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Assessing the Potential Impact of Nanotechnology on the Purification of Water

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Cover Page Footnote
I would like to express my appreciation to Dr. Rajasree Kannampuzha for her valuable suggestions during the development of this research article. I would like to express my gratitude to Professor Mike Broyles and Professor Greg Sherman as well for their constructive criticism and suggestions. Finally, I would like to offer my thanks to the consultants of Collin College's Writing Center for offering me their resources and their useful critiques of this article.

Independent Research Paper

Research in progress for PHYS 2426: University Physics II

Faculty Mentor: Raji Kannampuzha, Ph.D.

The following paper represents research work done by students in a University Physics 2426 class, the second half of a two-semester introductory course in physics. It is a calculus-based physics course, intended primarily for physics, chemistry, math, and engineering majors. Students are introduced to the concept of academic research by learning to ask research-focused questions and then use the library resources to pursue outside research to find answers. For this assignment, students are asked to investigate a physical science, biological science, or technology problem or topic of their choice by searching the academic literature and then writing a research paper. They are asked to include at least one professional journal article in the references, and the provided rubric contains the same requirements of any professional science journal. In addition, students are required to complete two peer reviews of the paper draft. This helps them see other students' work and get constructive criticism from their peers before they submit the final paper.

In the following paper, Noor Khan assesses the impact of nanotechnology in water purification. She also mentions pollution and its effect on the clean drinking water supply. Khan investigates two different processes used in water purification: electro-spinning with carbon nanotubes and photocatalysis. She also compares the advantages, disadvantages, and cost for each of these processes with traditional purification processes. The use of nano-fibrous filters to purify water samples at a faster rate suggests the possibility of utilizing this new process to better our water purification process. Even though it has its challenges, it is a promising technology that can be adapted in water purification.

Assessing the Potential Impact of Nanotechnology on the Purification of Water

Noor Khan

Introduction

The global population will increase in the future, and the availability of clean water will diminish as climate change continues to warm the planet. Using nanotechnology, scientists can find an efficient way to purify water in order to provide for the growing demand and reduce global water pollution. This research report will analyze how replacing the normal water purifying processes with nanotechnology can effectively rehabilitate water supplies by filtering out pollutants and contaminants by the use of nano-sized materials. In switching from normal processes to nanotechnology, there is great potential that one can successfully restore water systems in both of the main elements of water purification: electro-spinning and photocatalysis.

Two of the main concerns of the purification process are high energy consumption and technological demands. However, by allowing molecules contained in the water to stick to an adsorbent film, researchers have been able to simplify the technique for water purification devices. Understanding that carbon nanotubes have a high capacity for filtering contaminants, researchers have been applying them in other areas to remove pollutants in order to successfully treat water (Yang et al., 2013). With its co-catalysts, platinum and fluoride, scientists have been manipulating titanium dioxide nanoparticles (F-TiO2/Pt) to split water into hydrogen and oxygen using light in which pollutants stick to the nanotube and can be degraded and filtered out (Amal, 2014; Kim & Choi, 2010). Thus, nano-tools can speed up the process of water filtration without using too much energy.

Creating carbon nanotubes is said to be cost-ineffective, but due to the popularity and demand of nanotechnology, the price of nanotubes have increased tremendously. However, chemists have discovered a new, affordable design of a nano-filter through the use of electro-spinning, which creates these under an electrical field (Wang et al., 2010). Similarly, scientists have been trying to push forth the environmental remediation and water filtration properties acquired from the technology of nanotubes in everyday use by isolating carbon nanotubes (Gawlowicz, 2017).

