2009-2012

VORTEX TECHNOLOGY

Naturalists have long been fascinated with the geometry of natural spirals and the efficiency with which vortices are able to mix water, air, or any other fluid; however, this principle has not been universally applied because standard engineering designs are based on a different approach to fluid mechanics. A Bay Area researcher has designed a small (6x4 inch) stainless steel impeller that looks like the inside of a conch shell and is able to mix water in the large tanks that hold drinking water supplies for a majority of people in the industrialized world. The use of conventional pumps or aerators to mix drinking water, which facilitates its treatment and disinfection, is energy intensive and creates secondary problems. By contrast, the tiny vortex mixer employs nature's inherent efficiency in entraining all of the water in the tank and mixing it with only a fraction of the energy required by the pumps or stirrers it replaces.

SALTWATER POWER

An innovative conversion of seawater to power is illustrated by the so-called "salinity battery," which is driven by the osmotic gradient created between seawater and freshwater stored on either side of a synthetic membrane. As fresh water moves spontaneously through the membrane to dilute the dissolved salts on the other side, the seawater is pressurized and then piped through a turbine to generate electricity. Challenges to salinity power include developing an optimal membrane and building a facility that can operate in deltas, estuaries, or other locations where rivers and oceans meet. Anticipated environmental impacts include the disposal of brackish water (although less salty than the brines produced by conventional desalination plants) and the presence of platforms or pylons in potentially sensitive aquatic habitats. Nevertheless, this salinity-powered battery is based on emulating a natural process.

RESTORING WETLANDS

The widespread destruction of natural wetlands throughout the world has prompted the design and installation of artificial wetlands; however, the replacements can never fully mimic the original because nature's intricacies are too numerous and complex. Some of the most important design parameters include mimicking hydrodynamics (e.g., extent and duration of flooding, rates of infiltration and evaporation), which requires water inlets, outlets, weirs, and other engineering control structures. In addition, geotextiles for sediment covers, brush for shading and erosion prevention, and rocks for habitat improvement are required to achieve a balance among the mineral, aqueous, and organic phases of the soil. Even after a decade, the functioning of artificial wetlands has been observed to be markedly different than that of natural wetlands, illustrating the challenge that scientists face when emulating nature's water dynamics.

A WATER TREE

Scientists at Cornell University have developed a so-called synthetic tree composed of a special gel that is etched with 80 tiny channels running parallel to one another in a manner that simulates the tube-filled vascular system, or xylem, of a real tree trunk. Essentially, water wicks up in the nanometer-scale pores of a gel under the driving force of capillary action. This tree consists of a couple circles (one representing a root network and the other a leaf network) that could never be mistaken for a real tree; however, the mechanism for their transporting water is similar inasmuch as no added energy is required to pump water against the relentless force of gravity. The operating principle of the synthetic tree is one that employs design, rather than power, to achieve the desired goal and that integrates the behavior of water (hydromimicry), the biomechanics of trees (biomimicry), and the properties of gels (materials science) into a single solution.

LIFE'S TWO WATERS

The molecular mechanisms underlying many biochemical processes remain poorly understood (e.g., how enzymes cleave substrates, how nucleic acids are formed from their components). Water that is integral to all of these processes is believed to exist in one of two states—either low density (expanded) or high density (collapsed) in which hydrogen bonds of different strengths hold adjacent water molecules together. Organic and inorganic substances have different solubilities in the two types of water, which support distinct kinds of biochemical processes and switch back-and-forth depending on the water's microenvironment. Hence, no matter how water may be structured before it enters an organism, biomolecules constantly restructure it inside the organism. Moreover, the bonding dynamics between water and biomolecules permit an ultrafast exchange of energy, conformation, and perhaps even information between them.

