Introduction

- Human Drinking water requirement: It has a pH close to 7. This differs from the pH levels of fresh water which depends on the geology of the topographical surface containing it "ground/surface" and the intake feed (rain, stream discharge, agricultural / industrial drainage, etc) which end up affecting the suspended dissolved particles within the water that may affect the pH of it and could lead to increasing its hardness if Calcium ion concentrations increased. This pH could fluctuates within permissible limits (the Egyptian Code allows it to reach a range of 6.5 to 8.5.
- It needs to be safe for consumption from toxicity / hazard (an excerpt from the Egyptian Code, the list is much more extensive though):

Mineral / Contaminant	Maximum Concentration / Exposure	Mineral / Contaminant	Maximum Concentration / Exposure
Lead	1 mg/L	SO4	250 mg/L
Selenium	0.05 mg/L	CL (all CL compounds)	250 mg/L
Arsenic	0.2 mg/L	Fe	00.3 mg/L
Hexavalent Chromium	0.01-0.05 mg/L	Mn	0.4 mg/L
Fluoride	5 mg/L	Copper	2.0 mg/L
Nitrates	40 mg/L	Na	200 mg/L
Alpha Radiation	10(-9) Micro Curie per Milliliter	Al	0.2 mg/L
Beta Radiation	10(-8) Micro Curie per Milliliter	Mercury (Hg)	0.001 mg/L
CaCo3	350 mg/L	Cyanide	0.05 mg/L
Mg	150 mg/L	Cadmium	0.003
Ammonia (NH3)	0.5 mg/L	Nickel (NI)	0.02 mg/L
Boron	0.5 mg/L	Barium	0.7 mg/L
Molybdenum (Mo)	0.07 mg/L	Benzene	0.01 mg/L

Introduction (cont'd)

- Brackish water has Total Dissolved Solids (TDS) around from 500 ++ to 30,000 mg/L
- Saline water has TDS from 30,000 to 40,000 mg/L
- Hypersaline water has TDS greater than 40,000 mg/L
- The Turbidity of human drinking water as per the Egyptian Code is allowed with a maximum of 1 NTU.
- TDS affect both the safety of the water to consume and the taste:

DRINKING WATER TDS CHART ACCORDING TO TASTE	
TDS LEVEL (MG/L)	RATING
Less than 300	Excellent
300-600	Good
600-900	Fair
900-1200	Poor
Above 1200	Unacceptable

Seawater typical salt content

Element	Concentration (mg/l)	Element	Concentration (mg/l)
Oxygen	8.57 x 10+5	Molybdenum	0.01
Hydrogen	1.08 x 10+5	Zinc	0.01
Chlorine	19000	Nickel	0.0054
Sodium	10500	Arsenic	0.003
Magnesium	1350	Copper	0.003
Sulfur	885	Tin	0.003
Calcium	400	Uranium	0.003
Potassium	380	Chromium	0.0003
Bromine	65	Krypton	0.0025
Carbon	28	Manganese	0.002
Strontium	8.1	Vanadium	0.001
Boron	4.6	Titanium	0.001
Silicon	3	Cesium	0.0005
Fluoride	1.3	Cerium	0.0004
Argon	0.6	Antimony	0.00033
Nitrogen	0.5	Silver	0.0003
Lithium	0.18	Yttium	0.0003
Rubidium	0.12	Cobalt	0.00027
Phosphorus	0.07	Neon	0.00014
Iodine	0.06	Cadmium	0.00011
Barium	0.03	Tungsten	0.0001
Aluminum	0.01	Lead	0.00005
Iron	0.01	Mercury	0.00003
Indium	<0.02	Selenium	0.00002

What is Desalination?

- Water Desalination is the process of removing salts and minerals from otherwise saline water so that it could be used for irrigation, industry and animal / human consumption. The degree of tolerable salt content depends on the target consumers (purity levels in certain industrial processes require the absence of impurities / traces and hence require strict desalination process). It usually takes place for seawater, or highly saline groundwater.

- Desalination is utilized due to either unavailability of fresh water bodies nearby, poor rainfall records, or the difficulty of connecting pipelines from freshwater sources due to cost, distance, topographical terrain, or geo-political forces.

- 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. Currently, Kuwait is the ranked first in the world in its desalination water production as % of the local needs (100% comes from desalination). The largest hybrid desalination plant (producing both energy and desalinated water) is Ras El Khair Plant in Saudi Arabia, the Arab Gulf coast with production capacity of 1,025,000 cubic meters per day in 2014 (1^{st} year of operation); the plant uses a hybrid system of eight multi-stage flashing and 17 reverse osmosis units.

- Desalination has a variety of methods depending on the target resultant purity, the available energy source , the available technology and projected cost model of operations, like the following examples:

  - Distillation
  - Ion Exchange
  - Membrane filtration
  - Freeze-thaw desalination
  - Experimental techniques: Industrial Waste Heat, Low-temperature thermal desalination (LTTD) and others.