Methods and Materials

In order to start the electro-spinning filtration process, one must first create the carbon nanotubes by dissolving polyacrylonitrile (PAN) or polyvinyl alcohol (PVA) fibers through electro-spinning (Wang et al., 2010). Electro-spinning uses the electrostatic fields to make nano-fibers, which can then be applied as a membrane to serve as an adsorbent for pollutants like oil, bacteria, or salt. First, researchers dissolve the PAN or PVA fibers with an average molecular weight of 136,000 g/mol in N, N′-dimethylformamide at 55°C for 12 hours to receive a 8 wt% homogeneous solution. This liquid solution is then inserted in the syringe pump with a thickness of 100 µm while a voltage of 18kV is applied to charge the fibers. Because the syringe pump is positively charged and the collector plate is negatively charged, this action forms an electric field. As the syringe is pumped, the spinneret moves perpendicular to the collector plate's movement where the solution forms a cone-shape known as the Taylor cone. The spinneret picks up speed, and the solution is stretched as electrostatic repulsion counteracts the surface tension. The liquid is gradually spun longer and longer until it forms a fiber with wall thicknesses of approximately 19-22 nm on the collector plate, as shown in Figure 1. After some time, these nano-fibers dry out and collectively deposit on the collector plate, forming a mat. The mat is placed in water, and the extremely tiny pores between the nano-fibers allow the contaminants to be filtered out more precisely than with normal filters (Yang et al., 2013). In order to test how permeable the carbon nanotube filter is, the technique of dead-end filtration is used where contaminated water flows straight through the filter at room temperature (Wang et al., 2010). In the experiment, the researchers placed soybean oil and Dow Corning 193 fluid in the water, which was filtered through the film with the area of 0.002 m^2. Evaluating the filtered water for its pure water permeance required a UV-visible spectroscopy. This is based on the absorbance subject to ultraviolet light in order to test how much of the contaminants' chemical compounds had been purified from the water.

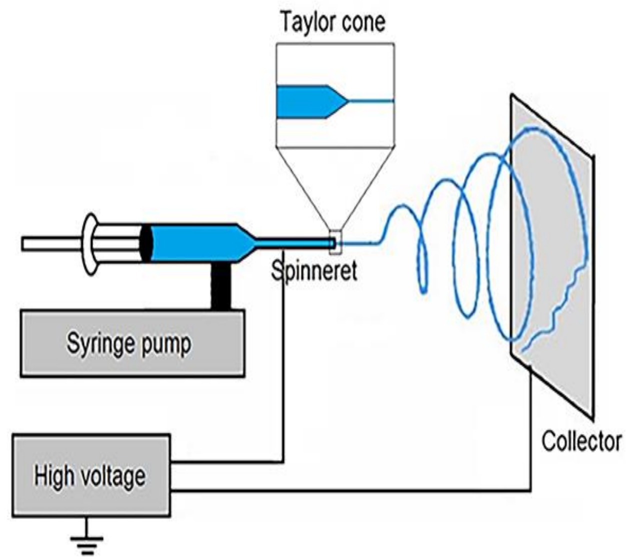

Figure 1. Schematic design of an electrospinning set-up (Li & Bou-Akl, 2016)

In photocatalysis, ultraviolet electromagnetic radiation is used to activate a catalyst substance (in this case, the semiconductor TiO2) in order to oxidize organic molecules (Amal, 2014). First, a nano-filter is coated with titanium dioxide with its bonded co-catalysts, platinum and fluoride (F-TiO2/Pt). Placing this coated substrate in polluted water allows the purification to occur when water enters the nanotube and pollutants are captured and broken down by the coating. To start this process, a photon of light with sufficient energy hits the semiconductor and its catalysts, which excites and releases the electrons from the valence band towards the conduction band (see Figure 2). The valence band, the outermost electron orbital of an atom, is the electron orbital band that excited electrons can jump out of and can move into the conduction band. The released electrons bind with oxygen in their surroundings to become superoxide anion. The titanium dioxide coating turns positively charged and takes electrons from moisture in the air while the moisture that has lost those electrons becomes hydroxyl radicals. In this strong decomposition reaction, the superoxide anions and hydroxyl radicals degrade oils and other organic pollutants into harmless substances that are then dispersed. Coupling the TiO2 with a carbon nanotube splits the water into hydrogen and oxygen as a result. To test how scientists could shorten the time for this decomposition and expulsion of contaminants, the researchers experimented with samples of TiO2, F-

