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NANOTECHNOLOGY FOR WATER TREATMENT

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Abstract*-The world's population is always consuming freshwater at a high rate. Demands for clean, desalinated water have led to improvements in the quality and quantity of viable desalination techniques. These improvements have helped solve major engineering problems regarding energy consumption and environmental health. Engineers have found the best way to answer these questions currently available.*

The use of nanotechnology in seawater desalination is a sustainable technique to supply freshwater in a more efficient and eco-friendly way. Applying nanotechnology to water desalination is most effectively done by revamping old processes. One of the oldest techniques for water desalination is reverse osmosis. Current reverse osmosis techniques produce highly salinized brine, is energy expensive, and maintenance intensive. These flaws of the process are inefficient. With a more efficient process comes a more eco-friendly process as desalination instruments would need less maintenance, and less energy would need to be produced to run the desalination plants. These innovations using nanotechnology create a way to obtain clean water from the sea while staying environmentally friendly. Along with demands for processes to increase in efficiency, water desalination techniques must be sustainable. Sustainability is a measure of a industries ability to stay modern and keep up with global expectations regarding efficiency, energy usage, environmental footprint, and more issues the world faces today. Organizations such as Cordis and NanoH2O have researched their own ways of improving desalination processes through the use of nanotechnology. This research in nanotechnology opens the doors for further applications and research into related fields manipulation of organic processes.

In this research paper we will evaluate the current techniques used to desalinate water and compare them to processes involving nanotechnology, allowing us to conclude how to implement nanotechnology to create clean water in the most efficient and sustainable way possible.

Key Words- Biofouling, Cordis, Desalination, Electrodialysis, Forward Osmosis, NanoH2O, Nanotechnology, NAWADES, Photocatalysis, Reverse Osmosis, Sustainability.

THE GROWING DEMAND FOR FRESHWATER

As the world's population exponentially increases, our need for natural resources grows as well. Of the vast variety of resources the world consumes, fresh water is among the most vital. While the demand for freshwater grows with the population, questions of sustainability of fresh water reserves are raised. For example, China represents nearly twenty percent of the worlds population but is home to only six percent of the worlds fresh water reserves [1]. China is no exception from the global norm. The global population is on pace to surpass 9.5 billion people by the year 2050 [2]. During this same time, demand for fresh water is projected to increase by 55 percent [3]. This demand is not only for water for people to drink, however. Population causes demand for water to increase in other implicit ways. More people means a greater demand for food, requiring more water to be delegated towards agriculture. Increased population means more water must be delegated for industry as well. We can expect to see an increase in the amount of fresh water we consume, which is cause for concern considering many fresh water reserves are draining faster than they are being replenished [3]. To solve the growing problem of supplying water, engineers have developed techniques for desalinating contaminated water. This allows brackish and ocean water to be converted to drinkable, fresh water. Many techniques have been developed to satisfy this goal, but none of them are perfect. Current techniques are energy expensive and/or harmful to the environment.

As well as being imperfect in their energy consumption and environmentally conscientious, current processes are not entirely sustainable. We define sustainability, as it relates to water desalination, as the ability to satisfy changing social and cultural expectations of industry and technology. The worlds expectations of efficiency are incomparable to expectations in place just one hundred years ago, for example. Environmental, cost and energy efficiency are all necessary components of sustainability. Sustainability has become an expectation of industry, and current desalination processes need to reflect this.

THE DESALINATION PROCESS

Water desalination, no matter the technique used, relies on the same fundamental process. Contaminated water is passed through a filtration membrane, stopping contaminants and allowing pure water molecules to pass through. While water desalination is fundamentally the same, there are many differing ways to achieve this. Some processes force the water through a membrane by applying pressure to the contaminated water while other processes encourage water to move by reducing pressure on the other side of the membrane, effectively pulling the water through the filter. Whatever the technique used, there is room for inefficiency. Many different processes have been engineered, but the current processes used are energy inefficient, maintenance intensive, or not sustainable by our definition.

