Desalination of seawater, nature's way

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Humanity faces an existential crisis like none it has ever faced before. Climate change is not simply a matter of global warming: Severe weather, intense fires and rising seas, have huge impacts, aggravated by the demands of earth's increasing population. Potable water and food are problems as serious as the implications of climate change.

Our innovative approach to desalination uses thermodynamics to separate ocean-water into potable water and salt.

The right panel outlines the five processing steps proposed to convert the seawater (OCEAN) into potable water. Using the sun as the sole source of thermal energy (1.37 [kW/m^2]), cold seawater is heated, causing it to evaporate on a mass scale (e.g., a million square miles of the Sahara desert), to create thousands of huge lakes (FRESH WATER LAKE). This is then replicated in many, if not all, the many arid deserts across the earth. As these arid wastelands evolve into jungles, they will naturally remove the CO_2 from the air, solving the problem of global warming over the long term. Water and food will become a free resource. Populations will become less of an issue as long as there are natural resources to support them.

We include humidity in the gas law by defining a virtual temperature $T_v = (1 + 0.61q)T$, allowing one to use the standard equation of state with T replace by T_v (Ambaum, 2010, p. 14). Here $q = \mu_d/\mu_w$ is the specific humidity, where μ_d and μ_w are the molar mass for dry air and water. Thus the virtual temperature increases with humidity. At a constant atmospheric pressure P_o, the virtual gas law becomes $P_oV = R(1 + 0.061q)T$. The increasing volume $\Delta V = 0.061qRT$ represents the increase in water vapor with temperature, which is 5% water vapor at 95°F, as shown in Fig. 2.

One of the key components of this proposal is to unite the faculty and students, drawing upon on the vast composite knowledge within university populations across the US, and eventually, the globe.

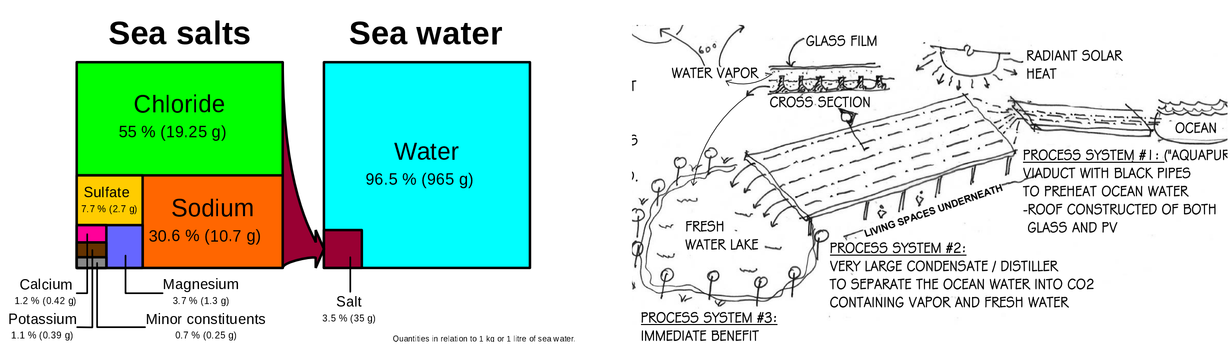

Figure A: LEFT: Sea water is 96.5% H_2O with NaCl (3%) being the largest contaminant. B: RIGHT: Outline showing 3 of the 5 `PROCESS SYSTEMS` *(PS) required to convert the seawater into potable water and salts. Potable water from sunlight and cold seawater is the primary goal of the proposal. The 3.5% of ocean salts may be extracted from the water as a solid. Given enough "free pure water" we can grow vast jungles on otherwise arid land.*

To be, or not to be, that is the question.
–Hamlet

Overview

The basic concept of this proposal is to take cold ocean water, and using sunlight as the sole power source, separate the pure water from the salt by evaporation. Potable water is essential for growing plants (trees, grass, food, etc.) on a massive scale.[1] The long-term goal is to restore the world's many arid deserts to jungles, returning them to their earlier state (i.e., 200,000 years ago). Given sufficient plant life, the CO_2 will be naturally absorbed. Given enough water (i.e., at least 40 inches/year of rainfall equivalent), plants will grow, making this is a feasible long-term desalination solution. But it will take at least several decades before it can be functional. In the meantime we need to directly deal with reducing CO_2 in the ocean, where it is presently causing the greatest damage to the environment.

