USE OF MEMBRANES IN PURIFICATION OF WATER

Ms. Radhika Bhadbhade, Mr. Aryan Musale and Dr. Ramesh Bhande

Thadomal Shahani Engineering College, University of Mumbai-India

DOI: http://dx.doi.org/10.24327/IJRSR.2020.1108.5513

ABSTRACT

The threat of environmental contamination looms large on the earth today having a major impact on the groundwater resources. It no longer remains an individual or national concern, but is now a global problem, to be addressed internationally. Currently, the annual availability of fresh water is 1123 Billion Cubic Meters in India and the demand is around 750 Billion Cubic Meters. However, by 2050 the annual demand for water will be 1180 Billion Cubic Meters which will exceed the fresh water availability. The development of original technologies and studies have been accelerated to satisfy the water demands of the world. As an immediate measure, establishment of emission norms on bans of potentially harmful chemicals in industries and discharge of wastes only after proper treatment has been imposed. The current state of water filtration technology needs to be ameliorated in order to provide access to sufficient clean water. Scientific innovations corroborate the development of conventionally used membranes of variegated properties, materials in glorifying this process of filtration. The elementary postulation for the membranes is to limit the entry of particles through diverse sizes of pores in order to acquire purest form of water which has been studied in thorough detail in this review study. These are the heart and soul of effluent treatment plants in the industry. The present spotlight on water treatment has divulged the perks of use membrane technology in efficiently providing immaculate water.

INTRODUCTION

Water scarcity and availability of fresh water has produced a scathingly alarming situation across the globe. By 2050, at least 1 in 4 people will likely live in a country affected by chronic or recurring fresh-water shortages. Furthermore, by 2025, it is estimated that water-scarce countries will increase by more than 30% compared to 1995 and 653 million people in 2025 and subsequently, 2.43 billion in 2050 will suffer direct water shortages as stated by a report from the World Meteorological Organization (WMO) report. This whopping increase in the demand is due to the frivolity of the masses and has in-turn cumulated with rapid urbanization, population growth and climate disruption.

Our planet earth, on the flip side doesn’t have “actual” water scarcity. The copious amount of water in the oceans and fresh water reservoirs has been substantially efficient in serving the needs. But nonetheless, the pivotal reason is the discharge of highly impure water by the industries in these fresh water resources. Besides being a Trojan to the water quality, it’s also fatally capitious to the marine life of utmost importance to the ecosystem. Hence in order to depreciate these causes in an economical manner, membranes were introduced. The detritus water before getting acquitted into these water resources gets treated in an Effluent Treatment Plant. The membranes are advantageous while purifying water at higher quality, considerable maintenance, minimize energy costs while operation, catering filtration at distinct levels (ultra, micro, nano filtration, reverse osmosis etc) to name a few. Also, in this separation process, there’s no involvement of phase change of the liquid under operation. This review paper specifically throws light on recent scientific, technological and innovative trends in membrane operations in a plant along with the controlling the size regime in different filtration processes through analysis of domestic and foreign patent information and publication of papers, technical trends and recent trends in the field of science and technology. Membrane fouling and materials used for construction are also stressed upon.

Membrane Operations

Microfiltration

Microfiltration is considered as one of the pre-treatment methods for other processes such as ultrafiltration whereas for a process like granular media filtration, it is a post-treatment method. The most common particle size which is filtered with efficacy in this process is about 1-0.1 µm. It filters
Macromolecules such as suspended solids, large colloids, algae, sediment, algae and large bacteria having molecular weight less than 100,000 g/mol. However, it isn’t precise in its functioning fundamentals when it comes to microscopic ionic compounds like water (H₂O), natural organic matter and small viruses. Membrane filtration processes can be distinguished by three major characteristics: driving force, retentate stream and permeate streams. The microfiltration process is pressure driven with suspended particles and water as retentate and dissolved solutes plus water as permeate. The use of hydraulic pressure accelerates the separation process by increasing the flow rate (flux) of the liquid stream but does not affect the chemical composition of the species in the retentate and product streams. The suspended liquid is passed through at a relatively high velocity of around 1–3 m/s and at low to moderate pressures (around 100-400 kPa) parallel or tangential to the semi-permeable membrane in a sheet or tubular form.

