Desalination

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This article is about removing salt from water. For soil desalination, see Soil salinity control.

Water desalination

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Desalination is a process that extracts mineral components from saline water. More generally, desalination refers to the removal of salts and minerals from a target substance,[1] as in soil desalination, which is an issue for agriculture.[2]

Saltwater is desalinated to produce water suitable for human consumption or irrigation. One by-product of desalination is salt. Desalination is used on many seagoing ships and submarines. Most of the modern interest in desalination is focused on cost-effective provision of fresh water for human use. Along with recycled wastewater, it is one of the few rainfall-independent water sources.[3]

Due to its energy consumption, desalinating sea water is generally more costly than fresh water from rivers or groundwater, water recycling and water conservation. However, these alternatives are not always available and depletion of reserves is a critical problem worldwide. Currently, approximately 1% of the world's population is dependent on desalinated water to meet daily needs, but the UN expects that 14% of the world's population will encounter water scarcity by 2025.[4]

Desalination is particularly relevant in dry countries such as Australia, which traditionally have relied on collecting rainfall behind dams for water.

According to the International Desalination Association, in June 2015, 18,426 desalination plants operated worldwide, producing 86.8 million cubic meters per day, providing water for 300 million people.[5] This number increased from 78.4 million cubic meters in 2013,[4] a 10.71% increase in 2 years. The single largest desalination project is Ras Al-Khair in Saudi Arabia, which produced 1,025,000 cubic meters per day in 2014,[4] although this plant is expected to be surpassed by a plant in California.[6]Kuwait produces a higher proportion of its water than any other country, totaling 100% of its water use.[7]

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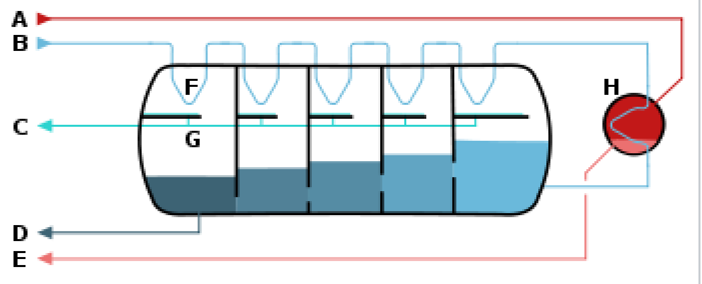
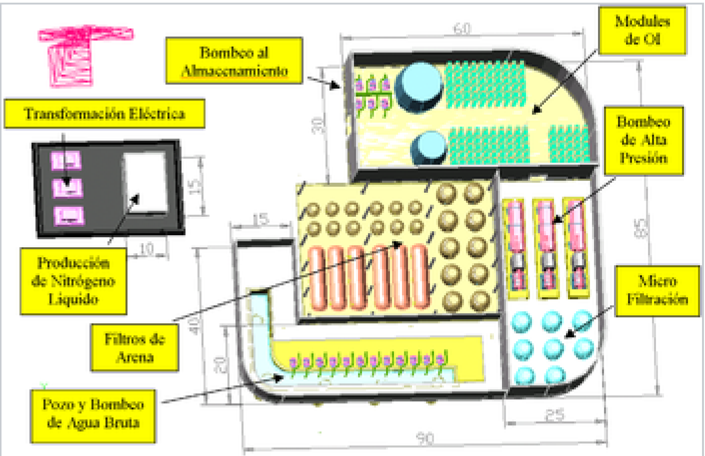


Schematic of a multistage flash desalinator
A – steam in
B – seawater in
C – potable water out
D – waste out

E – steam out
F – heat exchange
G – condensation collection
H – brine heater



Plan of a typical reverse osmosis desalination plant

Methods [edit]

There are several methods. Each has advantages and disadvantages.