Reverse Osmosis

Reverse osmosis is one of the earliest processes of desalination. While it is a process that is in used in many desalination plants across the globe, it is far from perfect. Reverse osmosis involves pushing all the water to be filtered through a membrane that allows water to pass through but stops any pollutants. While this process works, current membrane technology is not up to par with todays standards. Current membranes are susceptible to biofouling, requiring considerable maintenance [4]. Biofouling, defined as "The gradual accumulation of organisms such as algae, barnacles, and protozoa an underwater equipment, pipes, and surfaces, corroding or impairing structures and systems," impedes the flow of water through the membrane, reducing efficiency and increasing energy costs [4]. Another product of this biofouling is harm to the environment. Current reverse osmosis techniques create ample waste and is inefficient [4]. The harm caused by biofouling can be found in the cost of producing new membranes. With membranes needing replacement, more must be created, requiring energy and materials. Also, disposing of these old membranes can lead to environmental complications as well. The chemicals that are trapped in the resulting brine after the water is filtered is difficult to dispose of and is often dumped into the ocean, causing concerns for ocean ecosystems. Another environmental concern stems from the carbon footprint of producing the energy to run desalination plants [4]. These environmental concerns compounding with a concern regarding the productive efficiency of current reverse osmosis membranes lend themselves to the thought that this process is not sustainable as is. In order to achieve a satisfactory level of sustainability, current reverse osmosis technologies must be lifted past these barriers by innovation.

Electrodialysis

Electrodialysis is a process of desalination where water ions are passed through an ion selective membrane to electrodes of opposite charges on the other side [5]. This process is an unrealistic solution to the worlds water problems as it is used in waters with low total dissolved solids. Water with low dissolved solids includes brackish water, water with low contaminant levels, and water that had perhaps been filtered once or twice before. Electrodialysis is used primarily in the desalination of brackish water which has a salinity of 10,000mg/L [5]. While water with low dissolved solids is the easiest to filter and purify, there simply isn't enough of it globally to satisfy fresh water needs. Brackish water, for example, makes up less than 1% of the worlds water. Sea water, however, has a salinity in the range of 30,000 to 44,000 mg/L [5]. To meet freshwater demands, engineers must turn to sea water. The fact that electrodialysis cannot meet production demands by filtering the more abundant, more salinated water proves its lack of sustainability. This process is simply not efficient to use on an industrial scale required to satiate global demand for fresh water. This excludes electrodialysis from being a viable solution to the worlds freshwater needs.

Forward Osmosis

Forward osmosis is similar to reverse osmosis in that the water is filtered by being passed through a microscopic membrane, but it differs in the way water is encouraged to move. While reverse osmosis uses constant pressure to push water through the cleaning membrane, forward osmosis uses natural osmotic pressure to pull water through the film. The downsides of this process are it is not effective at producing the purest water, allowing some small contaminants to pass through with the water [5]. These contaminants are able to get through the membrane partially due to back salt diffusion. Since the osmotic pressure used in forward osmosis is less than the pressure used in reverse osmosis, some contaminants are able to travel through the membrane with the water particles, creating water that is less clean than water that is produced by other techniques [5]. This process is not as energy intensive as reverse osmosis, but the inability to create the purest water outweighs this energy benefit. The fact that forward osmosis is more energy efficient lends itself to sustainability, but the lack of a pure product over powers this energy efficiency. The process is less efficient than required as the water that is produced may be either unsatisfactory for consumption or may need to be filtered again. This fact takes away any evidence suggesting this process should be considered sustainable.

These processes do successfully provide fresh water, but they can be vastly improved upon. The integration of nanotechnology and nanoparticles into these methods is the best way to bring these outdated processes to the current world standards of efficiency. Nanoparticles increase energy efficiency and decrease maintenance required on the desalination membranes.

HOW NANOTECHNOLOGY APPLIES TO WATER DESALINATION

The cost of desalination water is considerable no matter what process one chooses. All processes require considerable amounts of energy in the filtration process. Desalination processes differ in the specific ways they filter, where the majority of the energy required is, and in the makeup of the membranes themselves. Filtration membranes can be made of many different materials, some of which work more efficiently than others. One can choose a material that increases permeability if the water molecules, increase the percentage of contaminants the membrane catches, reduce the rate at which membranes susceptible to biofouling, and more [5]. The ideal membrane would achieve all these qualities at a high level. Increasing the permeability of water through the membranes increases the energy efficiency of the process. This makes it easier for water to pass through the membrane, reducing the amount of pressure required in the filtration process. With less pressure required comes less energy required to create this pressure, making the process more efficient and cheaper. The equation relating pressure and energy inputted is shown below, with energy being represented in the form of heat.

$$\pi = iMRT$$

π=osmotic pressure
I = van't Hoff's factor
M= molar concentration of solution
R= Ideal gas constant (0.08206 L atm $mol^{-1}K^{1}$)

EQUATION 1 [5]
This equation shows the relation between osmotic pressure and energy in the form of heat.

