



Membrane biological reactors (MBR) and their applications for water reuse

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ABSTRACT

The term 'membrane bioreactor' expresses a combination of activated sludge and membrane separation processes. The need to processes like sedimentation and disinfection used in common methods is eliminated through MBR systems in a way that membranes are placed into or out of an aeration tank and the vacuumed wastewater created by the suction pump is pulled up from inside the membranes and leaves the Mixed Liquid Suspended Solids (MLSS) inside the aeration tank. MBR allows biological processes to work in a long SRT (20 to 100 days generally) and therefore concentration of the MLSS can increase even higher than 10000 mg/l. 93-99% removal of BOD, COD and 85-97% nitrification performance has been proved by different experiments. Membrane filtration removes biological pollutants, particulate materials and colloid dilution, turbidity, microorganisms, suspension impurities and elements such as iron and manganese. Concerning the advantages of this system, smaller required space due to the omission of sedimentation tank, extra disposable sludge production reduction about 60-75 percent, constant effluent quality and its independence from influent can be mentioned. Membrane fouling and its periodic replacement are the main disadvantages of this system. Membrane bioreactor technology can be used as a technology to treat different types of wastewater and to produce effluent with a good and suitable quality for reusing.

Key words: Membrane bioreactor (MBR), Activated sludge, Membrane fouling, Ultra filtration, Wastewater treatment.

INTRODUCTION

Nowadays, because of the shortage of water resources and continuous quality degradation, it is clearly essential that new generations of treatment processes have to be defined to achieve:

- Disinfection without any oxidation step that induces carcinogen molecule formation,
- Possibility of compactness to optimize aesthetics, environmental impact (odor and noise),

- Reliability notwithstanding the influent characteristic variation,
- Standards regarding sustainability (energy, chemicals and waste production) [1].

The membrane bioreactor (MBR) holds the potential to become one of the new generation treatment processes. This system is based on the combination of a suspended biomass reactor and a separation step on porous membrane filtration [1,2]. The first reported application of MBR technology was in 1969, when an ultrafiltration membrane was used to separate activated sludge from the final effluent of a biological wastewater treatment system and the sludge was recycled back into the aeration tank [3,4]. Since then, the MBR system has evolved, and research on MBR technology has increased significantly, particularly in the last 5 years [4,5]. Table 1 shows the historical way of evaluation of MBR and the companies that developed and improved this system and the technology that they used [7].

Table 1. The evolution of MBR [7] Table 1. The evolution of MBR [7]

| Time | Event | Technology |
|-------------|---|------------------------------------|
| Late 1960s | Dorr Oliver develops first MBR | Pressurized flat-sheet |
| Early 1970s | Thetfords-Systems (ZENON) commercialized Cycle-Let® for water reuse in USA. | Pressurized tubular membrane |
| Early 1980s | TechSep (Rhone-Poulence) commercializes PLEIADE for water reuse in Japan. | Pressurized flat-sheet |
| Mid 1990s | Nitto- Denko files a Japanese patent on a immersed MBR. | Immersed flat-sheet |
| | University of Tokyo experiments with hollow fiber MBR. | Immersed flat-sheet |
| Early 2000s | Kubota commercializes an MBR in Japan. | Immersed flat-sheet |
| | Mitsubishi Rayon commercializes an MBR in Japan. | Immersed unsupported. |
| | Zenon commercializes ZeeWeed® in North America and Europe. | hollow fibers |
| | | Immersed reinforced hollow fibers |
| Early 2010s | USF commercializes Memjet. | Immersed unsupported hollow fibers |
| | Puron (Germany) introduces a copy-like version of ZeeWeed®. | Immersed reinforced hollow fibers |
| | Kolon and Para (Korea) introduce copies similar of ZeeWeed®. | Immersed reinforced hollow fibers |
| | Toray introduces a copy-like version of Kubota module. | Immersed flat-sheet |
| | Mitsubishi Rayon replaces their fine hollowfiber with a braid based HF-membrane. ZeeWeed® | Immersed reinforced hollow fibers |

Membrane bioreactor (MBR) technology is a promising method for water and wastewater treatment because of its ability to produce high-quality effluent that meets water quality regulations [4]. The

advantages of the MBR system over conventional biological treatment processes such as less sludge production, longer SRT and better effluent quality spur the growing interest in MBR technology for water and wastewater treatment [4,6].

