

Water Purification Techniques

How to Purify Drinking Water

Contents

Articles

Water purification	1
Boiling	12
Distillation	15
Reverse osmosis	29
Desalination	38
In situ chemical oxidation	56

References

Article Sources and Contributors	64
Image Sources, Licenses and Contributors	66

Article Licenses

License	67
---------	----

Water purification

Water purification is the process of removing undesirable chemicals, biological contaminants, suspended solids and gases from contaminated water. The goal is to produce water fit for a specific purpose. Most water is purified for human consumption (drinking water), but water purification may also be designed for a variety of other purposes, including meeting the requirements of medical, pharmacological, chemical and industrial applications. In general the methods used include physical processes such as filtration, sedimentation, and distillation, biological processes such as slow sand filters or biologically active carbon, chemical processes such as flocculation and chlorination and the use of electromagnetic radiation such as ultraviolet light.

The purification process of water may reduce the concentration of particulate matter including suspended particles, parasites, bacteria, algae, viruses, fungi; and a range of dissolved and particulate material derived from the surfaces that water may have made contact with after falling as rain.

The standards for drinking water quality are typically set by governments or by international standards. These standards will typically set minimum and maximum concentrations of contaminants for the use that is to be made of the water.

It is not possible to tell whether water is of an appropriate quality by visual examination. Simple procedures such as boiling or the use of a household activated carbon filter are not sufficient for treating all the possible contaminants that may be present in water from an unknown source. Even natural spring water – considered safe for all practical purposes in the 19th century – must now be tested before determining what kind of treatment, if any, is needed. Chemical and microbiological analysis, while expensive, are the only way to obtain the information necessary for deciding on the appropriate method of purification.

According to a 2007 World Health Organization (WHO) report, 1.1 billion people lack access to an improved drinking water supply, 88 percent of the 4 billion annual cases of diarrheal disease are attributed to unsafe water and inadequate sanitation and hygiene, and 1.8 million people die from diarrheal diseases each year. The WHO estimates that 94 percent of these diarrheal cases are preventable through modifications to the environment, including access to safe water. Simple techniques for treating water at home, such as chlorination, filters, and solar disinfection, and storing it in safe containers could save a huge number of lives each year. Reducing deaths from waterborne diseases is a major public health goal in developing countries.

Sources of water

1. **Groundwater:** The water emerging from some deep ground water may have fallen as rain many tens, hundreds, or thousands of years ago. Soil and rock layers naturally filter the ground water to a high degree of clarity and often it does not require additional treatment other than adding chlorine or chloramines as secondary disinfectants. Such water may emerge as springs, artesian springs, or may be extracted from boreholes or wells. Deep ground water is generally of very high bacteriological quality (i.e., pathogenic bacteria or the pathogenic protozoa are typically absent), but the water may be rich in dissolved solids, especially carbonates and sulfates of calcium and magnesium. Depending on the strata through which the water has flowed, other ions may also be present including chloride, and bicarbonate. There may be a requirement to reduce the iron or manganese content of this water to make it acceptable for drinking, cooking, and laundry use. Primary disinfection may also be required. Where groundwater recharge is practised (a process in which river water is injected into an aquifer to store the



Control room and schematics of the water purification plant to Lac de Bret, Switzerland

water in times of plenty so that it is available in times of drought), the groundwater may require additional treatment depending on applicable state and federal regulations.

2. Upland lakes and reservoirs: Typically located in the headwaters of river systems, upland reservoirs are usually sited above any human habitation and may be surrounded by a protective zone to restrict the opportunities for contamination. Bacteria and pathogen levels are usually low, but some bacteria, protozoa or algae will be present. Where uplands are forested or peaty, humic acids can colour the water. Many upland sources have low pH which require adjustment.
3. Rivers, canals and low land reservoirs: Low land surface waters will have a significant bacterial load and may also contain algae, suspended solids and a variety of dissolved constituents.
4. Atmospheric water generation is a new technology that can provide high quality drinking water by extracting water from the air by cooling the air and thus condensing water vapor.
5. Rainwater harvesting or fog collection which collects water from the atmosphere can be used especially in areas with significant dry seasons and in areas which experience fog even when there is little rain.
6. Desalination of seawater by distillation or reverse osmosis.
7. Surface Water: Freshwater bodies that are open to the atmosphere and are not designated as groundwater are classified in the USA for regulatory and water purification purposes as surface water.

Treatment

The processes below are the ones commonly used in water purification plants. Some or most may not be used depending on the scale of the plant and quality of the raw (source) water.

Pre-treatment

1. Pumping and containment – The majority of water must be pumped from its source or directed into pipes or holding tanks. To avoid adding contaminants to the water, this physical infrastructure must be made from appropriate materials and constructed so that accidental contamination does not occur.
2. Screening (*see also screen filter*) – The first step in purifying surface water is to remove large debris such as sticks, leaves, rubbish and other large particles which may interfere with subsequent purification steps. Most deep groundwater does not need screening before other purification steps.
3. Storage – Water from rivers may also be stored in bankside reservoirs for periods between a few days and many months to allow natural biological purification to take place. This is especially important if treatment is by slow sand filters. Storage reservoirs also provide a buffer against short periods of drought or to allow water supply to be maintained during transitory pollution incidents in the source river.
4. Pre-chlorination – In many plants the incoming water was chlorinated to minimize the growth of fouling organisms on the pipe-work and tanks. Because of the potential adverse quality effects (see chlorine below), this has largely been discontinued.^[1]

Widely varied techniques are available to remove the fine solids, micro-organisms and some dissolved inorganic and organic materials. The choice of method will depend on the quality of the water being treated, the cost of the treatment process and the quality standards expected of the processed water.

pH adjustment

Pure water has a pH close to 7 (neither alkaline nor acidic). Sea water can have pH values that range from 7.5 to 8.4 (moderately alkaline). Fresh water can have widely ranging pH values depending on the geology of the drainage basin or aquifer and the influence of contaminant inputs (acid rain). If the water is acidic (lower than 7), lime, soda ash, or sodium hydroxide can be added to raise the pH during water purification processes. Lime addition increases the calcium ion concentration, thus raising the water hardness. For highly acidic waters, forced draft degasifiers can be an effective way to raise the pH, by stripping dissolved carbon dioxide from the water.^{[2][3][4]} Making the water

alkaline helps coagulation and flocculation processes work effectively and also helps to minimize the risk of lead being dissolved from lead pipes and from lead solder in pipe fittings. Sufficient alkalinity also reduces the corrosiveness of water to iron pipes. Acid (carbonic acid, hydrochloric acid or sulfuric acid) may be added to alkaline waters in some circumstances to lower the pH. Alkaline water (above pH 7.0) does not necessarily mean that lead or copper from the plumbing system will not be dissolved into the water. The ability of water to precipitate calcium carbonate to protect metal surfaces and reduce the likelihood of toxic metals being dissolved in water is a function of pH, mineral content, temperature, alkalinity and calcium concentration. ^[5]

Coagulation and flocculation

One of the first steps in a conventional water purification process is the addition of chemicals to assist in the removal of particles suspended in water. Particles can be inorganic such as clay and silt or organic such as algae, bacteria, viruses, protozoa and natural organic matter. Inorganic and organic particles contribute to the turbidity and colour of water.

The addition of inorganic coagulants such as aluminum sulfate (or alum) or iron (III) salts such as iron(III) chloride cause several simultaneous chemical and physical interactions on and among the particles. Within seconds, negative charges on the particles are neutralized by inorganic coagulants. Also within seconds, metal hydroxide precipitates of the aluminum and iron (III) ions begin to form. These precipitates combine into larger particles under natural processes such as Brownian motion and through induced mixing which is sometimes referred to as flocculation. The term most often used for the amorphous metal hydroxides is “floc.” Large, amorphous aluminum and iron (III) hydroxides adsorb and enmesh particles in suspension and facilitate the removal of particles by subsequent processes of sedimentation and filtration. ^{[6]:8.2–8.3}

Aluminum hydroxides are formed within a fairly narrow range, typically: 5.5 to about 7.7. Iron (III) hydroxides can form over a larger pH range including pH levels lower than are effective for alum, typically: 5.0 to 8.5. ^{[7]:679}

In the literature, there is much debate and confusion over the usage of the terms coagulation and flocculation—where does coagulation end and flocculation begin? In water purification plants, there is usually a high energy, rapid mix unit process (detention time in seconds) where the coagulant chemicals are added followed by flocculation basins (detention times range from 15 to 45 minutes) where low energy inputs turn large paddles or other gentle mixing devices to enhance the formation of floc. In fact, coagulation and flocculation processes are ongoing once the metal salt coagulants are added. ^{[8]:74–5}

Organic polymers were developed in the 1960s as aids to coagulants and, in some cases, as replacements for the inorganic metal salt coagulants. Synthetic organic polymers are high molecular weight compounds that carry negative, positive or neutral charges. When organic polymers are added to water with particulates, the high molecular weight compounds adsorb onto particle surfaces and through interparticle bridging coalesce with other particles to form floc. PolyDADMAC is a popular cationic (positively charged) organic polymer used in water purification plants. ^{:667–8}

Sedimentation

Waters exiting the flocculation basin may enter the sedimentation basin, also called a clarifier or settling basin. It is a large tank with low water velocities, allowing floc to settle to the bottom. The sedimentation basin is best located close to the flocculation basin so the transit between the two processes does not permit settlement or floc break up. Sedimentation basins may be rectangular, where water flows from end to end, or circular where flow is from the centre outward. Sedimentation basin outflow is typically over a weir so only a thin top layer of water—that furthest from the sludge—exits.

In 1904, Allen Hazen showed that the efficiency of a sedimentation process was a function of the particle settling velocity, the flow through the tank and the surface area of tank. Sedimentation tanks are typically designed within a range of overflow rates of 0.5 to 1.0 gallons per minute per square foot (or 1.25 to 2.5 meters per hour). In general,

sedimentation basin efficiency is not a function of detention time or depth of the basin. Although, basin depth must be sufficient so that water currents do not disturb the sludge and settled particle interactions are promoted. As particle concentrations in the settled water increase near the sludge surface on the bottom of the tank, settling velocities can increase due to collisions and agglomeration of particles. Typical detention times for sedimentation vary from 1.5 to 4 hours and basin depths vary from 10 to 15 feet (3 to 4.5 meters).^{9.39-9.40:790-1:140-2, 171}

Inclined flat plates or tubes can be added to traditional sedimentation basins to improve particle removal performance. Inclined plates and tubes drastically increase the surface area available for particles to be removed in concert with Hazen's original theory. The amount of ground surface area occupied by a sedimentation basin with inclined plates or tubes can be far smaller than a conventional sedimentation basin.

Sludge storage and removal

As particles settle to the bottom of a sedimentation basin, a layer of sludge is formed on the floor of the tank. This layer of sludge must be removed and treated. The amount of sludge that is generated is significant, often 3 to 5 percent of the total volume of water that is treated. The cost of treating and disposing of the sludge can be a significant part of the operating cost of a water treatment plant. The sedimentation tank may be equipped with mechanical cleaning devices that continually clean the bottom of the tank or the tank can be periodically taken out of service and cleaned manually.

Floc blanket clarifiers

A subcategory of sedimentation is the removal of particulates by entrapment in a layer of suspended floc as the water is forced upward. The major advantage of floc blanket clarifiers is that they occupy a smaller footprint than conventional sedimentation. Disadvantages are that particle removal efficiency can be highly variable depending on changes in influent water quality and influent water flow rate.⁸³⁵⁻⁶

Dissolved air flotation

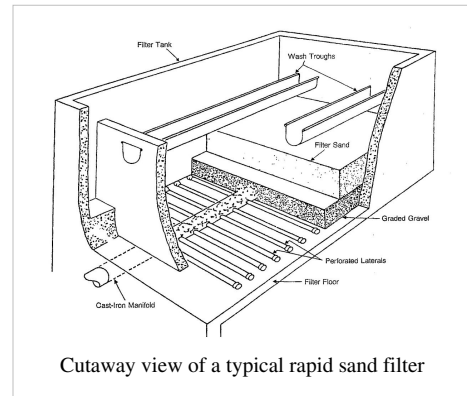
When particles to be removed do not settle out of solution easily, dissolved air flotation (DAF) is often used. Water supplies that are particularly vulnerable to unicellular algae blooms and supplies with low turbidity and high colour often employ DAF. After coagulation and flocculation processes, water flows to DAF tanks where air diffusers on the tank bottom create fine bubbles that attach to floc resulting in a floating mass of concentrated floc. The floating floc blanket is removed from the surface and clarified water is withdrawn from the bottom of the DAF tank.^{9.46}

Filtration

After separating most floc, the water is filtered as the final step to remove remaining suspended particles and unsettled floc.

Rapid sand filters

The most common type of filter is a rapid sand filter. Water moves vertically through sand which often has a layer of activated carbon or anthracite coal above the sand. The top layer removes organic compounds, which contribute to taste and odour. The space between sand particles is larger than the smallest suspended particles, so simple filtration is not enough. Most particles pass through surface layers but are trapped in pore spaces or adhere to sand particles. Effective filtration extends into the depth of the filter. This property of the filter is key to its operation: if the top layer of sand were to block all the particles, the filter would quickly clog.^[9]



To clean the filter, water is passed quickly upward through the filter, opposite the normal direction (called *backflushing* or *backwashing*) to remove embedded particles. Prior to this step, compressed air may be blown up through the bottom of the filter to break up the compacted filter media to aid the backwashing process; this is known as *air scouring*. This contaminated water can be disposed of, along with the sludge from the sedimentation basin, or it can be recycled by mixing with the raw water entering the plant although this is often considered poor practice since it re-introduces an elevated concentration of bacteria into the raw water

Some water treatment plants employ pressure filters. These work on the same principle as rapid gravity filters, differing in that the filter medium is enclosed in a steel vessel and the water is forced through it under pressure.

Advantages:

- Filters out much smaller particles than paper and sand filters can.
- Filters out virtually all particles larger than their specified pore sizes.
- They are quite thin and so liquids flow through them fairly rapidly.
- They are reasonably strong and so can withstand pressure differences across them of typically 2–5 atmospheres.
- They can be cleaned (back flushed) and reused.

Slow sand filters

Slow sand filters may be used where there is sufficient land and space, as the water must be passed very slowly through the filters. These filters rely on biological treatment processes for their action rather than physical filtration. The filters are carefully constructed using graded layers of sand, with the coarsest sand, along with some gravel, at the bottom and finest sand at the top. Drains at the base convey treated water away for disinfection. Filtration depends on the development of a thin biological layer, called the zoogeal layer or Schmutzdecke, on the surface of the filter. An effective slow sand filter may remain in service for many weeks or even months if the pre-treatment is well designed and produces water with a very low available nutrient level which physical methods of treatment rarely achieve. Very low nutrient levels allow water to be safely sent through distribution systems with very low disinfectant levels, thereby reducing consumer irritation over offensive levels of chlorine and chlorine by-products. Slow sand filters are not backwashed; they are maintained by having the top layer of sand scraped off when flow is eventually obstructed by biological growth. ^[citation needed]



A specific "large-scale" form of slow sand filter is the process of bank filtration, in which natural sediments in a riverbank are used to provide a first stage of contaminant filtration. While typically not clean enough to be used directly for drinking water, the water gained from the associated extraction wells is much less problematic than river

water taken directly from the major streams where bank filtration is often used.

Membrane filtration

Membrane filters are widely used for filtering both drinking water and sewage. For drinking water, membrane filters can remove virtually all particles larger than 0.2 μm —including *giardia* and *cryptosporidium*. Membrane filters are an effective form of tertiary treatment when it is desired to reuse the water for industry, for limited domestic purposes, or before discharging the water into a river that is used by towns further downstream. They are widely used in industry, particularly for beverage preparation (including bottled water). However no filtration can remove substances that are actually dissolved in the water such as phosphorus, nitrates and heavy metal ions.

Removal of ions and other dissolved substances

Ultrafiltration membranes use polymer membranes with chemically formed microscopic pores that can be used to filter out dissolved substances avoiding the use of coagulants. The type of membrane media determines how much pressure is needed to drive the water through and what sizes of micro-organisms can be filtered out.

Ion exchange: Ion exchange systems use ion exchange resin- or zeolite-packed columns to replace unwanted ions. The most common case is water softening consisting of removal of Ca^{2+} and Mg^{2+} ions replacing them with benign (soap friendly) Na^+ or K^+ ions. Ion exchange resins are also used to remove toxic ions such as nitrate, nitrite, lead, mercury, arsenic and many others.

Precipitative softening:^{13.12–13.58} Water rich in hardness (calcium and magnesium ions) is treated with lime (calcium oxide) and/or soda-ash (sodium carbonate) to precipitate calcium carbonate out of solution utilizing the common-ion effect.

Electrodeionization: Water is passed between a positive electrode and a negative electrode. Ion exchange membranes allow only positive ions to migrate from the treated water toward the negative electrode and only negative ions toward the positive electrode. High purity deionized water is produced with a little worse degree of purification in comparison with ion exchange treatment. Complete removal of ions from water is regarded as electro dialysis. The water is often pre-treated with a reverse osmosis unit to remove non-ionic organic contaminants.

Disinfection

Disinfection is accomplished both by filtering out harmful micro-organisms and also by adding disinfectant chemicals. Water is disinfected to kill any pathogens which pass through the filters and to provide a residual dose of disinfectant to kill or inactivate potentially harmful micro-organisms in the storage and distribution systems. Possible pathogens include viruses, bacteria, including *Salmonella*, *Cholera*, *Campylobacter* and *Shigella*, and protozoa, including *Giardia lamblia* and other *cryptosporidia*. Following the introduction of any chemical disinfecting agent, the water is usually held in temporary storage – often called a contact tank or clear well to allow the disinfecting action to complete.

Chlorine disinfection

The most common disinfection method involves some form of chlorine or its compounds such as chloramine or chlorine dioxide. Chlorine is a strong oxidant that rapidly kills many harmful micro-organisms. Because chlorine is a toxic gas, there is a danger of a release associated with its use. This problem is avoided by the use of sodium hypochlorite, which is a relatively inexpensive solution that releases free chlorine when dissolved in water. Chlorine solutions can be generated on site by electrolyzing common salt solutions. A solid form, calcium hypochlorite, releases chlorine on contact with water. Handling the solid, however, requires greater routine human contact through opening bags and pouring than the use of gas cylinders or bleach which are more easily automated. The generation of liquid sodium hypochlorite is both inexpensive and safer than the use of gas or solid chlorine.

All forms of chlorine are widely used, despite their respective drawbacks. One drawback is that chlorine from any source reacts with natural organic compounds in the water to form potentially harmful chemical by-products. These by-products, trihalomethanes (THMs) and haloacetic acids (HAAs), are both carcinogenic in large quantities and are regulated by the United States Environmental Protection Agency (EPA) and the Drinking Water Inspectorate in the UK. The formation of THMs and haloacetic acids may be minimized by effective removal of as many organics from the water as possible prior to chlorine addition. Although chlorine is effective in killing bacteria, it has limited effectiveness against protozoa that form cysts in water (*Giardia lamblia* and *Cryptosporidium*, both of which are pathogenic).

Chlorine dioxide disinfection

Chlorine dioxide is a faster-acting disinfectant than elemental chlorine. It is relatively rarely used, because in some circumstances it may create excessive amounts of chlorite, which is a by-product regulated to low allowable levels in the United States. Chlorine dioxide is supplied as an aqueous solution and added to water to avoid gas handling problems; chlorine dioxide gas accumulations may spontaneously detonate.

Chloramine disinfection

The use of chloramine is becoming more common as a disinfectant. Although chloramine is not as strong an oxidant, it does provide a longer-lasting residual than free chlorine and it won't form THMs or haloacetic acids. It is possible to convert chlorine to chloramine by adding ammonia to the water after addition of chlorine. The chlorine and ammonia react to form chloramine. Water distribution systems disinfected with chloramines may experience nitrification, as ammonia is a nutrient for bacterial growth, with nitrates being generated as a by-product.

Ozone disinfection

Ozone is an unstable molecule which readily gives up one atom of oxygen providing a powerful oxidizing agent which is toxic to most waterborne organisms. It is a very strong, broad spectrum disinfectant that is widely used in Europe. It is an effective method to inactivate harmful protozoa that form cysts. It also works well against almost all other pathogens. Ozone is made by passing oxygen through ultraviolet light or a "cold" electrical discharge. To use ozone as a disinfectant, it must be created on-site and added to the water by bubble contact. Some of the advantages of ozone include the production of fewer dangerous by-products and the absence of taste and odour problems (in comparison to chlorination). Although fewer by-products are formed by ozonation, it has been discovered that ozone reacts with bromide ions in water to produce concentrations of the suspected carcinogen bromate. Bromide can be found in fresh water supplies in sufficient concentrations to produce (after ozonation) more than 10 ppb of bromate — the maximum contaminant level established by the USEPA.^[10] Another advantage of ozone is that it leaves no residual disinfectant in the water. Ozone has been used in drinking water plants since 1906 where the first industrial ozonation plant was built in Nice, France. The U.S. Food and Drug Administration has accepted ozone as being safe; and it is applied as an anti-microbiological agent for the treatment, storage, and processing of foods.

Ultraviolet disinfection

Ultraviolet light (UV) is very effective at inactivating cysts, in low turbidity water. UV light's disinfection effectiveness decreases as turbidity increases, a result of the absorption, scattering, and shadowing caused by the suspended solids. The main disadvantage to the use of UV radiation is that, like ozone treatment, it leaves no residual disinfectant in the water; therefore, it is sometimes necessary to add a residual disinfectant after the primary disinfection process. This is often done through the addition of chloramines, discussed above as a primary disinfectant. When used in this manner, chloramines provide an effective residual disinfectant with very few of the negative effects of chlorination.

Various portable methods of disinfection

Available for disinfection in emergencies or in remote locations. Disinfection is the primary goal, since aesthetic considerations such as taste, odor, appearance, and trace chemical contamination do not affect the short-term safety of drinking water.

Solar water disinfection

One low-cost method of disinfecting water that can often be implemented with locally available materials is solar disinfection (SODIS).^{[11] [12]} Unlike methods that rely on firewood, it has low impact on the environment.

One recent study has found that the wild Salmonella which would reproduce quickly during subsequent dark storage of solar-disinfected water could be controlled by the addition of just 10 parts per million of hydrogen peroxide.

Additional treatment options

1. **Water fluoridation:** in many areas fluoride is added to water with the goal of preventing tooth decay. Fluoride is usually added after the disinfection process. In the U.S., fluoridation is usually accomplished by the addition of hexafluorosilicic acid, which decomposes in water, yielding fluoride ions.
2. **Water conditioning:** This is a method of reducing the effects of hard water. In water systems subject to heating hardness salts can be deposited as the decomposition of bicarbonate ions creates carbonate ions that precipitate out of solution. Water with high concentrations of hardness salts can be treated with soda ash (sodium carbonate) which precipitates out the excess salts, through the common-ion effect, producing calcium carbonate of very high purity. The precipitated calcium carbonate is traditionally sold to the manufacturers of toothpaste. Several other methods of industrial and residential water treatment are claimed (without general scientific acceptance) to include the use of magnetic and/or electrical fields reducing the effects of hard water.^[citation needed]
3. **Plumbosolvency reduction:** In areas with naturally acidic waters of low conductivity (i.e. surface rainfall in upland mountains of igneous rocks), the water may be capable of dissolving lead from any lead pipes that it is carried in. The addition of small quantities of phosphate ion and increasing the pH slightly both assist in greatly reducing plumbo-solvency by creating insoluble lead salts on the inner surfaces of the pipes.
4. **Radium Removal:** Some groundwater sources contain radium, a radioactive chemical element. Typical sources include many groundwater sources north of the Illinois River in Illinois. Radium can be removed by ion exchange, or by water conditioning. The back flush or sludge that is produced is, however, a low-level radioactive waste.
5. **Fluoride Removal:** Although fluoride is added to water in many areas, some areas of the world have excessive levels of natural fluoride in the source water. Excessive levels can be toxic or cause undesirable cosmetic effects such as staining of teeth. Methods of reducing fluoride levels is through treatment with activated alumina and bone char filter media.

Other water purification techniques

Other popular methods for purifying water, especially for local private supplies are listed below. In some countries some of these methods are also used for large scale municipal supplies. Particularly important are distillation (de-salination of seawater) and reverse osmosis.

1. **Boiling:** Bringing it to its boiling point at 100 °C (212 °F), is the oldest and most effective way since it eliminates most microbes causing intestine related diseases, but it cannot remove chemical toxins or impurities.^[13] For human health, complete sterilization of water is not required, since the heat resistant microbes are not intestine affecting. The traditional advice of boiling water for ten minutes is mainly for additional safety, since microbes start getting eliminated at temperatures greater than 60 °C (140 °F). Though the boiling point decreases with increasing altitude, it is not enough to affect the disinfecting process. In areas where the water is "hard" (that is, containing significant dissolved calcium salts), boiling decomposes the bicarbonate ions, resulting in partial

precipitation as calcium carbonate. This is the "fur" that builds up on kettle elements, etc., in hard water areas. With the exception of calcium, boiling does not remove solutes of higher boiling point than water and in fact increases their concentration (due to some water being lost as vapour). Boiling does not leave a residual disinfectant in the water. Therefore, water that is boiled and then stored for any length of time may acquire new pathogens.

2. Granular Activated Carbon filtering: a form of activated carbon with a high surface area, adsorbs many compounds including many toxic compounds. Water passing through activated carbon is commonly used in municipal regions with organic contamination, taste or odors. Many household water filters and fish tanks use activated carbon filters to further purify the water. Household filters for drinking water sometimes contain silver as metallic silver nanoparticle. If water is held in the carbon block for longer period, microorganisms can grow inside which results in fouling and contamination. Silver nanoparticles are excellent anti-bacterial material and they can decompose toxic halo-organic compounds such as pesticides into non-toxic organic products.
 3. Distillation involves boiling the water to produce water vapour. The vapour contacts a cool surface where it condenses as a liquid. Because the solutes are not normally vaporised, they remain in the boiling solution. Even distillation does not completely purify water, because of contaminants with similar boiling points and droplets of unvaporised liquid carried with the steam. However, 99.9% pure water can be obtained by distillation.
 4. Reverse osmosis: Mechanical pressure is applied to an impure solution to force pure water through a semi-permeable membrane. Reverse osmosis is theoretically the most thorough method of large scale water purification available, although perfect semi-permeable membranes are difficult to create. Unless membranes are well-maintained, algae and other life forms can colonize the membranes.
 5. The use of iron in removing arsenic from water. See Arsenic contamination of groundwater.
 6. Direct contact membrane distillation (DCMD). Applicable to desalination. Heated seawater is passed along the surface of a hydrophobic polymer membrane. Evaporated water passes from the hot side through pores in the membrane into a stream of cold pure water on the other side. The difference in vapour pressure between the hot and cold side helps to push water molecules through.
 7. Desalination - is a process by which saline water (generally sea water) is converted to fresh water. The most common desalination processes are distillation and reverse osmosis. Desalination is currently expensive compared to most alternative sources of water, and only a very small fraction of total human use is satisfied by desalination. It is only economically practical for high-valued uses (such as household and industrial uses) in arid areas.
 8. Gas hydrate crystals centrifuge method. If carbon dioxide or other low molecular weight gas is mixed with contaminated water at high pressure and low temperature, gas hydrate crystals will form exothermically. Separation of the crystalline hydrate may be performed by centrifuge or sedimentation and decanting. Water can be released from the hydrate crystals by heating^[14]
 9. In Situ Chemical Oxidation, a form of advanced oxidation processes and advanced oxidation technology, is an environmental remediation technique used for soil and/or groundwater remediation to reduce the concentrations of targeted environmental contaminants to acceptable levels. ISCO is accomplished by injecting or otherwise introducing strong chemical oxidizers directly into the contaminated medium (soil or groundwater) to destroy chemical contaminants in place. It can be used to remediate a variety of organic compounds, including some that are resistant to natural degradation
-

Safety and controversies

In April, 2007, the water supply of Spencer, Massachusetts became contaminated with excess sodium hydroxide (lye) when its treatment equipment malfunctioned.

Many municipalities have moved from free chlorine to chloramine as a disinfection agent. However, chloramine in some water systems, appears to be a corrosive agent. Chloramine can dissolve the "protective" film inside older service line, with the leaching of lead into residential spigots. This can result in harmful exposure to lead, with elevated blood levels of lead the outcome. Lead is a known neurotoxin.^[15]



Drinking water pollution detector Rainbow trout (*Oncorhynchus mykiss*) are being used in water purification plants to detect acute water pollution

Demineralized water

Distillation removes all minerals from water, and the membrane methods of reverse osmosis and nanofiltration remove most to all minerals. This results in demineralized water which is not considered ideal drinking water. The World Health Organization has investigated the health effects of demineralized water since 1980.^[16] Experiments in humans found that demineralized water increased diuresis and the elimination of electrolytes, with decreased blood serum potassium concentration. Magnesium, calcium, and other minerals in water can help to protect against nutritional deficiency. Demineralized water may also increase the risk from toxic metals because it more readily leaches materials from piping like lead and cadmium, which is prevented by dissolved minerals such as calcium and magnesium. Low-mineral water has been implicated in specific cases of lead poisoning in infants, when lead from pipes leached at especially high rates into the water. Recommendations for magnesium have been put at a minimum of 10 mg/L with 20–30 mg/L optimum; for calcium a 20 mg/L minimum and a 40–80 mg/L optimum, and a total water hardness (adding magnesium and calcium) of 2 to 4 mmol/L. At water hardness above 5 mmol/L, higher incidence of gallstones, kidney stones, urinary stones, arthrosis, and arthropathies have been observed.^[17] Additionally, desalination processes can increase the risk of bacterial contamination.

