ROLE OF MEMBRANE BIOREACTORS IN ENVIRONMENTAL ENGINEERING APPLICATIONS

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Abstract:

Replacement of conventional tertiary treatment components by membrane filtration was the first step of membrane application in water and wastewater treatment processes. Depletion of water resources, increasing water price and stringent regulation caused the development of various combination of membrane with other conventional treatment components. Membrane bioreactor is becoming one of such flourishing technology in water and wastewater treatment field. Researches are underway to find the most efficient and economical combination of biological and membrane processes for the purpose of water recycle and reuse. Based on the literature review and field experimental studies, submersible bioreactors are found economical compared with other combinations due to its low energy requirements and compact size. High energy saving, low F/M ratio, higher percentage of COD, BOD, nitrogen, pathogen removal are some of the advantages of membrane bioreactor.

Introduction:

Rapid population growth, urbanization and industrialization have exerted enormous pressure on earth's natural resources. Water, although available in large quantities, is not uniformly distributed. Most of the available water is either unsuitable for use or difficult to extract. Over extraction of available water has caused various environmental problems of land subsidence, salt-water intrusion, leaching of pollutants into ground and surface water. For example, Bangkok is experiencing an average land subsidence of 150mm per year due to over pumping of ground water. Disposal of waste generated from various activities are adding pollutants to these water bodies making these sources unsuitable without advanced water treatment. Scarcity of water in Middle East countries has caused the introduction of advanced water treatment or desalination plants to purify water suitable for their use. On the other hand increase in potable water demand and sewage volume also creating pressure on existing potable water supply networks as well as the sewer systems and it is not that easy to implement any expansion to existing systems in densely built-up cities.

After the invention of biological treatment process as a standard wastewater treatment method in late 19^{th} century (Rittmann, 1987), both aerobic and anaerobic biological treatment methods have become a common domestic and industrial wastewater treatment technology. The end products of both aerobic and anaerobic treatment processes are different. The final product of biological system, biomass is separated from the final effluent in settling tank.

The quality of the final effluent from conventional biological treatment systems depends on the hydrodynamic conditions in the sedimentation tank and the settling characteristics of the sludge. Consequently large volume sedimentation tanks offering resident times of several hours are required to obtain adequate solid/liquid separation (Fane and Fell, 1978), which increases the capital and operation and maintenance cost. At the same time close control of biological treatment unit is necessary to avoid the conditions, which lead to poor settleability and/or bulking of sludge.

Environmental awareness is continuously forcing governments to implement stringent effluent standards for wastewater to protect remaining water bodies. This forced the industries and municipal bodies to implement advanced wastewater treatment technologies. Physiochemical, chemical and biological treatment technologies alone are not been able to solve the problem. Scarcity of raw water sources, contaminated available sources, and stringent regulation supplemented by environmental awareness are some of the factors forcing the industries and water and wastewater treatment companies to look for a suitable advanced treatment technology for water treatment for potable use; and reuse and recycle of wastewater.

Some of the conventional advanced treatment technologies such as ion exchange, carbon adsorption etc. have their own disadvantages and cannot be considered reliable and long-term solution. In order to achieve, better effluent quality, membrane technologies are found effective and reliable technologies at present condition. The membrane offers a complete barrier to suspended solids and yields higher quality effluent. High effluent quality, compact size, easy to operate and maintain are some of the advantages. However, the disposal of retentate and fouling problem are some of the disadvantages. Presence of biodegradable organic compounds in contaminated water and wastewater has encouraged researchers to look for a technology, which can combine conventional biological processes and membrane processes.

Application of membrane separation (micro or ultra filtration) technique coupled with biological processes (known as Membrane Bioreactor-MBR) for biosolid separation can overcome the above disadvantages of the sedimentation tank and biological treatment step and problems with membrane separation processes. Although the concept (activated sludge process coupled with ultrafiltration) was commercialized in late 1960s by Dorr-Oliver (Smith et al., 1969) the application has only recently started to attract serious attention (**Figure 1**) and there has been a considerable development and application of membrane processes in combination with biological treatment over the last ten years.