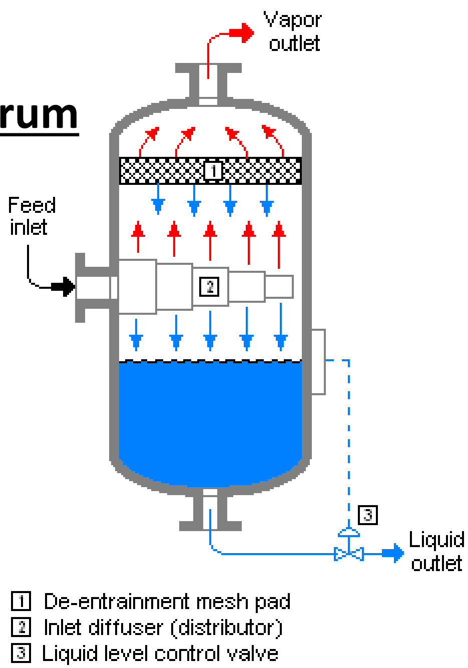
Distillation

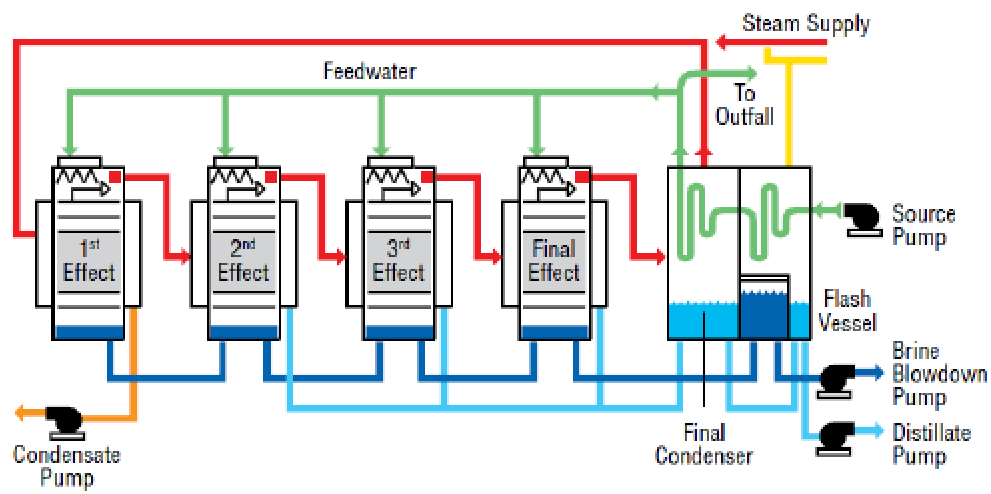
- Distillation is one method desalination could work which happens via applying thermal energy (heat) to saline solutions and allowing for evaporation and capturing water steam allowing it to condensate into fresh water as H2O while most if all the salts and mineral traces except very few volatiles reside behind. The idea is that salts and minerals are less volatile than water so they don't evaporate at the same water boiling temperature which may lead to the development of boilers scaling as salts and minerals keep accumulating. If the water being distilled has a soluble element that is volatile with a boiling point difference of less than 50 degrees, the distillation process may lead to the evaporation / condensation of that volatile substance along with the water.
- Distillation is not a modern invention to produce fresh water from salt-heavy waters. Historically , it was mentioned in Aristotle's work, Meteorologica and was outlined and illustrated by Alexander of Aphrodisias later on , in 200 AD.
- Simple water purification/treatment may not work in the pharmaceutical industries that require salts/mineral concentration precision ; another example is the the manufacturing of lead-acid batteries and cooling systems in automotive industries due to scaling and corrosion and affecting the work of antifreeze additives. Also, cigars (too luxurious and fancy product to have scaling salts as you light that joint).
- The principle of distillation via evaporation depends on the following heat / energy requirements; in order to increase the temperature of 1 gram of water by 1 degree °C is 4,184 J. This means that to raise the temperature of 1 liter of water (= 1 Kg = 1,000 grams) currently at 20 °C to 100 °C (boiling point, extra 80 °C) , you would need to apply the following energy (assuming no significant heat/energy losses occurred): = 1,000 * 4,194 * 80 = 334720000 Joules = 334720000 kilojoule.
- Seawater, being of saline content, has higher boiling point , the Mediterranean seawater boils at around 105-106 °C.

