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Industrial Waste Water Treatment by Membrane Bioreactor System

Aditi Pandey and Ravi Kant Singh*
Department of Biotechnology, IMS Engineering College, Ghaziabad, U.P. India.

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ABSTRACT

The development and application of a membrane bioreactor (MBR) for full-scale Municipal wastewater treatment is the most important recent technological advance in terms of biological wastewater treatment. The MBR is a suspended growth-activated sludge system which combines the use of biological processes and membrane technology to treat wastewater and provide organic and suspended solids removal instead of secondary clarifiers. Use of MBR offers the possibility to overcome a lot of problems in activated sludge processes which are mostly due to tertiary treatment. It represents a decisive step forward concerning effluent quality by delivering a hygienically pure effluent and by exhibiting a very high operational reliability. Advanced MBR wastewater treatment technology is being successfully applied at an ever-increasing number of locations around the world. This review article has covered several aspects of MBR. The membrane separation of microorganisms from the treated wastewater is discussed in detail. Problems of membrane fouling and membrane washing and regeneration, linked to activated sludge characteristics, are examined. Finally, advantages and disadvantages of MBR over conventional activated sludge are concerned.

Introduction

In the near future the availability of fresh clean water will become increasingly limited in many areas of the world, at the same time an increasing quality and quantity of water will be required to maintain and support the growing population. Areas with adequate supplies may face issues with quality. Salinity intrusion into ground water supplies, nutrient eutrophication, endocrine disruptors, and heavy metals are just a few sources of contamination that may be encountered in water supplies. One possible solution to these problems is the application of membrane bioreactors (MBR) for wastewater treatment and reuse. A membrane bioreactor can be operated in either an aerobic or anaerobic mode depending on project-specific nutrient removal objectives. Aerobic MBRs are commonly used for domestic wastewater, "night soil", industrial wastewater and municipal water treatment. Anaerobic MBRs have been mainly applied to industrial wastewaters of high organic strength. Anaerobic bacteria have slower growth rates than aerobic bacteria and so produce less residual sludge but require a relatively long retention time. Moreover, anaerobic biosolids exhibit poor settle ability due to their diffusible and filamentous nature. Therefore, anaerobic MBRs offer similar advantages over conventional processes as MBRs. In cases where complete removal of nitrogen is required, MBR processes adopting aerobic-anoxic cycling to obtain maximum denitrification have been used [1]. MBR applications have included batch chemical plant effluents, groundwater filtration, and landfill leachate, chlorinated solvents in manufacturing plant wastewaters, oily wastes, phosphorus control and pharmaceutical intermediates.

A process that uses both a biological stage and a membrane module has recently been developed for wastewater treatment and is called the membrane bioreactor (MBR) process. A high standard of wastewater treatment can be achieved, without the conventional arrangement of aeration tank, settling tank and filtration to produce a tertiary standard effluent of 5:5:5 BOD: suspended solids: ammonia. This and several other advantages have made the MBR system ideally suited for treatment of strong industrial wastewater and reclamation of water. Flow passes through the membrane, while solids remain in the biological treatment systems. The membrane bioreactor system combines the benefits of a suspended growth reactor with the solids separation capability of an ultra-filter or micro filter membrane unit. The dependence on disinfection is also reduced, since the membranes with pore openings, generally in the 0.1-0.5µm range, trap a significant proportion of pathogenic organisms. The membrane provides a long solids retention time, usually 30-60 days, which can greatly enhance the biological degradation of influent organics. Typical MLSS values are in range of 12-15g/L in immersed MBRs up to 30g/L in tubular system for industrial wastewater treatment. The Conventional activated sludge and Membrane Bioreactor process in various configurations are shown in Figure-1 [2].

