CAS Chemistry Research Report

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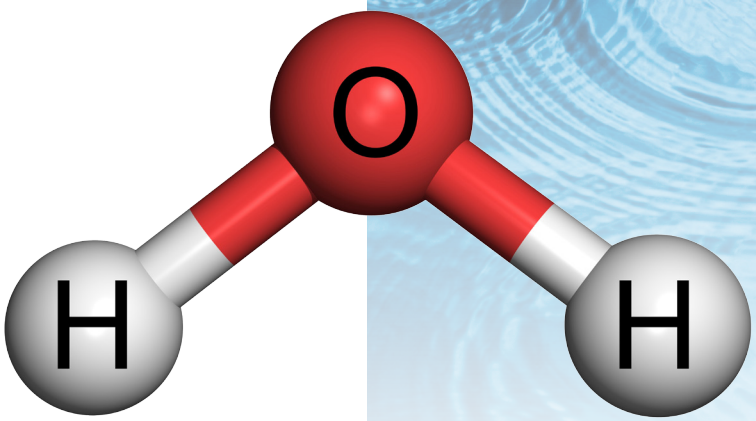
Nanofiltration Shows Promise in the Quest for Pure Water



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Safety and Scarcity Drives Water Purification Research

From April 20 until July 15, 2010, the Deepwater Horizon offshore oil drilling rig spilled more than 200 million gallons of oil into the Gulf of Mexico.[1] It was the latest notable setback in the worldwide quest to improve water safety.

The United Nations predicts that by 2015, five billion people (two-thirds of the world's population) will live in areas of significant water stress, lacking sufficient safe water for drinking, industry, or agriculture.[2] Approximately 3.5 million deaths—6.3 percent of all deaths worldwide—could be prevented through the simple provision of safe water.

Water purification is one way to address the world's inadequate supply of safe water. Researchers from CAS, a division of the American Chemical Society and the world's authority for chemical information, studied 40 years of water purification literature in patent and journal publications. They found that filtration, and particularly nanofiltration, is the emerging method of water purification studied and commercialized worldwide. CAS researchers also noted that from 1970 to 2009, the United States led in nanofiltration research, while Asian countries dominated the majority of commercial initiatives.

When the well's dry, we know the worth of water.

– Benjamin Franklin, Poor Richard's Almanack, 1746

The Need for Water Purification

Among the many environmental issues following the Deepwater Horizon oil spill is water purity. BP, the U.S. Government, and private contractors have already used chemical, physical, and biological methods of water purification to restore the Gulf waters to their pre-spill state.

Used individually or jointly, physical, biological, and chemical methods purify wastewater, drinking water, and even seawater. Waves, wind, and vessel operations physically disperse spilled oil in seawater. Filtration is the major physical method of purifying wastewater and drinking water. It works by trapping large particles or solutes in much the same way a colander lets water drain from cooked pasta. Different-sized membrane filters used in series remove progressively smaller solutes from microfiltration, through ultrafiltration, nanofiltration, and reverse osmosis (RO). In biological methods of water purification, microorganisms degrade organic materials. Chemical methods are usually specific (chlorine) to the contaminant (disinfectant) being addressed.

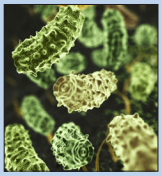
In addition to physically separating solutes by size, nanofiltration is influenced by the chemical composition and behavior of the membrane.[3] The asymmetrical membranes are commonly composed of polysulfone (CAS Registry Number [RN]: 25135-51-7) and superimposed with a thin top layer with a negative chemical charge. In some cases, the negative charge repels other negatively charged solutes, which may cause membrane swelling or shrinking in response.

Nanofiltration emerged in the late 1980s, filling the gap between ultrafiltration and RO. Nanofiltration removes smaller solutes than are captured by ultrafiltration and has a higher filtrate flow rate than RO at equal pressure, leading to smaller systems with the same

Multiple Methods Purify Water

PHYSICAL

Filtration: separates out solutes based on size (sand, screens, membranes)



BIOLOGICAL

Biological: uses bacteria and other microorganisms to destroy organic material naturally

CHEMICAL

Clarification: clusters solids to be removed by gravity

Ion Exchange: removes charged solutes (water softeners)

Disinfection: kills microorganisms (ozone, chlorine, UV-radiation)

Figure 1. Methods of Water Purification

CAS researchers investigated major physical, biological, and chemical water purification methods.

production capacity. Advances in new applications of nanofiltration technology such as desalination and self-cleaning may address the looming scarcity of safe water, according to the U.S. Environmental Protection Agency.[4]

This Chemistry Research Report investigates 40 years of water purification research to reveal increased interest in filtration as represented in the CAS databases, the world's most authoritative and comprehensive collection of chemistry and science-related information. Nanofiltration attracted increased research and commercial interest since its emergence in 1987, according to CAS researchers.