Manufacturers of home water distillers claim the opposite—that minerals in water are the cause of many diseases, and that most beneficial minerals come from food, not water.^{[18][19]} They quote the American Medical Association as saying "The body's need for minerals is largely met through foods, not drinking water." The WHO report agrees that "drinking water, with some rare exceptions, is not the major source of essential elements for humans" and is "not the major source of our calcium and magnesium intake", yet states that demineralized water is harmful anyway. "Additional evidence comes from animal experiments and clinical observations in several countries. Animals given zinc or magnesium dosed in their drinking water had a significantly higher concentration of these elements in the serum than animals given the same elements in much higher amounts with food and provided with low-mineral water to drink."

References

- [1] Chen, Jimmy, and Regli, Stig. (2002). "Disinfection Practices and Pathogen Inactivation in ICR Surface Water Plants." *Information Collection Rule Data Analysis*. Denver: American Water Works Association. McGuire, Michael J., McLain, Jennifer L. and Obolensky, Alexa, eds. pp. 376-378. ISBN 1-58321-273-6
- [2] Aeration and Gas Stripping (<http://ocw.tudelft.nl/fileadmin/ocw/courses/DrinkingWaterTreatment1/res00071/embedded/!4165726174696f6e20616e642047617320537472697070696e6732303037.pdf>), Accessed June 4, 2012.
- [3] CO2 Degasifiers/Drinking Water Corrosion Control (<http://www.lantecp.com/technical/CO2degasifierswithLANPAC.pdf>), Accessed June 4, 2012.
- [4] Degassing Towers (<http://www.forbesgroup.co.uk/environmental-technologies/degassing-towers-2/>), Accessed June 4, 2012.
- [5] American Water Works Association RTW corrosivity index calculator (<http://www.awwa.org/Resources/RTWCorrosivityCalc.cfm?navItemNumber=1576>), Accessed June 4, 2012.
- [6] Edzwald, James K., ed. (2011). *Water Quality and Treatment*. 6th Edition. New York: McGraw-Hill. ISBN 978-0-07-163011-5
- [7] Crittenden, John C., et al., eds. (2005). *Water Treatment: Principles and Design*. 2nd Edition. Hoboken, NJ: Wiley. ISBN 0-471-11018-3
- [8] Kawamura, Susumu. (2000). *Integrated Design and Operation of Water Treatment Facilities*. 2nd Edition. New York: Wiley. pp. 74-5, 104. ISBN 0-471-35093-1
- [9] United States Environmental Protection Agency (EPA)(1990). Cincinnati, OH. "Technologies for Upgrading Existing or Designing New Drinking Water Treatment Facilities." (<http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=300048WU.txt>) Document no. EPA/625/4-89/023.
- [10] Neemann, Jeff; Hulsey, Robert; Rexing, David; Wert, Eric (2004). "Controlling Bromate Formation During Ozonation with Chlorine and Ammonia." *Journal American Water Works Association*. 96:2 (February) 26-29.
- [11] Hobbins M. (2003). The SODIS Health Impact Study, Ph.D. Thesis, Swiss Tropical Institute Basel
- [12] B. Dawney and J.M. Pearce "Optimizing Solar Water Disinfection (SODIS) Method by Decreasing Turbidity with NaCl", *The Journal of Water, Sanitation, and Hygiene for Development* 2(2) pp. 87-94 (2012). open access (http://mtu.academia.edu/JoshuaPearce/Papers/1590504/Optimizing_the_solar_water_disinfection_SODIS_method_by_decreasing_turbidity_with_NaCl)
- [13] OA Guide to Water Purification, The Backpacker's Field Manual, by Rick Curtis, first edition published by Random House March, 1998 (<http://www.princeton.edu/~oa/manual/water.shtml>)
- [14] Hydrates for Gypsum Stack Water Purification (<http://www.aiche-cf.org/Clearwater/2009/Paper1/9.1.5.pdf>)
- [15] "Miranda, Kim, Hull, et.a. "Changes in Blood Lead Levels Associated with Use of Chloramines in Water Treatment Systems" 03/13/2007. Environmental Health Perspectives.
- [16] Health risks from drinking demineralised water (http://www.who.int/water_sanitation_health/dwq/nutdemineralized.pdf). (PDF) . Rolling revision of the WHO Guidelines for drinking-water quality. World Health Organization, Geneva, 2004
- [17] Kozisek F. (2004). Health risks from drinking demineralised water (https://www.who.int/entity/water_sanitation_health/dwq/nutrientschap12.pdf). WHO.
- [18] Water Distillers – Water Distillation – Myths, Facts, etc (<http://www.naturalsolutions1.com/ecodist2.htm>). Naturalsolutions1.com. Retrieved on 2011-02-18.
- [19] Minerals in Drinking Water (<http://www.aquatechnology.net/frame4751007.html>). Aquatechnology.net. Retrieved on 2011-02-18.

Further reading

- *Standard Methods for the Examination of Water & Wastewater* (<http://www.standardmethods.org/>). American Public Health Association. ISBN 0-87553-047-8.
- Masters, Gilbert M. *Introduction to Environmental Engineering*. 2nd ed. Upper Saddle River, NJ: Prentice Hall, 1998.
- US EPA. "Ground Water and Drinking Water." (<http://www.epa.gov/safewater/>) Overview of drinking water topics and detailed information on US regulatory program. (Updated 2012-03-07.)

External links

- EPA. "Water On Tap: What You Need To Know." (http://water.epa.gov/drink/guide/upload/book_waterontap_full.pdf) - Consumer Guide to Drinking Water in the US
- CDC Emergency Disinfection of Drinking Water- Camping, Hiking and Travel (http://www.cdc.gov/healthywater/drinking/travel/emergency_disinfection.html)
- Code of Federal Regulations, Title 40, Part 141 (http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=39f1366979712eca0ac4e22f5f52b290&tpl=/ecfrbrowse/Title40/40cfr141_main_02.tpl) – U.S. National Primary Drinking Water Regulations
- Code of Federal Regulations, Title 21, Part 129 (<http://watertank.net/why-we-use-plastic.html>) – U.S. Food and Drug Administration regulations on bottled water

Boiling

Boiling is the rapid vaporization of a liquid, which occurs when a liquid is heated to its boiling point, the temperature at which the vapor pressure of the liquid is equal to the pressure exerted on the liquid by the surrounding environmental pressure.

Types

Nucleate

Nucleate boiling is characterized by the growth of bubbles or pops on a heated surface, which rise from discrete points on a surface, whose temperature is only slightly above the liquid's. In general, the number of nucleation sites are increased by an increasing surface temperature.

An irregular surface of the boiling vessel (i.e. increased surface roughness) or additives to the fluid (i.e. surfactants and/or nanoparticles^[1]) can create additional nucleation sites,^[2] while an exceptionally smooth surface, such as plastic, lends itself to superheating. Under these conditions, a heated liquid may show boiling delay and the temperature may go somewhat above the boiling point without boiling.



Nucleate boiling of water over a kitchen stove burner

Critical heat flux

As the boiling surface is heated above a critical temperature, a film of vapor forms on the surface. Since this vapor film is much less capable of carrying heat away from the surface, the temperature rises very rapidly beyond this point into the transition boiling regime. The point at which this occurs is dependent on the characteristics of boiling fluid and the heating surface in question.

Transition

Transition boiling may be defined as the unstable boiling, which occurs at surface temperatures between the maximum attainable in nucleate and the minimum attainable in film boiling.

The formation of bubbles in a heated liquid is a complex physical process which often involves cavitation and acoustic effects, such as the broad-spectrum hiss one hears in a kettle not yet heated to the point where bubbles boil to the surface.

Film

If a surface heating the liquid is significantly hotter than the liquid then film boiling will occur, where a thin layer of vapor, which has low thermal conductivity, insulates the surface. This condition of a vapor film insulating the surface from the liquid characterizes *film boiling*.

In distillation, boiling is used in separating mixtures. This is possible because the vapor rising from a boiling fluid generally has a ratio of components different from that in the liquid.

Uses

For making water potable

As a method of disinfecting water, bringing it to its boiling point at 100 °C (212 °F), is the oldest and most effective way since it does not affect the taste, is effective despite contaminants or particles present in it, and is a single step process which eliminates most microbes causing intestine related diseases. In places having a proper water purification system, it is only advocated as an emergency treatment method or for obtaining potable water in the wilderness or in rural areas, but it cannot remove chemical toxins or impurities.^[3]

The elimination of micro-organisms by boiling follows first-order kinetics—at high temperatures it is achieved in less time and at lower, in more time. The heat sensitivity of micro-organisms varies, at 70 °C (158 °F), *Giardia* species (causes Giardiasis) can take ten minutes for complete inactivation, most intestine affecting microbes and *E. coli* (gastroenteritis) take less than a minute; at boiling point, *Vibrio cholerae* (cholera) takes ten seconds and hepatitis A virus (causes the symptom of jaundice), one minute. Boiling does not ensure the elimination of all micro-organisms, the bacterial spores *Clostridium* can survive at 100 °C (212 °F) but are not water-borne or intestine affecting. Thus for human health, complete sterilization of water is not required.

The traditional advice of boiling water for ten minutes is mainly for additional safety, since microbes start getting eliminated at temperatures greater than 60 °C (140 °F) and bringing it to its boiling point is also a useful indication that can be seen without the help of a thermometer, and by this time, the water is disinfected. Though the boiling point decreases with increasing altitude, it is not enough to affect the disinfecting process.

In cooking

Boiling is the method of cooking food in boiling water, or other water-based liquids such as stock or milk. Simmering is gentle boiling, while in poaching the cooking liquid moves but scarcely bubbles.

The boiling point of water is typically considered to be 100 °C or 212 °F. Pressure and a change in composition of the liquid may alter the boiling point of the liquid. For this reason, high elevation cooking generally takes longer since boiling point is a function of atmospheric pressure. In Denver, Colorado, USA, which is at an elevation of about one mile, water boils at approximately 95 °C or 203 °F. Depending on the type of food and the elevation, the boiling water may not be hot enough to cook the food properly. Similarly, increasing the pressure as in a pressure cooker raises the temperature of the contents above the open air boiling point.

Adding a water soluble substance, such as salt or sugar also increases the boiling point. This is called boiling-point elevation. At palatable concentrations of salt, the effect is very small, and the boiling point elevation is difficult to notice. However, while making thick sugar syrup, such as for Gulab Jamun, one will notice boiling point elevation. Due to variations in composition and pressure, the boiling point of water is almost never exactly 100 °C, but rather close enough for cooking.

Bringing water to a boil is generally done by applying maximal heat, then shutting off when the water has come to a boil, which is known as bang–bang control. Keeping water at or below a boil requires more careful control of temperature, particularly by using feedback.

Foods suitable for boiling include vegetables, starchy foods such as rice, noodles and potatoes, eggs, meats, sauces, stocks and soups.

Boiling has several advantages. It is safe and simple, and it is appropriate for large-scale cookery. Older, tougher, cheaper cuts of meat and poultry can be made digestible. Nutritious, well flavored stock is produced. Also, maximum color and nutritive value is retained when cooking green vegetables, provided boiling time is kept to the minimum.

On the other hand, there are several disadvantages. There is a loss of soluble vitamins from foods to the water (if the water is discarded). Boiling can also be a slow method of cooking food.

Boiling can be done in several ways: The food can be placed into already rapidly boiling water and left to cook, the heat can be turned down and the food can be simmered; or the food can also be placed into the pot, and cold water may be added to the pot. This may then be boiled until the food is satisfactory.

Water on the outside of a pot, i.e. a wet pot, increases the time it takes the pot of water to boil. The pot will heat at a normal rate once all excess water on the outside of the pot evaporates.

Boiling is also often used to remove salt from certain foodstuffs, such as bacon, if a less saline product is required.



Boiling milk

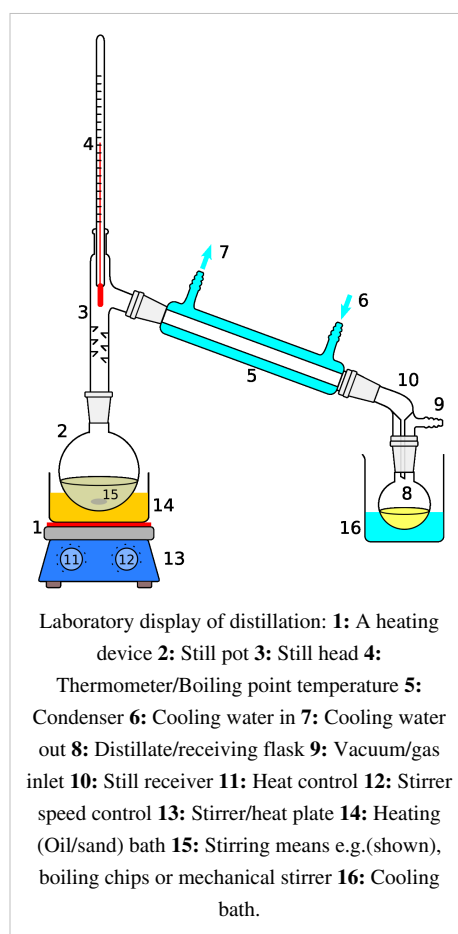
References

- [1] Taylor, R.A., Phelan, P.E., *Pool boiling of nanofluids: Comprehensive review of existing data and limited new data* (<http://www.sciencedirect.com/science/article/pii/S0017931009004153>), *International Journal of Heat and Mass Transfer*, Volume 52, Issues 23–24, November 2009, Pages 5339–5347
- [2] Robert A Taylor, Patrick E Phelan, Todd Otanicar, Ronald J Adrian, Ravi S Prasher, *Vapor generation in a nanoparticle liquid suspension using a focused, continuous laser* (http://digitalcommons.lmu.edu/cgi/viewcontent.cgi?article=1017&context=mech_fac), *Applied Physics Letters*, Volume:95 , Issue: 16, 2009
- [3] OA Guide to Water Purification, *The Backpacker's Field Manual*, by Rick Curtis, first edition published by Random House March, 1998 (<http://www.princeton.edu/~oa/manual/water.shtml>)

Distillation

Distillation is a method of separating mixtures based on differences in volatility of components in a boiling liquid mixture. Distillation is a unit operation, or a physical separation process, and not a chemical reaction.

Commercially, distillation has a number of applications. It is used to separate crude oil into more fractions for specific uses such as transport, power generation and heating. Water is distilled to remove impurities, such as salt from seawater. Air is distilled to separate its components—notably oxygen, nitrogen, and argon—for industrial use. Liquid chemicals for diverse uses are often distilled after synthesis to remove impurities and unreacted starting materials. Distillation of fermented solutions has been used since ancient times to produce distilled beverages with a higher alcohol content. The premises where distillation is carried out, especially distillation of alcohol, are known as a **distillery**. A **still** is the apparatus used for distillation.



History

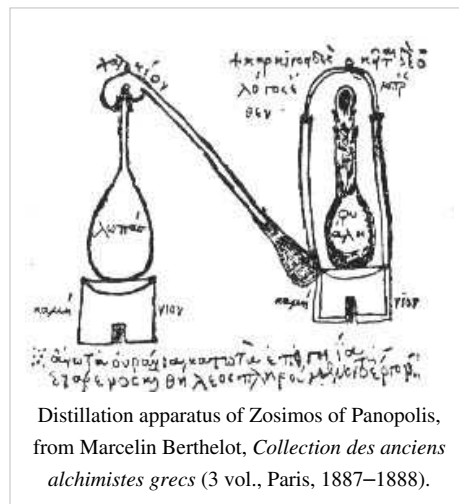
The first evidence of distillation comes from Greek alchemists working in Alexandria in the 1st century AD. Distilled water has been known since at least c. 200, when Alexander of Aphrodisias described the process. Distillation in China could have begun during the Eastern Han Dynasty (1st–2nd centuries), but archaeological evidence indicates that actual distillation of beverages began in the Jin and Southern Song dynasties. A still was found in an archaeological site in Qinglong, Hebei province dating to the 12th century. Distilled beverages were more common during the Yuan dynasty. Arabs learned the process from the Alexandrians and used it extensively in their chemical experiments^[citation needed].

Clear evidence of the distillation of alcohol comes from the School of Salerno in the 12th century. Fractional distillation was developed by Tadeo Alderotti in the 13th century.

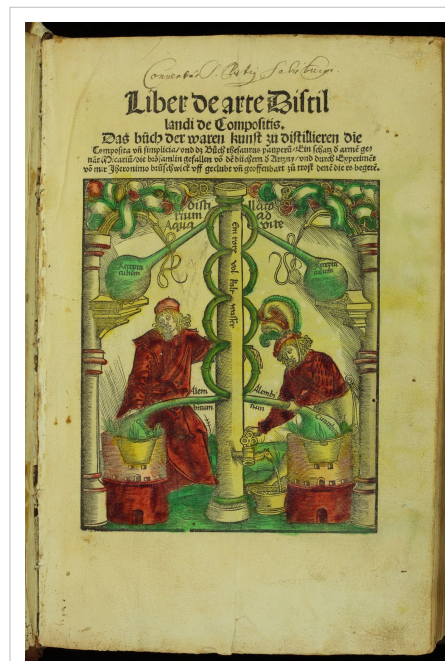
In 1500, German alchemist Hieronymus Braunschweig published *Liber de arte destillandi* (The Book of the Art of Distillation)^[1] the first book solely dedicated to the subject of distillation, followed in 1512 by a much expanded version. In 1651, John French published *The Art of Distillation*^[2] the first major English compendium of practice, though it has been claimed^[3] that much of it derives from Braunschweig's work. This includes diagrams with people in them showing the industrial rather than bench scale of the operation.

As alchemy evolved into the science of chemistry, vessels called retorts became used for distillations. Both alembics and retorts are forms of glassware with long necks pointing to the side at a downward angle which acted as air-cooled condensers to condense the distillate and let it drip downward for collection. Later, copper alembics were invented. Riveted joints were often kept tight by using various mixtures, for instance a dough made of rye flour.^[5] These alembics often featured a cooling system around the beak, using cold water for instance, which made the condensation of alcohol more efficient. These were called pot stills. Today, the retorts and pot stills have been largely supplanted by more efficient distillation methods in most industrial processes. However, the pot still is still widely used for the elaboration of some fine alcohols such as cognac, Scotch whisky, tequila and some vodkas. Pot stills made of various materials (wood, clay, stainless steel) are also used by bootleggers in various countries. Small pot stills are also sold for the domestic production^[6] of flower water or essential oils.

Early forms of distillation were batch processes using one vaporization and one condensation. Purity was improved by further distillation of the condensate. Greater volumes were processed by simply repeating the distillation. Chemists were reported to carry out as many as 500 to 600 distillations in order to obtain a pure compound.^[7]



Distillation apparatus of Zosimos of Panopolis, from Marcellin Berthelot, *Collection des anciens alchimistes grecs* (3 vol., Paris, 1887–1888).



Hieronymus Brunschwig's *Liber de arte Distillandi de Compositis* (Strassburg, 1512)
Chemical Heritage Foundation^[4]

In the early 19th century the basics of modern techniques including pre-heating and reflux were developed, particularly by the French, then in 1830 a British Patent was issued to Aeneas Coffey for a whiskey distillation column,^[8] which worked continuously and may be regarded as the archetype of modern petrochemical units. In 1877, Ernest Solvay was granted a U.S. Patent for a tray column for ammonia distillation^[9] and the same and subsequent years saw developments of this theme for oil and spirits.

With the emergence of chemical engineering as a discipline at the end of the 19th century, scientific rather than empirical methods could be applied. The developing petroleum industry in the early 20th century provided the impetus for the development of accurate design methods such as the McCabe-Thiele method and the Fenske equation. The availability of powerful computers has also allowed direct computer simulation of distillation columns.

Applications of distillation

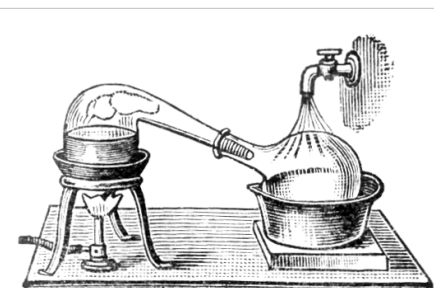
The application of distillation can roughly be divided in four groups: laboratory scale, industrial distillation, distillation of herbs for perfumery and medicinals (herbal distillate), and food processing. The latter two are distinctively different from the former two in that in the processing of beverages, the distillation is not used as a true purification method but more to transfer all volatiles from the source materials to the distillate.

The main difference between laboratory scale distillation and industrial distillation is that laboratory scale distillation is often performed batch-wise, whereas industrial distillation often occurs continuously. In batch distillation, the composition of the source material, the vapors of the distilling compounds and the distillate change during the distillation. In batch distillation, a still is charged (supplied) with a batch of feed mixture, which is then separated into its component fractions which are collected sequentially from most volatile to less volatile, with the bottoms (remaining least or non-volatile fraction) removed at the end. The still can then be recharged and the process repeated.

In continuous distillation, the source materials, vapors, and distillate are kept at a constant composition by carefully replenishing the source material and removing fractions from both vapor and liquid in the system. This results in a better control of the separation process.



A retort



Distillation



Old Ukrainian vodka still



Simple liqueur distillation in East Timor

Idealized distillation model

The boiling point of a liquid is the temperature at which the vapor pressure of the liquid equals the pressure around the liquid, enabling bubbles to form without being crushed. A special case is the normal boiling point, where the vapor pressure of the liquid equals the ambient atmospheric pressure.

It is a common misconception that in a liquid mixture at a given pressure, each component boils at the boiling point corresponding to the given pressure and the vapors of each component will collect separately and purely. This, however, does not occur even in an idealized system. Idealized models of distillation are essentially governed by Raoult's law and Dalton's law, and assume that vapor-liquid equilibria are attained.

Raoult's law states that the vapor pressure of a solution is dependent on 1) the vapor pressure of each chemical component in the solution and 2) the fraction of solution each component makes up aka the mole fraction. This law applies to ideal solutions, or solutions that have different components but whose molecular interactions are the same as or very similar to pure solutions.

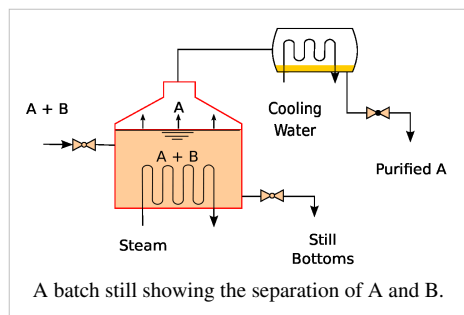
Dalton's law states that the total vapor pressure is the sum of the vapor pressures of each individual component in the mixture. When a multi-component liquid is heated, the vapor pressure of each component will rise, thus causing the total vapor pressure to rise. When the total vapor pressure reaches the pressure surrounding the liquid, boiling occurs and liquid turns to gas throughout the bulk of the liquid. Note that a mixture with a given composition has one boiling point at a given pressure, when the components are mutually soluble.

An implication of one boiling point is that lighter components never cleanly "boil first". At boiling point, all volatile components boil, but for a component, its percentage in the vapor is the same as its percentage of the total vapor pressure. Lighter components have a higher partial pressure and thus are concentrated in the vapor, but heavier volatile components also have a (smaller) partial pressure and necessarily evaporate also, albeit being less concentrated in the vapor. Indeed, batch distillation and fractionation succeed by varying the composition of the mixture. In batch distillation, the batch evaporates, which changes its composition; in fractionation, liquid higher in the fractionation column contains more lights and boils at lower temperatures.

The idealized model is accurate in the case of chemically similar liquids, such as benzene and toluene. In other cases, severe deviations from Raoult's law and Dalton's law are observed, most famously in the mixture of ethanol and water. These compounds, when heated together, form an azeotrope, which is a composition with a boiling point higher or lower than the boiling point of each separate liquid. Virtually all liquids, when mixed and heated, will display azeotropic behaviour. Although there are computational methods that can be used to estimate the behavior of a mixture of arbitrary components, the only way to obtain accurate vapor-liquid equilibrium data is by measurement.

It is not possible to *completely* purify a mixture of components by distillation, as this would require each component in the mixture to have a zero partial pressure. If ultra-pure products are the goal, then further chemical separation must be applied. When a binary mixture is evaporated and the other component, e.g. a salt, has zero partial pressure for practical purposes, the process is simpler and is called evaporation in engineering.

Batch distillation



Heating an ideal mixture of two volatile substances A and B (with A having the higher volatility, or lower boiling point) in a batch distillation setup (such as in an apparatus depicted in the opening figure) until the mixture is boiling results in a vapor above the liquid which contains a mixture of A and B. The ratio between A and B in the vapor will be different from the ratio in the liquid: the ratio in the liquid will be determined by how the original mixture was prepared,

while the ratio in the vapor will be enriched in the more volatile compound, A (due to Raoult's Law, see above). The vapor goes through the condenser and is removed from the system. This in turn means that the ratio of compounds in the remaining liquid is now different from the initial ratio (i.e. more enriched in B than the starting liquid).

The result is that the ratio in the liquid mixture is changing, becoming richer in component B. This causes the boiling point of the mixture to rise, which in turn results in a rise in the temperature in the vapor, which results in a changing ratio of A : B in the gas phase (as distillation continues, there is an increasing proportion of B in the gas phase). This results in a slowly changing ratio A : B in the distillate.

If the difference in vapor pressure between the two components A and B is large (generally expressed as the difference in boiling points), the mixture in the beginning of the distillation is highly enriched in component A, and when component A has distilled off, the boiling liquid is enriched in component B.

Continuous distillation

Continuous distillation is an ongoing distillation in which a liquid mixture is continuously (without interruption) fed into the process and separated fractions are removed continuously as output streams as time passes during the operation. Continuous distillation produces at least two output fractions, including at least one volatile distillate fraction, which has boiled and been separately captured as a vapor condensed to a liquid. There is always a bottoms (or residue) fraction, which is the least volatile residue that has not been separately captured as a condensed vapor.

Continuous distillation differs from batch distillation in the respect that concentrations should not change over time. Continuous distillation can be run at a steady state for an arbitrary amount of time. For any source material of specific composition, the main variables that affect the purity of products in continuous distillation are the reflux ratio and the number of theoretical equilibrium stages (practically, the number of trays or the height of packing). Reflux is a flow from the condenser back to the column, which generates a recycle that allows a better separation with a given number of trays. Equilibrium stages are ideal steps where compositions achieve vapor-liquid equilibrium, repeating the separation process and allowing better separation given a reflux ratio. A column with a high reflux ratio may have fewer stages, but it refluxes a large amount of liquid, giving a wide column with a large holdup. Conversely, a column with a low reflux ratio must have a large number of stages, thus requiring a taller column.

General improvements

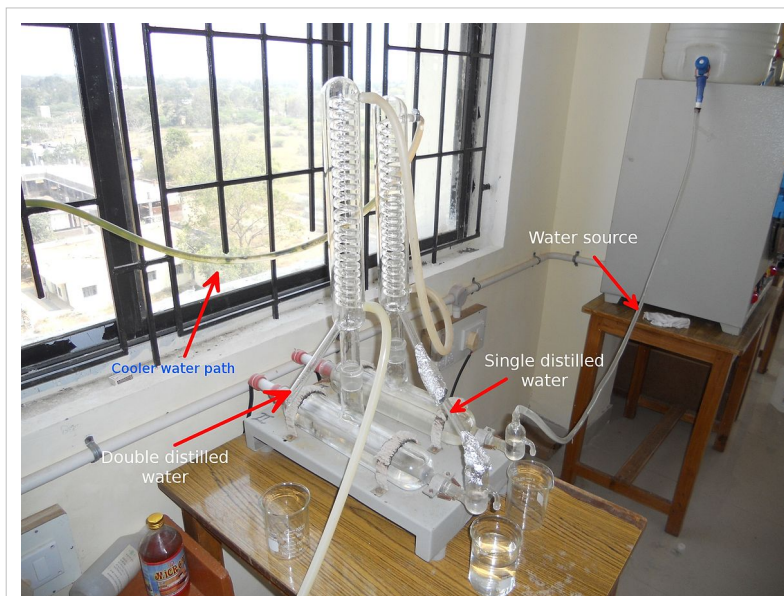
Both batch and continuous distillations can be improved by making use of a fractionating column on top of the distillation flask. The column improves separation by providing a larger surface area for the vapor and condensate to come into contact. This helps it remain at equilibrium for as long as possible. The column can even consist of small subsystems ('trays' or 'dishes') which all contain an enriched, boiling liquid mixture, all with their own vapor-liquid equilibrium.

There are differences between laboratory-scale and industrial-scale fractionating columns, but the principles are the same. Examples of laboratory-scale fractionating columns (in increasing efficiency) include:

- Air condenser
 - Vigreux column (usually laboratory scale only)
 - Packed column (packed with glass beads, metal pieces, or other chemically inert material)
 - Spinning band distillation system.
-

Laboratory scale distillation

Laboratory scale distillations are almost exclusively run as batch distillations. The device used in distillation, sometimes referred to as a *still*, consists at a minimum of a **reboiler** or *pot* in which the source material is heated, a **condenser** in which the heated vapour is cooled back to the liquid state, and a **receiver** in which the concentrated or purified liquid, called the **distillate**, is collected. Several laboratory scale techniques for distillation exist (see also distillation types).



Typical laboratory distillation unit

Simple distillation

In **simple distillation**, the vapor is immediately channeled into a condenser. Consequently, the distillate is not pure but rather its composition is identical to the composition of the vapors at the given temperature and pressure. That concentration follows Raoult's law.

