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The Use Of Membrane Processes To Promote Sustainable Environmental Protection Practices

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Abstract

The aim of this study is to promote membrane employment for sustainable environmental protection practices in terms of retaining the depletion of natural resources at a grade less than their proportion of renewal and consumption and employment of as much renewable resources as possible instead of depletion of unrenewable resources. Furthermore, information on life cycle assessment of products and manufacturing systems is provided. Energy and water are the indispensable resources for the mankind wealth. The increased energy needs arising from developing technologies, increasing population and limited resources have led people to turn to sustainable methods, especially in the case of limited water resources. There has been growing rate of interest for biological wastewater treatment methods by membrane employment. Separation of solid-liquid mixtures is implemented in the way of biological wastewater treatment; especially MBRs have critical role for treatment processes. MBR operations allow biological treatment and disinfection without utilization of chemicals and the amount of produced sludge is less due to unemployment of SRT. Although membrane technology still needs to be improved regarding energy consumption, membrane and/or module manufacturing costs, durableness and expertise, it has an important place in the energy-efficient sustainable water supply, industrial wastewater management processes and energy production. In addition to this, they are flexible and adaptable for module modification and latest novelties. In literature, limited researches have been practiced so far dealt with the issue of public acceptance of certain methods being applied. Future research may focus on overcoming the issue of membrane fouling, by devising methods for efficient cleaning, preferentially without employment of dangerous chemicals, as well as by investigating new types of membranes.

Key words

Biological treatment, MBR, Renewable and sustainable environmental protection

1. INTRODUCTION

Increased use of water and energy

Energy a word with simple meaning in linguistic but an issue for scientists. Societies grow in number as technology solves the equation for longer life, however planet has specific amount of energy. This is much true and also complicated in water sector as we realize that it possesses both life and energy. It is an awe-inspiring idea to develop a system to explore the energy stored in water and wastewater. There has long been a controversy surrounding what would be an ideal system to purify used water, as known it wastewater, and also reuse the impurity separated from. In 1969, Budd et al. [1] used ultra-filtrated membranes as a solution for high removal efficiency and also to separate sedimentation tank from activated sludge in water treatment plants. They reached an effluent with BOD under 5 mg/l and nearly no sign of coliform bacteria. This processes had some advantages such as low sludge production, high quality water production and low maintenance. However, high operation costs prevented its wide spread application. A group of Japanese researchers [2] installed Hollow-Fiber (HF) membranes inside an activated sludge reactor and operated a suction pump directly over the membrane to catch the permeated water. Treated water was produced at low suction pressure (13 kPa), short hydraulic retention times (4 h), high loading rate (1.5 kg COD/m3·days), and relatively long operating periods (120 days). This study was the beginning of wide-spread usage of MBR for treatment of both municipal and industrial wastewaters as it possessed the possibility to produce much cleaner water with low energy demands.

Life cycle assessment of products and manufacturing systems

Sustainability is principally defined as the appropriate integration of environmental fineness, economic affluence and socialeven-handedness [3,4]. In fact, it refers to the equilibrium between environment, industry and economic. Various tools have been developed to assess the behavior of industries and their associated manufacturing processes, among which Life Cycle Assessment (LCA) is the most popular and at the same time most reliable method. It is a structured and analytical procedure that provides detailed assessment for environmental sustainability. Unfortunately, LCA has been applied to MBR systems only in a few cases for treating urban wastewater [5, 6, 7]. It should be mentioned that the comparison of the results of different LCA studies, cannot be direct, since each study has a different goal and scope definition, different impact assessment methods are used, the assumptions made are not totally equivalent, while also the energy mix and the geographical location of each study are different [5]. In the study, the environmental impacts of an MBR used for the treatment of domestic wastewater were compared with those of three other treatment technologies (reedbeds, membrane chemical reactor and green roof recycling system) [8]. In addition, according to Ortiz et. al. [6] both externaland submerged MBR systems have lower environmental impacts than a CAS system followed by tertiary treatment, for the treatment of domestic wastewater. Hospido et al. [9] studied the footprints of four different MBR configurations. Their study indicated that electricity consumption and agricultural application of sewage sludge are playing the most important role as the environmental impactswere identical for all four MBR configurations.