Osmotic pressure is directly dependent on temperature. As seen by the equation above, a high temperature is required for the high osmotic pressure required in effective water desalinization. In order to produce this temperature, an exuberant amount of heat is required to start and fuel the process. Most heat produced in this process results in harmful biproducts that pollute the environment such as carbon dioxide [4]. Industrial plants that supply this power cost end up harming the environment. In order to reduce the energy costs of this process, either the process needs to be more efficient in filtering the water or reduce the overall osmotic pressure needed. Making the process more efficient serves to allow the producer to reduce the length of time water needs to be filtered as the filtered water would not need as many cycles. Reducing the overall osmotic pressure required directly reduces the temperature required, and thus ultimately reduces the amount of heat needed to produce the filtered water. From 1970 onward, energy costs of preforming reverse osmosis have been decreasing each decade. Figure 1 below shows this change in energy cost.

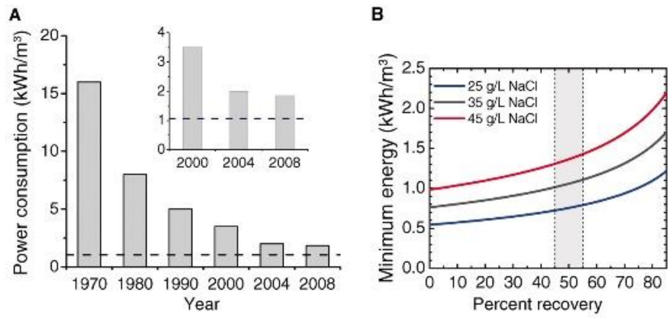

FIGURE 1 [5]
The bar graph shows the decreasing energy costs each year of reverse osmosis. The line graph shows the minimum energy required of the process and the amount of recovery.

However, energy costs in the past few years have been decreasing at lesser rates. From 2004 to 2008, energy cost only dropped .1kWh/m^3, as compared to the 1.5kWh/m^3 drop from 2000 to 2004 [5]. This leveling-off could be due to near optimization of current desalination techniques. This shows that new techniques with a higher energy efficiency ceiling are needed. large push is needed in order to further reduce the power consumption of reverse osmosis. If a membrane is designed with the intention of increasing the percentage of contaminants stopped during filtration, this improves the process as well. Cleaner water is always the goal of filtration, so the easier it is achieved the better. Membranes that are designed with the idea of reducing biofouling in mind reduce maintenance required on the system. As filtration membranes are in use for a considerable amount of time, they accumulate bacteria and microorganisms. As more and more of this organic material accumulates, permeability and effectiveness of the membranes reduces. To keep producing clean water these membranes must be replaces periodically. Replacing these requires shutting down the filtration facility, costing time, money, and resources. If a facility can minimize the frequency with which these membranes must be maitinenced, it would increase efficiency. All of these goals of the industry can be achieved by introducing nanotechnology into the desalination process.

Nanotechnology is restructuring molecules at a near atomic level. Typically, nanotechnology is the development and application of technology on a scale from one to one hundred nanometers. For a frame of reference, 25,400,000 nanometers are in one inch [5]. Scientists and engineers have applied this technique of manipulating molecules to the process of desalination through development of water filters [1]. While the end goal is the same, nanotechnology has been applied in many ways to separate water and salts. This use of nanotechnology helps to make what was a once tedious and inefficient process streamlined into an efficient means of production, feasible of providing freshwater on a commercial scale. Nearly 97% of earths water is undrinkable salt water [6]. The conversion of salt water to freshwater requires the boiling of the saltwater, evaporating the water. The solute is left behind as water then forms condensation in another area. This procedure is far too lengthy and energy expensive, making it impossible on an industrial scale. Nanotechnology offers alternative solutions to this, however. Using nanotechnology, current desalination techniques can be improved upon greatly, including the industries most common process reverse osmosis [7]. As Through improving filters and filter membranes, reverse osmosis makes water desalinization much more viable on an industrial level, in part by increasing efficiency and sustainability.