As a result, simple distillation is effective only when the liquid boiling points differ greatly (rule of thumb is $25\text{ }^{\circ}\text{C}$)^[10] or when separating liquids from non-volatile solids or oils. For these cases, the vapor pressures of the components are usually sufficiently different that the distillate may be sufficiently pure for its intended purpose.

Fractional distillation

For many cases, the boiling points of the components in the mixture will be sufficiently close that Raoult's law must be taken into consideration. Therefore, **fractional distillation** must be used in order to separate the components by repeated vaporization-condensation cycles within a packed fractionating column. This separation, by successive distillations, is also referred to as **rectification**.

As the solution to be purified is heated, its vapors rise to the fractionating column. As it rises, it cools, condensing on the condenser walls and the surfaces of the packing material. Here, the condensate continues to be heated by the rising hot vapors; it vaporizes once more. However, the composition of the fresh vapors are determined once again by Raoult's law. Each vaporization-condensation cycle (called a *theoretical plate*) will yield a purer solution of the more volatile component.^[11] In reality, each cycle at a given temperature does not occur at exactly the same position in the fractionating column; *theoretical plate* is thus a concept rather than an accurate description.

More theoretical plates lead to better separations. A spinning band distillation system uses a spinning band of Teflon or metal to force the rising vapors into close contact with the descending condensate, increasing the number of theoretical plates.^[12]

Steam distillation

Like vacuum distillation, **steam distillation** is a method for distilling compounds which are heat-sensitive. The temperature of the steam is easier to control than the surface of a heating element, and allows a high rate of heat transfer without heating at a very high temperature. This process involves bubbling steam through a heated mixture of the raw material. By Raoult's law, some of the target compound will vaporize (in accordance with its partial pressure). The vapor mixture is cooled and condensed, usually yielding a layer of oil and a layer of water.

Steam distillation of various aromatic herbs and flowers can result in two products; an essential oil as well as a watery herbal distillate. The essential oils are often used in perfumery and aromatherapy while the watery distillates have many applications in aromatherapy, food processing and skin care.



Dimethyl sulfoxide usually boils at 189 °C.
Under a vacuum, it distills off into the receiver at only 70 °C.

Vacuum distillation

Some compounds have very high boiling points. To boil such compounds, it is often better to lower the pressure at which such compounds are boiled instead of increasing the temperature. Once the pressure is lowered to the vapor pressure of the compound (at the given temperature), boiling and the rest of the distillation process can commence. This technique is referred to as **vacuum distillation** and it is commonly found in the laboratory in the form of the rotary evaporator.

This technique is also very useful for compounds which boil beyond their decomposition temperature at atmospheric pressure and which would therefore be decomposed by any attempt to boil them under atmospheric pressure.

Molecular distillation is vacuum distillation below the pressure of 0.01 torr.^[13] 0.01 torr is one order of magnitude above high vacuum, where fluids are in the free molecular flow regime, i.e. the mean free path of molecules is comparable to the size of the equipment. The

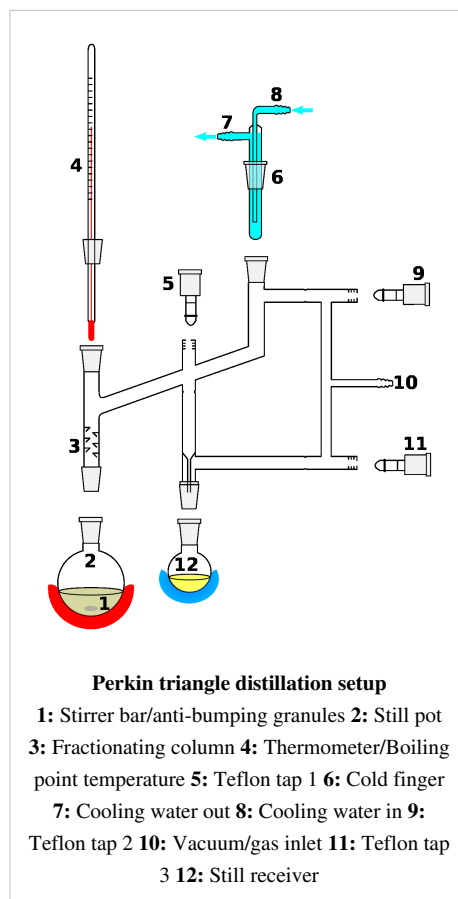
gaseous phase no longer exerts significant pressure on the substance to be evaporated, and consequently, rate of evaporation no longer depends on pressure. That is, because the continuum assumptions of fluid dynamics no longer apply, mass transport is governed by molecular dynamics rather than fluid dynamics. Thus, a short path between the hot surface and the cold surface is necessary, typically by suspending a hot plate covered with a film of feed next to a cold plate with a line of sight in between. Molecular distillation is used industrially for purification of oils.

Air-sensitive vacuum distillation

Some compounds have high boiling points as well as being air sensitive. A simple vacuum distillation system as exemplified above can be used, whereby the vacuum is replaced with an inert gas after the distillation is complete. However, this is a less satisfactory system if one desires to collect fractions under a reduced pressure. To do this a

"cow" or "pig" adaptor can be added to the end of the condenser, or for better results or for very air sensitive compounds a Perkin triangle apparatus can be used.

The Perkin triangle, has means via a series of glass or Teflon taps to allows fractions to be isolated from the rest of the still, without the main body of the distillation being removed from either the vacuum or heat source, and thus can remain in a state of reflux. To do this, the sample is first isolated from the vacuum by means of the taps, the vacuum over the sample is then replaced with an inert gas (such as nitrogen or argon) and can then be stoppered and removed. A fresh collection vessel can then be added to the system, evacuated and linked back into the distillation system via the taps to collect a second fraction, and so on, until all fractions have been collected.

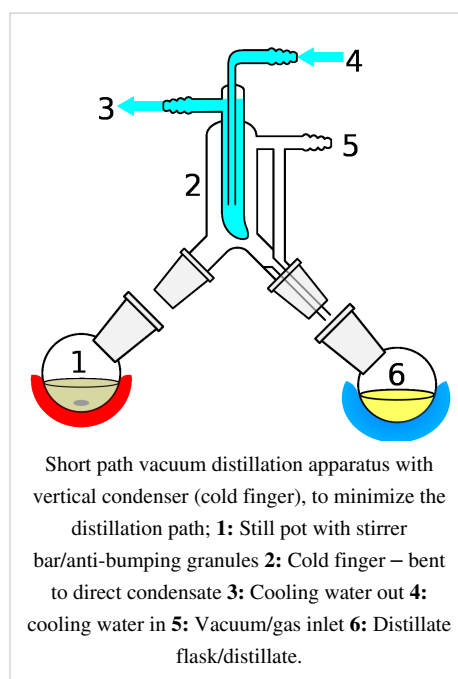


Short path distillation

Short path distillation is a distillation technique that involves the distillate travelling a short distance, often only a few centimeters, and is normally done at reduced pressure. A classic example would be a distillation involving the distillate travelling from one glass bulb to another, without the need for a condenser separating the two chambers. This technique is often used for compounds which are unstable at high temperatures or to purify small amounts of compound. The advantage is that the heating temperature can be considerably lower (at reduced pressure) than the boiling point of the liquid at standard pressure, and the distillate only has to travel a short distance before condensing. A short path ensures that little compound is lost on the sides of the apparatus. The Kugelrohr is a kind of a short path distillation apparatus which often contain multiple chambers to collect distillate fractions.

Zone distillation

Zone distillation is a distillation process in long container with partial melting of refined matter in moving liquid zone and condensation of vapor in the solid phase at condensate pulling in cold area. The process is worked in theory. When zone heater is moving from the top to the bottom of the container then solid condensate with irregular impurity distribution is forming. Then most pure part of the condensate may be extracted as product. The process may be iterated many



times by moving (without turnover) the received condensate to the bottom part of the container on the place of refined matter. The irregular impurity distribution in the condensate (that is efficiency of purification) increases with number of repetitions of the process. Zone distillation is a distillation analog of zone recrystallization. Impurity distribution in the condensate is described by known equations of zone recrystallization with various numbers of iteration of process – with replacement distribution efficient k of crystallization on separation factor α of distillation.

Other types

- The process of reactive distillation involves using the reaction vessel as the still. In this process, the product is usually significantly lower-boiling than its reactants. As the product is formed from the reactants, it is vaporized and removed from the reaction mixture. This technique is an example of a continuous vs. a batch process; advantages include less downtime to charge the reaction vessel with starting material, and less workup.
- Catalytic distillation is the process by which the reactants are catalyzed while being distilled to continuously separate the products from the reactants. This method is used to assist equilibrium reactions reach completion.
- Pervaporation is a method for the separation of mixtures of liquids by partial vaporization through a non-porous membrane.
- Extractive distillation is defined as distillation in the presence of a miscible, high boiling, relatively non-volatile component, the solvent, that forms no azeotrope with the other components in the mixture.
- Flash evaporation (or partial evaporation) is the partial vaporization that occurs when a saturated liquid stream undergoes a reduction in pressure by passing through a throttling valve or other throttling device. This process is one of the simplest unit operations, being equivalent to a distillation with only one equilibrium stage.
- Codistillation is distillation which is performed on mixtures in which the two compounds are not miscible.

The unit process of evaporation may also be called "distillation":

- In rotary evaporation a vacuum distillation apparatus is used to remove bulk solvents from a sample. Typically the vacuum is generated by a water aspirator or a membrane pump.
- In a kugelrohr a short path distillation apparatus is typically used (generally in combination with a (high) vacuum) to distill high boiling (> 300 °C) compounds. The apparatus consists of an oven in which the compound to be distilled is placed, a receiving portion which is outside of the oven, and a means of rotating the sample. The vacuum is normally generated by using a high vacuum pump.

Other uses:

- Dry distillation or destructive distillation, despite the name, is not truly distillation, but rather a chemical reaction known as pyrolysis in which solid substances are heated in an inert or reducing atmosphere and any volatile fractions, containing high-boiling liquids and products of pyrolysis, are collected. The destructive distillation of wood to give methanol is the root of its common name – *wood alcohol*.
- Freeze distillation is an analogous method of purification using freezing instead of evaporation. It is not truly distillation, but a recrystallization where the product is the mother liquor, and does not produce products equivalent to distillation. This process is used in the production of ice beer and ice wine to increase ethanol and sugar content, respectively. It is also used to produce applejack. Unlike distillation, freeze distillation concentrates poisonous congeners rather than removing them; As a result, many countries prohibit such applejack as a health measure. However, reducing methanol with the absorption of 4A molecular sieve is a practical method for production.^[14] Also, distillation by evaporation can separate these since they have different boiling points.

Azeotropic distillation

Interactions between the components of the solution create properties unique to the solution, as most processes entail nonideal mixtures, where Raoult's law does not hold. Such interactions can result in a constant-boiling **azeotrope** which behaves as if it were a pure compound (i.e., boils at a single temperature instead of a range). At an azeotrope, the solution contains the given component in the same proportion as the vapor, so that evaporation does not change the purity, and distillation does not effect separation. For example, ethyl alcohol and water form an azeotrope of 95.6% at 78.1 °C.

If the azeotrope is not considered sufficiently pure for use, there exist some techniques to break the azeotrope to give a pure distillate. This set of techniques are known as **azeotropic distillation**. Some techniques achieve this by "jumping" over the azeotropic composition (by adding an additional component to create a new azeotrope, or by varying the pressure). Others work by chemically or physically removing or sequestering the impurity. For example, to purify ethanol beyond 95%, a drying agent or a (desiccant such as potassium carbonate) can be added to convert the soluble water into insoluble water of crystallization. Molecular sieves are often used for this purpose as well.

Immiscible liquids, such as water and toluene, easily form azeotropes. Commonly, these azeotropes are referred to as a low boiling azeotrope because the boiling point of the azeotrope is lower than the boiling point of either pure component. The temperature and composition of the azeotrope is easily predicted from the vapor pressure of the pure components, without use of Raoult's law. The azeotrope is easily broken in a distillation set-up by using a liquid-liquid separator (a decanter) to separate the two liquid layers that are condensed overhead. Only one of the two liquid layers is refluxed to the distillation set-up.

High boiling azeotropes, such as a 20 weight percent mixture of hydrochloric acid in water, also exist. As implied by the name, the boiling point of the azeotrope is greater than the boiling point of either pure component.

To break azeotropic distillations and cross distillation boundaries, such as in the DeRosier Problem, it is necessary to increase the composition of the light key in the distillate.

Breaking an azeotrope with unidirectional pressure manipulation

The boiling points of components in an azeotrope overlap to form a band. By exposing an azeotrope to a vacuum or positive pressure, it's possible to bias the boiling point of one component away from the other by exploiting the differing vapour pressure curves of each; the curves may overlap at the azeotropic point, but are unlikely to be remain identical further along the pressure axis either side of the azeotropic point. When the bias is great enough, the two boiling points no longer overlap and so the azeotropic band disappears.

This method can remove the need to add other chemicals to a distillation, but it has two potential drawbacks.

Under negative pressure, power for a vacuum source is needed and the reduced boiling points of the distillates requires that the condenser be run cooler to prevent distillate vapours being lost to the vacuum source. Increased cooling demands will often require additional energy and possibly new equipment or a change of coolant.

Alternatively, if positive pressures are required, standard glassware can not be used, energy must be used for pressurization and there is a higher chance of side reactions occurring in the distillation, such as decomposition, due to the higher temperatures required to effect boiling.

A unidirectional distillation will rely on a pressure change in one direction, either positive or negative.

Pressure-swing distillation

Pressure-swing distillation is essentially the same as the unidirectional distillation used to break azeotropic mixtures, but here both positive and negative pressures may be employed.

This improves the selectivity of the distillation and allows a chemist to optimize distillation by avoiding extremes of pressure and temperature that waste energy. This is particularly important in commercial applications.

One example of the application of pressure-swing distillation is during the industrial purification of ethyl acetate after its catalytic synthesis from ethanol.

Industrial distillation

Large scale **industrial distillation** applications include both batch and continuous fractional, vacuum, azeotropic, extractive, and steam distillation. The most widely used industrial applications of continuous, steady-state fractional distillation are in petroleum refineries, petrochemical and chemical plants and natural gas processing plants.

Industrial distillation is typically performed in large, vertical cylindrical columns known as **distillation towers** or **distillation columns** with diameters ranging from about 65 centimeters to 16 meters and heights ranging from about 6 meters to 90 meters or more. When the process feed has a diverse composition, as in distilling crude oil, liquid outlets at intervals up the column allow for the withdrawal of different *fractions* or products having different boiling points or boiling ranges. The "lightest" products (those with the lowest boiling point) exit from the top of the columns and the "heaviest" products (those with the highest boiling point) exit from the bottom of the column and are often called the **bottoms**.



Typical industrial distillation towers

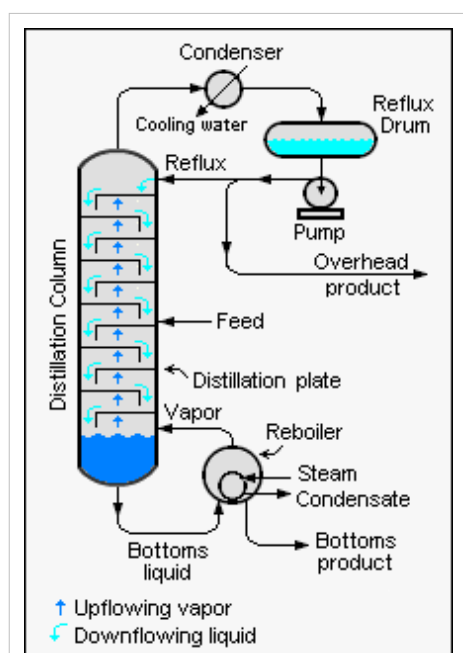


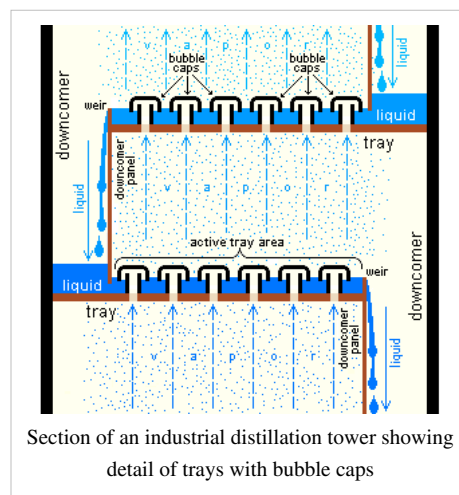
Diagram of a typical industrial distillation tower

Industrial towers use reflux to achieve a more complete separation of products. Reflux refers to the portion of the condensed overhead liquid product from a distillation or fractionation tower that is returned to the upper part of the tower as shown in the schematic diagram of a typical, large-scale industrial distillation tower. Inside the tower, the downflowing reflux liquid provides cooling and condensation of the upflowing vapors thereby increasing the efficiency of the distillation tower. The more reflux that is provided for a given number of theoretical plates, the better the tower's separation of lower boiling materials from higher boiling materials. Alternatively, the more reflux that is provided for a given desired separation, the fewer the number of theoretical plates required.

Such industrial fractionating towers are also used in cryogenic air separation, producing liquid oxygen, liquid nitrogen, and high purity argon. Distillation of chlorosilanes also enables the production of high-purity silicon for use as a semiconductor.

Design and operation of a distillation tower depends on the feed and desired products. Given a simple, binary component feed, analytical methods such as the McCabe-Thiele method or the Fenske equation can be used. For a multi-component feed, simulation models are used both for design and operation. Moreover, the efficiencies of the vapor-liquid contact devices (referred to as "plates" or "trays") used in distillation towers are typically lower than that of a theoretical 100% efficient equilibrium stage. Hence, a distillation tower needs more trays than the number of theoretical vapor-liquid equilibrium stages.

In modern industrial uses, a packing material is used in the column instead of trays when low pressure drops across the column are required. Other factors that favor packing are: vacuum systems, smaller diameter columns, corrosive systems, systems prone to foaming, systems requiring low liquid holdup and batch distillation. Conversely, factors that favor plate columns are: presence of solids in feed, high liquid rates, large column diameters, complex columns, columns with wide feed composition variation, columns with a chemical reaction, absorption columns, columns limited by foundation weight tolerance, low liquid rate, large turn-down ratio and those processes subject to process surges.



Large-scale, industrial vacuum distillation column^[15]

This packing material can either be random dumped packing (1–3" wide) such as Raschig rings or structured sheet metal. Liquids tend to wet the surface of the packing and the vapors pass across this wetted surface, where mass transfer takes place. Unlike conventional tray distillation in which every tray represents a separate point of vapor-liquid equilibrium, the vapor-liquid equilibrium curve in a packed column is continuous. However, when modeling packed columns, it is useful to compute a number of "theoretical stages" to denote the separation efficiency of the packed column with respect to more traditional trays. Differently shaped packings have different surface areas and void space between packings. Both of these factors affect packing performance.

Another factor in addition to the packing shape and surface area that affects the performance of random or structured packing is the liquid and vapor distribution entering the packed bed. The number of theoretical stages required to make a given separation is calculated using a specific vapor to liquid ratio. If the liquid and vapor are not evenly distributed across the superficial tower area as it enters the packed bed, the liquid to vapor ratio will not be correct in the packed bed and the required separation will not be achieved. The packing will appear to not be working properly. The height equivalent of a theoretical plate (HETP) will be greater than expected. The problem is not the packing itself but the mal-distribution of the fluids entering the

packed bed. Liquid mal-distribution is more frequently the problem than vapor. The design of the liquid distributors used to introduce the feed and reflux to a packed bed is critical to making the packing perform to its maximum efficiency. Methods of evaluating the effectiveness of a liquid distributor to evenly distribute the liquid entering a packed bed can be found in references.^[16] Considerable work has been done on this topic by Fractionation Research, Inc. (commonly known as FRI).

Multi-effect distillation

The goal of multi-effect distillation is to increase the energy efficiency of the process, for use in desalination, or in some cases one stage in the production of ultrapure water. The number of effects is inversely proportional to the kW·h/m³ of water recovered figure, and refers to the volume of water recovered per unit of energy compared with single-effect distillation. One effect is roughly 636 kW·h/m³.

- Multi-stage flash distillation Can achieve more than 20 effects with thermal energy input, as mentioned in the article.
- Vapor compression evaporation Commercial large-scale units can achieve around 72 effects with electrical energy input, according to manufacturers.

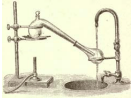
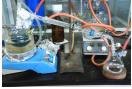
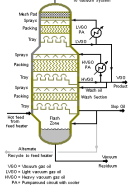


There are many other types of multi-effect distillation processes, including one referred to as simply multi-effect distillation (MED), in which multiple chambers, with intervening heat exchangers, are employed.

Distillation in food processing

Distilled beverages

Carbohydrate-containing plant materials are allowed to ferment, producing a dilute solution of ethanol in the process. Spirits such as whiskey and rum are prepared by distilling these dilute solutions of ethanol. Components other than ethanol, including water, esters, and other alcohols, are collected in the condensate, which account for the flavor of the beverage.

Gallery

	<p>Chemistry in its beginnings used retorts as laboratory equipment exclusively for distillation processes.</p>
	<p>A simple set-up to distill dry and oxygen-free toluene.</p>
	<p>Diagram of an industrial-scale vacuum distillation column as commonly used in oil refineries</p>
	<p>A rotary evaporator is able to distill solvents more quickly at lower temperatures through the use of a vacuum.</p>
	<p>Distillation using semi-microscale apparatus. The jointless design eliminates the need to fit pieces together. The pear-shaped flask allows the last drop of residue to be removed, compared with a similarly-sized round-bottom flask. The small holdup volume prevents losses. A pig is used to channel the various distillates into three receiving flasks. If necessary the distillation can be carried out under vacuum using the vacuum adapter at the pig.</p>

References

- [1] Magnum Opus Hermetic Sourceworks Series (<http://www.alchemywebsite.com/bookshop/mohs32.html>)
- [2] http://www.levity.com/alchemy/jfren_ar.html
- [3] *Industrial Engineering Chemistry* (1936) page 677
- [4] <http://www.chemheritage.org/>
- [5] Sealing Technique (http://www.copper-alembic.com/manufacturing/specs_sealing.php), accessed 16 November 2006.
- [6] Traditional Alembic Pot Still (<http://www.essentialoil.com/alembic5.html>), accessed 16 November 2006.
- [7] D. F. Othmer (1982) *Distillation – Some Steps in its Development*, in W. F. Furter (ed) *A Century of Chemical Engineering* ISBN 0-306-40895-3
- [8] A. Coffey British Patent 5974, 5 August 1830
- [9] Improvement in the Ammonia-Soda Manufacture
- [10] ST07 Separation of liquid–liquid mixtures (solutions) (http://www.iupac.org/didac/Didac_Eng/Didac05/Content/ST07.htm), DIDAC by IUPAC
- [11] Fractional Distillation (<http://wulfenite.fandm.edu/labtech/fractdistill.htm>). fandm.edu
- [12] Spinning Band Distillation (http://www.brinstrument.com/fractional-distillation/spinning_band_distillation.html). B/R Instrument Corporation (accessed 8 September 2006)
- [13] Vogel's 5th ed.
- [14] http://124.205.222.100/Jwk_spkx/EN/abstract/abstract15544.shtml
- [15] Energy Institute website page (<http://resources.schoolscience.co.uk/SPE/knowl/4/2/index.htm?vacuum.html>)
- [16] *Random Packing, Vapor and Liquid Distribution: Liquid and gas distribution in commercial packed towers*, Moore, F., Rukovena, F., Chemical Plants & Processing, Edition Europe, August 1987, p. 11-15

Further reading

- Allchin, F. R. (1979). "India: The Ancient Home of Distillation?". *Man* **14** (1): 55–63. doi: 10.2307/2801640 (<http://dx.doi.org/10.2307/2801640>). JSTOR 2801640 (<http://www.jstor.org/stable/2801640>).
- Forbes, R. J. (1970). *A Short History of the Art of Distillation from the Beginnings up to the Death of Cellier Blumenthal* (<http://books.google.com/?id=XeqWOkKYn28C&printsec=frontcover>). BRILL. ISBN 90-04-00617-6.
- Needham, Joseph (1980). *Science and Civilisation in China* (<http://books.google.com/books?id=JvLroG7r2MYC&printsec=frontcover>). Cambridge University Press. ISBN 0-521-08573-X.
- Geankoplis, Christie John (2003). *Transport Processes and Separation Process Principles* (4th ed.). Prentice Hall. ISBN 0-13-101367-X.

External links

- Alcohol distillation (<http://www.agcom.purdue.edu/AgCom/Pubs/AE/AE-117.html>)
- Case Study: Petroleum Distillation (http://www.members.tripod.com/historycheme/h_distill.html)
- "Binary Vapor-Liquid Equilibrium Data" (<http://www.cheric.org/research/kdb/hcvle/hcvle.php>) (searchable database). Chemical Engineering Research Information Center. Retrieved 5 May 2007.

Reverse osmosis

Reverse osmosis (RO) is a water purification technology that uses a semipermeable membrane. This membrane-technology is not properly a filtration method. In RO, an applied pressure is used to overcome osmotic pressure, a colligative property, that is driven by chemical potential, a thermodynamic parameter. RO can remove many types of molecules and ions from solutions and is used in both industrial processes and in producing potable water. The result is that the solute is retained on the pressurized side of the membrane and the pure solvent is allowed to pass to the other side. To be "selective," this membrane should not allow large molecules or ions through the pores (holes), but should allow smaller components of the solution (such as the solvent) to pass freely.

In the normal osmosis process, the solvent naturally moves from an area of low solute concentration (High Water Potential), through a membrane, to an area of high solute concentration (Low Water Potential). The movement of a pure solvent is driven to reduce the free energy of the system by equalizing solute concentrations on each side of a membrane, generating osmotic pressure. Applying an external pressure to reverse the natural flow of pure solvent, thus, is reverse osmosis. The process is similar to other membrane technology applications. However, there are key differences between reverse osmosis and filtration. The predominant removal mechanism in membrane filtration is straining, or size exclusion, so the process can theoretically achieve perfect exclusion of particles regardless of operational parameters such as influent pressure and concentration. Moreover, reverse osmosis involves a diffusive mechanism so that separation efficiency is dependent on solute concentration, pressure, and water flux rate.^[1] Reverse osmosis is most commonly known for its use in drinking water purification from seawater, removing the salt and other effluent materials from the water molecules.

History

The process of osmosis through semipermeable membranes was first observed in 1748 by Jean-Antoine Nollet. For the following 200 years, osmosis was only a phenomenon observed in the laboratory. In 1949, the University of California at Los Angeles (UCLA) first investigated desalination of seawater using semipermeable membranes. Researchers from both UCLA and the University of Florida successfully produced fresh water from seawater in the mid-1950s, but the flux was too low to be commercially viable until the discovery at UCLA by Sidney Loeb^[2] and Srinivasa Sourirajan at the National Research Council of Canada, Ottawa, of techniques for making asymmetric membranes characterized by an effectively thin "skin" layer supported atop a highly porous and much thicker substrate region of the membrane. By the end of 2001, about 15,200 desalination plants were in operation or in the planning stages worldwide.

Process

Osmosis is a natural process. When two liquids of different concentration are separated by a semipermeable membrane, the fluid has a tendency to move from low to high solute concentrations for chemical potential equilibrium.

Formally, reverse osmosis is the process of forcing a solvent from a region of high solute concentration through a semipermeable membrane to a region of low solute concentration by applying a pressure in excess of the osmotic pressure. The largest and most important application of reverse osmosis is the separation of pure water from seawater and brackish waters; seawater or brackish water is pressurized against one surface of the membrane, causing transport of salt-depleted water across the membrane and emergence of potable drinking water from the low-pressure side.

The membranes used for reverse osmosis have a dense layer in the polymer matrix—either the skin of an asymmetric membrane or an interfacially polymerized layer within a thin-film-composite membrane—where the separation occurs. In most cases, the membrane is designed to allow only water to pass through this dense layer, while preventing the passage of solutes (such as salt ions). This process requires that a high pressure be exerted on the high concentration side of the membrane, usually 2–17 bar (30–250 psi) for fresh and brackish water, and 40–82 bar (600–1200 psi) for seawater, which has around 27 bar (390 psi) natural osmotic pressure that must be overcome. This process is best known for its use in desalination (removing the salt and other minerals from sea water to get fresh water), but since the early 1970s it has also been used to purify fresh water for medical, industrial, and domestic applications.



A semipermeable membrane coil used in desalination

Fresh Water Applications

Drinking water purification

Around the world, household drinking water purification systems, including a reverse osmosis step, are commonly used for improving water for drinking and cooking.

Such systems typically include a number of steps:

- a sediment filter to trap particles, including rust and calcium carbonate
- optionally, a second sediment filter with smaller pores
- an activated carbon filter to trap organic chemicals and chlorine, which will attack and degrade thin film composite membrane reverse osmosis membranes
- a reverse osmosis (RO) filter, which is a thin film composite membrane (TFM or TFC)
- optionally, a second carbon filter to capture those chemicals not removed by the RO membrane
- optionally an ultra-violet lamp for sterilizing any microbes that may escape filtering by the reverse osmosis membrane



Marines from Combat Logistics Battalion 31 operate ROWPUs for relief efforts after the 2006 Southern Leyte mudslide

In some systems, the carbon prefilter is omitted, and cellulose triacetate membrane (CTA) is used. The CTA membrane is prone to rotting unless protected by chlorinated water, while the TFC membrane is prone to breaking down under the influence of chlorine. In CTA systems, a carbon postfilter is needed to remove chlorine from the final product, water.

