SURVEY OF THE FOULING CHARACTERISTICS BETWEEN ATTACHED AND SUSPENDED GROWTH MICROORGANISMS IN SUBMERGED MEMBRANE BIOREACTOR

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ABSTRACT

The stringent discharge limits with the requirements of capacity treatment increase have necessitated for developing new processes in the field of environmental engineering. There are a lot of processes which have developed to replace conventional activated sludge system. Membrane bio-reactor (MBR) and attached process are two of the two powerful alternative processes to meet high removal efficiency with cost effective advantage. Membrane bio-reactor is a process which replaces of a secondary sedimentation/ tank by membrane units. The attached system is defined as activated sludge system that incorporates media in the suspended growth reactor. The purpose of combining these two systems in one reactor is to reduce the MBR problem and increase the attached biomass concentration to enhance the level of treatment provided. This report is to compare the attached growth and the suspended system in submerged membrane bioreactor to elevate the further applications for existing wastewater treatment plant.

INTRODUCTION

Throughout several decades of application and evolution of activated sludge system, this system is fairly mature and reliable. However, the activated sludge process requires a relatively low food-to-microorganism ration to ensure its stability, complete nitrification and appropriate sludge settling ability. Besides, the suspended system requires the clarifier tank to complete the treatment. Therefore, it usually employs a low volumetric loading rate and requires a large space. Plus, the slow growth bacteria, such as nitrifying bacteria, are easily to be wash out, especially at low temperature conditions and low sludge age. On the other hand, with the needs of both a population growth and stringent effluent permits, upgrading and expending existing activated sludge wastewater treatment plant is needed to be done in the near future. Cost-efficient treatment processes are to be considered recently. Hybrid systems, such as the attached system and MBR systems, are alternatives. However, the combination of the attached system and MBR process is developed to merge all of advantages in one reactor.

For biological treatment of water, there are many different biofilm systems in use, such as trickling filters, rotating biological contactors (RBC), fixed media submerged biofilters, granular media biofilters, fluidized bed reactors, etc. Figure 1 shows one of the commercial media. An attached growth bioreactor was designed to minimize the effect of suspended microorganisms. Table 1 shows the existing full-scale attached system. The advantages of the attached system are (1) accumulation of high concentration of the biomass which could increase the removal rate and maintain the high sludge age, (2) the high resistance to toxic compounds and overloading.

On the other hand, conventional membrane bioreactor is a system which incorporates filtration. Figure 2 shows the electron micrographs of commercial non-woven polypropylene (NWPP) and polysulphone (PS) membranes. As a result, the MBR has many advantages over conventional wastewater treatment processes. These include small footprint and reactor requirements, high effluent quality, good disinfection capability, higher volumetric loading and less sludge production. However, the MBR filtration performance inevitably decreases with filtration time. This is due to the deposition of soluble and particulate materials onto and into the membrane, attributed to the interactions between activated sludge components and the membrane. So, it has been found that the attached system has the poorer settling problem comparing to the conventional one. And MBR has a problem of fouling which clogs the membrane surface and reduce the flux. However, the attached membrane reactor could solve the poor settling problem which is a drawback of the attached system. Also, the carriers could collide the surface of the membrane to mitigate the fouling by aeration. By combine these two systems in one reactor, the disadvantages of each system could not only keep both of advantages together but also compensate the drawbacks each other.

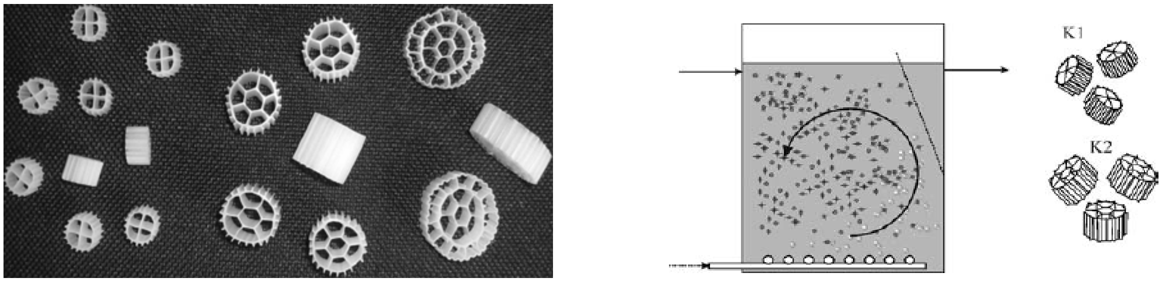


Figure 1 Photo of (from left to right) Kaldnes type K1, K2 and K3 biofilm carriers and schematic of the moving-bed-biofilm reactor (MBBR). (Rusten et al, 2006 and Leiknes and Ødegaard 2007)