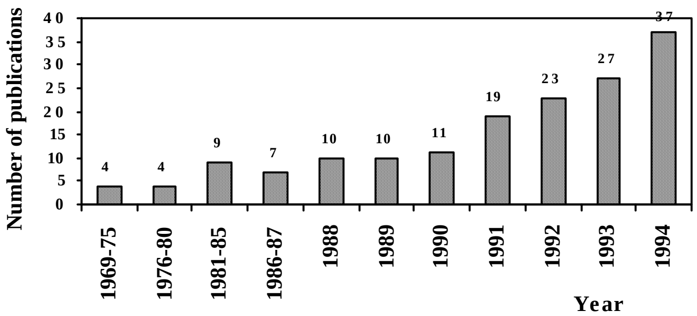

FIGURE 1. Number of Studies Published on MBR

The various advantages of MBR over conventional treatment processes are: production of excellent water quality, small foot print size of the treatment plant, reduced sludge production and the process reliability even at less attention. The objectives of this paper is to introduce the MBR concept; its development; role of MBR in Environmental Engineering applications especially water and wastewater treatment, reuse and recycle; and future research directions.

Membrane and Membrane Bioreactor Technologies:

Membrane is a selective barrier that allows specific entities to pass through, while restricting the passage of others. They exhibit selective transport properties under the influence of an external driving force. Based on the pore size and its selectivity, membranes are classified as Microfiltration (MF), Ultrafiltration (UF), Nanofiltration (NF) and Reverse Osmosis (RO). These membranes are used in water and wastewater treatment processes in order to attain the effluent of usable quality. Based on the requirement of final effluent quality, single, or a combination of different membranes is used in the processes. In wastewater treatment, use of microfiltration (for colloids/suspended solids removal) as a pretreatment followed by nanofiltration/reverse osmosis (for organic matter/salt removal) is normally practiced. The advantages of direct membrane separation are as follows.

- No biological systems involved, the operation can be shutdown readily and restarted when required without loss in water quality.
- Closed systems, breakthrough of odors and obnoxious smell can be eliminated.
- Process automation is easy thus the process control is much better.
- Product water quality does not suffer from feed water quality.
- Membrane technologies are very space efficient. A typical water reclamation facility consist of micrfiltration and reverse osmosis could occupy as little as 400 m^2 area for a capacity of 2,400 m^3/d (Johnson et al., 1996)

The second stage (NF/RO) operates at high pressure consuming high energy. The main objective of incorporating the second stage in the case of municipal wastewater is, removal of soluble organic matters. Combination of first stage with biological system can eliminate the second stage reducing significant amount of energy requirements. The benefits could be attained by this combination are stated bellow.

- Settleability of the sludge, which is the problem in conventional activated sludge, has absolutely no effect on the quality of the treated effluent. Consequently the system is easy to operate and maintain.
- Very long SRT can be maintained resulting in complete retention of slowly growing microorganisms, such as nitrifying bacteria, in the system.
- The overall activity level can be raised. In addition the system requires neither sedimentation nor any post treatment equipment to achieve reusable quality, so the space saving is enormous.
- Treatment efficiency is also improved by preventing leakage of un-decomposed polymer substances. Dissolved organic substance with low molecular weights, which cannot be eliminated by membrane separation alone, 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 water.
- Removal of bacteria and viruses can be expected, so the disinfection process is ecologically sound.
- Maintaining low F/M ratio will produce less excess sludge to be handled and treated.

- No odor dispersion can occur.

Membrane applications for wastewater treatment can be grouped into three major categories: a). biosolid separation, b). biomass aeration, and c). extraction of selected pollutants. Biosolid separation is most widely studied and has found full-scale applications in many countries.