The important advantage of this technology is considered to be the compactness, as the clarifier, where the separation of the sludge from the treated effluent occurs traditionally by gravity, is replaced by a membrane filtration which can be implemented directly in the aerated biological reactor. Moreover, the membrane system can be operated with sludge concentration in the biological reactor up to 20-25g TS (total solids)/L, unlike the conventional technology which is limited to max 5g/L in order to ensure good sludge sedimentation. Furthermore, unlike the conventional technology the MBR plants can be operated with a broader range of operation conditions such as sludge concentration, sludge age, organic load, etc. and are more robust to load variations. In addition, the modularity of the technology facilitates the use and planning in areas with quick population growth, where the amount of water to be treated is difficult to predict beyond few years. Last but not least, the MBR technology stands out for the excellent and constant treatment quality that is achieved: particle-free and disinfected effluent

Tele:
E-mail addresses: rksingh.iitr@hotmail.com

whatever the incoming raw water or pollutant load, and not withstanding usual problematic issues in conventional plants such as filamentous bacteria, bulking or floating sludge, pinpoint flocs, etc. this makes the MBR treated water particularly relevant when high treatment standards are required, such as to comply with bathing water directives and or unrestricted water reuse. Due to the advanced quality of the MBR permeate, devoid of particles, bacteria but also colloids, the MBR technology is also an excellent pre-treatment before nanofiltration or reverse osmosis.

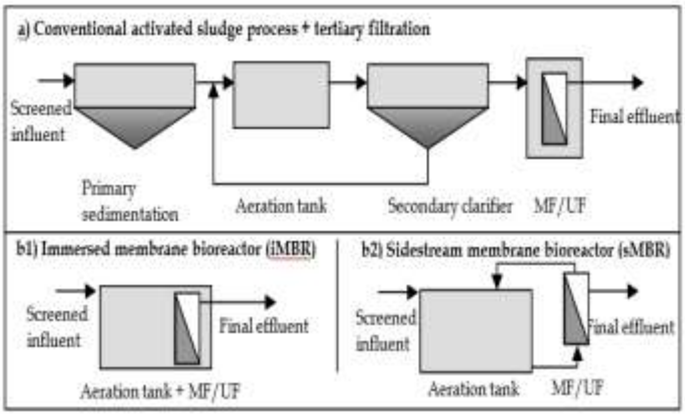
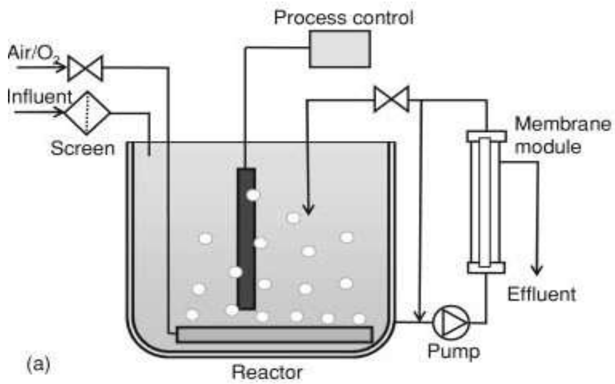


Figure 1. Conventional activated sludge process (a) and MBR in both configurations: immersed (b1) and side stream (b2)

Configurations of membrane bioreactor systems

There are two types of configurations for the membrane array: the membranes can be placed either outside or inside the bioreactor [3]. As shown in Figure-2 for the external configurations, the fouling control is achieved by a high water velocity across the filtration channel. The driving force is the pressure created by high cross-flow velocity along the membrane. As a result, this configuration provides more direct hydrodynamic control of membrane fouling and offers the advantages of easier membrane replacement and high fluxes but at the expense of frequent cleaning and high energy consumption (2–12 kWh/m3 products). For submerged configurations, membrane modules are directly placed in the mixed liquor. The driving force across the membrane is achieved by pressurizing the bioreactor or creating negative pressure on the permeate side [4]. Tran-membrane pressure differences as well as flux rates are very low. This kind of membrane is applied in municipal and industrial wastewater treatment and can be placed either inside the aeration tank or in an external filtration tank. Less frequent and less rigorous cleaning of the membrane is required to restore operational flux compared to the side stream system. The comparison of external and internal membrane based MBR system is also shown in table-1 [5].