Renewable energy sources and sustainable environmental protection

It is critical to remind that energy is a fundamental source for us in terms of development. It has been thought that present resources were found as abundant for a long time. Augmentation of the population in the world and also technological progresses swapped-in throughout the industrial revolution, demand to the energy swelled and it was hinged upon the inadequacy [10]. However, utilization and increment of the energy in the world ensured from petroleum, petroleum derivatives, coal, natural gas and electricity produced from the nuclear power plants (NPP). Since all the energy resources from underground are not being virginally comprised, they are once for all limited.It is estimated that energy demand will enduringly increase in following years which will be resulted as a prevailing need for the fertile use of it. Such resources which can be used under the name of renewability are differentiated as biologic entries for sustainability and acceleration of their expansion in a positive axis is worth of note. To provide sustainability, renewable energy sources can be listed as power from wind, water, biomass, solar light and photovoltaic energy, wave, tide, earth that provides geothermal energy and etc. [11]. Renewable energy sourceshave tremendous potential as a clean and environment friendly energy source and throughout its energy production, no irrecoverable pollution can occur [12]. Thus, they pave the way for sustainability of the environmental protection. In this context, membrane technologies, especially membrane bioreactor (MBR) systems, have great importance in water and energy sustainability. Although MBR operations have some handicaps, such as cost, energy consumption, maintenance etc., it has significant importance for productive land utilization, simple operation and applicability [13].

2. MEMBRANE TYPES AND PROCESSES

MBR systems generally integrate the employment of bio-processes and membrane engineering to refine wastewater. In late nineteenth century, employment of the treatment method, regarding upon biological way, can be observed but being a model procedure for the treatment of the wastewater begins from the 1930s [14]. Industrial and municipal wastewater samples are exposed to treatment processes in terms of having better permeate quality by employment of aerobic and/or anaerobic treatment processes [15]. When the soluble matter that can be degraded in biological way eliminated from the environment, generation of the biomass requires an entanglement from the liquid flow to ensure necessary permeate quality. Exposing permeate to the gravitational force in secondary tank, operation called traditional process, paves the way for the final separation of the solid/liquid mixture that is frequently a barrier for the permeate quality [16]. There are different types of materials in use for the selection of the membranes. Due to the congruity, only a few membrane typesare widely used and it is known that there are several limitations that diminish the number of materials in use. Membranes should have high acidic, basic, chemical and mechanical endurance properties and they should be performed in the pH range between 4-10. However, 1-12 pH is also employed during the membrane reuse and cleaning. There are still unknown toxic chemicals, oxidants, and membrane materials which may be subjected to these chemicals by providing high shear force from water and air, throughout the process. Some of the polymers used as a membrane material are listed as following; polysulfone (PSF), polyethersulfone (PES), polyolefins: polyethylene (PE), polypropylene (PP) and polyvinylchloride (PVC), polyvinylidene difluoride (PVDF), polytetrafluoroethylene (PTFE) and cellulose acetate (CA) [17, 18, 19]. Membrane processes diverse in each other according to density and porous structure. Pressure driven membrane operations are reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF) and microfiltration (MF). However there are extractive and/or diffusive membrane operations such as; electrodialysis (ED), pervaporation (PV), membrane extraction (ME) and gas transfer (GT).

A brief definition for every type of membrane processes

There are different types of membrane processes employed according to their type and pore size diameter which is directly dependent to the semi-permeability of a membrane in MBR systems. Biggest pore size and, thereby, lowest permeability property belongs to the microfiltration (MF, >50 nm)(IUPAC, 1985) and it provides a separation process for suspended solids (SS) by sifting through over the membrane pores. Controversially, RO has the highest semi-permeability characteristics and even single charged ions, like alkali metals/halogens, can be retained [20]. Nonetheless, it ensures that dividing the dissolvability and diffusion rate of solver and solute inside of the water. Therefore, RO and NF (<2 nm) are used for the solute elimination. While NF is called as 'leaky' RO, disentanglement succeeded throughout the combination of charge denial. In addition to this, MF and UF (2–50 nm), which are mostly used due to biological justifications, is employed for the small colloidal particles removal [21]. One of the fundamental extractive or diffusive membrane process is electrodialysis (ED) which is actually used for the separation quality of ionic size, charge and solute ions' density in terms of charge. On the other hand, since pervaporation (PV) represents the same principal with RO, it actually deals with the partial vacuuming of volatile constituents, which are tent to evaporate partially, on the surface of the membrane. Membrane extraction (ME) method interests the concentration of the matter which cannot be filtrated and effluent part of the membrane. Nevertheless, in gas transfer (GT) process, gas is transported under at significant rate of pressure into/out of liquid in molecular manner [17].