**Ultrafiltration**

Ultrafiltration (UF) is a variety of membrane filtration in which hydrostatic pressure forces a liquid against a semi permeable membrane. Suspended solids and solutes of high molecular weight are retained, while water and low molecular weight solutes pass through the membrane. Ultrafiltration is not fundamentally different from reverse osmosis, microfiltration or nanofiltration, except in terms of the size of the molecules it retains. Ultrafiltration (UF) is used to remove essentially all proteins, colloids and organic particles (0.1-0.01 µm) from water and some of the largest dissolved contaminants. Ultrafiltration uses hollow fibres of membrane material and the feed water flows either inside the shell, or in the lumen of the fibres. Suspended solids and solutes of high molecular weight are retained, while water and low molecular weight solutes pass through the membrane. Ultrafiltration is not fundamentally different from reverse osmosis, microfiltration or nanofiltration, except in terms of the size of the molecules it retains. When strategically combined with other purification technologies in a complete water system, ultrafiltration is ideal for processing of waste water, desalting and solvent-exchange of proteins, enzyme recovery and radiocarbon dating of bone collagen.

**Nanofiltration**

The penultimate level of water filtration provides an aristocratic level of clarification of water in the Effluent Treatment Plant. As the name suggests, the diameter of the pores ranges in certain nanometers, from 0.01-0.001 µm to be specific. It offers filtration at sub-molecular levels. This implies that, this level has the ability to segregate certain pyrogens, divalent ions and even some viruses. Similar to the formers, Nanofiltration is a pressure-driven membrane process that lies between ultrafiltration and reverse osmosis if discussed in terms of its propensity to reject molecular species. The operating pressure for the filtration spans from 200-250 psig. Since commendably finer species are permeated, consequently the molecular weight span is narrowed as well. It typically ranges from 200-20000. Nanofiltration removes divalent ions, which make water hard, so it finds application in softening the hard water. Furthermore, some honourable mentions include, removal of natural organic matter in water and sulphate removal from seawater and chemical processes, desalting of process streams in various industries and demineralization of lactose and whey in addition to concentration. As this offers penultimate level of filtration, the pre-treatment requisites and the maintenance costs can be a staggering number on the flip side.

**Reverse Osmosis**

The ultimate level of water purification caters aseptic level of clarification of water in the industries. Osmosis is the spontaneous net movement of solvent molecules through a selectively permeable membrane into a region of higher solute concentration, in the direction that tends to equalize the solute concentrations on the two sides. Whereas, reverse osmosis is the process by which a solvent pass through a semi permeable membrane in the direction opposite to that for natural osmosis when subjected to a hydrostatic pressure greater than the osmotic pressure. A fact worthy of noting is, the latter requires an influence of external pressure for the same which should be ideally greater than the natural osmotic pressure. The particle size is below 0.001 µm essentially filtering out minute organics, salts and some metals. Molecular weight is abruptly low (less than 300). As a certain operating pressure is required for this system, ideally it ranges typically from 200-800 psig. Fundamentally there are four distinct types of RO configurations: One and two stage; one and two pass RO with each possessing differential characteristics is terms of volume of permeate and concentrate water under process. The configurations are mentioned in a nutshell below:

If we talk about stages, in one stage RO, the feed water enters the RO system as a single stream and exits the RO as either concentrate or permeate water. But on the flip side, in a two stage RO, the concentrate water which is rejected from the first stage becomes the feed water of the second stage. The permeate water that is collected from the first stage is combined with the permeate from the second stages. As in when the stages increase, the recovery...
Percentages are increased manifolds

On the other hand, unlike the stages wherein the concentration water is the feed for the two stage RO, here the “permeate water” which is obtained from the first pass becomes the feed water to the second pass which in turn yields in the production of a much higher quality permeate because it is essentially been treated through two RO systems.

