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The Role of Nanotechnology to Convert Sea Water into Drinking Water.

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ABSTRACT

The world needs more drinking water, without damaging ecosystems, and the sea is one possible source. The rapid population growth has evolved the big problem of limited fresh water supply in the world. Desalination is a significant process to convert sea water into fresh water and this process is further improved by using nanoscale to make it more efficient at large scale. Major processes use either thermal energy (conventional distillation) or pressure energy (Reverse osmosis). Different methods of desalination are discussed and their influence on overall water production has been highlighted. Technology advancement has led us to the nanotechnology which is having tremendous scope for water treatment. Nanoadsorbents, magnetic nanoparticles, nanofiltration, nano zero valent iron, nanocatalysts, nanobiocides, nanofibers and mixed technology including catalytic wet air oxidation along with nanoparticles are the products and techniques which are evolved as a result of development in nanotechnology and are being used in water treatment. With the increase in appreciation for a green technology, desalination methods using renewable/waste energy are drawing significant attention in recent years.

Keywords: Desalination, nanoparticles, nanocatalysts, nanofibers

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INTRODUCTION

Many of the current world problems like high chemical contamination in air, water and soil including high carbon compounds, are related to this fast pace of population growth. Current world population is about 6.5 billion and increasing at an alarming rate and is projected to be 9 million by 2050 [1]. Efforts to tackle the population related issues have resulted in severe damage to the ecosystem thereby creating health hazards through environmental pollution. Increased demand for more habitation led to large-scale deforestation and decreased agricultural land, lowering the yield. The production level of food grains is of concern as it has been showing a downward trend over the last decade. Further, extensive use of persistent chemical pesticides to boost agriculture production has also adversely affected our ecosystem and is known to have contaminated ground water [2,3]. Similarly, industrialization is leading to increase in per capita consumption of available natural resources. Out of1,386 million cubic kilometers (km3) of water on Earth, 97%is saline and 99.7% of the freshwater is trapped in ice caps and glaciers, or found in groundwater (one third)(Fig.1). Only about 0.1 million km3 of water is above ground in lakes, swamps and rivers, and about 13,000 km3 in the atmosphere [4].

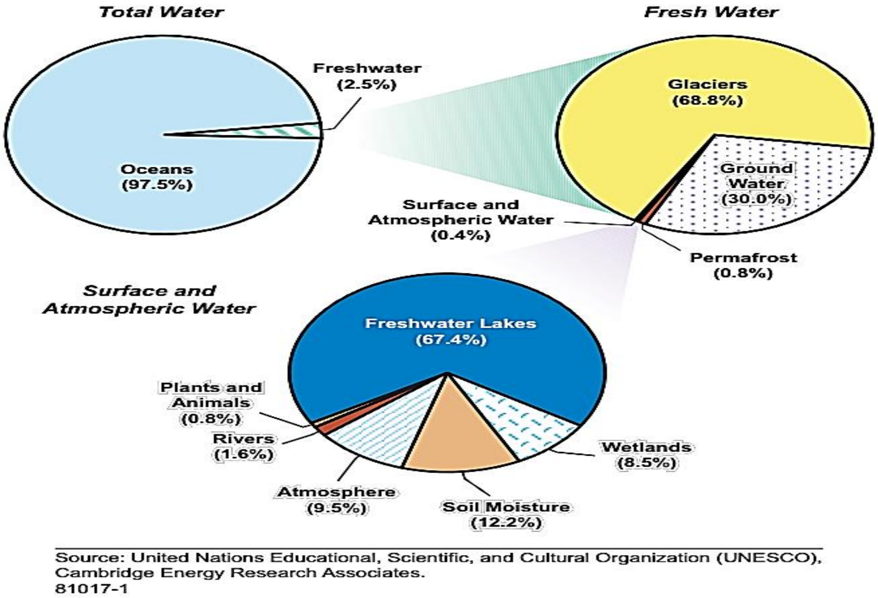

Figure 1: Presenet water resources across globe.

Surface water has not increased for the past 20 years, and simultaneously, groundwater tables have been dropping [5]. Water is a fundamental requirement for life. The availability of fresh water is crucial for life sustaining activities like drinking, cooking, cleaning, agriculture, etc. Nature has its own mechanism for water recycling to provide us with adequate quantity of fresh water with consumable purity level. Modern human activities have however disrupted the balance between the usage and natural purification processes leading to a shortage of potable water. Most of the natural resources of drinking water are found to be contaminated with diverse toxic materials and pathogenic microorganisms [2] 700 million people across the globe face water scarcity, and it is estimated that this problem will touch 1.8 billion people by 2025 [6]. According to a World Health Organization (WHO) report, water borne diseases kill nearly 12 million people every year [7]. About 90% of all diseases occurring in developing countries are related to the consumption of impure water leading to nearly 4 billion reported cases of diseases contracted from water in the world [8].

On earth's surface, only one percent of the available freshwater is easily accessible, which is the water found in lakes, rivers, reservoirs, glaciers and underground sources. Also, the groundwater is getting deeply buried with the explosion in world population and excessive concentration level of dissolved salts does not allow it even to be used for industrial applications. Scientists and researchers have explored the possibility of utilizing the biggest water source, the sea, employing various methods of desalination.

