Water Technology: A Critical Component to Clean Water Needs for the 21st Century

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Introduction.

The 5th World Water Forum included many discussions on the need to increase access to clean water. Access to clean water would counteract the severe health and poverty issues that affect approximately 40% of the world's population. More and more, decision-makers are evaluating water quantity and quality together and coordinating management efforts across borders. This article describes how advances in technology help address the challenge of supplying high quality, clean water in adequate quantities to everyone, everywhere in the world.

The Need and the Market for Water Technology.

Global freshwater resources are increasingly pressured due to demand linked to population growth and mobility, higher energy and evolving consumption needs, altered ecosystems, increased food production, and industrial needs. Human activity such as urbanization, population growth, increased living standards, growing competition for water, and pollution increases pressures on freshwater resources.

Water demand already exceeds supply in many parts of the world, including the United States. Most states expect water shortages during the next decade. Additionally, wastewater treatment operations are looking for alternatives to conventional chlorination and dechlorination prior to discharge. Attention to recently identified contaminants such as endocrine-disrupting chemicals (EDC) and pharmaceutical and personal care products (PPCP) is increasing globally. Economic development in China, India, and Vietnam will be the primary driver for water technology innovation in the near future. Future challenges addressed by water technology include: demand for improved water supply for cities, agriculture, and industry; protection of water sources and aquatic environment from pollution; sustainable strategies for waste residual disposal; cost-effective solutions; and “local” solutions and support for these innovations. The U.S. market for advanced drinking water technologies alone is estimated at more than $2.1 billion in 2011.

New technologies that improve water treatment capabilities and reduce energy consumption are poised for significant growth due to the continuous increased demand for water. Specific water improvement technologies that allow water to be reused or poor quality water to be used for human consumption include:

- Mmmbrane filtration, ultra-violet and ozone disinfection,
- Desalination and associated energy recovery devices,
- Efficient irrigation systems for the agriculture segment,
- Wastewater treatment equipment driving water reuse and biosolids-to-energy, and
- Modular water treatment systems.

A review of current practices and new developments in each of these technologies follows.

Membrane Filtration as Reverse Osmosis Pre-Treatment.

“Membrane technology” is a generic term for a number of different separation processes, each using a membrane. The membrane separation process is used more and more often for the creation of process water from groundwater, surface water or wastewater, where “process water” is defined as water that serves in any level of the manufacturing process of certain products. The semi-permeable membrane acts as a very specific filter that will let water flow through, while it catches suspended solids and other substances in the water. There are various methods to enable substances to penetrate a membrane where it is not energetically favorable, such as application of high pressure, maintenance of a concentration gradient on both sides of the membrane, and introduction of an electric potential into the system. The main advantage of membrane technology is the fact that water is improved without the addition of chemicals, with a relatively low energy use, and using simple processes.

When reverse osmosis was first introduced to the marketplace, many applications of reverse osmosis treated brackish groundwater, which tends to be low in suspended solids. As reverse osmosis became widely accepted for both industrial and potable applications, the water sources used to feed reverse osmosis systems have expanded and become more challenging. Reverse osmosis is a method where water passes through a semipermeable membrane in a direction opposite to that which is exhibited during osmosis, such as when water is subjected to a hydrostatic pressure greater than the osmotic pressure. Osmosis is the tendency of water to flow from a solution with a low concentration of dissolved substances to a solution with a higher concentration of dissolved substances across a semipermeable membrane in order to balance the solute/water on both sides of the membrane.

Surface water sources usually have high levels of suspended solids and bacteria. In some cases multimedia filters are sufficient to treat the water to feed a reverse osmosis system, but in other cases a more complicated system of coagulation, flocculation, clarification and filtration is needed. This kind of conventional system consumes large quantities of chemicals, produces biosolids, and requires operator attention to ensure that the appropriate chemical dosing is maintained as the surface water quality varies. There are many systems in operation using conventional pretreatment to a reverse osmosis system that operate with few problems. However, upsets in the performance of a conventional system can lead to solids causing excessive brine spacer plugging and increased pressure drop on the concentrate side of the membrane. Overdosing or use of the wrong chemicals in a conventional pretreatment system can increase trans-membrane pressure, sometimes irreversibly. The result of these types of upsets is increased power consumption, increased chemical cleanings, reduced membrane life, and overall, increased operating and maintenance costs.