The Emergence of Nanofiltration

From 1970 to 2009, global researchers produced more journal and patent publications about filtration than about any chemical or biological method of water purification (**Figure 2**). During this time, filtration-related publications increased 8,500 percent, with filtration-related patent publications exceeding journal publications by 25 percent in 2009.

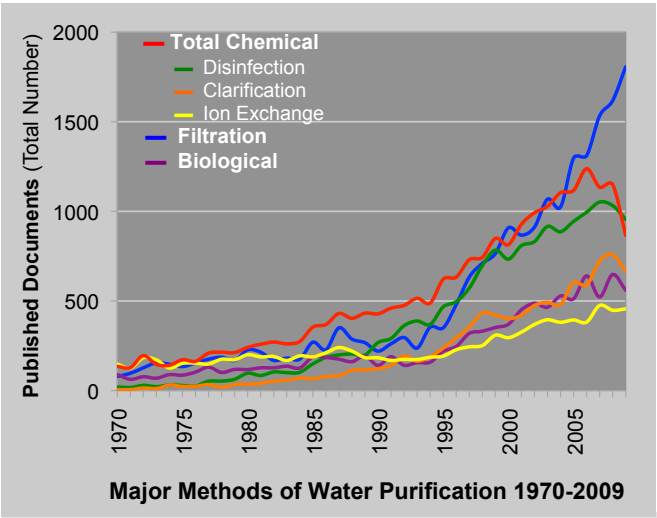


Figure 2. Filtration Ahead after 40 Years of Water Purification

Filtration-related journal and patent publications increased 8,500 percent from 1970-2009.

Nanofiltration Related Publications Emerged in 1987

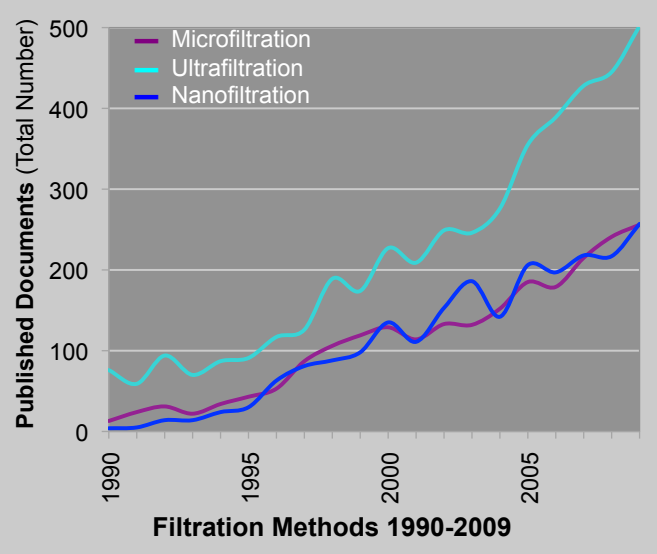


Figure 3. Nanofiltration Increased Most

Nanofiltration research emerged most recently, with total publications increasing five-fold between 1999 and 2009.

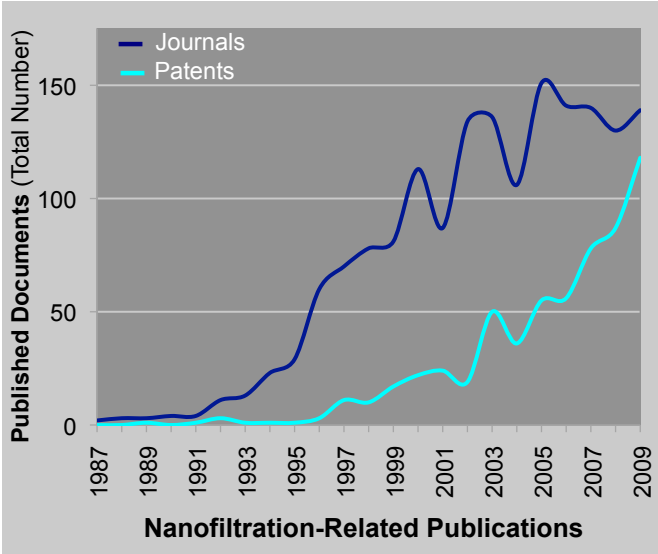


Figure 4. Nanofiltration Research Expands Exponentially

Nanofiltration-related journal and patent publications recently emerged in the past 20 years.