Advanced nanotechnology offers unprecedented opportunities for progress—defeating poverty, starvation and disease and expanding human capacities. Nanotechnology is defined as the ability to understand, control, and manipulate matter at the level of individual atoms and molecules, as well as at the "supramolecular" level involving clusters of molecules (in the range of about 0.1 to 100 nm), in order to create materials, devices, and systems with fundamentally new properties and functions because of their small structure . New approaches are continuously being examined to supplement traditional water treatment methods. These need to be lower in cost and more effective than current techniques for the removal of contaminants from water. In this context also nanotechnological approaches are considered. For the purpose of improving the traditional treatment methods, the use of nanomaterials is being researched to fabricate the separation and reactive media which is of high quality in terms of reactivity and performance.[9] Nanomaterials and nanoparticles are the advanced and significant approaches for the bioremediation and disinfection of wastewater.[10-11] For instance, metal oxide nanomaterials such as TiO_2 are among promising nano-catalysts that are tested successfully for their antimicrobial activity. Major potential environmental benefits of nanotechnology were reported in the draft nanomaterials research strategy, which includes early environmental treatment and remediation, stronger and lighter nanomaterials and more accurate sensitive sensing devices.[12] Other benefits include the cost-effective use of renewable energy, low energy requirement and low waste generation devices, pollution control and the prevention and remediation using improved systems. Desalination process is also improved by using nanomembrane making it cost efficient process which is helpful in resolving the problem of limited fresh water supply. Nanotechnology is effecting the environment, fauna and flora with positive effects along with some potential risks.

DESALINATION

Desalination is a process by which dissolved salts are removed from seawater or brines water thereby converting it into potable water. There are two classes of desalination: thermal or, distillation process, heats the saltwater to boiling, collects and condenses the steam producing purified water; the membrane class Reverse Osmosis (RO) and Electro-Dialysis reversal (EDR) method(Fig.2) involves forcing salt water across a semipermeable membrane that separate the salts from the water leaving a saline solution or brine on one side and a "de-saline" solution (drinkable water) on the other. The following are the most frequently used types of desalination:

Multi-Stage Flash Distillation (MSF) is a type of thermal desalination. Salt water is heated under extreme pressures and lead through a series of chambers. The first chamber is under a lower pressure than the salt water that enters it allowing a portion of the salt water to vaporize and be collected. Upon leaving the first chamber the salt water enters several more chambers each with a lower pressure than the previous one allowing even more of the pressurized salt water to vaporize. The sum of the vaporized water is collected and re-condensed into distilled water. The water that did not vaporize leaves the system with a higher saline concentration than when it entered; this is discarded properly as waste while the distilled water is put into the municipal water supply as drinkable water [13].

Multiple Effect Distillation (MED) is a type of thermal desalination. Salt water is heated under pressure and forced through a chamber. A portion of the salt water evaporates leaving behind a slightly more saline solution than the original salt water. However, in this system the water vapor from the first chamber is used to heat the water in the next chamber (that is under a lower pressure than the previous chamber). Though this pattern repeats throughout several chambers to increase the efficiency of the overall system, the underlying process is trying to use the heat of condensation to heat the next batch of salt water; this produces distilled water (the condensed water vapor) and more water vapor (the cycle repeats) [13].

Reverse Osmosis (RO): is a type of membrane desalination. Here salt water is forced under high pressures through a semipermeable membrane that produces relatively pure water on the downstream side and leaves saline-rich water on the source side. Because membrane cleanliness is crucial to the efficiency of this mechanism, salt water is treated with some initial filters to remove particulate matter. Additionally, after the water passes through the designated membrane, a post treatment generally occurs to to kill any microbes in the water as well as adjustment of the water's pH back to normal [13].Although there are a number of ways to convert seawater to fresh water, a common overall process applies to all schemes. Actual nature of each step would depend on the desalination method used. Figure 2 shows the steps involved in the process.

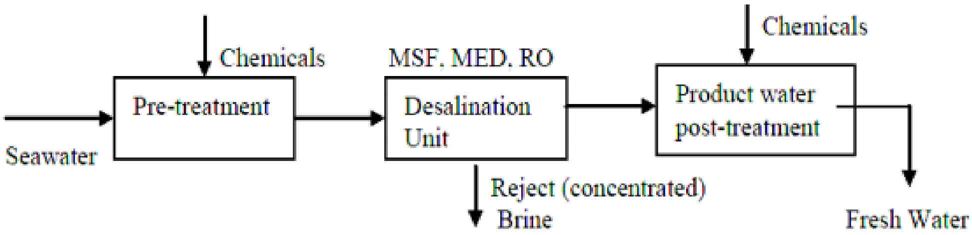

Figure 2: Schematic diagram of a desalination process [14].

The nature of the pre-treatment depends on the type of intake system and the extent of pollution in the surrounding sea. The supply of water directly from shallow bays near the shore may provide seawater with high contents of bacteria, algae and suspended solid. Normally, seawater drawn from open ocean is cleaner and requires less pre-treatment steps. Pre-treatment of raw feed water is necessary to preserve the life and reliability of the desalination equipment. As stated earlier, there are a number of methods available for the conversion of seawater to fresh water. Irrespective of the method of conversion process, the product water should have a total dissolved solid (TDS) content of less than 500 ppm [15]. Table1 shows the typical constituents of seawater and potable water. This product water is not suitable for direct human consumption and some form of post-treatment is necessary to control sodium and chloride ions, and its pH. Large-scale thermal desalination requires large amounts of energy and special infrastructure that makes it fairly expensive compared to the use of natural fresh water. As a result, recently, membrane processes are taken into consideration and these processes rapidly grew as a major competitor to thermal desalination in the later years because of lower energy requirements, easier maintenance, smaller area, quicker start up and cost effectiveness, and thus leading to a reduction in overall desalination costs over the past decade. Most new facilities operate with reverse osmosis (RO) technology which utilizes semi-permeable membranes and high pressure to separate salts from water. However, reverse osmosis process is not well-suited for hot or warm water as the membrane performance deteriorates with temperature above 40^{o}C.