Much of the trapped heat and CO_2, due in part to our increased burning of fossil fuel over recent centuries, has been absorbed by the oceans (Peixoto and Oort, 1992). This has obscured our awareness of the severity of the problem, and at the same time, lowered the PH of the ocean. Presently the PH is 8.1.[2] While the ocean is naturally base, acid rains and absorbed CO_2 have severely lowered the PH, causing the destruction of the coral, critical for bio-diversity in the ocean (i.e., on the planet).

Life in the ocean, one of our main sources of food, depends on the coral in a healthy ocean — this is where life began. Besides desalinating seawater, we also remove the CO_2 as carbonates. If we removed all the potable water from 1 ton of seawater, ony two 35 lb bags of salt would remain.

Where does rain come from? The sun evaporates the surface water from the ocean, forming clouds, which when mixed with cold air, dump the moisture as rain. Can this process be put under our control, so that we can make rain as needed? The water supply too important to be entrusted to the vagaries of the weather.

All modern commercial desalination systems use reverse-osmosis (RO) systems, which become clogged and are costly to maintain, and which requires large amounts of electricity (Shatat and Riffat, 2012). Solar panels are limited to 22% efficiency. We shall argue that direct solar approaches 100% efficiency when using a *counter-flow heat exchange* (CFHE) (Ghaffour et al., 2013; Deniz, 2015), which can be up to 10 times more effective in evaporating water.[3] Thus direct evaporation-condensation with CFHE is consistent with nature's way.[4] Ghaffour et al. (2013, p. 200) cites RO desal recovery ratios of 35 L/L in 1986 have increased 45% by 2020, and by the use of a second stage MSF, can be increased by 60% re 1986. By the use of direct solar evaporation, there are no direct energy costs, which is the critical advantage.

I have not yet found a mathematical analysis of CFHE, or a direct comparison with its multi-stage version, the MSF method, but hope to provide one (Allen, 2020).

We present a scenario on how to convert seawater into fresh water, and at the same time extract the CO_2, driven entirely by the energy from the sun. The maximum amount of water is ultimately determined by the solar constant[5] (1.3 [kW/m^2]), and by the efficiency of the Carnot cycle in reclaiming the large latent heat energy of the water vapor via the CFHE.

A specific proposal

Our proposal is presented in Fig. 1. On the far right 15 °C (59 °F) seawater is piped in and fed to an aqueduct, which we call an *aquipure*, denoting a conduit used to extract pure water, and to concentrate and eventually remove the dissolved salts. The aquipure is slightly angled, so as to gravity-feed the water inland. Ocean wind-farms could provide the electricity to run the deep-water pumps. Once available systems are prototyped, they would be replicated on a massive scale, creating thousands of fresh water lakes, and eventually jungles.

There are numbered *process systems* (PS) indicated in the diagram labeled as `PROCESS SYSTEM #N`, with $N = 1, 2, \cdots, 5$. Process System #1 (PS #1) delivers cold seawater to the aquipure.[6] PS #2 is the heart of the desal process, where the seawater is heated by the sun's radiant energy (solar heat), raising the temperature, causing the water to evaporate. The aquipure is covered by a thin transparent glass or plastic sheath that lets the sun's rays through but traps the water vapor.

[1] `https://www.goodnewsnetwork.org/using-sewage-water-to-grow-trees-in-egyptian-desert/`

[2] We are somewhere between 8.2 and 8.3 is ideal. Neutral is 7.

[3] `https://en.wikipedia.org/wiki/Multi-stage_flash_distillation`

[4] `https://en.wikipedia.org/wiki/Countercurrent_exchange`

[5] The *solar insolation* is a more meaningful metric, which depends on both the physical location and the daily variation of the solar input.

[6] Inland cold ground water could supplement the cold seawater to assist with the water vapor condensation process.