Membrane types

Membranes, having such a significant importance in the chemical and pharmaceutical industry, today, has a major spectrum classification. A number of factors have to considered in order to design effective membranes, such as, choice of membrane materials, high water flux, high solute rejection, module configuration, mechanical/chemical/thermal/temporal stability, system design including processability at large scale, and operating conditions for cost-effectiveness. Membranes have been classified on a number of parameters such as pore size and materials form which they been manufactured, to name a few.

Classification of membranes on the basis of the materials used in construction can be briefly viewed as follows:

**Organic Membranes**

As the name suggests, these consist of polymers of Carbon as a prime ingredient in the manufacturing of membrane. Some of the most widely and commonly used organic materials also called as 1st Generation organic materials, are Cellulose acetate and Nitrates, Polysulfone, polycrylonitrile, polyether sulfone polivinyldenefluoride, polypropylene (PP), poly vinyl alcohol (PVA) etc. But among these materials, most voguish materials are Polyethersulphone and polysulphone. These materials offer tremendous resistive properties and permeability features in terms of both; mechanical and chemical aspects. Nonetheless, Polysulfone also furnishes additional stabilities and resistance with respect to, pH and oxidation. Unfortunately, there is no such single material which caters all the above requisites. Hence, surface modification is performed in order to spike the hydrophilicity as the contaminants have hydrophobic properties. Some treatments include, UV & Gamma irradiation, surface grafting, plasma treatment etc. Particularly, amphiphilic copolymer (containing both; hydrophobic and hydrophilic ends), Pluronic F127, Polyvinyl Chloride are used as a surface modifier and pore-forming agent to develop anti fouling Polyethersulfone used for Ultrafiltration and even Microfiltration Membranes. These two are used as they are economical and provide a great chemical resistance and mechanical strengths. Cellulose acetate, yet another widely used classic class of organic membranes which is a cellulose-based membrane material which are used from Microfiltration to Reverse Osmosis Membranes. It has been discovered that cellulose acetate membranes, fabricated using nonaqueous solvent systems, can be used for the separation of polar solvents. Moreover, the cellulose acetate exhibit very good resistance to ketone solvents. They date back in the 60’s wherein an experiment was carried out by Loeb and Sourirajan where they inferred considerable salt rejection and flux values. They’re advantageous due to their abundance and hydrophilic properties but on the flip side lack stabilities in terms of chemical, biological and even thermal upto some extent. The corrective measures to these are blending it with above mentioned organic materials like Polyethersulphone, Polivinyldene fluoride etc. Now talking about cellulose nanofibers extracted from various natural sources, cultures (bacterial) are one of a kind, providing exceptional mechanical properties. But the latest technique is the fabrication of Cellulose Acetate Fibrous composite membranes with an exceptionally high rate of separation and staggering high-water permeability. The techniques used to incorporate this can be Electro-spinning, interfacial polymerization, phase inversion (liquid polymer solution is precipitated into two phases; solid, the polymer rich which forms the matrix and liquid phase, the polymer poor phase which forms the pores), stretching (method to create cracks/ruptures by mechanical stress) etc.