DIFFERENT DESALINATION METHODS

Desalination processes can be broadly classified into two major groups: (1) desalination with change in phase and (2) desalination without the phase change. Thermal desalination, freezing and carrier gas processes are example of the first one and RO is an example of the latter. Figure 3 provides a quick reference to all these processes:

Some of the desalination processes are most widely used like Multi-stage Flash(MSF), Multiple-effect Distillation (MED) and RO; while some are not commercially available yet like Membrane Distillation (MD), electro-dialysis or membrane pervaporation. The widely used thermal desalination processes are basically distillation processes that convert saline water to vapour and then the vapour is condensed to obtain the freshwater.

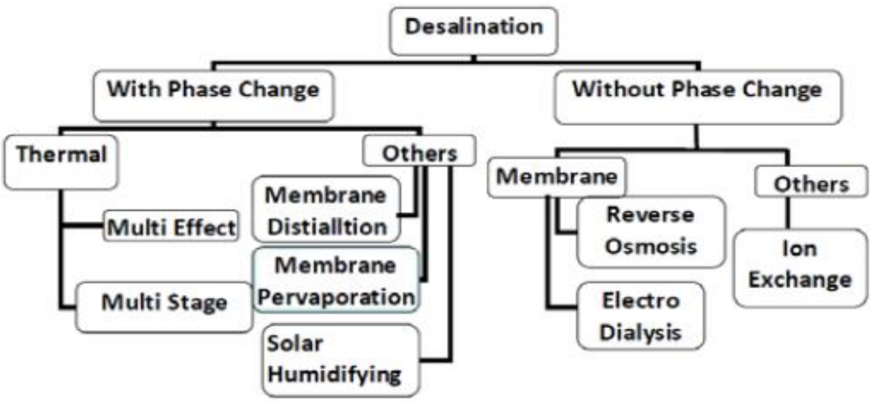

Figure 3: Classification of desalination Processes

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Table 1: Typical constituents of seawater and potable water [16]

Constituents	Seawater (mg/L)	Potable Water (mg/L)
Barium	0.02	1.0
Calcium	412	75
Carbonates	28	150
Chloride	19500	250
Copper	$1x10^{-4}$	1.0
Fluoride	1.3	1.5
Iron	0.002	0.3
Lead	$5x10^{-7}$	0.05
Magnesium	1290	50
Manganese	$2x10^{-4}$	0.05
Mercury	$3x10^{-5}$	0.001
Nitrates/Nitrogen	11.5	10
Phosphates	0.06	0.4
Potassium	380	10
Silica	2	7.1
Sodium	10770	200
Sulphates	905	400
Total dissolved solid	33387 (ppm)	500 (ppm)
pH	8.0	6.5 - 8.5
Turbidity	3 - 15 NTU	5 NTU

Although membrane technologies like RO are invading quickly, the thermal distillation processes produce the largest amount of freshwater in the Middle Eastern countries due to cheap cost of fossil fuel in that region.

The process flow diagram of the PV-RO system is shown in **Figure 4**. The system has three major components, a PV array, a spiral wound membrane module, and a softener. The softener treats raw water from mineral ions that cause scaling problems.

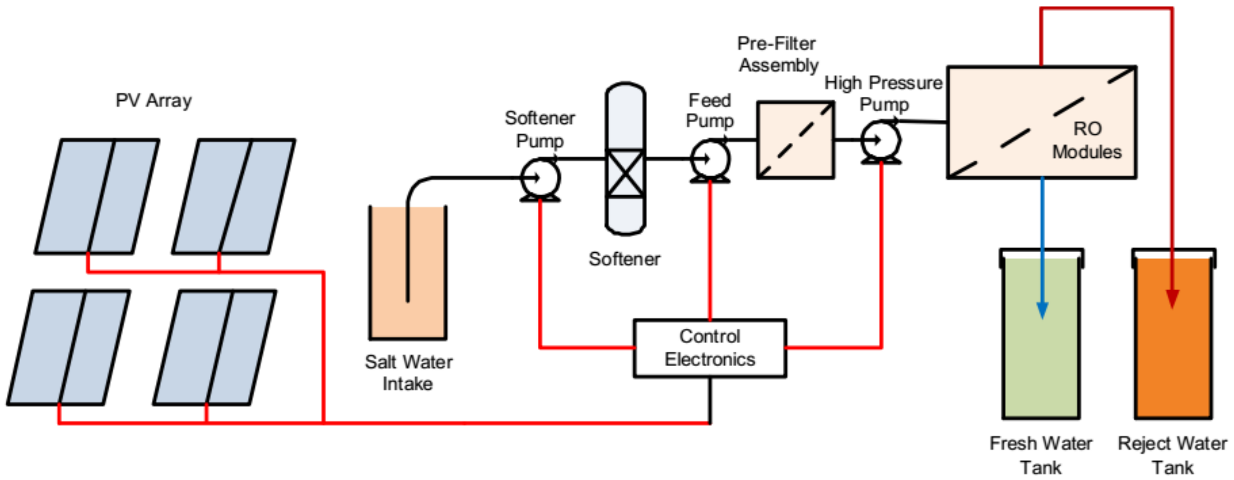

Figure 4: Process flow diagram

Reverse Osmosis Desalination

This membrane process does not involve phase change and the permeate (which is the product water) passes through a hydrophilic membrane under certain applied pressure, which is higher than the osmotic pressure of seawater. Thus, water flows in the reverse direction to the natural flow across the membrane, leaving the dissolved salts behind with an increase in salt concentration. The major energy required for desalting is for pressurizing the seawater feed which is recovered by pressure exchanger (PE). In the pressure exchanger the energy contained in the residual brine is transferred hydraulically. This reduces the energy demand for the desalination process significantly and thus the operating costs. The pressure needed for separation ranges within 50 bars (seawater) to 20 bars (brackish water)[17]. The osmotic pressure is dependant on the feed concentration. A typical large seawater RO plant consists of four major components namely a) feed water pretreatment, b) high pressure pumps, c) membrane separation, and d) permeate post-treatment. Figure 5 shows the RO desalination system. The RO plant energy consumption is approximately 6–8 kW h/m3 without energy recovery and with an energy recovery from the high pressure side, the energy consumption reduces to to 4–5 kW h/m3 [18]. RO has its limitations too. The major problem faced by RO plants is in the pre-treatment area and the membrane sensitivity to fouling. Also, the feed temperature must not exceed 40oC to avoid thermal damage of the membrane.

