APPLICATION OF THE AIR BACKFLUSHING TECHNIQUE IN A MEMBRANE BIOREACTOR FOR SEPTIC WASTEWATER TREATMENT

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ABSTRACT

In this study the possibility of application of air backflushing technique through hollow fiber microfiltration was investigated. The process employed direct solid-liquid separation by immersed two membrane modules with pore size of 0.2 μm directly in the activated sludge aeration tank of 80 L volume. This study was conducted with high concentration of activated sludge and divided into short-term and long-term experiments.

In short term experimental runs, the optimum air backflushing and filtration cycle was investigated. 15 minutes filtration and 15 minutes air backflushing provided the best result in term of flux improvement and stability. Due to the membrane module stability limitation, the applied compressed air pressure of 1 bar was not sufficient to remove the clogging completely. However this cyclic operation provided higher flux stability compared to operation without air diffusion.

In long-term experiments, the initial sludge concentration was 13,000 mg/L. Three different hydraulic retention times (HRT) of 26, 18 and 10.5 hour which corresponds to the permeate flux of 3.08, 4.44 and 7.62 L/m^2. h were investigated. Here, it was noted that the filtration pressure related to the MLSS concentration. But the stable operation could be obtained at 26 and 18 hours. All experimental runs provided more than 90% removal of COD, BOD and TKN with final MLSS of 40,000 mg/L in the reactor. Although the operation with daily sludge draining (1.6 L/d), the MLVSS/MLSS values seem slightly decreased. However, such conditions could not effect significantly to the process performance in term of physical, chemical, biological and bacteriological qualities of membrane bioreactor effluent.

KEYWORDS

Activated sludge, membrane bioreactor, air diffusion, air back flushing, septic wastewater

INTRODUCTION

The most common and classical wastewater treatment process which has been used to treat domestic wastewater is the activated sludge process (ASP). In this system the organic and inorganic matters present in the suspended solid, colloidal and soluble forms can be removed up to 95%.
However, there are some limitations in classical ASP when a high quality of effluent is required. In such situations, large secondary sedimentation tank is required to provide sufficient retention time.
Moreover, there are various factors that must be concerned to reach good settling characteristic. Therefore, various types of combination between ASP and membrane unit have been studied and adapted to overcome these problems and to obtain good effluent quality. Membrane separation technology in water and wastewater treatment can be categorized into four classes according to the membrane, namely, reverse osmosis(RO), ultrafiltration (UF), microfiltration (MF) and electrodialysis (ED). UF and MF techniques are useful in removing macromolecule, colloids and suspended solids. Membrane separation technology has been introduced for solid/liquid separation in biological treatment system. The advantages of employing membrane separation are minimum sludge wastage by maintaining low F/M ratio, reducing plant size by maintaining higher biomass concentration in the

reactor, and solid free effluent could be obtained. Complete retention condition could be maintained by operation without sludge wastage since the solid/liquid separation could be done regardless of sludge settleability.

For domestic wastewater treatment, combined activated sludge/membrane filtration can provide a high degree of treatment in terms of organic oxidation and nitrogen removal. However, the power/energy consumption that has been reported is much higher than the value for conventional ASP. (Yamamoto, 1989) As Yamamoto (1989) indicated, the process is not cost effective. The main reason for the high cost is due to the recirculation pump which connects the main reactor with a membrane unit and maintains high crossflow velocity on the membrane surface to keep the flux undeclined. The solution for this has been investigated by direct membrane separation using hollow fiber in an activated sludge aeration tank which still gives a stable operation and good quality of effluent.
Considering the process performance, direct membrane separation in ASP with continuous suction operation caused severe clogging of the membrane module whenever transmembrane pressure is increased. Using the intermittent suction operation enabled a stable flux to be maintained for suitable, particular conditions. (Yamamoto et al., 1989) Cyclic operation with air diffusion has been investigated by Chiemchaisri (1990). Air backflushing technique was applied to achieved the recovery of permeate flux and net cumulative volume. However, increasing the pressure applied for air backflushing to achieve complete membrane cleaning may damage the membrane.

