Fuel and Energy

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Solar Desalination

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Summary

Solar desalination is a process in which the feed is seawater, the energy source is the sun, and the product is pure water. Solar desalination plants come in many varieties. Our discussion will be limited to one of them. The basic scientific principles at play will be discussed, then the inner workings of one specific plant located in Spain, and in the last section the suggestions of many different engineers and scientists will be listed, along with how they help improve the process.

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Introduction

A lot of us no longer think about water. After all, tap water might as well be infinite, and bottled water is so cheap as to be practically free.

For 35% of the population, however, it simply isn't so [3]. To them water remains a precious resource, hard to obtain or even, far too often, *impossible* to obtain.

Our topic of discussion, solar desalination, is one proposed solution to the centuries-old problem of clean water scarcity. Solar desalination promises to be, if properly developed, economical, effective, and perhaps most importantly, suited for use where it is needed the most—in hot, arid countries which, it so happens, often have easy access to seawater.

Before I move on to what *solar* desalination in particular is, I'd like to direct your attention to this simple diagram that describes desalination in general:

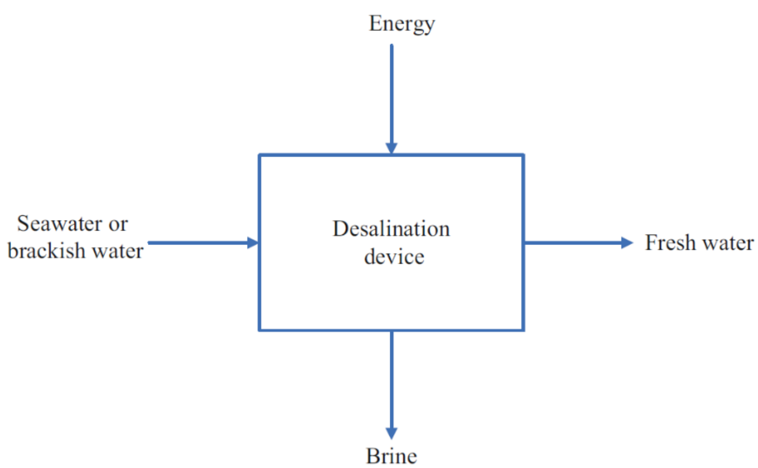

Figure 1: Desalination process[1].

Solar desalination is the kind of desalination in which the energy required is harnessed directly from sunlight. Solar desalination itself can be further divided into subcategories. Our discussion will be limited to one kind of solar desalination plant. More specifically, it will be limited to vertically stacked, forward-feed, low-temperature multi-effect distillation (FF LT-MED) plants.

The Scientific Principles at Play

The operation and design of FF LT-MED plants rely on a few of the principles of heat transfer, thermodynamics, and optics.

In general, the processes that take place at these plants are remarkably simple.

Solar radiation is indirectly used to convert water to steam. That steam is then fed to some kind of heat exchanger, and surrenders some of its energy to the seawater or brackish water we wish to desalinate. Upon receiving this energy the seawater or brackish water partly evaporates, and we end up with fresh water on the one hand, and a solution with a very high salt concentration on the other(1).

The general details of the process are only slightly more complicated than that. Parabolic mirrors are used to direct sunlight towards pipe segments carrying thermal oil. This is where the principles of optics come in.