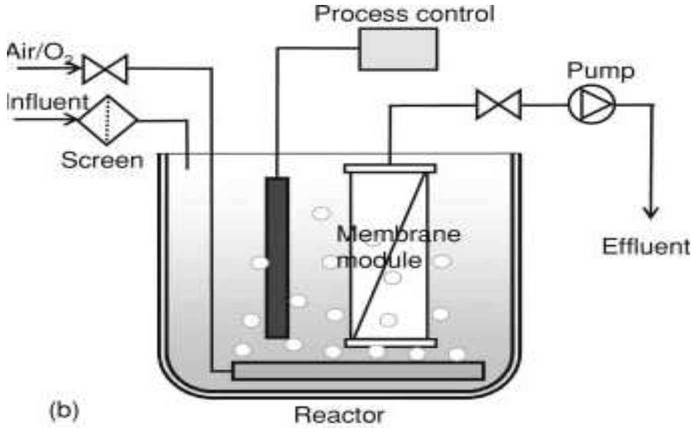


Figure 2. Membrane bioreactor configurations: (a) external configuration, (b) submerged configuration

Table 1. Comparison of External and Internal Membrane Based MBR System Configurations

Comparative Factor	External MBR Systems	Internal MBR Systems
Membrane Area Requirement	Characterized by higher flux and therefore lower membrane area requirement.	Lower flux but higher membrane packing density (i.e., membrane area per unit volume)
Space or Footprint Requirements	Higher flux membranes with bioreactor operating at higher VSS concentration and skidded assembly construction, results in compact system.	Higher membrane packing density and operation at bioreactor VSS concentration of 10 g/l or greater translates to compact system.
Bioreactor and Membrane Component Design and operation Dependency	Bioreactor can be designed and operated under optimal conditions including those to achieve biological N and P removal, if required.	Design and operation of bioreactor and membrane compartment or tank are not independent. High membrane tank recycle required (e.g., recycle ratio 4) to limit tank VSS concentration build-up
Membrane Performance Consistency	Less susceptible to changing wastewater and biomass characteristics.	More susceptible to changing wastewater and biomass characteristics requiring alteration in membrane cleaning strategy and/or cleaning frequency
Recovery of Membrane performance	Off-line cleaning required every 1 to 2 months. Simple, automated procedure normally requiring less than 4 hours.	Off-line “recovery” cleaning required every 2 to 6 months. A more complex procedure requiring significantly more time and manual activity, at least on occasion may be required (i.e., physical membrane cleaning).
Membrane Life or Replacement Requirements	Results to-date implies an operating life of 7 years or more can be achieved with polymeric prior to irreversible fouling. Operating life of ceramics much longer	Results to-date implies an operating life of 5 years may be possible prior to irreversible fouling and/or excessive membrane physical damage.
Full Scale Application Status	Conventional membrane based systems have a very long track record. Few non-conventional systems in operation in the U.S.	Full scale application widespread in the U.S.
Economics	Non-conventional designs translate to comparable power costs. Comparable capital cost at least at lower wastewater feed rates (e.g., approaching 1893 m^3/day).	Power and capital cost advantage at higher wastewater feed rates.

The fluxes obtained ranged from 0.05 to 10 m/d strongly depending on the configuration and membrane material. The membrane materials can be classified into three major categories: Polymeric, Metallic and Inorganic (ceramic) [4]. The emergence of less expensive and more resilient polymeric membranes along with lower pressure requirements and higher permeate fluxes have accelerated the worldwide commercial use of submerged MBRs.

Membrane Bioreactor Working And Design

Membrane Bioreactor Working

The MBR process is a suspended growth activated sludge system that utilises micro porous membranes for solid/liquid separation in lieu of secondary clarifiers [6]. The basic principle is that the feed water passes over the membrane surface and the product is called permeate, whereas the rejected constituents form concentrate or retentate as shown in Figure-3 [7].

