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Scope of aerobic and anaerobic membrane bioreactor in industrial wastewater treatment

Soumyadeep Bhaduri* and Debabrata Mazumder

Department of Civil Engineering, Indian Institute of Engineering Science and Technology (IIEST), Shibpur, Howrah-711 103, West Bengal, India

E-mail: bhaduri.soumyadeep@gmail.com

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The objective of this paper is to present the current status of membrane bioreactor in industrial wastewater treatment. Membrane bioreactor has been used in treating various type of industrial wastewater due to its advantages over conventional biological treatments. Membrane bioreactors are used in industries like textile, tannery, petrochemical, food processing, pharmaceutical, etc. Membrane bioreactor is used in either in external module or in submerged module. In external module a separate unit after the aeration tank is introduced for solid liquid separation whereas in submerged module the membrane is put inside the aeration tank. The COD removal efficiency of a membrane bioreactor is very high. Moreover, the nitrogen removal is more as sludge can be retained for more time which increases the amount of nitrogen removing organisms. The membrane bioreactor is still not widely adopted because of membrane fouling and high energy demand. Modification of the process can mitigate these problems.

Keywords: Membrane bioreactor, industrial wastewater, aerobic treatment, anaerobic treatment membrane fouling.

Introduction

Membrane bioreactor (MBR) is a hybrid of biological treatment and membrane filtration process[1]. Membrane bioreactor can treat wastewater up to such a level that it renders the effluent fit for discharge into any water body. This process was first reported by Smith *et al.*[2]. First, large-scale MBR was used in 1998 in North America to treat a food industry wastewater[3]. In membrane bioreactor membranes with a wide range of pore size is used starting from ultra-filtration to nanofiltration membrane. The membrane separation process occurs because of difference in pressure between permeate side and retentate side. Suction pressure is induced by centrifugal pump in permeate side. This pressure difference between permeate and retentate side is called transmembrane pressure (TMP). This pressure can be constant throughout the process or can be increased with time. The initial transmembrane pressure depends on the pore size of the membrane. The flow of permeate through the membrane i.e. flux is directly proportional to the TMP at lower TMP and is independent at high TMP[4]. MBR is used in two modes either as a separate unit after the aeration tank or as a movable attachment inside the aeration tank[4]. The MBRs can be used for aerobic treatment as well as in anaerobic treatment. The aerobic MBR (AeMBR) is successfully treating high-strength industrial wastewater of many industries. The main advantages of AeMBR are good effluent quality, independent control over sludge retention time and hydraulic retention time and small foot-print[5]. MBR is employed in treating wastewater in industries like textile, petrochemical, pharmaceutical, and also in leachate treatment. The membrane fouling and energy requirement are the main problems with AeMBR[6,7]. Anaerobic MBR (AnMBR) is suitable to treat a variety of wastewater. AnMBR uses less space and energy as compared to AeMBR. However, the AnMBR has a small share of the global MBR market as the fouling problem is more severe than AnMBR.

Application of MBR in industrial wastewater treatment

Generally industrial wastewater contains high-strength. But, other crucial characteristics are extreme pH condition, high TDS, toxicity[8]. The mode of the application of the MBR is determined by the unique characteristics of each specific industrial wastewater.

Table 1. Performance of AeMBR in industrial wastewater treatment

Industry	COD (mg/L)	HRT	SRT	COD removal (%)	Ref.
Paper-recycling wastewater	1376–1607	36 h	48 d	92–99	9
Pharmaceutical and chemical wastewater	1898± 532	14 days	30–51 d	80	14
Oil refinery wastewater	195–590	24 h	_	97	11
Pharmaceutical and chemical wastewater	700–1500	18–24 h	25 d	99	15
Dairy industry wastewater	2163–2604	36 h	10	97–98	48
Tannery wastewater	4050	48–96 h	30–90 d	70–90	49

Application of AeMBR:

The MBR is used in treatment of paper recycling wastewater with hydraulic retention time (HRT) 36 h and sludge retention time (SRT) up to 48 days. The MLSS was maintained at 4320–7500 mg/L at a temperature 20°–25°C. Removal of the chemical oxygen demand (COD) took place in a range of 92–99%. Total nitrogen (TN) removal efficiency was up to 92%[9]. Nitrification was observed in treatment of pharmaceutical and chemical industrial wastewater and 98.3% ammonia removal took place with effluent value of 0.56 mg/L NH_4-N[10]. The performance of AeMBR for treatment of industrial wastewater is presented in Table 1. Treatment of oil refinery wastewater was done using AeMBR with an MLSS of 8200–8500 mg/L. The maximum COD removal achieved was 97%[11]. High MLSS concentration is helpful in improving efficiency of the treatment but, also increase membrane fouling tendency[8,12]. It was observed that higher ammonia oxidation takes place when C/N ratio is maintain as high as 9.3 instead of lower value like 1.6[13]. MBRs have applicability potential for industrial wastewater but membrane fouling remains a big challenge for its faster acceptance. Fouling of membrane depends on many factors those can be classified into (a) membrane properties, (b) biomass or sludge characteristics, (c) operational parameters, (d) wastewater characteristics. Membrane fouling is more severe for industrial wastewater because of the extreme conditions. High salinity in wastewater not only cause inhibitory actions on biomass but also breaks the sludge flocs into fine sludge particles which have higher fouling potential[16]. pH is another crucial parameter for level of fouling in MBR. It has been tested that sludge cake layer formation occurs in a higher rate in low pH[17]. The filtration resistance first reduces when temperature is high but in long term the membrane resistance increases because of increase in EPS (extracellular polymeric substances) in the sludge. Moreover the cake layer is found to be denser at a high temperature[18]. Toxic substances and antibiotics also deteriorate treatment and filtration process[19]. Wastewaters containing heavy metals trigger the fouling in the MBRs. The heavy metals disintegrates the flocs and produce fine sludge particle which have higher potential of membrane fouling. Moreover, the heavy metals increase level of EPS viz. another fouling material[20]. AeMBR is efficient in removing the organic maters and contaminants from various industrial wastewaters. But, from applicability point of view, cost-effectiveness is the key parameter of any technology. The MBR requires high energy for aeration to prevent membrane fouling, as well as in pretreatment, if any.

Application of AnMBR:

The main benefits of AnMBR over AeMBR are high contaminants removal and generation of biogas which can be converted to electrical energy. Biogas is a renewable source of energy that can be used to generate energy for the processes in an industry for the wastewater treatment itself. AnMBR has higher quality of treatment and also produce lesser sludge as compare to aerobic treatment[21]. Moreover, the cost associated with aeration can be reduced as AnMBR operates without presence of oxygen and low sludge production reduces the cost of sludge treatment. The efficiency of the anaerobic treatment increases as the membrane retains the biomass, high SRT promotes growth of anaerobic bacteria in the AnMBR. Besides the treatment process the biogas recovery is an important aspect of AnMBR as it increases the practicality of AnMBR treatment application.

AnMBR can effectively treat textile industry wastewater. The color removal efficiency of AnMBR is higher than AeMBR[22]. Recovery of dye and water from wastewater can be achieved by using other processes like activated carbon adsorption, RO etc. with MBR[23]. Several studies reported

Table 2. Performance of AnMBR in industrial wastewater treatment

Industry	Flux (L/m^2h)	HRT	MLSS (g/L)	COD removal (%)	Ref.
Petrochemical industry wastewater	1.5–4.5	17 h	30–36	97	29
Pharmaceutical wastewater	5–20	10.6–42.6 h	6–8.4	15–43	30
Textile industry wastewater	1.8–14.4	24 h	–	90	31
Paper mill wastewater	–	–	11.2	86	50

better treatment efficiency with AnMBR of petrochemical industry wastewater which has high COD and low biodegradable organics like phenols, aromatic hydrocarbons, etc.[24,25]. AnMBR application to winery wastewater by Santos Clotas[26] gave satisfactory result. COD removal was achieved 97%, at an organic loading rate of 0.4–3.7 kg COD/m^3.day. Biogas recovery from this treatment was 7.5 kWh/m^3 of wastewater at influent COD of 3200 mg/L. Pharmaceutical wastewater was treated by AnMBR shows COD removal efficiency of 84–97% at a temperature of 30°C. The action of biological treatment and membrane filtration both contribute to the removal of COD, where 77–83% of removal is for biological action[27,28]. The performance data for treating industrial wastewater by AnMBR is given in Table 2.

Advantages and disadvantages of MBR application

MBR give better process control than conventional processes. Some of the major advantages of MBR are discussed below:

(a) Conventional biological treatment requires a large tank for the settlement of the bio-flocs whereas in MBR process the membrane itself acts as a solid-liquid separator.

(b) The membrane prevents loss of sludge with effluent. Thus control over SRT becomes independent of the HRT.

(c) The size of the reactor can be reduces as high concentration of biomass can be achieved through high SRT.

(d) As the SRT is high the sludge production is low. The SRT should be such that the MLSS concentration remains between 15 to 20 g/L, so that oxygen transfer can be effective.

(e) Biogas can be produced through AnMBR process. This biogas can be used to produce energy which reduces the overall cost of the process.

Along with these advantages MBR got some disadvantages as well.