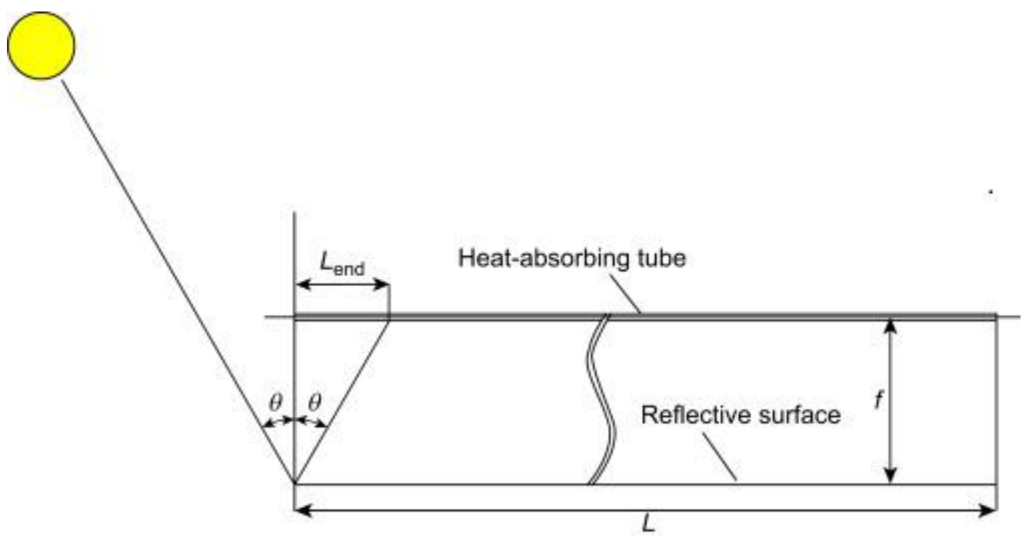

Figure 2: Nonvertical solar beam incidence on a parabolic trough solar collector (4).

The effectiveness of such setups is often measured with a concentration ratio, defined as follows (2):

$$\frac{Aperture\ area}{Reciever\ area}$$

The significance of concentration ratios is they show how much irradiation the collector receives relative to how much it would've received without the reflective surface. For parabolic trough collectors, concentration ratios range between 10 and 85 (2).

Far from being mere curved mirrors, parabolic trough solar collectors are also equipped with trackers and moving parts, so they harness as much energy as possible throughout daytime(1)(4).

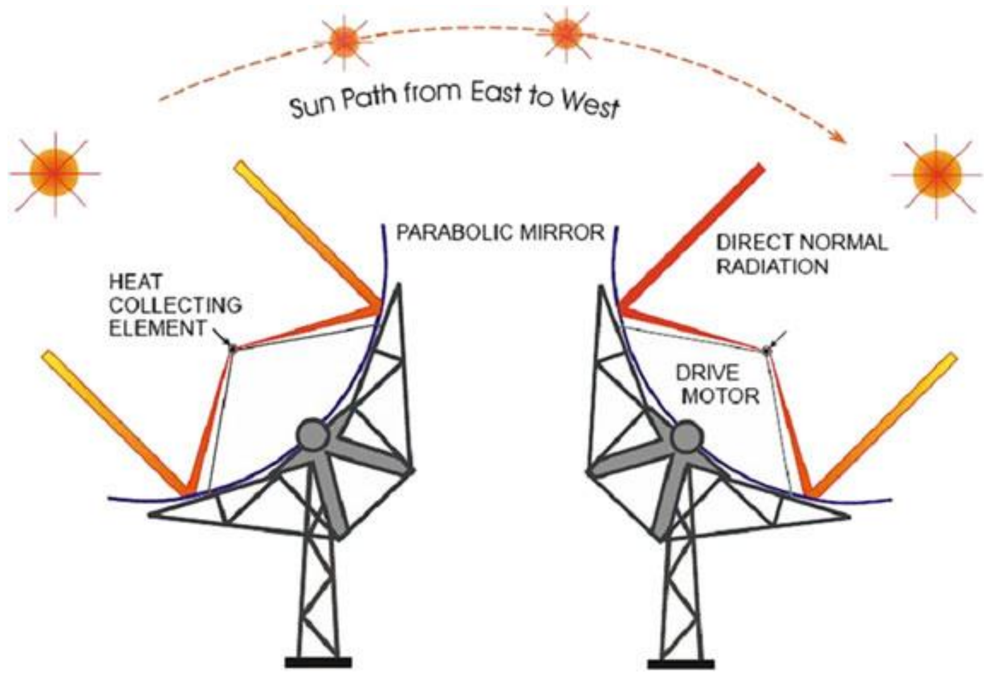

Figure 3: Parabolic-trough collector tracking[1].