APPLICATION OF NANOTECHNOLOGY IN DESALINATION

The organization Cordis has been exploring the use of nanotechnology for water desalination. Cordis' project regarding nanotechnology is called the Nanotechnological Application in Water Desalination, or NAWADES [8]. NAWADES is exploring the application of nanotechnology and nanoparticles within water desalination processes in two specific ways. First, they developed LED and self-cleaning membranes into demonstration prototypes and tested on-site [9]. At one of the Cordis test facilities in Barcelona, Spain, this new membrane technology was tested. Researchers tested their self-cleaning membranes with dead-end and cross flow settings, with and without UV- radiation [9]. The dead-end setting refers to dead end filtration, shown in the figure below. Dead end filtration is a process of filtration by which all waterflow is perpendicular to the filtration membrane. The cross-flow setting, also shown in the figure below, refers to the filtration process by which water flow is perpendicular to the filter membrane but also runs parallel [10]. Dead end filtration requires less energy as less water is being moved in the filtration process, but water production must be stopped semi frequently to clean out the "filter cake" that forms. This filter cake is made up of microparticles and contaminants. Cross flow filtration does not require stoppage, as the water running parallel to the filter membrane moves contaminants as they build up, but energy costs are higher as more water is being moved [10].

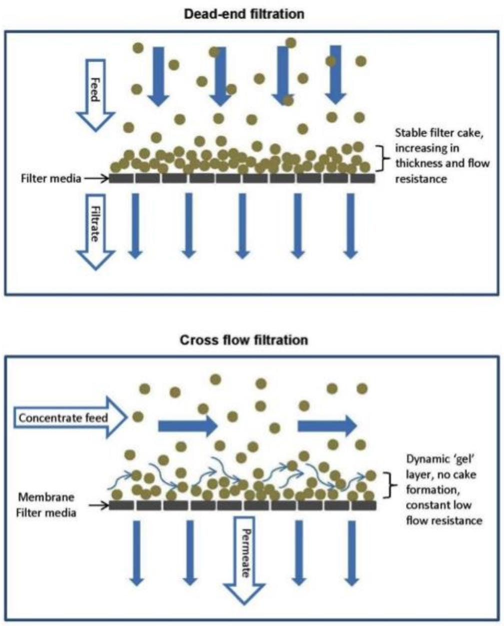

FIGURE 2 [10]

This figure shows the differing filtration processes, dead end filtration vs cross flow filtration. Dead end filtration involves all of the feed water running perpendicular to the filter membrane, while cross flow utilizes water flow to remove the build up of contaminants.

The self-cleaning membranes were developed by coating titanium dioxide particles on the membranes surface [9]. Coating the membranes in titanium oxide is just as involved a process as creating the membranes. The membrane to be coated must be put through a meticulous process to ensure the coating is applied correctly [11]. Dr. S. S. Madaeni of Razi University describes this process; "the membrane was immersed in a transparent colloidal solution containing 0.003 wt. % of TiO_2 particles for 1 hour. After that, the membrane was washed with an excess amount of distilled water and then illuminated by UV lamp for 10 minutes" [11]. The membrane then sits in distilled water for fifteen minutes before it is tested in an experiment rig to ensure the nano-titanium oxide particles are evenly spread, leaving no build ups or thin spots. This coating had the dual effect of minimizing fouling and giving the membrane photocatalytic properties, allowing UV radiation to be used to clean the surface without shutting down the plant or replacing membranes as often [12]. Photocatalytic abilities refers to the ability of some nanoparticles to increase the rate of a certain reaction. In the case of nano-titanium oxide, UV radiation speeds up the rate at which organic compounds are broken down [13]. This property of titanium oxide is utilized to reduce biofouling in the filtration process, making membranes "self-cleaning," and far less maintenance demanding. The UV radiation required to act as a catalyst in this reaction is delivered in the form of black light by submerged LED light sticks and LED curved coats [9]. This light is then propagated by side emitting quartz fibres and quartz glass surface integrated into the membrane housing with exchangeable membrane cartridge [14].

