Watts and Water

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1. Introduction

Electricity and water are invariably linked. Given enough inexpensive power, there will be no shortage of water. For instance, where I live, we frequently have water shortages, and yet a few miles to the west, we have a huge basin with 154 million cubic miles of water. There is just one problem, it's a wee bit salty (of course, so am I sometimes), as are many bodies of water near arid lands. Actually there is another "body of water" that is accessible to everyone: earth's atmosphere, we just need to add energy.

This post is about three technologies. One is the current state-of-the art technology for desalination, one is a potentially more efficient technology for desalinization, and a third is a technology for extracting water from the atmosphere.

2. Reverse Osmosis Desalinization

We briefly covered both this and the technology in the next section (solar desalinization) in the earlier paper linked below. Here we will take a deeper dive for both.

https://www.energycentral.com/c/ec/climate-change-two-challenges-and-five-solutions-%E2%80%93-part-2

As of 2015 California had eleven desalination plants, including one of the largest in the world in Carlsbad (near San Diego). The Carlsbad plant was completed in 2015, can deliver 54 Million gallons a day of water and consumes 35 MW of electricity doing this. All of these plants use reverse osmosis, which is described below.

Reverse osmosis (RO) is a water purification process that uses a partially permeable membrane to remove unwanted molecules and larger particles from drinking water. Reverse osmosis can remove many types of dissolved and suspended chemicals as well as biological ones (principally bacteria) from water. The result is that water with dissolved compounds and particulates is retained on the pressurized side of the membrane and the pure water is allowed to pass to the other side. To be "selective", this membrane should not allow large molecules or ions through the pores, but should allow smaller molecules such as water to pass.

A reverse osmosis system has four primary processes:[1]

Pretreatment: The incoming feedwater is pretreated to be compatible with the membranes by removing most suspended solids (that would clog the membranes), adjusting the pH, and adding a threshold inhibitor to control scaling caused by constituents such as calcium sulphate.

[1] The Organization of American States, Department of Sustainable Development, Desalination by reverse osmosis, https://oas.org/dsd/publications/Unit/oea59e/ch20.htm

Pressurization: The pump raises the pressure of the pretreated feedwater to an operating pressure appropriate for the membrane and the salinity of the feedwater. Much of the energy used by reverse osmosis is consumed by this pressurization process.

Separation: The pores in permeable membranes are large enough for pure water molecules to pass through but strongly resist the passage of molecules with ionically-bound salts and particulates. Applying pressurized feedwater to the membrane assembly results in a freshwater product stream passing through the membrane and a brine stream remaining on the pressurized side. Ultimately the brine stream is discarded once it reaches the target concentration. Because no membrane is perfect in its rejection of dissolved salts, a small percentage of salt passes through the membrane and remains in the product water. Reverse osmosis membranes come in a variety of configurations. They are generally made of cellulose acetate, aromatic polyamides, or, nowadays, thin film polymer composites. Reverse osmosis systems are used for brackish water and seawater desalination, although the specific membrane and the construction of the pressure vessel vary according to the different operating pressures used for the type of feedwater.

Stabilization: The product water from the membrane assembly usually requires pH adjustment and degasification before being transferred to the distribution system for potable water. The product passes through an aeration column in which the pH is elevated from a value of approximately 5 (acidic, due to dissolved gases) to a value close to 7 (neutral).

3. Solar Desalinization

Our capitalistic economic system is very good at picking the most efficient process. Take generating electricity: photovoltaic (PV) panels plus large lithium-ion battery banks are emerging as the most efficient way to generate power for many areas in the U.S. Coal-fired power plants, and large nuclear power plants are dying, not because of some grand conspiracy, but because it costs less to produce power with PV plus batteries. Also, power purchase agreement pricing for the latter continues to drop rapidly.

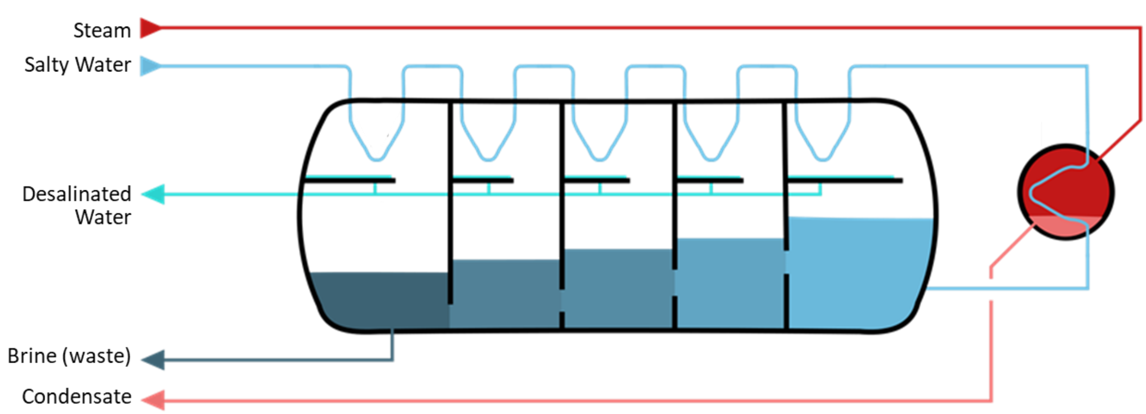
Given a starting-point of using electricity to desalinate ocean-water, reverse osmosis is probably the most efficient way of doing this. But if we use a process that cuts out the middle-man (conversion of sunlight to electricity, and storing it), and use the sunlight to provide most of the energy for desalinization directly, then the economic-cost of this process may be lower.