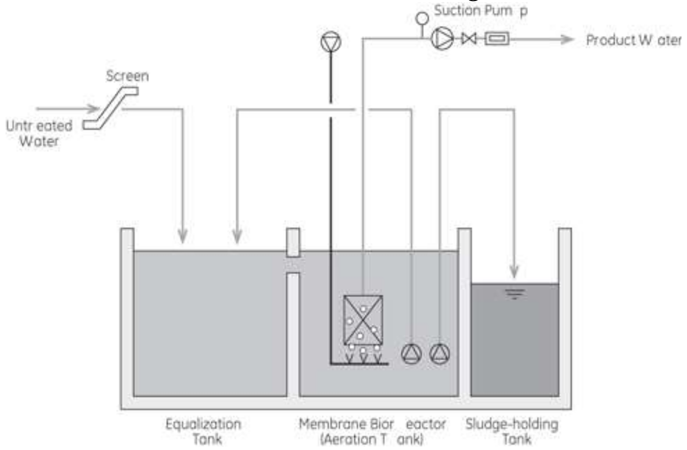


Figure 3. Basic principle of membrane filtration

A pressure difference draws raw wastewater through an advanced microfiltration membrane to remove suspended material. The 0.4μm micro filters present in submerged system are placed into an aeration basin. A vacuum is applied downstream of the membranes to allow for the solid/ liquid separation process to occur. The membranes eliminate the need for a secondary clarifier because they act as an absolute barrier. Air is introduced into the system to scour the membranes and drive the biological treatment. Tubular systems are also available. These systems will treat a side stream of the mixture in the aeration tank. This type of system requires a high amount of pumping power to keep the velocities high to prevent membrane fouling, and high pressure to force the water through the membrane [7].

Design of Membrane Bioreactor

As the MBR is an activated sludge process, the same generally accepted design regulations for the conventional activated sludge process can be applied for MBR design. The food-to-microorganism (F/M) ratio is the key design parameter and as high mixed liquor suspended solids (MLSS) can be achieved, the resulting tank volumes are smaller. The aeration equipment has to be adapted to the resulting high specific volumetric oxygen rates. The hydraulic load and achievable flux are the key parameters for the design of the membrane surface, whereby the membranes have to permeate the maximal flow.

For the design of the configuration, maintenance and membrane cleaning facilities, it is important to specify the type of membrane and membrane modules early as possible. Overall, in MBRs the automation level is higher compared to conventional wastewater treatment plants due to back flush, cleaning procedures.

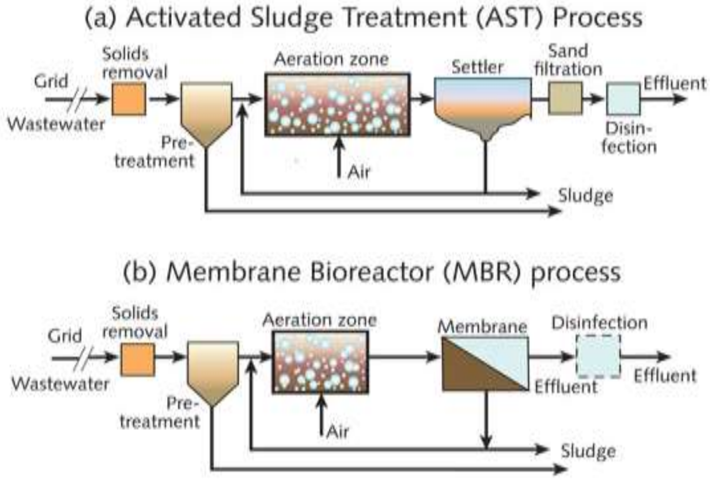


Figure 4 (a) activated sludge process (b) membrane bioreactor (MBR) process

Pre-treatment

The wastewater needs to be carefully pre-treated or screened before entering the MBR plant because membranes are sensitive to damage with abrasive and stringy materials, such as grit, hair and fibrous materials which can clog the membranes (modules), and lead to dramatic and rapid decrease of the flux. Therefore a multi-step mechanical process, including coarse screening, grit removal, primary clarification and fine screening, is the most efficient pre-treatment for large scale municipal MBRs. For small and medium scale, MBRs course screening, grit removal and primary clarifiers are optional and dependant on the designer's/owner's choice and economic analysis. For very small MBRs, such as those used for communal developments, fine screening is optional [8]. Screens or even better sieves, with mesh sizes ≤ 0.5mm have proved suitable. Further, a grease trap should be installed because oil and grease may influence the flux of the membranes negatively. The hydraulic equalisation is of importance, because the costly membrane surface has to be designed according to the maximum inflow.

Design flux, hybrid system and equalisation tanks

The design of the membranes surface area is important for economic efficiency. The flux depends on the membrane, the modules, the transmembrane pressure, and the wastewater composition and on fouling/scaling. Design flux is an important parameter which characterises the overall flow rate including breaks and back flushes. For industrial wastewater in general, pilot tests have to be performed. The resulting flux is often as low as 8-15L/ (m^2h) for immersed membranes and up to 120 L/ (m^2h) for tubular membranes. The design has to consider that initial flux will not stay constant. The flux will decrease with time at constant pressure, respectively; the pressure difference has to be increased to keep the flux at a constant level. These phenomenons are a result of fouling or scaling, hence the accumulation of organics, colloids, particles and precipitates on and in the membranes.