Reverse osmosis desalination plant in Barcelona, Spain

Vacuum distillation [edit]

The traditional process used in these operations is vacuum distillation—essentially boiling it to leave impurities behind. In desalination, atmospheric pressure is reduced, thus lowering the required temperature needed. Liquids boil 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 employed.[*citation needed*]

Multi-stage flash distillation [edit]

Water is evaporated and separated from sea water through multi-stage flash distillation, which is a series of flash evaporations.[8] Each subsequent flash process utilizes energy released from the condensation of the water vapor from the previous step and so on.[8]

Multiple-effect distillation [edit]

Multiple-effect distillation (MED) works through a series of steps called “effects”.[8] Incoming water is sprayed onto vertically or, more commonly, horizontally[8][9] oriented pipes which are then heated to generate steam. The steam is then used to heat the next batch of incoming sea water.[8] To increase efficiency, the steam used to heat the sea water can be taken from nearby power plants.[8] Although this method is the most thermodynamically efficient, a few limitations exist such as a max temperature and max number of effects.[9]

Vapor-compression distillation [edit]

Vapor-compression evaporation involves using either a mechanical compressor or a jet stream to compress the vapor present above the liquid. The compressed vapor is then used to provide the heat needed for the evaporation of the rest of the sea water.[8] Since this system only requires power, it is more efficient if kept at a small scale.[8]

Reverse osmosis [edit]

The principal competing process uses membranes to desalt saline water, principally applying reverse osmosis (RO).[10] The RO membrane processes use semipermeable membranes and applied pressure (on the membrane feed side) to preferentially induce water permeation through the membrane while rejecting salts. Reverse osmosis plant membrane systems typically use less energy than thermal desalination processes. Desalination processes are driven by either thermal (e.g., distillation) or electrical (e.g., RO) as the primary energy types. Energy cost in desalination processes varies considerably depending on water salinity, plant size and process type. At present the cost of seawater desalination, for example, is higher than traditional water sources, but it is expected that costs will continue to decrease with technology improvements that include, but are not limited to, reduction in plants footprint, improvements to plant operation and optimization, more effective feed pretreatment, and lower cost energy sources.[11]

The Reverse Osmosis process is not maintenance free. Various factors interfere with efficiency: ionic contamination (calcium, magnesium etc.); DOC; bacteria; viruses; colloids & insoluble particulates; biofouling and scaling. In extreme cases destroying the RO membranes. To mitigate damage, various pretreatment stages are introduced. Anti-scaling inhibitors include acids and other agents like the organic polymers Polyacrylamide and Polymaleic Acid), Phosphonates and Polyphosphates. Inhibitors for fouling are biocides (as oxidants against bacteria and viruses), like chlorine, ozone, sodium or calcium hypochlorite. At regular intervals, depending on the membrane contamination; fluctuating seawater conditions; or prompted by monitoring processes the membranes need to be cleaned, known as emergency or shock-flushing. Flushing is done with inhibitors in a fresh water solution. Thus the system needs to go offline. This procedure is environmental risky, since contaminated water is rejected into the ocean without treatment. Sensitive marine habitatscan be irreversibly damaged.[12][13]

Freeze-thaw [edit]

Freeze-thaw desalination uses freezing to remove fresh water from frozen seawater.[14]

Solar evaporation [edit]

Solar evaporation mimics the natural water cycle, in which the sun heats the sea water enough for evaporation to occur.[8] After evaporation, the water vapor is condensed onto a cool surface.[8]

Electrodialysis reversal [edit]

Electrodialysis utilizes electric potential to move the salts through a membrane.[15]

Considerations and criticism [edit]

Energy consumption [edit]

Energy consumption of seawater desalination has reached as low as 3 kWh/m^3,[16] including pre-filtering and ancillaries, similar to the energy consumption of other fresh water supplies transported over large distances,[17] but much higher than local fresh water supplies that use 0.2 kWh/m^{3}or less.[18]

A minimum energy consumption for seawater desalination of around 1 kWh/m^3 has been determined,[19][20] excluding prefiltering and intake/outfall pumping. Under 2 kWh/m^3[21] has been achieved with reverse osmosis membrane technology, leaving limited scope for further energy reductions.