Portable reverse osmosis (RO) water processors are sold for personal water purification in various locations. To work effectively, the water feeding to these units should be under some pressure (40 pounds per square inch (280 kPa) or greater is the norm).^[citation needed] Portable RO water processors can be used by people who live in rural areas without clean water, far away from the city's water pipes. Rural people filter river or ocean water themselves, as the device is easy to use (saline water may need special membranes). Some travelers on long boating, fishing, or island camping trips, or in countries where the local water supply is polluted or substandard, use RO water processors coupled with one or more UV sterilizers. RO systems are also now extensively used by marine aquarium enthusiasts. In the production of bottled mineral water, the water passes through an RO water processor to remove pollutants and microorganisms. In European countries, though, such processing of Natural Mineral Water (as defined by a European Directive^[3]) is not allowed under European law. In practice, a fraction of the living bacteria can and do pass through RO membranes through minor imperfections, or bypass the membrane entirely through tiny leaks in surrounding seals. Thus, complete RO systems may include additional water treatment stages that use ultraviolet light or ozone to prevent microbiological contamination.

Membrane pore sizes can vary from 0.1 nanometres (3.9×10^{-9} in) to 5,000 nanometres (0.00020 in) depending on filter type. "Particle filtration" removes particles of 1 micrometre (3.9×10^{-5} in) or larger. Microfiltration removes particles of 50 nm or larger. Ultrafiltration removes particles of roughly 3 nm or larger. "Nanofiltration" removes particles of 1 nm or larger. Reverse osmosis is in the final category of membrane filtration, "hyperfiltration", and removes particles larger than 0.1 nm.

In the United States military, Reverse Osmosis Water Purification Units are used on the battlefield and in training. Capacities range from 1,500 to 150,000 imperial gallons (6,800 to 681,900 l) per day, depending on the need. The most common of these are the 600 and 3,000 gallons per hour units; both are able to purify salt water and water contaminated with chemical, biological, radiological, and nuclear agents from the water. During 24-hour period, at normal operating parameters, one unit can produce 12,000 to 60,000 imperial gallons (55,000 to 270,000 l) of water, with a required 4-hour maintenance window to check systems, pumps, RO elements and the engine generator. A single ROWPU can sustain a force the size of a battalion, or roughly 1,000 to 6,000 servicemembers.^[citation needed]

Water and wastewater purification

Rain water collected from storm drains is purified with reverse osmosis water processors and used for landscape irrigation and industrial cooling in Los Angeles and other cities, as a solution to the problem of water shortages.

In industry, reverse osmosis removes minerals from boiler water at power plants. The water is distilled multiple times. It must be as pure as possible so that it does not leave deposits on the machinery or cause corrosion. The deposits inside or outside the boiler tubes may result in under-performance of the boiler, bringing down its efficiency and resulting in poor steam production, hence poor power production at turbine.

It is also used to clean effluent and brackish groundwater. The effluent in larger volumes (more than 500 cu. meter per day) should be treated in an effluent treatment plant first, and then the clear effluent is subjected to reverse osmosis system. Treatment cost is reduced significantly and membrane life of the RO system is increased.^[citation needed]

The process of reverse osmosis can be used for the production of deionized water.

RO process for water purification does not require thermal energy. Flow through RO system can be regulated by a high pressure pump. The recovery of purified water depends upon various factors including membrane sizes, membrane pore size, temperature, operating pressure and membrane surface area.

In 2002, Singapore announced that a process named NEWater would be a significant part of its future water plans. It involves using reverse osmosis to treat domestic wastewater before discharging the NEWater back into the reservoirs.

Food industry

In addition to desalination, reverse osmosis is a more economical operation for concentrating food liquids (such as fruit juices) than conventional heat-treatment processes. Research has been done on concentration of orange juice and tomato juice. Its advantages include a lower operating cost and the ability to avoid heat-treatment processes, which makes it suitable for heat-sensitive substances like the protein and enzymes found in most food products.

Reverse osmosis is extensively used in the dairy industry for the production of whey protein powders and for the concentration of milk to reduce shipping costs. In whey applications, the whey (liquid remaining after cheese manufacture) is concentrated with RO from 6% total solids to 10–20% total solids before UF (ultrafiltration) processing. The UF retentate can then be used to make various whey powders, including whey protein isolate used in bodybuilding formulations. Additionally, the UF permeate, which contains lactose, is concentrated by RO from 5% total solids to 18–22% total solids to reduce crystallization and drying costs of the lactose powder.

Although use of the process was once avoided in the wine industry, it is now widely understood and used. An estimated 60 reverse osmosis machines were in use in Bordeaux, France in 2002. Known users include many of the elite classed growths (Kramer) such as Château Léoville-Las Cases in Bordeaux.^[citation needed]

Maple syrup production

In 1946, some maple syrup producers started using reverse osmosis to remove water from sap before the sap is boiled down to syrup. The use of reverse osmosis allows approximately 75-90% of the water to be removed from the sap, reducing energy consumption and exposure of the syrup to high temperatures. Microbial contamination and degradation of the membranes has to be monitored.

Hydrogen production

For small-scale production of hydrogen, reverse osmosis is sometimes used to prevent formation of minerals on the surface of electrodes.

Reef aquariums

Many reef aquarium keepers use reverse osmosis systems for their artificial mixture of seawater. Ordinary tap water can often contain excessive chlorine, chloramines, copper, nitrates, nitrites, phosphates, silicates, or many other chemicals detrimental to the sensitive organisms in a reef environment. Contaminants such as nitrogen compounds and phosphates can lead to excessive, and unwanted, algae growth. An effective combination of both reverse osmosis and deionization (RO/DI) is the most popular among reef aquarium keepers, and is preferred above other water purification processes due to the low cost of ownership and minimal operating costs. Where chlorine and chloramines are found in the water, carbon filtration is needed before the membrane, as the common residential membrane used by reef keepers does not cope with these compounds.

Window cleaning

An increasingly popular method of cleaning windows is the so-called "water-fed pole" system. Instead of washing the windows with detergent in the conventional way, they are scrubbed with highly purified water, typically containing less than 10ppm dissolved solids, using a brush on the end of a long pole which is wielded from ground level. Reverse osmosis is commonly used to purify the water. This method is especially popular in the UK where health and safety regulations militate against the use of ladders, which may lead workers and even lawmakers to believe their use is subject to a *de-facto* ban.

Desalination

Areas that have either no or limited surface water or groundwater may choose to desalinate. Reverse osmosis is an increasingly common method of desalination, because of its relatively low energy consumption. In recent years energy consumption has dropped to around 3 kWh/m³, with the development of more efficient energy recovery devices and improved membrane materials. According to the International Desalination Association, for 2011, reverse osmosis was used in 66% of installed desalination capacity (44.5 of 67.4 Mm³/day), and nearly all new plants.^[4] Other plants mainly use thermal distillation methods: Multi-effect distillation and Multi-stage flash.

Sea water reverse osmosis (SWRO) is a reverse osmosis desalination membrane process that has been commercially used since the early 1970s. Its first practical use was demonstrated by Sidney Loeb from UCLA in Coalinga, California and Srinivasa Sourirajan of NRC, Canada. Because no heating or phase changes are needed, energy requirements are low, around 3 kWh/m³, in comparison to other processes of desalination, but are still much higher than those required for other forms of water supply, including reverse osmosis treatment of wastewater, at 0.1 to 1 kWh/m³. See WIKI "Desalination". Up to 50% of the sea water input can be recovered as fresh water, though lower recoveries may reduce membrane fouling and energy consumption.

Brackish water reverse osmosis (BWRO) refers to desalination of water with a lower salt content than sea water, usually from river estuaries or saline wells. The process is substantially the same as SWRO, but requires lower pressures and therefore less energy. Up to 80% of the feed water input can be recovered as fresh water, depending on feed salinity.

The Ashkelon seawater reverse osmosis (SWRO) desalination plant in Israel is the largest in the world.^{[5][6]} The project was developed as a BOT (Build-Operate-Transfer) by a consortium of three international companies: Veolia water, IDE Technologies and Elran.

The typical single-pass SWRO system consists of the following components:

- Intake
- Pretreatment
- High pressure pump (if not combined with energy recovery)
- Membrane assembly
- Energy recovery (if used)
- Remineralisation and pH adjustment
- Disinfection
- Alarm/control panel

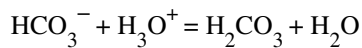
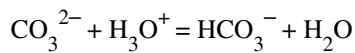
Pretreatment

Pretreatment is important when working with RO and nanofiltration (NF) membranes due to the nature of their spiral wound design. The material is engineered in such a fashion as to allow only one-way flow through the system. As such, the spiral wound design does not allow for backpulsing with water or air agitation to scour its surface and remove solids. Since accumulated material cannot be removed from the membrane surface systems, they are highly susceptible to fouling (loss of production capacity). Therefore, pretreatment is a necessity for any RO or NF system. Pretreatment in SWRO systems has four major components:

- Screening of solids: Solids within the water must be removed and the water treated to prevent fouling of the membranes by fine particle or biological growth, and reduce the risk of damage to high-pressure pump components.
- Cartridge filtration: Generally, string-wound polypropylene filters are used to remove particles of 1–5 µm diameter.
- Dosing: Oxidizing biocides, such as chlorine, are added to kill bacteria, followed by bisulfite dosing to deactivate the chlorine, which can destroy a thin-film composite membrane. There are also biofouling inhibitors, which do

not kill bacteria, but simply prevent them from growing slime on the membrane surface and plant walls.

- Prefiltration pH adjustment: If the pH, hardness and the alkalinity in the feedwater result in a scaling tendency when they are concentrated in the reject stream, acid is dosed to maintain carbonates in their soluble carbonic acid form.



- Carbonic acid cannot combine with calcium to form calcium carbonate scale. Calcium carbonate scaling tendency is estimated using the Langelier saturation index. Adding too much sulfuric acid to control carbonate scales may result in calcium sulfate, barium sulfate or strontium sulfate scale formation on the RO membrane.
- Prefiltration antiscalants: Scale inhibitors (also known as antiscalants) prevent formation of all scales compared to acid, which can only prevent formation of calcium carbonate and calcium phosphate scales. In addition to inhibiting carbonate and phosphate scales, antiscalants inhibit sulfate and fluoride scales, disperse colloids and metal oxides. Despite claims that antiscalants can inhibit silica formation, there is no concrete evidence to prove that silica polymerization can be inhibited by antiscalants. Antiscalants can control acid soluble scales at a fraction of the dosage required to control the same scale using sulfuric acid.
- Some small scale desalination units use **beach wells**; they are usually drilled on the seashore in close vicinity to the ocean. These intake facilities are relatively simple to build and the seawater they collect is pretreated via slow filtration through the subsurface sand/seabed formations in the area of source water extraction. Raw seawater collected using beach wells is often of better quality in terms of solids, silt, oil and grease, natural organic contamination and aquatic microorganisms, compared to open seawater intakes. Sometimes, beach intakes may also yield source water of lower salinity.

High pressure pump (If not combined with energy recovery)

The HP pump supplies the pressure needed to push water through the membrane, even as the membrane rejects the passage of salt through it. Typical pressures for brackish water range from 225 to 375 psi (15.5 to 26 bar, or 1.6 to 2.6 MPa). In the case of seawater, they range from 800 to 1,180 psi (55 to 81.5 bar or 6 to 8 MPa). This requires a large amount of energy. Where energy recovery is used, all or part of the high pressure pump's work is done by the energy recovery device, reducing the system energy input.

Membrane assembly

The membrane assembly consists of a pressure vessel with a membrane that allows feedwater to be pressed against it. The membrane must be strong enough to withstand whatever pressure is applied against it. RO membranes are made in a variety of configurations, with the two most common configurations being **spiral-wound** and **hollow-fiber**.

Only a part of the saline feed water pumped into the membrane assembly passes through the membrane with the salt removed. The remaining "concentrate" flow passes along the saline side of the membrane to flush away the concentrated salt solution. The percentage of desalinated water produced versus the saline water feed flow is known as the "recovery ratio". This varies with the salinity of the feed water and the system design parameters: typically 20% for small sea water systems, 40% for larger sea water systems and 80% for brackish water. The concentrate flow is at typically only 3 bar / 50 psi less than the feed pressure, and thus still carries much of the HP pump input energy.



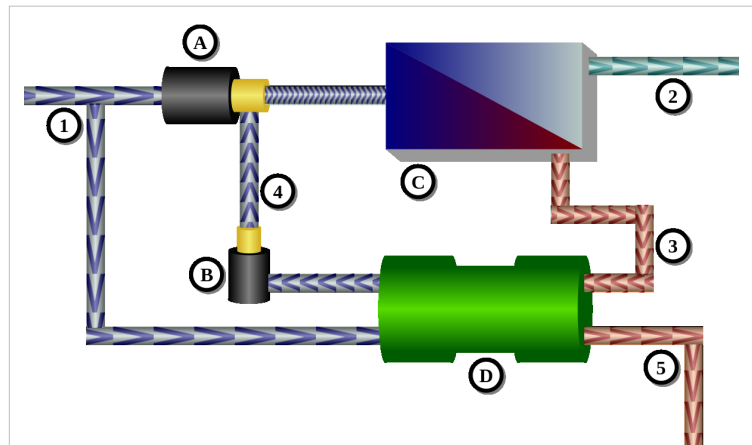
The layers of a membrane

The desalinated water purity is a function of the system design. Higher purity needs more equipment and more energy. Purity expressed as Total dissolved solids typically varies from 100 to 400 ppm (parts per million = milligram/litre). 500ppm is generally accepted as the upper limit for drinking water, while the U.S. Food and Drug Administration classifies mineral water as water containing at least 250ppm.

Energy recovery (If used)

Energy recovery can reduce energy consumption by 50% or more. Much of the HP pump input energy can be recovered from the concentrate flow, and it is the increasing efficiency of energy recovery devices that has greatly reduced the energy needs of reverse osmosis desalination. Devices used, in order of invention, are...

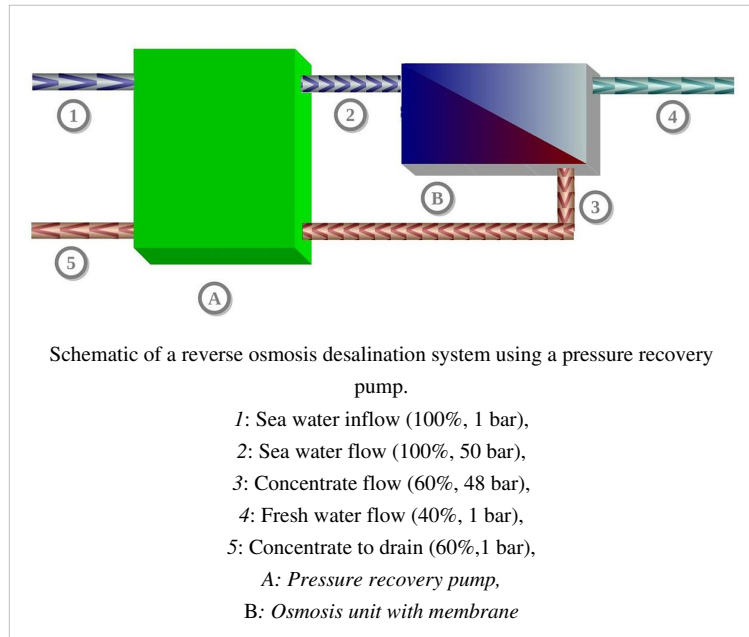
- Turbine or Pelton Wheel: a water turbine driven by the concentrate flow, connected to the HP pump drive shaft to provide part of its input power. Positive displacement axial piston motors have also been used in place of turbines on smaller systems.
- Turbocharger: a water turbine driven by the concentrate flow, directly connected to a centrifugal pump which boosts the high pressure pump output pressure, reducing the pressure needed from the HP pump and thereby its energy input. Similar in construction principle to car engine turbochargers
- Pressure Exchanger: using the pressurised concentrate flow, in direct contact or via a piston, to pressurise part of the membrane feed flow to near concentrate flow pressure. A boost pump then raises this pressure by typically 3 bar / 50 psi to the membrane feed pressure. This reduces flow needed from the high pressure pump by an amount equal to the concentrate flow, typically 60%, and thereby its energy input. These are widely used on larger low-energy systems. Capable of 3kWh/m^3 or less energy consumption. Examples are the DWEER, the rotary pressure exchanger and the Danfoss iSave^[7]



Schematics of a reverse osmosis desalination system using a pressure exchanger.

- 1: Sea water inflow,
- 2: Fresh water flow (40%),
- 3: Concentrate flow (60%),
- 4: Sea water flow (60%),
- 5: Concentrate (drain),
- A: Pump flow (40%),
- B: Circulation pump,
- C: Osmosis unit with membrane,
- D: Pressure exchanger

- **Pressure Recovery Pump:** a reciprocating piston pump having the pressurised concentrate flow applied to one side of each piston to help drive the membrane feed flow from the opposite side. These are the simplest energy recovery devices to apply, combining the HP pump and energy recovery in a single self-regulating unit. These are widely used on smaller low-energy systems. Capable of 3kWh/m^3 or less energy consumption. Examples are the Clark Pump,^[8] the Katadyn desalinators,^[9] and the Spectra Pearson Pump.^[10]



Remineralisation and pH adjustment ^[11]

The desalinated water is "stabilized" to protect downstream pipelines and storages, usually by adding lime or caustic to prevent corrosion of concrete lined surfaces. Liming material is used to adjust pH between 6.8 and 8.1 to meet the potable water specifications, primarily for effective disinfection and for corrosion control. Remineralisation may be needed to replace minerals removed from the water by desalination

Disinfection

Post-treatment consists of preparing the water for distribution after filtration. Reverse osmosis is an effective barrier to pathogens, however post-treatment provides secondary protection against compromised membranes and downstream problems. Disinfection by means of UV lamps (sometimes called germicidal or bactericidal) may be employed to sterilize pathogens which bypassed the reverse osmosis process. Chlorination or chloramination (chlorine and ammonia) protects against pathogens which may have lodged in the distribution system downstream, such as from new construction, backwash, compromised pipes, etc.^[citation needed]

Disadvantages

Household reverse osmosis units use a lot of water because they have low back pressure. As a result, they recover only 5 to 15 percent of the water entering the system. The remainder is discharged as waste water. Because waste water carries with it the rejected contaminants, methods to recover this water are not practical for household systems. Wastewater is typically connected to the house drains and will add to the load on the household septic system. An RO unit delivering 5 gallons of treated water per day may discharge anywhere between 20 and 90 gallons of waste water per day.^[12]

Large-scale industrial/municipal systems recover typically 75% to 80% of the feed water, or as high as 90%, because they can generate the high pressure needed for higher recovery reverse osmosis filtration. On the other hand, as recovery of waste-water increases in commercial operations, effective contaminant removal rates tend to become reduced, as evidenced by product water total dissolved solids (TDS) counts.

Due to its fine membrane construction, reverse osmosis not only removes harmful contaminants that may be present in the water, it may strip many of the good, healthy minerals from the water. A number of peer-reviewed studies have looked at the long term health effects of drinking demineralized water.^[13] However, demineralized water can be remineralized and this process has been done in instances when processing demineralized water for consumption.

An example of this process is Dasani, which adds sodium chloride (salt) and potassium chloride (salt) to its water for "taste," according to the company.

New developments

Prefiltration of high fouling waters with another, larger-pore membrane with less hydraulic energy requirement, has been evaluated and sometimes used, since the 1970s. However, this means the water passes through two membranes and is often repressurized, requiring more energy input in the system, increasing the cost.

Other recent development work has focused on integrating RO with electrodialysis to improve recovery of valuable deionized products or minimize concentrate volume requiring discharge or disposal.

References

- [1] Crittenden, John; Trussell, Rhodes; Hand, David; Howe, Kerry and Tchobanoglous, George. Water Treatment Principles and Design, Edition 2. John Wiley and Sons. New Jersey. 2005 ISBN 0-471-11018-3
- [2] ^ Weintraub, Bob. "Sidney Loeb," Bulletin of the Israel Chemical Society, Dec. 2001, issue 8, page 8-9. Weintraub, B. (<http://www.chemistry.org.il/booklet/8/pdf/sidney.pdf>)
- [3] Council Directive of 15 July 1980 on the approximation of the laws of the Member States relating to the exploitation and marketing of natural mineral waters (<http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG:1980L0777:19961213:EN:PDF>). eur-lex.europa.eu
- [4] International Desalination Association (<http://www.globalwaterintel.com/advertise/ida-desalination-yearbook/>) Yearbook 2012-13
- [5] Israel is No. 5 on Top 10 Cleantech List (<http://www.israel21c.org/briefs/israel-is-no-5-on-top-10-cleantech-list>) in Israel 21c A Focus Beyond (<http://www.israel21c.org/technology/archive>) Retrieved 2009-12-21
- [6] Desalination Plant Seawater Reverse Osmosis (SWRO) Plant (<http://www.water-technology.net/projects/israel/>). Water-technology.net
- [7] Danfoss iSave (<http://www.isave.danfoss.com/index.asp?inc=isave>) Danfoss A/S. Retrieved on 2013-06-26
- [8] The Spectra Clark Pump (<http://www.spectrawatermakers.com/technology/clark-pump.html>) Spectra Watermakers Inc. Retrieved on 2013-06-26.
- [9] Katadyn desalinators (<http://www.katadyn.com/usen/katadyn-products/products/katadynshopconnect/katadyn-desalinators/>) Katadyn Products Inc. Retrieved on 2013-06-26
- [10] Spectra Pearson Pump (<http://www.spectrawatermakers.com/technology/pearson-pump.html>) Spectra Watermakers Inc. Retrieved on 2013-06-26
- [11] Seawater Desalination Post-treatment Processes (<http://www.lenntech.com/processes/desalination/post-treatment/general/desalination-posttreatment.htm>) Lenntech B.V. Retrieved on 2013-07-02
- [12] Treatment Systems for Household Water Supplies (<http://www.ag.ndsu.edu/pubs/h2oqual/watsys/ae1047w.htm#disadvantage>). Ag.ndsu.edu. Retrieved on 2011-06-19.
- [13] Health risks from drinking demineralised water (http://www.who.int/water_sanitation_health/dwq/nutrientschap12.pdf)

External links

- Sidney Loeb – Co-Inventor of Practical Reverse Osmosis (<http://www.chemistry.org.il/booklet/8/pdf/sidney.pdf>)

Desalination

Water desalination
Methods
<ul style="list-style-type: none"> • Distillation <ul style="list-style-type: none"> • Multi-stage flash distillation (MSF) • Multiple-effect distillation (MED/ME) • Vapor-compression (VC) • Ion exchange • Membrane processes <ul style="list-style-type: none"> • Electrodialysis reversal (EDR) • Reverse osmosis (RO) • Nanofiltration (NF) • Membrane distillation (MD) • Freezing desalination • Geothermal desalination • Solar desalination <ul style="list-style-type: none"> • Solar humidification-Dehumidification (HDH) • Multiple-effect humidification (MEH) • Methane hydrate crystallization • High grade water recycling • Seawater greenhouse

Desalination, desalinization, desalinisation or **desalting** refers to any of several processes that remove some amount of salt and other minerals from saline water. More generally, desalination may also refer to the removal of salts and minerals,^[1] as in soil desalination.^[2]

Salt water is desalinated to produce fresh water suitable for human consumption or irrigation. One potential byproduct of desalination is salt. Desalination is used on many seagoing ships and submarines. Most of the modern interest in desalination is focused on developing cost-effective ways of providing fresh water for human use. Along with recycled wastewater, this is one of the few rainfall-independent water sources.

Costs of desalinating sea water (infrastructure, energy and maintenance) are generally higher than the alternatives (fresh water from rivers or groundwater, water recycling and water conservation), but alternatives are not always applicable. Achievable costs in 2013 range from 0.5 to 1 US\$/cubic metre (2 to 4 US\$/kgal). (See below: "Economics"). The cost of untreated fresh water in the developing world can reach 5 US\$/cubic metre^[3]

Average Water Consumption & Cost of Supply by Sea Water Desalination (+/-50%)...

Area	Consumption USgal/person/day	Consumption litre/person/day	Desalinated Water Cost US\$/person/day
USA	100	380	0.29
Europe	50	190	0.14
Africa	15	60	0.05
UN recommended minimum	13	50	0.04

Energy consumption of sea water desalination can be as low as 3 kWh/m³,^[4] similar to the energy consumption of existing fresh water supplies transported over large distances,^[5] but much higher than local fresh water supplies which use 0.2 kWh/m³ or less.^[6]

The laws of physics determine a minimum energy consumption for sea water desalination around 1 kWh/m³,^[7] excluding pre-filtering and intake/outfall pumping. Under 2 kWh/m³^[8] has been achieved with existing reverse osmosis membrane technology, leaving limited scope for further energy reductions.

Supplying all domestic water by sea water desalination would increase US Domestic energy consumption by around 10%, about the amount of energy used by a domestic refrigerator^[9]

Energy Consumption of Sea Water Desalination Methods...^[10]

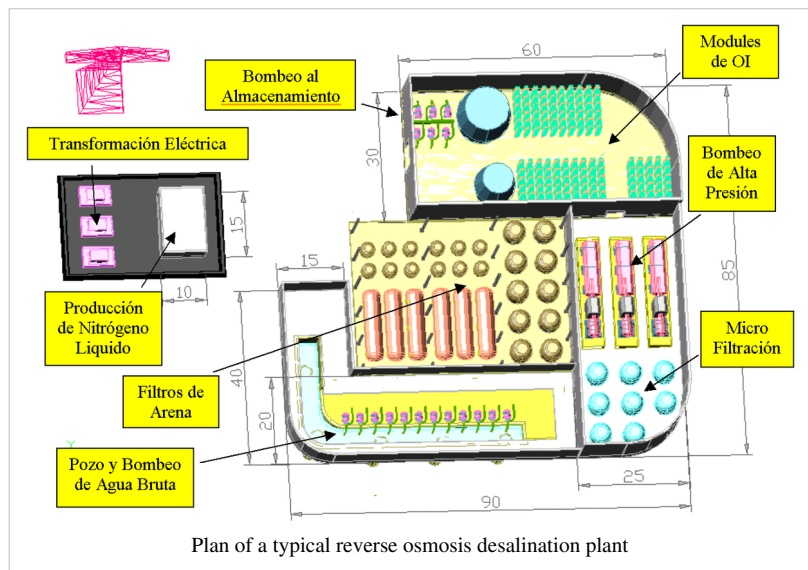
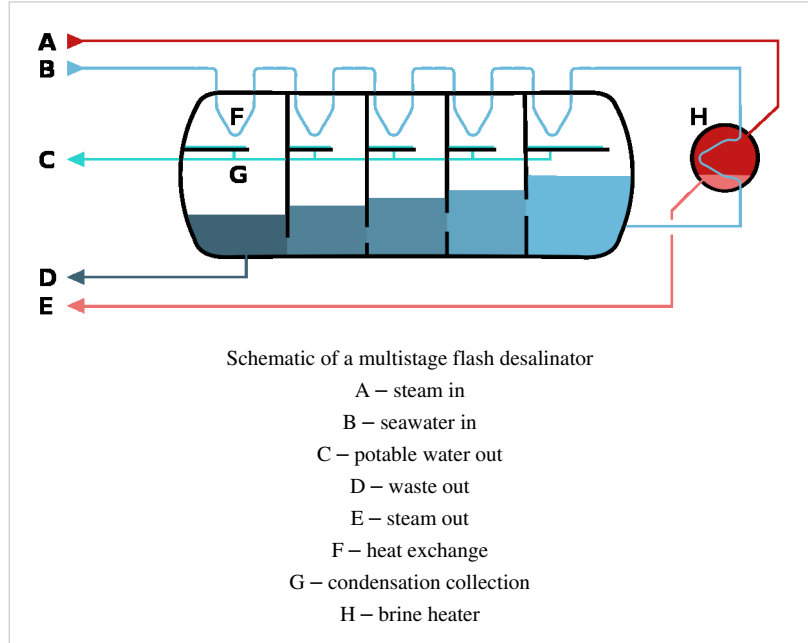
Desalination Method >>	Multi-stage Flash MSF	Multi-Effect Distillation MED	Mechanical Vapor Compression MVC	Reverse Osmosis RO
Electrical energy kWh/m ³	4-6	1.5-2.5	7-12	3-5.5
Thermal energy kWh/m ³	50-110	60-110	None	None
Electrical equivalent of thermal energy kWh/m ³	9.5-19.5	5-8.5	None	None
Total equivalent electrical energy kWh/m ³	13.5-25.5	6.5-11	7-12	3-5.5

Note: "Electrical equivalent" of thermal energy is that electrical energy which cannot be produced in a turbine because of extraction of the heating steam

Desalination is particularly relevant to countries such as Australia, which traditionally have relied on collecting rainfall behind dams to provide their drinking water supplies. According to the International Desalination Association, in 2009, 14,451 desalination plants operated worldwide, producing 59.9 million cubic meters per day, a year-on-year increase of 12.3%. The production was 68 million m³ in 2010, and expected to reach 120 million m³ by 2020; some 40 million m³ is planned for the Middle East.^[11] The world's largest desalination plant is the Jebel Ali Desalination Plant (Phase 2) in the United Arab Emirates.

Methods

The traditional process used in these operations is vacuum distillation—essentially the boiling of water at less than atmospheric pressure and thus a much lower temperature than normal. This is because the boiling of a liquid occurs when the vapor pressure equals the ambient pressure and vapor pressure increases with temperature. Thus, because of the reduced temperature, low-temperature "waste" heat from electrical power generation or industrial processes can be used.



The principal competing processes use membranes to desalinate, principally applying reverse osmosis technology. Membrane processes use semipermeable membranes and pressure to separate salts from water. Reverse osmosis plant membrane systems typically use less energy than thermal distillation, which has led to a reduction in overall desalination costs over the past decade. Desalination remains energy intensive, however, and future costs will continue to depend on the price of both energy and desalination technology.