The heat collecting element depicted in the figure is, as was previously said, a pipe segment. In such pipe segments flows some kind of thermal oil. Desirable thermal oils are economical and capable of reaching high temperatures without suffering chemical decomposition. As things stand, viably priced thermal oils can be heated to 395°C, but if heated above 400°C, they will decompose[1].

Having absorbed a significant amount of heat, the thermal oil is then forced to give up the heat it has to a certain amount of water, which, in turn, evaporates. This is where the principles of heat transfer come in.

Assuming no heat loss to the surroundings[5]:

$$\dot{m}_{oil}\overline{c_{p,thermal\ oil}}\Delta T_{oil} = \dot{m}_{water}(\,\overline{c_{p,water}}\Delta T_{water} + h_{vap} + \overline{c_{p,steam}}\Delta T_{steam})$$

Now thermodynamics comes into play, because the steam that has absorbed the thermal oil’s heat isn’t simply used to directly evaporate the water we wish to purify.

Instead, it’s used to evaporate part of the water and simply heat the rest, before the rest is isenthalpicly flashed in a lower-pressure chamber[1].

By applying the first law of thermodynamics and, again, assuming no heat loss to the surroundings, we can describe the flashing process with this simple equation[5]:

$$h_{in} = \ h_{out}$$

The water that hasn’t evaporated is flashed again, after being preheated with energy extracted from the water that *was* evaporated. Every flashing process is called an effect.

This is why such plants are called multi-effect distillation plants. They are called low temperature plants because they are operated at such low pressures that the heating steam, the steam that absorbed its energy from the hot thermal oil, is only at 70°C[1].

The next section will go into more detail, but by necessity its scope will be even more limited. In fact, the next section will only discuss the workings of a single FF LT-MED plant, the pilot plant in the southeast of Spain, at the Plataforma Solar de Almería.

Flowsheet of the MED plant at the Plataforma Solar de Almería

Using an open-source simulation package, I created figure 4, which shows a representative slice of the desalination process that takes place at the MED plant in Almería.