Table 1 Comparison of various attached systems in wastewater treatment (Li, 2004)

Reactor Type	Test Scale	Carrier Property	Substrate	Removal Rate (kg/m^3-d)	Biomass Concentration (g/L)	References
Trickling filter	Full scale	Crushed rocks 25-100 mm 40 m^2/m^3	Municipal wastewater	0.08-0.4(BOD_5) with nitrification	N/A*	Rittmann, 2001
Trickling filter	Full scale	Crushed rocks 25-130mm 45-60 m^2/m^3	Municipal wastewater	0.3-1.0(BOD_5) without nitrification	N/A*	Metcalf & Eddy, 2003
RBC	Full scale	Circular discs, 100-200 m^2/m^3	Municipal wastewater	5-26 g BOD_5/m^2-d	N/A*	Henze, 2002
Three –phase fluidized bed	Lab scale	Granular activated carbon 1.3mm	Synthetic wastewater	1.9 (NH_3-N)	5	Cheng *et al.*, 1994
Airlift reactor	Lab scale	Basalt, 0.26mm 1150 m^2/m^3	Synthetic wastewater	5 (COD)	16	Tijjuis *et al.*, 1994a
	Lab scale	Basalt 0.26mm 1150 m^2/m^3	Synthetic wastewater	5(NH_3-N)	25	Tijjuis *et al.*, 1995
Moving bed reactor	Pilot scale	Plastic media (FLOCOR) 160 m^2/m^3	Municipal wastewater	1.5 (COD) 0.15(NH_3-N)	N/A*	Andreottola *et al.*,2000
	Pilot scale	Kaldnes elements	Municipal wastewater	3(COD)	N/A*	Ødegaard *et al.*, 1994
	Pilot scale	Kaldnes elements	Paper and pulp wastewater	12.5(COD)	N/A*	Dalentoft *et al.*, 1997
	Bench scale	Macro-porous cellulose carrier	Synthetic wastewater	12 kg N/m^3-carrier.d	N/A*	Matsumura *et al.*, 1997

Note: N/A means not available.