Fifteen or twenty years ago, there was a competitor for PV + batteries – concentrated solar-thermal power, but it lost the race. However, perhaps we can repurpose some the components from the former and define a more efficient method of desalinating water than generating electric power and using this power in the technology described in the prior section.

When concentrated solar-thermal power was competing for the leading electric production role, the most efficient way to heat water (on a calorie-basis) was a parabolic trough concentrator (see image below). Although central-receiver systems could generate much higher temperatures, high temperature-steam is not required for desalinization.

The parabolic trough operates by focusing the sun's rays on the central tube. The assembly is oriented north and south, and tracks the sun as it moves east-to-west by varying its tilt-angle.

Given source of solar heat that can produce steam, there is a process for producing fresh water that may be more efficient than reverse osmosis: Multi-stage flash distillation. This starts out with two inputs: steam and salty or brackish water. See the figure below.[2]



[2] Wikipedia Article on "Multi-stage flash distillation", https://en.wikipedia.org/wiki/Multi-stage_flash_distillation

There are multiple condensation compartments. The right-most compartment is fed with the hottest salt water, which produces vapor. The salty water input serves two purposes: (1) the cool input water (light blue) feeds coils that condense the vapor into fresh water, and (2) by doing this the salt water is preheated. The steam feeds a heat exchanger (red circle on the far right) which provides the final heating of the salt-water before it enters the first chamber (on the right). The steam is condensed by the heat exchanger and will be reheated by the concentrators to produce steam and complete the cycle. The waste brine will be either returned to the saltwater source or sent to evaporation ponds to produce sea-salt.

Each chamber, going from the right to left, has lower temperatures and pressures.

4. Water from the Winds

An incredible new substance is emerging with many applications: metal-organic frameworks (MOF). Professor Omar Yaghi's team at the University of California at Berkeley is known for their discovery of MOFs in 1995. These materials have the ability to selectively adsorb a wide variety of substances (guests), and then release these materials. MOFs also "compact" gasses without pressurization or low temperature when it adsorbs them. Gasses adsorbed include hydrogen, methane, and carbon dioxide. MOFs can also be used to position organic and organometallic catalysts, charge storage for supercapacitors and bind biological molecules such as proteins and metabolites. [3]

And MOFs very effectively absorb water from the atmosphere, even in very arid regions.

From the above reference: *"The Yaghi group was the first to uncover the porosity of MOFs. In 1998 and 1999, we reported their synthesis and architectural stability. Using gas adsorption isotherms we showed that zinc terephthalate MOFs (MOF-2 and MOF-5) retain their open structure in the absence of guests and that gases can pass in and out of the pores with full retention of the MOF structure. Since then we showed that MOFs can be functionalized and their components (metal containing units and organic links) can be widely varied. This made available a large class of MOF materials whose gas adsorption properties continue to be studied by our group. Specifically, we have several ongoing programs focused on hydrogen storage and methane storage and transport for automobile fueling. We also work extensively on carbon capture from the atmosphere, automobiles and power plants. More recently, we have initiated research programs where it is possible to use amyloids (long known to be important in the onslaught of diseases such as Alzheimer's) for demonstrating that lysine functionalities can trap carbon dioxide in the presence of water. MOFs are also being investigated in our group for their applications to clean water using artificial leaf constructs, and as thermal batteries for heating and cooling automobiles."*

Yaghi's team first developed a zirconium-based MOF in 2014 that could hold and release water. There is just one problem, at over $70 per pound, zirconium is too expensive for bulk use. Last year they came up with MOF-303, based on aluminum, which costs less than $1.50 per pound. Initially this MOF could produce less than a cup of water per day. However with recent improvements, this design can produce over a pint of water per pound of MOF per day. This production rate was in the desert in Arizona. Yaghi's team can foresee improvements that will boost that to more than two gallons of water per day per pound of MOF.

[3] Yaghi Laboratory, University of California, Berkeley, http://yaghi.berkeley.edu/index.html

Yaghi has formed a company called Water Harvesting (link below) that shortly plans to release a microwave-size device able to provide over two gallons of water per day, and promises a larger version in 2020 that will produce over 5,900 gallons per day.

http://waterharvestinginc.com/

It appears that Water Harvesting will initially target applications that require a self-contained systems that can provide small to medium volumes of water. Initial prototypes were powered by photovoltaic panels, and it is reasonable to assume that larger systems can be so powered.