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Effects of SRT and HRT on Treatment Performance of MBR and Membrane Fouling

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Abstract**—**40L of hollow fiber membrane bioreactor with solids retention times (SRT) of 30, 15 and 4 days were setup for treating synthetic wastewater at hydraulic retention times (HRT) of 12, 8 and 4 hours. The objectives of the study were to investigate the effects of SRT and HRT on membrane fouling. A comparative analysis was carried out for physiochemical quality parameters (turbidity, suspended solids, COD, NH_3-N and PO_4^{3-}). Scanning electron microscopy (SEM), energy diffusive X-ray (EDX) analyzer and particle size distribution (PSD) were used to characterize the membrane fouling properties. The influence of SRT on the quality of effluent, activated sludge quality, and membrane fouling were also correlated. Lower membrane fouling and slower rise in trans-membrane pressure (TMP) were noticed at the longest SRT and HRT of 30d and 12h, respectively. Increasing SRT results in noticeable reduction of dissolved organic matters. The best removal efficiencies of COD, TSS, NH_3-N and PO_4^{3-} were 93%, 98%, 80% and 30% respectively. The high HRT with shorter SRT induced faster fouling rate. The main fouling resistance was cake layer. The most severe membrane fouling was observed at SRT and HRT of 4 and 12, respectively with thickness cake layer of 17µm as reflected by higher TMP, lower effluent removal and thick sludge cake layer.

Keywords**—**Membrane bioreactor, SRT, HRT, membrane fouling.

I. Introduction

MEMBRANE bioreactor (MBR) has gained considerable interest as one of the most promising treatment process concerning wastewater treatment and water reclamation. Fouling has been identified to be the major drawback for MBR future operation, expansion and upgrading. Membrane fouling leads to the membrane flux decrease, operational pressure increase and frequent membrane cleaning or replacement. It is recognized that the hydraulic performance of MBRs may be improved by the optimization of the operating conditions [1].

All the parameters involved in the design and operational conditions of MBR processes have an influence on membrane fouling. The factors are depending on the feed and biomass characteristics, operating conditions such as hydraulic retention time (HRT), solids retention time (SRT) and the type of membrane [2]. The effects of biomass characteristics are very complicated due to the fact that the mixture of activated sludge comprises of fine particles, solute, colloidal, flocs and microorganisms.

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Many investigators have reported that the biological constituents of activated sludge have a contribution to membrane fouling. A number of studies for mitigation of membrane fouling have been carried out, such as the improvement of membrane materials and modules [3]-[5], the modification of sludge characteristics [6]-[8] and the optimization of operational parameters including flux, fluid dynamics, membrane flux enhancer, vibration, chemical cleaning, ultrasonication, etc [9]-[14]. Recognizing the importance of controlling the operating conditions, this study aims to identify the effects of SRT and HRT on the performance of MBR treating synthetic wastewater. The other major focus of this work related to membrane fouling which was analyzed through the changes of trans-membrane pressure (TMP) and scanning electron microscope (SEM) of membrane.

II. Materials and Methods

A. Description of MBR

A laboratory-scale submerged membrane bioreactor was constructed and installed at the Civil and Environmental Engineering Laboratory of SEGi University, Kota Damansara. The overview of the MBR system is shown in Fig. 1. The MBR tank has an effective working volume of 40 L, in which a hollow fibre membrane module (Table I) was submerged in the central compartment.

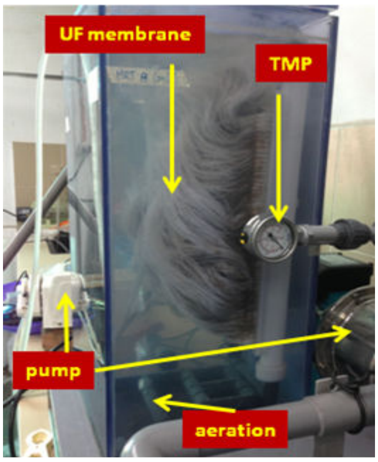

Fig. 1 The overview of the membrane bioreactor during the start-up process

The MBR was aerated from beneath the ultrafiltration module through a diffuser to provide the cross flow effect, and on the other hand to supply oxygen requirement for the biological process, and to mix the mixed liquor in the reactor. The pH value in the MBR tank was maintained at 7.2 ± 0.1 by adding NaOH - $NaHCO_3$ solution, and the dissolve oxygen (DO) concentration was controlled at 2.0 mg/L.