METHODOLOGY

The experimental study carried out in this study can be classified into three parts as follows:
gas transfer efficiency of aeration units and measurement of initial membrane resistance, short-term experiments and long - term experiments

Measurement of Gas Transfer Efficiency of Aeration units

The ordinary ceramic porous diffusers and microporous membrane with pore size of 0.2μm are immersed separately in acrylic-rectangular reactor which held a working volume of 80 L. The reactor was filled with clean water, and the increase in oxygen concentration was measured by dissolved oxygen probe. Vertical turbine mixer was used for promoting turbulence with the speed of 50 rpm. The effect of pressure was studied in batch operation in order to define the appropriate K_La. To compare the transfer efficiency of two aeration devices, the membrane modules and ordinary air diffusers, were operated as shown in Figure 3.1. The testing procedure began with the removal of oxygen from water by addition of 60 mg/L sodium sulfite (Na_2SO_3) with 0.2 mg/L cobalt ($CoCl_2$) as a catalyst. (Pierre, 1989) The increase in oxygen concentration was measured during aeration under specified pressure, and the overall transfer coefficient was calculated from Equation. (2.10)

$$\log (C_S-C_L) = \log (C_S - C_0) - (K_La /2.3)* t \qquad (1)$$

Taking C_0 and C_L as initial concentration of gas in liquid phase and final concentration of gas in liquid phase, respectively, the gas which was sent to the testing unit comes as purified ambient air and pure oxygen. Dissolved oxygen was measured by using dissolved oxygen probe. Three sampling points are at the middle of water depth along the tank; head, middle and end. DO and water temperature were recorded until the dissolved oxygen reached a constant level. The pressure which was applied in this study was 0.2, 0.4, 0.6, 0.8 and 1.0 bar. The maximum K_La were then indicated the appropriate operating pressure for air diffusion which was used for short term and long term experiments. The effect of gas flow velocity was seen with value of 9, 14 and 18 L/min.

Measurement of Initial Membrane Resistance

The measurement of initial membrane resistance was conducted by immersing membranes in the rectangular reactor. Clean water was fed to the reactor. The speed controlled roller pump was used for extracting permeate. The transmembrane pressure was measured by mercury-filled manometer and the filtered water was recorded and returned to the reactor to keep the volume constant during the experiment. The relationship between the flux and transmembrane pressure is given in the following equation:

$$J = \delta P / \mu R_m \qquad (2)$$

Where,

J	= flux (L/m^2-h.)
δ	= transmembrane pressure (kN. $/m^2$)
μ	= viscosity (kN.s $/m^2$)
R_m	= apparent membrane resistance
	= $Rm_o + Rd$

Where,

Rm_o	= initial membrane resistance
R_d	= membrane resistance due to the deposition of solids

The modified equation to find the initial membrane resistance, when clean water is used, is:

$$\delta P = \mu . Rm_o . J + \delta P_o \qquad (3)$$

δP_o = initial transmembrane pressure required to over come the air blocking effect.

So, by modifying the transmembrane pressure and measuring the permeate flux, the value of Rm_o could be determined.