The second area where NAWADES explored the possibility of the application of nanotechnology is within the materials the membrane itself is made of. The project team aimed to create a membrane that allowed water to be filtered at a lower energy cost. The team achieved this by using polyvinylpyrrolidone within the porous substrate layer of the membrane, one of three main layers. "Layer by layer assembly of catalyst on flat polyvinylpyrrolidone membrane was tested, as well as production of mixed matrix hollow fibre ultrafiltration membranes made of polyvinylpyrrolidone and titanium dioxide catalyst, including polyvinylidene fluoride and titanium oxide catalyst and aluminum oxide and titanium oxide catalyst [14]. NAWADES found both of these processes to be effective in reducing biofouling and increasing permeability [14]. The success of the project has been measured in its implementation in desalination plants. In the desalination plant in Llogregat, Barcelona. This desalination plant implemented the self-cleaning titanium oxide membranes and reported a significant reduction in energy costs, ranging from a 2-5% reduction [14]. This 2-5% reduction is very significant. If on average it costs anywhere from $3.60 to $5.80 to desalinate 1000 gallons of sea water, and 86.8 million cubic meters of water is desalinated daily, just a 2% reduction in cost could save 1.65 to 2.66 million dollars a day globally [15]. This stems from an increase in permeability due to a reduction in restrictive biofouling and a decrease in required maintenance on the plants implements. This reduction in cost lends itself to creating a more sustainable process. NAWADES managed to make the desalination process more energy and cost efficient with their self-cleaning titanium oxide membranes. This increase in efficiency directly leads to sustainability. Less energy is needed to be produced to produce fresh water reducing costs of production and decreasing the environmental footprint of desalination plants. The benefits found by the project team prove the need to integrate nanotechnology and nanoparticles into water desalination.

NanoH2O and the QuantumFlux Membrane

NanoH2O's QuantumFlux membranes is another example of the application of nanotechnology for desalination. Eric Hoek, the creator of this QuantumFlux membrane, wanted to work on a new reverse osmosis membrane material that would perform better in desalination applications [16]. The majority of reverse osmosis plants use thin-film composite (TFC) membranes for desalination. These membranes are proven and work, but plants that use them face challenges with relatively low water permeability and high fouling tendency [16]. These issues with TFC membranes are the reason new technology was required to make the process of desalination more efficient. Eric Hoek and the team at NanoH2O worked on improving membranes to tackle the inefficiency in the desalination process. Hoek incorporated zeolite, a nanoparticle in the reverse osmosis membrane to make it more effective and resistant to fouling [17]. Zeolite, a low density crystalline material, is known and used for its micropores sizing from eight to twelve nanometers [18]. These micropores are what attracted Hoek to the material. The team called this new and improved membrane structure the thin film nanocomposite (TFN) [16]. Its molecular pores take in water like a sponge, letting water in and rejecting salt particles due to the microscopic size of the pores within the material. The zeolite particles within the membrane also create preferential water pathways as water travels from micropore to micropore, reducing the required pressure to filter large amounts of water [16]. The permeability of the TFN membrane is nearly double that of the TFC membranes, thanks to the addition of nanoparticles [16]. Hoek synthesized zeolite nanoparticles and embedded them within the reverse osmosis membrane to reduce the overall energy demanded in the desalination process [17]. Hoek says the new membrane got its name "for its unique structure where a 100- to 200-nanometer thin film contains both nanoparticles and polymers working together to produce a better material than either could alone." [17]. The structure of the TFN membrane is only slightly different than the structure of the TFC membrane. "A typical TFC membrane consists of three layers: a dense polyamide rejection layer, a porous substrate commonly made of polysulfone or polyethersulfone, and a non-woven fabric layer as a mechanical support" [16]. The figure below gives a visual representation of the two membranes and their three-layered structure. [16].