Considerations and criticism

Cogeneration

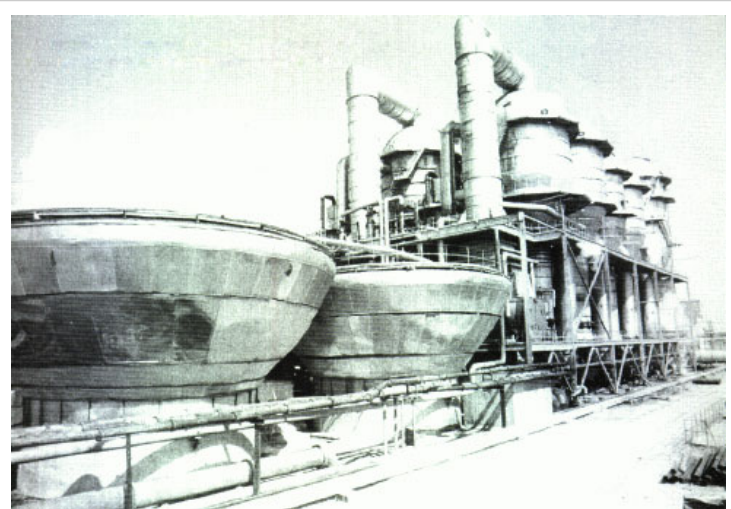
Cogeneration is the process of using excess heat from electricity generation for another task: in this case the production of potable water from seawater or brackish groundwater in an integrated, or "dual-purpose", facility where a power plant provides the energy for desalination. Alternatively, the facility's energy production may be dedicated to the production of potable water (a stand-alone facility), or excess energy may be produced and incorporated into the energy grid (a true cogeneration facility). Cogeneration takes various forms, and theoretically any form of energy production could be used. However, the majority of current and planned cogeneration desalination plants use either fossil fuels or nuclear power as their source of energy. Most plants are located in the Middle East or North Africa, which use their petroleum resources to offset limited water resources. The advantage of dual-purpose facilities is they can be more efficient in energy consumption, thus making desalination a more viable option for drinking water.

In a December 26, 2007, opinion column in the *The Atlanta Journal-Constitution*, Nolan Hertel, a professor of nuclear and radiological engineering at Georgia Tech, wrote, "... nuclear reactors can be used ... to produce large amounts of potable water. The process is already in use in a number of places around the world, from India to Japan and Russia. Eight nuclear reactors coupled to desalination plants are operating in Japan alone, nuclear desalination plants could be a source of large amounts of potable water transported by pipelines hundreds of miles inland..."^[12]

Additionally, the current trend in dual-purpose facilities is hybrid configurations, in which the permeate from a reverse osmosis desalination component is mixed with distillate from thermal desalination. Basically, two or more desalination processes are combined along with power production. Such facilities have already been implemented in Saudi Arabia at Jeddah and Yanbu.



Reverse osmosis desalination plant in Barcelona, Spain



The Shevchenko BN350, a nuclear-heated desalination unit

A typical aircraft carrier in the US military uses nuclear power to desalinate 400,000 US gallons (1,500,000 l; 330,000 imp gal) of water per day.^[13]

Economics

Factors that determine the costs for desalination include capacity and type of facility, location, feed water, labor, energy, financing, and concentrate disposal. Desalination stills now control pressure, temperature and brine concentrations to optimize efficiency. Nuclear-powered desalination might be economical on a large scale.^[14]

While noting costs are falling, and generally positive about the technology for affluent areas in proximity to oceans, a 2004 study argued, "Desalinated water may be a solution for some water-stress regions, but not for places that are poor, deep in the interior of a continent, or at high elevation. Unfortunately, that includes some of the places with biggest water problems.", and, "Indeed, one needs to lift the water by 2,000 metres (6,600 ft), or transport it over more than 1,600 kilometres (990 mi) to get transport costs equal to the desalination costs. Thus, it may be more economical to transport fresh water from somewhere else than to desalinate it. In places far from the sea, like New Delhi, or in high places, like Mexico City, high transport costs would add to the high desalination costs. Desalinated water is also expensive in places that are both somewhat far from the sea and somewhat high, such as Riyadh and Harare. In many places, the dominant cost is desalination, not transport; the process would therefore be relatively less expensive in places like Beijing, Bangkok, Zaragoza, Phoenix, and, of course, coastal cities like Tripoli."^[15] After being desalinated at Jubail, Saudi Arabia, water is pumped 200 miles (320 km) inland through a pipeline to the capital city of Riyadh.^[16] For coastal cities, desalination is increasingly viewed as an untapped and unlimited water source, undermining the very significant environmental impacts associated to the process.

In Israel as of 2005, desalinating water costs US\$ 0.53 per cubic meter (0.053¢ per liter).^[17] As of 2006, Singapore was desalinating water for US\$ 0.49 per cubic meter.^[18] The city of Perth began operating a reverse osmosis seawater desalination plant in 2006, and the Western Australian government announced a second plant will be built to serve the city's needs.^[19] A desalination plant is now operating in Australia's largest city, Sydney,^[20] and the Wonthaggi desalination plant was under construction in Wonthaggi, Victoria.

The Perth desalination plant is powered partially by renewable energy from the Emu Downs Wind Farm.^[21] A wind farm at Bungendore in New South Wales was purpose-built to generate enough renewable energy to offset the Sydney plant's energy use,^[22] mitigating concerns about harmful greenhouse gas emissions, a common argument used against seawater desalination.

In December 2007, the South Australian government announced it would build a seawater desalination plant for the city of Adelaide, Australia, located at Port Stanvac. The desalination plant was to be funded by raising water rates to achieve full cost recovery.^{[23][24]} An online, unscientific poll showed nearly 60% of votes cast were in favor of raising water rates to pay for desalination.^[25]

A January 17, 2008, article in the *Wall Street Journal* stated, "In November, Connecticut-based Poseidon Resources Corp. won a key regulatory approval to build the \$300 million water-desalination plant in Carlsbad, north of San Diego. The facility would produce 50,000,000 US gallons (190,000,000 l; 42,000,000 imp gal) of drinking water per day, enough to supply about 100,000 homes ... Improved technology has cut the cost of desalination in half in the past decade, making it more competitive ... Poseidon plans to sell the water for about \$950 per acre-foot [1,200 cubic meters (42,000 cu ft)]. That compares with an average [of] \$700 an acre-foot [1200 m³] that local agencies now pay for water."^[26] Each \$1,000 per acre-foot works out to \$3.06 for 1,000 gallons, or \$.81 per cubic meter.^[27]

While this regulatory hurdle was met, Poseidon Resources is not able to break ground until the final approval of a mitigation project for the damage done to marine life through the intake pipe is received, as required by California law. Poseidon Resources has made progress in Carlsbad, despite an unsuccessful attempt to complete construction of Tampa Bay Desal, a desalination plant in Tampa Bay, FL, in 2001. The Board of Directors of Tampa Bay Water was forced to buy Tampa Bay Desal from Poseidon Resources in 2001 to prevent a third failure of the project. Tampa Bay Water faced five years of engineering problems and operation at 20% capacity to protect marine life, so stuck to

reverse osmosis filters prior to fully using this facility in 2007.^[28]

In 2008, a San Leandro, California company (Energy Recovery Inc.) was desalinating water for \$0.46 per cubic meter.^[29]

While desalinating 1,000 US gallons (3,800 l; 830 imp gal) of water can cost as much as \$3, the same amount of bottled water costs \$7,945.^[30]

Environmental

Intake

In the United States, due to a 2011 court ruling under the Clean Water Act, ocean water intakes are no longer viable without reducing mortality of the life in the ocean, the plankton, fish eggs and fish larvae, by 90%.^[31] The alternatives include beach wells to eliminate this concern, but require more energy and higher costs, while limiting output.^[32]

The Kwinana Desalination Plant opened in Perth in 2007. Water there and at Queensland's Gold Coast Desalination Plant and Sydney's Kurnell Desalination Plant is withdrawn at only 0.1 meters per second (0.33 ft/s), which is slow enough to let fish escape. The plant provides nearly 140,000 cubic meters (4,900,000 cu ft) of clean water per day.^[33]

Outflow

All desalination processes produce large quantities of a concentrate, which may be increased in temperature, and contain residues of pretreatment and cleaning chemicals, their reaction byproducts, and heavy metals due to corrosion. Chemical pretreatment and cleaning are a necessity in most desalination plants, which typically includes the treatment against biofouling, scaling, foaming and corrosion in thermal plants, and against biofouling, suspended solids and scale deposits in membrane plants.

To limit the environmental impact of returning the brine to the ocean, it can be diluted with another stream of water entering the ocean, such as the outfall of a wastewater treatment or power plant. While seawater power plant cooling water outfalls are not as fresh as wastewater treatment plant outfalls, salinity is reduced. With medium to large power plant and desalination plant, the power plant's cooling water flow is likely to be at least several times larger than that of the desalination plant. Another method to reduce the increase in salinity is to mix the brine via a diffuser in a mixing zone. For example, once the pipeline containing the brine reaches the sea floor, it can split into many branches, each releasing brine gradually through small holes along its length. Mixing can be combined with power plant or wastewater plant dilution.

Brine is denser than seawater due to higher solute concentration. The ocean bottom is most at risk because the brine sinks and remains there long enough to damage the ecosystem. Careful reintroduction can minimize this problem. For example, for the desalination plant and ocean outlet structures to be built in Sydney from late 2007, the water authority stated the ocean outlets would be placed in locations at the seabed that will maximize the dispersal of the concentrated seawater, such that it will be indistinguishable beyond between 50 and 75 meters (164 and 246 ft) from the outlets. Typical oceanographic conditions off the coast allow for rapid dilution of the concentrated byproduct, thereby minimizing harm to the environment.

Alternatives without pollution

Some methods of desalination, particularly in combination with evaporation ponds and solar stills (solar desalination), do not discharge brine. They do not use chemicals in their processes nor the burning of fossil fuels. They do not work with membranes or other critical parts, such as components that include heavy metals, thus do not cause toxic waste (and high maintenance). A new approach that works like a solar still, but on the scale of industrial evaporation ponds is the Integrated Biotechnical System.^[34] It can be considered "full desalination" because it

converts the entire amount of saltwater intake into distilled water. One of the unique advantages of this type of solar-powered desalination is the feasibility for inland operation. Standard advantages also include no air pollution from desalination power plants and no temperature increase of endangered natural water bodies from power plant cooling-water discharge. Another important advantage is the production of sea salt for industrial and other uses. Currently, 50% of the world's sea salt production still relies on fossil energy sources.

Alternatives to desalination

Increased water conservation and efficiency remain the most cost-effective priorities in areas of the world where there is a large potential to improve the efficiency of water use practices.^[35] Wastewater reclamation for irrigation and industrial use provides multiple benefits over desalination.^[36] Urban runoff and storm water capture also provide benefits in treating, restoring and recharging groundwater.^[37]

A proposed alternative to desalination in the American Southwest is the commercial importation of bulk water from water-rich areas either by very large crude carriers converted to water carriers, or via pipelines. The idea is politically unpopular in Canada, where governments imposed trade barriers to bulk water exports as a result of a claim filed in 1999 under Chapter 11 of the North American Free Trade Agreement (NAFTA) by Sun Belt Water Inc., a company established in 1990 in Santa Barbara, California, to address pressing local needs due to a severe drought in that area.^[38]

Experimental techniques and other developments

Many desalination techniques have been researched, with varying degrees of success.

One such process was commercialized by Modern Water PLC using forward osmosis, with a number of plants reported to be in operation.

The US government is working to develop practical solar desalination.^[citation needed]

The Passarell process uses reduced atmospheric pressure rather than heat to drive evaporative desalination. The pure water vapor generated by distillation is then compressed and condensed using an advanced compressor. The compression process improves distillation efficiency by creating the reduced pressure in the evaporation chamber. The compressor centrifuges the pure water vapor after it is drawn through a demister (removing residual impurities) causing it to compress against tubes in the collection chamber. The compression of the vapor causes its temperature to increase. The heat generated is transferred to the input water falling in the tubes, causing the water in the tubes to vaporize. Water vapor condenses on the outside of the tubes as product water. By combining several physical processes, Passarell enables most of the system's energy to be recycled through its subprocesses, namely evaporation, demisting, vapor compression, condensation, and water movement within the system.^[39]

Geothermal energy can drive desalination. In most locations, geothermal desalination beats using scarce groundwater or surface water, environmentally and economically.^[citation needed]

Nanotube membranes may prove to be effective for water filtration and desalination processes that would require substantially less energy than reverse osmosis.

Hermetic, sulphonated nano-composite membranes have shown to be capable of cleaning most all forms of contaminated water to the 'parts per billion' level. These nano-materials, using a non-reverse osmosis process, have little or no susceptibility to high salt concentration levels.

Biomimetic membranes are another approach.

On June 23, 2008, Siemens Water Technologies announced technology based on applying electric fields that purports to desalinate one cubic meter of water while using only 1.5 kWh of energy. If accurate, this process would consume only one-half the energy of other processes.^[40] Currently, Oasis Water, which developed the technology, still uses three times that much energy.

Freeze-thaw desalination uses freezing to remove fresh water from frozen seawater.

Membraneless desalination at ambient temperature and pressure using electrokinetic shocks waves has been demonstrated. In this technique anions and cations in salt water are exchanged for carbonate anions and calcium cations respectively using electrokinetic shockwaves. Calcium and carbonate ions then react to form calcium carbonate, which then precipitates leaving behind fresh water. Theoretical energy efficiency of this method is on par with electrodialysis and reverse osmosis.

In 2009, Lux Research estimated the worldwide desalinated water supply will triple between 2008 and 2020.^[41]

Desalination through evaporation and condensation for crops

The Seawater greenhouse uses natural evaporation and condensation processes inside a greenhouse powered by solar energy to grow crops in arid coastal land.

Low-temperature thermal desalination

Originally stemming from ocean thermal energy conversion research, low-temperature thermal desalination (LTTD) takes advantage of water boiling at low pressures, potentially even at ambient temperature. The system uses vacuum pumps to create a low-pressure, low-temperature environment in which water boils at a temperature gradient of 8–10 °C (46–50 °F) between two volumes of water. Cooling ocean water is supplied from depths of up to 600 m (2,000 ft). This cold water is pumped through coils to condense the water vapor. The resulting condensate is purified water. LTTD may also take advantage of the temperature gradient available at power plants, where large quantities of warm wastewater are discharged from the plant, reducing the energy input needed to create a temperature gradient.

Experiments were conducted in the US and Japan to test the approach. In Japan, a spray-flash evaporation system was tested by Saga University.^[42] In Hawaii, the National Energy Laboratory tested an open-cycle OTEC plant with fresh water and power production using a temperature difference of 20 C° between surface water and water at a depth of around 500 m (1,600 ft). LTTD was studied by India's National Institute of Ocean Technology (NIOT) from 2004. Their first LTTD plant opened in 2005 at Kavaratti in the Lakshadweep islands. The plant's capacity is 100,000 L (22,000 imp gal; 26,000 US gal)/day, at a capital cost of INR 50 million (€922,000). The plant uses deep water at a temperature of 7 to 15 °C (45 to 59 °F).^[43] In 2007, NIOT opened an experimental, floating LTTD plant off the coast of Chennai, with a capacity of 1,000,000 L (220,000 imp gal; 260,000 US gal)/day. A smaller plant was established in 2009 at the North Chennai Thermal Power Station to prove the LTTD application where power plant cooling water is available.^{[44][45]}

Thermoionic process

In October 2009, Saltworks Technologies, a Canadian firm, announced a process that uses solar or other thermal heat to drive an ionic current that removes all sodium and chlorine ions from the water using ion-exchange membranes.^[46]

Existing facilities and facilities under construction

Estimates vary widely between 15,000-20,000 desalination plants producing more than 20,000 m³/day. Micro desalination plants are in operation nearly every where there is a natural gas or fracking facility in the United States.

Algeria

Believed to have at least 15 desalination plants in operation

- Arzew IWPP Power & Desalination Plant, Arzew
- Cap Djinet Seawater Reverse Osmosis(SWRO) 100,000 m³/d
- Tlemcen Souk Tleta 200,000 m³/day

- Tlemcen Hounaine 200,000 m³/day
- Beni Saf 200,000 m³/day
- Tenes 200,000 m³/day
- Fouka 120,000 m³/day
- Skikda 100,000 m³/day
- Hama Seawater Desalination Plant 200,000 m³/day built by GE
- Mostaganem, once considered the largest in Africa
- Magtaa Reverse Osmosis (RO) Desalination Plant, Oran, Algeria

Aruba

The island of Aruba has a large (world's largest at the time of its inauguration) desalination plant, with a total installed capacity of 11.1e6 US gallons (42,000 m³) per day.^[47]Wikipedia:Link rot

Australia

A combination of increased water usage and lower rainfall/drought in Australia caused state governments to turn to desalination, including the recently commissioned Kurnell Desalination Plant serving the Sydney area. While desalination helped secure water supplies, it is energy intensive (~\$140/ML) and has a high carbon footprint due to Australia's coal-based energy supply.^[citation needed] In 2010, a Seawater Greenhouse went into operation in Port Augusta.^{[48][49][50]}

Bahrain

Completed in 2000, the Al Hidd Desalination Plant on Muharraq island employed a multistage flash process, and produces 272,760 m³ (9,632,000 cu ft) per day.^[51] The Al Hidd distillate forwarding station provides 410 million liters of distillate water storage in a series of 45-million-liter steel tanks. A 135-million-liters/day forwarding pumping station sends flows to the Hidd, Muharraq, Hooraa, Sanabis, and Seef blending stations, and which has an option for gravity supply for low flows to blending pumps and pumps which forward to Janusan, Budiya and Saar.^[52]

Upon completion of the third construction phase, the Durrat Al Bahrain seawater reverse osmosis (SWRO) desalination plant was planned to have a capacity of 36,000 cubic meters of potable water per day to serve the irrigation needs of the Durrat Al Bahrain development.^[53] The Bahrain-based utility company, Energy Central Co contracted to design, build and operate the plant.^[54]

Chile

- Copiapó Desalination Plant

China

China operates the Beijing Desalination Plant in Tianjin, a combination desalination and coal-fired power plant designed to alleviate Tianjin's critical water shortage. Though the facility has the capacity to produce 200,000 cubic meters of potable water per day, it has never operated at more than one-quarter capacity due to difficulties with local utility companies and an inadequate local infrastructure.

Cyprus

A plant operates in Cyprus near the town of Larnaca.^[55] The Dhekelia Desalination Plant uses the reverse osmosis system.

Egypt

- Dahab RO Desalination Plants Dahab 3,600 m³/day completed 1999
- Hurgada and Sharm El-Sheikh Power and Desalination Plants
- Oyoum Moussa Power and Desalination
- Zaafarana Power and Desalination

Gibraltar

Fresh water in Gibraltar is supplied by a number of reverse osmosis and multistage flash desalination plants.^[56] A demonstration forward osmosis desalination plant also operates there.

Grand Cayman

- West Bay, West Bay, Grand Cayman
- Abel Castillo Water Works, Governor's Harbour, Grand Cayman
- Britannia, Seven Mile Beach, Grand Cayman

Hong Kong

The HK Water Supplies Department had pilot desalination plants in Tuen Mun and Ap Lei Chau using reverse osmosis technology. The production cost was at HK\$7.8 to HK\$8.4 /m³.^{[57][58]} In 2011, the government announced a feasibility study whether to build a desalination plant in Tseung Kwan O.^[59] Hong Kong used to have a desalination plant in Lok On Pai.^[60]

India

The largest desalination plant in South Asia is the Minjur Desalination Plant near Chennai in India, which produces 36.5 million cubic meters of water per year.

A second plant at Nemmeli, Chennai is expected to reach full capacity of 100 million litres of sea-water per day in March 2013.

Iran

An assumption is that around 400,000 m³/d of historic and newly installed capacity is operational in Iran. In terms of technology, Iran's existing desalination plants use a mix of thermal processes and RO. MSF is the most widely used thermal technology although MED and vapour compression (VC) also feature.

Israel

Israel Desalination Enterprises' Sorek Desalination Plant in Palmachim is to provide up to 26,000 m³ of potable water per hour (2.300 m³ p.a.). At full capacity, it will be the largest desalination plant of its kind in the world.^[61]

The Hadera seawater reverse osmosis (SWRO) desalination plant in Israel is the largest of its kind in the world.^{[62][63]} The project was developed as a build-operate-transfer by a consortium of two Israeli companies: Shikun and Binui, and IDE Technologies.

Existing Israeli water desalination facilities^[64]

Location	Opened	Capacity (million m ³ /year)	Cost of water (per m ³)	Notes
Ashkelon	August 2005	120 (as of 2010)	NIS 2.60	[65]
Palmachim	May 2007	45	NIS 2.90	[66]
Hadera	December 2009	127	NIS 2.60	[67]

Israeli water desalination facilities under construction

Location	Opening	Capacity (million m ³ /year)	Cost of water (per m ³)	Notes
Ashdod	2013	100 (expansion up to 150 possible)	NIS 2.40	[68]
Soreq	2013	150 (expansion up to 300 approved)	NIS 2.01 – 2.19	[69]

Malta

Ghar Lapsi II 50,000 m³/day

Oman

A pilot seawater greenhouse was built in 2004 near Muscat, in collaboration with Sultan Qaboos University, providing a sustainable horticultural sector on the Batinah coast.^[70]

- Ghubrah Power & Desalination Plant, Muscat
- Sohar Power & Desalination Plant, Sohar
- Sur R.O. Desalination Plant 80,000 m³/day 2009
- Qarn Alam 1000 m³/day
- Wilayat Diba 2000 m³/day

There are at least two forward osmosis plants operating in Oman

- Al Najdah 200 m³/day (built by Modern Water)
- Al Khaluf

Saudi Arabia

The Saline Water Conversion Corporation of Saudi Arabia provides 50% of the municipal water in the Kingdom, operates a number of desalination plants, and has contracted \$1.892 billion^[71] to a Japanese-South Korean consortium to build a new facility capable of producing a billion liters per day, opening at the end of 2013. They currently operate 32 plants in the Kingdom; one example at Shoaiba cost \$1.06 billion and produces 450 million liters per day.^[72]

- Corniche RO Plant (Crop) (operated by SAWACO)
- Jubail 800,000 m³/day
- North Obhor Plant (operated by SAWACO)
- Rabigh 7,000 m³/day (operated by wetico)
- planned for completion 2018 Rabigh II 600,000 m³/day (under construction Saline Water Conversion Corporation)

- Shuaibah III 150,000 m³/day (operated by Doosan)
- South Jeddah Corniche Plant (SOJECO) (operated by SAWACO)
- Yanbu Multi Effect Distillation (MED), Saudi Arabia 68,190 m³/day

South Africa

- Richards Bay Desalination Plant 100,000 m³/day

Spain

Lanzarote is the easternmost of the autonomous Canary Islands. It is the driest of the islands, of volcanic origin and has limited water supplies. A private, commercial desalination plant was installed in 1964. This served the whole island and enabled the tourism industry. In 1974, the venture was injected with investments from local and municipal governments and a larger infrastructure was put in place. In 1989, the Lanzarote Island Waters Consortium (INALSA)^[73] was formed.

A prototype seawater greenhouse was constructed in Tenerife in 1992.^[74]

- Alicante II 65,000 m³/day (operator Inima)
- Tordera 60,000 m³/day
- Barcelona 200,000 m³/day (operator Degremont) El Prat, near Barcelona, a desalination plant completed in 2009 was meant to provide water to the Barcelona metropolitan area, especially during the periodic severe droughts that put the available amounts of drinking water under serious stress.
- Oropesa 50,000 m³/day (operator TECNICAS REUNIDAS)
- Moncofa 60,000 m³/day (operator Inima)
- Marina Baja - Mutxamel 50,000 m³/day (operator Degremont)
- Torreveja 240,000 m³/day (operator ACCIONA)
- Cartagena Escombreras 63,000 m³/day (operator COBRA | TEDAGUA)
- Edam Ibiza + Edam San Antonio 25,000 m³/day (operator Ibiza - Portmany)
- Mazarron 36,000 m³/day (operator TEDAGUA)
- Bajo Almanzora 65,000 m³/day

United Arab Emirates

The Jebel Ali desalination plant in Dubai, a dual-purpose facility, uses multistage flash distillation and is capable of producing 300 million cubic meters of water per year^[citation needed].

- Kalba 15,000 m³/day built for Sharjah Electricity and Water Authority completed 2010(operator CH2MHill)
- Khor Fakkan 22,500 m³/day (operator CH2MHill)
- Ghalilah RAK 68,000 m³/day (operator AQUATECH)
- Hamriyah 90,000 m³/day (operator AQUA Engineering)
- Taweelah A1 Power and Desalination Plant has an output 385,000,000 L (85,000,000 imp gal; 102,000,000 US gal) per day of clean water.
- Al Zawrah 27,000 m³/day (operator Aqua Engineering)
- Layyah I 22,500 m³/day (operator CH2MHill)
- Emayil & Saydiat Island ~20,000 m³/day (operator Aqua EPC)
- Umm Al Nar Desalination Plant has an output of 394,000,000 L (87,000,000 imp gal; 104,000,000 US gal)/day.
- Al Yasat Al Soghrih Island 2M gallons per day (GPD) or 9,000 m³/day
- Fujairah F2 is to be completed by July 2010 will have a water production capacity of 492,000,000 L (108,000,000 imp gal; 130,000,000 US gal) per day.^[75]

- A seawater greenhouse was constructed on Al-Aryam Island, Abu Dhabi, United Arab Emirates in 2000.

United Kingdom

The first large-scale plant in the United Kingdom, the Thames Water Desalination Plant, was built in Beckton, east London for Thames Water by Acciona Agua.^[76]

Jersey

The desalination plant located near La Rosière, Corbiere, Jersey, is operated by Jersey Water. Built in 1970 in an abandoned quarry, it was the first in the British Isles.

The original plant used a multistage flash (MSF) distillation process, whereby seawater was boiled under vacuum, evaporated and condensed into a freshwater distillate. In 1997, the MSF plant reached the end of its operational life and was replaced with a modern reverse osmosis plant.

Its maximum power demand is 1,750 kW, and the output capacity is 6,000 cubic meters per day. Specific energy consumption is 6.8 kWh/m³.

United States

Texas

There are a dozen different desalination projects in the State of Texas, both for desalinating groundwater and desalinating seawater from the Gulf of Mexico.^{[77][78]}

El Paso

Brackish groundwater has been treated at the El Paso, Texas, plant since around 2004. It produces 27,500,000 US gallons (104,000,000 l; 22,900,000 imp gal) of fresh water daily (about 25% of total freshwater deliveries) by reverse osmosis.^[79]

California

Carlsbad

The United States' largest desalination plant is being constructed by Poseidon Resources and is expected to go online 2016.

Santa Barbara

The Charles Meyer Desalination Facility^[80] was constructed in Santa Barbara, California, in 1991–92 as a temporary emergency water supply in response to severe drought. While it has a high operating cost, the facility only needs to operate infrequently, allowing Santa Barbara to use its other supplies more extensively.

Florida

Tampa Bay

The Tampa Bay Water desalination project near Tampa, Florida, was originally a private venture led by Poseidon Resources, but it was delayed by the bankruptcy of Poseidon Resources' successive partners in the venture, Stone & Webster, then Covanta (formerly Ogden) and its principal subcontractor, Hydranautics. Stone & Webster declared bankruptcy June 2000. Covanta and Hydranautics joined in 2001, but Covanta failed to complete the construction bonding, and then the Tampa Bay Water agency purchased the project on May 15, 2002, underwriting the project. Tampa Bay Water then contracted with Covanta Tampa Construction, which produced a project that failed performance tests. After its parent went bankrupt, Covanta also filed for bankruptcy prior to performing renovations that would have satisfied contractual agreements. This resulted in nearly six months of litigation. In 2004, Tampa

Bay Water hired a renovation team, American Water/Acciona Aqua, to bring the plant to its original, anticipated design. The plant was deemed fully operational in 2007, and is designed to run at a maximum capacity of 25 million US gallons (95,000 m³) per day.^[81] The plant can now produce up to 25 million US gallons (95,000 m³) per day when needed.^[82]

Arizona

Yuma

The desalination plant in Yuma, Arizona, was constructed under authority of the Federal Colorado River Basin Salinity Control Act of 1974 to treat saline agricultural return flows from the Wellton-Mohawk Irrigation and Drainage District into the Colorado River. The treated water is intended for inclusion in water deliveries to Mexico, thereby keeping a like amount of freshwater in Lake Mead, Arizona and Nevada. Construction of the plant was completed in 1992, and it has operated on two occasions since then. The plant has been maintained, but largely not operated due to sufficient freshwater supplies from the upper Colorado River.^[83]

An agreement was reached in April 2010 between the Southern Nevada Water Authority, the Metropolitan Water District of Southern California, the Central Arizona Project, and the U.S. Bureau of Reclamation to underwrite the cost of running the plant in a year-long pilot project.^[84]

Trinidad and Tobago

The Republic of Trinidad and Tobago uses desalination to open up more of the island's water supply for drinking purposes. The country's desalination plant, opened in March 2003, is considered to be the first of its kind. It was the largest desalination facility in the Americas, and it processes 28,800,000 US gallons (109,000 m³) of water a day at the price of \$2.67 per 1,000 US gallons (3.8 m³).^[85]

This plant will be located at Trinidad's Point Lisas Industrial Estate, a park of more than 12 companies in various manufacturing and processing functions, and it will allow for easy access to water for both factories and residents in the country.^[86]

In nature

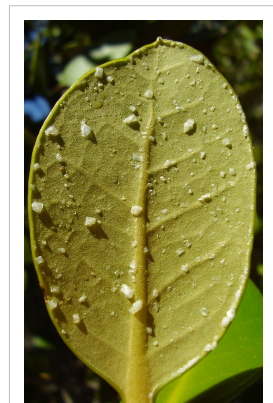
Evaporation of water over the oceans in the water cycle is a natural desalination process.