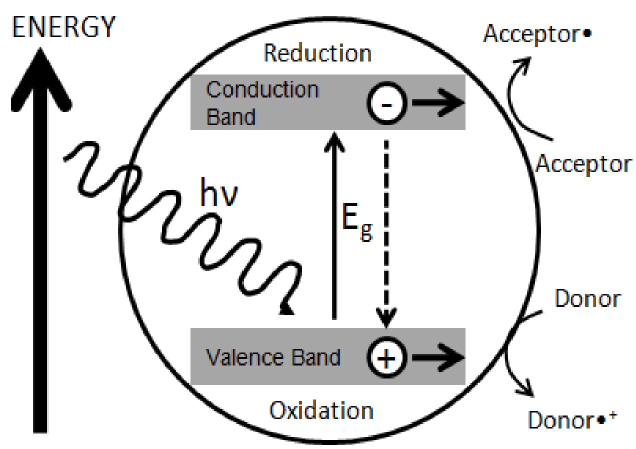

Figure 2. The process of photocatalysis: solar energy excites the electrons in the valence band, which travel to the conduction band. In turn, this oxidizes the valence band and degrades the contaminants (Gray, n.d.).

TiO2, Pt/TiO2, and F-TiO2/Pt in water to see the degradation of the contaminants, using 4-chlorophenol (4-CP) and bisphenol A (BPA) in each sample.

Results

During the electro-spinning process, researchers observed that as the water concentration increased, the pure water permeance of the contaminated water increased when using filters made out of polyacrylonitrile (PAN) and polyvinyl alcohol (PVA) nano-fibers (Wang et al., 2010). As time progressed, the nano-fiber mats could properly filter out the soybean oil and the Dow Corning 193 fluid; both contaminants steadily accumulated behind the filter and could not pass through, shown by the blue rejection line in Figure 3. Although the mats did relatively well at purifying the water sample, their ability to filter the polluted water decreased tremendously when the pressure increased higher than 0.3MPa, meaning some pollutant particles managed to pass through as the water poured through the filter faster.

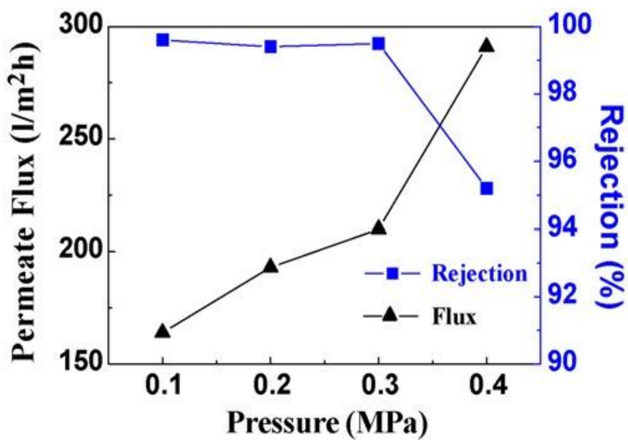

Figure 3. The water pressure dependence of the permeate flux and the rejection rate of the nano-filter made of PAN and PVA when the water and contaminant solution was dead-end filtered through the fibers' pores (Wang, et al., 2010).

Compared to the samples without fluoride and platinum, the F-TiO2/Pt semiconductor successfully maximized the photocatalysis process for degrading the pollutants in the water and the splitting of water, due to the catalytic properties of platinum and fluorine (Kim & Choi, 2010). Graph A of Figure 4 depicts the degradation of 4-chlorophenol (4-CP) and the amount of hydrogen produced as the water splits into hydrogen and oxygen over the time span of five hours. One can see on the graph that F-TiO2/Pt's purple line most effectively degrades 4-CP in under an hour, followed by Pt/TiO2, F-TiO2, and TiO2 itself. Similarly, F-TiO2/Pt produces the highest value of hydrogen at 12 micro-moles, whereas the other samples produced nearly zero hydrogen. Similar to graph A, graph B shows the degradation of bisphenol A (BPA) where F-TiO2/Pt's purple line once again degraded the pollutant almost down to nothing, whereas the other three samples barely degraded it. Likewise, F-TiO2/Pt created the highest value of hydrogen at approximately 35 micro-moles, whereas the other samples lacked in hydrogen production.