Different Distillation Methods

- **Multi-Stage Flash Distillation (MSF):** This process depends on the evaporation of the heated liquid (seawater) as it is passes through a flash drum (low pressure vessel) that turns some of the heated liquid into steam (that escapes the vessel into next stages to condensate) and the remaining liquid goes to the second stage, another vessel at lower pressure where another partial evaporation occurs and the residual liquid goes to subsequent stages, each one at lower more reduced pressure. The number of stages in such plants reach more than 24 stages. It accounts for 45% of produced desalinated fresh water and 93% of all thermal methods>

Flash Drum

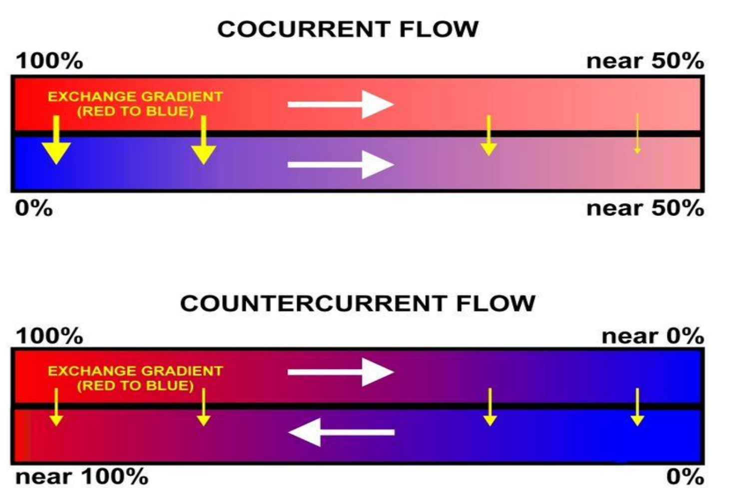




Simplified diagram of the process

Countercurrent Heat Exchangers in MSF Distillation

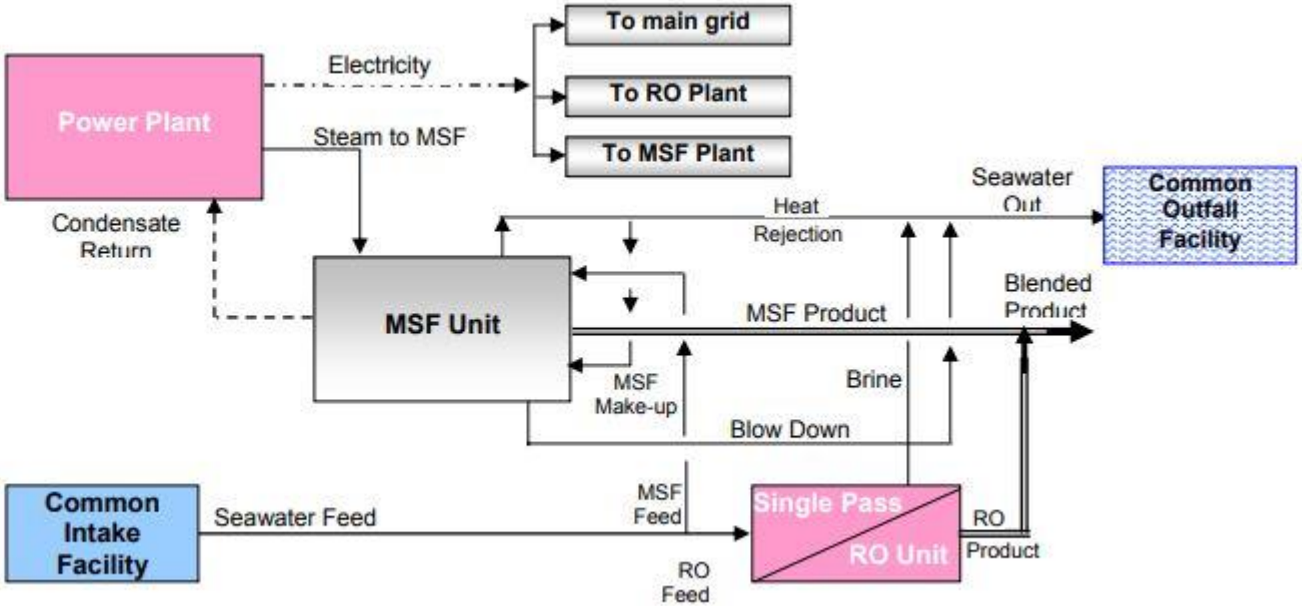
- Such principle is based on the physical phenomenon of heat exchange between objects, bodies, or any flowing substance flowing , or moving in close proximity. If they two flowing streams are in the same direction, it is called “cocurrent” which doesn’t lead to much heat transfer as the two bodies end up achieving equilibrium as they move in the same direction (two streams, one at 100 °C and the other at 50 °C in the same direction separated by thermo-conductive side would end up having an equilibrium degree of 75 °C) while in countercurrent heat exchanging, the two streams having opposite direction leads to the establishment of a gradient that “transfers” most of the heat / energy.
- The application of this in distillation is that the hot freshwater steam would transfer its heat to the cold saline water which would help the freshwater stream to condensate and would help preserve the energy by using it to heat up another incoming amount of saline water that would be further heated , would go into the flash low pressure drum, then it would start a new cycle as it evaporates, turn into steam then condensate giving its heat to another stream of saline water.