The formation of sea ice is also a process of desalination. Salt is expelled from seawater when it freezes. Although some brine is trapped, the overall salinity of sea ice is much lower than seawater.

Seabirds distill seawater using countercurrent exchange in a gland with a rete mirabile. The gland secretes highly concentrated brine stored near the nostrils above the beak. The bird then "sneezes" the brine out. As freshwater is not available in their environments, some seabirds, such as pelicans, petrels, albatrosses, gulls and terns, possess this gland, which allows them to drink the salty water from their environments while they are hundreds miles away from land.^[87]

Mangroves trees grow in seawater; they secrete salt by trapping it into parts of the root, which are then eaten by animals (usually crabs). Additional salt removal is done by storing it in leaves which then fall off. Some types of mangroves have glands on their leaves, which work in a similar way to the seabird desalination gland. Salt is extracted to the leaf exterior as small crystals, which then fall off the leaf.

Willow trees and reeds are known to absorb salt and other contaminants, effectively desalinating the water. This is used in artificial constructed wetlands, for treating sewage.^[citation needed]



Mangrove leaf with salt crystals

References

- [1] "Desalination" (<http://dictionary.reference.com/browse/desalination>) (definition), *The American Heritage Science Dictionary*, Houghton Mifflin Company, via dictionary.com. Retrieved on 2007-08-19.
- [2] "Australia Aids China In Water Management Project." (http://english.people.com.cn/english/200108/03/eng20010803_76423.html) *People's Daily Online*, 2001-08-03, via english.people.com.cn. Retrieved on 2007-08-19.
- [3] "Finding Water in Mogadishu" (<http://www.ipsnews.net/2008/08/development-somalia-finding-water-in-mogadishu/>) *IPS news item 2008*
- [4] "Energy Efficient Reverse Osmosis Desalination Process" (<http://www.ijesd.org/papers/243-B20001.pdf>), p343 Table 1, *International Journal of Environmental Science and Development*, Vol. 3, No. 4, August 2012
- [5] "Analysis of the Energy Intensity of Water Supplies for West Basin Municipal Water District" (<http://www.westbasin.org/files/general-pdfs/Energy--UCSB-energy-study.pdf>), Table on p4, Robert C. Wilkinson Ph.D, March 2007
- [6] "U.S. Electricity Consumption for Water Supply & Treatment" (<http://www.circleofblue.org/waternews/wp-content/uploads/2010/08/EPRI-Volume-4.pdf>), p1-4 Table 1-1, Electric Power Research Institute (EPRI) Water & Sustainability (Volume 4), 2000
- [7] "Seawater Desalination" (http://www.nwri-usa.org/documents/Elimelech_000.pdf), p12 et seq, Menachem Elimelech, 2012
- [8] "Optimizing Lower Energy Seawater Desalination" (http://www.usbr.gov/research/AWT/reportpdfs/ADC_SWRO_DA.pdf), p6 figure 1.2, Stephen Dundorf at the IDA World Congress November 2009
- [9] "Membrane Desalination Power Usage Put In Perspective" (http://www.amtaorg.com/wp-content/uploads/7_MembraneDesalinationPowerUsagePutInPerspective.pdf), American Membrane Technology Association (AMTA) April 2009
- [10] "ENERGY REQUIREMENTS OF DESALINATION PROCESSES" (<http://www.desware.net/desa4.aspx>), Encyclopedia of Desalination and Water Resources (DESWARE), Retrieved on 2013-06-24
- [11] Opportunities aplenty | H2O Middle East (<http://www.h2ome.net/en/2012/02/opportunities-aplenty/>). H2ome.net (2012-02-06). Retrieved on 2012-05-14.
- [12] Nuclear Desalination (<http://www.world-nuclear.org/info/inf71.html>). Retrieved on 2010-01-07
- [13] Tom Harris (2002-08-29) How Aircraft Carriers Work (<http://science.howstuffworks.com/aircraft-carrier2.htm>). Howstuffworks.com. Retrieved on 2011-05-29.
- [14] Barlow, Maude, and Tony Clarke, "Who Owns Water?" (<http://www.thenation.com/doc/20020902/barlow>) *The Nation*, 2002-09-02, via thenation.com. Retrieved on 2007-08-20.
- [15] Yuan Zhou and Richard S.J. Tol. "Evaluating the costs of desalination and water transport." (http://web.archive.org/web/20090325031333/http://www.uni-hamburg.de/Wiss/FB/15/Sustainability/DesalinationFNU41_revised.pdf) (Working paper). Hamburg University. 2004-12-09. Retrieved on 2007-08-20.
- [16] Desalination is the Solution to Water Shortages (http://www.redorbit.com/news/science/1367352/desalination_is_the_solution_to_water_shortages/), redOrbit, May 2, 2008
- [17] Sitbon, Shirli. "French-run water plant launched in Israel," (<http://www.ejpress.org/article/4873>) *European Jewish Press*, via ejpress.org, 2005-12-28. Retrieved on 2007-08-20.
- [18] "Black & Veatch-Designed Desalination Plant Wins Global Water Distinction," (http://www.edie.net/news/news_story.asp?id=11402&channel=0) (Press release). Black & Veatch Ltd., via edie.net, 2006-05-04. Retrieved on 2007-08-20.
- [19] Perth Seawater Desalination Plant, Seawater Reverse Osmosis (SWRO), Kwinana (<http://www.water-technology.net/projects/perth/>). Water Technology. Retrieved on 2011-03-20.
- [20] "Sydney desalination plant to double in size," (<http://abc.net.au/news/stories/2007/06/25/1961044.htm>) *ABC News* (Australian Broadcasting Corporation), via abc.net.au, 2007-06-25. Retrieved on 2007-08-20.
- [21] Australia Turns to Desalination (<http://www.npr.org/templates/story/story.php?storyId=11134967>) by Michael Sullivan and PX Pressure Exchanger energy recovery devices from Energy Recovery Inc. An Environmentally Green Plant Design (http://www.energyrecovery.com/installations/documents/Perth_CS109EE.pdf). Morning Edition, National Public Radio, June 18, 2007
- [22] Fact sheets (<http://replay.waybackmachine.org/20090412234403/http://www.sydneywater.com.au/EnsuringtheFuture/Desalination/Factsheets.cfm>), Sydney Water
- [23] Water prices to rise and desalination plant set for Port StanvaclAdelaide Now (<http://www.news.com.au/adelaidenow/story/0,22606,22873600-5006301,00.html?from=mostpop>). News.com.au (2007-12-04). Retrieved on 2011-03-20.
- [24] Desalination plant for Adelaide (<http://replay.waybackmachine.org/20090524074010/http://www.ministers.sa.gov.au/news.php?id=2515>). ministers.sa.gov.au. December 5, 2007
- [25] Bernard Humphreys AdelaideNow readers mostly back desalination plant (<http://replay.waybackmachine.org/20090616031331/http://www.news.com.au/adelaidenow/story/0,22606,22881155-5006301,00.html>). AdelaideNow. December 6, 2007
- [26] Kranhold, Kathryn. (2008-01-17) Water, Water, Everywhere... – WSJ.com (http://online.wsj.com/article/SB120053698876396483.html?mod=googlenews_wsj). Online.wsj.com. Retrieved on 2011-03-20.
- [27] Desalination gets a serious look – Friday, March 21, 2008|2 a.m. (<http://www.lasvegassun.com/news/2008/mar/21/desalination-gets-serious-look/>). Las Vegas Sun. Retrieved on 2011-03-20.
- [28] Desalination: A Component of the Master Water Plan (<http://replay.waybackmachine.org/20090418154645/http://www.tampabaywater.org/watersupply/tbdesalhistory.aspx>). tampabaywater.org

- [29] Hydro-Alchemy (http://www.forbes.com/technology/2008/05/08/mitra-energy-recovery-tech-science-cx_sm_0509mitra.html), Forbes, May 9, 2008
- [30] The Arid West—Where Water Is Scarce – Desalination—a Growing Watersupply Source (<http://www.libraryindex.com/pages/2644/Arid-West-Where-Water-Scarce-DESALINATION-GROWING-WATERSUPPLY-SOURCE.html>), Library Index
- [31] UNITED STATES COURT OF APPEALS FOR THE SECOND CIRCUIT August Term, 2005 (http://www.desalresponsegroup.org/files/RiverkeeperEPA1-25-07_decision.pdf). (PDF) . Retrieved on 2011-05-29.
- [32] Heather Cooley, Peter H. Gleick, and Gary Wolff DESALINATION, WITH A GRAIN OF SALT. A California Perspective (http://www.pacinst.org/reports/desalination/desalination_report.pdf), Pacific Institute for Studies in Development, Environment, and Security, June 2006 ISBN 1-893790-13-4
- [33] Australia Turns to Desalination Amid Water Shortage (<http://www.npr.org/templates/story/story.php?storyId=11134967>). NPR. Retrieved on 2011-03-20.
- [34] *Desalination without brine discharge – Integrated Biotechnical System* (<http://www.prototype-creation.de/release3.pdf>), by Nicol-André Berdellé, 02.20.2011
- [35] Gleick, Peter H., Dana Haasz, Christine Henges-Jeck, Veena Srinivasan, Gary Wolff, Katherine Kao Cushing, and Amardip Mann. (November 2003.) "Waste not, want not: The potential for urban water conservation in California." (http://www.pacinst.org/reports/urban_usage/waste_not_want_not_full_report.pdf) (Website). *Pacific Institute*. Retrieved on 2007-09-20.
- [36] Cooley, Heather, Peter H. Gleick, and Gary Wolff. (June 2006.) "Desalination, With a Grain of Salt – A California Perspective." (<http://www.pacinst.org/reports/desalination/index.htm>) (Website). *Pacific Institute*. Retrieved on 2007-09-20.
- [37] Gleick, Peter H., Heather Cooley, David Groves. (September 2005.) "California water 2030: An efficient future." (http://pacinst.org/reports/california_water_2030/ca_water_2030.pdf). *Pacific Institute*. Retrieved on 2007-09-20.
- [38] Sun Belt Inc. Legal Documents (<http://www.sunbeltwater.com/docs.shtml>). Sunbeltwater.com. Retrieved on 2011-05-29.
- [39] The "Passarelli" Process (<http://www.waterdesalination.com/theory.htm>). Waterdesalination.com (2004-11-16). Retrieved on 2012-05-14.
- [40] Team wins \$4m grant for breakthrough technology in seawater desalination (<http://news.asiaone.com/News/AsiaOne+News/Singapore/Story/A1Story20080623-72473.html>), The Straits Times, June 23, 2008
- [41] A Rising Tide for New Desalinated Water Technologies (<http://www.msnbc.msn.com/id/29735521/>), MSNBC, March 17, 2009
- [42] Haruo Uehara and Tsutomu Nakaoka Development and Prospective of Ocean Thermal Energy Conversion and Spray Flash Evaporator Desalination (http://www.ioes.saga-u.ac.jp/VWF/general-review_e.html). ioes.saga-u.ac.jp
- [43] Desalination: India opens world's first low temperature thermal desalination plant – IRC International Water and Sanitation Centre (<http://www.irc.nl/page/24010>). Irc.nl (2005-05-31). Retrieved on 2011-03-20.
- [44] Floating plant, India (http://www.headlinesindia.com/archive_html/18April2007_35210.html). Headlinesindia.com (2007-04-18). Retrieved on 2011-05-29.
- [45] Tamil Nadu / Chennai News : Low temperature thermal desalination plants mooted (<http://www.hindu.com/2007/04/21/stories/2007042109200400.htm>). The Hindu (2007-04-21). Retrieved on 2011-03-20.
- [46] Current thinking (http://www.economist.com/sciencetechnology/displayStory.cfm?story_id=14743791), The Economist, October 29, 2009
- [47] W.E.B. Aruba N.V. – Water Plant (http://www.webaruba.com/index.php?option=com_content&task=view&id=44&Itemid=159). Webaruba.com. Retrieved on 2011-05-29.
- [48] Sundrop Farms Pty Ltd (<http://www.sundropfarms.com.au>). Sundropfarms.com.au. Retrieved on 2012-05-14.
- [49] Seawater Greenhouse Australia construction time lapse (2010) (<http://www.youtube.com/user/SeawaterGreenhouse#p/u/2/yY53De4kQ-Y>). Youtube.com. Retrieved on 2012-05-14.
- [50] Seawater Greenhouse Australia on Southern Cross News (2010) (<http://www.youtube.com/user/SeawaterGreenhouse#p/u/5/gzeBca4kJs0>). Youtube.com. Retrieved on 2012-05-14.
- [51] AL HIDD IWPP – BAHRAIN (<http://web.archive.org/web/20091005112900/http://www.sidem-desalination.com/en/main-references/Hidd/>). sidem-desalination.com
- [52] Al Hidd Desalination Plant (<http://www.water-technology.net/projects/hidd/>). Water Technology. Retrieved on 2011-05-29.
- [53] Durrat Al Bahrain desalination plant (<http://www.water-technology.net/projects/durrat-desalination/>). Water Technology. Retrieved on 2011-05-29.
- [54] Construction starts on Durrat Al Bahrain desalination plant (http://www.desalination.biz/news/news_story.asp?id=4775). Desalination.biz. Retrieved on 2011-05-29.
- [55] Larnaca SWRO Water Desalination Plant (<http://www.water-technology.net/projects/larnaca/>). Water Technology. Retrieved on 2011-03-20.
- [56] AquaGib: Gibraltar – Present Plant (http://www.aquagib.gi/present_plant.html). Aquagib.gi. Retrieved on 2011-03-20.
- [57] LCQ5 : Study on desalination (<http://www.info.gov.hk/gia/general/200701/10/P200701100158.htm>). info.gov.hk (2007-01-10)
- [58] Pilot Plant Study on Development of Desalination Facilities in Hong Kong (http://www.wsd.gov.hk/filemanager/en/share/pdf/pilot_plant_study.pdf). Water Supplies Department, Government of Hong Kong, October 2007, wsd.gov.hk
- [59] Policy Address 2011
- [60] Advisory Committee on the Quality of Water Supplies Minutes of Meeting No. 8 (<http://www.wsd.gov.hk/acqws/filemanager/common/minutes8.pdf>). 1 April 2003. wsd.gov.hk

- [61] With desalination, a once unthinkable water surplus is possible Extracting the Mediterranean Sea's water could provide Israel with an unquenchable supply of the resource it lacks (<http://www.timesofisrael.com/with-desalination-a-once-unthinkable-water-surplus-is-possible/>), Ben Sales, May 30, 2013, Times of Israel, same in Water surplus in Israel? With desalination, once unthinkable is possible (<http://www.jta.org/2013/05/28/news-opinion/israel-middle-east/water-surplus-in-israel-with-desalination-once-unthinkable-is-possible#ixzz2Zm8KCwWR>)
- [62] Israel is No. 5 on Top 10 Cleantech List (<http://www.israel21c.org/briefs/israel-is-no-5-on-top-10-cleantech-list>) in Israel 21c A Focus Beyond (<http://www.israel21c.org/technology/archive>) Retrieved 2009-12-21
- [63] Ashkelon Desalination Plant Seawater Reverse Osmosis (SWRO) Plant (<http://www.water-technology.net/projects/israel/>). Water-technology.net. Retrieved on 2011-05-29.
- [64] Public-Private Partnership Projects (<http://ppp.mof.gov.il/Mof/PPP/MofPPPTopNavEnglish/MofPPPProjectsEnglish/>), Accountant General, Ministry of Finance
- [65] water-technology.net: "Ashkelon Desalination Plant Seawater Reverse Osmosis (SWRO) Plant, Israel" (<http://www.water-technology.net/projects/israel/>)
- [66] Globes Business and Technology News: "Palmachim desalination plant inaugurates expansion" (<http://www.globes.co.il/serveen/globes/docview.asp?did=1000601526>), November 17, 2010
- [67] Globes Business and Technology News: "Funding agreed for expanding Hadera desalination plant" ([http://archive.globes.co.il/searchgl/Production at the plants in Hadera, Palmachim and_s_hd_2L34nD3aqCbmnC30mD3KtE3GsBcXqRMm0.html](http://archive.globes.co.il/searchgl/Production%20at%20the%20plants%20in%20Hadera,%20Palmachim%20and%20s_hd_2L34nD3aqCbmnC30mD3KtE3GsBcXqRMm0.html)), November 6, 2009
- [68] Globes Business and Technology News: "Mekorot wins battle to build Ashdod desalination plant" (<http://www.globes.co.il/serveen/globes/docview.asp?did=1000625564&fid=1725>), February 22, 2011
- [69] Desalination & Water Reuse (<http://www.desalination.biz/about.asp?channel=0>): "IDE reported winner of Soreq desalination contract" (http://www.desalination.biz/news/news_story.asp?id=5163), 15 December 2009
- [70] Seawater Greenhouse wins Tech Awards (2006, Oman & Tenerife) (<http://www.youtube.com/user/SeawaterGreenhouse#p/u/1/6NyDruLA3tY>). Youtube.com. Retrieved on 2012-05-14.
- [71] Sasakura, Samsung \$1.89bn bid lowest for Saudi plant (<http://www.reuters.com/article/idUSLDE64A0WL20100511>). Reuters.com. Retrieved on 2011-05-29.
- [72] Map on this page (<http://www.water-technology.net/projects/shuaiba/shuaiba2.html>). Saudi Arabian plants Retrieved on 2011-05-29.
- [73] INSULAR DE AGUAS DE LANZAROTE S.A. (<http://www.inalsa.es/quienessomos.asp?lang=ing>). INALSA Retrieved on 2011-07-05.
- [74] Seawater Greenhouse Pilot Project – Canary Islands (1994) (<http://www.youtube.com/user/SeawaterGreenhouse#p/u/0/w16rFXzIVY0>). Youtube.com. Retrieved on 2012-05-14.
- [75] Abu Dhabi to Build Three Power and Water Desalination Plants by 2016 to Meet Demand (<http://www.industrialinfo.com/showAbstract.jsp?newsitemID=152606>). industrialinfo.com (2009-11-18). Retrieved on 2011-03-20.
- [76] Thames Water Desalination Plant (<http://www.water-technology.net/projects/water-desalination/>). water-technology.net. Retrieved on 2011-05-29.
- [77] Desalination Facts (<http://www.twdb.state.tx.us/innovativewater/desal/facts.asp>). Texas Water Development Board
- [78] Desalination Projects (<http://www.twdb.state.tx.us/innovativewater/desal/projects.asp>). Texas Water Development Board
- [79] El Paso Water Utilities – Public Service Board\Desalination Plant (http://www.epwu.org/water/desal_info.html). Epwu.org. Retrieved on 2011-03-20.
- [80] Charles Meyer Desalination Facility (<http://www.santabarbaraca.gov/Government/Departments/PW/DesalSum.htm>). santabarbaraca.gov. Retrieved on 2012-06-10.
- [81] Tampa Bay Seawater Desalination Plant (http://www.tampabaywater.org/facilities/desalination_plant/index.aspx). Tampabaywater.org. Retrieved on 2011-03-20.
- [82] Richard Danielson (February 16, 2010) Tampa Bay Water stands to get \$31 million for reaching milestones at desal plant – St. Petersburg Times (<http://www.tampabay.com/news/environment/water/tampa-bay-water-gets-31-million-for-reaching-milestones/1073392>). Tampabay.com. Retrieved on 2012-07-13.
- [83] "Yuma Desalting Plant" (http://www.usbr.gov/lc/yuma/facilities/ydp/yao_ydp.html) U.S. Bureau of Reclamation, retrieved May 1, 2010
- [84] "A fresh start for Yuma desalting plant" (<http://www.latimes.com/news/custom/topofthetimes/topstories/la-me-water-20100501-15,0,1233621.story>) Los Angeles Times, May 1, 2010
- [85] Ionics to build \$120M desalination plant in Trinidad\Boston Business Journal (<http://www.bizjournals.com/boston/stories/1999/10/04/story7.html>). Bizjournals.com. Retrieved on 2011-03-20.
- [86] Trinidad Desalination Plant ([http://www.waterindustry.org/New Projects/ionics-2.htm](http://www.waterindustry.org/New%20Projects/ionics-2.htm)). Waterindustry.org (2000-10-26). Retrieved on 2011-03-20.
- [87] including images of the gland and its function

Further reading

- Committee on Advancing Desalination Technology, National Research Council. (2008). *Desalination: A National Perspective* (http://www.nap.edu/catalog.php?record_id=12184). National Academies Press.

Articles

- Desalination: The next wave in global water consumption (http://www.tlvinsider.com/tlvinsider/nl3/interviews?name=nl3_interview2) from TLVInsider (<http://www.tlvinsider.com>)
- Elimelech, M.; Phillip, W. A. (2011). "The Future of Seawater Desalination: Energy, Technology, and the Environment" (<http://physics.indiana.edu/~brabson/p310/WaterDesalEgy.pdf>). *Science* **333** (6043): 712–717. doi: 10.1126/science.1200488 (<http://dx.doi.org/10.1126/science.1200488>). PMID 21817042 (<http://www.ncbi.nlm.nih.gov/pubmed/21817042>). Significant review article.

External links

- International Desalination Association (<http://www.idadesal.org>)
- Desalination timeline (<http://www.desalyearbook.com/desalination-timeline>)
- Examples of sea water desalination plants by the WWWS AG (<http://wwws-ag.com/Sea-water-treatment.732.0.html>)
- GeoNoria Solar Desalination Process (<http://geonoria.org>)
- National Academies Press|Desalination: A National Perspective (http://books.nap.edu/openbook.php?record_id=12184&page=R1)
- World Wildlife Fund|Desalination: option or distraction? (<http://assets.panda.org/downloads/desalinationreportjune2007.pdf>)
- European Desalination Society (<http://www.edsoc.com>)
- IAEA – Nuclear Desalination (<http://www.iaea.org/nucleardesalination/>)
- DME – German Desalination Society (<http://www.dme-ev.de>)
- Large scale desalination of sea water using solar energy (<http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.142.5296>)
- Desalination by humidification and dehumidification of air: state of the art (<http://www.desline.com/articoli/4107.pdf>)
- Zonnewater – optimized solar thermal desalination (distillation) (<http://www.zonnewater.net>)
- SOLAR TOWER Project – Clean Electricity Generation for Desalination. (<http://www.enviromission.com.au>)
- Desalination bibliography Library of Congress (<http://www.loc.gov/rr/scitech/tracer-bullets/desalinationtb.html>)
- Water-Technology (<http://www.water-technology.net/projects/>)
- Cheap Drinking Water from the Ocean (http://www.technologyreview.com/read_article.aspx?ch=nanotech&sc=&id=16977&pg=1) – Carbon nanotube-based membranes will dramatically cut the cost of desalination
- Solar thermal-driven desalination plants based on membrane distillation (<http://www.desline.com/articoli/5140.pdf>)
- Encyclopedia of Water Sciences, Engineering and Technology Resources (<http://www.eolss.net/>)
- wind-powered desalination plant in Perth, Australia, is an example of how technology is insulating rich countries from impacts of climate change, while poor countries remain particularly vulnerable. (<http://www.nytimes.com/2007/04/03/science/earth/03clim.html/The>)
- The Desal Response Group (<http://www.desalresponsegroup.org>)
- Encyclopedia of Desalination and water and Water Resources (<http://www.desware.net/>)
- Desalination & Water Reuse – Desalination news (<http://www.desalination.biz/>)
- Desalination: The Cyprus Experience (http://www.ewra.net/ew/pdf/EW_2004_7-8_04.pdf)

- Desalination: The Jersey Water plant at La Rosière, Corbiere (http://www.jerseywater.je/pdf/files/fact_sheets/raw_water_processing.pdf)
- Desalination and Membrane Technologies: Federal Research and Adoption Issues (<http://www.fas.org/sgp/crs/misc/R40477.pdf>) Congressional Research Service

In situ chemical oxidation

In situ chemical oxidation (ISCO), a form of advanced oxidation processes and advanced oxidation technology, is an environmental remediation technique used for soil and/or groundwater remediation to reduce the concentrations of targeted environmental contaminants to acceptable levels. ISCO is accomplished by injecting or otherwise introducing strong chemical oxidizers directly into the contaminated medium (soil or groundwater) to destroy chemical contaminants in place. It can be used to remediate a variety of organic compounds, including some that are resistant to natural degradation.

Chemical oxidation is one half of a redox reaction, which results in the loss of electrons. One of the reactants in the reaction becomes oxidized, or loses electrons, while the other reactant becomes reduced, or gains electrons. In ISCO, oxidizing compounds, compounds that give electrons away to other compounds in a reaction, are used to change the contaminants into harmless compounds.^[1] The *in situ* in ISCO is just Latin for "in place", signifying that ISCO is a chemical oxidation reaction that occurs at the site of the contamination.

The remediation of certain organic substances such as chlorinated solvents (trichloroethene and tetrachloroethene), and gasoline-related compounds (benzene, toluene, ethylbenzene, MTBE, and xylenes) by ISCO is possible. Some other contaminants can be made less toxic through chemical oxidation.^[2]

A wide range of ground water contaminants react either moderately or highly with the ISCO method, and ISCO can also be used in a variety of different situations (ex. unsaturated vs saturated ground, above ground or underground, etc.), so it is a popular method to use.

History

Fenton's reagent (hydrogen peroxide catalyzed with iron) and potassium permanganate are the oxidants that have been used the longest, and are now used the most widely. The systems of using hydrogen peroxide were based on the work of H.J.H. Fenton, who used iron salts to catalyze the compound. Hydrogen peroxide was first used in 1985 to treat a formaldehyde spill at Monsanto's Indian Orchard Plant in Springfield, Massachusetts. At this site, a 10% solution of hydrogen peroxide was injected into a formaldehyde plume. Fenton's reagent was initially used to treat hydrocarbon sites where benzene, toluene, and ethylbenzene were present.

As the industry shifted its focus to the remediation of chlorinated solvents, hydrogen peroxide was found to be effective in both the hydrocarbon industry and the chlorinated solvent industry. Scientists also found that permanganate could be used on chlorinated solvents. Permanganate based ISCO started to be used in the late 1990s. At this time, ISCO had also become an established remedial technology.

The development of sodium persulfate for ISCO began in the late 1990s because of the limitations in using peroxide or permanganate as oxidants. Peroxide has such a short life that it can not be transported properly. Permanganate only treats chlorinated solvents with double bonds and is easily used up by organic material in soil. Persulfate is more stable, treats a wider range of contaminants, and is not used up by soil organics as easily.

Agents of Oxidization

Common oxidants used in this process are permanganate (both sodium permanganate and potassium permanganate), Fenton's Reagent, persulfate, and ozone. Other oxidants can be used, but these four are the most commonly used.

Permanganate

Permanganate is used in groundwater remediation in the form of potassium permanganate (KMnO

4) and sodium permanganate (NaMnO

4). Both compounds have the same oxidizing capabilities and limitations and react similarly to contaminants. The biggest difference between the two chemicals is that potassium permanganate is less soluble than sodium permanganate.

Potassium permanganate is a crystalline solid that is typically dissolved in water before application to the contaminated site. Unfortunately, the solubility of potassium permanganate is dependent on temperature. Because the temperature in the aquifer is usually less than the temperature in the area that the solution is mixed, the potassium permanganate becomes a solid material again. This solid material then does not react with the contaminants. Over time, the permanganate will become soluble again, but the process takes a long time. This compound has been shown to oxidize many different contaminants but is notable for oxidizing chlorinated solvents such as perchloroethylene (PCE), trichloroethylene (TCE), and vinyl chloride (VC). However, potassium permanganate is unable to efficiently oxidize diesel, gasoline, or BTEX.

Sodium permanganate is more expensive than potassium permanganate, but because sodium permanganate is more soluble than potassium permanganate, it can be applied to the site of contamination at a much higher concentration. This shortens the time required for the contaminant to be oxidized. Sodium permanganate is also useful in that it can be used in places where the potassium ion cannot be used. Another advantage that sodium permanganate has over potassium permanganate is that sodium permanganate, due to its high solubility, can be transported above ground as a liquid, decreasing the risk of exposure to granules or skin contact with the substance.

The primary redox reactions for permanganate are given by the equations:

1. $\text{MnO}_4^- + 8\text{H}^+ + 5\text{e}^- \rightarrow \text{Mn}^{2+} + 4\text{H}_2\text{O}$ (for pH < 3.5)
2. $\text{MnO}_4^- + 2\text{H}^+ + 3\text{e}^- \rightarrow \text{MnO}_2 + 4\text{OH}^-$ (for pH 3.5 to 12)
3. $\text{MnO}_4^- + \text{e}^- \rightarrow \text{MnO}_4^{2-}$ (for pH > 12)

The typical reaction that occurs under common environmental conditions is equation 2. This reaction forms a solid product, MnO

2.

The advantage of using permanganate in ISCO is that it reacts comparatively slowly in the subsurface which allows the compound to move further into the contaminated space and oxidize more contaminants. Permanganate can also help with the clean up of **materials** that are not very permeable. In addition, because both sodium permanganate and potassium permanganate solutions have a density greater than water's density, permanganate can travel through the contaminated area through density-driven diffusion.