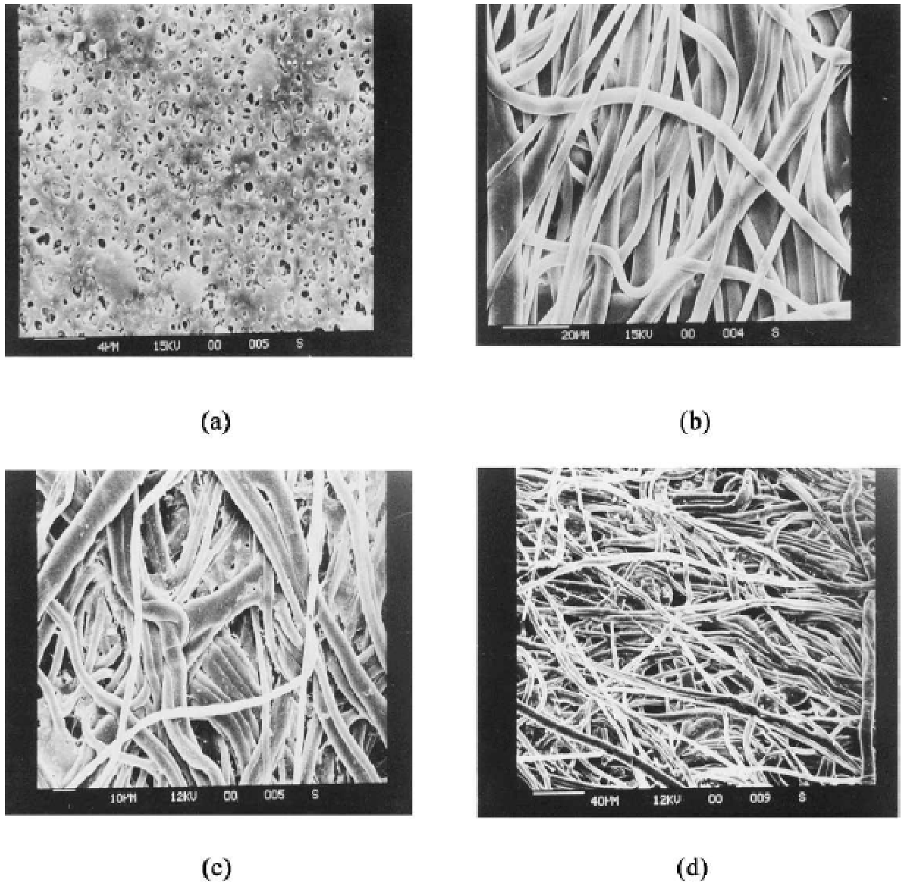


Figure 2 Electron micrographs of non-woven polypropylene (NWPP) and polysulphone (PS) membranes: (a) PS (0.3 mm); (b) NWPP (5 mm); (c) NWPP (3 mm); (d) NWPP (1.5 mm). (Chang, 2001)

THE ATTACHED SYSTEM IN MEMBRANE BIOREACTOR

The mechanism of membrane fouling by formation of cake layer in the membrane surface

It is important to understand the formation of cake layer which causes membrane fouling in order to find a way to lessen fouling rate. As membrane filtration process starts, cake is formed on the membrane surface. The cake layer offers an additional resistance for filtration. Figure 3 and 4 shows the formation of cake layer. The permeability of the cake layer can be affected by flux, electrostatic interactions, and particle size. General observations by Petsev et al. (Le-Clech et al., 2006) include:

a) When salts do not cause aggregation in the feed, the permeability of the cake layer sharply decreases with the increase in electrolyte concentration.
b) The permeability of the cake layer sharply decreases with the increase in permeate flux because the increased flux results in a more compressed cake layer.
c) The permeability of the cake layer increases with the surface potential of the particles due to the increase in the interparticle repulsion. However, above a certain value of surface potential, a plateau value for the permeability is reached.
d) The permeability of the cake layer passes through a minimum with the increase in the particle size.

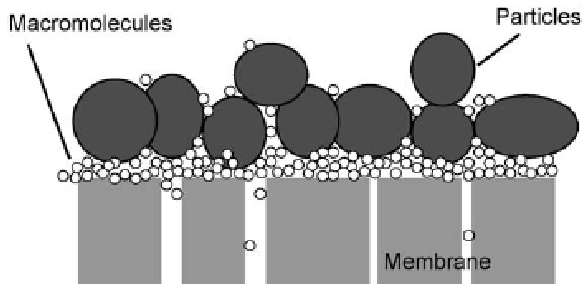


Figure 3 Composite cake structure (Le-Clech et al., 2006)

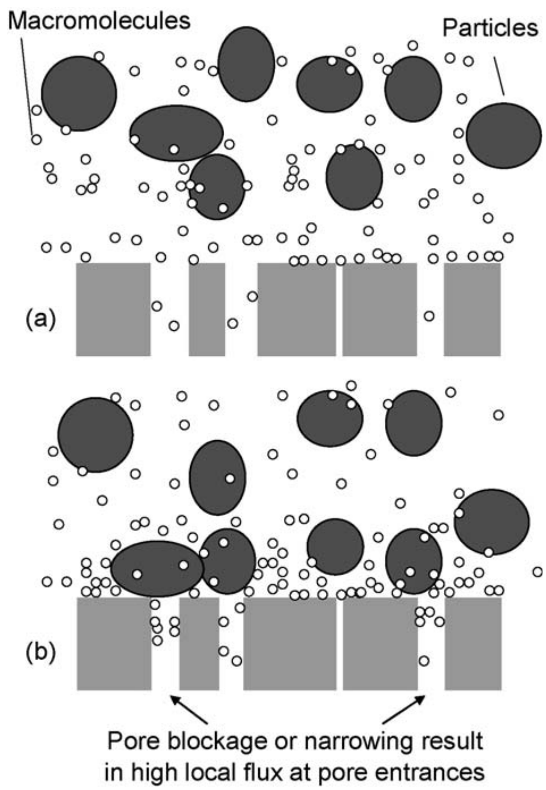


Figure 4 Fouling formation in membrane surface (Le-Clech et al., 2006)

The schematics of the attached membrane bioreactor

The typical attached membrane bioreactor consists of a bioreactor with a membrane module and media submerged in the bioreactor. There are blowers in the bottom of the bioreactor to supply air for the biomass and suspend the media in the bioreactor. The media are used to collide the membrane surface to reduce the thickness of cake layer. On the other hand, the biomass could attach on the surface of media to increase the biomass concentration and reduce the sludge production. So, the attached membrane system does not required large space, since clarifier is not need in the system. Also, retaining relatively high biomass concentration in attached membrane system over MBR or attached system would increase removal efficiency and retain nitrifiers for increasing nitrification. The lab scale attached membrane bioreactor is showed in Figure 5.