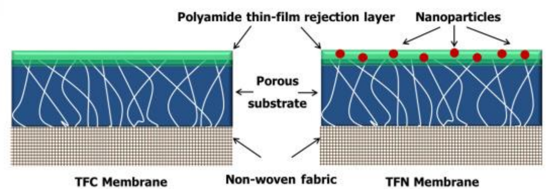

FIGURE 3 [16]
In this figure, the three-layered structure of the TFC and TFN membranes is shown. The location of the zeolite nanoparticles is shown here, in the top polyamide rejection layer.

The polyamide rejection layer determines the water permeability and salt rejection of the membrane. This is where NnoH2O made the greatest improvements to the TFC membrane structure. This layer can be prepared by the interfacial polymerization of an amine monomer in aqueous phase and acyl chloride monomer in organic phase[16]. Interfacial polymerization is a type of step-growth polymerization in which polymerization occurs at an interface between an aqueous solution containing one monomer and an organic solution containing a second monomer [19]. The chemical structure of this the polyamide layer is also shown in Figure 5. The second layer of the TFC and TFN membrane consists of a porous substrate made of either polysulfrone or polyethersulfrone. The chemical structures for these materials can be found here.

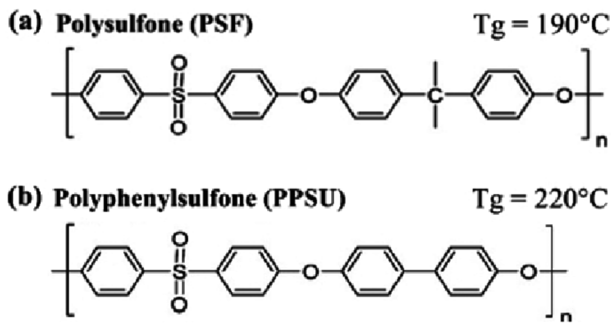

FIGURE 4 [20]
This figure shows the chemical structure for polysulfrone and polyethersulfrone, the two chemicals used in the middle layer of the TFN membrane, providing a porous substrate to aid in the filtering process.

The final layer consists of fabric to support the fragile upper layers of the membrane, allowing for a large volume of water to be pushed through. While this three layer structure has been in use for years in the TFC membranes, the addition of zeolite nanoparticles in the polyamide rejection layer has revolutionized the water desalination process as a whole. The nanoparticles increase permeability and decrease the rate of biofouling within the membrane, decreasing operational costs. The increased permeability decreases the energy cost to process water as more water can be passed through the membranes with less pressure. The decreased rate of biofouling reduces the maintenance required on the membrane, which in turn also reduces costs and increases efficiency. A decrease in maintenance of the membranes proves sustainability in a slightly different way than previous processes. While the zeolite TFN membranes do increase efficiency and reduce energy costs as did the NAWADES titanium oxide membrane, NanoH2O emphasizes a reduction in maintenance. This reduction in maintenance lessens the amount of man hours required to run a desalination plant, increases efficiency in employees time spent of the job. If employees can spend less time cleaning or replacing the membranes, they can spend more time optimizing other part of the desalination plant. The QuantumFlux membrane developed by Eric Hoek and his team at NanoH20 is an example of how nanotechnology is used within the plants to improve the production and efficiency of the desalination of saltwater.

NanOasis's nanotubes

Another process of desalinization is through the manufacturing of efficient membranes containing carbon nanotubes. Carbon nanotubes are a sheet of carbon atoms that are cylindrical tubes that are one atom thick and have a diameter less than 1 nm. Carbon nanotubes have become an emerging prospect in the use of desalination membranes because they have such miniscule size [21]. Carbon nanotubes allow for water to pass through the pipe while rejecting salt molecules.

Carbon nanotubes also have the unique structural property of being able to reject dissolved ions while allowing water to pass. The small diameter creates energy barriers to reject unwarranted ions like salt. However, the issue with the small diameter of the carbon nanotubes is only a small amount of water can travel through at a time. Increasing diameter to increase the flux of water by adding charged function groups to the tip of the tube such as carboxylate or amine groups have only resulted in better filtration, but no increase in flow [21]. Flow rate is holding the process back, but the increase in diameter was not able to increase this aspect of the process. Different geometry's of nanotubes that have been tested are shown below in figure 5.

