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Review on Membrane Bioreactor (MBR) Technology in Wastewater Treatment

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Abstract—Membrane bioreactor (MBR) is the membrane process that includes ultrafiltration with a biological wastewater treatment process and activated sludge process. The membranes are used to separate the solid/liquid mixture. The membranes allow the clear water solution to pass through blocking the solid mass that needs to be discharged from the waster water. Microfiltration (100 to 1000 nm), ultrafiltration (5 to 100 nm), nanofiltration (1 to 5 nm), reverse osmosis (0.1 to 1 nm), electrodialysis (ED), and electro deionization (EDI) are the most commonly used membrane separation methods. The advantage of this technology is effortlessly upgrade older wastewater treatment plants that cannot produce the discharge, easy retrofit of technology, operate at higher concentration of Mixed Liquor Suspended Solids (MLSS), with reduction sludge Retention time (SRT). The membrane separation is carried out by pressure-driven filtration inside-stream MBRs or vacuum-driven membranes immersed directly into the bioreactor, and side stream MBR. Shear enhancement is essential for fostering permeate flux and preventing membrane fouling, but producing shear requires electricity, like in submerged configuration. The extractive MBR has greater scope for nitrogen reduction applications in anoxic/oxic (A/O) systems with occasional aeration. The process of denitrification and phosphorus recovery using hybrid MBR is advantage of this MBR technology.

Index Terms— Membrane Bioreactor (MBR), Mixed liquor suspended solids (MLSS), Conventional Activated Sludge (CAS), simultaneous nitrification-denitrification (SND), wastewater treatment plants (WWTPs), SRT (Sludge Retention Time), Activated Sludge Process (ASP).

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1 Introduction

Membrane Bioreactor (MBR) is a comparatively new technology in wastewater treatment for both industrial and municipal operations. As the word itself defines, this is a combination of passing the wastewater through membranes and pre-treating this wastewater through biological treatment processes. Most commonly used are the Microfiltration (MF) and Ultrafiltration (UF) membranes, with the biological treatment being Activated Sludge Process (ASP) (Meng et al., 2009).

After the domestic wastewater is treated with this process, the permeate is suitable for disposing into coastal or any other natural water sources depending on each respective area's laws and its restrictions. The permeate can also be reclaimed into the urban water system after some tertiary treatment. MBR is essentially a version of the traditional CAS (Conventional Activated Sludge). This technology's main advantages are the smaller footprint as clarifiers are not needed (internal/submerged MBR), which take up a large area in the traditional setting. This advantage proves to be a big one due to the growing population in densely populated areas, making land a costly resource in the process's overall planning. This technology, though expensive, is most widely used in urban areas that have a lack of area (Ma et al., 2017). Other advantages are the easy retrofit of technology. This technology is also effortless to upgrade older wastewater treatment plants that cannot produce the discharge as per the new and stricter regulations by the various governments. It is also possible to operate MBR on a higher concentration of MLSS (Mixed Liquor Suspended Solids), which makes the biological aspect of the process much faster and makes higher-capacity water and effluent treatment plants at a much higher discharge rate due to the reduction of SRT (Sludge Retention Time)(Judd, 2008).

Almost all commercial MBR solutions use the membrane as a filter to separate the by-products due to the biological step. The membranes are used to separate the solid/liquid mixture. The membranes do not allow the solids to pass and permeate the clear water that needs to be discharged. The membranes pore size is generally less than 0.1 μm which produces a clear permeate and separates the impurities that the biological process has not reduced before passing the effluent through the membranes. MBR process has been used successfully in large-scale residential wastewater treatment plants (WWTPs), small-scale commercial WWTPs, and drinking water treatment plants worldwide.

Membrane fouling is the disadvantage faced in this process. Due to the membrane being used as a filter, the pores clogging and the blockage were inevitable. This clogging reduced the membranes permeability and decreased the system's flux, thus increasing the cost for maintenance of the process. Suspended particulates (microorganisms and cell debris), colloids, solutes, and sludge flocs cause membrane fouling in MBRs.