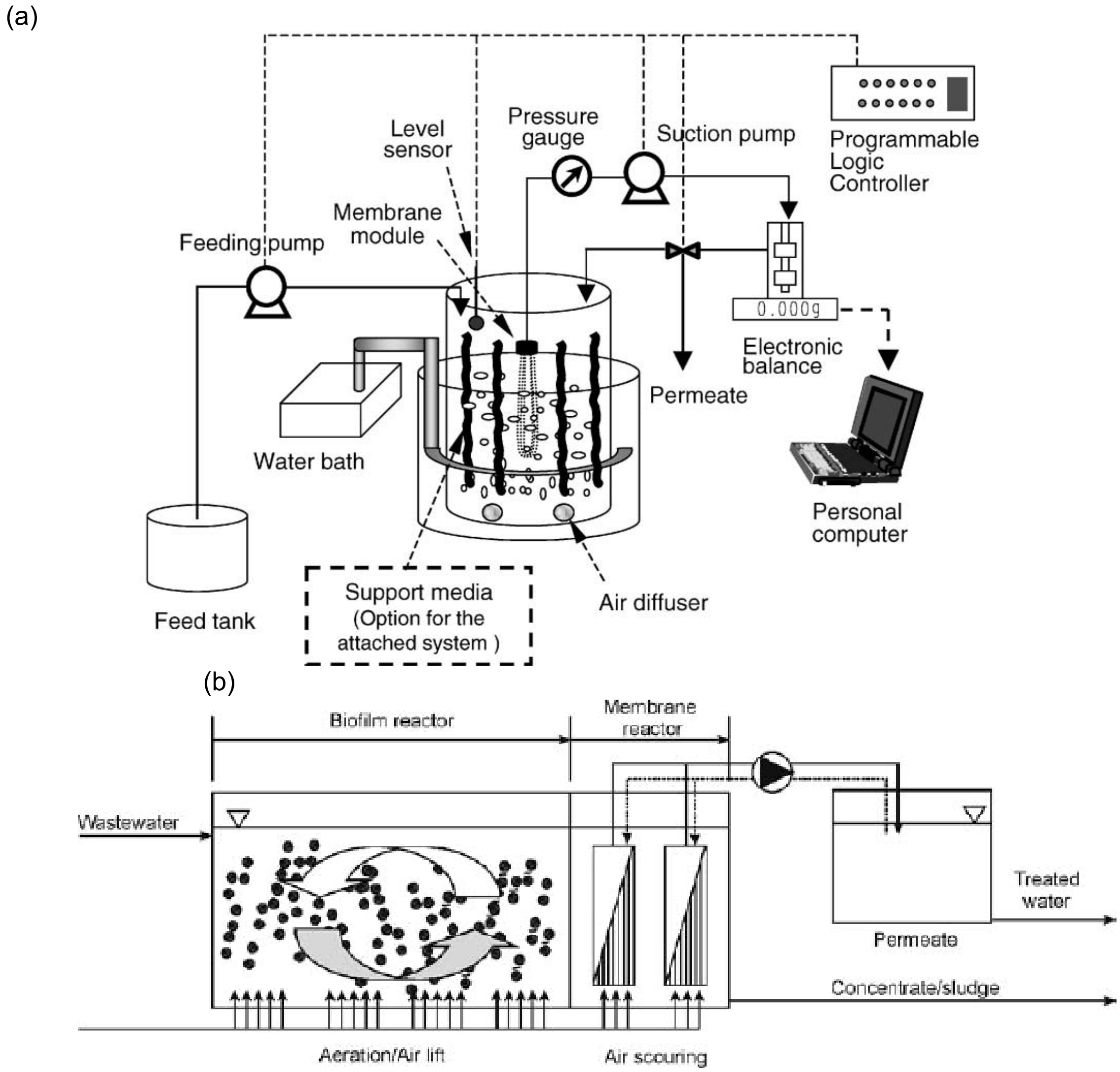


Figure 5. (a) and (b) Two typical schematics of a attached membrane bioreactor and (b) (Lee et al., 2001 and Leiknes and Ødegaard 2007)

Treatment efficiency

Table 2 shows summary of the attached membrane system operational conditions and performance. From previous studies, the influent of COD and TN varied from 1000 to 500 mg/L and 80 to 40 mg-N/L, respectively. Operational condition of HRTs and SRTs are from 2 to 8 hrs and 8 to 15 days. Flux also varied from 15 to 30 L/m^2/h. CODs of effluents in all studies were all below 30 mg/L and ammonium was not detectable. But, DO of the reactor was usually higher than 5 mg/L which consumes more energy than conventional one for media suspension.

