# Nanofiltration

*by Steven Kaul*

Calling Earth the blue planet may in fact be a cruel joke. Only 1% of the world's water lies in a usable, reachable form (1). 97% is saltwater. And demand for pure water increases every day. In the next 25 years, the needs for fresh water by industry alone will likely increase by 70% (1). As the human population is set to double within the next century, conservation by itself will not be enough to curb the supply shortage. The solution may lie in materials and techniques based on nanotechnology.

As the supply of clean water grows scarce, the privatization of water is already becoming an issue. Jason Bricker points out that the United Nations Declaration of Human Rights states that every human should have access to clean water (2). Even so, as private companies take control of water systems, expensive water management systems are often required (2). In underdeveloped regions, particularly in South America, the public must decide between maintaining a stable economy and ensuring clean water in the future (2). It is hoped that nanofiltration technologies will help to cut, or eliminate, the costs of providing clean water such that everyone everywhere will have access to clean, quality water.

Since 97% of the world's water is saltwater, it would make sense to attempt to utilize seawater as a source of usable water. Seawater cannot be used in its initial form, obviously; the contaminating salts need to be removed. Desalinization is the process of removing salts and other chemicals from water. Current desalinization techniques include distillation, evaporating and condensing water, and reverse osmosis, separation by a membrane. Despite the outstanding costs of these techniques, they prove quite inefficient and inadequate to provide a reliable source of clean water. Nanofiltration will serve as an inexpensive pretreatment to current distillation techniques providing for reduced overall costs and higher overall efficiency in the preparation of usable water.

Problems pertaining to water, be it availability or quality, are widespread. The "lack of clean, affordable water is not a problem confined to the developing world. Southern Europe, Israel, the Western United States, the Middle East and areas of South-East Asia such as Singapore all suffer from increasing pressure on scarce water resources" (3). Industrial and natural sources contribute to the global problem of groundwater contamination (3). In underdeveloped countries, children who are required to gather water all day are unable to gain an adequate education to succeed in society (4). According to the World Health Organization, reports the Meridian Institute consulting firm, "waterborne diseases and water-related illnesses kill more than five million people a year worldwide, 85% of these being children" (4). ZENON Environmental, Inc. reports that over 50,000 communities in the United States do not have adequate access to quality drinking water (5). There is a big push to gain access to a system that would allow for solutions to these numerous, and damaging, problems.

"Increasing throughput, improving selectivity…reducing clogging…(and) self-assembly…offer potential for novel and cheap manufacture" of nanofiltration devices (3). While a few individuals have begun research into nanofiltration, Tim Harper, considered Europe's nanotech spokesman outside of government and also the founder and President of CMP Cientific, claims that "no one has any money to fund a project…(and) governments and companies around the world have not yet made the connection between nanotechnology and water" (3). Focus may shift, however, once a potential profit margin is realized. The global water market is presently $287 billion and by 2010 it is expected to be $413 (1). Harper states:

> "We don't expect to see safe, affordable water across the globe in the timescales that some nanotech pundits have claimed we will see a cure for cancer. We have to be realistic…. If there is money to be made at the same time, then we have a better chance of success" (3).

While the focus of nanofiltration as the solution to the growing problems increases slowly and steadily among interested parties, a number of academic professors and industry leaders have realized the potential early and made progress. Zhifeng Ren, associate professor of physics at Boston College, has begun research into areas of study that provide "potential applications (that) include filtration systems for converting seawater to drinking water" (6). A number of companies and institutions are working to develop nanofiltration technologies [Table 1]. The specifications of these technologies focus on making pores small enough to filter out extremely small organisms, polymers that self-assemble into artificial membranes, membrane pores which are straighter (allowing for faster flow through), separation by charge, enzymes that react with analytes to detect contaminants, or the destruction of contaminants by UV light (1).