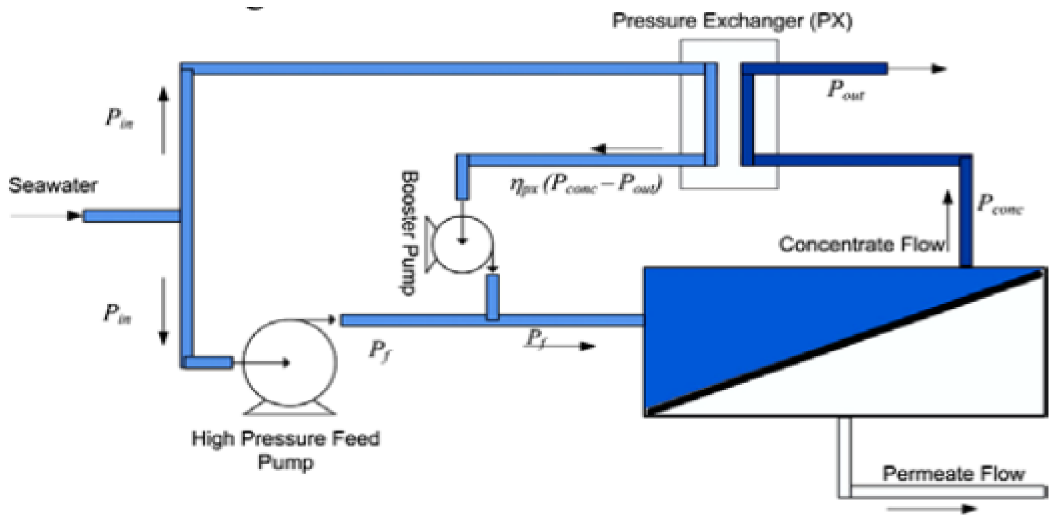

Figure 5: The RO desalination process [19]

NANOTECHNOLOGY BASED WATER PURIFICATION

Nanoadsorbents

Adsorption had been reported as the most technically and economically viable option[20]. Furthermore, research in wastewater treatment by adsorption has resulted in development of different materials for removal of metals from solutions, these materials include: natural product Activated Carbon, Zeolites, Aluminosilicate, Peat Kaolin and Clay and polysaccharides [20-25]. Recently, Carbon nanomaterials (CNMs) mainly in the form of Carbon nanotubes (CNTs) and Carbon nanofibers (CNFs) are being used as new adsorbents with superior performance due to their high specific surface area and high aspect ratio. Work on the effect of morphology, surface functional groups on adsorption capacity of heavy metals by CNMs had been carried out. [26-28] Multiwall carbon nanotubes (MWCNTs) are having metal-ion sorption capacity of 3–4 times larger than the widely used powder and Granular activated carbon (GAC) [29]. Adsorption is being carried out as per equation V(A) and V(B).

Magnetic Nanoparticles

Polyrhodanine-encapsulated Magnetic Nanoparticles (PR-MNPs) are a new efficient way of effectively removing heavy metal ions from solution. Particles are manufactured from an aqueous solution of Rhodanine (7.5mM), Iron Chloride (6.2mM), and Sodium Borohydride (26mM), and synthesized by a one-step chemical oxidation polymerization. Drag force on magnetic particle is determined by equation V(D). Adsorbing will commence due to the metal-binding functional groups provided by the Rhodanine monomeric unit(Fig.6).

Harvesting of the final product is as simple as subjecting the solution to a magnetic field. The particles magnetic properties and large surface area also give it an edge when attracting unwanted metals. [30]. Treatment of chemically contaminated wastewater has strongly profited from the development of scale-up correlations for sewage treatment plants. Prior to exposure to oxide nanoparticle dispersions, the sludge is stabilized following the OECD guidelines. With the broad range of now available nanoparticles, detailed characterization of materials in their form of application is a prerequisite to both toxicological and environmental studies. All studies have shown a dominating effect of surface charge on the kinetics of agglomeration and, as a consequence, on the physical behavior of the nanomaterials.