Table 2 The summary of the attached membrane system operational conditions and performance

	Lee et al., 2006	Leiknes and Ødegaard 2007	Melin et al., 2005	Yang et al., 2006	Basu and Huck 2005	Lee et al., 2001
Influent	COD = 1,000 mg/L	COD = 7-24 gCOD/m^2d (178-242 mg/L)	COD = 4.1-26.6 g COD/m^2 d)	COD = 1310- 1810 mg/L	TOC =2.43-4.33 mg/L	COD = 250 mg/L
Effluent	COD < 20 mg/L	N.D.	COD < 50 mg/L	-	1.0-2.05 mg/L	COD = 3-5 mg/L
HRT	10 h	45-180 min	3.45-4 h	7.2	-	8
SRT	10 d	-	-	50	-	
Flux (l/m^2 h)	25	20-60	3.3-5.6	4.5	38	25
TMP	< 30 kPa	0.1-0.5 bar	0.1-0.55 bar	5-30kPa	0-8 bar	26 kPa
Medium volume fraction (%)	5-20	60-70	> 6	20	0-40	-
Air flow rate	5-9 L/min	-	-	0.15 m3/h	-	2.5 L/min
DO (mg/L)	4.9-5.1	-	-	-	-	6.0-6.2
pH	6.5-7.5	-	-	-	-	6.8-7.2
Working Volume (L)	6	-	60	10	-	5
Suspended biomass (mg/L)	4,500-5,500	-	200-800	-	-	-
Attached biomass (mg/L)	3,900-4,700	-	-	-	-	-
Membrane porous size (μm)	0.1 (Polyethylene hollow fiber)	30kD (hollow fiber)	30kD (hollow fiber)	0.1-0.2 polyethylene	Zenon ZW-1 membrane	0.1 (Polyethylene hollow fiber)
Attached media	1.3 cm Virgin polyurethane cubes coated with	7-15 mm (Polyethylene Kaldnes K1 media)	7-15 mm (Polyethylene Kaldnes K1 media)	1.0 mm	-	Biomatrix (Looped cord media)
Attached media surface area (m^2/m^2)	35,000	350	350	Porosity = 90 %	690	4.37m^2 (Total surface area)
Temperature (^{o}C)	25	-	-	-	-	25
Surface Area (m^2)	0.1	0.8	0.8	0.4	-	0.1

Comparison of fouling problem between conventional MBR and attached MBR

All of the attached membrane process stated that the fouling rate of attached MBRs were all much lower than convectional MBRs. Figure 6, 7, 8, and 9 shows permeability increases as media volume fraction and airflow rate increase. Figure 10 and 11 shows the cake layer formed on the membrane surface (A) with and (B) without the iron net. Using energy model to evaluate collide energy between the membrane surface and media. Previous studies (Sombatsompop et al, 2006) also introduced some new parameters which is the collision energy of the moving media to evaluate the mechanical carrier shear force towards the membrane surface. In the result, the increasing potential collision energy of moving media did mitigate the formation of cake layer on the membrane surface and thus improved the membrane permeability. But, the energy collision energy is proportional to the carrier velocity in the reactor which could not get persuasive date, because the values carriers circulating velocity could not evaluate without the apparatus. Also, the media could shear the surface of the non-woven membran to mitigate the fouling rate. In addition, the membrane permeability was greatly enhanced.