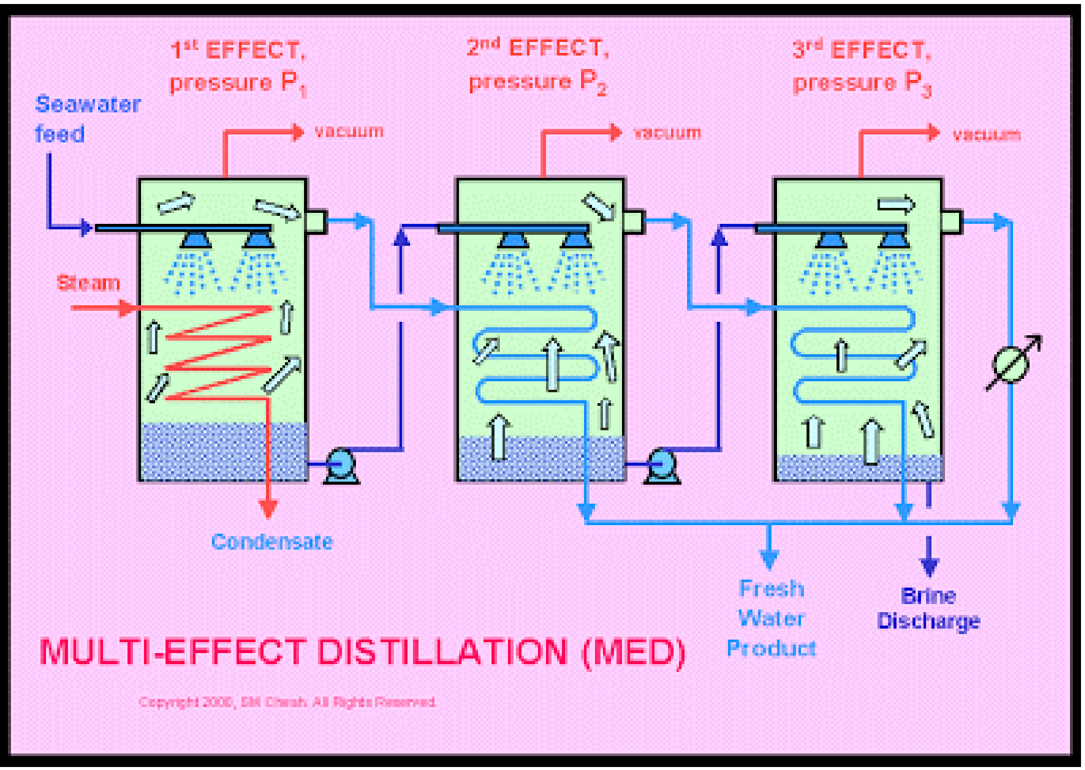
Pairing Multi-Stage Flash (MSF) with heat cogeneration (Waste Heat Method)

- In order to benefit from the relatively low temperatures needed to evaporate water (maximum of 120 °C) and using the countercurrent heat exchange principles, some MSF desalination plants are built within industrial complexes which would integrate designs and structures so that the heat captured from industrial process like power generation would be used and in return, the water flow would be used in cooling which would achieve economical gains and energy efficiencies for both plants.

Simple diagram of the hybrid power plant where the power generation excess heat is used generate steam and the incoming water cools down the power plant



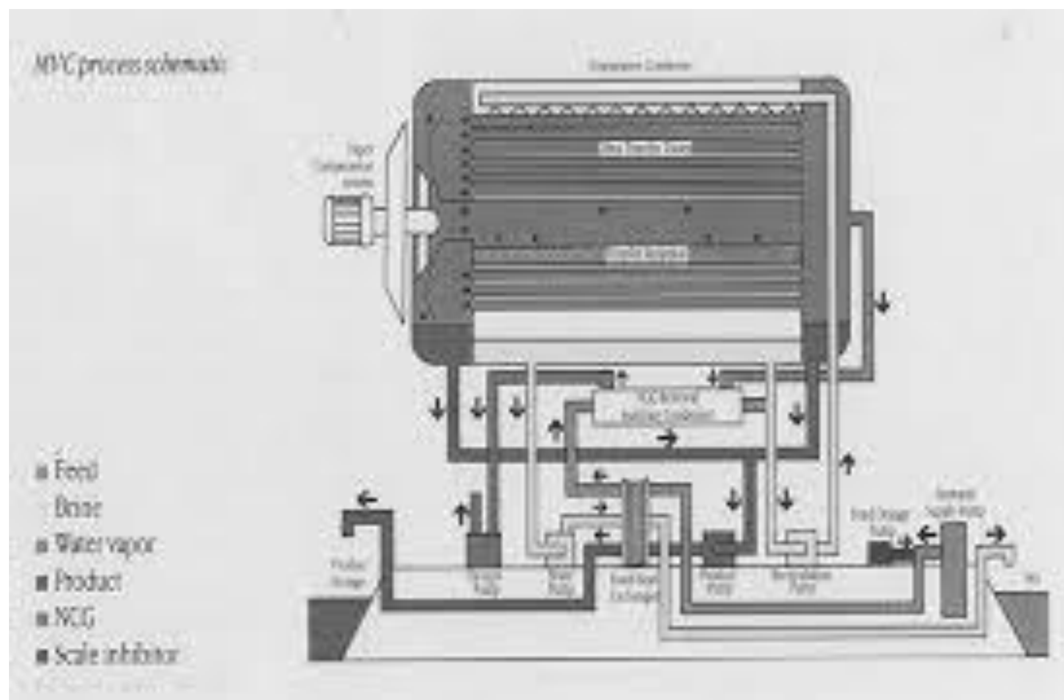
Multiple-effect Distillation (MED)