To minimise the discrepancy between higher membrane surface demand and higher membrane replacement costs, different solutions have been proposed: a plant has been designed in parallel to conventional activated sludge systems (hybrid systems), which can absorb the peak flows, or by addition of a buffer tank for flow equalisation. While comparing a hybrid system with an MBR designed to manage maximum flow conditions, results indicate that the average energy demand for the full-flow MBR is 57% higher, as a result of underutilization of the membrane available area and excess of membrane aeration. With regard to the adding of a buffering tank, the authors pointed out that the cost of buffering would be covered by reducing the required membrane surface area. However, this solution should increase the scale size of the plant by 10% compared to CAS treating the same flow. Therefore, the authors conclude that hybrid MBR plant is the most desirable option [9].

Membrane fouling control and cleaning

A decrease in the permeate flux or increase in transmembrane pressure during a membrane process is generally understood by the term "fouling" [10]. Membrane fouling represents one of the most challenging issues constraining the more extensive applications of MBRs. The main causes for membrane fouling are as follows:

- feed characteristics
- biomass characteristics
- membrane characteristics
- operational conditions

Membrane fouling may be due to following mechanisms [11]:

- Formation of surface layer or filter cake on the membrane surface.
- Fouling within the membrane structure. It has been proved that some proteins deposit within membrane pores and surface.
- Fouling at pore entrance.

Regular cleaning of membrane is essential to remove membrane fouling and keep the permeability loss in a given range. Different types of cleaning procedures for membrane regeneration are classified as:

- Physical methods
- Chemical methods
- Physic-chemical methods
- Biological methods

Physical cleaning of membrane is mainly done to remove reversible fouling and can be achieved either by back-flushing or by relaxation (stopping the permeate flow and continuing to scour the membrane with air bubbles). It is simple and short although it is not possible to remove all the material deposited on the membrane surface. It usually lasts for about 2 minutes.

Chemical cleaning is done to remove irreversible fouling and is more efficient in removing adsorbed deposits from membrane surface. It is carried out mostly with sodium hypochlorite and sodium hydroxide for organic deposits removal, or with acidic solutions for removal of lime or other inorganic deposits. This method is employed on a weekly basis which lasts for about 30-60 minutes.

The physico-chemical cleaning methods use physical cleaning methods along with chemical agents to enhance cleaning effectiveness. Kuiper et al. operated a 16 m^3/d RO plants for 19 months on a highly polluted source using turbulence cellulose acetate membranes. Mechanical cleaning with foam balls, supplemented by acid washing, proved to be the most effective cleaning method [11].

Biological method of cleaning employs use of micro-organisms or enzymes to enhance removal of foulants. This method is gaining popularity due to firstly, biological components do not lead to membrane damage and secondly, to minimise the adverse effects that chemicals have on environment.

Sludge retention time and biomass concentration

Membrane bioreactor is characterised by complete retention of biomass because of the use of membrane separation as a result of which, sludge retention time (SRT) increases independently from hydraulic retention time (HRT). Increasing SRT increases the sludge solid concentration and applied organic load, thereby increasing the pollutant degradation. The specific sludge activity during organic matter decomposition and nitrification depends on the SRT. The SRT is a significant operational factor for the biological process [12]. The average sludge age, the time the biomass spends in the aeration tank, or sludge retention times (SRT) is 15-45 days.

It has been reported that high values of SRT can increase membrane permeability by decreasing soluble microbial products (SMP) production [13]. Conversely, high solids concentration results in a higher viscosity of the microbial suspension [14], as a consequence, higher concentrations decrease air sparging efficiency and oxygen transfer rate to the microorganisms, resulting in a higher energy demand as well as increasing membrane fouling and the risk of membrane clogging. Given all of these factors, for economic reasons, most full-scale facilities are designed for MLSS range of 8-12 g/l and SRT range of 10-20 d [15].

Membrane life

Analysis of the oldest plants has shown that membrane life can reach, or even exceed, 10 years [16]. A correlation of permeability loss and operation time was found, indicating that the membrane permeability reaches non-operative value after seven years of operation. The authors also suggested a significant effect of inorganic scaling on permeability loss. The correct functioning during membrane cartridge life, determined by the strength of the welding at its perimeter, appears to be related to the total volume of water permeated and the total mass of oxidant (NaOCl) used during chemical cleanings [9].