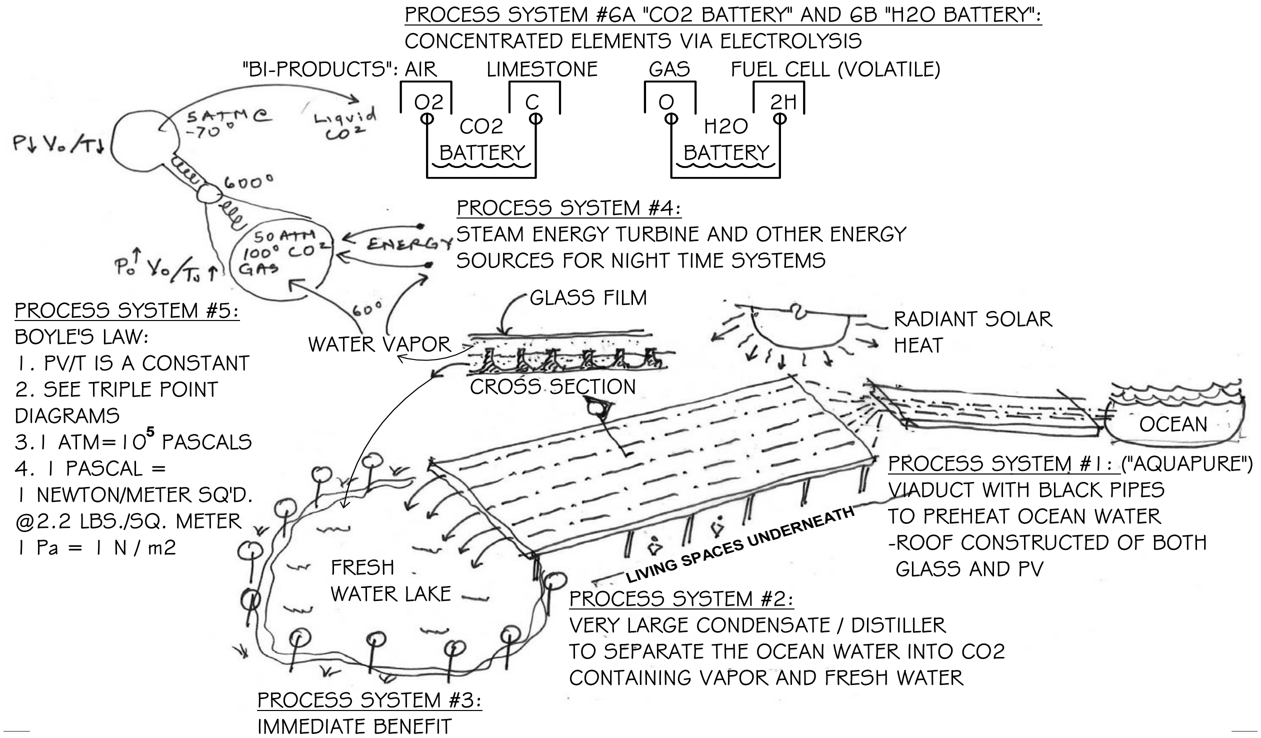

Figure 1: *Process diagram showing the five different proposals for converting seawater into pure water (96.5%) and salts (3.5%). (Graphic by AllenPepa.com)*

PS #4 shows a cross-section of the aquipure, with corrugated channels to transport the seawater. PS #4 further describes the inner workings of the system for extracting the desalinated water, leaving behind the sea salts, including the carbonates. A few centimeters above the water surface is a film (i.e, a transparent layer) to trap the hot water vapor.

Heating phase: To the right and above the aquipure is the sun, which provides the sole energy source to heat, to evaporate the seawater. The ideal strategy is to raise the humidity to 100% within the air space between the water surface and the cover. The humidity (partial pressure $\mathcal{P}(T)$ of the water vapor) depends on temperature T [°C] (Ambaum, 2010, p. 11), as given by Tetens' equation[7]

$$\mathcal{P}(T) = ae^{bT/(T+c)}, \tag{1}$$

where a, b, c are known constants (Ambaum, 2010, p. 98), as shown in the psychometric chart (Fig. 2).

One hundred percent humidity (the dew point) at 95 [°F] (35 [°C]) corresponds to 5% [kg/kg] water vapor. We shall abbreviate the temperature differences as ΔT.

Condensation phase: This water vapor is continuously evacuated through small holes in the duct, where it meets the chill-plate, a ceramic material with high heat capacity and thermal conductivity. When the water vapor comes in contact with the chilled seawater via the chill-plate, a lower dew point is met, and the water vapor becomes water, where it is collected and transported by gravity to the fresh water lake (PS #3).