Short Term Experiments

Membranes were immersed directly in the reactor of activated sludge system. Glucose solution and tap water were used for concentrating or diluting the activated sludge mixture respectively to the desired COD concentration, around 5,000 mg/L. Speed controlled roller pump was used for extracting the permeate while the gas was sent through the membrane module for declogging purpose. This operation was carried out alternatively. The intermittent extraction and air injection was then controlled by intermittent controller and solenoid valves. The transmembrane pressure was measured by mercury manometer. The filtered water was then returned to the reactor to keep the volume and concentration constant during the runs. Compressed air which was sent through membrane had to pass air filter to remove oil vapor and was maintained at 1 bar. Compressed air was also sent to the stone diffusers located at the bottom of the reactor. The air flow rate was controlled at 14 L/min. by air flow meter while the permeate flux was then recorded. The main purpose of aeration were to : allow homogenous mixture in the reactor, provide additional dissolved oxygen for biomass and remove or shear off solids deposited on the membrane surfaces. The effect of suction pressure was studied with 7, 23, 32 and 40 kPa. The operating conditions for these test were then fixed at 15:15* and 15:15 operation mode. (15:15* = 15 minutes of filtration then 15* minutes without effluent filtration or sending any air diffusion while 15:15 = 15 minutes of filtration then 15 minutes of air diffusion) The effect of operation modes with air diffusion and effluent filtration were studied. The suction pressure of 7 kPa and 1 bar compressed air were kept for all the operational modes. All runs were conducted as batch experiments for duration of five hours. The following five different modes were studied: (1) 30: 30 (2) 25: 25 (3) 20:20 (4) 15:15 (5) 10:10 (where 30:30: indicates 30 minutes of filtration then 30 minutes of air diffusion) The effect of compressed air for air diffusion was also studied. The operating conditions for this test were kept at 15:15 operation mode with 7 kPa suction pressure. Five different runs were studied with 0.3, 0.5, 0.7, 1.0 and 2.0 bars.

Acclimatization of Biomass

Acclimatization procedure of this biomass to actual raw septic wastewater was properly conducted by daily fill and draw operation before being placed in the reactor. Glucose solution was fed in order to concentrate biomass mixture in the acclimatization unit. By considering the initial characteristics of raw influent septic wastewater which presents in Table 1, glucose solution was prepared and fed daily in proportion to maintain COD concentration around 5,000 mg/L. Stock solution of 98.2 g-glucose/L is equivalent to 100 g- COD/L.

Table 1: Characteristics of raw septic wastewater

Parameters	Values	Units
1. Settled solid	700	mL/L
2. Suspended solids	2,200-3,500	mg/L
3. COD	3,500-5,500	mg/L
4. Filtered COD	300-400	mg/L
5. BOD	600-1200	mg/L
6. Filtered BOD	158-560	mg/L
7. Total nitrogen	240-350	mg/L
8. Total phosphate	30-38	mg/L
9. pH	8.88	

Long Term Experiments

Figure 1 presents schematics of membrane bioreactor. In order to evaluate the process efficiency: physical, chemical and microbiological parameters were recorded regularly. In addition, the permeate flux and transmembrane pressure were also monitored to assess the membrane bioreactor performance. The effect of HRT was studied in this experiment. The initial HRT of membrane bioreactor process was varied at 7, 12 and 26 hours by controlling the effluent permeate fluxes. The change in transmembrane pressure was monitored every-day to monitor the clogging of the membrane during the long term operations. The effect of sludge draining was also studied with SRT equal to 50 days. This could be achieved by draining 1.6 liters of mixed liquor out of the bioreactor everyday.

RESULTS AND DISCUSSION

Gas Transfer Efficiency of Aeration Units

The oxygen concentration versus time was recorded and gas transfer coefficient (K_La) values were then calculated corresponding to the Equation 1. Both using ambient air and pure oxygen, the higher diffusion rate of air to water could be observed with the higher flow rates. Figure 2 presents gas transfer coefficient when using ambient air with membrane diffusers. The maximum gas transfer coefficient was 28.05 h^{-1} when using 1 bar of ambient air. It clearly demonstrated the effectiveness of the membrane module as an air diffuser in comparison to the conventional stone diffusers.

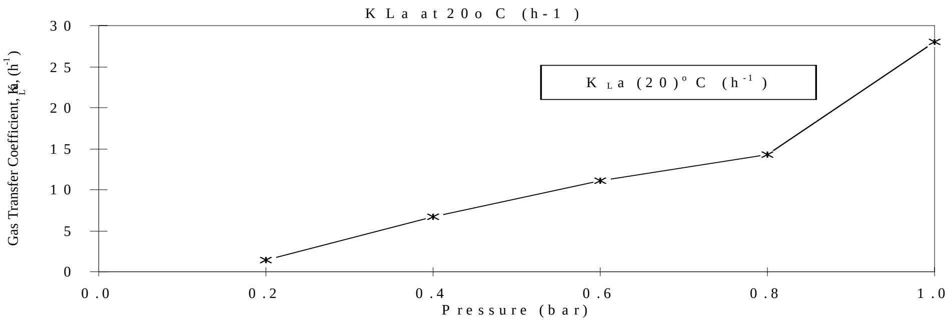

Figure 2: K_La (20) ^oC at different pressure (membrane diffusers)