Membrane processes main applications

MBR system modifications have been applied in various industrial processes wastewater such as food industry, petrochemical industry, dying wastewater, hospital wastewater, and textile industry. The reasons for the wide usage of MBR processes in industries are the resistance of toxic substances, high heavy metal removal capacity and treatment ability of refractory substances [22, 23, 24]. In drinking water treatment operations, coagulation, flocculation, sedimentation, filtration and disinfections processes can be integrated into a single process with MBR systems [24]. Besides wastewater treatment, one of the main applications of membrane processes isbiofuel (bioenergy) production in the form of bioethanol, biogas (methane and hydrogen), and biodiesel. Biofuels are designated as first, second or third generation based on the raw material they are produced from. First generation biofuels are derived from sugar, starch and vegetable oil [25]. Second generation biofuels are produced from the stalks of wood, wheat, corn, and some non-food based feedstocks [26]. Algae are the raw material for the third generation [27]. The process of biomass conversion to biofuel requires appropriate separation technologies. Some of the membrane processes that are applied in the process of bioenergy production are: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), pervaporation (PV), membrane distillation (MD), etc. [28]. Due to the properties of ethanol, the most suitable processes for its obtainment are PV and MD. In the case of biogas and biodiesel, those are MF and UF, and for the latter product also NF. The most common configurations applied are flat sheet, tubular, hollow fiber, plate-and-frame, capillary and spiral wound [28].

3. SUSTAINABLE ENVIRONMENTAL PROTECTION AND MEMBRANE PROCESSES

Membrane processes receive a growing amount of interest due to their advantages over conventional systems. MBR systems have an extensive usage field from water treatment to water reuse, because of high quality effluent, high biomass capacity, low space requirement, low sludge production, high chemical durability of some membrane types and high disinfection capacity [29]. MBR systems have increasing importance in municipal water treatment and water supply all around the world. MBR systems are defined as the "best available technology" for many industries, because of the reuse potential of MBR effluents [30]. MBR systems are used for municipal and domestic wastewater treatment systems, because of high removal capacity of organic matter, suspended solids, phosphorus and nitrogen [24]. Furthermore, they contribute to a sustainable environmental protection through their role in biofuel production, a renewable energy source.

Advantages and disadvantages of CAS, MBR and D-MBR associated with sustainable environmental protection

Scientists and researchers are directed to alternative energy sources due to previous uncontrolled usage of fossil fuels and current rapid growth of the world population, advancing technology and energy storage ideas for the future. In this context, MBR and D-MBR systems have attracted to increasing interest and it become more of the issue for both academic and commercial environment in wastewater treatment with respect to energy saving over the conventional activated sludge system (CAS systems). Sustainable environmental protection is the most important issue connected with energy saving. Especially, MBR and D-MBR systems play a significant role for both wastewater and drinking water applications to provide sustainable environmental protection. The membrane bioreactor (MBR) employed for microfiltration (MF) / ultrafiltration (UF) support materials are used to provide solid and liquid separation in the bioreactor, and the reaction eventually does not require secondary clarifier. In this context, when comparison is made among CAS, MBR and D-MBR, use of membrane filtration for solid–liquid separation ensures higher effluent quality for wastewater reclamation and reuse. MBR and D-MBR have many advantages such as, higher biomass concentration, smaller footprint, lower sludge production and rejection of SS (effluent from SS is close to zero) [31]. Especially, MBR and D-MBR systems' features, such as less treatment time, less manpower and less energy consumption, can be evaluated in the sustainable environmental protection when compared to the CAS. Also, D-MBR and MBR systems can be affected by the amount of biomass, the metabolic activities of the microorganisms and the microbial products of the biomass. In a struggle to understand the latter, a range of molecular microbial ecology methods have been developed [32] corresponding with sustainable environmental. MBR and D-MBR systems have been widely applied in full scale and laboratory scale wastewater treatment process thanks to supply higher MLSS concentration, better control of SRT, higher volumetric loading, production of high-quality effluent when compare with CAS [33]. However, the application of MBR is restricted by its high membrane module cost and membrane fouling [34]. So, many researchers attempted to use cheap covered material for replacing the expensive micro-/ultra-filtration membrane for decrease the high cost [35]. Despite it is claimed advantages of better treatment method performance and occupation of much less land, broader application of MBRs is still hindered by their relatively high construction cost and energy consumption [36]. For these reasons, in recent years done extensive research on D-MBR instead of MF and UF membrane is trying to eliminate the cost of the MBRs. Dynamic membrane is formed on the underlying a support materials when filtering the wastewater from the reactor, so is also called secondary membrane [37]. Mesh, woven and nonwoven fabrics are used instead of MF or UF [38] in the D-MBR, by this means operating costs of D-MBR are much lower than the CAS and MBR systems, also environmentally friendly practices from the point of view sustainable environmental protection. Based on the findings of several studies in the literature about the considering the relative advantages and disadvantages of MBR, D-MBR and CAS systems general information , Sustainable environmental protection taking into account, are tabulated in the Table 1.