After a cycle of filtration period ends, where TMP readings have reached 30 kPa, the fouled membrane was cleaned following a three-step method: (i) rinsed with RO water, (ii) backwashed using air followed by water for 20min, (iii) desorbed in 1M NaOH solution (pH 12) for 24 hours.

The membrane flux of the MBR was kept constant at 4 L/m^2.h. The membrane permeate was extracted intermittently with a negative pressure pump connected to the membrane module. The MBR was operated in temperature within the range of 25 to 35^{o}C.

TABLE I
SPECIFICATION OF THE MEMBRANE MODULE

Module specification	Hollow fibre
Membrane material	Polypropylene
Inner diameter	270 µm
Outer diameter	450 µm
Pore size	0.01 – 0.2 µm
Surface area	8 m^2
Length	0.5 m^2

B. Activated Sludge Sample

The sludge samples were taken from the return sludge tank of Taman Tun Dr Ismail (TTDI) municipal wastewater treatment plant in Kuala Lumpur, Malaysia. The sludge was stored in filled plastic container during the transportation from the plant site to the laboratory.

C. Wastewater

Synthetic wastewater was used in this study instead of actual wastewater to control variable nature of nutrient concentration in raw wastewater. The feed ingredients and compositions of wastewater are included in Table II. The concentrations of the chemicals were taken from Banu et al. [15]. The synthetic wastewater was prepared periodically and stored in a refrigerator to hinder its decomposition. The acclimatization period for the sludge was approximately 40 days.

The synthetic wastewater constituted of glucose, NH_4Cl, KH_2PO_4, K_2HPO_4 and $Na_2HPO_4.12H_2O$ as primary nutrients, while $MgSO_4.7H_2O$, $FeCl_3$, and $CaCl_2.H_2O$ as trace nutrients. Sodium bicarbonate ($NaHCO_3$) was added to adjust pH between 7 and 8.

III. ANALYTICAL METHOD

A. Wastewater Quality Analysis

TABLE II
COMPOSITION OF SYNTHETIC WASTEWATER

Composition	Concentration (mg/L)
KH_2PO_4	8.50
K_2HPO_4	21.75
$Na_2HPO_4.12H_2O$	44.60
NH_4Cl	1.70
$MgSO_4.7H_2O$	22.50
$CaCl_2$	27.50
$FeCl_3.6H_2O$	0.25
$C_6H_{12}O_6$	1
Peptone	0.25

All activated sludge characteristics including COD, ammonia nitrogen, phosphates, suspended solids (SS) and volatile suspended solids (VSS) were measured according to Standard Methods [16]. The turbidity and SS were measured to indicate the performance of the sludge flocculation. The sludge volume index (SVI) was used to evaluate the settleability of the flocs. A turbidity meter (HACH, Model 2100 AN) measured the turbidity.

Particle Size Analyzer

The particle size was determined by a Malvern Mastersizer instrument with a 300mm lens which enables the measurement of particles in the range of 0.9–546µm. The activated sludge samples were continuously recycled through the sample cell of the Malven with a peristaltic pump to be exposed at a 2 mW He-Ne laser (wavelength 633 nm) at a speed of 500 m/s. The scattered light is detected by means of a detector that converts the signal to a size based on volume. The average size of the flocs given as the mean based on the volume equivalent diameter.

TABLE III
DETAILED OPERATING CONDITIONS OF MBR

Reactor	**R_{30}**	**R_{15}**	**R_4**	**R_{30}**	**R_{15}**	**R_4**	**R_{30}**	**R_{15}**	**R_4**
HRT (hr)		12			8		4		
SRT (days)	30	15	4	30	15	4	30	15	4
OLR	0.2 (kgCOD/L.day)								
Flux	4 (L/m^2.h)								
Suction cycle	10 min on/ 4 min off								

B. Membrane Fouling Analysis

Scanning Electron Microscopy with an EDX probe (SEM-EDX)

The membrane fouling was observed with scanning electron microscope coupled with energy dispersive X-ray spectroscopy (SEM-EDX) (Thermo Scientific, accelerating voltage of 20 kV, Universiti Putra Malaysia). Before SEM-EDX analysis, samples were Au-Pd coated. Most of the results were taken from the average duplicate samples.

IV. Results and Discussion

A bench-scale MBR tests were conducted to evaluate the effects of pertinent MBR operating variables, including the effects of HRT on the contaminant removals, the effects of reactor wasting and solids retention time (SRT) as shown in Table III. The MBR was monitored over a period of 103 days.

A. Influence of SRT on Effluent Quality

Chemical oxygen demand (COD), biological oxygen demand (BOD), total suspended solids (TSS), ortho-phosphorus (PO_4^{3-}) and ammoniacal nitrogen (NH_3-N) were measured in the influent and the effluent. Synthetic wastewater was fed to the MBR and the compositions are given in Table IV.