MBR applications in wastewater treatment plant

MBR treatment is applicable to many sectors, including municipal, industrial and water reclamation. Municipal wastewater treatment is both the earliest and largest application of MBR, and it is predicted that this will continue to be its primary use. Due to its small footprint and potential for reuse of high-quality effluent, MBR is capable of coping with population growth and limited space. For industrial applications where more stringent regulations are imposed, it provides an effluent that can be safely discharged into the environment. The main applications of membrane technology reported in industry are for treatments of heavily loaded wastewaters such are oily wastewaters or discharges from tanneries and textile industries [17, 18, 19]. Promising applications also exist in treating landfill leachate, chlorinated solvents in manufacturing wastewater, and for groundwater remediation.

Applications in Municipal Wastewater Treatment

MBR systems were initially used for municipal wastewater treatment, primarily in the area of water reuse and recycling. Compactness, production of reusable water, and trouble – free operation made the MBR an ideal process for recycling municipal wastewater in water and space limited environments. By the mid-1990s, the development of less expensive submerged membranes made MBRs a real alternative for high flow, large scale municipal wastewater applications. Over 1,500 MBRs are currently in operation around the world in Japan, Europe and North America [20].

Applications in Industrial Wastewater Treatment

High organic loadings and very specific and difficult to treat compounds are two major characteristics of industrial waste streams that render alternative treatment techniques such as the MBR desirable. Since, traditionally wastewater with high COD content applications for industrial wastewater was in the field of anaerobic treatment [20].

Applications in Fields of Landfill Leachate and Sludge Digestion

In addition to municipal and industrial wastewater treatment, MBRs have been utilized in a number of others areas. One such area is the treatment of landfill leachates. Landfill leachates usually contain high concentrations of organic and inorganic compounds. Conventionally, the treatment of leachates involves a physical, biological, or membrane filtration process. MBR systems have been successfully utilized with an additional treatment step for inorganics and heavy metal removal, such as reverse osmosis (RO). Another application of the MBR is in the area of sludge treatment. Conventionally, sludge stabilization in wastewater treatment plants is achieved by a single pass, anaerobic digester. Since the HRT and the SRT are identical in these systems, the capacity is limited and long solid retention times are required for effective solids destruction [20].

Development of MBR technology

The use of MBRs in municipal and industrial wastewater treatment has grown widely in past decade. This is primarily due to its ability to remove organic and inorganic contaminants as well as microorganisms from wastewaters and has gained increasing popularity due to more stringent environmental regulations and growing water reuse initiatives in recent years.

The concept of immersed or submerged membranes was conceived in the late 1980s or early 1990s by independent teams in Japan and Canada. The idea for coupling the activated sludge process and membrane separation was firstly reported by research conducted at Rensselaer Polytechnic Institute, Troy, New York, and Dorr-Oliver, Inc. Milford, Connecticut, US [10]. Although it did not gain much interest in North America but it got its success in Japan in the 1970s and 1980s. The breakthrough for the MBR technology came in 1989 to submerge membranes in the bioreactor. In 1989, the Japanese Government launched a year R&D project with many large Japanese companies, in order to develop low cost treatment processes utilising MBR to produce reusable water from industrial, municipal and domestic wastewater. This program led to development of systems such as the Kubota and Hitachi-Plant flat sheet module and the Zenon and Mitsubishi- Rayon hollow fibre module.

Current status and market trends of MBR technology

About 200 MBRs are currently in operation for various wastewaters and 90% of them are employed in municipal treatment. Many other developments of MBR technologies based on submerged modules followed since the mid-90's, including among others the BIOSEP® process developed since 1993 by Anjou Recherche (Veolia Water) with successively hollow-fibre submerged modules produced by Zenon Environmental, Canada, and by Memcor, Australia. Thanks to the rapid development of the BIOSEP® process, Veolia Water could commission in 1999 the plant of Perthes-en-Gâtinais (4,500 p.e.), which was one of the first full-scale MBR plants to be constructed in Europe for municipal wastewater treatment. All technological advances confirmed the supremacy and cost-effectiveness of low pressure submerged module configurations in comparison with cross-flow systems for the treatment of low loaded wastewater such as municipal or domestic wastewater. In 2004, the largest MBR plant in the world was commissioned in Kaarst (Germany). It was designed by VA Tech Wabag Germany to serve a population of 80,000 p.e., and is equipped with Zenon modules. In March 2005, Zenon announced the contract award for an MBR plant to treat 144,000 m3/d volume of water in Washington. This is very representative of the quick development and application pace of the MBR technology, with sizes of constructed plant growing from few thousands to hundreds of thousand population equivalent in few years only.