Table 1: The comparison of comparatively advantages and disadvantages of *MBR, D-MBR and CAS*

MBR		**D-MBR**		**CAS**	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**
High MLSS	----------	High MLSS	----------	----------	Lower MLSS
Low footprint	----------	Low footprint	----------	----------	Large footprint
Higher volumetric loading	----------	Higher vol. loading	----------	----------	Lower vol. loading
Fine control of SRT	----------	Fine control of SRT	----------	----------	Workload for SRT control
----------	Greater operational and process complexity	----------	Greater ope. and process complexity	Easier ope. and process complexity	----------
Lower sludge production	----------	Lower sludge production	----------	----------	Higher sludge production
----------	Higher capital Low ope. costs	Low capital Low ope. costs	----------	----------	Higher capital High ope. costs
----------	Greater foaming propensity	----------	Greater foaming propensity	Lower foaming propensity	----------
Treated water that reusable	----------	Treated water that reusable	----------	----------	----------
Unlimited by settling due to gravity	----------	Unlimited by settling due to gravity	----------	----------	It is limited by settling due to gravity
----------	High Module Cost	Low module cost	----------	----------	----------
Sample TMP control based on constant flow	----------	----------	Complex TMP control based on constant flow	----------	Indifference
Sample fouling control	-----------	-----------	Complex fouling control	-----------	Indifference
Chemical wash easer applied	----------	----------	Chemical wash not easily applied by taking into account microorganisms	----------	Indifference
Very high physical disinfection performance	----------	Normal physical disinfection performance	----------	----------	Indifference
Affected undirectly by Bulking problem	----------	Affected undirectly by Bulking problem	----------	----------	Affected directly by Bulking problem

Chemical treatment is not preferred because it is a secondary cause pollution. At this point, D-MBR systems have importance for used only microorganisms for wastewater treatment. But, D-MBR systems have also some disadvantage as fouling. The main fouling reason was reported in the previous studies due to increased bacterial growth [39]. So, they do not frequently needed to chemical and physical cleaning [40]. Despite physical operations such as, water backwashing , air back washing, brushing, intermittent suction (relaxation) and cross flow are enough for MBR and D-MBR sysmtens, sometimes these operations temporarily cause to effluent quality (high MLSS). In the light of all these findings, although D-MBRs are more advantageous compared to MBR and CAS, some disadvantages associated with the cake layer develop on the the membrane surface. So, a well-defined and systematic comparison of D-MBR, MBR and CAS about wastewater treatment, must be of fundamental importance, thoroughly and meticulously [41]. The main advantage of MBR and D-MBR systems is sludge retention time (SRT) can be controlled easly as completely independent from hydraulic retention time (HRT). So, a very long SRT can be operated resulting in the complete retention of slow-growing microorganisms such as nitrifying or methanogenic bacteria and this results in greater flexibility of operation sustainable environmental protection taking into account [42].

Involvement of MBR systems in the sustainable environmental practices

Sustainable environmental practices is getting importance with each passing day. Development of green built environments is one of the most important sustainable environmental act. The main purpose of green buildings act is eliminated negative impact of buildings on their environments, and create eco-friendly, energy-efficient buildings for future green eco-cites [43]. In this connection, water management and wastewater treatment have vital importance for future [28]. Hybrid membrane techniques like MBR methods and their sub-categories have an important role in green design for urban and municipal applications, because of membrane systems advantages such as cost-effectiveness, user-friendliness and eco-friendliness [43].

4. CONCLUSION

Membrane-based methods play an increasingly important role in sustainable processes such as renewable energy production and wastewater treatment. Their main advantages are high processing efficiency, lower energy consumption over conventional systems, high chemical durability as well as wide applicability. Membrane systems are available in various configurations and are based on different principles, and as such are not without drawbacks - the main being membrane fouling. Further R&D will surely build upon the current findings and provide even more advanced solutions for sustainable environmental protection and biofuel production.

5. PERSPECTIVES FOR THE FUTURE

Since membrane fouling is the main challenge associated with the use of membrane-based systems, future research has to be focused on controlling this phenomenon. This can be achieved by careful optimization of operating conditions, such as backwashing/scouring aeration, SRT, HRT and TMP (transmembrane pressure). This is significant not only for the increase in the membrane life and the decrease in washing frequency, but also for efficient energy consumption. Furthermore, different materials should be investigated so as to find more efficient and/or cheaper alternatives to the currently used ones. Additionally, integration of different membrane methods into one system may contribute to the maximization of efficiency and minimization of the flaws the methods display when applied solely. Besides the technical aspects, room for improvement is also present on the biological side. Research into new sprecies/strains of microorganisms should lead to the discovery of more efficient and adaptable types. Alternatively, known species may be genetically engineered to improve their properties. The properties to be targetted hereby would be: process efficiency, adaptability to various conditions, adaptation time, requirements for optimal growth etc.

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