermittent aeration time of 150-150 minutes and comparison of BPAC-MBR at an intermittent aeration time 120-120 minutes with the BPAC-MBR at an intermittent aeration time150-150 minutes, the percent removal of substrates of BPAC-MBR was more than MBR and BPAC-MBR at an intermittent aeration time150-150 minutes was more than BPAC-MBR at an intermittent aeration time120-120 minutes. Therefore, the highest substrate removal was reached when the BPAC-MBR was performed at an intermittent aeration time 150-150 minutes.

The reason might be that the microorganisms had longer time for anoxic-oxic period to sufficiently degrade slowly biodegradable organic matters and added the activated carbon for helping adsorbed slowly biodegrade organic matters. Since the degradation mechanism needed consecutive aerobic and anaerobic periods and a longer intermittent aeration time also resulted in selection of the microorganisms that used substrates in a landfill leachate. The degradation of normally non-degradable substances was increased exposure time and reduced of inhibition by adsorption process on activated carbon. Therefore, the BPAC-MBR at an intermittent time of 150-150 minutes was highest efficiency in treating leachate from co-operate of activated carbon and a longer intermittent aeration time.

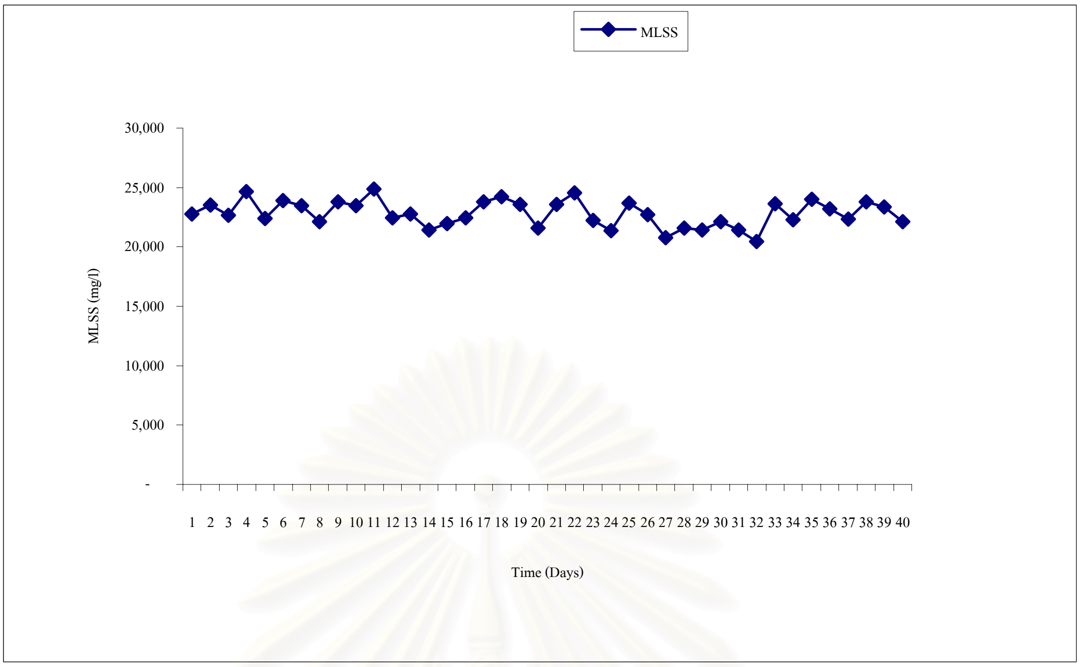

Figure 4.33 Variation of MLSS with time in BPAC-MBR at an intermittent aeration time of 150-150 minutes

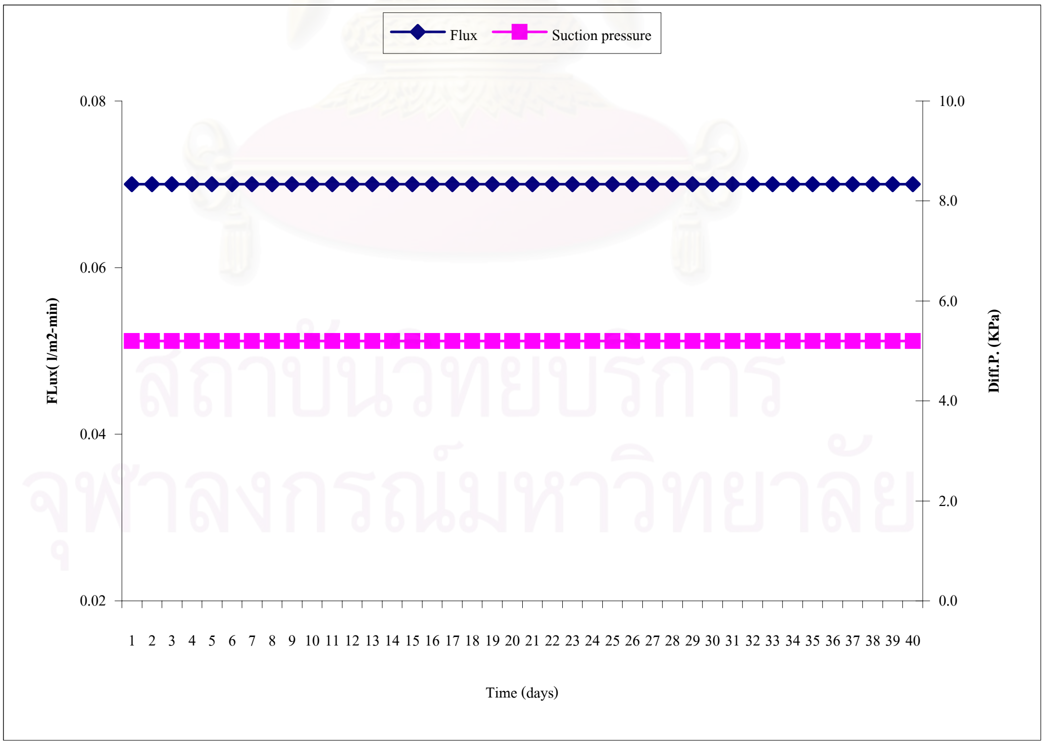

Figure 4.34 Variation of Flux and suction pressure in BPAC-MBR at an intermittent aeration time of 150-150 minutes

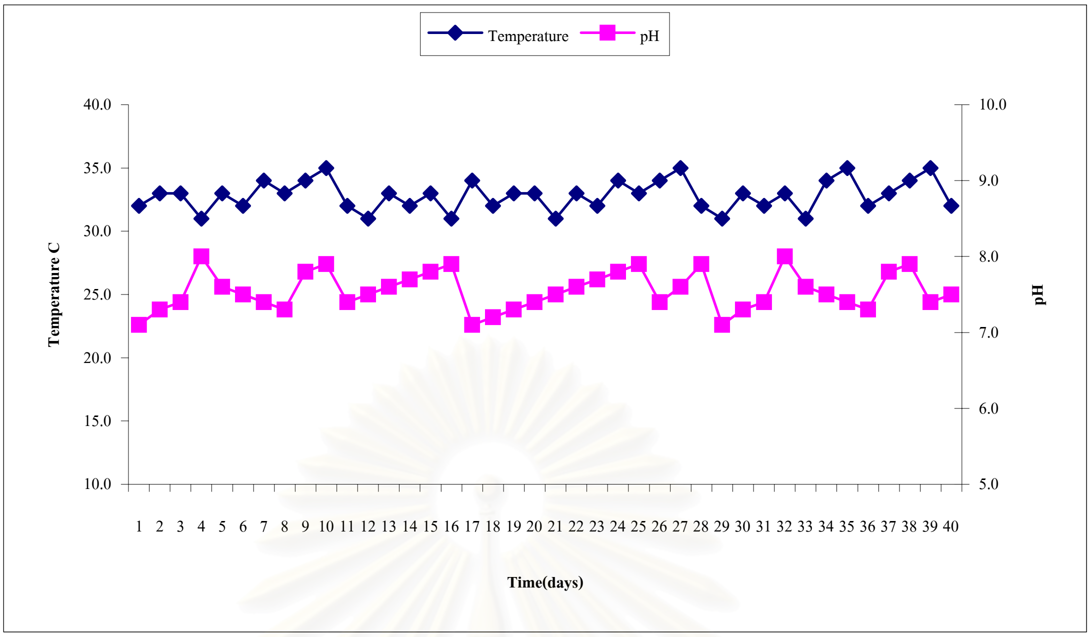

Figure 4.35 Variation of temperature and pH in BPAC-MBR at an intermittent aeration time of 150-150 minutes