**Inorganic Membranes**

Inorganic membranes are usually manufactured from synthetic substances like ceramic which offers a much greater tensile strength and toughness as compared to other membrane materials thus proving it to be of tremendous advantage. With the advancement of nanoscience and technology, applications
of inorganic nanoparticles (NPs) for water purification and remediation have progressively increased. The most dominant inorganic membrane in the modern market is a porous membrane with its crux material TiO$_2$/SiO$_2$. In the case of ceramic membranes, photocatalytic materials such as TiO$_2$ and composites containing TiO$_2$ have been actively studied due to their multi-functionality and wide applications including remediation of ground water and wastewater. Along with a separation function, TiO$_2$ offers photocatalytic ability for decomposition of organic species/microorganisms/pollutants, photolysis, and superhydrophilicity, which reduces unwanted adsorption of organic/biological species to the membrane surface. Also, TiO$_2$ is a non-toxic, readily available, and inexpensive material. Two of the most extensively studied applications areas of photocatalytic materials are disinfection (E. coli bacteria id the most commonly studied model) and removal of targeted organic pollutants (such as methyl orange, methylene blue, Rhodamine B, Hemic acid, phenol, aniline and benzylamine). However, today, photocatalytic membranes are rapidly degrading with time thereby reducing their efficiencies. In order to have more efficient utilization of photo catalytically driven devices including membranes, recently many studies have been conducted to increase the sensitivity of the devices by broadening their solar absorption bands into the visible light range. The results of one such experiment which was performed in a reactor in the presence of azo dyes, the membranes showed an increase in water permeability. This improvement was attributed to the photo-induced hydrophilicity effect of the membrane under solar illumination serving as the only energy input without significant fouling problems.

**Membrane Modelling and Simulation**

A modelling system predicts the membrane performance and optimizes the separation process. Accurate modelling will shed light on the separation mechanisms during filtration that can produce substantial opportunities for productivity improvements and cost savings thus increasing the overall efficiency of the process.

The membrane modelling has been further branched down into Molecular modelling, Mesoscale modelling and Macroscale modelling.

Macroscopic modelling, which is beyond the focus of this review, deals with design and optimization of processing parameters of membrane-based filter modules for application in, for example, wastewater treatment plants. Mesoscale modelling (such as at the single-filter module level) generally deals with flow, rejection, flux, and fluidic transport. In UF and MF processes, when a membrane is porous and water flow is laminar (flow layers travel a regular path or travel smoothly over one another cf turbulent flow, in which the flow pattern involves irregular fluctuations and is time-dependent) a simple hydrodynamic theory can be applied and modelled using empirical equations: Darcy's Law, Hagen–Poiseuille equation, and Carman–Kozeny equation. Application of a specific equation depends on the pore structure factors such as pore size, shape, porosity, average capillary length, pore-size distribution, surface area, and tortuosity.

**CONCLUSION**

The sole impetus and attempt of drafting this review paper is to stress on the fact about the influential role of membranes in purifying the water to a very highly refined level. With the advent of upcoming technologies, membranes clearly have the capacity to not only clarify the “Effluent Water” in a highly cost-effective manner, but also in a controlled and an efficient manner as seen in the size regimes of the pores (microfiltration, ultrafiltration, nano filtration & reverse osmosis). Moreover, the introduction of several modern innovations in membrane technologies including the non-porous membranes, the hybrid membranes etc really make this process of refining uncomplicated. As discussed earlier, the sole purpose of a membrane is also to maintain the permeability and rejection of contents through maybe two standard operating procedures: dead end and cross flow filtration. These two methods of procedures give birth to a phenomenon which is unfortunately a con-side of membranes i.e.; “Membrane Fouling”. Fouling up to this date is implied as an unforced human error which causes excessive operational costs alongside careful attention to the maintenance services. Intensive efforts or even replacement of the old membrane can be a go to step for this repercussion. Hence, we wish an innovation of anti-fouling and antimicrobial technology by simulation of a new composite matrix. Inorganic membranes have the advantage of resisting harsh chemical cleaning, high temperature and wear resistance, high chemical stability, long lifetime, and autoclavable. All of these outstanding properties have over time made inorganic membranes good candidates to be used for water treatment and desalination.

The organic composite materials on the other hand consists of 1st generation organic materials such as Cellulose Acetate, Polysulfone poly vinyl alcohol etc. which lacked thermal and chemical stabilities when used as a standalone material but improved significantly when used as a consolidated material with appropriate blending. Desalination of salt water and proving a feasible option for this global-crisis they can be transformed into a highly happening option through technological advancement in Material Sciences, structural matrices, pore sizes, charge on the membranes and so on.

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How to cite this article:

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