Figure 12 (Yang, et al., 2006) shows SEM images of cake layers on external membrane surfaces after fouling. The results stated that the fouling phonemes between conventional MBR and attached MBR were totally different. In other wrds, These observations indicate that the suspended carriers in a state of three-phase fluidity could affect the removal of cake layer by souring (physical removal of the cake layers)

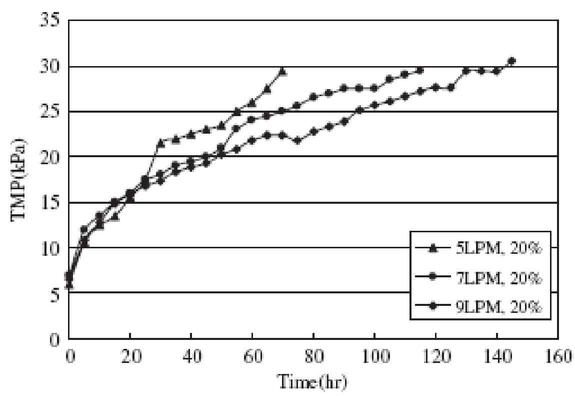


Figure 6. TMP variation as a function of air flow rate at 20% media volume fraction (Lee et al., 2006)

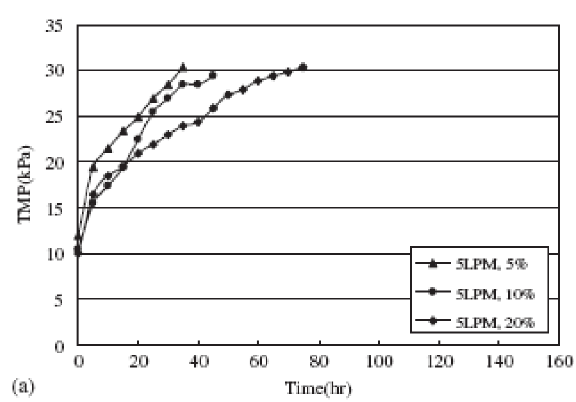


Figure 7. TMP variation as a function of media volume fraction at the air flow rates of 5LPM (Lee et al., 2006)

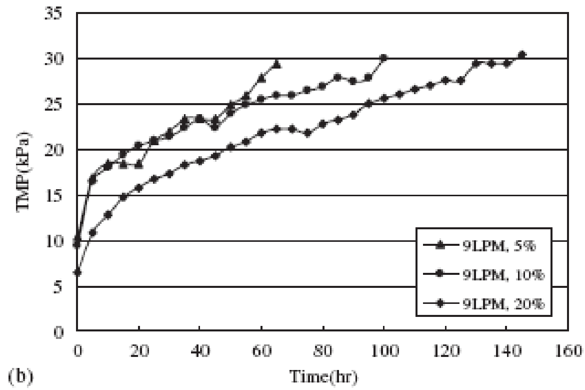


Figure 8. TMP variation as a function of media volume fraction at the air flow rates of 9 LPM (Lee et al., 2006)

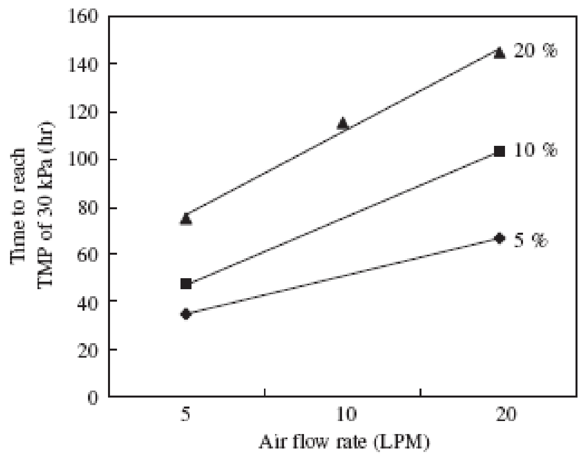


Figure 9 Time to reach TMP of 30 kPa as a function of air flow rate and media volume fraction (Lee et al., 2006)

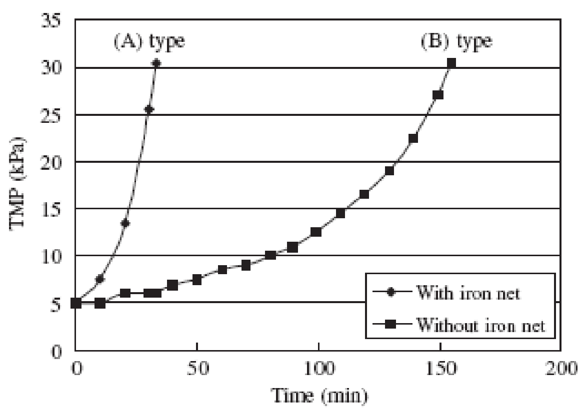


Figure 10Comparison of TMP rise-up between membrane modules with and without the iron net (Lee et al., 2006)