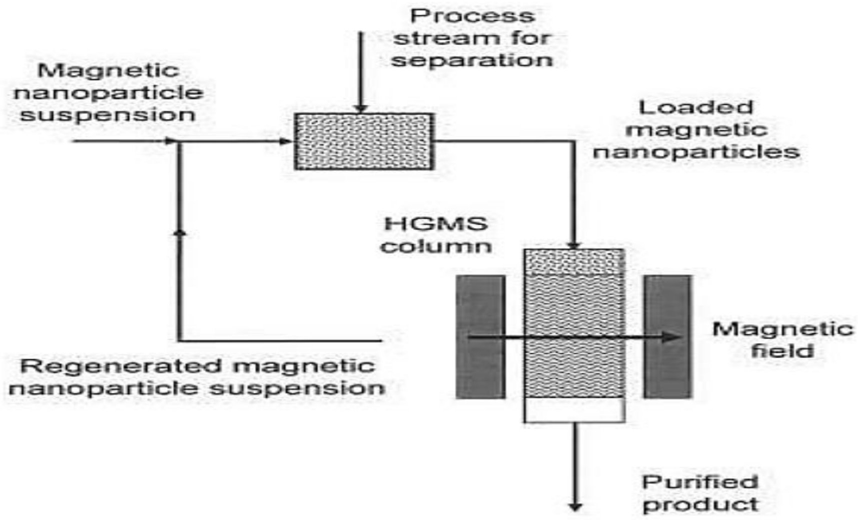

Figure 6: A generalized process using functionalized magnetic nanoparticles as separation agents. Reprinted from AIChE Journal, 2004, 50 (11): 2835-2848

Nanofiltration

Nanofiltration (NF) is a rapidly advancing membrane separation technique for water and wastewater treatment due to its unique charge-based repulsion property and high rate of permeation. NF can be defined as a pressure driven process wherein the pore size of the membrane (0.5-1 nm) as well as the trans-membrane pressure (5-21 atm) lies between reverse osmosis and ultrafiltration. Due to the lower operating pressure and higher flow rates, nanofiltration is inexpensive when compared to reverse osmosis. NF membranes allow partial permeation of monovalent salts such as sodium chloride while rejecting bivalent salts and hardness to a greater extent from aqueous solutions. NF can lower Total dissolved solids (TDS) and hardness, reduce color and odor, and remove heavy metal ions from ground water[31-32]. Flux rate is determined by equation V(C). NF systems are usually operated at medium pressures in the range of 10-50 bar, and have much higher water fluxes compared to RO membranes. NF can be applied for separation between ions with different valences and for separation of low- and high-molecular weight components. Polymeric NF membranes show diversity in separation behaviour but they are common in rejecting highly charged ions (such as Sulphate, Carbonate and Phosphate) in a higher degree, while in comparison, rejection of single charge ions (Cl^-, Na^+, K^+) is much less. The transportation of non-charged solutes through an NF membrane is usually characterized by the term of molecular weight cut-off (MWCO), which is a number expressed in Dalton indicating the molecular weight of a hypothetical non-charged solute that is in 90% rejected. The MWCO of NF membranes is usually given by the manufacturers and typically in the range of about 200-1500 Dalton. However, there are currently no standard methods for characterizing and reporting MWCO.(fig.7) The meaning of this information can vary between different membrane manufactures, thus limiting its value. Besides, the different techniques for MWCO make membranes from different manufacturers hardly comparable without further experimental investigations. Moreover, the concept of MWCO does not address the question of how great the permeation of solutes smaller and larger than the indicated MWCO can be. Membranes have been historically characterized by MWCO rather than by membrane pore size. It should be noted that this concept is based on practical aspects and has no true physical meaning. The molecular weight is not a straightforward measure of the size and it ignores the shape of the permeating molecule, and thus, it gives only a rough estimation of the membrane's ability to remove dissolved uncharged components. Several direct characterization methods are known for NF membranes such as permporometry, gas adsorption-desorption and microscopy techniques. However, the pore size determination of polymeric membranes seems to be still an unsolved problem. Permporometry analysis requires pores larger than 2 nm, and the nitrogen adsorption-desorption method only for inorganic membranes can be effectively applied.

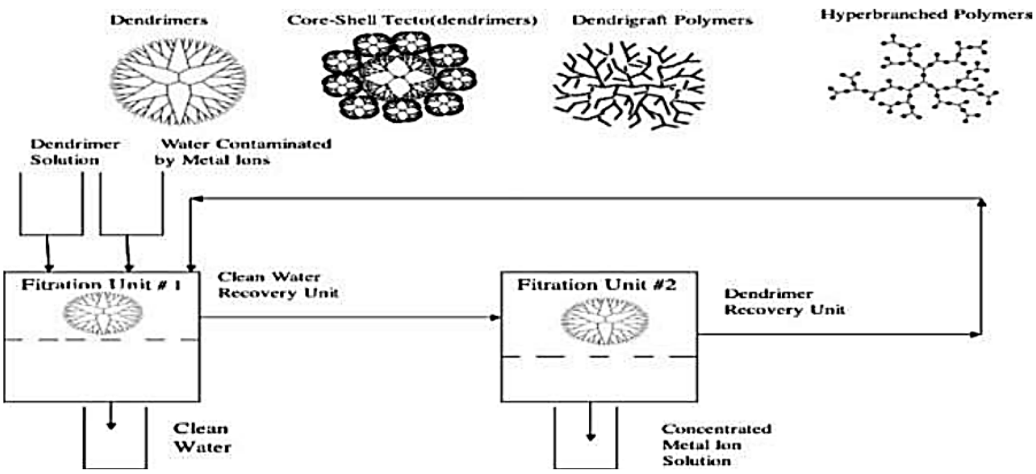

Figure 7: Recovery of metal ions from aqueous solutions by dendrimer enhanced filtration. Reprinted with permission from Environmental Science and Technology, 2005, 39: 1366–1377. Copyright 2005 American Chemical Society