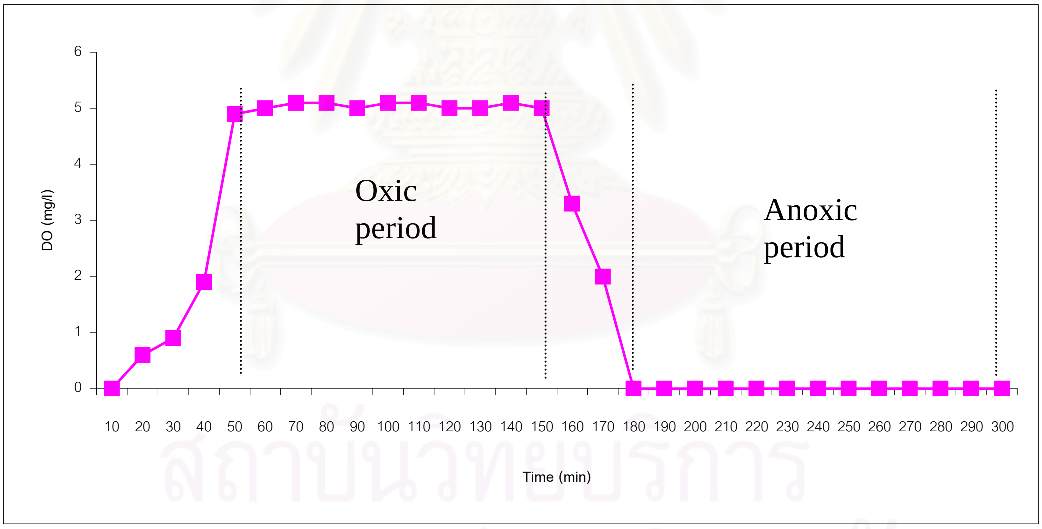

Figure 4.36 Relationship between DO and intermittent aeration time of 150-150 minutes

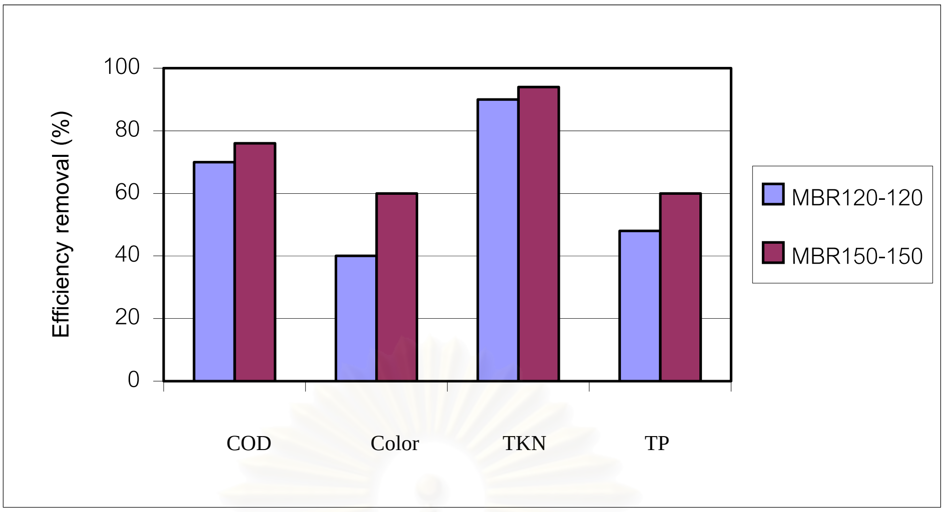

Figure 4.37 Comparison of MBR intermittent aeration time of 120-120 minutes and MBR intermittent aeration time of 150-150 minutes

4.6 Comparison of MBR at an intermittent aeration time of 120-120 minutes and MBR at an intermittent aeration time of 150-150 minutes

The removal efficiency of COD, TKN, and TP in MBR at an intermittent of 150-150 minutes a slight increase from MBR at an intermittent of 120-120 minutes but color efficiency at an intermittent of 150-150 minutes was 50% better than at an intermittent of 120-120 minutes

The COD, color, TKN, and TP removal efficiency at an intermittent aeration time 150-150 minutes were higher than 120-120 minutes because the microorganisms had a longer time for both aeration and non-aeration time in a cycle time for using more substrates than in the short intermittent aeration time. Since the degradation mechanism needed consecutive aerobic and anaerobic periods. The long intermittent aeration time not only resulted in the selection of the microorganisms but also led the microorganisms to be tolerated and provided better utilization.

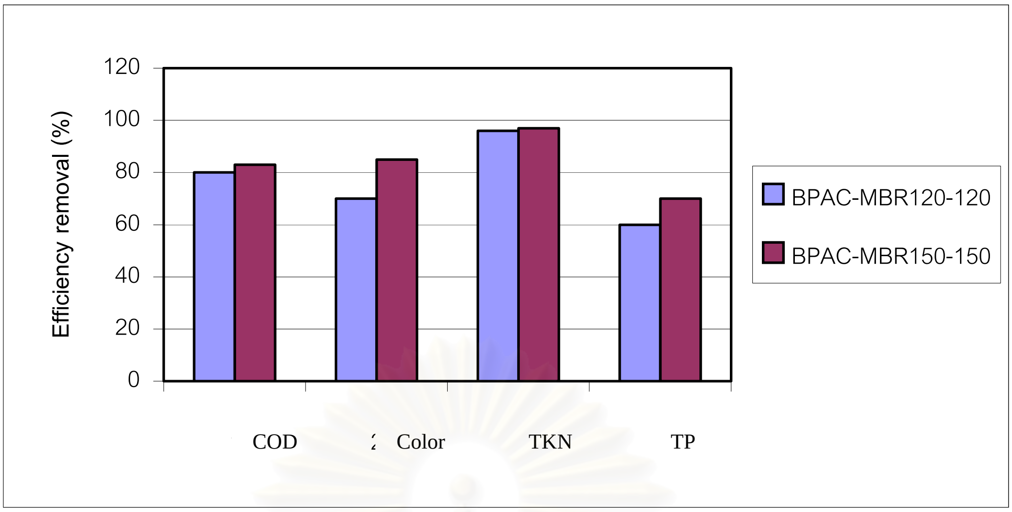

Figure 4.38 Comparison of BPAC-MBR intermittent aeration time of 120-120 minutes and BPAC-MBR intermittent aeration time of 150-150 minutes

4.7 Comparison of BPAC-MBR at an intermittent aeration time of 120-120 minutes and BPAC-MBR at an intermittent aeration time of 150-150 minutes

The efficiency removal of COD, TKN, and TP in BPAC-MBR at an intermittent of 150-150 minutes a slight increase from BPAC-MBR at an intermittent of 120-120 minutes but color efficiency at an intermittent of 150-150 minutes was 16% better than at an intermittent of 120-120 minutes

The COD, color, TKN, and TP removal efficiency at an intermittent aeration time 150-150 minutes were higher than 120-120 minutes. Since the degradation mechanism needed consecutive aerobic and anaerobic periods. The long intermittent aeration time not only resulted in the selection of the microorganisms but also led the microorganisms to be tolerated and provided better utilization. The BPAC-MBR removal efficiency higher than MBR was the reason might be helping from the activated carbon in adsorption slowly biodegrade organic matters, increased exposure time, and reduced of inhibition.