Developments to watch:

Challenges such as those listed above have led to membrane filtration, both microfiltration and ultrafiltration, being selected for reverse osmosis pretreatment. Nanomaterials are providing opportunities to develop more efficient and cost effective nanostructured and reactive membranes for water purification. Carbon nanotube filtration membranes consist of hollow cylinders with radially aligned carbon nanotube walls. The filters have been shown to be effective at removing bacteria from contaminated water. Alumina ultrafiltration membranes using alumina nanoparticles have also been developed. A hybrid membrane solution, e.g. a membrane bioreactor (MBR) for full-scale municipal wastewater treatment is another important recent technological advance. The MBR is a suspended growth-activated biosolids system that utilizes microporous membranes for solid/liquid separation in place of the conventional secondary clarifier or settling tank. MBRs display an improved capability to remove organic contaminants present in trace concentration levels.

Desalination and Energy Recovery Devices.

Seawater reverse osmosis (SWRO) is a subset of the process described previously, which creates drinking water from salt water using a semi-permeable membrane and high pressure. SWRO has been around from many years, but has been an energy-intensive and cost-prohibitive process. However, isobaric energy recovery devices (ERDs) have reduced SWRO energy costs and enabled large-scale SWRO plants to operate all over the world. Positive-displacement isobaric devices place the reverse osmosis reject and filtered feedwater in contact inside pressure-equalizing, or isobaric, chambers. The energy required to operate the high-pressure portion of an RO system equipped with isobaric ERDs is the sum of a high-pressure pump and circulation pump energy consumption. The flow rate through the high-pressure pump is approximately equal to the permeate flow rate. This means that the high-pressure pump only pumps the amount of water that leaves the system as permeate. This aspect of the technology benefits reverse osmosis operation by reducing the required size and energy consumption of the high-pressure pump and allowing a plant to operate affordably at a low conversion rate. Lower conversion rates correspond with lower membrane pressures and longer membrane life in seawater reverse osmosis systems. ERDs can reduce the amount of energy required in SWRO desalination by up to 60 percent, resulting in more economical production of drinking water and a reduced carbon footprint.

Developments to watch:
Researchers at the Massachusetts Institute of Technology have developed a new, energy-efficient desalination system able to directly desalinate sea water. The system uses ion concentration polarization as its core mechanism, in which both salts and any charged colloids in seawater are diverted into a micro or nanofluidic brine channel, leaving the other channel relatively salt- and particle-free. The technology is based on ion concentration polarization, a phenomenon that occurs when an ion is passed through ion-selective membranes. During the process, the technology removes salts as well as larger particles such as cells, viruses, and microorganisms. This helps to prevent membrane fouling and salt accumulation, which are typical problems associated with other membrane microfiltration methods.

Ultra-Violet and Ozone Disinfection.
Both the U.S. Environmental Protection Agency's (EPA) Enhanced Surface Water Treatment Rule and the Ground Water Rule require public water systems to disinfect water obtained from surface water supplies, groundwater sources under the influence of surface water, and protected groundwater sources. Primary disinfection methods include but are not limited to: enhanced filtration (physical removal of larger organisms/parasites, Cryptosporidium and Giardia); disinfection with oxidizing biocides (inactivation of microorganisms) such as chlorine (gas or liquid), chloramination, chlorine dioxide and ozone; and other disinfection methods such as using ultraviolet (UV) light.

UV light has been used successfully in wastewater disinfection, but it has grown most significantly in drinking water applications over the past ten years due to the discovery that it is effective at low dosage for inactivation of Giardia and Cryptosporidium. Cellular DNA and RNA absorb light in the UVC range. The absorbed UV energy causes damage to these nucleic acids and prevents cell replication by stopping the ability to multiply. The use of ozone and UV technologies for primary disinfection allows utilities to use lower chlorination levels for water distribution.