This Distillation method is similar to MSF in reliance on heat counter- current exchanging , however, it does transport seawater intended for evaporation via sprayers / sprinkler systems that drops agitated seawater on heat transfer tubes in adjacent subspaces; this allows for harnessing more energy efficiencies as the process may be carried out in lower-temperature situation (70 °C and less) due to the tubes increasing the surface area of heat exchange; also, with increasing the surface area , the walls of such tubes could be thinner allowing for faster heat transfer and increased thermo-conductivity. The main drawback is that it works best with relatively low temperatures (ideal for waste heat integration), but scaling forms at higher temperature and may lead to clogging the sprayer systems. It also requires large scale operations to benefit from the idea of maximizing heat transfer / exchange via tube systems.

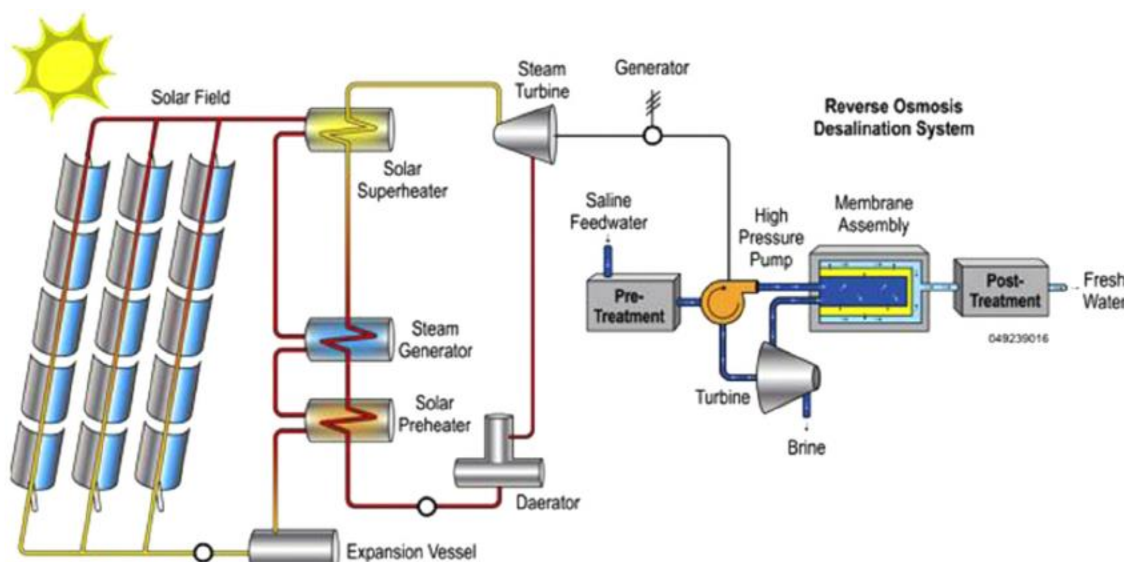
Vapor Compression Distillation

- Simply, this system uses a compressor that captures the heat of the evaporating heated water via applying a compressor that, due to compression, would increase the agitation, pressure and temperature of the steam that in return would be used to transfer the energy /heat and exchange it to another fresh amount of water that are to be distilled. The idea is to use that external compressor to increase energy efficiency by prolonging the high-temperature state of the evaporating water into steam to maximize heat capturing and distribution via increasing temperature and reducing pressure via compression.
- Mechanical and electric driven.