Initial Membrane Resistance

The initial membrane resistance (Rm_o) of membrane module 1 and module 2 were 8.01 x 10^{12} m^{-1} and 9.26 x 10^{12} m^{-1} at 24.7 ^{o} C respectively. The flux obtained for membrane module 1 and 2 were 310 $L/m^2.h$ and 350 $L/m^2.h$ respectively. Rm values are useful not only for modeling purposes, but also for evaluating the effectiveness of the cleaning procedure and for designing long-term operation stability of the membrane which is discussed in the next section.

Short term experiments

This test was conducted without air backflushing operation. Two membrane modules were used with alternative operation of effluent filtration and then stopping the filtration process. The intermittent mode of 15:15* was used for this run. The flux seems to be constant during 5-hour operation. At any rate, the higher flux could be obtained when the transmembrane pressure was increased. As shown in Figuure 3, application with air backflushing provided higher flux improvement beyond 23 kPa of suction pressure.

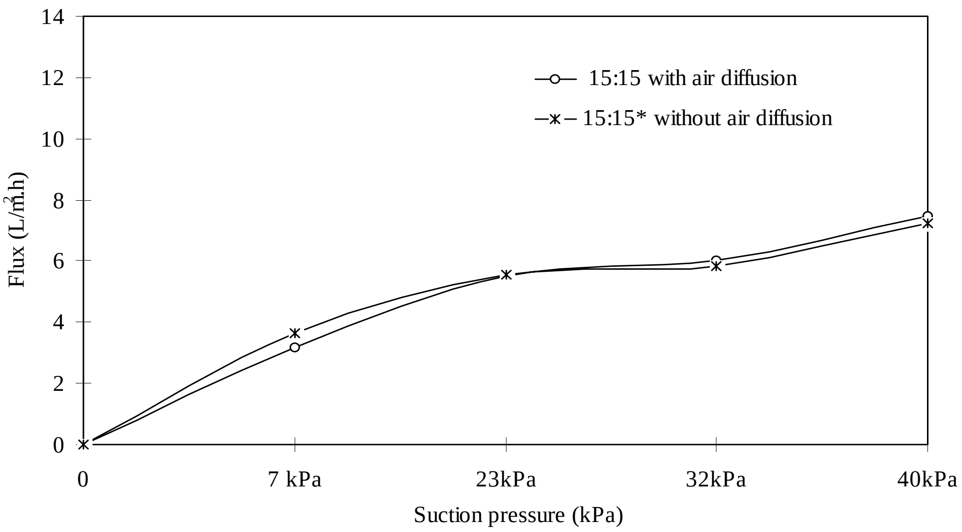

Figure 3: Comparison of flux with different suction pressure

The effect of operation time was then studied by extent the operation time from five hours to ninety hours. By operating without air diffusion, permeate flux declined apparently after ten hours of operation. In turn, operation with air diffusion provide constant permeate flux beyond this critical period of time. The effects of different operation modes on permeate flux were investigated. Two membrane modules were used in alternative function of air diffusion and effluent filtration. In all these experimental runs, transmembrane pressure was maintained at the critical value of 7 kPa. The MLSS values in all cases were maintained in the range of 12,500-12,875 mg/L.For longer frequency, 60:60, provided longer air diffusion time which will increase the cleaning ability, however this will allow high solids compaction on membrane surface due to longer effluent filtration time. By considering flux improvement and cleaning ability, 15:15 operation was selected as the optimum condition for long term experiments.