MATERIALS AND METHODS

There are broadly four categories of membrane types, with classification being dependent on the pore size of the membrane. These categories, from smallest to largest pore size, are reverse Osmosis (RO), Nanofiltration (NF), Ultrafiltration (UF) and Microfiltration (MF) [6,8,9,10]. The effect of increasing the pore size of the membrane has a marked effect on the performance of the membrane and the quality of the filtered effluent. MF membranes will essentially reject particulate matter, whilst RO membranes are capable of rejecting macromolecular fractions, such as dissolved salts [8,9,11]. Historically, membranes have not been commonly used for the treatment of sewage effluents. Today, however, there are several large-scale membrane treatment plants being used for sewage treatment. One of the most promising newer technologies is the membrane bioreactor (MBR), a process that couples membrane filtration with biological treatment to achieve excellent effluent quality with a small design footprint [8,9,10,11]. The influent to the membrane is known as the feedstream, the liquid that passes through the semipermeable membrane is known as permeate and the liquid containing the retained constituents is known as the concentrate (also known as retentate) [6,9]. In the membrane field, the term module [Fig 1] is used to describe a complete unit comprised of the membranes, the pressure support structure for the membranes, the feed inlet and outlet permeate and retentate ports, and an overall support structure. The principal types of membrane modules used for wastewater treatment are (1) tubular, (2) hollow fiber, and (3) spiral wound. Plate and frame and pleated cartridge filters are also available but are used more commonly in industrial applications. Two types of membrane modules are most commonly used in MBR:

Hollow Fiber

The hollow-fiber membrane module consists of a bundle of hundreds to thousands of hollow fibers. The entire assembly is inserted into a pressure vessel. The feed can be applied to the inside of the fiber (inside-out flow) or the outside of the fiber (outside-flow).

Plate and Frame

Plate and frame membrane modules are comprised of a series of flat membrane sheets and support plates. The water to be treated passes between the membranes of two adjacent membrane assemblies. The plate supports the membranes and provides a channel for the permeate to flow out of the unit. The plate and frame configuration is used most commonly for electrodialysis modules [9].

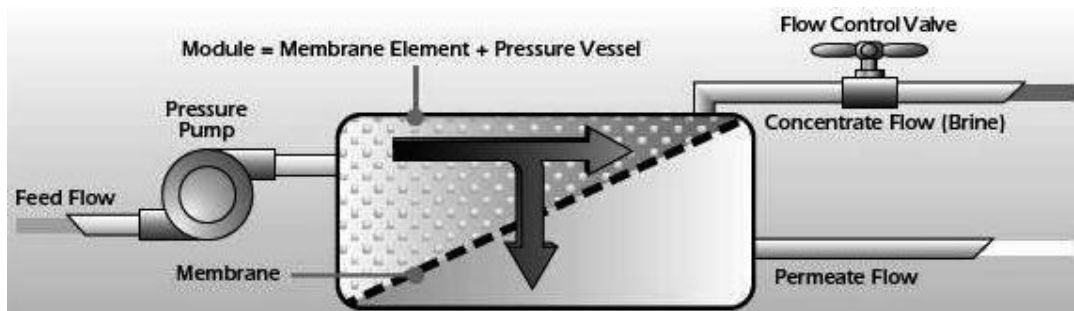


Fig. 1. a module configuration

Types of MBR

Basic MBR configurations are shown in Fig 2. The first is a recirculated configuration with an external membrane unit (Fig. 2.b). Mixed liquor is circulated outside of the reactor to the membrane module, where pressure drives the separation of water from the sludge. The concentrated sludge is then recycled back into the reactor. The second is a submerged configuration with the membrane module immersed in the activated sludge (Fig. 2.a). A suction force is applied to draw the water through the membrane, while the sludge is retained on the membrane surface. A manifold at the base of the reactor diffuses compressed air within the reactor, providing oxygen to maintain aerobic conditions. The air bubbles also function to scour the membrane surface and clean the exterior of the membrane as they rise in the reactor. The submerged configuration is more commonly used than the recirculated configuration because it is less energy-intensive and provides a cleaning mechanism to reduce membrane fouling [5,6,8].