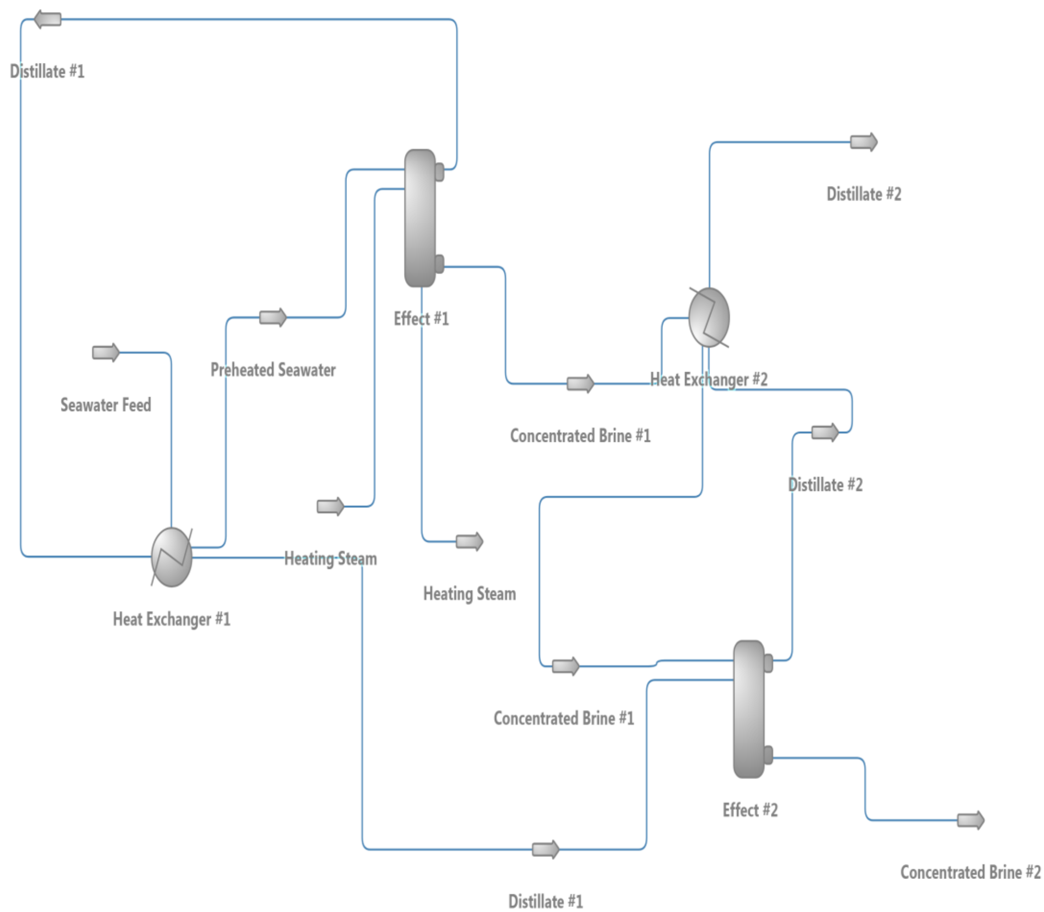

Figure 4: Multi-effect distillation.

First, preheated seawater is sprayed onto a bundle of tubes in the first effect through which the heating steam (whose heat comes from the thermal oil) flows. The heating steam gives up some of its latent heat to the sprayed seawater, which, in turn, partly evaporates. The water vapor (called Distillate #1 in the figure) is used to preheat the seawater in the fresh feed stream. It is worth mentioning that the vapor, before entering the preheater, is forced through a wire mesh demister in order to remove any brine droplets. The leftover seawater falls by gravity to the next effect, which is at a lower pressure than the first. Distillate #1, which still has useful energy to give, is used to evaporate the seawater that made it to the second effect[(1)].

And so on, effect after effect, in the same way.

There are 14 effects in total, as can be seen in figure 5.