TABLE IV
Influent Parameters and Effluent Quality at Different SRT

Parameter mg/L	SRT 30 days		SRT 15 days		SRT 4 days	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
COD	1300	63 (95%)	1267	86 (93%)	1496	105 (92%)
BOD_5	538	35 (93%)	760	53 (93%)	897	79 (90%)
TSS	52	6.6 (99%)	74	9.3 (99%)	87	11 (99%)
NH_3-N	50	1.1 (98%)	65	1.4 (98%)	51	7.8 (84%)
PO_4^{3-}	10	1.9 (81%)	12.3	2.5 (79%)	9	2.8 (68%)

A satisfactory organic removal of over 93% was achieved throughout the experiment at HRT of 12h. The average effluent COD was 17mg/L or less, regardless of the soluble COD content and the operating SRT and DO. This is consistent with other MBR studies reporting an effluent COD of 18mg/L and less during the treatment of synthetic wastewater [17], [18]. Apart from COD, nitrification reduced at lower SRT. Throughout the complete period of SRT 4 days, only 84% of the influent ammonia could be removed. For higher SRT of 15 and 30 days, nitrification rates were 98%.

As was expected, for all three SRTs no particulate matter could be detected in the effluent. Hence, the membrane can be considered as an absolute physical barrier for suspended solids. The membranes performed very well throughout the experiment period, producing good quality of effluent with almost complete rejection of suspended solids. Turbidity measurements were quite low, varying from 0.04 to 0.18 NTU.

B. Influence of HRT on Effluent Quality

HRT is an important parameter in MBR operation. Lower HRT values result in higher organic loading rates (OLR), which result in reduction of reactor volumes required to achieve a specified removal performance. It will also enhance the growth of microorganisms. On the other hand, higher HRTs usually results in better removal performance.

Considering the best operational parameter was at SRT 30 days, experimental results showed that the average removal efficiencies for COD, BOD, TSS, NH_3-N and PO_4^{3-} were 95, 93, 99, 97 and 81%, respectively. Fig. 2 represents the overall percentage removal with respect to the operating condition for three different experiments evaluated at three different HRTs. The results showed that at all three HRTs employed, COD and TSS removal efficiencies was consistently higher than 93%, whereas the NH_3-N and PO_4^{3-} removal treatment were lower than 2 mg/L. It should be noted that high HRTs are suitable applied effluent treatment that contains high concentration of COD and/or BOD or for a slowly biodegradable compounds.

At SRT 15, the lowest removal achieved was for ortho-phosphorus concentration, which only 69% treated at HRT 4. This shows that membrane filtration alone is not capable to tackle phosphorus removal. Hence, biological treatment with sufficient contact time coupled with membrane could enhance the treatment.

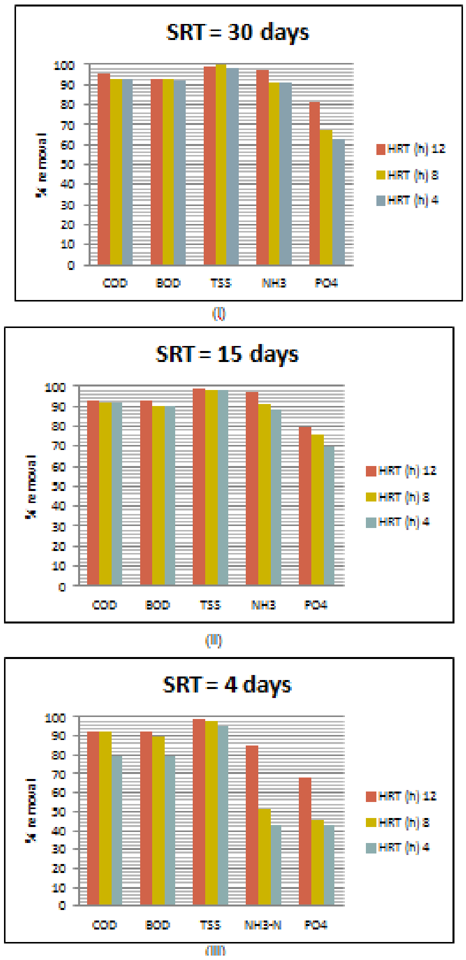

Fig. 2 Removal percentage at different SRT and HRT: (i) SRT 30, (ii) SRT 15, (iii) SRT 4 days

C. Hydraulic Performance

The membrane fouling of MBR was demonstrated by an increase of TMP readings. Temporal profiles of reversible and irreversible filtration resistance have been evaluated as shown in Fig. 3, under various operating conditions. It is obvious that SRT 4 exhibit the fastest TMP increase rate, followed by 15 and 4 days, regardless of HRT. TMP rise in the first stage might due to pore blockage and closure. Slow TMP rise prolongs in the second phase might due to deposition of membrane foulants, which either deposited from the bulk liquid or produced in biofilms on the membrane surface [19]. These results indicate that different MLSS concentration had a crucial impact on the fouling behaviour.