Development of MBR:

Developments in membrane separation technology in biological wastewater treatment are schematically represented in **Figure 2** (Visvanathan et al., 2000). The conventional approach to get reusable quality water is by applying tertiary treatment techniques such as multimedia filtration, carbon adsorption, etc (Figure 2a).

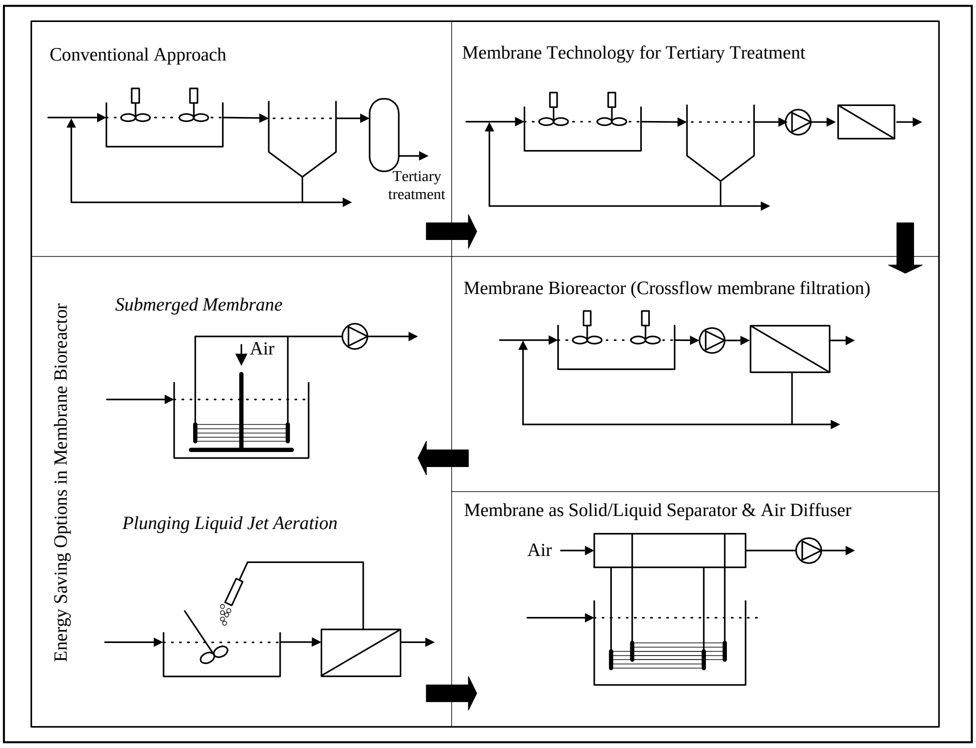

Figure 2: Developments in membrane coupled biological wastewater treatment for water reuse

The first step of the development is the replacement of these tertiary treatment methods with membrane (ultra/micro) filtration, which ensures almost bacterial and viral free effluent in addition to colloids and solid removal (Pouet et al., 1994; Langlais et al., 1992; Kolega et al., 1991) as shown in Figure 2b.

In the effort of utilizing membrane technology more effectively, the secondary sedimentation tanks in biological process were replaced with cross flow membrane filtration (Figure 2c). These solid liquid separation bioreactors employ micro- or ultrafiltration modules for the retention of biomass. Chaize and Huyard (1991) used this type of arrangement in a pilot plant study with completely mixed biological reactor connected to an ultrafltration module (MWCO=50,000 D) to treat domestic wastewater. In first run of the experiment (160 days, HRT=8h, SRT=100 days), reduction in COD from 250-550 mg/L to less than 30 mg/L; TKN from 65-150 mg/L to less than 10 mg/L was reported. The F/M ratio was found between 0.06 to 0.1 kg COD/kg MLSS.d. Second run of the experiment with different HRT and SRT

(HRT= 8, 4, 2 h; SRT = 100,100, 50 days) did not produced any significant carbonaceous removal efficiency.