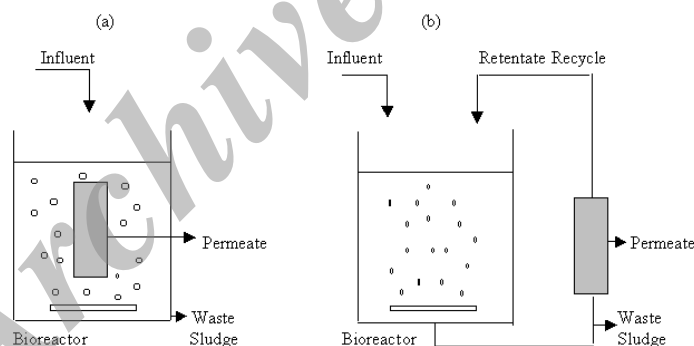


Fig. 2. (a) Submerged MBR configuration (b) External MBR configuration [5].

Membrane Fouling

Major problem in MBR

In recent reviews covering membrane applications to bioreactors, it has been shown that, as with other membrane separation processes, membrane fouling is the most serious problem affecting system performance [12]. Fouling leads to a significant increase in hydraulic resistance, manifested as permeate flux decline or transmembrane pressure (TMP) increase when the process is operated under constant-TMP or constant-flux conditions respectively. Frequent membrane cleaning and replacement is therefore required, increasing significantly the operating costs [6]. This membrane fouling is dependant

on various parameters concerning the suspension characteristics, the membrane characteristics and the operating conditions (Fig. 3)[1,13,14]. Membrane fouling results from interaction between the membrane material and the components of the activated sludge liquor, which include biological flocs formed by a large range of living microorganisms along with soluble and colloidal compounds. The suspended biomass has no fixed composition and varies both with feed water composition and MBR operating conditions employed. Thus though many investigations of membrane fouling have been published, the diverse range of operating conditions and feedwater matrices employed, and the limited information reported in most studies on the suspended biomass composition, has made it difficult to establish any generic behaviour pertaining to membrane fouling in MBRs specifically [6].

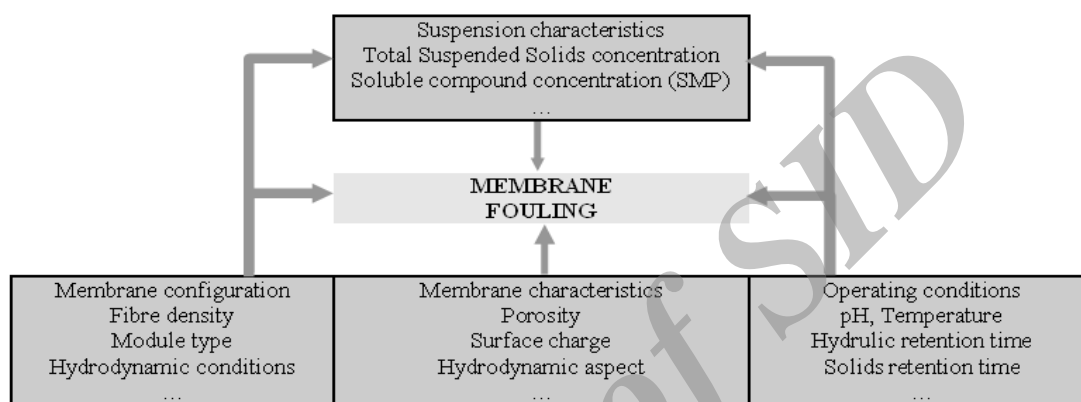


Fig. 3. Key parameters in membrane fouling.

Fouling control

Three families of compounds (particular compounds, colloidal and soluble compounds) take part in membrane fouling that can be considered to be either reversible or irreversible (Fig. 4). A long-term diminution in flux which is not recovered by simple hydrodynamical techniques is indicative of irreversible fouling, and this is often attributable to colloidal deposition or soluble adsorption onto the membrane [13, 14]. Chemical cleanings are necessary to eliminate such fouling. The deposition of particular compounds is considered as reversible fouling and can be avoided by suitable filtration conditions. Indeed, this deposition of solids and high-molecular weight compounds can be controlled during the operation by achieving specific cleaning procedures by means of high shear stress at the membrane surface [1].