Solar Energy Distillation

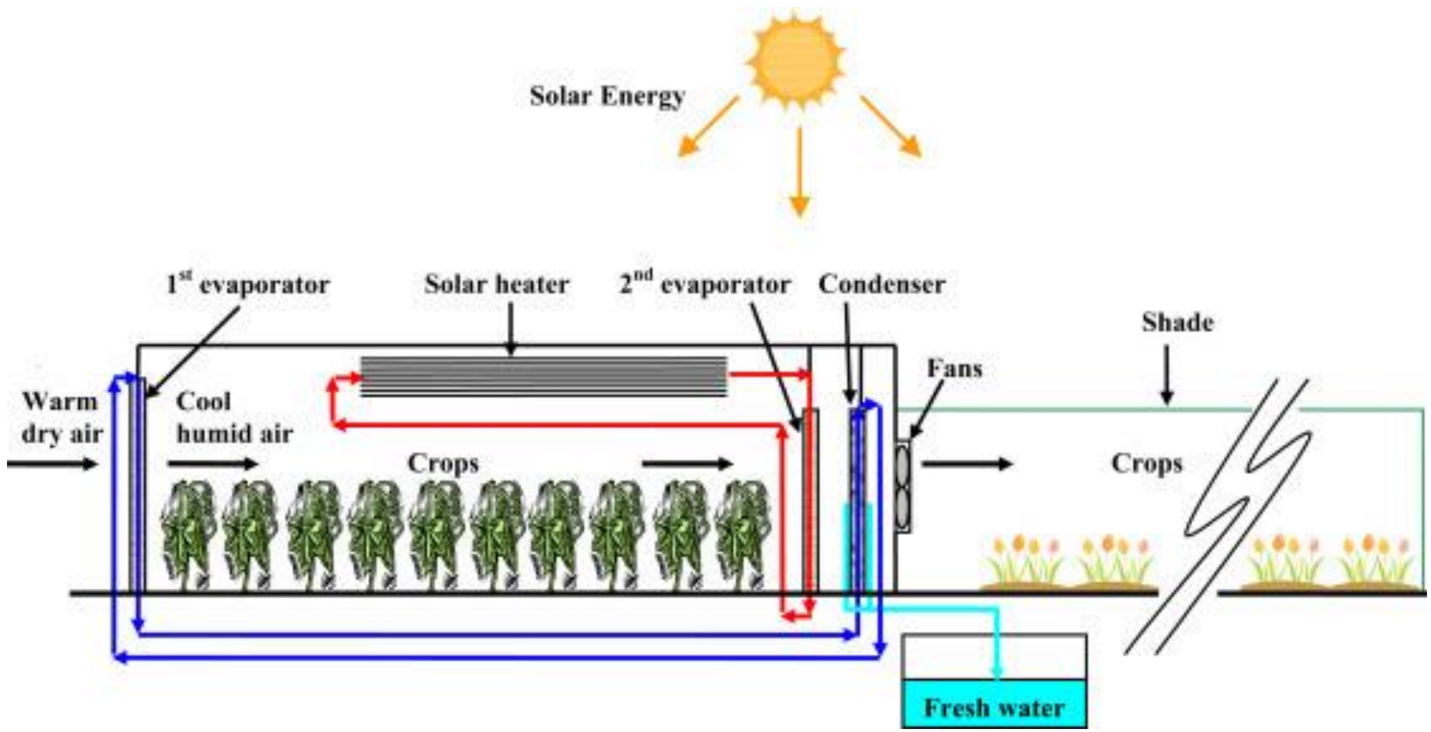
- This distillation system uniqueness is in the utilization of concentrated solar energy which is a clean source to heat seawater. The design challenge is in the wasted heat that get reflected off the large scale solar collectors / concentrators dishes / systems. Accordingly, the thermal solution is to use heat recovery systems in addition to pairing the system with lower pressure vacuum pumps of the seawater tanks as this would lead to lower boiling / evaporation point (at 0.1 atmospheric pressure, water would boil at 50 °C).
- Another challenge is the large land area needed to collect enough energy for commercially viable desalination; due to this, such projects could pair up with other energy sources like wind power. However, both are dependent on natural local weather patterns and hence require careful planning for the site based on wind speed/direction and volume and solar illumination. An MSF solar Distillation plant could generate up to 60 liters of fresh water per utilized m2 per day.



<u>While there are standalone systems, some solar systems pair up with RO to increase commercial viability</u>