(a) Membrane fouling is the major problem in MBR process. The maintenance cost also increases because of fouling.

(b) The requirement of energy is more than the conventional treatment. The main energy demand is for the process of aeration and production of transmembrane pressure.

(c) The sludge produces in the process is thicker and cannot be dewatered easily.

(d) The cost of membrane is the main investment in setting up an MBR plant. The life of membrane and cost of replacement also a major factor in overall cost of the process.

(e) The requirement of skilled labor is another drawback of the MBR process.

Fouling and fouling control

Any process that increases the resistance of the membrane and decreases the flux is called fouling. Fouling can be classified into main two types, namely reversible fouling and irreversible fouling. Irreversible fouling are those which cannot be removed by any process other than chemical cleaning. Fouling can be caused by inorganic, organic and/or biological mattes present inside the MBR. Fouling control can be done by the following ways: (a) pretreatment, (b) process optimization, (c) changing mixed liquor characteristics, (d) modifying membranes. Due to the extreme conditions and variation of wastewater characteristics fouling control is more challenging in industrial wastewater than municipal wastewater. The use of advance oxidation[32] and electrocoagulation[33] before MBR can reduce fouling. The process of ozonation reduces the EPS producing biomass by reshaping the biomass community[34]. Providing intermittent aeration can reduce the fouling and it has been used in full-scale MBRs also. Biomass carriers can be added to reduce the biofilm growth on the membrane itself. Adding materials like activated carbon, sponge, etc. that adsorbs the soluble microbial products (SMP) is another way to minimize the fouling. Membranes which are resistant to fouling can be used in MBR to minimize fouling. Membranes coated with hydrophilic substances have anti-fouling properties. But the coating is not so durable[35]. The irreversible fouling cannot be removed by these physical means. The chemical cleaning is used at this time. Bases, acids or oxidants which dissolve the foulant can be used for this purpose. But the chemicals used must not damage the membrane itself and should be environment friendly. Some of the chemicals used for membrane cleaning are caustic soda, hydrochloric acid, nitric acid, sodium hypochlorite (NaOCl), hydrogen per-oxide (H_2O_2), etc. Caustic soda removes the microbial foulant whereas acidic chemicals remove inorganic fouling like scaling and metal dioxides. NaOCl and H_2O_2 remove the biological fouling by oxidizing them.

MBR configurations

Second MBR can be coupled with other bioreactors such as MBBR (moving-bed biofilm reactor), SBR (sequencing batch reactor), etc. These types of processes are called hybrid MBR process. The MBR and RO (reverse osmosis) was put to use to treat a semiconductor wastewater and the effluent was of high quality and fit for reuse[36]. The MBR can be mainly of two types according to where the membrane is placed. If the membrane is used in a separate unit after the aeration tank then it is called side-stream configuration or external configuration of MBR (Fig. 1). If the membrane is placed inside the aeration tank itself then it is called submerged configuration or internal configuration of MBR (Fig. 2). In case of AnMBR another configuration can be external submerged configuration (Fig. 3) where the membrane is submerged in a chamber which is fed with aeration tank effluent. The chamber can be separated when the membrane needed to be cleaned. AnMBR can also be combined with AeMBR. This combination was used to treat textile wastewater where COD, color and suspended solids removal were achieved up to 99%, 99% and 100% respectively[37]. Maintaining high SRT in AnMBR increases biomass growth but can lead to decrease in permeate flux[38]. The HRT is a crucial factor in determining the size of the reactor and in turn the cost. Higher MLSS tent to reduce the HRT keeping the efficacy constant so the cost also reduces.

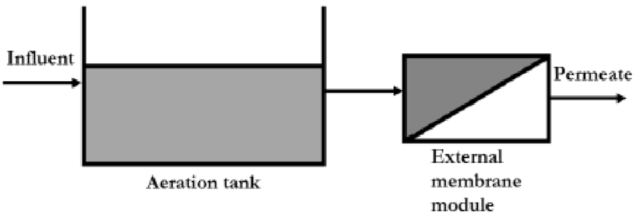

Fig. 1. External membrane bioreactor.

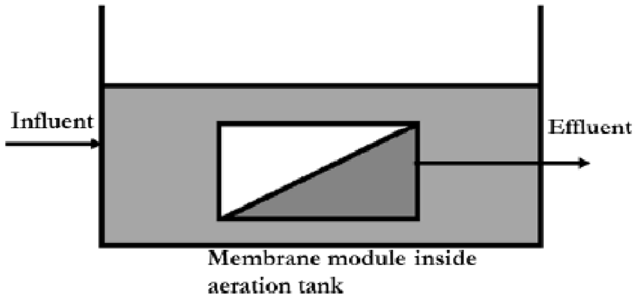

Fig. 2. Internal membrane bioreactor.