Long term experiments

In these experiments, three different experimental runs (RUN 1, RUN 2 and RUN 3) were conducted by keeping HRT at 26, 18 and 10.5 hours respectively. Average values of volumetric organic loading were fluctuated with 3.38 kg-COD/m^2.d for RUN 1, 6.73 kg-COD/m^2.d for RUN 2 and 12.2 kg-COD/m^2.d for RUN 3. In order to maintain log phase of biomass growth, activated sludge was wasted 1.6 L everyday (SRT = 50 days). It was found that transmembrane pressures increased with increasing permeate flow. This increased flux caused the increase in solid deposition of membrane surfaces.

Table 2 presents average values of transmembrane pressure for each experimental runs. Once the membrane gets clogged, it increases the transmembrane pressure which, again in turn, promotes membrane clogging. At this point, the air diffusion at 1 bar pressure is insufficient to remove most of the deposited solid material on the membrane surface. This results an unrecoverable dead end operation. Therefore periodic membrane cleaning was then necessary in order to maintain required hydraulic retention time (HRT).

Table 2:Transmembrane Pressure of each Experimental Runs

Experimental Runs	Transmembra Pressure (kPa)	
	Module 1	Module 2
RUN 1	13.9	20.1
RUN 2	38.6	43.9
RUN 3	58.8	64.1

Activated sludge concentration increased with increasing volumetric organic loading. Effect of activated sludge attachment on membrane surfaces was increased when MLSS in the bioreactor became concentrated for each experimental runs. The attached sludge on external membrane surfaces was detached due to the agitation in the bioreactor and membrane air diffusion. It allows sludge to move and shear off the solidified sludge from membrane which assists the cleaning abilities by membrane air diffusion. The limit for membrane filtration of activated sludge mixture is 30,000 - 40,000 mg/L which called as “Threshold Limits of Sludge Concentration” (Yamamoto, 1994). This caused less abilities of sludge movement and promoted cake compaction on membrane surfaces, especially among hollow fibers. The variation of permeate flux with time presents the same pattern with transmembrane pressure. Operating at lower HRT caused higher permeate flux. In any case, constant permeate flux can be observed for 5 days at the early stage of this run after membranes were cleaned. There was no significant different in the permeate turbidity. The average turbidity for RUN 1, 2 and 3 were 1.1, 0.4 and 0.3 NTU, respectively. This low effluent turbidity meets well below the required Thailand effluent standard of 30 mg/L. The reasons for this result can be delineated based on the operation with high concentration of activated sludge. This operation caused high cake layer formation on the external surface of membranes. Cake layer assist to absorb the macromolecules which contribute to yellow color in the effluent. However, high yellowish color was observed at the initial stage of membrane bioreactor operation, but later it became relatively clear. The influent COD was maintained in the range of 4000 - 6000 mg/L. The removal efficiency in all run was maximum from the beginning which was greater than 90% as presented in Figure 4. During all the experimental runs the effluent BOD was maintained below the expected standard of 20 mg/L. This means that effluent BOD_5 is independent from the variation of F/M ratio.

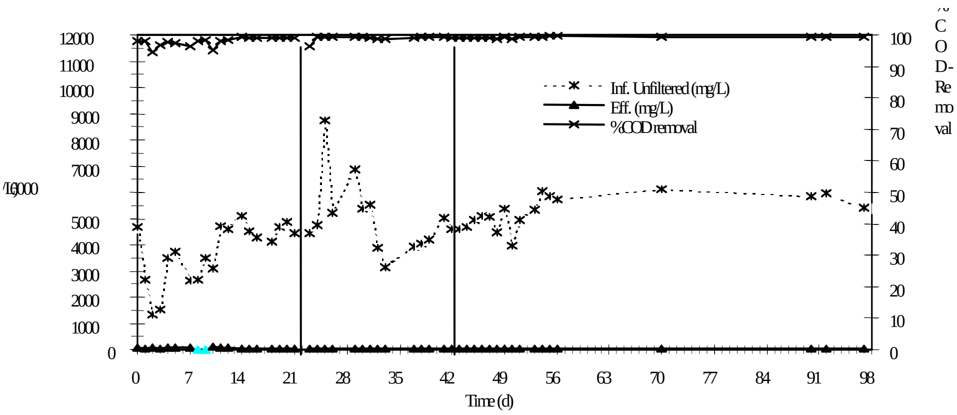

Figure 4. Variation of COD concentration for different experimental runs

It was found that TKN removal efficiency was maintained above 95% for all runs. High degree of nitrification was due to long sludge age condition which promoted the enrichment of low growth rate bacteria such as nitrifying bacteria.