Latent heat recovery: A key point of the proposal is to recover almost all the latent heat of the water vapor by pre-heating the cold inlet seawater. Recycling the latent heat of the vapor, known to the industry as *counter-flow heat exchange* or in a modular form, as *multi-stage flash* (MSF) (Ghaffour et al., 2013; Deniz, 2015, 5), raising the overall process efficiency by latent heat recycling.

To the best of our understanding, this could have an exponential increase in the effective heat input. The final total heat gained depends critically on the amount of lost heat. For example, if half the heat were lost, the gain would be 2x. If only 10% were lost, the gain would be 10x. Given the large latent heat in the water vapor (4.2 [kJ/kgm]), this is an important tool (Al-Karaghouli and Kazmerski, 2013; Wang et al., 2019).

The condensation temperature can be obtained from 1) cold seawater before it has been heated by the sun, or 2) via a heat pump buried deep in the earth. Misting the water above the aquipure increasing the surface area, and thus the rate of evaporation, and mixing the vapor with dry hot desert air will accelerate evaporation and raise efficiency providing an auxiliary heat input. Additionally, deserts can become quite cold once the sun goes down (e.g., 5 [°C]). If

[7] A variant of the Clausius-Clapeyron equation.

the hot vapor were stored, it could be further cooled by the night air. Further analytic and experimental analysis needs to be performed to determine the actual efficiency of the evaporation and water vapor condensation rates.

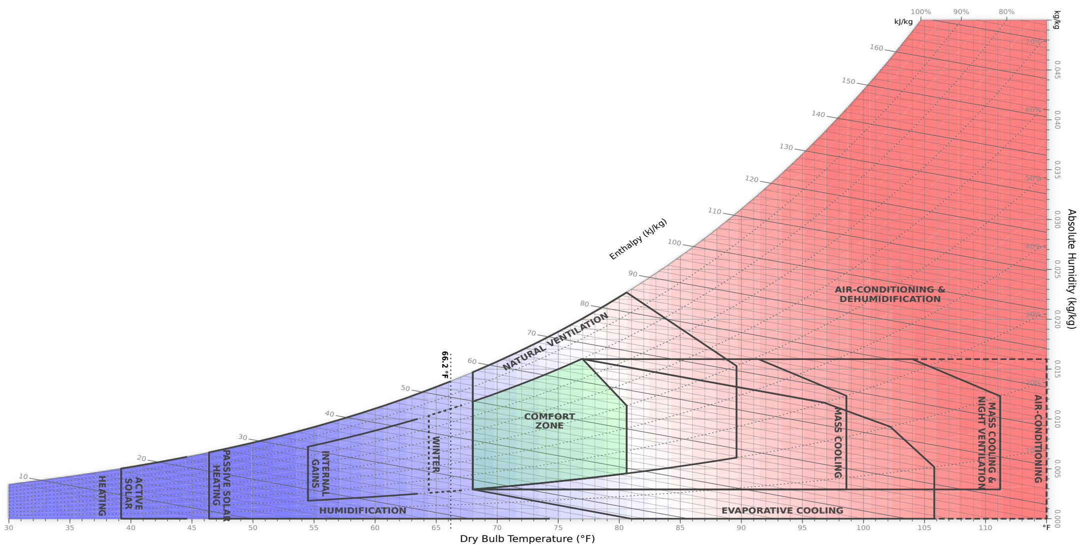

Figure 2: *A* psychometric chart *provides the quantitative relationship between the dry-bulb temperature, humidity, and the dew-point (Lawrence, 2005). The exponential growth as a function of the dry-bulb temperature is given by* Teten's equation *(Eq.* 1*) (Ambaum, 2010). For example, given a dry-bulb temperature of 105 [°F] (40 [°C]) and a relative humidity of 100%, the absolute humidity is 50 g/kg (5.0%). If the dry-bulb temperature is reduce to 38 [°F] (3 [°C]), the dew-point will drop to 5 [g/kg] (0.5%), releasing 50-5=45 [g] of water per kg of air (4.5% of the air mass in water). Ref:* `https://drajmarsh.bitbucket.io/psychro-chart2d.html`.