Typical surface water taste and odor issues are due to algae. Ozone oxidation has been proven effective in reduction of these compounds. These compounds can be naturally occurring or synthetic compounds from industrial pollution or agricultural runoff. Oxidation reactions break chemical bonds to change the refractive index, reducing apparent color and making many compounds more biodegradable. Utilities using pre-ozonation in combination with biologically active filtration can experience reductions in undesirable water color and chlorinated disinfection by-product formation in water. Addition of biologically active filters can consume more of the dissolved organic compounds.

Ozone preoxidation delivers multiple process benefits delivered in combination with other processes, such as: improving filtration performance, reducing taste and odor compounds by inactivating biological contaminants, and breaking down most natural and synthetic organic contaminants.

Developments to watch:
A technology using ozone nano-bubbles mixed with oxygen micro-bubbles produces almost completely bacteria-free water for use in food processing or cleansing seafood. Using this process to purify water allows food product manufacturers to forego the use of chlorine and other chemicals used to disinfect water. Additionally, while ozone can usually only be retained in water for a very short time, when ozone is supplied in the form of nano-bubbles it can be retained for several months.

Irradiating water with high-intensity ultraviolet light kills bacteria. Some water filters made for campers and hikers, for example, use this technology. Adding a photocatalyst that gets activated by UV light and generates reactive chemical compounds that break down microbes into carbon dioxide and water enhances this effect. This new photocatalyst improves on the breakdown by using visible, rather than UV, light and consists of fibers of titanium oxide doped with nitrogen to make it absorb visible light. Alone, the nitrogen-doped titanium oxide kills bacteria, though not efficiently. Nanoparticles of palladium added to the surface of the fibers greatly increases the efficiency of the disinfection.

Efficient Irrigation Systems for Agriculture.
Agricultural use represents 69 % of all water withdrawal in the world and is thus the current largest user of fresh water globally**.** Greater efficiency in agricultural use clearly represents an enormous water savings. Efficient irrigation systems are popular due to high efficiency and low water usage. Agriculture and associated irrigation practices in many parts of the world are biologically, economically, and socially unsustainable: wasting water, energy, and money; drying up rivers and lakes; reducing crop yields; harming fish and wildlife; and causing water pollution. Today's irrigators are struggling to cope with rising energy and water costs at the same time that agencies are working to reduce environmental impacts from irrigation.

As cities draw on more water resources for rapidly growing populations, agriculture must significantly improve its water use efficiency and productivity. Drip-based irrigation systems aid agricultural productivity in the long term and help realize the goal of food self-sufficiency. Drip or sprinkler type technology has already been adopted on a wide scale in various countries including the United States, Israel, and Europe. The use of sprinkler technology is however quite low in most Asian countries. Within Asia, India and China are utilizing the technology the most, but the market potential is still high because of a huge and continuously rising population.

The site-specific nature of irrigation generally requires an on-the-ground approach, one that begins with an audit of the equipment as well as the management techniques being used. To improve irrigation performance, it is necessary not only to promote the implementation of irrigation scheduling methods, but also to concurrently to improve system design and performance and to enhance farmers' skills to control and manage the irrigation system more efficiently during its operation.

The three major irrigation techniques are surface irrigation, sprinkler/drip irrigation, and micro-irrigation. “Surface irrigation” includes basin irrigation, border irrigation, furrow irrigation, and uncontrolled flooding. Two features that distinguish a surface irrigation system are that the flow has a free surface responding to the gravitational gradient; and the on-field means of conveyance and distribution is the field surface itself. The term "micro-irrigation" describes a family of irrigation systems that apply water through small devices. These devices deliver water onto the soil surface very near the plant or below the soil surface directly into the plant root zone.

Methods used to improve on-farm irrigation efficiency vary widely by region and with the commodity under irrigation. The ways on-farm irrigation efficiency can be improved include adopting technology that better matches irrigation water application to plant water requirements; reconfiguring irrigation layouts; installing infrastructure such as recycling systems and piping to improve on-farm storage and delivery systems; and installing new infrastructure, such as drip or spray systems, to improve in-field application systems.