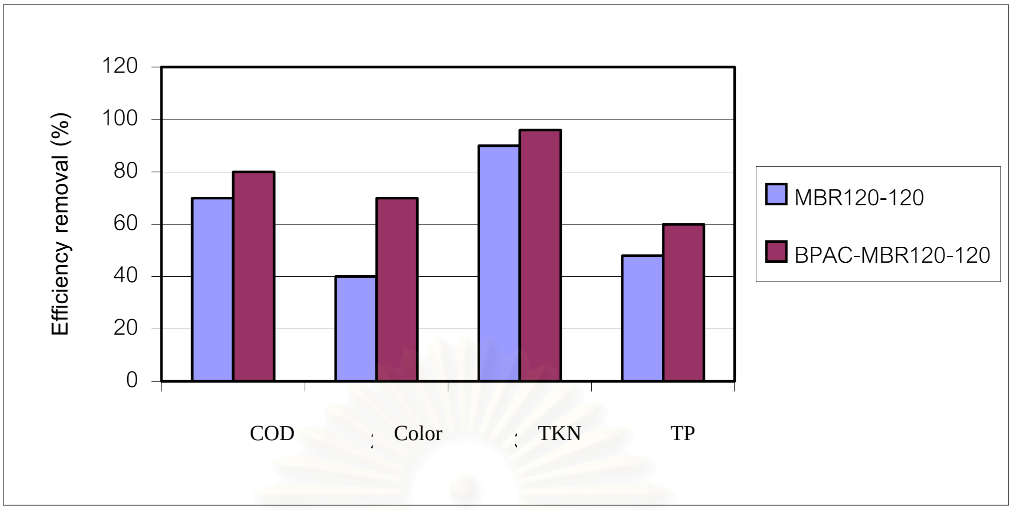

Figure 4.39 Comparison of MBR and BPAC-MBR at an intermittent aeration time of 120-120 minutes

4.8 Comparison of MBR and BPAC-MBR at an intermittent aeration time of 120-120 minutes

The removal efficiency of TKN in the BPAC-MBR a slight increase from the MBR at an intermittent aeration time of 120-120 minutes but COD, color and TP removal efficiency of BPAC-MBR were 15%, 75%, and 25% better than of MBR.

The COD, color, TKN, and TP removal efficiency in BPAC- MBR were higher than MBR. The activated carbon in BPAC-MBR system also helped adsorb slowly biodegrade organic matters, increased exposure time, and reduced inhibition, which resulted in higher substrates removal than single MBR systems.

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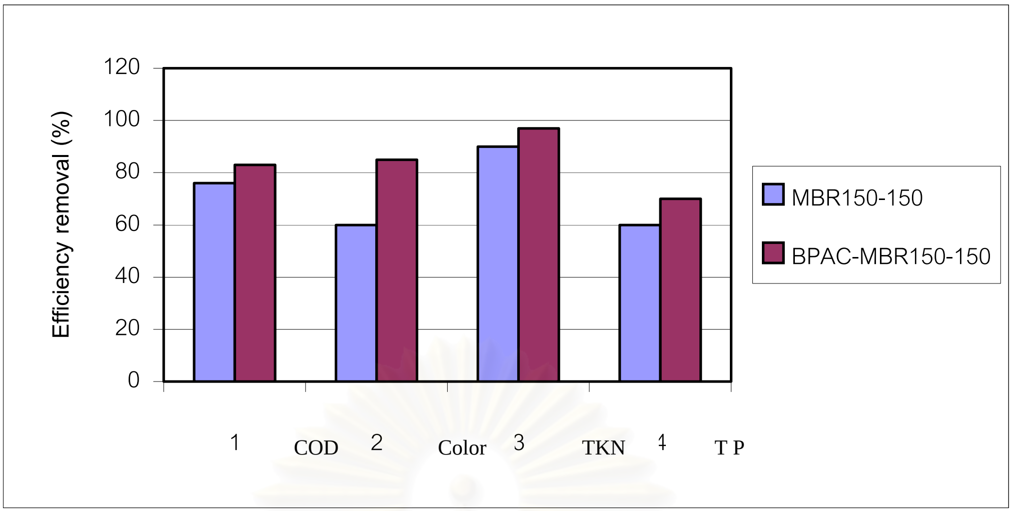

Figure 4.40 Comparison of MBR and BPAC-MBR at an intermittent aeration time of 150-150 minutes

4.9 Comparison of MBR and BPAC-MBR at an intermittent aeration time of 150-150 minutes

The removal efficiency of COD and TKN in the BPAC-MBR a slight increase from the MBR at an intermittent of 150-150 minutes but color and TP removal efficiency of BPAC-MBR were 42%, and 16% better than of MBR.

The COD, color, TKN, and TP removal efficiency in BPAC- MBR were higher than MBR. The activated carbon in BPAC-MBR system also helped adsorb slowly biodegrade organic matters, increased exposure time, and reduced inhibition, which resulted in higher substrates removal than single MBR systems.

Therefore, the BPAC-MBR at an intermittent time of 150-150 minutes was highest efficiency in treating leachate from co-operate of activated carbon and a longer intermittent aeration time.

4.10 Consideration of Advantages and Disadvantages of MBR and BPAC-MBR

From Figures 4.41 and 4.42, the effluent color of BPAC-MBR was clearer than that of MBR and the effluent color for the operation at an intermittent 150-150 minutes was clearer than that of 120-120 minutes. Table 4.2 shows that BPAC-MBR had better performance in terms of COD and color removal than MBR but investment cost is rather high due to the added activated carbon in process.

Table 4.2 Summary of advantages and disadvantages of MBR and BPAC-MBR

Description	MBR	BPAC-MBR
Effluent color	Brown color	Yellow color
Odor	No smell	No smell
Treatment efficiencies for COD and color	High	Higher than MBR
Investment cost	High	Higher than MBR
Operation cost	Medium*	Higher than MBR
Power consumption	Medium*	Medium*

* In the case of intermittent aeration mode

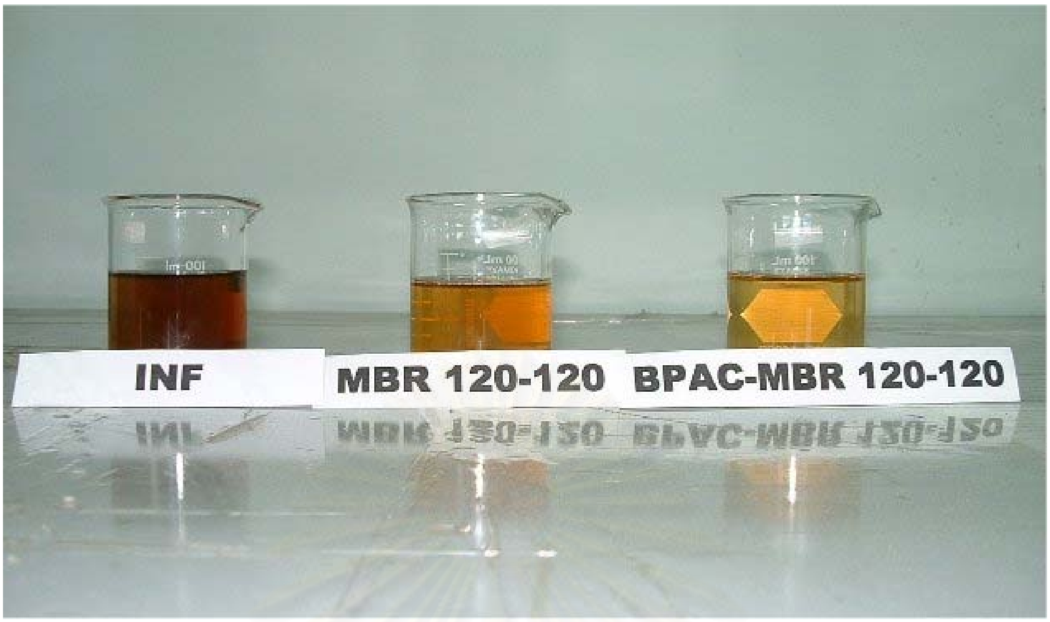

Figure 4.41 Influent and effluent color of MBR and BPAC-MBR at an intermittent aeration time of 120-120 minutes