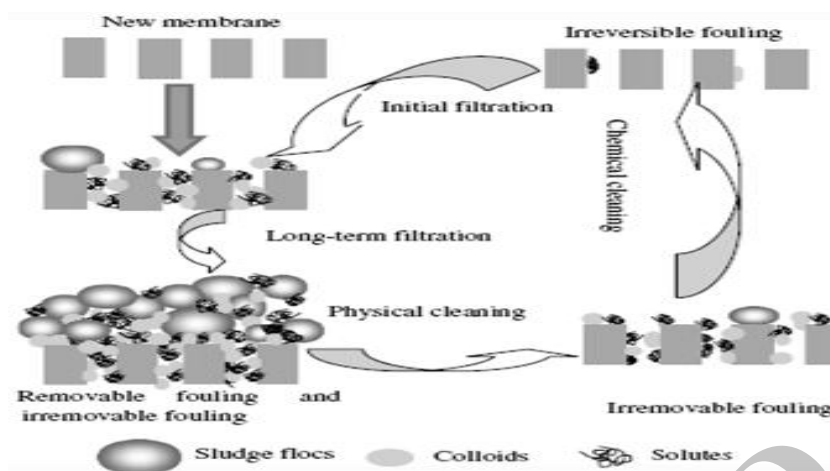


Fig. 4. Schematic illustration of the formation and removal of removable and irreversible fouling in MBRs.

Many other anti-fouling strategies have been proposed for MBR applications. They comprise, for example, intermittent permeation, where the filtration is stopped at regular time interval for a couple of minutes before being resumed. Particles deposited on the membrane surface tend to diffuse back to the reactor; this phenomena being increased by the continuous aeration applied during this resting period. Membrane backwashing is another common anti-fouling technique, where permeate water is pumped back to the membrane, and flow through the pores to the feed channel, dislodging internal and external foulants. A small amount of cleaning agents (like hypochloride) could be added to the permeate water to improve the removal efficiency. Because of the relative long time necessary to build up liquid back-pressure, the efficiency of the liquid backwash is somehow limited as the liquid prefers to go through open (not fouled) pores. This could be improved by using pressurized air in the permeate side of the membrane to build up and release a significant pressure within a very short period of time. Membrane modules therefore need to be in a pressurized vessel coupled to a vent system. Air usually does not go through the membrane. If it was, the air would dry the membrane and a rewet step would be necessary, by pressurizing the feed side of the membrane [6,12].

Advantages and disadvantages of MBR

Advantages

- MBR produce extremely good quality filtered effluent with less than 1 NTU turbidity and less than 5 mg/L BOD consistently.
- MBR improves effectiveness of biological process by allowing it to operate at high solids concentration and eliminating problem such as sludge bulking, sludge rising, nocardia Foam, etc.
- When used before RO, MBR eliminates need for secondary and tertiary treatment equipment. In spite of this, the filtered water quality is acceptable to RO which operates smoothly.
- Single package unit with minimum civil construction.
- Low energy consumption.
- Filtration Up to 6 log (99.999%) removal of total coli form.

- No chemical required during treatment.
- MBRs typically operate at higher biomass concentrations than conventional biological treatment processes. The advantage that this provides is increased volumetric loading and less sludge production, which in turn lowers capital investment costs for civil works and reduces sludge disposal costs.
- Potential Reuse of effluent water.
- Higher rate of nitrification and denitrification.
- Greater control of longer SRT allow for retention and degradation of slowly biodegradable contaminant.
- Constant effluent quality and its independence from influent [4,8,9,15,16,17,18,19].

Disadvantages

- High investment and operation cost.
- Membrane lifetime and replacement.
- Membrane fouling problem [4,8,9,15,20,21].

MBR application in wastewater treatment

Today MBR systems are most widely used in treatment of wastewater (industrial and municipal) in many countries of the world like USA, England, Germany, Norway, Denmark, Netherland, Kuwait, UEA and specialty countries from Fareast of Asia such as Japan, South Korea and china. MBRs are used for the the treatment of chemical wastewater, oily wastewater, Landfill Leachate, Color Industry, Leather Industry, Dying Industry, Paper Industry, Dairy Industry, Hospitals and Lab waste water Liquid, hazardous waste water, Waste Oil Processing, Chemical-pharmaceutical waste water, Tank cleaning waste water, Groundwater redevelopment, Automobile Industry, Laundry waste water, municipal wastewater and gray water [6,15,16].