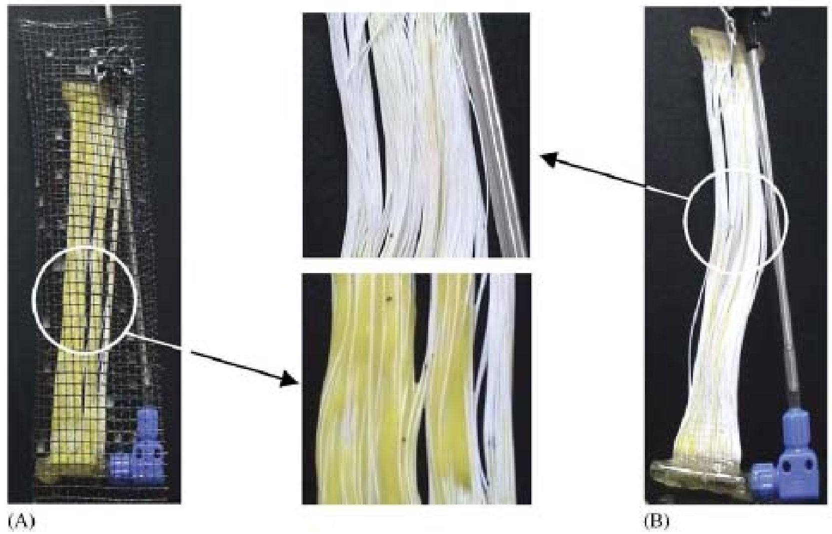


Figure 11. Comparison of cake layer formed on the membrane surface (A) with and (B) without the iron net (Lee et al., 2006)

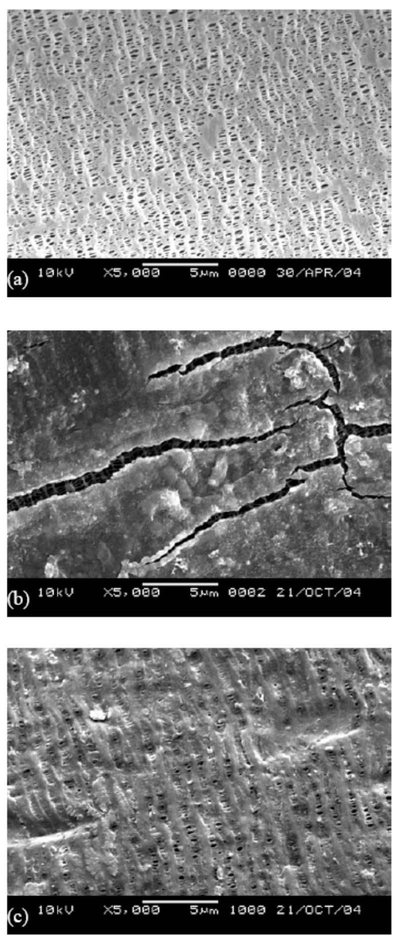
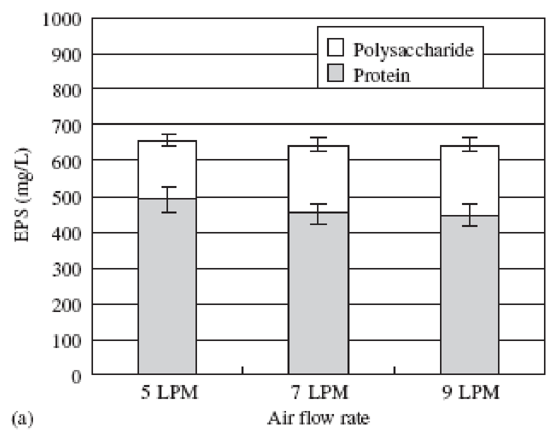


Figure 12. SEM images of cake layers on external membrane surfaces after fouling: (a) new membrane (×5,000), (b) fouled membrane for MBR (×5,000), and (c) fouled membrane for HMBR(×5,000) (Yang et al., 2006)

Biochemical parameters to evaluate conventional MBRs and attached MBRs

Soluble organic contents, such as total organic carbon and protein and extracellular polysaccharide (EPS) have been reported as key membrane foulant in MBR system. Protein and polysaccharide concentrations are known to be the main constituents of EPS (Lee et al., 2006). Fig. 13 shows bound EPS concentration in freely suspended flocs as a function of air flow rate and media volume fraction. The authors expected that bound EPS concentration would be decreased because of increase in mixing intensity and collision frequency caused by increase in air flow rate and media volume fraction. However, soluble organic contents, such as total organic carbon and protein and extracellular polysaccharide (EPS) in mixed liquor for attached membrane system and conventional membrane were not significant different. The author concluded that the mechanism of reducing fouling rate in the attached membrane system is not affected biochemical characteristics. In other words, it cause physical sour to increase permeability in the attached membrane system.



