9.8: The Many Uses of Water

Beyond its well known domestic uses and for irrigation, water has many applications. A renewable, sustainable green resource, next to air water is the cheapest and most universally available raw material and, because it is totally renewable, it is the greenest of raw materials. Here are addressed just a few of the huge number of water-based technologies.

Many of water's uses come from its unique physical properties, especially as they relate to water's extraordinarily high capacity to absorb and release heat energy. At 100°C,a very high 40.7kilojoules/mole (kJ/mol) is required to change liquid water to steam and a correspondingly large amount of heat is released when steam condenses to liquid water, the highest heat of vaporization of any common substance. Advantage is taken of this characteristic by vaporizing water in a boiler, moving it as steam, and condensing it back to liquid, a very effective means of moving heat energy from one place to another, such as for heating multiple buildings on a university campus, for example. Some European cities use such a **district heating** system to heat residential houses and apartments, often with boilers fueled in part by municipal refuse. The high heat of fusion for ice enables the use of solid water to absorb heat.

Steam is a very effective **working fluid** to convert heat energy to mechanical energy. This used to be done with piston engines including those on steam locomotives, but is now performed by steam turbines. Steam is produced in **water-tube** boilers in which liquid water is evaporated inside 2-8 cm diameter tubes around which hot combustion gases are circulated. Water drums for water storage and steam drums for steam storage are isolated from the fire to prevent an explosion in case they rupture, which would happen if their contents got into the firebox.

An interesting application of steam which greatly facilitates the sustainable use of wood is **steam explosion pulping** of wood in which wood is heated with pressurized steam at 180°C to 210°C. This step is followed by very rapid decompression such that the wood literally explodes releasing wood fibers that can be used in numerous applications including making paper pulp and fiber board. The cellulose in the fibers can be treated to produce sugars that can be fermented to produce alcohol.

An important consideration in producing steam for any purpose is the prevention of scaling, fouling, and corrosion, which generally requires very pure and carefully treated water. The best source of such water is the steam itself, which is condensed for **makeup water** to return to the boiler. The feed water to a boiler is treated to remove contaminants that can cause solid buildup in the boiler tubes. Phosphate salts are added to remove dissolved calcium and magnesium (hardness) by reactions such as the following:

$$5\,\mathrm{Ca}^{2+}(\mathrm{aq}) + 3\,\mathrm{PO}_4^{3-}(\mathrm{aq}) + \mathrm{OH}^-(\mathrm{aq}) \longrightarrow \mathrm{Ca}_5\mathrm{OH}(\mathrm{PO}_4)_3(\mathrm{s}) \tag{9.8.1}$$

The removal of silicon from boiler feedwater is required because it can carry over with steam and cause damaging deposits of SiO_2 on turbine blades. Both dissolved carbon dioxide and oxygen are corrosive. Hydrazine can be used to remove traces of residual oxygen by the following reaction:

$$\mathrm{N_2H_4} + \mathrm{O_2} \rightarrow 2\,\mathrm{H_2o} + \mathrm{N_2} \tag{9.8.2}$$

Anticorrosive agents, such as cyclohexylamine are added to boiler feedwater.

Videos of floodwaters uprooting structures and carrying them away attest to water's ability to transmit mechanical energy. Advantage is taken of this capability by using jets of pressurized water to harvest sand and gravel from river beds and to mine and process some kinds of minerals.

The greatest use of moving water's mechanical energy is the application of **waterpower**. Employed for many centuries as a renewable energy source, waterpower is the oldest source of non-animal energy harnessed, for example, by waterwheels powering grain-grinding applications or sawmills. Energy may be harvested from water flowing downhill from a dammed stream and from rising and falling ocean tides. The greatest current use of moving water is for **hydroelectric power** to run electricity generators. The U.S. now has about 100,000 megawatts of hydroelectric capacity (a large fossil-fueled or nuclear power plant typically has a capacity of 1000 MW). This capacity could be doubled by using all available sites in the U.S., including Alaska for hydroelectric power, although this will not happen for economic and environmental reasons. A useful adaptation of hydroelectric power is **pumped storage** in which turbines are reversed to pump water to containment structures at higher elevations during periods of low electricity demand and the stored water is used to run turbines attached to electrical generators when demand is high.

Water power affords economic and environmental advantages including a free source of "fuel" and the lack of emissions or ash, making waterpower one of the "greenest" sources of energy. Problems may arise under extreme drought conditions when water is simply unavailable.

Unfortunately, the vast reservoirs required for most waterpower developments destroy free-flowing rivers and are detrimental to fish migration, such as that required for salmon reproduction. Most potentially remaining available sites are in remote regions from which the transfer of electricity to population centers requires massive power lines, which also present environmental problems. Because of this there is now a trend toward dismantling dams to restore normal stream flow, the esthetics of river valleys and gorges, and wildlife habitat. (Sediments accumulated in reservoirs, some of which contain hazardous material, can be released when dams are removed and cause problems downstream.) New technologies have also been developed that utilize the power of moving water in river beds without the need for dams.

Water as a Solvent

Water is an extraordinarily good solvent for a variety of materials and its solvent properties can be enhanced with suitable additives, especially surfactants that reduce its surface tension making it a powerful cleaning agent. Mixed with suspended lubricants, water is very useful as a lubricant and cooling agent, such as in metal-stamping operations. Substitution of appropriately treated water for organic solvents, which generally come from nonrenewable petroleum and are expensive, has extended water's use for washing small parts, such as electronic constituents. As a solvent for chemical reactants, water serves as a medium for many chemical synthesis and processing applications. Substances can be purified by dissolving them in water, then evaporating some of the water off to leave a purified form of the substance; some salts are purified by this means.

Water is useful for its chemical properties and is a chemical ingredient for a number of industrial chemical reactions. It is required for the hardening of Portland Cement to make concrete. It can be used as the reagent in treating some kinds of hazardous wastes by hydrolysis. Water serves as a source of elemental hydrogen used as a fuel in fuel cells and as a raw material in making some chemicals, such as ammonia. Elemental hydrogen is generated along with oxygen gas when a direct electrical current is passed through water that has been made conducting by the addition of a salt. Hydrogen is produced at the negatively charged cathode when electrons (*e*-) are added to molecules of water,

$$2\,H_2O + 2\,e^- \rightarrow H_2(g) + 2\,OH^- \tag{9.8.3}$$

and oxygen is generated at the positively charged anode by the removal of electrons from water:

$$2\,H_2O \rightarrow O_2(g) + 4\,H^+ + 4\,e^- \tag{9.8.4}$$

The net reaction is simply the following:

$$2\,H_2O \rightarrow 2\,H_2(g) + O_2(g) \tag{9.8.5}$$

The process is certainly an example of green chemistry because the only reagent is water and the only byproduct is oxygen gas, which has a number of uses or can be released harmlessly to the atmosphere. In Iceland, hydrogen gas made by the electrolysis of water generated from abundant hydroelectric and geothermal sources of electricity is used to fuel automobiles.