Process Capabilities

The treatment capability of MBR is evaluated in terms of BOD, TSS, coliform, and nitrogen removal based on laboratory, pilot-plant, and full- scale plant studies. Because the activated- sludge effluent from MBRs is treated by filtration through a nominal 0.10 - 0.40 μ m membrane, very low concentrations of effluent suspended solids, turbidity, and BOD are produced that provide an effluent suitable for water reuse following disinfection. Reported operational and performance characteristics for MBR systems are summarized in Table (2,3). Low effluent BOD and turbidity concentrations are possible for MBR systems with MLSS concentrations in the range of 6000 to 16,000 mg/L. Full- scale and pilot- plant systems have been operated with the anoxic/aerobic MLE biological nitrogen- removal process with the result that effluent total nitrogen concentrations of <10 mg/L have been achieved (Mourato et al., 1999; ReVair et al., 2000; and Giese et al., 2000). Influent recycle flowrate ratios of 4.0 to 6.0 have been used in those studies to feed nitrate to a separate preanoxic tank [6,9]. Table 3 gives the results of comparison of the MBR performances with the performances of conventional treatment processes [1,22,23].

Table 2. Operational data [9]

| Parameter | Unit | range |
|----------------|----------------------|-------------|
| COD loading | Kg/m ³ .d | 1.2-3.2 |
| MLSS | mg/L | 5000-20.000 |
| MLVSS | mg/L | 4000-16.000 |
| F/M | g COD/g.MLVSS.d | 0.1-0.4 |
| SRT | d | 5-20 |
| τ | h | 4-6 |
| Flux | L/m ² .d | 600-1100 |
| Applied vacuum | kPa | 4-35 |
| DO | mg/L | 0.5-1.0 |

Table 3. Performance data [9]

| Parameter | Unit | range |
|--------------------------|------|-------|
| Effluent BOD | mg/L | <5 |
| Effluent COD | mg/L | <30 |
| Effluent NH ₃ | mg/L | <1 |
| Effluent TN | mg/L | <10 |
| Effluent turbidity | NTU | <1 |

Table 4. MBR performance vs. conventional processes

| | Raw water | | | | Treated water | | | |
|--------------------------|-----------------------------|-----------------------------|--------------------|-------------------|-----------------------------|-----------------------------|--------------------|-------------------|
| | TSS (kg/m ³) | COD (kg/m ³) | Turbidity (NTU) | Germs (/100ml) | TSS (kg/m ³) | COD (kg/m ³) | Turbidity (NTU) | Germs (/100ml) |
| Trickling bed | 0.2 | 0.7 | 120 | 10 ⁸ | 0.035 | 0.125 | 10 | 10 ⁶ |
| Activated sludge | 0.2 | 0.7 | 120 | 10 ⁸ | 0.030 | 0.080 | 5 | 10 ⁶ |
| Physico-chemical process | 0.2 | 0.7 | 120 | 10 ⁸ | 0.060 | 0.130 | 20 | 10 ⁷ |
| MBR | 0.2 | 0.7 | 120 | 10 ⁸ | 0 | 0.020 | <2 | <10 ² |

COMMERCIAL MBR SYSTEMS

The two main suppliers of MBR systems for wastewater treatment are Kubota (Japan) and Zenon (USA). Other suppliers are Degremont (France), X-Flow (Netherlands), Membratek (S. Africa), Orelis/Mitsubishi (Japan), US Filter (USA), Wehrle Werk (Germany), etc [5,7].