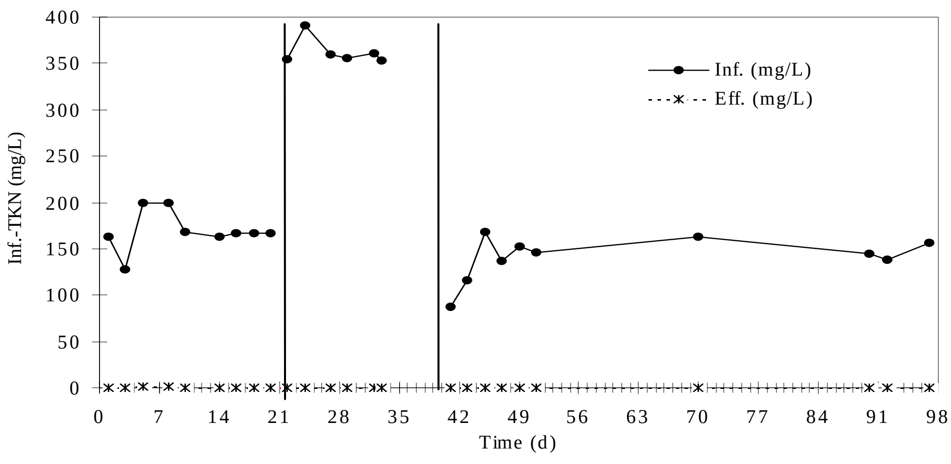

Figure 5: Variation of TKN concentration for different experimental runs

The removal efficiency of phosphorus fluctuated with value of 28.3, 48.6 and 97.1% for RUN 1, 2 and 3, respectively. Phosphorus was removed by biomass assimilation.

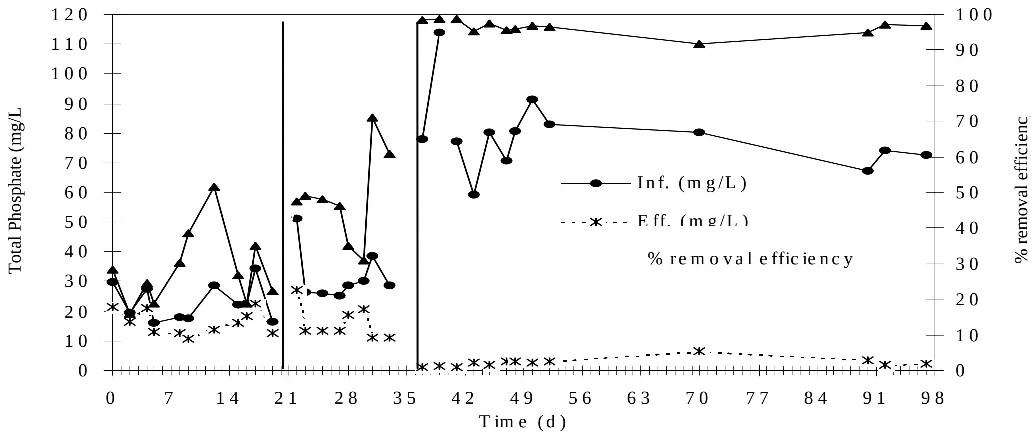

Figure 6: Variation of total phosphate concentration for different experimental run

Organic Removal

As this study was operated with long SRT, θ_c = 50 days, therefore adequate sludge retention time allows dissolved organic substances with both high and low molecular weights can be taken up, broken down and gasified by microorganisms or converted into polymers as constituents of bacterial cells, thereby raising the quality of treated effluent.