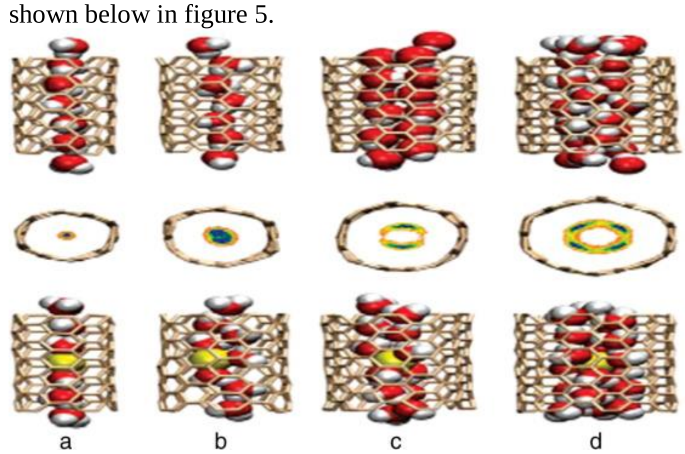

FIGURE 5 [21]
This figure displays the exclusion process of unwanted ions

There are two main types of carbon nanotubes membranes: vertically aligned carbon nanotubes and mixed composite carbon nanotubes membranes. Vertically aligned carbon nanotubes are comprised of carbon nanotubes aligned to form 5-10μm film [21]. The vertically aligned carbon nanotubes do have a higher flow of water, but also are more prone to fouling [21]. The mixed composite carbon membranes are polymeric membranes with multi-walled carbon nanotubes. Mixed composite carbon nanotubes have nearly double the water flow, while still maintaining a high salt rejection rate [21]. Unlike most processes, carbon nanotubes work in both forward and reverse osmosis, however they are most effective in reverse osmosis [21].

NanOasis is one of the leading companies in the implementation of carbon nanotubes in water desalinization. NanOasis, located in Richmond, CA, aims to carbon nanotubes to lower the cost and energy requirements for desalination. Their membranes consist of a thin, dense polymer film having carbon nanotube pores atop a highly porous support. NanOasis is using carbon nanotubes in membranes to increase membrane permeability by several-fold without loss of rejection [22]. This permeability results in a significant reduction in the required energy to produce a high water flow. While this company has found success in initial trials, they have yet to implement the technology on large commercial scales. The application of carbon nanotubes in the process of water desalination is relatively unproven, but is very promising.

WHERE THESE CHANGES ARE BEING APPLIED

Nanotechnology is used across the world in the process of desalinating water. The NAWADES project tested their applications of nanotechnology at the Barcelona Sea Water Desalination Plant, located next to the mouth of the Llobregat river in the municipality of El prat del Llobregat, Barcelona [8]. This plant is the largest reverse osmosis-based desalination plant in Europe with an output of 200,000 cubic meters per day and it holds the responsibility of supplying water to the city of Barcelona and the surrounding eight districts [8]. A picture of the desalination plant in Barcelona is shown below in figure 6. The "egg-shape" of these tanks allows for the continual movement of water with little energy input [8].

FIGURE 6 [11]
This image shows a picture of the desalination plant in Llobregat, Barcelona.

The test runs started in June of 2015 and ran until September of 2016 when the operators of the plant agreed to a deal with Cordis to commit to using this technology full time [11].

NanoH2O has also implemented its technology across the globe. The company opened its first reverse osmosis plant in Los Angeles, California [1]. After this plant had been running efficiently, proving the membranes to be more cost effective and requiring less maintenance, NanoH2O started to get international recognition. This international recognition cumulated into China commissioning NanoH2O to build them a TFN plant of their own. In October of 2013 NanoH2O announced plans to build a TFN desalination plant in Liyang, China, a city in the Yangtze River Delta about 150 miles west of Shanghai [1]. The cost of building the plant totaled out at $45 million. This plant is NanoH2O's second fully integrated desalination plant following the Los Angeles plant [1]. In addition to these two plants already implemented, a spokesperson for NanoH2O has said they have made deals to sell the TFN technology to two desalination plants in Saudi Arabia [25]. NanoH2O's Quantumflux TFN membranes have proven themselves in the industry as a demand for them has spread worldwide. NanoH2O is expanding and does not seem to be slowing down, proving their use of nanotechnology is needed in the desalination process as it increases efficiency and is more environmentally friendly than traditional membranes.