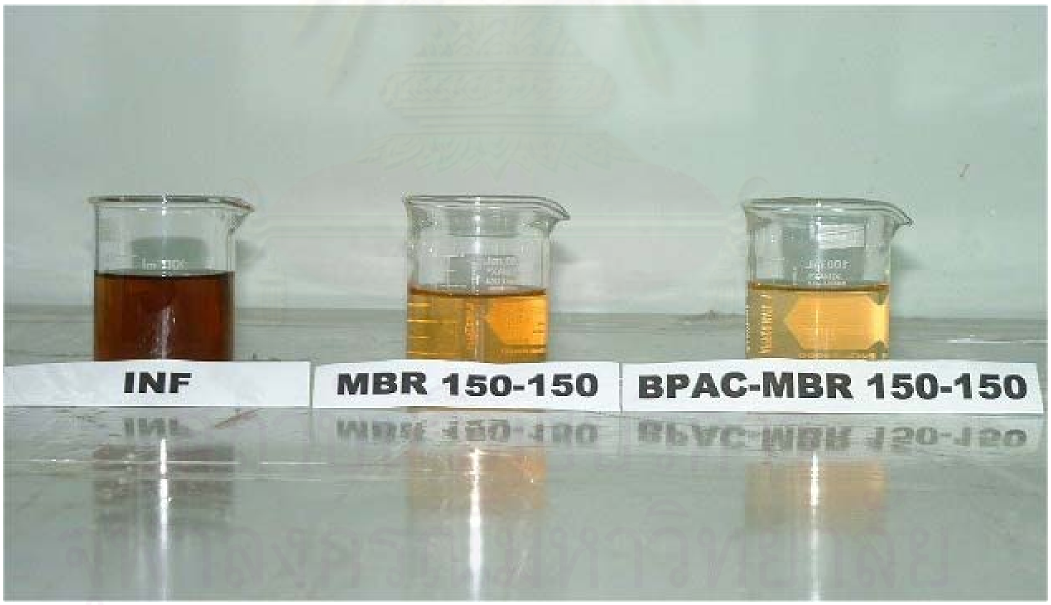

Figure 4.42 Influent and effluent color of MBR and BPAC-MBR at an intermittent aeration time of 150-150 minutes

4.11 Economic Aspects of MBR and BPAC-MBR

Table 4.3 and 4.4 show the investments cost for construction of membrane bioreactor. The cost in laboratory scale depends mainly on the membrane module.

Table 4.3 Investments cost for construction of reactor

Number	Materials	Cost (Baht)
1	Microfiltration membrane pore size 0.1 µm, suface area 0.3 m^2	15,000
2	Rectangular reactor	1,500
3	Suction pump	3,000
4	Pipe and fitting	500
5	Submerged pump	1,000
6	Automatic control systems	2,000
7	Pressure gauge	350
	Total	23,350

Table 4.4 Electricity cost

Operating	Cost (Baht/year)
MBR (1.596 Unit /d)	1748
BPAC-MBR (1.596 Unit /d)	1748

Calculation Assumptions:

- Flow rate 10.95 m^3/year
- Membrane module duration time 3 years
- Systems duration time 15 years
- Activated carbon price 300 Baht/kg used 0.6 kg every 6 months. The cost was 5,400 Baht

Table 4.5 Calculation of total cost per unit wastewater volume

Item	MBR	BPAC-MBR
1.Replacement cost for membrane module (Baht)	60,000	60,000
2.Invesment cost (Baht)	23,350	23,350
3.Electricity Cost (Baht)	26,214	26,214
4.Activated carbon cost (Baht)	-	5,400
Total cost	109,564	114,564
5.Operating volume in 15 year (m^3)	164	164
6. Cost per unit volume(Baht/m^3)	667	697

The cost per unit volume is rather high due to using low flow rate in operating the system in order to prevent membrane clogging.

4.12 Suggestion of Design Criteria for MBR and BPAC-MBR

From overall experimental results, the design criteria for both MBR and BPAC-MBR in treating landfill leachate with the intermittent aeration mode can be suggested as follows;

Table 4.6 Suggestion of Design Criteria for MBR and BPAC-MBR

Criteria	MBR	BPAC-MBR
1. HRT (Day)	1	1
2. Sludge age	Infinity (no sludge wastage)	Infinity (no sludge wastage)
3. Intermittent aeration time (minutes)	150-150	150-150
4. PAC dose (mg/l)	-	20,000
5. MLSS (mg/l)	3,000	23,000
6. Pressure drop (kPa)	<10	<10

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The first objective was to compare performances between MBR and BPAC-MBR in treating leachate using the Effective Microorganisms (EM). The removal efficiency of the BPAC- MBR was higher than that of the MBR. The Highest treatment efficiency in all experiments was achieved in BPAC-MBR at an intermittent aeration time of 150-150 minutes. The removal efficiency for COD was 83 %, color 85%, TKN 97%, and TP 70%. Therefore, the EM was effective in treating landfill leachate when combined with activated carbon. The activated carbon in BPAC-MBR system also helped adsorb slowly biodegradable organic matters, increased exposure time, and reduced inhibition, which resulted in higher substrate removal than single MBR systems.

The second objective was to study the effect of the anoxic-oxic period on leachate treatment by MBR and BPAC-MBR. The substrates removal efficiency at an intermittent aeration time of 150-150 minutes was more than at an intermittent aeration time of 120-120 minutes. The reason might be that the microorganisms had a longer time for both aerobic and anaerobic period to treat readily biodegradable influent COD and to reduce soluble inert COD from microbial activities. The degradation mechanisms needed consecutive aerobic and anaerobic periods. Anaerobic process utilized the high molecular compounds as a source of energy in aerobic process. The long intermittent aeration time not only resulted in the selection of the microorganisms but also led the microorganisms to be tolerated and provided better utilization.

5.2 Recommendations

1. The treatment process should find some process for assimilation landfill leachate (Ozone, biological, or chemical) before treat by MBR.

2. Investigate the possibility of the creation of using hydraulic turbulence (high pressure jet, or mixer) to eliminate the possible excess cake formation on the membrane.

3. Investigate the possibility of operating the membrane reactors at the critical pressure values (extremely low pressure). Thus, the possibility of membrane clogging could be totally eliminated.

4. Cost benefits of the MBR system over conventional system should be evaluated to identify the competitiveness of the system from an economic standpoint.

5. Mathematical modeling should be carried out so that the systems performance can be predicted during the fluctuation in influent concentration and any variation in environmental conditions.