Contaminants or Impurities Removed Depend on Filtration Method

Method of Filtration	Pore Size	Operating Pressure Required	Materials Removed
Microfiltration (MF)	≥ 0.1 µm	Low	Bacteria, large viruses, solids
Ultrafiltration (UF)	≥ 0.005 µm	Moderately Low	Viruses, proteins, starches
Nanofiltration (NF)	≥ 0.0005 µm	Moderate	Pesticides, herbicides, iron, nickel, mercury, sulfate and hardness

Table 1. Major Methods of Filtration Remove Large and Small Solutes

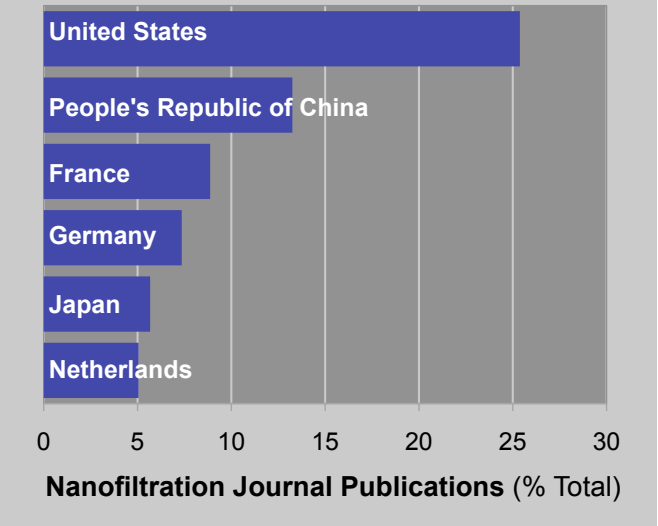


Figure 5. U.S. Ahead in Nanofiltration Research

U.S. affiliated authors accounted for one-quarter of all nanofiltration-related journal articles.

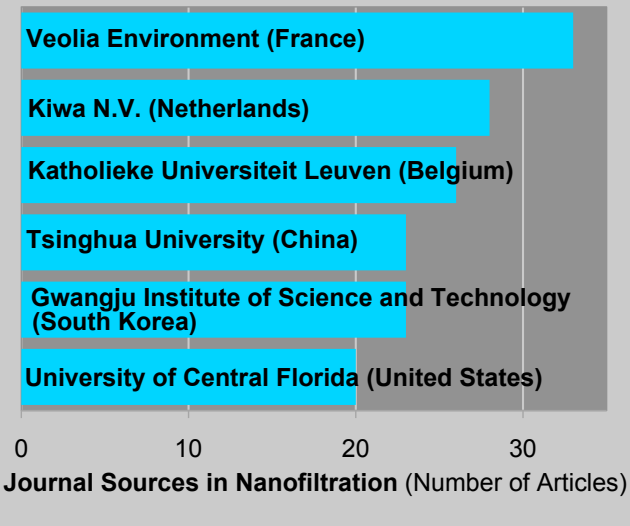


Figure 6. France Tops Corporate Nanofiltration Research

Veolia Environment topped other corporate sources for the most nanofiltration-related publications with 2 percent of all journal documents.

CAS scientists analyzed research publications covering microfiltration, ultrafiltration, and nanofiltration methods of water purification (**Figure 3, Table 1**). Nanofiltration-related patent and journal publications increased 6,300 percent from 1990 through 2009, advancing more than microfiltration and ultrafiltration.

Research Interest in Nanofiltration Accelerates

Total published nanofiltration-related journal articles increased 3,375 percent from 1990-2009 (**Figure 4**). Nanofiltration-related patent publications grew nearly 600 percent from 1999-2009, despite having fewer documents than journal article publications overall. Growth in nanofiltration research supports worldwide efforts to improve water quality and quantity.

As nanofiltration-related research increases, safe drinking water becomes more environmentally and economically affordable. Due to lower operating pressures, nanofiltration reduces energy consumption, operation costs, and waste. It is also environmentally friendly, removes pathogens and pharmaceuticals, and can desalinate brackish water. According to a 2007 report, the commercial success of nanofiltration technology will reach $310 million worldwide by 2012.[5]

U.S., France Author Most Research

CAS scientists determined that through 2009, the United States (U.S.) authored more than one-quarter of nanofiltration-related journal articles (**Figure 5**). U.S. authorship almost doubled Chinese authorship, the second most prolific nation in nanofiltration publications.

Among academic and corporate affiliations on nanofiltration-related journal articles, the French entity Veolia Environment was the leading individual firm (**Figure 6**), despite that U.S. combined corporate sources are three times greater. Veolia was established as Compagnie Générale des Eaux by Napoleon III in 1853 and today provides drinking water and wastewater services to 163 million people in France.[6]

Asia Commercializes Nanofiltration

Asian patent authorities represent 60 percent of all nanofiltration-related patent publications. The State Intellectual Patent Office (SIPO) of the People's Republic of China had 33 percent of nanofiltration-related patent publications (**Figure 7**), while the Japan Patent Office (JPO) and Korean Intellectual Property Office (KIPO) published 16 percent and 10 percent, respectively.

CAS researchers found that most Asian patent assignees were domestic. In fact, KIPO patent publications were completely domestic, while less than 2 percent of JPO and SIPO patent publications had nondomestic assignees.