Nano Zero Valent Iron

Nano Zero Valent Iron (nZVI) is emerging as new option for the treatment of contaminated soil and groundwater. Due to their small size, the particles are very reactive (more reactive than granular iron which is conventionally applied in reactive barriers) and can be used for in situ treatment. nZVI effectively reduces chlorinated organic contaminants and also inorganic anions (Perchlorate). It can even be used to recover/remove dissolved metals from solution (e.g. Cr (VI), U (VI)). The mobility and the lifetime of nZVI particles are limited. Therefore several modifications of nZVI are studied, tested and commercialized. The most important are surface-modified nZVI, emulsified nZVI (better miscibility with DNAPL), bimetallic nZVI (higher reactivity) and nZVI on carbon support (better distribution within the soil). If nZVI reacts with ionic heavy metals such as Pb2+, the following reaction takes place:

$$Pb^{2+} + Fe^0 \rightarrow Pb^0 + Fe^{2+}$$

If chlorinated hydrocarbons are present, the following reaction takes place: $R\text{-}Cl + Fe^0 + H_2O \rightarrow R\text{-}H + Fe^{2+} + Cl^- + OH^-$nZVI is not particularly stable. In dry form, the powder ignites immediately when in contact with air. Storage in dry form is only possible in an inert atmosphere. For safety reasons, nZVI is thus in most cases provided as slurry. However, in suspension it also oxidizes fairly rapidly to iron oxides. Possible oxidants – besides the target contaminants - are oxygen, sulphate, nitrate or water. This fact has implications not only for the application in the soil, but also for its transport and storage[33-34].

Nanocatalysts

Nanocatalysts have the advantage of very high reaction rates due to high specific surface areas and low mass-transfer restrictions. For special applications in wastewater treatment we were able to generate extremely active palladium catalysts on the basis of ferromagnetic carrier colloids. The magnetic nano-sized carriers (such as Zero Valent Iron or Magnetite) are spiked with traces of Pd. These nanocatalysts have been successfully tested in different reactor systems at the laboratory scale. Using Pd on nano-scale supports leads to enormous activity of the catalyst which is several orders of magnitude higher than reached in conventional fixed-bed reactors. The ferromagnetism of the carriers enables a separation of the catalysts from the treated water by means of magneto-separation[35](Fig.8). This gives the chance to reuse the catalyst several times. N-doped TiO_2 are also the advanced nanocatalysts because of higher catalytic activity[36].

Nanofibers

Nanofiber technology in combination with biological removal of toxic xenobiotics is the advanced method in industrial wastewater treatment process. Microbial biofilm formation can be greatly supported using nanofiber structures, and the whole system provides stable and accelerated biodegradation. Nanofiber carriers are examined on various parameters like cleaning efficiency of toxic compounds, stability of carrier and nanofiber layer, rate of carrier ingrowths by relevant microorganisms, disintegration of nanofibers and sorption properties. Each biomass carrier must meet the basic parameters (microorganism colonization ability, chemical and physical stability, surface morphology, maximum specific surface). The exceptional properties of nanofiber carriers are primarily the large specific surface, high porosity and small pore size. Electrospun Polyacrylonitrile nanofiber mats are being used for heavy metal ion removal because of tremendous potential as a heterogeneous adsorbent for metal ions [37].

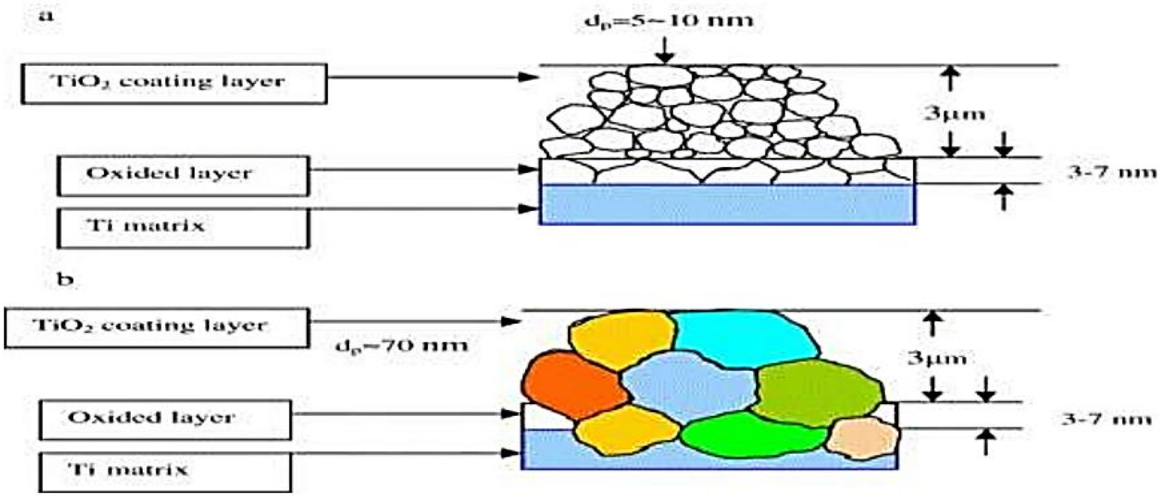

Figure 8: Sketch map of the changing process between nano-TiO2 particles coating and oxided film at the sintering temperature. (a) nano-TiO2 particles coating on the oxided film of Ti matrix; (b) nano-TiO2 particles conglomerate and grow up, and knit with the oxided layer on the surface of Ti matrix at the sintering temperature. Reprinted from Materials Letters, 59 (24-25): 3144-3148.

Depending on the type of polymer, nanofibers are durable, easily moldable and chemical resistant. The principal advantage of nanofiber materials is their comparability with the dimensions of micro-organisms, the surface morphology and biocompatibility, which allows for faster colonization of the nanofiber surface by the microorganisms. An important advantage of the technology is the possibility of a bacterial biofilm buildup not only on the surface of the carrier but also closer to its center (inside the carrier), where the bacteria are much more protected against the toxic effects of the surrounding environment and shear forces during hydraulic mixing. In addition, penetration of substrate and oxygen to the microorganisms is also possible. High specific surface of the nanofiber layer allows to the bacteria great adhesiveness and as a result it simplifies the immobilization of microorganisms, especially in the initial stages of colonization of the surface carriers and also even during difficult emergency conditions (reducing the required regeneration time). After a longer period of colonization the microbial biomass grows naturally on the places without the nanofibers thus making the process of wastewater treatment more efficient. Fe-Grown Carbon Nanofibers are being used for removal of Arsenic (V)(Table-2) in wastewater[38].