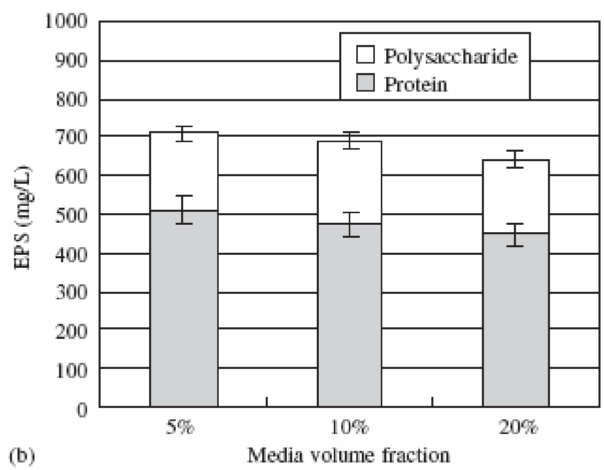


Figure 13. Analysis of bound EPS concentration in suspended flocs as a function of air flow rate and media volume fraction (Lee et al., 2006)

CONCLUSION

Despite of the high removal efficiency and low fouling characteristics of this process, the application of it (the membrane and the media) must be limited by the cost of operation and maintenance in the full scale plant. Moreover, the high aeration requirement in the system is usually higher than 5 mg/l DO for suspension of media. It is one of disadvantages of high energy obligation in this system. However, if the land of upgrading the existing facility is not available or the land is very expensive, the compact processes, such as the attached MBR system is an alternative to apply in this situation. Also, The application of the cheaper membrane and carriers, such as non-woven membrane, are required in this system for the full scale application. Furthermore, the configuration of reactor with less requirement of less aeration for circulating all of the media in the reactor is also an issue needed to be considered before the application.

REFERANCE

Basu, and O. D., and Huck, P. M. (2005) Impact of support media in an integrated biofilter-submerfed membrane system. Water research, 39, 4220

Choi, H.; Zhang, K; Dionysiou, D. D.; Oerther, D.; and Sorial, G. A.; (2006) Effect of activated sludge properties and membrane operation conditions on fouling characteristics in membrane bioreactors. Chemosphere, 63, 1699.

Changa, M. C., K.; Hornga, R. Y.; Shaoa, H., and Hub, Y. J.; (2006) Performance and filtration characteristics of non-woven membranes used in a submerged membrane bioreactor for synthetic wastewater treatment. Desalination, 191, 8.

Melin, E.; Helness, H.; Leiknes, T.; and Ødegaard, H.; (2005) Effect of organic loading raye on a wastewater treatment process combining moving bed biofilm and membrane ractors. Water science & technology, 6-7, 421.

Lee, W. N.; Kang, I. J.; and Lee, C. H.; (2006) factors affecting filtration characteristics in membrane-coupled moving bed biofilm reactor. Water Research, 40, 1827.

Leiknes, T.; and Ødegaard, H.; (2007) The development of a biofilm membrane bioreactor. Desalination, 202, 135.

Sombatsompop, K.; Visvanathan, C.; and Ben Aim, R.; (2006) Evaluation of Biofouling Phenomenon in Suspended and Attached Growth Membrane Bioreactor systems. Desalination, 201, 138.

Wang, X. J., Xia, S. Q., Chen, L., Zhao, J. F., Renault, N. J., Chovelon, J. M. (2006) Nutrients removal from municipal wastewater by chemical precipitation in a moving bed biofilm reactor. Process Biochemistry, 41, 824.

Wei, C. H.; Huang, X.; Wang, C. H. and Wen, X. H.; (2006) Effect of a suspended carrier on membrane fouling in a submerged membrane bioreactor. Water Science & Technology, 53, 221.

Yang, Q.; Chen, J.; and Zhang, F.; (2006) Membrane Fouling Control in a Submerged membrane Bioreactor with Porous, Flexible Suspended Carriers. Desalination, 189, 292.