| Company/Institute | Nanofiltration Technology |
|---|---|
| Argonide | Positively charged nanofilters that attract negatively charged germs, called NanoCeram (1,3,4). |
| Berghof | Nanofiltration membranes for liquid filtration in industrial processes (4). |
| eMembrane | Nanoscale brushes coated with molecules to capture and remove poisonous metals, proteins and germs (1). |
| Fluxxion | Nanofiltration membranes for liquid filtration in industrial processes (3,4). |
| Inframat | (3). |
| KX Industries | Anti-bacterial and anti-viral filter system that can form clean water from raw sewage (1). |
| NanoSight | System to detect waterborne nanoparticles and viruses in real time (3,4). |
| Oklahoma State University | Zinc oxide nanoparticles to remove arsenic from water (4). |
| Saehan | Nanofiltration membranes for liquid filtration in industrial processes (4). |
| Seldon Laboratories | Nanomesh fabric of fused carbon nanotubes that filter bacteria, viruses, waterborne pathogens, lead, arsenic, and uranium (4). |
| Rensselaer Polytechnic Institute (collaborating with Banaras Hindu University) | Manufacture carbon nanotube filters to remove nanoscale contaminants from water by controlling the cylindrical geometry of the structure (4). |
| Zenon | Transverse flow hollow fiber nanofiltration module (5). |

Table 1: Companies & institutions developing nanofiltration technologies.

A company that has provided detailed insights into their development of nanofiltration membranes is ZENON Environmental, Inc. While they initially developed a nanofiltration system that worked, an optimized system was required that could be widely employed, could operate at high pressures for brackish water desalination, and would be cost effective (5). Essentially, Zenon seeks to develop a system that can last for long periods, is effective after many uses, requires minimal pretreatments, and fundamentally costs less than current systems which are not as efficient. The nanofiltration device would provide an effective pretreatment of seawater prior to reverse osmosis, reducing salt content to allow for reduced osmotic pressure and associated operating pressures required by reverse osmosis (5). Zenon's transverse flow system works by effectively limiting the formation of a boundary layer, which limits the performance of a crossflow filtration membrane [Figure 1] (5). A nanofiltration membrane has two separate parts: -1- the thin barrier layer (membrane) which acts as the separating layer, and -2- the microporous sublayer (base fiber) to support the barrier layer (5).

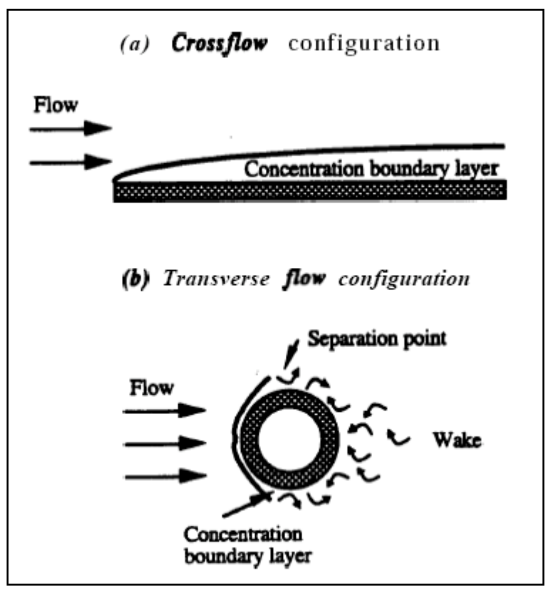


Figure 1: From ZENON Environmental, Inc.

The base layer is composed of hollow fiber reinforced with fiberglass to give a higher compression and collapse pressure (5). Base fibers must have the appropriate molecular weight cutoff, pure water flux, and compression pressure for nanofiltration applications, so three different polymers were studied to determine the best suitable in production (5). The goal is to create a thin membrane on an adequate support such that the strength of the fiber comes from the support and the membrane acts only as a separation layer (5). Fibers are wound by first passing a hollow fiberglass braid through a jet which coats it in a polymer, through a second jet to remove excess polymer, through a conjugation bath to gradually replace the polymer solvent with water (causing the viscosity of the polymer solution to increase, and the speed of replacement controls the pore size) to solidify the polymer, then to a winder to wind the fiber, and finally through a wash to remove any remaining solvent and impregnate the fibers with preservative (5). The most effective of the fibers studied by Zenon were the polysulfone fibers (5).