The desal market today: Detroit, California and India are a few of the many markets for desalination today. The water was shut off for lack of payment in Detroit, making it difficult for people to wash their hands during the COVID-19 pandemic. "Water is a local problem and India needs local solutions," said Priyanka Jamwal, a fellow at the Ashoka Trust for Research in Ecology and the Environment in Bangalore.[8] In both cases an immediate solution is needed.

To solve this worldwide crisis we need to go where the water is, the ocean. Desalination plants around the world are all based on reverse osmosis (RO), an expensive resource that is not ideally suited to the huge demands for fresh water. The oceans are slowly become more acidic due to the slow buildup of CO_2, which is highly soluble in water. In fact a third of the CO_2 generated by the burning of fossil fuels and cement production, ends up in the ocean, where it acidifies the ocean and kills the coral.[9]

The amount of energy required from the sun to evaporate the seawater is very large (4.2 [kCal/J]). If that stored energy were lost, the process would lose significant efficiency. Wang et al. (2019) categorically argues that the latent heat of the watervapor is not recoverable, thus concludes that photo-voltaics is the alternative of choice. In fact, by cooling the vapor with the cold seawater (CFHE), we gain a double advantage: 1) this condensation of the vapor using cold seawater, thereby recovering the large latent heat (energy) in the vapor (Shatat and Riffat, 2012; Deniz, 2015), and 2) pre-heating of seawater so less energy will be required to evaporate the water by the solar input. To the extent that no heat energy is lost to the environment, the integral of the daily solar heat input (i.e., the solar insolation) can be harnessed.

Estimate of water flux per day An estimate of the water output from the proposed process is a multi-step calculation. The amount of water L given insolation (energy) P_t to heat the water by ΔT =40-5 [°C] = 35 [°C] is

$$L = \frac{3600 P_t}{4.2 \Delta T}, \qquad \text{[liters/m}^2\text{-day]}$$

where ΔT [°C] is the change in temperature, P_t [kW-hr/day] is the input energy (insolation), and 4.2 [kJ/kg] is the heat capacity of water.

[8] `https://www.nytimes.com/interactive/2019/08/06/climate/world-water-stress.html`

[9] `https://www.epa.gov/ocean-acidification/understanding-science-ocean-and-coastal-acidification#self`

Basic constants:

- 4.3 [kJ] heats 1 [kgm] water 1 [°C]
- 1 [kgm] of water is 1 liter = $(0.1)^3$ [m^3] (1 [gal]= 3.8 [liters])
- Insolation: $P_t = 0.5$ [kW/m^2] $\cdot$ 5 [hr/day] $= 9 \times 10^3$ [kJ/m^2-day]
- ΔT = 104-41 [$°F$] = 40-5 [°C] = 35 [$°C$]
- Water vapor @ 40 [$°C$] = water/20 (i.e., $V = W/20 = W\cdot$ 5%)
- 1 [km^2] = 10^6 [m^2]
- 1 [mi^2] = $2.6 \cdot 10^6$ [m^2]

Using these numbers, 1 [m^2] of Insolation can produce 3 [kg] of water per day, or 3×10^6 [liters/day] for a 1 [km^2] of collection area. Alternatively, 1 [mi^2] would release 8,000 [tons] of pure water per day. If CFHE is used, these number can be greatly increased, by as much as 15 times (Al-Karaghouli and Kazmerski, 2013; Wang et al., 2019).

Management of the aquipure: The aquipure will need people to manage it. This is not a minor detail. This could be a way to manage displaced peoples. Of course such a proposal is not a scientific one and thus will not be further explored here. Nevertheless, this need for labor could, in theory, solve much of the world's displaced people problem, which is as serious as our fresh water, energy, and food shortage problems.

Collaboration: We will be working with the water division of Burns and McDonnell; Chicago, Kansas City, MO. See the letter of support from Burns and McDonnell:

-`http://jontalle.web.engr.illinois.edu/MISC/DesalVideo-July.20/BMcD_Letter_of_Support_Jont_Allen.pdf`
-Critical Infrastructure Water: `https://www.youtube.com/watch?v=O5eXTrGxww4`
-One Water: `https://info.burnsmcd.com/one-water-burns-mcdonnell`
-Background (Brand Video): `https://www.youtube.com/watch?v=SpjP1EbR9rg`

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