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APPENDICES

APPENDIX A

Results of Experimental MBR 120-120

Table A-1 Experimental Results COD and color of MBR 120-120

No.	Date	COD (mg/l)			Color (Su.)		
		Inf	Eff	%removal	Inf	Eff	%removal
1	1/5/2545	1012.0	316.4	68.7	106.8	66.3	37.9
2	2/5/2545	956.6	301.5	68.5	103.5	64.1	38.1
3	3/5/2545	962.4	324.1	66.3	104.6	62.8	40.0
4	4/5/2545	1023.0	315.8	69.1	107.5	63.4	41.0
5	5/5/2545	1041.0	304.6	70.7	108.9	63.9	41.3
6	6/5/2545	993.2	318.6	67.9	106.3	64.1	39.7
7	7/5/2545	998.1	297.5	70.2	102.4	65.2	36.3
8	8/5/2545	1009.7	318.4	68.5	105.2	64.8	38.4
9	9/5/2545	990.5	305.5	69.2	99.6	62.8	36.9
10	10/5/2545	998.3	302.4	69.7	98.4	63.4	35.6
11	11/5/2545	1043.2	286.5	72.5	106.4	62.8	41.0
12	12/5/2545	1017.6	298.6	70.7	102.3	66.4	35.1
13	13/5/2545	1021.2	305.6	70.1	104.5	64.1	38.7
14	14/5/2545	1018.0	321.4	68.4	101.2	60.5	40.2
15	15/5/2545	1003.7	314.3	68.7	104.3	63.8	38.8
16	16/5/2545	990.8	313.2	68.4	98.7	64.7	34.4
17	17/5/2545	975.0	308.7	68.3	99.5	65.7	34.0
18	18/5/2545	1026.0	324.6	68.4	104.3	66.4	36.3
19	19/5/2545	1021.4	290.5	71.6	102.3	62.1	39.3
20	20/5/2545	1037.6	309.7	70.2	104.5	63.8	38.9
21	21/5/2545	1041.0	320.5	69.2	105.4	61.9	41.3
22	22/5/2545	1028.7	314.6	69.4	101.8	65.0	36.1
23	23/5/2545	1019.5	287.4	71.8	101.1	64.8	35.9
24	24/5/2545	995.4	314.5	68.4	98.4	62.0	37.0
25	25/5/2545	960.8	320.8	66.6	106.8	63.7	40.4

Table A-1 Experimental Results COD and color of MBR 120-120 (contiuous)

No.	Date	COD (mg/l)			Color (Su)		
		Inf	Eff	%removal	Inf	Eff	%removal
26	26/5/2545	1029.0	300.4	70.8	105.2	64.5	38.7
27	27/5/2545	1045.8	331.0	68.3	103.4	63.2	38.9
28	28/5/2545	1032.2	297.5	71.2	107.6	64.1	40.4
29	29/5/2545	1018.0	318.5	68.7	101.5	60.7	40.2
30	30/5/2545	996.5	306.6	69.2	99.8	65.8	34.1
31	31/5/2545	1024.6	324.8	68.3	104.6	66.4	36.5
32	1/6/2545	1005.8	304.1	69.8	106.4	62.4	41.4
33	2/6/2545	1034.3	289.1	72.0	95.6	60.5	36.7
34	3/6/2545	1051.8	324.1	69.2	102.3	64.2	37.2
35	4/6/2545	1021.0	306.1	70.0	104.5	61.8	40.9
36	5/6/2545	1014.0	296.1	70.8	105.6	64.0	39.4
37	6/6/2545	1035.0	304.7	70.6	106.4	63.1	40.7
38	7/6/2545	1046.5	326.4	68.8	106.5	63.1	40.8
39	8/6/2545	1039.0	311.8	70.0	98.4	64.8	34.1
40	9/6/2545	1016.7	324.7	68.1	105.3	65.1	38.2

Table A-2 Experimental Results TKN, TP, and MLSS of MBR 120-120

No.	Date	TKN (mg/l)			T P (mg/l)			MLSS (mg/l)
		Inf	Eff	%removal	Inf	Eff	%removal	
1	1/5/2545	513.7	50.4	90.2	15.5	8.2	47.1	3,740
2	2/5/2545	541.6	59.4	89.0	14.4	7.6	47.2	3,660
3	3/5/2545	551.6	57.8	89.5	15.6	7.4	52.6	3,800
4	4/5/2545	583.6	59.1	89.9	13.4	8.2	38.8	4,010
5	5/5/2545	573.5	59.6	89.6	15.3	8.4	45.1	4,220
6	6/5/2545	560.7	53.4	90.5	15.6	8.1	48.1	4,500
7	7/5/2545	547.9	52.7	90.4	15.8	7.4	53.2	4,180
8	8/5/2545	558.4	58.8	89.5	16.0	8.3	48.1	4,270
9	9/5/2545	569.2	51.2	91.0	15.1	8.1	46.4	4,540
10	10/5/2545	528.3	53.3	89.9	15.2	8.2	46.1	4,740
11	11/5/2545	557.6	52.7	90.5	16.1	8.3	48.4	4,460
12	12/5/2545	568.5	59.7	89.5	15.7	8.4	46.5	4,400
13	13/5/2545	561.3	48.4	91.4	14.8	8.3	43.9	4,620
14	14/5/2545	570.3	49.1	91.4	15.4	8.0	48.1	4,480
15	15/5/2545	558.4	57.4	89.7	15.6	8.4	46.2	4,540
16	16/5/2545	546.9	50.5	90.8	15.7	7.9	49.7	4,960
17	17/5/2545	564.5	53.9	90.5	15.2	7.8	48.7	4,730
18	18/5/2545	532.9	59.6	88.8	14.8	8.4	43.2	4,620
19	19/5/2545	544.6	55.4	89.8	15.3	8.2	46.4	4,660
20	20/5/2545	532.6	57.8	89.1	15.2	8.3	45.4	4,320
21	21/5/2545	570.4	53.8	90.6	15.7	8.2	47.8	4,460
22	22/5/2545	564.5	53.6	90.5	16.2	8.4	48.1	4,730
23	23/5/2545	575.3	54.2	90.6	15.9	8.5	46.5	4,850
24	24/5/2545	513.7	50.4	90.2	15.5	8.2	47.1	3,740
25	25/5/2545	541.6	59.4	89.0	14.4	7.6	47.2	3,660

Table A-2 Experimental Results TKN, TP and MLSS of MBR 120-120 (Continuous)

No.	Date	TKN (mg/l)			T P (mg/l)			MLSS (mg/l)
		Inf	Eff	%removal	Inf	Eff	%removal	
26	26/5/2545	572.3	50.8	91.1	15.4	7.9	48.7	4,350
27	27/5/2545	532.6	58.9	88.9	15.3	8.0	47.7	4,540
28	28/5/2545	546.8	57.1	89.6	16.3	8.6	47.2	4,600
29	29/5/2545	535.9	58.8	89.0	14.9	8.3	44.3	3,970
30	30/5/2545	546.7	51.2	90.6	15.6	8.4	46.2	4,860
31	31/5/2545	532.6	56.5	89.4	15.4	8.1	47.4	4,670
32	1/6/2545	571.4	54.4	90.5	15.1	8.2	45.7	4,550
33	2/6/2545	554.6	55.2	90.0	15.3	8.5	44.4	4,630
34	3/6/2545	562.3	51.5	90.8	15.5	8.3	46.5	4,820
35	4/6/2545	586.2	56.4	90.4	15.4	8.2	46.8	4,330
36	5/6/2545	532.1	50.8	90.5	15.6	8.4	46.2	4,760
37	6/6/2545	546.8	54.1	90.1	15.2	8.3	45.4	4,560
38	7/6/2545	541.3	56.7	89.5	15.7	8.2	47.8	4,830
39	8/6/2545	563.2	54.2	90.4	15.2	8.3	45.4	4,480
40	9/6/2545	544.2	56.8	89.6	16.4	8.4	48.8	4,560