Developments to watch:
New precision agriculture entails emitters that measure the moisture level and then uses automatical irrigation processes to maintain the most beneficial watering schedule, monitoring each plant automatically and delivering to the plant the exact requirements of fertilizers, chemicals, and biologicals. Additionally, improved coatings, such as an advanced zinc aluminium externallayer complementing a 300µm-thick, high-tech internal coating of high-impact resistance Ductan thermoplastic are employed in pipes. Another novel nanotechnology coating for the water industry includes an anti-bacterial C60 buckyball pipe coating. Coating the inside of pipes with these tiny carbon particles not only directly impairs microbial attachment and biofilm formation, but also inhibits bacterial respiration. The respiratory inhibition and anti-attachment exhibited by the nanoparticle is useful as an anti-fouling agent.

Wastewater Treatment Equipment that Drives Water Reuse and Biosolids-to-Energy.
Traditional water and wastewater treatment plants comprise pumps and motors that move water and wastewater through filtration systems. Three processes are typically included in the wastewater process: water treatment; biosolids treatment; and air treatment. Collected wastewater (the influent) enters the installation and after biological treatment, clean water (the effluent) is returned to the sea or other water body.

Biosolids are typically derived from the primary settling tanks. The most important by-product of water treatment, after water, is biosolids. biosolids does not leave the treatment plant directly, and can be used as a source of energy if it still contains a certain concentration of organic matter, and this is one of the roles of the primary settling tanks – to collect primary biosolids with a large quantity of organic matter for biosolids treatment. A second source of biosolids is the biological treatment, although this so-called excess biosolids is less rich in fuel.

The treatment of primary biosolids starts with gravel and sand removal. Excess biosolids is then thickened in thickening centrifuges in order to 'wring out' the biosolids. The biosolids is then fermented to consume part of its organic matter, which produces a reduction of the total volume of biosolids that requires treatment. Biogas is also produced and usually consists of methane (65-70%) and carbon dioxide (35-30%) and contains small quantities of other gasses such as ammonia gas. Small compressors take the biogas from the storage tanks to feed the biogas generators where it is incinerated to generate electricity, which is used directly by the wastewater treatment plant. This green energy reduces the operating costs and gives the wastewater treatment plant a degree of independence. The thermal motors also produce heat that can be reused to ensure the biosolids fermentation tanks operate at the correct temperature. A recently-developed process takes de-watered biosolids from a wastewater plant, efficiently dries it to the point that it can be gasified into syngas, and then burns it to produce electricity. This therefore solves two problems at once for the wastewater plant: it gets rid of the biosolids, which is usually expensive to dispose of; and it produces electricity -- nearly half the amount needed to run the wastewater plant.

Developments to watch:
Wet air oxidation destroys biosolids while using air as a source of oxygen. The oxidation reactions occur at temperatures of 150º C to 320º C and pressures from 150 to 3200 psig. The wet oxidation

process pretreats difficult wastewater streams, making them amenable for discharge to a conventional biological treatment plant for polishing. The process is also used for oxidation of contaminants in production liquors for recycle/reuse.

Modular Treatment Systems.

Modules that offer biological treatment stages for small- to medium-sized wastewater treatment plants provide low-cost alternatives to building expensive infrastructure to burgeoning communities. Wastewater treatment modules are easy to install and highly efficient, and are the most cost-effective answer for treatment of larger flows with total flexibility for design and onsite layout. These modules can replace or supplement existing, overloaded biological treatment stages in domestic and industrial wastewater treatment plants. Treatment for populations of up to 750 PE (persons equivalent) within a single factory-built module are available, with larger flows for up to 5000 PE covered by the installation of multiple factory-built modules.

Another innovation that is revolutionizing the stormwater industry is the Modular Wetlands System (MWS). The MWS incorporates screening, hydrodynamic separation, filtration and bioretention into a modular pre-cast concrete structure, which serves as a simulated wetlands area. The system treats pollutants including fine suspended solids, trash, floatables, oil and grease, sediments, heavy metals, particulate and dissolved metals, as well as nutrients and bacteria.

Developments to watch:

Hybrid municipal waste water treatment plant solutions integrate multiple state-of-the-art technologies into standardized modular plan designs. Complete removal of nutrients and trace contaminants is possible. No or low biosolids disposal; compact, robust, modular designs; and “smart” controls are part of the package.

Conclusion.

In conclusion, the availability of clean water for billions of humans depends on the implementation of every type of technology available.