The use of permanganate creates the byproduct MnO

₂, which is naturally present in the soil and is therefore a safe byproduct. Unfortunately, several studies have shown that this byproduct seems to cement sand particles together forming rock-like material that has very low permeability. As the rock-like materials build up, it blocks the permanganate from getting to the rest of the contaminant and lowers the efficiency of the permanganate. This can be prevented by extracting the MnO₂ from the contaminated area.

Fenton's Reagent

Fenton's reagent is basically a mixture of ferrous iron salts as a catalyst and hydrogen peroxide. A similar sort of reaction can be made by mixing hydrogen peroxide with [ferric] iron (Iron III). At a low pH, it forms hydroxyl radicals (·OH) that oxidize contaminants such as chlorinated solvents, fuel oils, and BTEX. Unfortunately, the contaminated groundwater that needs to be treated has a pH level that is at or near neutral. Due to this, there are controversies on whether ISCO using Fenton's reagent is really a Fenton reaction. Instead, scientists call these reactions Fenton-like.

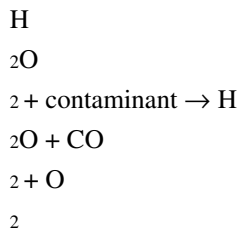
The Fenton chemistry is complex and has many steps, including the following:

1. $\text{Fe}^{2+} + \text{H}_2\text{O}_2 \rightarrow \text{Fe}^{3+} + \text{OH}\cdot + \text{OH}^-$
2. $\text{Fe}^{3+} + \text{H}_2\text{O}_2 \rightarrow \text{Fe}^{2+} + \text{OOH}\cdot + \text{H}^+$
3. $\text{HO}\cdot + \text{H}_2\text{O} \rightarrow \text{Fe(III)} + \text{HO}\cdot$
4. $\text{HO}\cdot + \text{H}_2\text{O} \rightarrow \text{H}^+ + \text{O}_2$
5. $\text{Fe(III)} + \text{HO}\cdot \rightarrow \text{Fe(II)} + \text{O}_2$
6. $\text{Fe(II)} + \text{HO}\cdot \rightarrow \text{Fe(III)} + \text{H}_2\text{O}$
7. $\text{HO}\cdot + \text{H}_2\text{O} \rightarrow \text{H}^+ + \text{O}_2$

These reactions do not occur step by step but simultaneously.

When applied to In Situ Chemical Oxidation, the collective reaction results in the degradation of contaminants in the presence of Fe²⁺

as a catalyst. The overall end result of the process can be described by the following reaction:



Advantages of this method include that the hydroxyl radicals are very strong oxidants and react very rapidly with contaminants and impurities in the ground water. Moreover, the chemicals needed for this process are inexpensive and abundant.

This method, however, is very exothermic. Over the course of the reaction, the water starts heating up and, in some cases, can boil water out of the soil. The chemicals used in the process are detrimental to microbes and rapidly degrade the soil, so Fenton's reagent must be used with extreme caution. The hydroxyl radicals also react with many other substances other than the targeted contaminant, so it is not as effective in soils containing carbonate, bicarbonate, and organic matter.

Persulfate

Persulfate is a newer oxidant used in ISCO technology. The persulfate compound that is used in groundwater remediation is in the form of peroxodisulfate or peroxydisulfate (S

2O_2^-

8) but is generally called a persulfate ion by scientists in the field of environmental engineering. More specifically, sodium persulfate is used because it has the highest water solubility and its reaction with contaminants leaves least harmful side products. Although sodium persulfate by itself can degrade many environmental contaminants, the sulfate radical SO^-

4 is usually derived from the persulfate because sulfate radicals can degrade a wider range of contaminants at a faster pace (about 1,000–100,000 times) than the persulfate ion. Various agents, such as heat, ultraviolet light, high pH, hydrogen peroxide, and transition metals, are used to activate persulfate ions and generate sulfate radicals.

The sulfate radical is an electrophile, a compound that is attracted to electrons and that reacts by accepting an electron pair in order to bond to a substance called a nucleophile. Therefore the performance of sulfate radicals is enhanced in an area where there are many electron donating organic compounds. The sulfate radical reacts with the organic compounds to form an organic radical cation. Examples of electron donating groups present in organic compounds are the amino ($-\text{NH}_2$), hydroxyl ($-\text{OH}$), and alkoxy ($-\text{OR}$) groups. Conversely, the sulfate radical does not react as much in compounds that contain electron attracting groups like nitro ($-\text{NO}_2$) and carbonyl ($\text{C}=\text{O}$) and also in the presence of substances containing chlorine atoms. Also, as the number of ether bonds increases, the reaction rates decrease.

When applied in the field, persulfate must first be activated (it must be turned into the sulfate radical) to be effective in the decontamination. The catalyst that is most commonly used is ferrous iron (Iron II). When ferrous iron and persulfate ions are mixed together, they produce ferric iron (iron III) and two types of sulfate radicals, one with a charge of -1 and the other with a charge of -2 . New research has shown that Zero Valent Iron (ZVI) can also be used with persulfate with success. The persulfate and the iron are not mixed beforehand, but are injected into the area of contamination together. The persulfate and iron react underground to produce the sulfate radicals. The rate of contaminant destruction increases as the temperature of the surroundings increases.

The advantage of using persulfate is that persulfate is much more stable than either hydrogen peroxide or ozone above the surface and it does not react quickly by nature. This means fewer transportation limitations, it can be injected into the site of contamination at high concentrations, and can be transported through porous media by density driven diffusion. The disadvantage is that this is an emerging field of technology and there are only a few reports of testing it in the field and more research needs to be done with it.

Ozone

While oxygen is a very strong oxidant, its elemental form O_2

is not very soluble in water. This poses a problem in ground water remediation, because the chemical must be able to mix with water to remove the contaminant. Fortunately, ozone (O_3)

is about 12 times more soluble than O_2

and, although it is still comparably insoluble, it is a strong oxidant.

The unique part of ozone oxidation is its in-situ application. Because, unlike other oxidants used in ISCO, it is a gas, it needs to be injected into the contamination site from the bottom rather than the top. Tubes are built into the ground to transport the ozone to its starting place; the bubbles then rise to the surface. Whatever volatile substances are left over are sucked up by a vacuum pump. Because the bubbles travel more vertically than horizontally, close placement of ozone injection wells is needed for uniform distribution.

The biggest advantage in using ozone in ISCO is that ozone does not leave any residual chemical like persulfate leaves SO_4^{2-}

or permanganate leaves MnO_2

2. The processes involved with ozonation (treating water with ozone) only leave behind O_2

2. Ozone can also react with many of the important environmental contaminants. In addition, because ozone is a gas, adding ozone to the bottom of the contaminant pool forces the ozone to rise up through the contaminants and react.

Because of this property, ozone can also be delivered more quickly. Also, in theory, H_2O_2

$2O_2$

2 co-injected with ozone will result in $-OH$ ions, which are very strong oxidants.

However, ozone has many properties that pose problems. Ozone reacts with a variety of contaminants, but the problem is that it also reacts quickly with many other substances such as minerals, organic matter, etc. that are not the targeted substances. Again, it is not very soluble and stays in gas form in the water, which makes ozone prone to nonuniform distribution and rising up to the top of contamination site by the shortest routes rather than traveling through the entire material. In addition, ozone must be generated, and that requires a huge amount of energy.

Implementation

The primary delivery mechanism for ISCO is through perforated, hollow metal rods hammered into the ground by "direct-push" drilling methods or by injecting the oxidant into wells installed using hollow stem auger, rotary drilling methods. One advantage of injection wells is that they can be used for multiple applications of the oxidant material, while direct push injection techniques are generally quicker and less expensive. Injection wells for ozone are typically constructed of a 1–2" stainless-steel screen set in sand pack, grouted to the surface using a combination of cement and bentonite clay. Often, a field pilot study must be performed to determine injection parameters and well spacing.

Oxidants such as Permanganate and Fenton's Reagent are delivered as water-based solutions. These substances are injected into the aquifer and then allowed to propagate by gravity and water current. As contaminants are encountered, the substances oxidize them and purify the water. Ozone is delivered (sparged) as a gas in either a dry air or oxygen carrier gas. Specialized equipment is required for in-situ oxidation via ozone gas injection. The ozone has to be pumped into the groundwater from the bottom of the aquifer because the ozone gas is less dense than the water. As the ozone travels through the aquifer against gravity, it reacts with contaminants along the way. However, there are some specific methods of oxidant delivery including injection probes, hydraulic fracturing, soil mixing, vertical wells, horizontal wells, and treatment walls.

Injection probes

Injection probes are used in areas where there is very low permeability. A small diameter probe (2 to 4 cm in diameter) is rotated or pushed into the ground while reagents are inserted into it at low pressure. The reagents travel down the core of the probe and exit out through small perforations along the sides of the probe which are located at certain intervals. The reagents travel away from the core by going into existing cracks and pores and create a "halo of reactivity" (from pg. 182 or *Principles and Practices of In Situ Chemical Oxidation Using Permanganate*). In order to optimize the amount of contaminant that is oxidized, the probes are set into the ground relatively close together, about .6-1.2 meters apart.

Hydraulic fracturing

Hydraulic fracturing is the process of artificially creating fractures in a site that has low permeability and then filling the fractures with oxidants. First a hole is drilled into the ground, and then a forceful jet of water is used to create fractures. Course sand, which allows just enough permeability for oxidants to get through, is used to fill the fractures and prevent them from closing up, and after that, the oxidant is injected into the fracture.

Soil mixing

Soil mixing can be used to deliver solid or liquid forms of oxidants to contaminated soil. For near surface contamination, standard construction equipment can be used. In order to apply this method in-situ and in deep soil, the oxidant must be pumped through a Kelly bar (a piece of earth drilling equipment) to the place where the soil needs to be oxidized. The soil then has to be mixed by using mixing blades attached to the Kelly bar.

Horizontal and vertical wells

Horizontal and vertical well networks are basically the use of long pipes that lead in and out of the contaminated aquifer or plume used to inject oxidants and extract the treated ground water. Vertical wells consist of one injection well and a number of extraction wells surrounding it. Horizontal well networks work similarly, but the pipe is slightly L-shaped at the bottom and injects oxidants and extracts treated groundwater horizontally. Horizontal wells are used especially when oxidants need to be delivered to thin layers of saturation.

Treatment walls

Treatment walls are used to deliver oxidants to the end of a contaminant plume and can be used to prevent the migration of an oxidant. The walls usually consist of continuous trenches that are connected to a piping network into which oxidants can be injected into. Another version of this delivery system is the use of a disconnected series of vertical wells to inject the oxidant into the ground water. The factors that affect treatment wall application and performance are similar to the factors that effect the performance of permeable reactive barriers.

Case studies

The ISCO technology has been tested many times in the field. The following are a few examples of studies that have been conducted to observe the effectiveness of ISCO.

Naval Air Station North Island

In January 2007, the groundwater around the Naval Air Station North Island in San Diego County, California was treated. This test treated a total of 60,000 gallons of groundwater and used about 22,646 pounds of sodium persulfate to do it. No catalysts were added to the persulfate, but there was a significant amount of contaminant reduction. The production of radical was concluded to be due to the elevated temperature of the groundwater (20 °C-24 °C). At the end of 19 days after the last injection of sodium persulfate, there was an overall TCE concentration reduction of

greater than 90%.^[3]

Space Launch Complex 37

Space Launch Complex 37 supported the Saturn spacecraft launches from 1961–1971. Activities in the Complex included parts cleaning and engine flushing, which left two chlorinated volatile organic compound (CVOCs) source areas. The United Launch Alliance also used the area for launching the Delta IV launch vehicles prior to any remediation activities on the site. Maximum concentrations of CVOCs in the site were 9500 micro grams/Liter of cis 1,2-DCE and 7900 micro grams/Liter of vinyl chloride. Both sites were cleaned up with the use of ozone. An ozone injection grid was used that consisted of 116 stainless steel wells. After 16 months of ozone treatment, there was a contaminant mass reduction of 44% in one site and 70% in the other site.^[4]

Nebraska Ordnance Plant

The Nebraska Ordnance Plant is located near Mead, Nebraska was a military facility in World War II that produced bombs, rockets, and shells. In the process of creating these products, high explosives like 2,4,6-trinitrotoluene (TNT) and hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) were used; to reduce the plant's workers' chemical exposure to these materials, RDX and TNT residues that collected on the floor were washed away with water routinely. The water went outside and into unlined ditches. The soil in the plant consequently became contaminated with RDX and TNT. Use of trichloroethene (TCE) to degrease pipelines further contaminated the area. The contaminants over the course of fifty years has also entered the groundwater in that area.

In order to stop the spread of the contaminated groundwater, an elaborate system of 11 extraction wells has been placed to contain the plumes. This method treats the water with granular activated carbon. This field was chosen as a testing site to see how effectively permanganate could remove explosive contaminants. On the field, two injection wells were placed so that a curtain of permanganate existed between them through which the contaminant plume would flow through. The results of the oxidation was a temporary decrease of the contaminant in the wells by 70–80%, but permanganate was not evenly distributed through the curtain. However, the test showed that permanganate was an effective tool to use to remove explosive contaminants from groundwater.

Performance application

The effectiveness of the oxidation is contingent on the site lithology, the residence time of the oxidant, the amount of oxidant used, the presence of oxidizing materials other than the targeted contaminant, the degree of effective contact between the oxidant and the contaminant(s), and the kinetics of the oxidation reaction between the oxidant and contaminant.

The soil and groundwater are tested both before and after oxidant application to verify the effectiveness of the process. Monitoring of gases given off during oxidation can also help determine if contaminants are being destroyed. Elevated levels of CO₂ is an indicator of oxidation.

Safety and hazards

The four main types of oxidants that are used in ISCO—Fenton's reagent, ozone, permanganate, and persulfate—are all strong oxidizing agents and pose serious hazards to the people who are working with them. For worker safety, site that are using ozone as the oxidant must test ozone levels in the air periodically because ozone has adverse respiratory effects. All oxidants must be stored properly so that they do not decompose and workers must ensure that they do not have skin contact with any of the oxidants.

Some ISCO compounds can react aggressively with organic contaminants and must be used with care on the site. Fenton's reagent in particular is highly exothermic and can cause unwanted effects on microbial life in the aquifer if it is not used carefully.

Potential improvements

Currently ISCO is mostly applied by itself, but it may be possible to combine ISCO with other technologies such as in situ chemical reduction (ISCR). Because ISCO is not effective at treating contaminant plumes, ISCO could be used to treat the source of the contaminant while ISCR treats the plumes.^[5]

The ISCO delivery technology also could be enhanced. Currently, an oxidant is injected into the contaminated site and is spread by the natural movement of water. This method is not very effective because many of the oxidants, especially the stronger ones, are not very stable and react with other substances soon after being injected into the site. This problem could be fixed by creating oxidants that are more stable and specifically targeted to contaminants, so that they do not oxidize other substances. The delivery systems could also be improved so that the oxidants are sent to the correct locations.

References

- [1] <http://www.clu-in.org/download/citizens/oxidation.pdf>
- [2] <http://www.mecx.net/papers/SOQs/MECX%20Environmental%20Consulting%20&%20%20Remediation%20SOQ.pdf>
- [3] D-028, in K.A. Fields and G.B. Wickramanayake (Chairs), *Remediation of Chlorinated and Recalcitrant Compounds—2010. Seventh International Conference on Remediation of Chlorinated and Recalcitrant Compounds* (Monterey, CA; May 2010). ISBN 978-0-9819730-2-9, Battelle Memorial Institute, Columbus, OH, www.battelle.org/chlorcon.
- [4] D-030, in K.A. Fields and G.B. Wickramanayake (Chairs), *Remediation of Chlorinated and Recalcitrant Compounds—2010. Seventh International Conference on Remediation of Chlorinated and Recalcitrant Compounds* (Monterey, CA; May 2010). ISBN 978-0-9819730-2-9, Battelle Memorial Institute, Columbus, OH, www.battelle.org/chlorcon.
- [5] Siegrist, R.L.; Crimi, M.; Simpkin, T.J.; Brown, R.A.; Unger, M.. "ISCO status and future directions". In *In Situ Chemical Oxidation for Groundwater Remediation*; Siegrist, R.L.; Crimi, M.; Simpkin, T.J. (Eds.); Springer, February 2011.

External links

Additional information on this topic may be found at the following sites:

1. *In Situ Chemical Oxidation for Groundwater Remediation—Book* (<http://www.amazon.co.uk/Oxidation-Groundwater-Remediation-Environmental-Technology/dp/1441978259>)
2. *Principles and Practices of In Situ Chemical Oxidation: A Short Course* (<http://symposium.serdp-estcp.org/Short-Courses/SC2>)
3. *Reaction and Transport Processes Controlling In Situ Chemical Oxidation of DNAPLs* (<http://www.serdp.org/content/download/5486/76571/file/ER-1290-FR.pdf>)
4. *Technology Practices Manual* (<http://www.serdp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Persistent-Contamination/ER-200623>)
5. US EPA Clean-Up Information (http://www.clu-in.org/techfocus/default.focus/sec/In_Situ_Oxidation/cat/Overview/)
6. Oregon Health and Science University Rate Constant Database (<http://cgr.ebs.ogi.edu/iscokin/>)

Article Sources and Contributors

Water purification *Source:* <http://en.wikipedia.org/w/index.php?oldid=585259180> *Contributors:* 11Dunc11, 16@r, 2over0, 5 albert square, 7, A Softer Answer, ABF, Acalamari, Acroterion, AdjustShift, Agesworth, Agua estructurada, Ahruman, Akamad, Alan Liefting, Alansohn, AlexGWU, Alexius08, Alienraider, Allen4names, Alobodig, Alpha Quadrant (alt), AlternateAlternateHamburger, Andrewman327, Andrewpmk, Anna512, Ansell, Aoi, Arakunem, Arthena, Ashvidia, AstroHurricane001, Avenged Eightfold, Avoided, Ayls, B DYatkin, Bantman, BedWellington, Beland, Benzy16, BigStickCharly, Bigbrand, Biswasinha, Bjorn som tegner, Blathnaid, Bobblewik, Bobbnex, Bobo192, Bongwarrior, Bozoid, Bunnyhop11, Bushford, CDCwater, CDM2, Cacycle, Caltas, CambridgeBayWeather, Can't sleep, clown will eat me, CanadianLinuxUser, CanisRufus, Capricorn42, Captain-tucker, Casomerville, CecilWard, CharlesC, Chazchaz101, Ched, ChildSurvival, ChrisGualtieri, Chriswaterguy, Closedmouth, Cometstyles, Cool Science 1234, Corvus cornix, Cromwell, DARTH SIDIOUS 2, DSchantz, Dvdm, Dalstadt, DanielCD, DarkShroom, Darkmer, Darknval man, Darth Panda, Daven200520, Davidbking, Debresser, Dekatech, Deli nk, DerHexer, Dhollm, Dhp1080, Diannaa, Dincon, Discospinster, Djcam, Dlohcierkim's sock, Dmmaus, Dmurbans, Donner60, Dozenist, Dr.Bhatta, DrFod, Dreindorf, Drinkingwaterdoc, Dspanogle, Dycedarg, Dzubint, EHartweg, ESKog, EagleOne, EarthPerson, Edgar181, Edward, Eequor, Egradsss, Ejhoeckstra, Eloquence, Elsp, Emvn, EncMstr, Encyo, Epbr123, Epicgenius, Espoo, Eubulides, Everyking, Ewen, Excirial, Expertwatersolutions, Fagopyrum, Fawcett5, FayssalF, Fedir, Feedmecereal, Femto, Finalius, Flannel-wing jay, Flewis, FoPen, Foxj, Fraggel81, Frakey17, Fratrep, Freedomlinux, Freefighter, Fæ, GTZ-44-ecosan, Gabriel Kiehlund, Gail, Gaius Cornelius, Galmicmi, Ghaly, Giftlite, Ginsuloff, Gobonobo, Gogo Dodo, GraemeL, GregorB, Gstricky, Guidod, Gurch, Gwen Gale, Gwscience, Gwltld, Gz33, H2O, HSSoient, HRS IAM, Happysailor, Hard Raspy Sci, Harvcahoon, Hawaiian717, Hazard-SJ, Heracles31, Hmains, Hobartimus, Hobsonlane, Husond, Hut 8.5, Hydrargyrum, Hydrogen Iodide, I am One of Many, IRP, ISTB351, Iain99, Icairms, Iconprocessys, IddoGenuth, Immunize, ImperatorExercitus, ImperfectlyInformed, Incan warrior, Ineck, Ingolfson, Ioth, ItascaSystems, ItsZippy, Ivney, Ixf64, J.delanoy, J44xm, JHunterJ, JIMBOB2001, JNW, JSterling, JTN, Jabam, Jac16888, Jackelfive, Jaganath, JavierMC, Jbillh, Jcw69, Jeffalbert, Jim1138, JimVC3, Jimjamjak, Jimmy Hammerfist, Joel D. Reid, John Cline, John Nevard, John Reaves, John Wormell, John254, JohnOwens, Jothuton, Joviegat, JonFD, Jonrwilson, Jossi, Jovianeye, Jrcrn001, Jtg, Juande, Julagi0oolia, Jwy, KVDP, Karuna8, Kate, Kcs2c, Keilana, Khalid hassani, Kikos, Kingutd, Krinos2, Kruckenberg.1, Ksyrie, Kukuni, L Kensington, LFaraneu, Langbein Rise, Lawnrnd, LeadSongDog, Leafyplant, Leca67, Lingo Design, M dorothy, MER-C, Ma8thw, MaRiGra, Mac, Madhero88, Manguela, Mapamapa, Marcinj, Marek69, Margin1522, MarkBolton, Marnevell, Materialscientist, Maxis ftw, Mbrell, Mbeychok, Mbrock9, Mbshea, Mdebets, Mdewan6, Mean as custard, Megan.rw1, MelbourneStar, Mentifisto, Metaeducation, Mets501, Mfotia, Michaelianier, Mike Rosoff, Mikeo, Mion, Mirboj, MithrandirAgain, Mmarrre, Moreau1, MrOllie, Murray Langton, Mushroom, Myfanwy, Mysiad, N419BH, Nabesue, Nabla, Nagy, Gabriel Cornelius, NawlinWiki, Ncmvocalist, Ndkl, New9699, Nick, Nickflybob, Nima-Related, Ninington, NotAbel, Nsaa, NuclearWarfare, Numbermaric, Nv8200p, OMCV, OMF12, Oasisbob, Oda Mari, OhanaUnited, Ohnoitsjamie, Oliver brookes 99, Omegatron, Omicron18, One Night In Hackney, Optichan, OrangeLisa, Otaersiarom, Oxymoron83, PC78, PaddyM, PandemoniumFortress, PapaLeo NL, Paul 012, Pavankng, Pb30, Peardon, Persian blue, Peter Horn, Peter in s, PetieDP, Philip Trueman, Phmoreno, Physchim62, Picrophilus, Pietrow, Pimpstick69, Pinethicket, Piroroakill, Pjacob, Planetbitter, Plugwash, Pmlineditor, Pornstar1234, Professor water, Promethea, Quantinv57, R'n'B, Racarv11, Radagast, Radon210, Rainbird, Ralajer, Rama, Ravedave, Rcsprinter123, Rdsmith4, Rettetast, Revotfel, RexNL, Rhobite, Rich Farmbrough, Rjwilmsi, Rlaeger, Robert Bond, Ronz, SHRIPADVAIDYA, SJP, Salvo giuliano, Sam Hocevar, Sanjhee, Saved theirs, SchiftyThree, Schzmo, Seaphoto, Sekar2001, Senatorjpt, Seraphim, Shanel, Shiftchange, Shinkolobwe, Sinus, Skamecray123, Skeksike, Skysmith, Slimserver, Smack, Smalljim, Smokefoot, Snehakrishna, SoSaysChappy, Sonnet72, Sophus Bie, Spathi, Speciate, Spiffy sperry, SpuriousQ, Stacy55077, Stemonitis, Sterichindrance, Steven Zhang, Sun Creator, Sunnyoraish, Sushiflinger, SweetP112, Sweettooth89, Soko, Syrthiss, Tabor, TastyPoutine, Tencv, Techman224, Tedickey, Teilhardo, Tentinator, The Anome, The Thing That Should Not Be, TheJonathanLoja, Thingg, Thumperward, Tide rolls, TimVickers, Tom harrison, Tommy2010, Tonyedmonds, Trlabarge, TurboChan, TwoTwoHello, Uber-Nerd, Ugog Nizdast, UkPaolo, Ukexpat, Ulric1313, Uyanga, V8rik, Valerius Tygart, Vegaswikivian, Vellela, Vexorg, Vingerhoet, Vinmax, Vladislav.dobrovann, Vrenator, Vsmith, WLU, Waterfilters, Waterpizaf, Watertruth, Wavelength, Waycool27, WhatamIdoing, Widr, WikiDao, Wikipelli, Wikiprakashphp, Wikiwaterboy, Will Beback, William Avery, Woohokitty, Wsiemund, Y2000, Yaf, Ykh Wong, Yobol, Yousaf465, Yuckfoo, Yuyudevil, Zrmpx95, 1191 anonymous edits

Boiling *Source:* <http://en.wikipedia.org/w/index.php?oldid=574757421> *Contributors:* 16@r, 63.192.137.xxx, Acidburn24m, Ahoerstemeier, AjaxSmack, Alansohn, Alex Bakharev, Alexav8, Amberroom, Amp, Angela, Anonymous56789, Ansh666, Ap, Avjoska, Awkwardseaturtle7, Baiji, Barbara Shack, Bdentremont, Bibliomaniac15, Bkell, Bobo192, Brandon5485, Brcopeland, Bro(sv), BruceLee, Burschik, CanisRufus, Chemical Engineer, Clark89, Cntras, Conversion script, Cont Frankenberry, Css, DJ Clayworth, DMacks, Dectype, Devinhgaffney, Discospinster, Dominus, Donareiskoffer, Dreadstar, EdC, Elvim, Enirac Sum, Epbr123, Erianna, Felix0411, Flowerpotman, Fluouss, FocalPoint, Fubar Obfusco, Furrykef, Gail, Gentegen, GianniG46, Gilliam, Glaue23, Graham87, Grim23, Gveret Red, Hello Kelson, Herbal Lemon, Heron, Hintswen, Hobsonlane, Iokseeng, Irpen, Isaac, J.delanoy, JRRobinson, Jakhohn, Jamesontai, Jan eissfeldt, Jahnienji, Jdpipe, Jitanni, Karada, Kelvinsong, Khvalamde, Kilopi, Kjolb, Kms, Krystine, LCMJ, La goutte de pluie, LeaveLeaves, Lee J Hayward, Legotech, Liffey, LiHelpa, LingNut, Linuxlad, Longhair, Lowellian, M0rphzone, Mandarax, Mark Arsten, Marvinandmilo, MaxEnt, Mbeychok, Mentifisto, Mlindstr, Muriel Gottrop, Musiccra, Naufana, Nbarth, Neelix, Nickkim123, NotWith, OfTheGreen, Ohconfucius, Ojigiri, Olivier, OllieFury, Onimesh, Orangutan123, Oxymoron83, Paradoctor, Patrick, Pharaoh of the Wizards, Philip Trueman, Pion, Ppntori, Quantpole, Qxz, R.N.Jacobson.Ph.D., RFeireira, Racexr11, Ratdz70095, Reatlas, RexNL, Rifleman 82, Saran2008msc, Schmendrick, Shoofdeath, Sjö, Slaviboy, Smk1895x, SpaceFlight89, Stangbat, Stephenb, Stevedeele, Synergy, Tanner Swett, Tanner-Christopher, Tanthalas39, Tawker, The Anome, The Thing That Should Not Be, Thecheesykid, Thegod2121, Thingg, Thumperward, Tide rolls, Tlnv7, Trovatore, Trusilver, Ubiquity, Ugog Nizdast, Umbralcorax, Una Smith, Unobtruse, Vellela, Venny85, Vqors, WOSlinker, Wetman, Whatthismornings, Widr, Wizardman, Wolfkeeper, Yyy, Zalgo, Zarcadia, Zephalis, ლეჭიჭიჭიჭიჭი, 367 anonymous edits