However higher energy cost to maintain the cross flow velocity led to the next development of submerging membranes in the reactor itself and withdrawing the treated water through membranes (Yamamoto et al., 1989). The external circuit membrane can be outer- or inner skinned. However, the submerged membrane should be outer-skinned. A number of experimental studies were carried out on MBR with submerged membranes. More than 90% COD removal, 80% nitrate removal was reported by Yamamoto et.al (1989) using 0.1 μm hollow fiber membrane used as submerged MBR. Most importantly, the power consumption was found to be as low as0.007 kWh/m^3. Chiemchaisri (1990) used 0.1 μm hollow fiber membrane module for the treatment of low strength domestic wastewater under aerated and non aerated condition and different initial HRT of 1, 3 and 6 hours with intermittent extraction of 10:10 minutes operating time. The non-aerated bioreactor was found better over the aerated condition at an initial HRT of 3 and 6 hours due to low energy requirements to achieve similar effluent quality and process stability. The critical value of the flux was reported as 4.17 L/m^2.h.

Jet aeration in the bioreactor was studied in order to save more energy required for the aeration in biological systems (Yamagiwa et al., 1991). In this arrangement, membrane module is incorporated into the liquid circulation line for the formation of the liquid jet so that both the operation of aeration and membrane separation could be accomplished using only one pump. The jet aeration works on the principle that, a liquid jet after passing through a gas layer plunges into a liquid bath, entrain considerable amount of air. A pilot scale unit was installed and performance was investigated for 10:10 minute intermittent operation by Chiemchaisri et.al. (1993) using two numbers of hollow fiber membranes with pore size 0.03 μm and 9 m^2 surface area. The selected values jet aeration period was 0.5 and 1 hour, and jet aeration pattern was 15 and 30 minutes twice and once a day respectively. More than 90% nitrification was reported throughout the experiments. Some other studies conducted with jet aeration submerged bioreactors are Chiemchaisri et.al. (1993) (two hollow fiber membranes with 0.03 and 0.1 μm pore, 0.3 m^2 surface area; organic matter reduction > 85%; nitrification and denitrification >90%); Buisson et.al. (1998) (hollow fiber modules for upgrading wastewater treatment plants; 96% COD and 95% total Kjeldahl nitrogen (TKN) removal)

Japanese researchers conducted study on submerged flat plate membrane “Kuboto”. The system was able to remove almost 96% BOD and COD when tested with degritted sludge. The sludge production rate was reported to be 0.3 kg/kg BOD, approximately 40% of the normal ASP sludge production rate.

Use of two sets of membrane module immersed in reactor air back washing technique for membrane de-clogging was the next invention (see Figure 2e). In this technology, permeate is extracted through one module, the other one is supplied with compressed air for back washing. The cycle was repeated alternatively. Therefore there is continuous airflow into the aeration tank, which is sufficient enough to aerate the mixed liquor. Scott and Smith (1997) used ceramic membrane (0.2 μm) in an external circuit for food processing industry wastewater and were found to produce fine bubble superior to traditional aerators. More than 95% of COD and BOD reduction was reported with influent COD and BOD of 13,330 mg/L and 6,500 mg/L respectively.

Visvsanathan et al. (1997) used a 0.1 μm hollow fiber membrane module for domestic wastewater treatment and reported an improvement in flux by 370% in intermittent operation (15:15 minutes) compared to continuous operation although clogging was not completely eliminated. COD, TKN and P removal was found to be >90%, >90% and 50% respectively. Effects of TMP were also investigated and 13 kPa was reported to be the limiting pressure for all the experiments. Membrane modules are found better air diffusers than stone air diffusers by Parameshwaran et al (1998) after an experiment with two hollow fiber microfiltraiton membrane (pore size 0.2 μm). Irrespective of the operating conditions, in all experiments COD, BOD, TKN and total nitrogen removal of more than 95, 98, 95 and 80 % respectively were achieved.