WATER CHANNELS

A need to move water quickly and efficiently in living organisms is paramount; however, the understanding of how water moves through cell membranes is relatively recent. Nobel Laureate Peter Agre discovered that, in addition to simple diffusion, there are proteins (aquaporins) embedded in the membranes that transport water in and out of cells. A human aquaporin channel can transport about three billion water molecules per second in single file order! The orientation of water molecules moving through the channels is very precise and is believed to correspond to electrical fields formed by atoms comprising the channel walls. In any case, the structuring of water outside the cell does not seem to be preserved inside the cell, and biological life's requirement for rapidly moving water across cellular membranes suggests that it may be essential in ways that remain as mysterious as they are intriguing.

CONTAMINANT PULSES

The use of human engineering to alter the hydrologic connectivity among landscapes, groundwater aquifers, and surface waters (e.g., streams, rivers) has permitted water to be rapidly transported through urban storm drains, agricultural ditches, and diversion canals. This alteration of water's natural flow paths has contributed to the rapid movement of pollutants as so-called contaminant "pulses." These pulses are frequently detected in both fresh and coastal waters as a result of the loss of headwaters, wetlands, and other natural features that slow the transport of sediments or pollutants (e.g., metals, nutrients, pesticides) and reduced their concentrations. Often, the pulses are too rapid to warn downstream receptors (either human or ecological) of their imminent exposure to pollutants—an occurrence that has become commonplace as the climate variability has increased. Researchers are developing methods to better predict such events.

WATER FOOTPRINTS

The concept of a water footprint arose when researchers tried to quantify the per capita volume used for direct (e.g., drinking, cooking, bathing) and indirect (e.g., products, services) purposes. Consumptive use is the most obvious component of the water footprint, but water is also lost to pollution, evaporation, and relocation to places where it cannot be reused. Perhaps not surprisingly, the water inherent in producing food and energy comprises a major portion of a person's water footprint. Americans have the highest water consumption, with an annual per capita use (about 2600 cubic meters) that is more than double the global average. Because of their population density, cities require an area as much as 600 times that of their geographic boundaries to provide sufficient water. In addition, the electricity required to pump (relocate) water from productive watersheds to cities comprises a major portion of their energy footprint.

WATER'S EXCLUSION ZONE

Bioengineer Gerald Pollack found that water adjacent to common types of surfaces or exposed to sunlight creates so-called "exclusion zones," where dissolved substances (solutes) are excluded in favor of a more ordered, or less random, network. Applications of this unusual behavior within water's molecular network include removing salts, pollutants, and even microbes without expensive filters or the energy required to force water through them. He also discovered an electrical charge separation between ordered water and the more common forms of disordered water, thus creating a battery—albeit a tiny one. The electrical charge separation created by light may someday lead to the production of a usable electric current, which is based on a process that mimics photosynthesis in plants. Water treatment and energy production are among the highest priorities for researchers currently exploring hydromimicry.

WATER AND ARCHITECTURE

In addition to management schemes and sustainable technologies, water can also serve as a design tool for architecture. The flow forms and rhythms of water in the natural world create an imagery and symbolism that architects use to create spatial relationships between different aspects of a building. Water connects and, in some respects, defines the relationship between physical and energetic aspects of the planet via complex cycles operating on its surface and within its interior. From the ancient architects of Europe's fountains and cathedrals to the modern designs of Frank Lloyd Wright to the famous Blur Building of Switzerland, both the substance and essence of water have been utilized to create a wide variety of visual and sensory effects. Because water is an integral component (both visible and invisible) of everything around us, we respond to its presence in architectural designs.

FRACKING GROUNDWATER

The topic of "natural gas fracking" has made front page news during the last several years—more for its role in contaminating groundwater aquifers than in extracting cheap energy. The allure of hydraulically fracturing geologic formations is to permit trapped natural gas to flow efficiently from its source rocks to subsurface locations where it can be more easily extracted. An unfortunate consequence of such fractures is that they permit the gas (mostly methane) and the associated hydrofracturing fluids (used to enhance the process) to contaminate adjacent drinking water aquifers. Whereas the fossil fuel industry is now focused on producing nontoxic fluids and, perhaps, stripping flammable gases from domestic water supplies, the potential water-related problems don't end there. Fractures that remain "open" following gas extraction act as conduits for any future pollutants that may be either released to or produced within near-surface soils.