This experimental data indicates that an increase in biomass concentration within the reactor will increase the operational TMP (corresponding to a reduction in operating flux under hydraulic pressure operation). It appears that high SRT and HRT, hence low organic concentrations inhibit self-accelerating phenomena leading to TMP jump, thus permitting a longer sustainable filtration operation.

The duration of the initial filtration stage limited the rise of TMP. A suitable duration could form a firm cake layer, which might capture more substrate. Formation of cake layer by MLSS accelerated at high flux due to the increase of permeation drag force, which definitely will influence TMP by reducing resistance in gel layer.

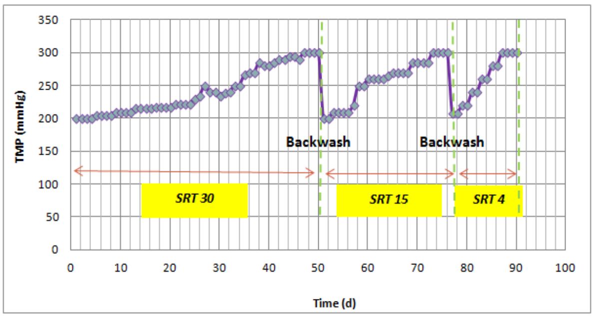

Fig. 3 TMP versus time of the mixed mode runs at HRT 12h.

D. Fouling Layer Morphology

An important consideration in the operation of MBR processes is effective control of fouling and mitigation of permeate flux decline. In order to evaluate the fouled membrane surfaces, the SEM images at magnification of 20,000 times for three different experimental conditions are shown in Fig 4. New hollow-fiber membrane surfaces were porous and free of particles. It revealed that the fouled membrane was covered with the slime gel layer and the sludge cake layer. Fig. 5 showed that the gel layer formed on membrane surfaces had a very smooth morphology while the sludge cake layer were comprises of larger particles and exhibited uneven and rough surfaces.

SEM images of fouled membrane were taken at the end of the experiment, which when the TMP reading have reached 30 kPa. It has been reported that fouling is more significant at higher MLSS concentration, and conversely that higher MLSS concentration results in less fouling under certain conditions [20]. It should be noted that the fouling layer developed in MBR operation is composed of living and dead microbes, biopolymers and inorganic compounds.

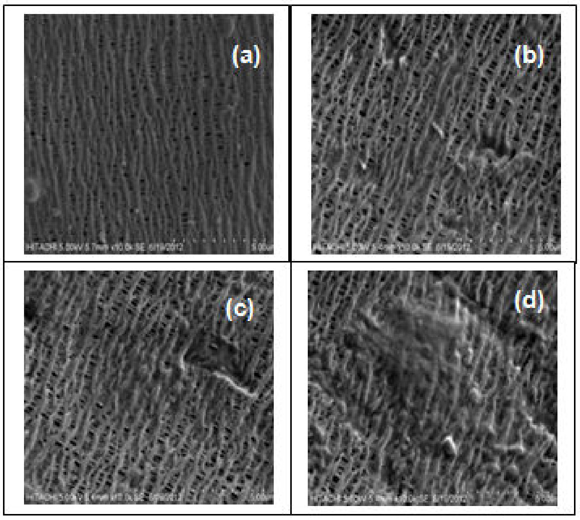

Fig. 4 SEM images of surfaces and cross section of the membrane used in this study (a) clean membrane, (b) at SRT4 (c) at SRT15 (d) at SRT30

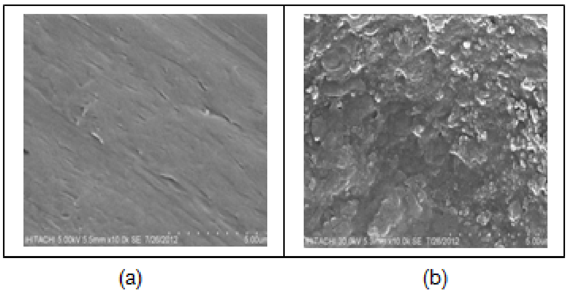

Fig. 5 SEM images of fouled membrane: (a) biofilm layer, (b) cake layer

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REFERENCES

[1] Judd, S., *The MBR book: principles and applications of membrane bioreactors in water and wastewater treatment.* London, Oxford, 2006, pp. 2-17.