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2 Membrane Categorization

The membrane process is a fundamental separation process in water and wastewater technology, which becomes increasingly competitive and is superior to traditional water technology with proven performance and process economics. Microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), reverse osmosis (RO), electrodialysis (ED), and electro deionization (EDI) are the most commonly used membrane separation methods. MF separation ranges are 100 to 1000 nm, UF separation ranges are 5 to 100 nm, NF separation ranges are 1 to 5 nm, and RO separation ranges are 0.1 to 1 nm (Radjenović et al., 2008). For starters, the use of membrane-based technology in wastewater treatment has focused chiefly on the tertiary treatment of secondary effluent to provide high-quality final effluent that can be reused for various purposes. However, over the last ten years, MBRs have emerged as an essential secondary treatment technology, given the fact that the membranes used are typically in the MF and UF range.

Membranes are mostly made of various plastic and ceramic materials, but metallic membranes are also available. Celluloses, polyamides, polysulphone, charged polysulphone, and other polymeric materials such as polyacrylonitrile (PAN), polyvinylidene difluoride (PVDF), polyethylsulphone (PES), polyethene (PE), and polypropylene (PP) are the most commonly used materials. All of these polymeric materials have desirable chemical and physical resistance. They are also hydrophobic, and are well recognized that hydrophobic membranes are more vulnerable to fouling than hydrophilic ones due to the hydrophobic nature of the connections between the membrane and the foulants (Liu et al., 2008). To obtain a more hydrophilic surface, all commercially available membranes are modified through chemical oxidation, organic chemical reaction, plasma treatment, or grafting. This method typically distinguishes one membrane from another as well as the processing of the membrane module (Radjenović et al., 2008).

3 Membrane Arrangement based on application

As demonstrated in this document, the numbering for sections upper case Arabic numerals, then upper case Arabic numerals, separated by periods. Initial paragraphs after the section title are not indented. Only the initial, introductory paragraph has a drop cap. Membrane separation is carried out either by pressure-driven filtration inside-stream MBRs or vacuum-driven membranes immersed directly into the bioreactor, which operates in dead-end mode in submerged MBRs. The above, with immersed membranes, is the more common MBR configuration for wastewater treatment, though a side-stream configuration, with wastewater pumped through the membrane module and then returned to the bioreactor, is also possible. The amount of energy needed for filtration in a submerged MBR is considerably less. Both configurations need a shear over the membrane surface to prevent membrane fouling with mixed liquor constituents. Side-stream MBRs, like most other membrane systems, generate this shear by pumping, while immersed processes generate it by aeration in the bioreactor (Cote & Thompson, 2000). Shear enhancement is essential for fostering permeate flux and preventing membrane fouling, but producing shear requires electricity, which is likely why the submerged configuration predominates. Also, in the side-stream MBR module, fouling is more pronounced due to its higher permeate flux. Pumping activated sludge allows microbial flocs to break up, resulting in a reduction in particle size and the release of foulant content from the flocs. This may significantly promote the membrane fouling rate. MBR configurations are either planar or cylindrical. There are five principal membrane configurations currently employed in practice (Wisniewski & Grasmick, 1998):

1. Flat Sheet (FS)
2. Tubular
3. Spiral Bound (SB)
4. Hollow Fibre (HF)
5. Filter Cartridge (FC)

Large numbers of HF membranes form a bundle in the HF module, and the ends of the fibres are enclosed in an epoxy block attached to the outside of the housing. The water can flow from inside to the outside of the membrane and vice versa, produced differently by different manufacturers. These

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membranes can work under pressure and vacuum. The spiral-wound configuration is used chiefly for the NF and RO processes and is coiled around the perforated tube through which permeate goes out. Most major manufacturers offer spiral-wound modules in suitable sizes, making installation simpler and membrane manufacturing less expensive. In high-capacity plants, several membrane modules may be deployed in series or parallel. Plate-and-frame membrane modules comprise FS membranes with separators and support membranes (Radjenović et al., 2008).
These sheet parts are clamped to a plate. Water flows through the membrane, with permeate gathered from pipes emanating from the membrane module's interior in a vacuum-operated operation. Other membrane configurations, such as the plated filter cartridge and tubular module, are not as usual as the other three modules. Tubular membranes are often encased in pressure vessels and pumped with mixed liquor; they are mainly used for side-stream setups (Radjenović et al., 2008). The HF and FS modules are often soaked in mixed liquor, with permeate pulled through vacuum pumps' membranes. In the case of HF membranes, it is preferred to use a 0.8 mm to 1.5 mm fine filter upstream of the membranes to shield them from hair and other stringy materials resulting in unnecessary cleaning frequencies. A fine screen of 2–3 mm is usually employed for FS membrane systems.