APPENDIX B

Results of Experimental MBR 150-150

Table B-1 Experimental Results COD and color of MBR 150-150

No.	Date	COD (mg/l)			Color (Su.)		
		Inf	Eff	%removal	Inf	Eff	%removal
1	19/6/2545	1000.8	250.4	75.0	104.5	45.4	56.6
2	20/6/2545	1023.4	263.4	74.3	107.4	44.2	58.8
3	21/6/2545	1062.4	244.2	77.0	102.4	42.5	58.5
4	22/6/2545	1050.3	258.9	75.3	103.5	43.7	57.8
5	23/6/2545	1051.1	260.4	75.2	104.6	43.9	58.0
6	24/6/2545	1060.0	249.7	76.4	105.2	44.2	58.0
7	25/6/2545	1021.3	257.1	74.8	106.8	45.7	57.2
8	26/6/2545	1041.3	244.6	76.5	107.3	44.8	58.2
9	27/6/2545	1008.6	260.3	74.2	106.3	42.7	59.8
10	28/6/2545	1024.3	243.1	76.3	104.6	43.1	58.8
11	29/6/2545	1001.3	240.6	76.0	105.2	42.5	59.6
12	30/6/2545	1072.1	263.0	75.5	106.2	46.7	56.0
13	1/7/2545	1047.3	257.8	75.4	105.7	44.3	58.1
14	2/7/2545	1110.8	249.3	77.6	102.8	43.5	57.7
15	3/7/2545	1030.6	255.6	75.2	101.3	43.6	57.0
16	4/7/2545	1045.6	253.4	75.8	104.6	44.8	57.2
17	5/7/2545	1075.6	258.7	75.9	107.3	45.6	57.5
18	6/7/2545	1078.3	253.1	76.5	102.3	46.1	54.9
19	7/7/2545	1005.6	260.4	74.1	104.6	42.3	59.6
20	8/7/2545	1007.4	259.3	74.3	106.1	43.8	58.7
21	9/7/2545	1045.6	250.7	76.0	103.2	41.6	59.7
22	10/7/2545	1024.3	255.7	75.0	104.5	45.0	56.9
23	11/7/2545	1033.1	263.1	74.5	106.4	44.1	58.6
24	12/7/2545	1065.7	253.4	76.2	105.4	42.3	59.9
25	13/7/2545	1043.1	250.3	76.0	104.7	43.8	58.2

Table B-1 Experimental Results COD and color of MBR 150-150 (continuous)

No.	Date	COD (mg/l)			Color (Su.)		
		Inf	Eff	%removal	Inf	Eff	%removal
26	14/7/2545	1032.6	258.7	74.9	103.6	43.7	57.8
27	15/7/2545	1033.8	241.5	76.6	106.8	43.8	59.0
28	16/7/2545	1047.1	267.6	74.4	105.2	44.2	58.0
29	17/7/2545	1084.5	258.4	76.2	103.6	40.2	61.2
30	18/7/2545	1096.4	263.6	76.0	105.1	45.7	56.5
31	19/7/2545	1045.6	244.7	76.6	106.5	46.5	56.3
32	20/7/2545	1100.3	249.1	77.4	103.4	42.8	58.6
33	21/7/2545	1040.6	252.1	75.8	103.8	40.3	61.2
34	22/7/2545	1072.8	245.6	77.1	104.6	44.5	57.5
35	23/7/2545	1121.5	264.6	76.4	106.4	41.8	60.7
36	24/7/2545	1134.8	240.5	78.8	105.3	44.8	57.5
37	25/7/2545	1133.4	241.6	78.7	105.3	43.1	59.1
38	26/7/2545	1051.3	248.6	76.4	105.6	43.6	58.7
39	27/7/2545	1003.5	250.1	75.1	106.4	43.7	58.9
40	28/7/2545	1023.4	261.7	74.4	106.5	48.3	54.6

Table B-2 Experimental Results TKN, TP, and MLSS of MBR 150-150

No.	Date	TKN (mg/l)			T P (mg/l)			MLSS (mg/l)
		Inf	Eff	%removal	Inf	Eff	%removal	
1	19/6/2545	542.8	38.6	92.9	12.8	5.8	54.7	4,800
2	20/6/2545	533.6	34.6	93.5	11.8	5.7	51.7	4,720
3	21/6/2545	573.5	37.5	93.5	12.6	5.9	53.2	4,890
4	22/6/2545	547.4	39.2	92.8	11.6	6.2	46.6	4,760
5	23/6/2545	543.6	35.6	93.5	11.7	6.4	45.3	4,650
6	24/6/2545	583.7	33.8	94.2	10.8	6.1	43.5	4,960
7	25/6/2545	563.4	33.4	94.1	11.0	5.8	47.3	5,120
8	26/6/2545	555.1	38.8	93.0	10.8	6.3	41.7	4,960
9	27/6/2545	572.1	32.6	94.3	11.9	6.1	48.7	4,870
10	28/6/2545	541.2	33.5	93.8	11.3	6.2	45.1	4,890
11	29/6/2545	533.5	33.7	93.7	12.1	6.3	47.9	4,860
12	30/6/2545	546.2	37.8	93.1	11.5	6.4	44.3	4,974
13	1/7/2545	526.9	35.2	93.3	11.4	6.3	44.7	5,010
14	2/7/2545	562.8	35.2	93.7	11.7	5.9	49.6	5,230
15	3/7/2545	543.8	37.8	93.0	11.9	6.4	46.2	5,240
16	4/7/2545	532.9	33.3	93.8	11.6	6.1	47.4	5,040
17	5/7/2545	544.6	33.7	93.8	11.3	6.2	45.1	4,890
18	6/7/2545	565.1	38.6	93.2	15.8	6.4	59.5	4,950
19	7/7/2545	534.2	35.6	93.3	16.1	6.2	61.5	4,820
20	8/7/2545	546.1	37.1	93.2	17.3	6.3	63.6	4,960
21	9/7/2545	562.7	33.8	94.0	15.5	6.3	59.4	5,004
22	10/7/2545	543.7	34.5	93.7	17.4	6.4	63.2	5,550
23	11/7/2545	562.7	37.4	93.4	16.7	6.5	61.1	5,120
24	12/7/2545	532.6	36.2	93.2	15.8	5.9	62.7	5,140
25	13/7/2545	564.2	35.3	93.7	16.6	6.3	62.0	5,040

Table B-2 Experimental Results TKN, TP, and MLSS of MBR 150-150(continuous)

No.	Date	TKN (mg/l)			T P (mg/l)			MLSS (mg/l)
		Inf	Eff	%removal	Inf	Eff	%removal	
26	14/7/2545	535.9	37.4	93.0	16.4	6.4	61.0	4,970
27	15/7/2545	561.8	33.8	94.0	15.6	6.3	59.6	4,920
28	16/7/2545	542.6	32.6	94.0	17.6	6.2	64.8	4,970
29	17/7/2545	555.8	36.1	93.5	16.3	6.1	62.6	5,180
30	18/7/2545	545.7	34.4	93.7	15.6	6.8	56.4	4,970
31	19/7/2545	564.9	35.2	93.8	15.3	6.6	56.9	5,020
32	20/7/2545	543.2	32.7	94.0	16.8	6.1	63.7	5,140
33	21/7/2545	546.8	36.4	93.3	15.9	6.9	56.6	5,200
34	22/7/2545	541.3	31.9	94.1	17.7	6.7	62.1	4,860
35	23/7/2545	546.8	34.1	93.8	15.1	6.4	57.6	4,980
36	24/7/2545	532.5	36.3	93.2	15.5	6.5	58.1	5,190
37	25/7/2545	519.6	34.2	93.4	17.7	6.7	62.1	5,240
38	26/7/2545	538.5	36.7	93.2	16.4	6.8	58.5	4,960
39	27/7/2545	537.4	33.7	93.7	16.8	6.4	61.9	4,760
40	28/7/2545	549.3	33.9	93.8	15.8	6.0	62.0	5,310