To date, two types of technologies of submerged modules are available on the market for MBR applications, both featuring outside-in permeate filtration: the flat-sheet (or plate & frame) membrane module, which is exemplified by the Kubota technology, and the hollow fibre membrane module such as this commercialised by Zenon. An analysis of the current applications for municipal wastewater treatment, shows that the flat sheet system is competitive for smaller units (below 10,000 or 20,000ep), whereas larger plants are favourably equipped with the hollow fibre system [21].

Two recently published reports provide details of the global and European membrane bioreactor markets. The detailed market survey of the European MBR industry showed that the municipal sector generated the strong market revenue growth observed since 2002. This is a consequence of the process has become technically and economically viable for large municipal plants with the successful introduction and commercialization of the immersed configuration. This trend is expected to continue in the coming years, although promising novel products are entering the market and will compete with the two immersed technologies (Zenon-GE and Kubota) which have dominated since 2002 [22].

According to the report "Membrane Bioreactor Systems Market by Types [Hollow Fibre, Flat Sheet, Multi Tubular], Configuration [Internal (Submerged/Immersed) & External (Side stream)] & Applications [Municipal & Industrial Wastewater Treatment] – Trends & Forecasts To 2017", MBR market was worth an estimated $746 million in 2011. This value is expected to increase at a CAGR of 14.6% during the period from 2012-2017. Asia-Pacific (APAC) leads the global MBR market with share of 38.7% followed by Europe and North America in terms of revenue in the year 2011.

The global membrane systems bioreactor market is growing due to its ability to meet stringent effluent criteria along with its compact size and less operational cost as compare to other systems and equipment which are used for wastewater treatment. According to WHO, about one fifth of the world's population resides in areas where water is physically scarce, while one fourth face scarcities due to lack of infrastructure to transport water. Governments and industries have realized the importance of wastewater treatment, as a necessity and also as means to improve the bottom line. Stringent legislations for the implementation of the treatment facilities, combined with the space and operational advantages that MBRs provide, are expected to be key drivers of the market going forward. The sophistication and high capital costs associated with the system could however prove to be key obstacles.

APAC holds major market share in MBR market. Europe is the second largest consumer. Countries in this region such as China and Japan use membrane bioreactors extensively for water reuse purpose in municipal application. With new factors coming into play, the MBR technology is now beginning to mature and will continue to penetrate further in the wastewater effluent treatment market.

APAC market share is 38% in the global MBR revenue market; Europe has 17% of share. However it is still the APAC region which is on the rise with a CAGR of 15.1% from 2012 to

2017. The MBR market by application is segmented into key segments as municipal and industrial wastewater treatments. The municipal wastewater applications occupy a major share in the consumption market, and are expected to be the fastest growing segment, going ahead.

Among the various types of MBR marketed, hollow fibre and flat sheet cover the major market of the membrane bioreactor, which is approximately 95.3% of the overall membrane bioreactor market. Selection is based on an evaluation of various criteria, including packing density, investment cost, fouling tendency, cleaning and operating costs, and membrane replacement costs [23].

Conclusion

Membrane Bioreactors (MBRs) will be used in future whenever high quality effluents are required, because of sensitive receiving water body or due to the fact of water reuse as process water. MBRs are prefect pre-treatment in industrial application when further treatment with nano-filter or reverse osmosis is considered. The coupling of activated sludge and membrane separation has been proven as a simple, single step process to produce outstanding effluent quality

Recent membrane and system design advances have resulted in comparable economics for external versus internal membrane MBRs over a much broader wastewater flow rate range. Future developments are likely to include the emergence of cost-effective anaerobic MBR systems and full scale application of alternative MBR configurations in which membranes are used for other purposes than simply biomass-effluent separation.

Growing acceptance of MBRs, escalating interest in water re-use & recycling technology and increased demand for advanced waste water treatment solutions and systems assure them of a bright future.

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