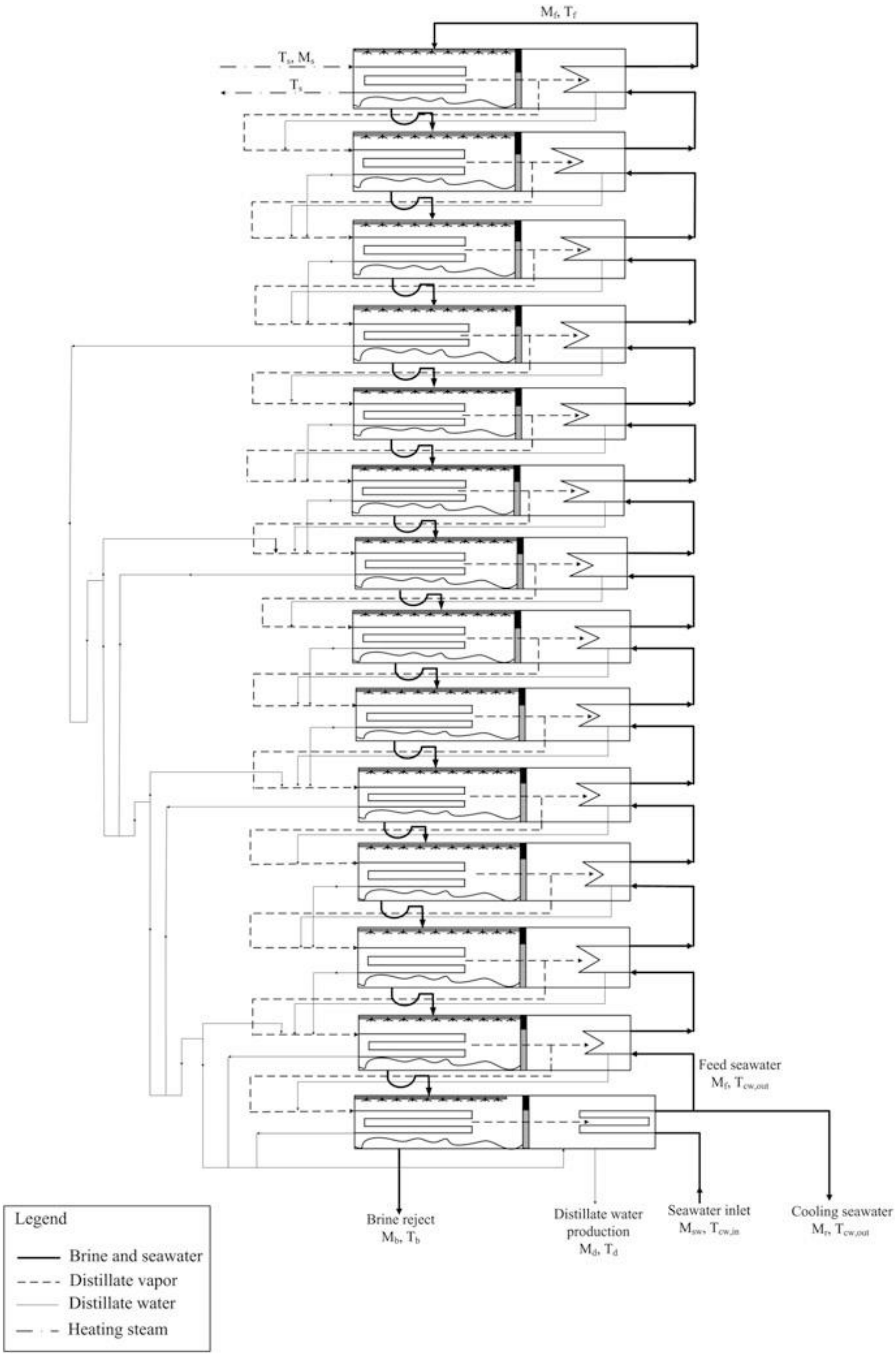

Figure 5: Schematic of MED plant at the Plataforma Solar de Almería[1]

Comments and Conclusions

Solar desalination is in its infancy. Few plants exist, and there is a lot of room for improvement in those that do.

I have not yet graduated and I do not have any experience, but from what little I know, I imagine that as desalination plants improve, there will be fewer heat transfer processes. Heat needn't be transferred from thermal oil to heating steam and then to seawater—a little is wasted at every step, and if the kinks can be ironed out, it would be much more efficient to use sunlight to directly heat the seawater we wish to desalinate.

More senior engineers and scientists have their own ideas, which are of course more valuable than mine. Druetta et al. studied MED plants and was able to determine which flow patterns are most effective. Some flow patterns decrease the required process-specific heat transfer area by as much as 5%[1].

Jyoti and Khanam's work is also remarkable. They developed a model for MED plants and tried different operating configurations (introducing steam splitting, condensate flashing, and vapor bleeding, and changing the number of flash tanks) and found that the modified system outperformed its original counterpart. The system's steam economy was enhanced by 23.77% and its steam consumption was reduced by 36.76%[1].

Yilmaz and Söylemez proposed a model of an FF-MED plant that uses hybrid energy sources (solar and wind), and Reddy et al. proposed coupling such a plant with flat plat collectors[1].

In conclusion, solar desalination plants have the potential to be an economically viable and effective solution, especially as fresh water sources are depleted and fossil fuel reservoirs run dry. Further research is needed, but the future of solar desalination is bright and sunny.

Nomenclature

$\dot{m}$: mass flow rate.

$\overline{c_p}$: average heat capacity over relevant temperature range.

ΔT: temperature difference.

h: enthalpy.
h_{vap}: latent heat of vaporization.

References

1. Palenzuela, Alarcón-Padilla, Zaragoza. (2015). Concentrating Solar Power and Desalination Plants: Engineering and Economics of Coupling Multi-Effect Distillation and Solar Plants. Springer International Publishing.
2. Kalogirou, S. (2014). Solar Energy Engineering: Processes and Systems. Elsevier.
3. Global WASH Fast Facts. (2016, April 11). Retrieved April 17, 2020, from https://www.cdc.gov/healthywater/global/wash_statistics.html
4. Parabolic Trough Solar Collector. (n.d.). Retrieved April 14, 2020, from https://www.sciencedirect.com/topics/engineering/parabolic-trough-solar-collector
5. Çengel, Y. A., & Boles, M. A. (2011). Thermodynamics: An engineering approach. New York, NY: McGraw-Hill.