Table 2: Polymers and solvents applied for electrospun nanofibrous material.

Polymer	Solvent	Concentration (wt %)
Polyurethane	Dimethyl formamide	10
Polylactic acid	Dichloromethane	20
Polyethylene oxide	Isopropyl alcohol & water	5
Polyvinylcarbazole	Dichlormethane	10
Polystyrene	Tetrahydrofuran	7.5
Cellulose acetate (CA)	Acetone, acetic acid	17

Nanobiocides

Biofouling of membranes caused by the bacterial load in water reduces the quality of drinking water and has become a major problem. Several studies showed inhibition of these bacteria after exposure to nanofibers with functionalized surfaces. Nanobiocides such as metal nanoparticles and engineered nanomaterials are successfully incorporated into nanofibers showing high antimicrobial activity and stability in water. Nanofibers with embedded nanobiocides are currently being used in medical treatments and air filters. Nanobiocides are divided into three categories, namely, metal and metal oxides (nAg, ZnO, CuO, TiO2), engineered/synthesized nanomaterials (Fullerenes e.g., nanomagnetite (nC60) and carbon nanotubes), and natural antibacterial substances (antimicrobial substances, chitosan)[39-42]. Chitosan is also applied in a high flux ultrafiltration media by replacing flux-limiting asymmetric porous membrane with porous electrospun nanofibrous scaffolds. The demonstrated systems consisted of a three-tier composite structure:

- Nonporous hydrophilic coating that is water permeable i.e. Chitosan.
- Polyacrylonitrile (PAN), an electrospun nanofibrous support.
- Polyethylene terephthalate (PET), a non-woven microfibrous substrate.

PAN is resistant to most solvents and has therefore been widely used for ultrafiltration, nanofiltration and reverse osmosis. Carbon nanofibers were also fabricated with electrospun PAN as precursor (Fig.9). The PAN fibrous networking is used to support a top coating layer based on chitosan. Chitosan has been used for anti-fouling enhancement of filtration membranes duo to its insolubility in neutral pH conditions and thus water resistance.

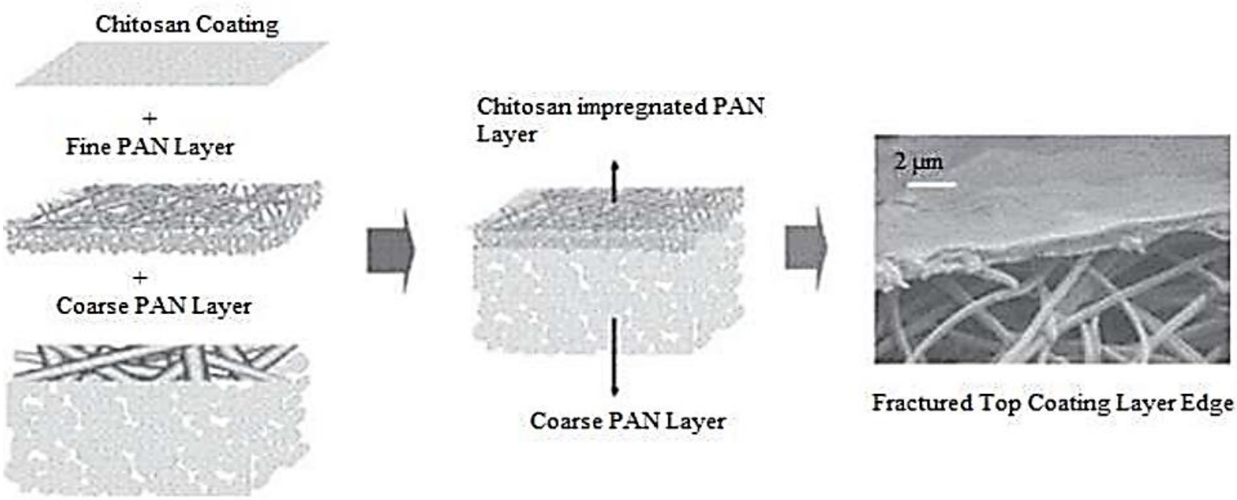

Figure 9: Fabrication schematics of the electrospun scaffold with a coating layer. SEM image represents the fractured composite membrane containing PAN nanofibrous scaffold (with 4 + 12 wt% sequential electrospinning) and chitosan coating (Yoon *et al*., 2006).

Catalytic Wet Air Oxidation using Nanoparticles

A great challenge in nanotechnology is to design highly selective catalysts comprising of an active site with the correct ensemble of metal atoms and other active components. The main advantage of nanocatalysts prepared in organic functional polymers is the easy tailoring via variation of the polymer nature. Such catalysts are characterized by high activity-selectivity-stability. Here we report the synthesis of Pt, Pd, Ru nanoparticles impregnated in hypercrosslinked polystyrene matrix as efficient catalysts for CWAO of phenol. CWAO treatment of phenol compounds realized on the base of hypercrosslinked polystyrene impregnated with platinum nanoparticles leads to high phenol conversion[43]. Catalytic wet air oxidation of Oxalic Acid using Platinum catalysts in Bubble Column Reactor provides an efficient method of combustion at very low temperature as compared to thermal incineration[44].