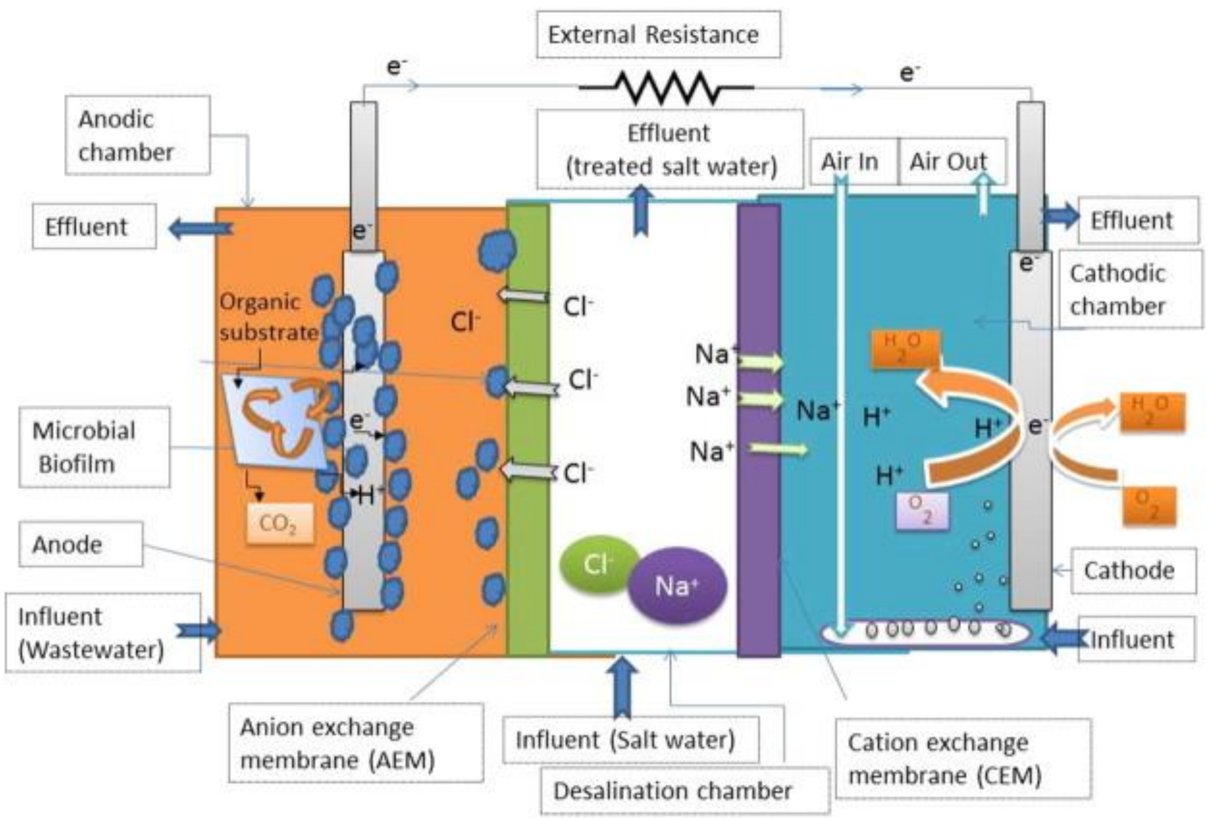
Solar Seawater Greenhouse

- While this method is not meant to generate drinking water; it is a futuristic design to help with irrigation and farming in arid areas near the coast line or in places with highly saline groundwater. Such project mimics the natural water cycle and has been tried in Australia at "Sundrop Farms" over more than 20 acres of successful experimental expansion>



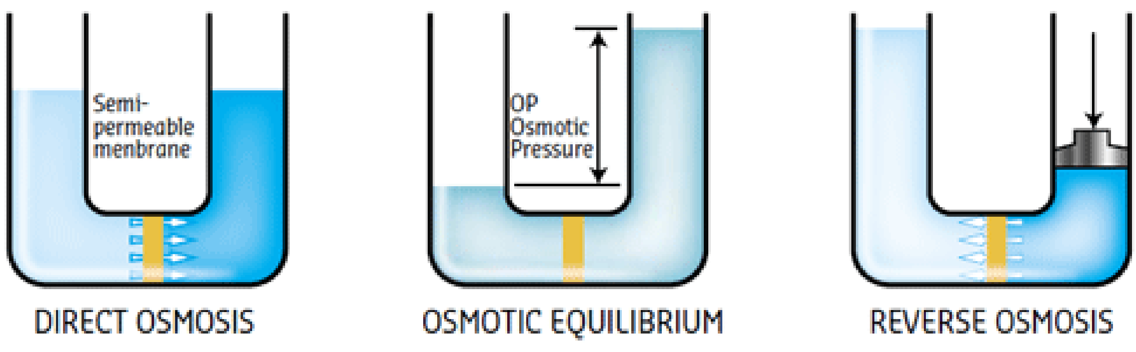
Ion Exchange and Electrodiyalisis

- This process allows for desalination via attracting the ions of soluble salts and minerals as per their electric charge onto Anion Exchange Membrane (AEM) and Cation Exchange Membrane (CEM). While the process is not adopted for drinking water desalination, it is adopted in some industrial processes and to remove water hardness by exchanging the ions of Calcium and Magnesium for Sodium ions.