COMPARING METHODS

When looking at the methods being implemented currently, the question of which process is the most efficient arises. The fundamental issues with the reverse osmosis process are the eventual breakdown of the membranes causing heavy maintenance, and the heavy costs associated with osmotic pressure. Unfortunately, carbon nanotubes are still in their infantile development when used in desalinization, and there is not enough data current application to compare to the other methods.

Both the NAWDES project and NanoH2O produces membranes that are less susceptible to fouling. NAWDES's membranes are self-cleaning, essentially eliminating the need to shut down the process in order to perform maintenance. However, the materials needed for the NAWDES membrane are more expensive, requiring quartz, polyvinylpyrrolidone, and titanium dioxide. NanoH2O's membranes are essentially just modified TFCs, allowing for an easy switch over to the new TFNs as the materials are very similar.

NAWDES would require entire new systems to run as the UV light process is a new idea and is dissimilar to the current systems being used. With such different techniques being used by NAWDES, there is less plants testing this process as it must be built from scratch. NanoH2Os membranes have more research and implementations due to the nature of the membranes. NanoH2O also lowers the osmotic pressure required for desalinization. However, NAWDES's membranes are more self-sufficient and lasts longer than those from NanoH2O due to the nature of them being self-cleaning and more efficient. This boost of efficiency reduces the cost of production since not as many need to be made for replacement. Overall, the NanoH2O membranes have a lower bar of entry for current plants to switch over to, but NAWDES membranes are longer lasting if implemented from the ground up.

OUT WITH THE OLD, IN WITH THE NEW

There are still many unknowns in the world of water desalination, however, one thing is known for sure, the techniques of the past are not the solution to the worlds water treatment problem. The primary method of reverse osmosis is the most effective but has its limitation. Reverse osmosis requires a high input of energy to produce clean water. In addition, the membranes used in reverse osmosis have their glaring downsides. With a predisposition to failing due to fouling and a lack of self-maintenance, plants are forced to produce a high amount of membranes and shut down portions of the site in order to replace them. All processes have their flaws, but nanotechnology aids to remedy them. Nanotechnology stream lines the process of water desalinization, making it a viable option on the industrial level. The NAWADES project and NanoH2O have proved this with their research into new technologies for desalination.

The NAWADES project has developed new, self-cleaning membranes that allow their membranes to last longer and require less maintenance. The use of nanoparticles in their membrane coating allowed them to create membranes that resist biofouling better than membranes have ever done previously. NanoH2O used nanotechnology to increase permeability of their desalination membranes. The inclusion of zeolite parties in the polyamide rejection layer allowed them to create a membrane that increased permeability by 50 to 100 percent [16]. This increase in permeability reduces energy costs to run the desalination plants as less pressure is required to filter the same amount of water. Both technologies have been implemented in plants in various locations across the globe. The NAWADES project has been implemented in Spain. NanoH2O's TFN membranes have been implemented in Los Angeles, China, and the company has plans to expand to the middle east. In addition to these methods, the use of carbon nanotubes has opened a new avenue for water desalinization. With new research coming out weekly about nanotubes and such high potential, only the future holds the answer to if these will become the preferred method of desalinization. With these new, more efficient options the process of water desalination will be revolutionized. As more desalination plants replace old reverse osmosis techniques with these new technologies, efficiency will increase and more clean, potable water will be produced, helping satiate the growing global demand for fresh water. These developments in desalination technologies can only increase the sustainability of the overall process. As desalination water becomes more efficient in the areas of energy, production, environmental footprint and more, the publics expectations of industry will be met. The International Water Association recognizes the importance of these improvements; "Technology advances are expected to reduce the cost of desalinated water by 20% in the next five years, and by up to 60% in the next 20 years, making it a viable and cost-effective competitor for potable water production" [7]. This recognized increase in cost efficiency is evidence of the foreseeable increase in sustainability of water desalination as a means by which to supply the world with fresh water. Through the use of nanotechnology eco-friendlier and cost-effective methods are being developed, making it the most viable option for water desalination in the present onward. With an overwhelming amount of evidence supporting nanotechnology and its application to water desalinization, one cannot ignore nanotechnology as a viable option for the future of water desalination.

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