Distillation *Source:* <http://en.wikipedia.org/w/index.php?oldid=584767896> *Contributors:* 10metreh, 16@r, 2D, ABF, APerson, Abhisheks.nv, Acm, Agrawal.abhishek, Alansohn, Alex297cat, Alexandria, Alfred Barnard, AlphaEta, Anaxial, Anbu121, Andre Engels, Animum, Antonrojo, Araku, Atomician, Audioio, Azhura, BUF4Life, Baffle gab1978, Berek, Baristarim, BarrelProof, BeastRHIT, Beestiza, Ben Ben, BenC7, Betterusername, Big Brother 1984, Bill Owens Photography, Billinghurst, Blechnic, Bob, Bobo192, Bongwarrior, Brain40, Brian Crawford, Brygator, Bubba hotep, Bubdz431, Bwrs, C3r4, CJHackett, COGDEN, Calabe1992, Caltas, Canadian-Bacon, Candyland251, Canthusus, Capricorn42, Carl Henderson, Catmerl, Cblack2, Charles Matthews, Chem-awb, ChemE50, Chemical Engineer, Childzy, ChillDeity, Chinaranger, Chris fluppy, ChrisGualtieri, Cindy Jones1, Closedmouth, Colonies Chris, Cometstyles, CommonsDelinker, Conversion script, Copper-alembic, CopperKettle, Courcelles, D.c.camerio, D3von, DGaw, DMacks, Daniele Pugliesi, Darrien, Daniel Hedlund, David Justin, David boy stein, D broadwell, Dhbfz, DerHexer, Dforest, Dillard421, Distortionmaster20, Dither 56, Dj Capricorn, DocWatson42, Doughtar, Drbreznjev, Dsmurat, Dvd-junkie, Dwmyers, East of Borschov, Edgar181, ElationAviation, Elo69007, Epbr123, EugeneForrester, Everytime, Excirial, Exor674, Falcon Kirtaran, Fanghong, FisherQueen, Fourthgeek, Fraggel81, Freakofnurture, Fri117336, Funandtrvl, Funky Monkey, Fuzhead, Fæ, Fëaluinix, General Eisenhower, Gentegen, Giftlite, Gilliam, Glacialfox, Glen, Glrx, GoShow, GoneAwayNowAndRetired, GregRM, Gtrmp, Gun Powder Ma, Gunslinger1812, Gurchzilla, Guruleninn, Götz, H Bruthzoo, H Padleckas, HJ32, Hallenrm, Hallzer73, HappyApple, Harland1, Hbackman, Hede2000, Hi878, Hmains, Homonation, Hooperbloob, Horst 75, Hugo Dufort, Ii SUPERNOVA, Ike9898, Ioscius, Itub, IvanLanin, Ixf64, J Di, J Patrick Fischer, J.delanoy, J8079s, JForget, JNW, Ja 62, Jacek Kendysz, JacobSpire98, Jagged 85, JamesBWatson, Jaxl, Jcarroll, Jebba, Jeraphine Gryphon, Jermonian, Jetul, Jfiredrickson, Jfreyre, Jfurr1981, Jguk 2, Jmescraig, Joe Rodgers, JoeSmack, JonRichfield, Jose77, Joststeiner, JoshuaZ, Jrefere, Jzamar, Julesd, Juliancolton, Just Another Dan, KVDP, Karlhahn, Kbh3rd, Kdn1982, Kevin Dornier, KingAbdul, Kkolmetz, Knight1993, Kniptang, Konci, Koyaanis Qatsi, Kpjas, Krshwunk, Ksyrie, KudzuVine, Kwertii, La goutte de pluie, Lasse Clausen, LeaveLeaves, Legajoe, Leonard G., Lightning, Lihaas, Little Mountain 5, Llywyrch, Lockeownz00, Lockesodlog, Logan, Loonymoonk, LouisBB, Luna Santin, Lupo, LyleHoward, Lysy, MacGyverMAGIC, Mahanchian, Malikajumbe, Manager00104, Mandarax, Markpe, Mary Mark Ockerbloom, MassimoAr, Masteremoguy, Mat-C, Materialscientist, Mat, Matchess, Mays5043, MaxGyver, Maziotis, Mbeychok, Megane, Melchoir, Mentifisto, Merenta, Merlinme, Michael Hardy, Mike Rosoff, Mike hayes, MiltonT, Minimac, Mur61j, Mzajac, Nahaj, Naruto1990, Neelix, Neffk, Neutrality, Neverquick, NewEnglandYankee, News0969, Nicketje666, Nihiltes, Nijanand, Nitin70, Nonexistent User, Nunquam Dormio, Nuttycoconut, Oasisbob, Oatmeal batman, Oceanoconsulting, Ohnoitsjamie, Ojay123, Olivier, Omicronpersei8, Omsco, PaddyM, PamD, Paul P, Pdcocok, Pckimensis, Peko, Pendimethalin, Peyre, Phantomsteve, Philip Trueman, Phonixmofu, Physchim62, Piano non troppo, Pinethicket, Pindakdelica, Pinky sl, PociiScript, Poetaris, Polenth, Polyparadigm, Ponder, Prashanthns, Prodego, Pundesser, Quadell, Quantockgoblin, Qurozon, Qxz, RA0808, Randy549, Redoubts, Rerooks, Rich Farmbrough, Richard Harvey, Richard Taytor, Ridow, Rifleman 82, Rinroad, Rjwilmsi, Rocco8, Rossami, Rurik the Vorganian, Ruy Pugliesi, SMC, SGA City, Sakageewa, Samchafin, Sansri, Sardanaphalus, Sasuke1990, Satellizer, ScAvenger, ScaldingHotSoup, Schaber, SchiftyThree, Scientific29, Scott14, Scottbagner, Sepideh7, Shalom Yechiel, SheeEttin, Shoesss, Sikkema, Skarebo, Skier Dude, Slashme, Smokey82, Snigbrook, Snowolf, Squids and Chips, Stbalbach, Strontium5, Stuartmccormick, Swadeep.shrivastava, Syncategoremata, Syrthiss, TPK, Teecorbs, Tentinator, The Thing That Should Not Be, The wub, Thebigboy1, Tommy2010, Torqmaster, TortoiseWrath, Trusilver, Tsemii, Unconcerned, User A1, V8rik, Van helsing, Veinor, Versus22, Vuo, WDavis1911, Weyes, Widr, Wiki Jared 21, Wikipelli, Wilking1979, Woland37, Wsloand, Wtmitchell, Zangala, Zigmaz, Zundarc, 811 anonymous edits

Reverse osmosis *Source:* <http://en.wikipedia.org/w/index.php?oldid=585144092> *Contributors:* 11Dunc11, 1966batfan, 2Plus2Is4, Aarticles, Acalamari, Adavidb, Aeonsbluer, Afizah Osili, AhmadH, Ahoerstemeier, Alex.tan, Alex.fletcher, Ampac usa, Andrewpmk, Andhyo, AndyBQ, Angstorn, Anonymi, Arm, Armeria, Armymanmikey, ArthurDenture, Ashley.margery, Ashvidia, Astaroth5, Astralian, Astronaut, Avaya1, AxelBoldt, Axl, BAMopedia, Bahamut0013, Beetsta, Behind The Wall Of Sleep, Beland, Bennythewoof, Benzy16, Berlo84, Bigbut82, Bilbo1507, Blackangel25, Bob, Bob Kreisher, Bobblewik, Bobo192, Bogdangiusca, Borameer, BorgQueen, Bork, BrandonVXX, Bree's Block, BrokenSegue, Buzzbo, CDM2, Cambrasa, Can't sleep, clown will eat me, Carroy, CharlesC, Cheffalin, Chemalg12, Chemsiguy, Chenzw, ChildofMidnight, Chowbok, Chris the speller, Christian75, Chriswaterguy, Chrk1, Ktatz, Coasterlover1994, Cocoaguy, Col16, Corn cheese, Coro, Corpx, Creavolution, Cristivivo, Ctsspruill13, Cymbalta, DMahalko, Da Joe, Dannable, David Shankbone, Davidpaulson, Deb, Deli nk, Delirium, Dennis Schmitz, Desalinfo, Dirac66, Discospinster, Dlfelps, Dman727, DocWatson42, Doron, Dpl yho, Drakhrub, Ds13, Duckdive117, Duncan, Dureo, Dlugosz, Eddieque, Edgar181, Edward, Eike Welk, Emoneyk, Enliten9, Epbr123, Espwateer, Euryalus, Evalowyn, Excirial, Fabiform, Falcon8765, Fieldday-sunday, Flatline, Flyer22, FreplySpang, From-cary, Froth, Fæ, Gail, Gary Cziko, Gem fr, George Kienzle, Gerwen, Getterstraight, Giftlite, Gigemag76, Gilderien, Gilliam, Give Peace A Chance, Glenn, Goldenrowley, Grundle2600, Gtk123, Gtstricky, Gwernol, Gwuffey, Gzucka, H2O, HEL, HYC, HarlandQPitt, Hydrargyrum, Ibadibam, Igodard, Immunize, Isaac, Inove, ItascaSystems, Izakjacobuslouw, J J Messerly, Jaganath, Jake Wartenberg, Jallotta, JamesWatson, Jasonch011, Jeremymobile, Jessieunderhill, Jigibb, Jimscontuck, Jodarom, John Reaves, John Riemann Soong, JohnSRoberts99, Jonathan.s.kt, Jsharpminor, JudahH, Juliancolton, KJ6MYQ, Karuna8, Kateshortforb, Keserbob, Khalid hassani, Kingfish101, Kjolb, Knuckles, Kolbasz, Kummi, Kuru, Lamro, Landon1980, LeaveLeaves, Lerho, Libertyblues, Ligar, Lightmouse, Limup, Llywelyn, Loewenstein, Lord Roem, Lpoulsen, Luk, LurkingInChicago, M7, MER-C, Maisy101, Maksdo, Mark.murphy, Markhurd, Markj99, MartinHarper, Materialscientist, Maxhugen, Mbrell, Mbeychok, Mcarmier, Mentifisto, Mere Mortal, Mgiganteun1, MikeCHE, Mindak3, Mindmatrix, Mion, Mkwaise, Mmarrre, Mmtejeri, Mmalko76, Mono, MopSeeker, Morn, MrOllie, Mrosaclo, Mschpdpdch, Msnicki, Mtsensig, Mxn, Mysid, NTox, Nave.notic, NawlinWiki, Ndkl, NeetuBarmecha21, NewEnglandYankee, Newstrens, Nick UA,

Nihonjoe, Nostammai, Nsaa, Oldmanwalyn, Omicronperseï8, Omjmark, Osmoflo, Paine Ellsworth, Palnatoke, Paloma Walker, Pama73, Pcirus, Peter in s, PeterSymonds, Philip Trueman, Phonkee, PierreAbbat, Pinethicket, Pinzo, Pjetter, Pmberly, Poeloo, Powderblue, Pundesser, R'n'B, R000t, Racexr11, Raghunathan.vs, Rahim6464, Randyoo, Raven in Orbit, Reaper Eternal, Redjar, Register112, Rhys jw, Rifleman 82, Robert Merkel, Rohan Jayasekera, Romanm, Ronz, Roscoe x, Rror, Rtfarrel15, Sagaciousuk, Sammy1462, Samtheboy, ScaldingHotSoup, ScientistInTraining, Scratch, Screen stalker, Sean Heron, Senator Palpatine, Shenme, Sicvolo, Sid Loeb, SidP, Sidneyloeb, Sikkema, Silviacalvotome, Sir Lunch-a-lot, SirLamer, Skizzik, Sldenable, Sleep pilot, Sleibler, Slimserver, Starsend, StaticGull, Stepa, Steve Wise, SyntaxError55, Syrthiss, Tandonna, TastyPoutine, Telso, Testem, ThatKid98, The Magnificent Clean-keeper, The Thing That Should Not Be, The Transhumanist, ThePrudle, Themaab, Tickle me gusta, Tide rolls, Tiger304, Timo Honkasalo, Trilobitealive, TurboChan, Ubiquinaut, Unixcrab, Vald, Valinmo, Vanished user ikjeirw34uaoelaseriffic, Vatassery, Vegaswikian, Velella, Vinifera, VinophilussyIvestris, Vishnava, Vsmith, Wade.david, Water and Land, WaterSuperhero, Wavelength, WeniWikiWiki, WhiteOakTree, Wimahan, Wnissen, Woudloper, Wtmitchell, Wvoutlaw2002, Xeno, Xeyback, Yaf, YordanGeorgiev, Zodon, Zundark, Zyllox, قلي زادگان, غامدي.أحمد, 719 anonymous edits

Desalination *Source:* <http://en.wikipedia.org/w/index.php?oldid=584426476> *Contributors:* 124eric, 12b3, 4I7.4I7, 5ko, 7, 7k7p1mm, A. B., AJHalliwell, Acroterion, Aengus, Afa86, Agyle, Aitias, Alansohn, Alborz Fallah, Alex.muller, Alexius08, Allansiew, AlphaCrest, Anbu121, Andonic, Andrew wilson, AndrewLeeson, Anonymous Dissident, Antandrus, Anthere, Apacheneo, Aquaepulse, Ashvidia, Awesomeayla, Axeman, Axl, B4hand, BBird, BD2412, BW52, Badgernet, BastiaanNaber, Bayerischermann, Bdx, Beland, Benmac129, Berserker Crit, Betterusername, Bevo, Bgpaulus, Bigtimepeace, Bioarchie1234, Bluewind, Bob5021, BobM, Bobbo, Bobo192, Bogeys97, Bongwarrior, Bovineone, Bovlb, Bravo31, Brodmont, Bumm13, Bundy197, C45207, Calabe1992, Calm, CalumH93, Camw, Can't sleep, clown will eat me, Capricorn42, Ceyockey, Charvest, Chefallen, Choi9999, Chriswatery, Chriswiki, Chuckre, ChungLW, Chuunen Baka, Ckatz, Coemgenus, Common Man, CommonsDelinker, Contact '97, CopperSquare, Coro, Cremepuff222, Crystal sparkle96, Cst17, Cureden, Curps, CurranH, CustardJack, Czx111, DARTH SIDIOUS 2, DMacks, DMurphy, DVD R W, Dan653, Dancxjo, Dannydied, Darth Mike, Davewho2, Dawkeye, Dawnseeker2000, Dd1958, DeadEyeArrow, Deen rose, Dengua, DennisDaniels, Desal2908, Desalinfo, Dgiroux, Dgw, Dinopop, Diptanshu.D, Dirtyharry2, Disavian, Discospinster, Djembayz, Doradus, Doseiaï2, Doug Coldwell, Doulos Christos, Drat, DrexRockman, Drmies, Dryguy, DynamoDegsy, Dysepsion, Eastlaw, EdBever, Edward321, Ehrenkater, El C, Engineman, Eprb123, Eregli bob, Erianna, Everyking, Eyesnore, FF2010, Fabrictramp, Figma, Finnring, Fireice, Fivemack, Flumstead, Fooobar, Fraggle81, FrankTobia, Fratrep, Frosted14, Fui in terra aliena, Funnyhat, Furrykef, GHE, GVOLT, Gaius Cornelius, Gatemansgc, Geanixx, Gerhardvalentin, Ghunter3016, Gigemag76, Gilliam, Gimboïd13, Glane23, Grafen, Ground Zero, Groyolo, Grundle2600, Guanaco, Gus 795, Gwernol, HHahn, Halesw, Halvorseno, Haoie, HarlandQPitt, HarryHenryGebel, Hartz, Haukurth, Henare, Hmrox, Hobartimus, Hu12, Huangdi, Hugo Bogarov, Hungry homer, Hungry homer1, Huntster, ILOVEPONY, IRP, IReceivedDeathThreats, Iames, Ianisalistyle, Ibnzintzo, ImperfectlyInformed, Inferno, Lord of Penguins, Inwind, Iorsh, Iridescent, Itschris, J. Johnson, J.delany, JForget, JNW, JTN, Jack Greenmaven, Jackol, Jalwikip, James xeno, James086, Jamott, Janko, Jarble, Jasonwilson1972, Javawizard, Jcdillon, Jelemens, Jeff Silvers, Jeremy Visser, Jessdog, Jimjamjak, John Kjos, Johnfos, Joostvandeputte, JorisvS, Jpkotta, Jpp42, Jrtayloriv, Jsmith86, Julesd, Julia.italiana, Juliancolton, Jyrl, KDS4444, KFP, KVDP, Kablammo, Karen Johnson, Katalaveno, Kevin Rector, Khalid hassani, Khazar, Khoikhoi, King Zebu, Kingpin13, Kjkolb, Kneejerk, KnowledgeOfSelf, Kolbasz, Krusty627, Ksyrie, Kuru, Kylefoley76, Kylemcinnes, Lcolson, Lfstevens, Librsh, Life=search, Lightmouse, Lihaa, Lincolnite, LinguistAtLarge, Little Mountain 5, Lldenke, Loodog, Luckyherb, Lugia2453, Luk, Mackdady8, Macpunc, Macy, Maharaja9933, Mahudhy, Mardavij31, Marek69, Mark Arsten, Mark R Johnson, MarkBolton, MaterialsScientist, MattieTK, Mav, Maxis ftw, Mediran, Meg egg, Megan 189, Mennato, Mentality, Merzbow, Michael Cockrell, MichaelAndersonatSpectra, Midgley, Midusunknown, Mike Rosoft, Mike1942f, Mikeycybaby, Millionaire, Mirffy, Mkweise, Mlpearc, Monterey Bay, MrOllie, MrX, Mucky Duck, Mueller42, Musides, NJR ZA, Nahteecirp, Narcberry, NathanHurst, NawlinWiki, NeilN, NerdyScienceDude, NescioNomen, Neum, NickBush24, Oliver202, OliverTwisted, Omega025, One Salient Oversight, Opelio, Ost316, Pakaran, Paleorhith, Pandemias, Para, Pashute, Pengo, Persian Poet Gal, Perx1, Peter Kaminski, PeterNetsu, Phantomsnake, Pharaoh of the Wizards, PhilKnight, Philip Trueman, Pinethicket, Plumbago, Plvekamp, Predator1087, PrinceRegentLuitpold, Professor Newcomb, Pseudomonas, Pstudier, Punkishlyevil, Pwt898, Quebec99, Quest for Truth, Quinn d, R'n'B, RJaguar3, RKloti, RUL3R, Rachaeldez, RadManCF, Raffa be, Rajivrkr, Ralpharama, Raymondwin, Rbrandonmoore, Rd232, Rearden Metal, Revth, Rich Farmbrough, Rick Block, Rifleman 82, Rjwilmsi, Ronz, Rory096, Ryanbayona, SFReinier, SJP, Sam Korn, Sango123, Scarian, Serten, Shadowjams, Shandzoo, Shaun, Sillybilly, SimonHong69, Sinus, Slakr, Slwnix, Smithbrenon, Some jerk on the Internet, Spacemountainmike, Spencer, Spiros71, Splette, Srbauer, Stanleycr1, Starsend, Stemonitis, Stepa, Stephen G. Brown, Stephenb, Steve G, Steven Zhang, Stormie, Struthious Bandersnatch, Suffusion of Yellow, Swallow2011, Taestell, Take My Bike ... Please!, Tamás Kádár, Tarheel95, Taxman, Tcncv, TeH nOmInAtOr, Teejay17, Telecineguy, TempestSA, Tempodivalse, Tewfik, Tgeairn, Thatguyflint, The Thing That Should Not Be, TheKhakinator, TheMathinator, Themadchopper, Thingg, Thinking of England, Thorwald, Thumperward, Tide rolls, Tierneyjohn, Tiki God, TimProof, Timneu22, Titoxd, Tntpkt, Tohd88BohaihuGh1, Tomcenc, Tommy2010, Tony Fox, Tony14k, Tonythermo, Trovatore, True Pagan Warrior, U890, UV254, UbUb, Ultramarine, Uncle Dick, Unyoyega, Useight, Vague Rant, Vegaswikian, Verbum Veritas, Vianello, Vinceouca, Viriditas, Vjockin, Vmenkov, Vsmith, WODUP, WadeSimMiser, Wadems, Warut, Water and Land, Wavelength, Waynebeast, Wedgeline, Wenli, Wiki12345678, WikiBrik, WikiDan61, WikiHaquinator, Wikieditor06, Wikip rhye, Wikipeditor, Wikispaceman, Willking1979, Wisq, Wjfox2005, Wmas01, Wtshymanski, Xabian40409, Y2000, Yamamoto Ichiro, Yermi888, Yintan, Yobol, Yomangani, Youghurt, Yuckfoo, Yvh11a, Zeeyanwiki, ZooFari, Zsero, Žiedas, 1151 anonymous edits

In situ chemical oxidation *Source:* <http://en.wikipedia.org/w/index.php?oldid=582061521> *Contributors:* Beagel, Chris the speller, John of Reading, Klemen Kocjancic, KylieTastic, Lamro, LilHelpa, Mark Arsten, Mmjejeri, Rjwilmsi, Sblint, Snehakrishna, SomeFreakOnTheInternet, Δ, 7 anonymous edits

Image Sources, Licenses and Contributors

file:Usine Bret MG 1638.jpg *Source:* http://en.wikipedia.org/w/index.php?title=File:Usine_Bret_MG_1638.jpg *License:* Creative Commons Attribution-Sharealike 2.0 *Contributors:* User:Rama

File:Rapid sand filter EPA.jpg *Source:* http://en.wikipedia.org/w/index.php?title=File:Rapid_sand_filter_EPA.jpg *License:* Public Domain *Contributors:* US Environmental Protection Agency

File:Vsakovací nádrže umělé infiltrace v ÚV Káraný.jpg *Source:* http://en.wikipedia.org/w/index.php?title=File:Vsakovací_nádrže_umělé_infiltrace_v_ÚV_Káraný.jpg *License:* Creative Commons Attribution-Sharealike 3.0 *Contributors:* Che(Please credit as "Petr Novák, Wikipedia" in case you use this outside WMF projects.)

File:Detektor znečištění pstruhů ÚV Káraný.jpg *Source:* http://en.wikipedia.org/w/index.php?title=File:Detektor_znečištění_pstruhů_ÚV_Káraný.jpg *License:* Creative Commons Attribution-Sharealike 3.0 *Contributors:* Che(Please credit as "Petr Novák, Wikipedia" in case you use this outside WMF projects.)

Image:Kochendes wasser02.jpg *Source:* http://en.wikipedia.org/w/index.php?title=File:Kochendes_wasser02.jpg *License:* GNU Free Documentation License *Contributors:* user:Markus Schweiss

Image:Milk boiling.jpg *Source:* http://en.wikipedia.org/w/index.php?title=File:Milk_boiling.jpg *License:* Creative Commons Attribution-Sharealike 3.0 *Contributors:* User:Parvathisri

File:Simple distillation apparatus.svg *Source:* http://en.wikipedia.org/w/index.php?title=File:Simple_distillation_apparatus.svg *License:* Public Domain *Contributors:* Original PNG by User:Quantockgoblin, SVG adaptation by User:Slashme

File:Zosimosapparat.jpg *Source:* <http://en.wikipedia.org/w/index.php?title=File:Zosimosapparat.jpg> *License:* Public Domain *Contributors:* Original uploader was Adragoor at sv.wikipedia

File:Hieronymus Brunschwig Liber de arte Distillandi CHF AQ13x3.jpg *Source:*

http://en.wikipedia.org/w/index.php?title=File:Hieronymus_Brunschwig_Liber_de_arte_Distillandi_CHF_AQ13x3.jpg *License:* Public Domain *Contributors:* Chemical Heritage Foundation

File:My retort.jpg *Source:* http://en.wikipedia.org/w/index.php?title=File:My_retort.jpg *License:* Public domain *Contributors:* 6. клас, Chatsam, Nk, Spiritia, Toto-tarou

File:Distillation by Retort.png *Source:* http://en.wikipedia.org/w/index.php?title=File:Distillation_by_Retort.png *License:* Public Domain *Contributors:* H Padleckas, Jarek, LeastCommonAncestor, Luigi Chiesa, Marcus Cyron, Pjetter, 1 anonymous edits

File:UkrainianVodkaStill.jpg *Source:* <http://en.wikipedia.org/w/index.php?title=File:UkrainianVodkaStill.jpg> *License:* Creative Commons Attribution-Sharealike 3.0 *Contributors:* Arne Hüchelheim

File:Dorf Lore - Schnaps-Destillation.jpg *Source:* http://en.wikipedia.org/w/index.php?title=File:Dorf_Lore_-_Schnaps-Destillation.jpg *License:* GNU Free Documentation License *Contributors:* Hans-Peter Grumpe

File:BatchDistill.svg *Source:* <http://en.wikipedia.org/w/index.php?title=File:BatchDistill.svg> *License:* unknown *Contributors:* Original uploader was User A1 at en.wikipedia. Later version(s) were uploaded by Xyzzy n at en.wikipedia.

File:DDW.JPG *Source:* <http://en.wikipedia.org/w/index.php?title=File:DDW.JPG> *License:* Creative Commons Attribution-Sharealike 3.0 *Contributors:* User:Guruleninn

File:Vacuum distillation of DMSO at 70C.jpg *Source:* http://en.wikipedia.org/w/index.php?title=File:Vacuum_distillation_of_DMSO_at_70C.jpg *License:* Public Domain *Contributors:* Original uploader was Rifleman 82 at en.wikipedia

File:perkin triangle distillation apparatus.svg *Source:* http://en.wikipedia.org/w/index.php?title=File:Perkin_triangle_distillation_apparatus.svg *License:* Creative Commons Attribution-Share Alike *Contributors:* Original PNG by User:Quantockgoblin, SVG adaptation by User:Slashme

File:short path distillation apparatus.svg *Source:* http://en.wikipedia.org/w/index.php?title=File:Short_path_distillation_apparatus.svg *License:* Public Domain *Contributors:* Original PNG by User:Quantockgoblin, SVG adaptation by User:Slashme

File:Colonne distillazione.jpg *Source:* http://en.wikipedia.org/w/index.php?title=File:Colonne_distillazione.jpg *License:* Creative Commons Attribution 3.0 *Contributors:* User:Luigi Chiesa

File:Continuous Binary Fractional Distillation.PNG *Source:* http://en.wikipedia.org/w/index.php?title=File:Continuous_Binary_Fractional_Distillation.PNG *License:* Creative Commons Attribution-ShareAlike 3.0 Unported *Contributors:* User:H Padleckas, User:Mbeychok, User:mbeychok

File:Bubble Cap Trays.PNG *Source:* http://en.wikipedia.org/w/index.php?title=File:Bubble_Cap_Trays.PNG *License:* Creative Commons Attribution-Sharealike 2.5 *Contributors:* H Padleckas created this image file in the middle of November 2006 for use in the article "Fractionating column" in Wikimedia.

File:Vacuum Column.jpg *Source:* http://en.wikipedia.org/w/index.php?title=File:Vacuum_Column.jpg *License:* GNU Free Documentation License *Contributors:* I do not know the name of the individual who actually took the photograph.

File:Retort-in-operation-early-chemistry.PNG *Source:* <http://en.wikipedia.org/w/index.php?title=File:Retort-in-operation-early-chemistry.PNG> *License:* Public Domain *Contributors:* HappyApple, 2 anonymous edits

File:Distillation of dry and oxygen-free toluene.jpg *Source:* http://en.wikipedia.org/w/index.php?title=File:Distillation_of_dry_and_oxygen-free_toluene.jpg *License:* Public Domain *Contributors:* Original uploader was Rifleman 82 at en.wikipedia

File:Vacuum Column.png *Source:* http://en.wikipedia.org/w/index.php?title=File:Vacuum_Column.png *License:* Public Domain *Contributors:* Mbeychok

File:Rotavapor.jpg *Source:* <http://en.wikipedia.org/w/index.php?title=File:Rotavapor.jpg> *License:* GNU Free Documentation License *Contributors:* Geni

File:Semi-microscale distillation.jpg *Source:* http://en.wikipedia.org/w/index.php?title=File:Semi-microscale_distillation.jpg *License:* Public Domain *Contributors:* user:Rifleman_82

File:Reverse osmosis membrane coil.jpg *Source:* http://en.wikipedia.org/w/index.php?title=File:Reverse_osmosis_membrane_coil.jpg *License:* Creative Commons Attribution 3.0 *Contributors:* David Shankbone

File:US Navy 060220-M-2061L-063 U.S. Marines assigned to the 31st Marine Expeditionary Unit (MEU) Service Support Group 31, prepares a chlorine solution for water.jpg *Source:* [http://en.wikipedia.org/w/index.php?title=File:US_Navy_060220-M-2061L-063_U.S._Marines_assigned_to_the_31st_Marine_Expeditionary_Unit_\(MEU\)_Service_Support_Group_31_prepares_a_chlorine_solution_for_water.jpg](http://en.wikipedia.org/w/index.php?title=File:US_Navy_060220-M-2061L-063_U.S._Marines_assigned_to_the_31st_Marine_Expeditionary_Unit_(MEU)_Service_Support_Group_31_prepares_a_chlorine_solution_for_water.jpg) *License:* Public Domain *Contributors:* Daniele Pugliesi

File:Reverse osmosis membrane element layers.jpg *Source:* http://en.wikipedia.org/w/index.php?title=File:Reverse_osmosis_membrane_element_layers.jpg *License:* Creative Commons Attribution 3.0 *Contributors:* David Shankbone

File:ReverseOsmosis with PressureExchanger.svg *Source:* http://en.wikipedia.org/w/index.php?title=File:ReverseOsmosis_with_PressureExchanger.svg *License:* Creative Commons Attribution-Sharealike 3.0,2.5,2.0,1.0 *Contributors:* chris 論

File:Reverse Osmosis with Pressure Recovery Pump.jpg *Source:* http://en.wikipedia.org/w/index.php?title=File:Reverse_Osmosis_with_Pressure_Recovery_Pump.jpg *License:* Creative Commons Attribution-Sharealike 3.0 *Contributors:* User:Desalinfo

File:Multiflash.svg *Source:* <http://en.wikipedia.org/w/index.php?title=File:Multiflash.svg> *License:* Creative Commons Attribution-Sharealike 2.5 *Contributors:* Multiflash.png: Ruben Castelnovo (myself) derivative work: NJR_ZA (talk)

File:PlantaSchemaFiction.png *Source:* <http://en.wikipedia.org/w/index.php?title=File:PlantaSchemaFiction.png> *License:* GNU Free Documentation License *Contributors:* Daniele Pugliesi, Maksim, Wst

File:Reverse osmosis desalination plant.JPG *Source:* http://en.wikipedia.org/w/index.php?title=File:Reverse_osmosis_desalination_plant.JPG *License:* Creative Commons Attribution-Sharealike 3.0 *Contributors:* James Grellier

File:Shevchenko BN350 desalinati.jpg *Source:* http://en.wikipedia.org/w/index.php?title=File:Shevchenko_BN350_desalinati.jpg *License:* Public Domain *Contributors:* User:Lcolson

File:Saltcrystals on avicennia marina var resinifera leaves.JPG *Source:* http://en.wikipedia.org/w/index.php?title=File:Saltcrystals_on_avicennia_marina_var_resinifera_leaves.JPG *License:* Public Domain *Contributors:* Peripitus

License

Creative Commons Attribution-Share Alike 3.0
[//creativecommons.org/licenses/by-sa/3.0/](https://creativecommons.org/licenses/by-sa/3.0/)