[2] Le-Clech P., Chen V., Fane A.G., *Fouling in membrane bioreactors used in wastewater treatment.* J. Membr Sci. 284, 2006, pp. 17-53.

[3] Chuyang Y. Tang, T. H. Chong, Anthony G. Fane. *Colloidal interactions and fouling of NF and RO membranes: A review.* Advanced in Colloid and interface science 164, 2011, pp. 126 – 143.

[4] Pierre Cote, Zamir Alam, Jeff Penny, *Hollow fiber membrane life membrane bioreactors (MBR).* Desalination 258, 2012, pp. 145-151.

[5] Sheng Cheng, *Application of submerged hollow fiber membrane in membrane bioreactors: filtration principles, operation and membrane fouling.* Desalination 283, 2011, pp.31 – 39.

[6] Yu Tian and Xinying Su. *Relation between the stability of activated sludge flocs and membrane fouling in MBR: under different SRTs.* Bioresource Technology 118, 2012, pp. 477-482.
[7] R. Van den Broeck, P. Krzeminski, J. Van Dierdonck, G. Gins, M. Lousada, J. F. M. Van Impe, J. H. J. M. van der Graaf, I. Y. Smets, J.B. van Lier. *Activated sludge characteristics affecting sludge filterability in municipal and industrial MBRs: Unraveling correlations using multi-component regression analysis.* Journal of Membrane Science 378, 2011, pp. 330-338.
[8] Sangmin Lee and Mi-Hyung Kim. *Fouling characteristics in pure oxygen MBR process according to MLSS concentrations and COD loadings*. Journal of Membrane Science 428, 2013, pp. 323-330.
[9] M. Tiranuntakul, P.A. Schneider, V. Jegatheesan. *Assessments of critical flux in a pilot-scale membrane bioreactor.* Biosource technology 102, 2011, pp. 5370-5374.
[10] Lutz Bohm, Anja Drews, Helmut Prieske, Pierre Berube, Matthias Kraume. *The importance of fluid dynamics for MBR fouling mitigation.* Bioresource Technology 122, 2012, pp. 50 – 61.
[11] Vera Iversen, Hasan Koseoglu, Nevzat O. Yigit, Anja Drews, Mehmet Kitis, Boris Lesjean, Mathias Kraume. *Impacts of membrane flux enhancers on activated sludge respiration and nutrient removal in MBRs.* Water research 43, 2009, pp. 822-830.
[12] Muhammad R. Bilad, Gergo Mezohegyi, Priscilla Declerck, Ivo F.J. Vankelecom. *Novel magnetically induced membrane vibration (MMV) for fouling control in membrane bioreactors.* Water research 46, 2012, pp. 63-72.
[13] T. Zsirai, P. Buzatu, P. Aerts, S. Judd. *Efficacy of relaxation, back flushing, chemical cleaning and clogging removal for an immersed hollow fibre membrane bioreactor.* Water research 46, 2012, pp. 4499 – 4507.
[14] Xu Li, Jinsong Yu, A.G. Agwu Nnanna. *Fouling mitigation for hollow fiber UF membrane by sonication*. Desalination 281, 2011, pp. 23 – 29.
[15] Rajesh Banu J., Do Hac-Uan and Ick-Tae Yeom. *Nutrient removal in an A2/O-MBR reactor with sludge recycling.* Biosource Technology 100, 2009, pp. 3820-3824.
[16] APHA, *Standard Methods for the Examination of Water and Wastewater,* American Public Health Association/American Water Works Association/ Water Environment Federation, Washington, 2005.
[17] Mark D. Williams and Massoud Pirbazari. *Membrane bioreactor process for removing biodegradable organic matter from water.* Water Research 41, 2007, pp. 3880 – 3893.
[18] Min Gu Kim and George Nakhla. *Comparative studies on membrane fouling between two membrane-based biological nutrient removal systems*. J.Membr Sci., 2009, pp. 91-99.
[19] J.Zhang, H.C.Chua, J.Zhou, A.G.Fane. *Factors affecting the membrane performance in submerged membrane bioreactors*. J. Membr. Sci. 284, 2006, pp. 54-66.
[20] Winzeler, H.B., Belfort G. *Enhanced performance for pressure driven membrane processes: the argument for fluid instabilities.* J. Membr. Sci. 80, 1993, pp. 35-47.