Nutrient Removal

Membrane bioreactor also does not allow the washout of nitrifying bacteria. Because this operation contains highly concentrated activated-sludge, agitation inside the bioreactor might not be sufficient. Therefore, there was possible tendency of sludge attachment, accumulation and settlement in dead-zone which can be observed at the bottom of bioreactor. Besides this occurrence, there was the compaction of cake layer on membrane surface which cause the anoxic conditions and limitation of substrates and nutrients at inner part of the attached sludge among hollow fibers. Chang and Moo Yang (1988) has been studied the oxygen penetration depth for animal cell immobilized in hollow fibers. The oxygen penetration was about 500 - 1,000 μm (0.5-1.0 mm). As Chang and Moo Yang indicated, the shortage of oxygen concentration was probably due to limitation of oxygen penetration from both sides of membrane surface. Hence, high degree of denitrification can be observed in the bioreactor. Nitrate was reduced to the gaseous products and stripped by air bubbles and released out from the system.

To achieve lower concentration of total phosphate in the effluent, the jar test was conducted to find the optimum dosage of $FeCl_3$ being applied to the bioreactor. The result from the calculation of total phosphate mass balance shows that phosphate was removed by biomass assimilation. Only the active soluble phosphorus, ortho-phosphate, was consumed by the activated sludge in the bioreactor for their growth. For HRT 10.5 hours, there were some amounts of total phosphorus retained and accumulated in the sludge. Due to the operation with high concentration of activated sludge in the bioreactor, complex phosphate (pyro- and poly phosphate) and organic - bound phosphate which normally presented in combined sewage wastewater can be removed by sludge attachment, flocculation and settlement. In order to clearly demonstrate the effects of sludge settlement, it is necessary to find out phosphorus containing sludge and the active soluble phosphorus which presented in influent. To determine the amounts of the phosphorus which is contained in sludge can be accomplished by digesting sludge nd then settled at the bottom of bioreactor.

Sludge Characterization

Operation with highly concentrated activated sludge caused high sludge density but less settleability. Reducing HRT caused the increasing of biological solids concentration. Capillary Suction Time (CST) which was monitored as a simple, useful and rapid way to evaluate filterability of sludge, it presented higher values than the conventional activated sludge. Specific resistance was analyzed for all runs. They also confirmed the same trend with CST values. High values of such parameters imply less dewaterability of sludge. While sludge retention time (θ_c) of bioreactor was maintained at 50 days, typical value of sludge retention time of conventional activated sludge is shorter, around 10 days. By considering all these results, there is a particular advantage of bioreactor in term of less sludge wastage. However, it has to face with handling difficulties problem of such volume of wasted sludge. To obtain sludge which can be "trucked" or "shoveled", additional dewatering units are necessary. Conditioning is generally essential to prepare the sludge for various equipments. Difficulties are often encountered in the processes used for reduction of the volume of liquid sludge; these difficulties are closely linked with the hydrophilic colloidal mass, of which sludge suspension are mainly formed. However, to increase removal efficiency of total phosphate, addition of metal coagulant ($FeCl_3$) was planned to dose directly to bioreactor. This application may assist to modified the internal cohesive forces of the sludge, to "break down" colloidal stability and to artificially increase the size of the particles. In the case of hydrophilic sludge, part of the bound water must be freed and transformed into free water which is the basis of efficient operation of dewatering units.

Microbiological Quality

It was found that 100% of bacterial rejected in all experimental runs. By considering size of membrane pore, it is expected that no bacteria is allowed to pass through this membranes. As *Escherichia coli* which is a bioindicator for polluted water, the absence of fecal coliform could imply that this permeate is safe from further pathogenic organisms.