4 Performance of MBR

Compared with the conventional water treatment process, MBR, with high effluent water quality and treatment efficiency, is a more efficient technology and has a more favourable benefit for society, commercial companies, and the environment. The main application of MBR is municipal wastewater treatment, especially domestic wastewater treatment; however, it is also an attractive option for industrial wastewater treatment; especially in India, using MBR for industrial wastewater treatment has more commercial applications. Besides, MBR applications in the contaminated surface water supply have gained increased interest. In this section, we will look at how MBR performs in a variety of scenarios.

4.1 Organic Matter, Suspended Solids, and other Pollutants

In the MBR systems, most organic matter decomposed by the microorganisms, and the membrane rejection enhanced their removal efficiency. In general, Chemical Oxidation demand (COD), Biological oxidation Demand (BOD), suspended solids (SS), and UV254 removal efficiencies in MBR systems, especially for municipal wastewater treatment, are greater than 90% (Table 1 and 2)(Ma et al., 2017). Almost all of the suspended solids are separated in an MBR operation. Consequently, the removal of heavy metals and micropollutants attached to the suspended solids is also improved. In the past, some research work showed that the MBR process is highly efficient for removing bacteria. Many studies demonstrated that viruses are generally much more resistant to disinfection than classical fecal indicator bacteria. However, there is limited literature and knowledge on virus elimination, which has become an essential topic in recent years. According to some reports, the membrane can reject the virus, and the size of the membrane pores can influence the removal efficiency (Antony et al., 2012). Besides, the cake layer or the gel layer can also work as a barrier.

4.2 Nitrogen Metamorphosis

With high biomass concentrations, better retention of slow-growing microorganisms such as nitrifies can be obtained. MBR has enhanced nitrogen removal, and the results are often satisfactory. Both aerobic and anoxic stages are needed for nitrogen removal processes. In the continuously fed MBR method, cyclical (on/off) aeration will cause simultaneous nitrification-denitrification (SND). Diffusion limitation may create an anoxic zone within the biological floc when the dissolved oxygen (DO) is low, allowing denitrification.
Furthermore, achieving SND through the shortened pathway, i.e., nitrites, is superior to use in traditional nitrogen removal processes. Reduced aeration, COD, alkalinity requirements, and lower biomass yield are SND advantages through nitrite introduction. SND is mainly affected by ambient DO concentration and floc size. Despite its high operational Mixed liquor suspended solids (MLSS) concentration, MBR floc sizes are smaller than those of Conventional Activated Sludge (CAS) (Ma et al., 2017). The SND experiments in MBR published are all in anoxic/oxic (A/O) systems with occasional aeration. It was discovered that complete nitrogen removal efficiency of 95 percent and 83 percent could be obtained in A/O MBR (Table 1 and 2). Furthermore, extractive MBR has greater scope for nitrogen reduction applications.

4.3 Phosphorus Elimination

Phosphorus reduction is most generally accomplished using chemicals such as metal coagulants or lime, which may form sparingly soluble precipitates. However, biological technology without additional chemicals is environmentally friendly and economical technology. The bulk of wastewaters treated by biological processes contain biomass, but phosphorus is not significantly eliminated. Phosphorus exclusion can be unaffected by membrane rejection. Some improvements have been applied for biological phosphorus removal, for example, an anaerobic zone was added at the front of an activated sludge plant, and the nitrate-free sludge from the aerobic zone was returned. The process of denitrification and phosphorus recovery using hybrid MBR is based on MBR technology that a filling has biofilm carrier is placed in the reactor. This hybrid MBR system provides an anoxic microenvironment formed by biofilm and suspended and activated sludge Zoogloea with high concentration. Nitrogen removal is accomplished by the process of synchronous nitrification and denitrification in the same reactor (Ma et al., 2017). Simultaneously, it transfers phosphorus-rich sludge to the anaerobic zone by supplementary cycling to achieve phosphorus release, and the phosphorus is recovered by chemical precipitation or crystallization (Table 1 and 2).