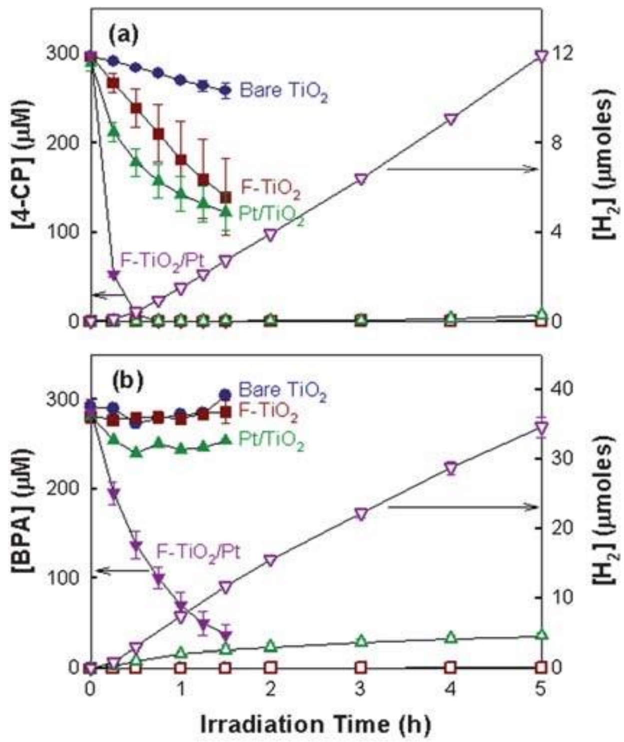

Figure 4. The degradation of the substrates 4-CP in chart A and BPA in chart B and the creation of hydrogen as water splits (Kim & Choi, 2010).

Discussion

Overall, the data depicted positive trends for how water systems can be purified after being devastated by pollution and unwanted chemicals. The electro-spinning process and the photocatalytic process could potentially be used to restore water supplies riddled with contaminants and pollutants.

In the electro-spinning process, the carbon nanotube film mats made of PAN or PVA successfully filtered the soybean oil and the Dow Corning 193 fluid from the water supply. Shrinking the material of the filter to a nano-scale could accurately keep contaminants from passing through and from disturbing the water supply. However, increasing the water pressure higher than 0.3MPa seemed to be the only disadvantage to these filters. When the water pressure is increased, the pressure allowed the contaminants to pass through along with the supply of water, and they disrupted the filtration process. Besides that drawback, these nano-composite films proved to have a higher flux than the normal composite film. Therefore, this process can make a positive impact when it comes to filtering out unwanted pollution from water supplies.

In the photocatalysis process, using F-TiO_2/Pt successfully sped up the degradation of the pollutants and the splitting of water, with the help of its two co-catalysts involved: fluoride and platinum. The comparison of graph A and graph B in Figure 4 shows that as the co-catalysts were added, the effects activated faster than if they were not used or if only one of the two was used. This experiment successfully proved that the process of filtering water samples can be improved by using titanium dioxide alongside fluorine and platinum. Researchers at the Lawrence Livermore National Laboratory have found that using carbon nanotube filters with the titanium dioxide coating allows water to be filtered six times faster than through regular treatments (Urquhart, 2017). This knowledge can be harnessed to clean up water systems globally.

Conclusion

These results give hope as to how our planet's water resources can be maintained. Realistically, scientists are always trying to improve a chemical process while taking into account how much time, money, and energy is used in the process. Developing the nano-fibrous filters allowed researchers to clear water samples at an exciting rate, illustrating the possibility of utilizing this new process to improve water filtration. The speed of using F-TiO2/Pt nanoparticles in the photocatalytic process of water filtration can save both time and money for water treatment. Used responsibly, carbon nanotubes can be used for good; however, using carbon nanotubes as a filter for purifying drinking water is not entirely safe. They are said to be a carcinogenic hazard because of the polymers potentially entering the lungs through inhalation and causing mesothelioma (Maynard, 2016). Utilizing these abilities, more research should be done about how scientists can transform this into wide commercial use. Is there a way to take the filtration process to homes and allow residents to clean their own water? Researchers at Rochester Institute of Technology believe that there will be a way to reuse the carbon nanotube filters in homes. Due to the regenerative properties of these nanotube film mats, an average person can heat the filter up in a microwave, and the contaminants will be evaporated (Gawlowicz, 2017). However, this cannot be known for sure until multiple thorough tests are completed. Although it is extremely wrong to pollute, the tools and technology (at the nano-scale) are now available to appropriately clean up the messes that humans have made.

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