Dynamic Population of microorganisms in the Bioreactor

Microorganism's population was observed regularly by using microscope. Predominated microorganisms which constantly found in all experimental runs were bacterial flocs (mixed culture of bacteria). Filamentous organisms can not be found for all runs. The absent of filamentous bacteria in bioreactor was due to the operation with: high concentration of substrate, narrow range of pH-variation and sufficient dissolved oxygen (DO). When concentration of substrate was controlled, the effects of flow rate variation on microorganisms dynamic were then studied. It was found that the variation of influent flow rate caused less effect on the population of bacterial flocs and free-swimming protozoa. Reducing HRT caused the increase of incoming substrates to bioreactor which promoted bacterial growth and created larger size of bacterial flocs. Free-swimming protozoa which constantly presented in all runs were the ciliate protozoa such as *Colpoda*, *Stylonychia* and *Aspidisca*. The present of rotifer was observed in run 1 (HRT = 26 hours which operated within low F/M ratio (0.25 kg-COD/ kg-MLVSS. d) and long hydraulic retention time (HRT) conditions.

Membrane cleaning efficiency

It was found that periodic mechanical cleaning with air diffusion could not prevent total internal resistance. Therefore, the chemical membrane cleaning might provide an effective cleaning in term of removing internal clogging which caused an internal membrane resistance (Rif).

CONCLUSIONS

Membrane air diffusion/aeration process, it plays an important role in the improvement of permeate flux stability by removing external deposits on the membrane surface, preventing the compaction of cake layer and improving internal pore clogging of the membranes. To use the membrane as an air diffuser, the compressed air pressure should be high enough to produce steady stream of micro-air bubbles according to the bubble point concept. For 0.2 μm microfiltration membranes, the highest gas transfer coefficient (K_La) could be obtained when compressed air was sent through membrane at 1 bar, was 28.05 h^{-1} , at 20 ^oC . Although variation of permeate flux in five hours operation of cyclic operation with air diffusion was not substantially different to cyclic operation without sending air, the flux stability of cyclic operation with air diffusion could be observed beyond ten hours of operation. By considering the recovery of permeate flux and lag time to overcome air blocking in membrane pore, 15:15 (15 minutes of membrane filtration and 15 minutes of air diffusion) operation was found to be the optimum operation mode. Higher compressed air pressure will increase the backflushing ability in order to remove external deposits on membrane surface and prevent the compaction of cake layer. However, maximum limits of compressed air pressure in term of membrane module stability should be considered. For this experiment, 1 bar compressed air provided the highest flux improvement compared to the cyclic operation without air diffusion.

COD removals in all experimental runs were greater than 95%. Due to high solids retention time (SRT), around 50 days, and biomass concentration in the bioreactor, there was no significant effects on COD removal efficiency for various volumetric organic loading. The effluent quality in term of SS was extremely good. There was no solids loss (approximately 0 mg/L) in the effluent stream. Due to aerobic condition constantly maintained in the bioreactor, TKN removal efficiency was more than 95%. Total phosphate removal efficiency of more than 35% could be observed in all experimental runs. Addition of $FeCl_3$ into the biorector to enhance higher removal efficiency of total phosphate did not show any effects to the bioreactor performance during the longterm experiment. Due to high concentration of activated sludge was maintained in bioreactor, therefore the limitation of oxygen concentration inside the biological flocs, the settled sludge within dead zones in bioreactor and the compact cake layer among hollow fibers probably caused high degree of denitrification. The MLVSS/MLSS in the bioreactor was in the order of 70-75%. Although 1.6 liters of sludge was drained out every day to meet 50 days SRT, inorganic portion in the bioreactor was slightly increased with time. In any case, the increase in inorganic portions in the bioreactor did not show any significant effect on process efficiency. Nevertheless, it is anticipated that in longer run it might affect the process. The increase in inorganic portions to a certain level could limit the biomass activities. Thus it is advisable to conduct further experiment to measure active microorganisms in the bioreactor. Operation with low HRT, the membrane cleaning process adopted in this study was found to be not sufficient to remove external membrane resistance. From the process efficiency point of view, the membrane bioreactor produced extremely good quality over the conventional activated sludge process. So the common operational problem of settleability and bulking of sludge could be utterly eliminated by the membrane bioreactor.

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