Supplying all US domestic water by desalination would increase domestic energy consumption by around 10%, about the amount of energy used by domestic refrigerators.[22] Domestic consumption is a relatively small fraction of the total water usage.[23]

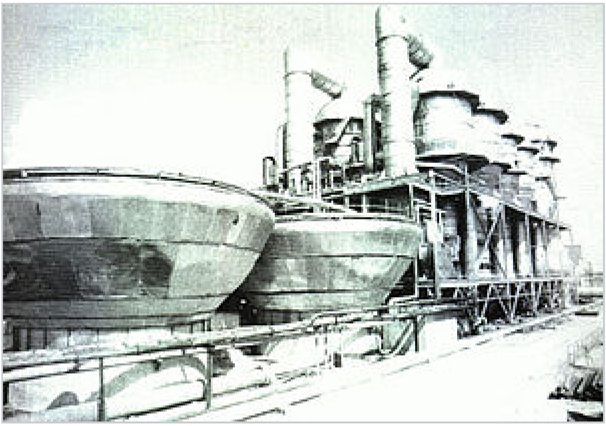
Energy consumption of seawater desalination methods.[24]

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" refers to the amount of electrical energy that could be generated using a given quantity of thermal energy and appropriate turbine generator. These calculations do not include the energy required to construct or refurbish items consumed in the process.

Cogeneration [edit]

Cogeneration is generating excess heat and electricity generation from a single process. Cogeneration can provide usable heat for desalination 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. 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 more viable.[25][26]



The Shevchenko BN350, a nuclear-heated desalination unit

The current trend in dual-purpose facilities is hybrid configurations, in which the permeate from reverse osmosis desalination is mixed with distillate from thermal desalination. Basically, two or more desalination processes are combined along with power production. Such facilities have been implemented in Saudi Arabia at Jeddah and Yanbu.[27]

A typical Supercarrier 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.[28]

Economics [edit]

Costs of desalinating sea water (infrastructure, energy, and maintenance) are generally higher than fresh water from rivers or groundwater, water recycling, and water conservation, but alternatives are not always available. Desalination costs in 2013 ranged from US$0.45 to $1.00/cubic metre ($US2 to 4/kgal). (1 cubic meter is about 264 gallons.) More than half of the cost comes directly from energy cost, and since energy prices are very volatile, actual costs can vary substantially.[29]

The cost of untreated fresh water in the developing world can reach US$5/cubic metre.[30]

Average water consumption and cost of supply by sea water desalination at US$1 per cubic metre(±50%)

Area	Consumption USgal/person/day	Consumption litre/person/day	Desalinated Water Cost US$/person/day
USA	100	378	0.38
Europe	50	189	0.19
Africa	15	57	0.06
UN recommended minimum	13	49	0.05

Factors that determine the costs for desalination include capacity and type of facility, location, feed water, labor, energy, financing and concentrate disposal. Desalination stills control pressure, temperature and brine concentrations to optimize efficiency. Nuclear-powered desalination might be economical on a large scale.[31][32]

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 m (6,600 ft), or transport it over more than 1,600 km (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, transport costs could match 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. By contrast in other locations transport costs are much less, such as Beijing, Bangkok, Zaragoza, Phoenix, and, of course, coastal cities like Tripoli."[33] After desalination at Jubail, Saudi Arabia, water is pumped 200 mi (320 km) inland to Riyadh.[34] For coastal cities, desalination is increasingly viewed as a competitive choice.

In 2014, the Israeli facilities of Hadera, Palmahim, Ashkelon, and Sorek were desalinizing water for less than US$0.40 per cubic meter.[35] As of 2006, Singapore was desalinating water for US$0.49 per cubic meter.[36] The city of Perth began operating a reverse osmosis seawater desalination plant in 2006.[37] A desalination plant now operates in Sydney,[38] and the Wonthaggi desalination plantwas under construction in Wonthaggi, Victoria.

The Perth desalination plant is powered partially by renewable energy from the Emu Downs Wind Farm.[39][40] 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,[41] mitigating concerns about harmful greenhouse gas emissions.

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.[42][43]

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.[44] As of June 2012, the cost for the desalinated water had risen to $2,329 per acre-foot.[45] Each $1,000 per acre-foot works out to $3.06 for 1,000 gallons, or $.81 per cubic meter.[46]

Poseidon Resources made an unsuccessful attempt to construct a desalination plant in Tampa Bay, FL, in 2001. The board of directors of Tampa Bay Waterwas forced to buy the plant from Poseidon 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. The facility reached capacity only in 2007.[47]

In 2008, a Energy Recovery Inc. was desalinating water for $0.46 per cubic meter.[48]

Environmental [edit]

Factors that determine the costs for desalination include capacity and type of facility, location, feed water, labor, energy, financing and concentrate disposal.