Kubota

Kubota uses a flat sheet membrane made of polyolefin with a non-woven cloth base giving a nominal pore size of 0.4mm. Each membrane cartridge consists of solid acrylonitrile butadiene styrene (ABS)

support plate with a spacer layer between it and an ultrasonically welded flat sheet membrane on both sides. The typical membrane cartridge (Type 510) has dimensions of 1.0m (H) x 0.49 (W) x 6mm thick-filtered water passes through to the interior of each membrane to an outlet nipple cast into the top of the support plate. Each cartridge provides an effective filtration area of 0.8m². The Kubota MBR operates with membrane treatment units submerged in the reactor in which the MLSS is maintained within the range of 15,000 to 20,000mg/L. The standard Kubota unit has a glass fibre reinforced plastic casing and consists of 2 sections. The upper section contains up to 150 membrane cartridges, each connected to a filtered effluent manifold with a gap of approximately 7mm between cartridges. The lower section is a matching unit containing a coarse bubble diffuser. The lower section supports the upper section and directs the mixture of air bubbles and mixed liquor between the membrane cartridges in the upper section. This air-water mixture maintains an upward cross flow over the membrane surface of approximately 0.5 m/s, minimising fouling of the membranes. The minimum air requirement is 10L/min.cartridge. The Kubota system operates by gravity, with a head of 1-1.5m above the membranes sufficient to drive permeate through the membranes. Grit removal and fine (2-3mm) screening are prerequisites prior to the MBR. The membrane flux for the Kubota system is approximately 20L/m².h (submerged system at a TMP of ~0.1bar). Chemical cleaning of the membranes is required every 3-6 months using sodium hypochlorite and oxalic acid. Cleaning requires 3L of chemical solution per cartridge and the cleaning cycle takes upto 2 hours. Kubota has a reference list of over 400 plants treating domestic and industrial wastewater, with most of the sites located in Japan. The Kubota plants range in size from systems to treat the equivalent of individual households to the 23,000 EP (5,800m³/d ADWF) plant at Swanage in the south of England. The Kubota technology is to be utilized at a new MBR plant (2,000 EP) to be built at Magnetic Island in Queensland [6,8,10,11].

Zenon

Zenon markets the ZenoGem system, based on the ZeeWeed membrane, which is a hollow fibre with an external diameter of 1.9mm and a nominal pore size of 0.4mm. The fibres are mounted on vertical frames into modules with filtered effluent passing into the centre of the fibre and extracted from both ends. The ZW-500 module is 2.0m (H) x 0.7m (W) x 0.2m thick with 46m² of filtration surface area. Cassettes are made up of 8 modules each. Air is supplied to the system by a combination of coarse bubble aerators integrated into the bottom header of modules, to gently agitate the membrane fibres and to keep the tank contents mixed, and by fine bubble aeration to supply the balance of the total biological oxygen demand. The filtration capacity is in the range of 40-70L/m²h under a driving transmembrane pressure of 10-50 kPa. This pressure is provided by the head of water over the membranes and by maintaining a negative pressure on the permeate side using conventional centrifugal pumps. Sludge wastage is claimed to be 1.5-2.0% of the influent flow.

ZenoGem biological design parameters are:

- MLSS 15,000-20,000mg/L
- F: M < 0.2kg BOD/kg MLSS.d
- Volumetric Loading 1.8-5.7kg BOD/m³.d
- HRT > 2 hours
- SRT > 15 days
- Flux 15-25 L/m².h (TMP of ~0.5 bar)

In addition to the scouring action of the coarse bubble aeration, cleaning of the membranes to control fouling is provided by automatic pulses of backwashing with stored permeate and periodic in-situ membrane cleaning with a hypochlorite solution or other chemicals.

Zenon has a reference list of over 150 plants treating domestic and industrial wastewater [6,8,10,11].

CONCLUSION

MBR technology is widely accepted today as the key technology for wastewater treatment. Almost globally, the MBR approach is used for wastewater reuse or to provide superior effluent quality.

The system showed a high robustness providing a fairly constant effluent with a large reduction of the entry pollutants and thus providing a highly reliable operation. High TSS, COD, BOD, NH_4 and TN removal efficiencies up to 97, 94, 95, 98 and 81% respectively were achieved. The implementation of MBR will also reduce the space required and provides room for future expansion. Recently, rapidly decreasing membrane costs is another important driving force for the widespread application of MBRs. Many regions in the world even south of Europe are suffering an acute lack of water. One way to solve this hydric deficit is to use membrane bioreactors (MBR) to reuse the treated wastewater in tasks where drinking water is not required, e.g. irrigation.

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