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Table 1. Inlet parameters at aerocity STP to analyze performance of MBR

Sr.No.	Parameters	Test Results	Standards (MOEFF Rules 2017)	Test Methods
1	pH	**7.37**	6.5-8.5	IS:3025 (Part-11) 2002, Reaff. 2017. APHA 23rd Edition:2017-4500 B
2	Total Suspended Solids, mg/l	**210**	200-250	IS:3025 (Part-17) 2012, Reaff. 2017. APHA 23rd Edition:2017-2540 D
3	Bio-Chemical Oxygen Demand at 27°C, 3 days, mg/l	**210**	200-250	IS:3025 (Part-44) 2003, Reaff. 2014. APHA 23rd Edition:2017-5210 B
4	Chemical Oxygen Demand, mg/l	**400**	350-600	IS:3025 (Part-58) 2006, Reaff. 2017. APHA 23rd Edition:2017-5220 B
5	Oil and Grease, mg/l	**12**	≤30	IS:3025 (Part-39) 2003, Reaff. 2014. APHA 23rd Edition:2017-5520 B
6	Fecal Coliform as MPN/100ml	**12350**	15000	IS:3025 (Part-39) 2002, Reaff. 2017. APHA 23rd Edition:2017-9221 C
7	Dissolved Phosphorus, mg/l, as P	**<6**	≤10	IS:3025 (Part-31) 2003, Reaff. 2014. APHA 23rd Edition:2017-9221 C
8	Total Kjeldahl Nitrogen as N	**34**	≤45	IS:3025 (Part-34) 2003, Reaff. 2014. APHA 23rd Edition:2017-4500 B

Table 2. Outlet parameters at aerocity STP to analyze performance of MBR

Sr.No.	Parameters	Test Results	Standards (MOEFF Rules 2017)	Test Methods
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4.4 Pathogenic Bacteria and Virus Abolition

MBR is investigated with the cake layer's key influence (irreversible fouling) for bacteria and virus removal. Due to a higher density of enzymes and predators, bacteria and virus inactivation during the solid phase are more significant than in the liquid phase. The attachment of bacteria and viruses to biomass is also beneficial to removal because operation at higher MLSS concentrations and longer residence times improved the removal of organisms and viruses. The main mechanisms are as follows (Chaudhry et al., 2015):

a) Bacteria and viruses adhere to the MLSSs, which are retained by the membrane;
b) Bacteria and viruses are inactivated using a chemically modified backwash.
c) Bacterial and viral retention by the cake layer formed on the membrane surface during long-term activity.
d) Bacterial and viral inactivation by predation or enzymatic degradation as a result of the long HRT and SRT

4.5 Organic Carbon and Nitrogen

As a result of economic development and uncritical supervision and management, domestic and industrial wastewaters have been discharged into natural water-bodies without sufficient treatment, which has led to grave pollution situation of the surface water supplies in some areas, with organics and ammonia nitrogen (NH_3–N) as the primary pollutants. Since nitrate is water-soluble and does not bind to soil, it is more likely to pass into drinking water supplies, and nitrate in partial groundwater used for drinking water reaches maximum contaminant limits worldwide. Hence, nitrogen and pollutant removal become stringent for water supply safety, and as an innovative and promising process, MBR should exert its advantages on drinking water treatment. From the pieces of literature in this field, the conclusions of some studies seem to be controversial. In submerged MBR for treating simulated contaminated surface water, achieved over 60% TOC removal and 95% ammonia removal (Tian et al., 2009); achieved less than 50% TOC removal and around 90% ammonia removal studies recorded low-performance MBR used in this situation (Table 1 and 2). As a result, we can conclude that MBR for drinking water treatment is unstable and enhanced with integrated technologies. MBR has a nearly 100 percent turbidity removal rate. The use of MBR for drinking water denitrification is still in the early stages of research and development. Like the MBR wastewater treatment, a novel extractive MBR can overcome the limitations of conventional biological denitrification systems for drinking water treatment.