APPENDIX C

Results of Experimental BPAC-MBR 120-120

Table C-1 Experimental Results COD and color of BPAC- MBR 120-120

No.	Date	COD (mg/l)			Color (Su.)		
		Inf	Eff	%removal	Inf	Eff	%removal
1	1/5/2545	1012.0	316.4	68.7	106.8	66.3	37.9
2	2/5/2545	956.6	301.5	68.5	103.5	64.1	38.1
3	3/5/2545	962.4	324.1	66.3	104.6	62.8	40.0
4	4/5/2545	1023.0	315.8	69.1	107.5	63.4	41.0
5	5/5/2545	1041.0	304.6	70.7	108.9	63.9	41.3
6	6/5/2545	993.2	318.6	67.9	106.3	64.1	39.7
7	7/5/2545	998.1	297.5	70.2	102.4	65.2	36.3
8	8/5/2545	1009.7	318.4	68.5	105.2	64.8	38.4
9	9/5/2545	990.5	305.5	69.2	99.6	62.8	36.9
10	10/5/2545	998.3	302.4	69.7	98.4	63.4	35.6
11	11/5/2545	1043.2	286.5	72.5	106.4	62.8	41.0
12	12/5/2545	1017.6	298.6	70.7	102.3	66.4	35.1
13	13/5/2545	1021.2	305.6	70.1	104.5	64.1	38.7
14	14/5/2545	1018.0	321.4	68.4	101.2	60.5	40.2
15	15/5/2545	1003.7	314.3	68.7	104.3	63.8	38.8
16	16/5/2545	990.8	313.2	68.4	98.7	64.7	34.4
17	17/5/2545	975.0	308.7	68.3	99.5	65.7	34.0
18	18/5/2545	1026.0	324.6	68.4	104.3	66.4	36.3
19	19/5/2545	1021.4	290.5	71.6	102.3	62.1	39.3
20	20/5/2545	1037.6	309.7	70.2	104.5	63.8	38.9
21	21/5/2545	1041.0	320.5	69.2	105.4	61.9	41.3
22	22/5/2545	1028.7	314.6	69.4	101.8	65.0	36.1
23	23/5/2545	1019.5	287.4	71.8	101.1	64.8	35.9
24	24/5/2545	995.4	314.5	68.4	98.4	62.0	37.0
25	25/5/2545	960.8	320.8	66.6	106.8	63.7	40.4

Table C-1 Experimental Results COD and color of BPAC- MBR 120-120 (continuous)

No.	Date	COD (mg/l)			Color (Su.)		
		Inf	Eff	%removal	Inf	Eff	%removal
26	26/5/2545	1029.0	216.3	79.0	105.2	31.5	70.1
27	27/5/2545	1045.8	225.5	78.4	103.4	32.8	68.3
28	28/5/2545	1032.2	196.4	81.0	107.6	33.6	68.8
29	29/5/2545	1018.0	204.8	79.9	101.5	29.7	70.7
30	30/5/2545	996.5	228.6	77.1	99.8	29.9	70.0
31	31/5/2545	1024.6	216.7	78.9	104.6	31.4	70.0
32	1/6/2545	1005.8	210.7	79.1	106.4	32.6	69.4
33	2/6/2545	1034.3	234.6	77.3	95.6	28.9	69.8
34	3/6/2545	1051.8	200.5	80.9	102.3	31.2	69.5
35	4/6/2545	1021.0	214.7	79.0	104.5	32.4	69.0
36	5/6/2545	1014.0	241.3	76.2	105.6	32.6	69.1
37	6/6/2545	1035.0	221.6	78.6	106.4	32.8	69.2
38	7/6/2545	1046.5	198.4	81.0	106.5	31.4	70.5
39	8/6/2545	1039.0	203.5	80.4	98.4	29.4	70.1
40	9/6/2545	1016.7	206.9	79.6	105.3	33.7	68.0

Table C-2 Experimental Results TKN, TP, and MLSS of BPAC- MBR 120-120

No.	Date	TKN (mg/l)			T P (mg/l)			MLSS (mg/l)
		Inf	Eff	%removal	Inf	Eff	%removal	
1	1/5/2545	513.7	20.4	96.0	15.5	6.2	60.0	19,860
2	2/5/2545	541.6	18.7	96.5	14.4	5.6	61.1	18,790
3	3/5/2545	551.6	22.3	96.0	15.6	5.4	65.4	19,680
4	4/5/2545	583.6	23.4	96.0	13.4	6.2	53.7	18,560
5	5/5/2545	573.5	19.8	96.5	15.3	6.4	58.2	19,480
6	6/5/2545	560.7	22.1	96.1	15.6	6.1	60.9	18,630
7	7/5/2545	547.9	23.4	95.7	15.8	5.4	65.8	19,740
8	8/5/2545	558.4	26.1	95.3	16.0	6.3	60.6	18,650
9	9/5/2545	569.2	25.3	95.6	15.1	6.1	59.6	19,430
10	10/5/2545	528.3	23.4	95.6	15.2	6.2	59.2	18,750
11	11/5/2545	557.6	24.3	95.6	16.1	6.3	60.9	19,620
12	12/5/2545	568.5	21.5	96.2	15.7	6.4	59.2	18,590
13	13/5/2545	561.3	19.4	96.5	14.8	6.3	57.4	18,760
14	14/5/2545	570.3	24.1	95.8	15.4	6.4	58.4	19,830
15	15/5/2545	558.4	21.6	96.1	15.6	6.2	60.3	20,130
16	16/5/2545	546.9	20.4	96.3	15.7	5.9	62.4	21,340
17	17/5/2545	564.5	23.4	95.9	15.2	5.9	61.2	20,780
18	18/5/2545	532.9	18.9	96.5	14.8	6.4	56.8	20,940
19	19/5/2545	544.6	21.4	96.1	15.3	6.2	59.5	19,860
20	20/5/2545	532.6	22.3	95.8	15.2	6.3	58.6	20,750
21	21/5/2545	570.4	23.8	95.8	15.7	6.3	59.9	19,740
22	22/5/2545	564.5	21.0	96.3	16.2	6.4	60.5	19,860
23	23/5/2545	575.3	22.6	96.1	15.9	6.5	59.1	19,850
24	24/5/2545	572.3	25.1	95.6	15.4	5.9	61.7	19,740
25	25/5/2545	532.6	24.6	95.4	15.3	6.0	60.8	20,870

Table C-2 Experimental Results TKN, TP, and MLSS of BPAC- MBR 120-120 (continuous)

No.	Date	TKN (mg/l)			T P (mg/l)			MLSS (mg/l)
		Inf	Eff	%removal	Inf	Eff	%removal	
26	26/5/2545	546.8	21.7	96.0	16.3	6.6	59.5	18,470
27	27/5/2545	535.9	22.5	95.8	14.9	6.3	57.7	21,750
28	28/5/2545	546.7	24.0	95.6	15.6	6.4	59.0	19,560
29	29/5/2545	532.6	26.3	95.1	15.4	6.4	58.4	18,760
30	30/5/2545	571.4	24.7	95.7	15.1	6.1	59.6	19,350
31	31/5/2545	554.6	24.7	95.5	15.3	6.5	57.5	18,760
32	1/6/2545	562.3	20.9	96.3	15.5	6.3	59.4	19,630
33	2/6/2545	586.2	23.4	96.0	15.4	6.2	59.7	18,450
34	3/6/2545	532.1	21.3	96.0	15.6	6.4	59.0	18,620
35	4/6/2545	546.8	23.6	95.7	15.2	6.3	58.6	20,840
36	5/6/2545	541.3	24.3	95.5	15.7	6.2	60.5	19,730
37	6/6/2545	563.2	24.1	95.7	15.2	6.3	58.6	18,640
38	7/6/2545	544.2	25.2	95.4	16.4	6.4	61.0	19,740
39	8/6/2545	561.6	20.4	96.4	15.9	6.3	60.4	17,990
40	9/6/2545	558.4	19.6	96.5	14.3	6.1	57.3	18,940