OCEANIC HIGHWAYS

Small organisms located miles beneath the ocean surface are unlikely to be affected by winds and other weather conditions at the surface—or are they? Marine scientists have discovered that the same sea surface events that affect our climate and the distribution of fresh water around the globe also generate oceanic currents that can extend as deep as the seafloor, transporting otherwise stationary organisms across entire ocean basins. As a result, marine life originating on the seafloor in one part of the ocean can end up thousands of miles away. One might wonder whether changing ocean conditions (particularly the increased temperature and acidity linked to global climate change) might affect organisms relocated so far from home. While some species are adversely affected by the more "hostile" conditions, many others have demonstrated a surprising tolerance to conditions associated with their move.

WATERSHED PATTERNS

The fractal attributes of water, ranging in scale from molecular to planetary, were discussed in a previous insight. Fractal relationships among the patterns created by water's sculpting landscapes have been used to interpret and predict watershed characteristics. Spatial fractals have permitted the delineation of entire watersheds or their subsections for purposes of establishing appropriate boundaries and for predicting the soil properties that affect the infiltration and subsurface flow of water. Spatial analyses have also been used to identify interconnected channel networks and the nodes (exact locations) that may be most critical for flooding. Temporal fractals have permitted the formulation of algorithms for watershed flows and discharge (essential to sustainable development), the estimation of how quickly pollutants move through landscapes, and the designation of which areas are most vulnerable to floods and pollution.

THE MASTER RESOURCE

Analysts often divide critical resources into five major categories, which include water, food, energy, human health, and ecosystem function. Water is placed at the center because it is required by each of the other four and, as such, is the subject of studies that estimate the resources available for future use. Each region has different threats to water quality and quantity depending on its geography, climate, population, and susceptibility to contamination. Whereas threat identification and quantification is a logical first step to reducing future water impacts, similar approaches have produced disappointing results. From an economic perspective, water's cost has been subsidized because industry, energy, and agriculture sectors are so dependent on it. Some experts have suggested that fostering a "culture of water" may be the best way to elevate this substance to its master status.

SPACEY WATER

The distribution and origin of water in the solar system is a mystery that continues to unfold as astronomers report new findings. Gas-giant planets like Uranus and Neptune have rather strange magnetic fields that may be due to an unusual type of water known as "superionic," whereby the oxygen atoms form a lattice or crystalline structure through which the smaller hydrogen atoms are able to flow. Superionic water is created at temperatures and pressures much greater than those present on Earth and has a distinct yellow glowing appearance. While on the subject of solar system water, the latest theory regarding an extraplanetary source of earthly water is that asteroids, rather than comets, were the primary contributors. Based on the relative abundance of deuterium (an isotope of hydrogen) in water, asteroids seem to be more likely to have contributed this vital substance to the inner solar system planets such as Earth.

ALGAE'S WORLDS

Whereas the ability of freshwater algae to produce hydrogen gas (as a clean energy source) was discussed in a previous insight, it seems that these algae possess a much broader repertoire. Researchers have shown that several genera of microalgae are capable of surviving in municipal wastewater and converting inorganic pollutants (e.g., ammonia, nitrate, phosphate) into natural oils that can be used for biodiesel. The required lipids are produced in the algal cells over a timespan of about a week, after which the algae are harvested and mechanically pressed to extract the oil. Finally, the algae are either composted or used as a feedstock to produce methane and ethanol. The seawater cousins of freshwater microalgae, known as phytoplankton, play an equally critical role in the oceans where they form the base of the food chain and assist in regulating atmospheric levels of oxygen and carbon dioxide.