5 General Process Used in Aerocity STP, Mohali, Punjab, India

Process for a 200 KLD sewage treatment plant located in Mohali, Punjab.

a) The sewage is lifted from the central pumping station of the entire plant. It is the central pumping station where the sewers from multiple parts of the area are dropped to.
b) The raw sewage is lifted to the stilling chamber with the help of non-clog submersible pumps. This stilling chamber is provided because we need to convert the turbulent flow into laminar flow to work efficiently for our process design calculations.
c) The sewage is then taken through a coarse screen which can be either mechanical or manual.
d) Sewage is then passed through fine mechanical screens, after which it travels to the oil and grease removal chamber.
e) The wastewater is then taken to the Anoxic Tank, where the effluent's denitrification occurs. This takes place in the lack of air/anaerobic conditions. Denitrification is the microbial process of reducing nitrate and nitrite to gaseous nitrogen forms, principally nitrous oxide (N_2O) and nitrogen (N_2). An extensive range of microorganisms can denitrify. Denitrification occurs as a result of variations in the oxygen (O_2) content in their natural surroundings. This process also increases the F/M (food to microbes ratio), which is suitable for the proper growth of MLSS in the aeration chamber, where the biological part of the MBR takes place.
f) After the anoxic tank, the sewage is taken to the aerobic chamber. In this chamber, the activated sludge is formed. The air blowers diffuse air into the chamber to increase the DO (dissolved oxygen) and agitate the sludge so that it does not settle down. The increased DO increase the growth of certain microorganisms, which break down the complex organic matter in the sewage into simpler organic compounds. Aeration can be controlled based on process parameters such as MLSS and DO concentrations, oxidation-reduction potential (ORP), with DO-based aeration control usually favoured for reducing energy consumption.
g) The submerged membranes are in the aeration chamber itself. A negative pressure vacuum is created with a pump on top of the membranes, which sucks in the activated sludge. The membrane has multiple hollow PDVF tubes, which separate the solid/liquid mixture and acts as a filter, and the clean and clear water is taken out from the top header of the membranes.
h) The membranes maintenance is a critical task due to pores clogging due to the sewage impurities that need to be separated. After every 10 minutes of operation, the permeate line on the top of the membranes is reversed, and the clean water is backflushed into the membranes, and the impurities are taken out of the feed line. Another line from bottom potting is giver for the air line. This air line agitates the membranes to reduce the impurities that get stuck on the membranes. This air line agitation is called air scouring and helps maintain the membranes, increasing the skids durability.

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i) The membranes also need additional cleaning with the help of certain chemicals determined by the fibre manufacturer. This process of cleaning the membranes is called Cleaning in Place (CIP). A yearly CIP involved the following steps; isolation of the activated sludge compartments and the drain down of the membrane compartment, soaking the membranes in 1000 mg.L-1 NaCl overnight, discharge of the cleaning solution refill of the membrane compartment with activated sludge. Backwash and CIP increase the flux and performance of the membranes drastically.
The sludge collected is then put into a sludge dewatering bag that takes out the excess water from the sludge and puts it back into the plant's inlet. This is done to reduce the water losses that occur while dewatering.

6 CONCLUSIONS

Membrane separation is employed by pressure-driven filtration, vacuum-driven membranes immersed directly into the bioreactor, and by side stream MBR. The heavy metals and micropollutants attached to the suspended solids are separated, along with high efficient bacteria elimination in an MBR operation process. Denitrification process removes the nitrogen, transfers phosphorus-rich sludge to the anaerobic zone to achieve phosphorus release and recovery by chemical precipitation. In submerged MBR, treatment of simulated contaminated surface water, achieved over organic carbon and nitrogen removal with ease. The extractive MBR has greater scope for nitrogen reduction applications in anoxic/oxic (A/O) systems with occasional aeration.
The MBR technology provides the few advantages like High-quality effluent, higher loading rates, longer solid retention times (SRT), less sludge production, and impending for synchronised nitrification/denitrification process in long SRT. Membrane fouling moderation in MBRs is the important areas of wide-ranging research to improvise the application of the MBR technology in wastewater engineering. In conclusion, MBR is an proficient and in expensive process that deal with the growing demands for transforming wastewater into clean water that can be resued without detrimental effects.

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