Anaerobic MBR:

Application of MBR in anaerobic wastewater treatment was also reported by some researchers. Removal of colloidal and suspended solids; increase in biomass concentration without increasing the reactor volumes; improvement in treatment efficiency; removal of toxins and higher methane production rates are some of the advantages of anaerobic MBR. Septic tank membrane system was studied by Grethlein (1978). Flat sheet membrane module and helicore RO units were used in this experiment. Using 2:2 minute operating cycle, the system was able to produce effluent with very low (below detection limit) E coli and turbidity; 85-90% BOD removal (influent BOD=270 mg/L); 75% nitrate removal and excellent pH value (6.5 to 7.2).

Ross and Strohwald (1994) conducted a comprehensive study on ADUF (anaerobic digestion-ultrafiltration) process for the treatment of different industrial wastewater in South Africa. The performance of AUDF plant was encouraging with around 95% COD removal. The operating parameters and some of the results of the ADUF are given in **Table 1**. Study on wheat starch wastewater, pulp and paper wastewater, high strength SS distillery wastewater, Brewery wastewater were also conducted by various researchers (Kimura, 1991; Nagono et al, 1994; Fakhru'l Razi, 1994). In most of these studies significant amounts of COD removals (~90%) were reported.

Cost aspects of MBR:

Membrane processes are considered to be expensive in terms of investment and operating cost. However cost of potable water and the disposal cost of wastewater supported by the stringent legislation lead to the full-scale application of MBR processes in Japan (Aya, 1994). Additionally, introduction of submerged membrane in MBR processes have contributed to reduce energy requirement significantly. Submerged membranes could reduce the pumping energy requirement merely to 0.007 kwh/m^3 of permeate (Yamamoto et al., 1989) compared to more than 3 kwh/m^3 permeate required for crossflow mode. Based on the comparison made between ASP and MBR for small-scale wastewater treatment process by Visvanathan et al (2000), MBR systems seem to be more attractive than ASP in terms of land and space requirements and energy consumptions.

Table 1: Mean Operating Criteria of ADUF Plants Treating Various Industrial Effluents

	Brewery	Wine Distillery	Malting	Egg Process	Maize Process
Volume of digester (m^3)	0.05	2.4	3.0	80	2610
Operational period (month)	3	18	5	8	36
Feed COD (kg/L)	6.7	37	3.5	8	4-15
Permeate COD (kg/L)	0.18	0.26	0.8	0.35	0.3
COD removal (%)	97	93	77	95	97
Space load rates (kg COD / m^3.d)	17.0	12.0	5.0	6.0	3.0
Sludge load rate (kg COD/kg VSS.d)	0.7	0.58	0.5	0.33	0.24
HRT (day)	0.8	3.3	0.8	1.3	5.2
Temperature (^oC)	35	35	35	30	35
MLSS (kg/m^3)	30-50	50	10	10-30	23
Membrane area (m^2)	0.44	1.75	9.6	200	800
Flux (L/m^2.h)	10-40	40-80	20-40	15-30	10-70
Inlet pressure (kPa)	340	400	500	500	600
Crossflow velocity (m/s)	1.5	2.0	1.8	1.8	1.6
Tube diameter (mm)	9.0	12.7	9.0	12.7	9.0

From Ross and Strohwald, 1994

Summary:

Application of membrane bioreactors in water and wastewater treatment processes has brought a new revolution in environmental engineering. Problems associated with conventional biological and tertiary treatment systems are being solved by the application of MBR. Water treatment and wastewater reuse has become a major achievement of MBR due to its excellent effluent characteristics. Increasing production due to increasing demand has reduced the capital cost of membrane modules and low energy requirement and small land area requirements are the attraction of MBR. Continuous researches on different combination of biological processes with membrane are generating new and effective ideas of MBR combinations and it is becoming economical and easy to operate.

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