Two methods of coating the thin film membrane were investigated, with the most effective being solvent evaporation. Solvent evaporation is completed by dipping the base fiber into a solution of dissolved polymer (and other additives) in a volatile solvent and then allowing the solvent to evaporate away to yield the thin film membrane (5). Systems of cross flow modules and systems of transverse flow modules were then formed and tested and Zenon concluded that the transverse flow system was more efficient (5). The cross flow system provided higher initial flux than the transverse flow system, but the difference was dramatically shifted after 24 hours (5). Although having a low flux in the transverse flow system, after over 205 hours it decreases only slightly, indicating that the membrane is very efficient and long lasting (5). The low flux being observed in early tests is likely due to air being trapped in the module flow, and could subsequently be eliminated in an automatic coating system (5). The transverse flow module allows for minimal pretreatments, reduced spoiling, reduced costs, and shows success on low pressure applications (5). Saltwater could be treated by transverse flow to initially remove solids, followed by treatment with an additional nanofiltration system or reverse osmosis to achieve a pure water product (5).

eMembrane has also provided minimal insights into their developments of a nanofiltration device. They are working to develop nanoscale brushes containing functional groups which are capable of simultaneously capturing and removing toxic metal ions, soluble proteins, viruses or cells from the filtrate [Figure 2] (7). The density and length of the brushes can be easily controlled, allowing for high specificity in removal of unwanted elements (7).

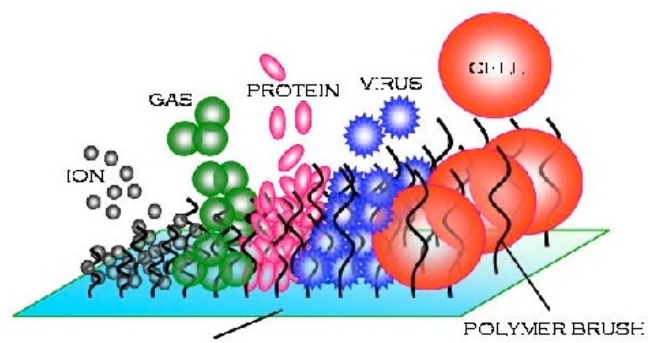


Figure 2:
From http://www.emembrane.com/index.html

One more company to share developmental information on their product is Argonide. Argonide has developed a product called NanoCeram®. NanoCeram® is a form of alumina fibers composed mainly of Boehmite (AlOOH - - an aluminum derivative) (8). The surface of these nanofibers are positively charged and attract and retain negatively charged particles including bacteria, viruses, organic and inorganic colloids, and negatively charged macromolecules (8). Argonide develops the filters by creating a white, free flowing power of the nanofibers that have collected in aggregates (8). The fibers, approximately two nanometers in diameter and up to hundreds of nanometers long, are dispersed throughout a microglass fiber matrix (8). This membrane has an approximate average pore size of two microns with a water flux of nearly equal size (8). However, taking into consideration the charged surface of the fibers, the system functions as if it was a 0.03 micron pore size filter (8). In Argonide's tests there was no measurable decrease in flow rate or clogging until well past the breakthrough point of the membrane. They also determined that the capacity of the system is directly proportional to the ratio of nano alumina fibers in the filter and also to the filter thickness (or number of layers) (8). Argonide has also come to the conclusion that the NanoCeram® nanofiltration device would best be utilized as an important application in the prefiltration of solutions upstream of reverse osmosis membranes (8).

While some research is currently being conducted to tie nanofiltration with improving the world's water supply, not nearly enough is being done to develop a full solution. It is evident that nanofiltration will play a vital role in providing a quality, usable form of water in the future. From systems currently in development, that role seems to be utilizing nanofiltration as a pretreatment to reverse osmosis. Until a large profit margin is realized, private companies appear to be pioneering the research and development of nanofiltration systems with little support from the government. Government, private industry, and society all need to focus on this issue not solely for its economic benefits, but for the benefits of mankind.

This student-produced report is part of a larger pamphlet on nanotechnologies circa 2005, the partial output of a course on "Nanotechnology and Society" (Science and Technology Studies, Section 84405, by C. Tahan) which was taught in the spring semester of 2005 at the University of Wisconsin-Madison. Visit http://tahan.com/charlie/nanosociety/course201/ for the other reports and more information.

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