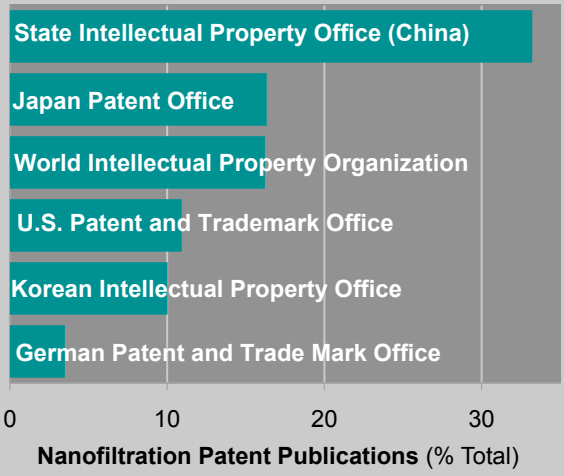


Figure 7. Asian Patent Offices Dominate Nanofiltration

Asian authorities accounted for 60 percent of nanofiltration-related patent publications.

U.S. Leads WIPO Patent Publications

The U.S. contributed four times as many nanofiltration-related patent publications to the World Intellectual Property Organization (WIPO) as any other country (**Figure 8**). Patent applications to WIPO may indicate a desire for worldwide commercialization.

U.S. assignees General Electric (GE) and the Dow Chemical Company produced 20 percent of WIPO patent publications (**Figure 9**). Notably, GE nanofiltration technology recycled rainwater in the National Stadium in Beijing, China for the 2008 World Olympics, while Dow technology (FILMTEC™) has provided purified drinking water to Sweden's resort community in Lofsdalen since 1998. Dow's nanomembrane technology utilizes polyamide (CAS RN: 83044-99-9P) thin film composites along with other sulfone copolymers to better separate charged particles. Akzo Nobel N.V. leads among WIPO patent assignees with nanofiltration-related publications on salt recovery, wastewater treatment, and nanomembrane cleaning. Recently, Akzo Nobel endorsed the CEO Water Mandate, making it among more than 50 companies committed to developing, implementing, and sustaining water practices and policies.

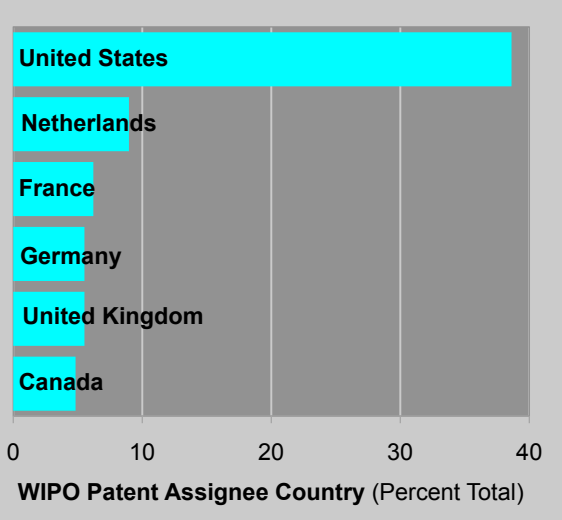


Figure 8. WIPO Patent Publications Are Mostly U.S.

Through 2009, the U.S. was the chief assignee on nanofiltration-related patent publications from WIPO.

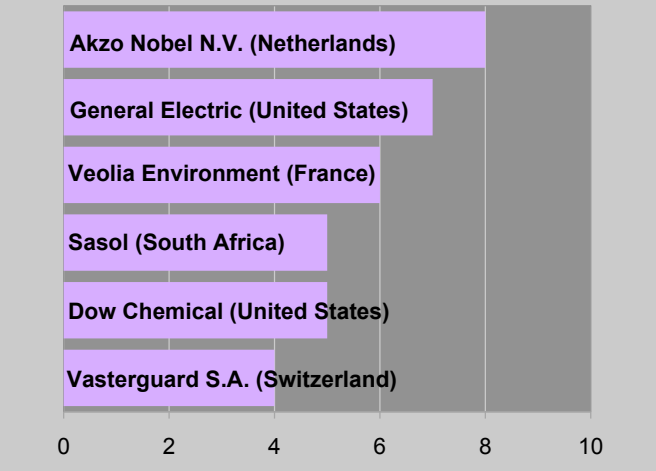


Figure 9. Netherlands Company Leads Corporate Nanofiltration

Among corporate sources, Akzo Nobel N.V. had the most WIPO nanofiltration-related patent publications.

Conclusion

This CAS Chemistry Research Report highlights increased water purification research and commercialization from 1970-2009, focusing on nanofiltration. Water purification research conducted now will address environmental and humanitarian water stressors to preserve global health and a safe environment for future generations to enjoy.

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