Reverse Osmosis

- Reverse Osmosis Desalination: it works via utilizing the osmotic pressure properties of solvent water as it pass from salt-rich side (higher concentration) to fresh water side of lower concentration (350 psig); via applying much greater pressure than the osmotic pressure (600-1200 psig = 40-82 bar) , solvent salt-rich water would be forced to move through the membrane (semipermeable). The force resultant from the applied extra pressure (beyond Osmotic pressure of 350 psig) and the small size of pores (from 0.1 to 5,000 nanometer, water desalination deploys hyperfilteration, particles larger than 0.1 nanometer) lead to the resultant solution to be from 90-99% free of the TDS of the initial solution. The system would need activated carbon filters before and after .
- Challenges: Since membranes depend on porosity for filtering out water, they are subjected to fouling and clogging; in addition, them being made of cellulose-based substance (Cellulose Triacetate), are subject to decay and bio-fouling. This leads to needing a pretreatment process and post-treatment process. Membranes would have to be replaced regularly adding to operating costs.



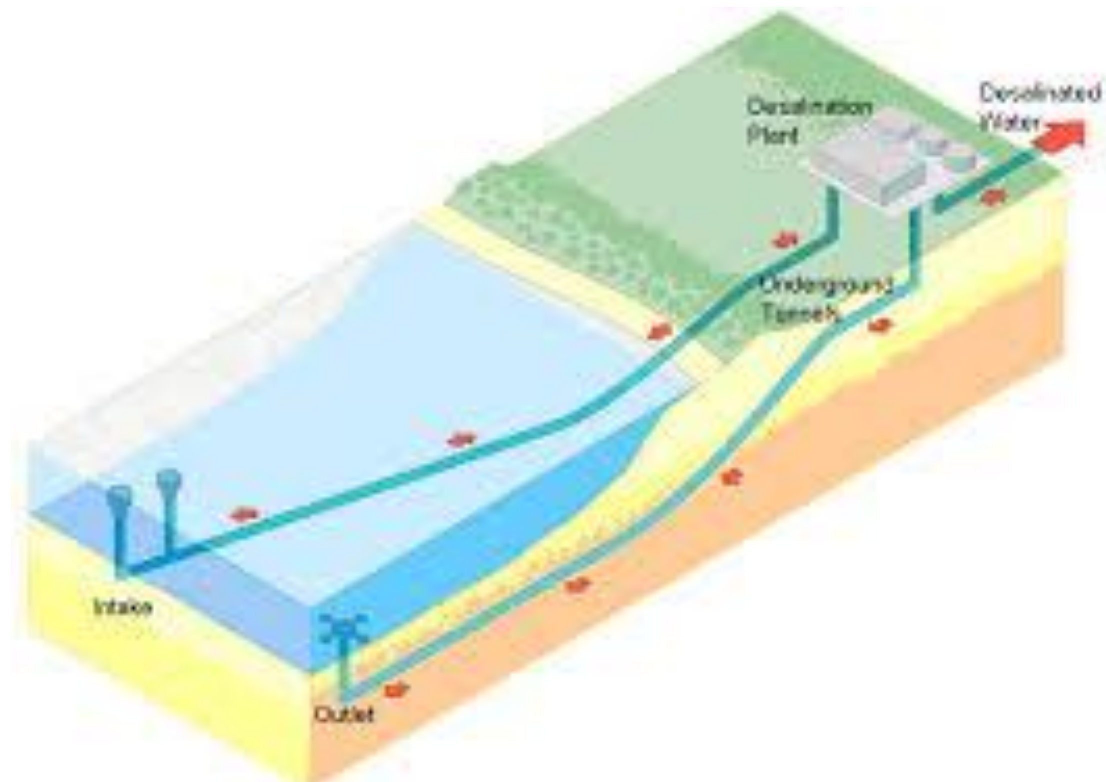
Reverse Osmosis operating principle

Reverse Osmosis membrane pretreatment

Fouling	Cause	Appropriate Pre-treatment
Biological fouling	Bacteria, microorganisms, viruses, protozoan	**Chlorination**
Particle fouling	sand, clay (turbidity, suspended solids)	Filtration
Colloidal fouling	Organic and inorganic complexes, colloidal particles, micro-**algae**	Coagulation + Filtration Optional: Flocculation / sedimentation
Organic fouling	**Natural Organic Matter** (NOM) : humic and fulvic acids, biopolymers	Coagulation + Filtration + Activated carbon adsorption Coagulation+ Ultrafiltration
Mineral fouling	**Calcium**, Magnesium Barium or Strontium **sulfates**and carbonates	Antiscalant dosing Acidification
Oxidant fouling	**Chlorine**, Ozone, KMnO4	Oxidant scavenger dosing: Sodium (meta)bilsulfite Granulated Activated Carbon

Some environmental issues of desalination projects

- Intake Designs and effect on marine life
- Brine Discharge



Thank you !!!!

- والراحمون يرحمهم الله!!!!