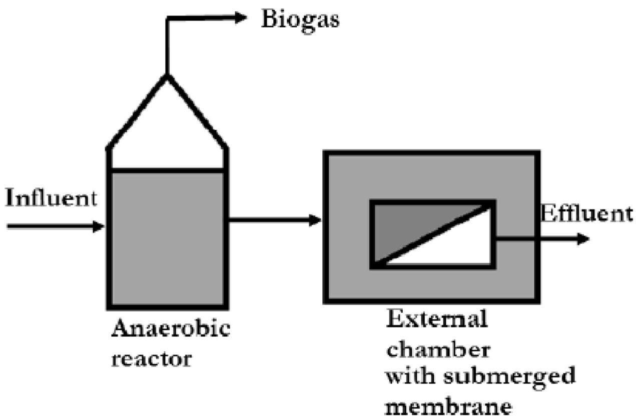

Fig. 3. External submerged membrane bioreactor.

Cost associated with MBR treatment

Most of the cost associated with MBR is for the investment in membrane and fouling control. Moreover, energy required for pretreatment can be added to the cost of MBR application. Energy consumption during MBR process is around 1–4 kWh/m^3 [39] whereas conventional treatment requires only 0.3–0.6 kWh/m^3 [40]. Higher energy demand of MBR technology can affect the environment but fine effluent quality and other unique advantages can offset these disadvantages. The MBR configuration highly influences the energy demand as submerged MBR requires 0.03–5.7 kWh/m^3 where side-stream MBR requires 0.23–16.52 kWh/m^3.

The energy demand also depends of the COD input to the reactor, the presence of fouling agents in the wastewater and the hydraulic loading rate. In AnMBR about 85–90% of total energy demand is for fouling control and maintaining the flux. Treatment of 2000 m^3/day of wastewater by AnMBR takes 0.4 million USD annually[41]. It has been reported that MBRs reduce 25% of land requirement and 50% of labor as compared to the conventional treatment as clarifier and similar operations are not required[42]. The factors that promote the use of MBR are stringent effluent quality regulation, decreasing availability of fresh water, scope of wastewater reuse.

Table 3. Performance of AnMBR in biogas production

Industry	MBR configuration	COD removal (%)	Methane (L/kg COD)	Ref.
Raw tannery	Submerged	90	160	51
Landfill leachate	Submerged	90	460	52
Food wastewater	Side-stream	81–94	136	53
Meat packing wastewater	Submerged	88–98	130–180	54

Generation of biogas in AnMBR

Depletion of nonrenewable energy sources compelling us to look for alternate energy sources. In this context biogas can be a solution. It has been up to 20% of the global energy demand can be fulfilled by energy recovered from biomass released by human activities[43]. Biogas consists of mostly methane (CH_4), up to 80%. The production of methane increases as the organic loading increase in AnMBR. The methane production data are shown in Table 3. The conversion rate of COD to biogas can be raised up to 98% which can provide energy more than required for the process[44]. But, loss of CH_4 is there due to its solubility in water. Liu *et al.*[45] reported that about 45% of the CH_4 is lost after being dissolved into permeate a temperature of 30ºC. The lost CH_4 not only reduce the energy recovery but also contribute to global warming as CH_4 is a potent greenhouse gas. Many processes like vacuum packed tower, bubble columns, forced drafted aerator and membrane separation can be used to remove the CH_4 from the effluent[46,47].

Scope of water reclamation with MBR

The depletion in ground water source and increasing pollution in surface water bodies compelling advancement in wastewater reclamation technologies. MBR system is a reliable option in this regard. The MBR effluent can be further treated to get useable water. The post treatment consist reverse osmosis, UV treatment, granular activated carbon adsorption, oxidation with H_2O_2. The effluent after post treatment has TOC < 3 mg/L, turbidity < 0.2 NTU, no multivalent ions and almost no viruses and bacteria. The cost is high for these post treatments and should be incorporated only where water scarcity is prominent. The water cost of an industry can be minimized if the effluent of the MBR is reused.

Conclusions

In this paper different aspects of MBR application for treatment of industrial wastewater have been discussed. The ability of treating high strength wastewater, low footprint, low labor cost and flexibility in configuration are the major advantages of MBR process, though, for some of the draw backs like membrane fouling, high energy demand, and process complexity, the mass scale adoption has not been possible yet. With recent development in anti-fouling membranes, novel configurations the market of MBR is growing at a rate of around 19% annually. The crucial step to boost the adoption of MBR is to stringent regulations for wastewater discharge. For future development, the goal of zero liquid discharge from industries is a major driving force for researches in this field.

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