APPENDIX D

Results of experimental BPAC-MBR 150-150

Table D-1 Experimental Results COD and color of BPAC- MBR 150-150

No.	Date	COD (mg/l)			Color (Su.)		
		Inf	Eff	%removal	Inf	Eff	%removal
1	19/6/2545	1000.8	172.4	82.8	104.5	14.5	86.1
2	20/6/2545	1023.4	180.5	82.4	107.4	17.5	83.7
3	21/6/2545	1062.4	164.8	84.5	102.4	16.4	84.0
4	22/6/2545	1050.3	183.8	82.5	103.5	13.6	86.9
5	23/6/2545	1051.1	163.4	84.5	104.6	18.9	81.9
6	24/6/2545	1060.0	174.3	83.6	105.2	14.1	86.6
7	25/6/2545	1021.3	185.1	81.9	106.8	16.2	84.8
8	26/6/2545	1041.3	163.7	84.3	107.3	18.7	82.6
9	27/6/2545	1008.6	166.8	83.5	106.3	14.3	86.5
10	28/6/2545	1024.3	170.5	83.4	104.6	15.9	84.8
11	29/6/2545	1001.3	184.3	81.6	105.2	13.8	86.9
12	30/6/2545	1072.1	186.3	82.6	106.2	16.4	84.6
13	1/7/2545	1047.3	175.3	83.3	105.7	15.2	85.6
14	2/7/2545	1110.8	170.5	84.7	102.8	14.9	85.5
15	3/7/2545	1030.6	165.4	84.0	101.3	16.5	83.7
16	4/7/2545	1045.6	164.7	84.2	104.6	13.8	86.8
17	5/7/2545	1075.6	162.3	84.9	107.3	17.6	83.6
18	6/7/2545	1078.3	176.8	83.6	102.3	15.5	84.8
19	7/7/2545	1005.6	180.4	82.1	104.6	16.2	84.5
20	8/7/2545	1007.4	176.4	82.5	106.1	17.8	83.2
21	9/7/2545	1045.6	186.7	82.1	103.2	15.6	84.9
22	10/7/2545	1024.3	175.4	82.9	104.5	16.3	84.4
23	11/7/2545	1033.1	169.5	83.6	106.4	18.0	83.1
24	12/7/2545	1065.7	161.7	84.8	105.4	14.9	85.9
25	13/7/2545	1043.1	164.3	84.2	104.7	16.7	84.0

Table D-1 Experimental Results COD and color of BPAC- MBR 150-150

No.	Date	COD (mg/l)			Color (Su.)		
		Inf	Eff	%removal	Inf	Eff	%removal
26	14/7/2545	14/7/2545	1032.6	173.4	83.2	103.6	18.2
27	15/7/2545	15/7/2545	1033.8	178.9	82.7	106.8	15.4
28	16/7/2545	16/7/2545	1047.1	186.2	82.2	105.2	16.3
29	17/7/2545	17/7/2545	1084.5	174.5	83.9	103.6	17.4
30	18/7/2545	18/7/2545	1096.4	168.7	84.6	105.1	18.6
31	19/7/2545	19/7/2545	1045.6	165.4	84.2	106.5	16.4
32	20/7/2545	20/7/2545	1100.3	162.4	85.2	103.4	15.8
33	21/7/2545	21/7/2545	1040.6	180.2	82.7	103.8	18.2
34	22/7/2545	22/7/2545	1072.8	192.1	82.1	104.6	14.9
35	23/7/2545	23/7/2545	1121.5	169.8	84.9	106.4	16.7
36	24/7/2545	24/7/2545	1134.8	174.6	84.6	105.3	15.3
37	25/7/2545	25/7/2545	1133.4	181.3	84.0	105.3	16.4
38	26/7/2545	26/7/2545	1051.3	188.9	82.0	105.6	17.3
39	27/7/2545	27/7/2545	1003.5	174.2	82.6	106.4	17.8
40	28/7/2545	28/7/2545	1023.4	168.9	83.5	106.5	17.6

Table D-2 Experimental Result TKN, TP, MLSS of BPAC-MBR 150-150

No.	Date	TKN (mg/l)			T P (mg/l)			MLSS (mg/l)
		Inf	Eff	%removal	Inf	Eff	%removal	
1	19/6/2545	542.8	15.4	97.2	12.8	4.3	66.4	22,780
2	20/6/2545	533.6	17.8	96.7	11.8	4.7	60.2	23,540
3	21/6/2545	573.5	13.8	97.6	12.6	4.1	67.5	22,650
4	22/6/2545	547.4	14.6	97.3	11.6	4.6	60.3	24,670
5	23/6/2545	543.6	18.4	96.6	11.7	4.5	61.5	22,370
6	24/6/2545	583.7	12.6	97.8	10.8	4.2	61.1	23,890
7	25/6/2545	563.4	13.7	97.6	11.0	4.6	58.2	23,460
8	26/6/2545	555.1	14.0	97.5	10.8	4.8	55.6	22,130
9	27/6/2545	572.1	12.9	97.7	11.9	4.0	66.4	23,780
10	28/6/2545	541.2	13.8	97.5	11.3	4.6	59.3	23,450
11	29/6/2545	533.5	14.5	97.3	12.1	4.4	63.6	24,860
12	30/6/2545	546.2	16.7	96.9	11.5	4.2	63.5	22,440
13	1/7/2545	526.9	18.1	96.6	11.4	4.1	64.0	22,750
14	2/7/2545	562.8	16.4	97.1	11.7	4.5	61.5	21,420
15	3/7/2545	543.8	13.2	97.6	11.9	4.2	64.7	21,980
16	4/7/2545	532.9	15.9	97.0	11.6	4.9	57.8	22,450
17	5/7/2545	544.6	14.1	97.4	11.3	4.6	59.3	23,780
18	6/7/2545	565.1	17.8	96.9	15.8	4.7	70.3	24,240
19	7/7/2545	534.2	15.5	97.1	16.1	4.1	74.5	23,560
20	8/7/2545	546.1	13.6	97.5	17.3	4.3	75.1	21,570
21	9/7/2545	562.7	12.8	97.7	15.5	4.6	70.3	23,580
22	10/7/2545	543.7	11.9	97.8	17.4	4.4	74.7	24,550
23	11/7/2545	562.7	14.8	97.4	16.7	4.5	73.1	22,250
24	12/7/2545	532.6	12.9	97.6	15.8	4.7	70.3	21,340
25	13/7/2545	541.6	59.4	89.0	14.4	7.6	47.2	3,660

Table D-2 Experimental Result TKN, TP, MLSS of BPAC-MBR 150-150 (continuous)

No.	Date	TKN (mg/l)			TP (mg/l)			MLSS (mg/l)
		Inf	Eff	%removal	Inf	Eff	%removal	
26	14/7/2545	535.9	14.2	97.4	16.4	4.3	73.8	22,740
27	15/7/2545	561.8	12.8	97.7	15.6	4.2	73.1	20,790
28	16/7/2545	542.6	11.9	97.8	17.6	4.6	73.9	21,560
29	17/7/2545	555.8	16.5	97.0	16.3	4.1	74.8	21,430
30	18/7/2545	545.7	14.4	97.4	15.6	4.5	71.2	22,130
31	19/7/2545	564.9	15.2	97.3	15.3	4.7	69.3	21,440
32	20/7/2545	543.2	11.7	97.8	16.8	4.8	71.4	20,450
33	21/7/2545	546.8	16.5	97.0	15.9	4.2	73.6	23,640
34	22/7/2545	541.3	11.8	97.8	17.7	4.6	74.0	22,310
35	23/7/2545	546.8	14.1	97.4	15.1	4.3	71.5	24,020
36	24/7/2545	532.5	16.4	96.9	15.5	4.2	72.9	23,210
37	25/7/2545	519.6	14.3	97.2	17.7	4.3	75.7	22,340
38	26/7/2545	538.5	15.8	97.1	16.4	4.4	73.2	23,790
39	27/7/2545	537.4	12.6	97.7	16.8	4.1	75.6	23,340
40	28/7/2545	549.3	13.8	97.5	15.8	4.6	70.9	22,120

BIOGRAPHY

Mr.Numchai Nilthong was born on 30th April 1974 in Bangkok. He finished higher secondary course from Satit Thepsatri Teacher College, Lopburi in March 1992. After that, He graduated a bachelor's degree in Environmental Engineering King Mongkut's Institute of Technology Thonburi on 27th March 1996. He continued further study for Master's degree of Science in Environmental Management inter-Departmental Program in Environmental Management Graduate School Chulalongkorn University and achieved Master' s degree in April 2003.