Intake [edit]

In the United States, cooling water intake structures are regulated by the Environmental Protection Agency (EPA). These structures can have the same impacts to the environment as desalination facility intakes[*according to whom?*]. According to EPA, water intake structures cause adverse environmental impact by sucking fish and shellfish or their eggs into an industrial system. There, the organisms may be killed or injured by heat, physical stress, or chemicals. Larger organisms may be killed or injured when they become trapped against screens at the front of an intake structure.[49] Alternative intake types that mitigate these impacts include beach wells, but they require more energy and higher costs.[50]

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 0.1 m/s (0.33 ft/s), which is slow enough to let fish escape. The plant provides nearly 140,000 m^3 (4,900,000 cu ft) of clean water per day.[39]

Outflow [edit]

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Desalination processes produce large quantities of brine, possibly at above ambient temperature, and contain residues of pretreatment and cleaning chemicals, their reaction byproducts and heavy metals due to corrosion.[51] Chemical pretreatment and cleaning are a necessity in most desalination plants, which typically includes prevention of biofouling, scaling, foaming and corrosion in thermal plants, and of biofouling, suspended solids and scale deposits in membrane plants.[52]

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. With medium to large power plant and desalination plants, the power plant's cooling water flow is likely to be several times larger than that of the desalination plant, reducing the salinity of the combination. Another method to dilute the brine is to mix it via a diffuser in a mixing zone. For example, once a 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 and therefore sinks to the ocean bottom and can damage the ecosystem. Careful reintroduction can minimize this problem. Typical ocean conditions allow for rapid dilution, thereby minimizing harm.

Alternatives without pollution [edit]

Some methods of desalination, particularly in combination with evaporation ponds, solar stills, and condensation trap (solar desalination), do not discharge brine. They do not use chemicals or burn fossil fuels. They do not work with membranes or other critical parts, such as components that include heavy metals, thus do not produce 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 biotectural system.[53] It can be considered "full desalination" because it converts the entire amount of saltwater intake into distilled water. One of the advantages of this system is the feasibility for inland operation. Standard advantages also include no air pollution 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. As of 2015, 50% of the world's sea salt production relies on fossil energy sources.[54]

Alternatives to desalination [edit]

Increased water conservation and efficiency remain the most cost-effective approaches in areas with a large potential to improve the efficiency of water use practices.[55] Wastewater reclamation provides multiple benefits over desalination.[56] Urban runoff and storm water capture also provide benefits in treating, restoring and recharging groundwater.[57]

A proposed alternative to desalination in the American Southwest is the commercial importation of bulk water from water-rich areas either by oil tankersconverted to water carriers, or pipelines. The idea is politically unpopular in Canada, where governments imposed trade barriers to bulk water exports as a result of a North American Free Trade Agreement(NAFTA) claim.[58]

Public health concerns [edit]

Desalination removes iodine from water and could increase the risk of iodine deficiency disorders. Israeli researchers claimed a possible link between seawater desalination and iodine deficiency,[59]finding deficits among euthyroid adults exposed to iodine-poor water[60] concurrently with an increasing proportion of their area's drinking water from seawater reverse osmosis (SWRO).[61] They later found probable iodine deficiency disorders in a population reliant on desalinated seawater.[62] A possible link of heavy desalinated water use and national iodine deficiency was suggested by Israeli researchers.[63] They found a high burden of iodine deficiency in the general population of Israel: 62% of school-age children and 85% of pregnant women fall below the WHO's adequacy range.[64] They also pointed out the national reliance on iodine-depleted desalinated water, the absence of a universal salt iodization program and reports of increased use of thyroid medication in Israel as a possible reasons that the population's iodine intake is low. In the year that the survey was conducted, the amount of water produced from the desalination plants constitutes about 50% of the quantity of fresh water supplied for all needs and about 80% of the water supplied for domestic and industrial needs in Israel.[65]

Other issues [edit]