Desalination by Nanomembrane

To overcome the problem of limited fresh water supply, an energy-efficient approach to converting sea water into fresh water could be of substantial benefit, but current desalination methods require high power consumption and operating costs, which make them difficult to implement and this problem can be resolved by using nanomembrane in desalination(Fig.10). In desalination process a continuous stream of sea water is divided into desalted and concentrated streams by ion concentration polarization. During operation, both salts and larger particles (cells, viruses and microorganisms) are pushed away from the nanomembrane, which significantly reduces the possibility of membrane fouling and salt accumulation, thus avoiding two problems that plague other membrane filtration methods. To implement this approach, a simple microfluidic device is fabricated and shown to be capable of continuous desalination of sea water (~99% salt rejection at 50% recovery rate) at a power consumption of less than 3.5 Wh l−1, which is comparable to current state-of-the-art systems[45].

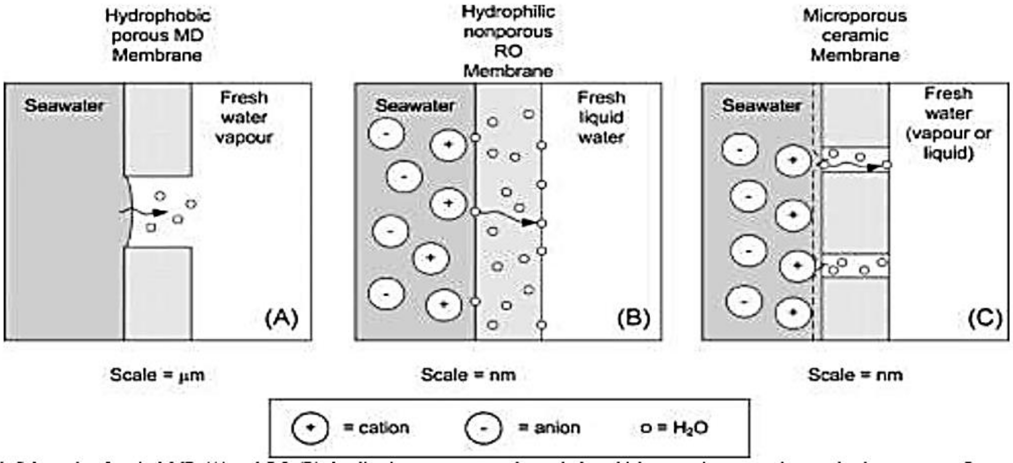

Figure 10: Schematic of typical MD (A) and RO (B) desalination processes at the scale by which governing separation mechanisms operate. Porous ceramic membrane process (C) describes the molecular level transport applicable to both MD and RO. Dotted line in (C) represents the negative surface charge applicable to silica based materials at neutral pH which creates a static double layer of ions in feed. Reprinted from Separation and Purification Technology, 2009, 68 (3): 343-350.

BENEFITS OF USING NANOTECHNOLOGY IN WASTEWATER TREATMENT

Increased Effectiveness

Contaminants could be more effectively removed, even at low concentrations, due to the increased specificity of nanotechnology and the development of "smart" filters tailored for specific uses.

Removal of New Contaminants

Contaminants that were previously impossible to remove could now be removed. This will be achieved through novel reactions at the nanoscale due to the increased number of surface atoms.

Simplification

Nanotechnology could radically reduce the number of steps, materials and energy needed to purify water, making it easier to implement widely in rural communities.

Reduced cost

Substantial initial investment would be needed to incorporate or switch to nanotechnology–based water treatments. However, once adopted, these techniques could considerably lower water treatment costs over the long term.

POTENTIAL ISSUES

Nanotechnology risks can be best understood in conjunction with its benefits. The catalytic activity of a nanoparticle can be advantageous when used for the degradation of pollutants, but can induce a toxic response when taken up by a cell The complexity of the technology, the breadth of nanomaterials and applications, coupled with the possibility of its wide dissemination in the globalized world renders the technology unpredictable in many senses. The risks are heterogeneous as the field of nanotechnology itself and include environmental, health, occupational and socio economic risks. The unusual properties of nanomaterials that can enable rewarding applications for society might pose unknown or unforeseen environment, health and safety challenges. A consistent body of evidence shows that nanosized particles can be taken up by a wide variety of mammalian cell types, are able to cross the cell membrane and become internalized[46]. The pro-technology stance taken in several developed and developing countries at the cost of risk related research has led to an information gap around the impacts of nanomaterials. These aspects together with the commercialization and pervasiveness of nanoproducts serve to heighten the risk from this emergent technology. Another major challenge is the availability of suppliers of nanomaterials. As mentioned earlier, nanomaterials are known for their high surface area to mass ratio and can therefore perform their function at a more affordable price. However, if suppliers of these materials are not readily available, it could seriously undermine the potential advantages of using this technology [47-48].

CONCLUSION

The world is facing formidable challenges in meeting rising demands of clean water as the available supplies of freshwater are decreasing continuously with increasing population. Nanomaterials are having various significant characteristics that make them particularly attractive as separation media for water purification. They are having much large surface areas than bulk particles. They also have high capacity/selectivity for toxic substances in aqueous solutions. Nanomaterials also provide unprecedented opportunities to develop more efficient water-purification catalysts like TiO2 due to their large surface areas and their size and shape-dependent optical, electronic and catalytic properties. Nanomaterials are also being used to develop nanobiocides through functionalization with chemical groups and these nanobiocides are having good antimicrobial activity. Along with the benefits nanotechnology is having risks too in terms of side effects that are to be minimized. Nanomaterials will become essential component of industrial and public waste water treatment systems as more progress is made in nanotechnology in terms of economically efficient and ecofriendly technology development.

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