A Concentric Solar Still - Details

Herbert Weidner [a]

Abstract: The yield of potable water in a still can be increased when the saturated steam layer over all surfaces is blown away. In a concentric distiller, this task may be achieved by natural convection without any external energy. The necessary temperature difference is generated by optimized components, which are separated from the distiller (boiler).

Introduction

The huge amounts of salt water that exist on earth are useless as drinking water. One way to remove the salt is to condense water vapor on a cooled surface. But before that, steam must be generated. In technical systems, one usually chooses expensive methods such as high temperature and / or low pressure. In nature, steam is generated by wind blowing over relatively cool water. This observation is the basis of the described plant. Temperature differences generate wind. To create this difference in the distiller, you need a solar collector (as warm as possible) and a cooling tower (as cold as possible). At the edge of the sea, air cooling can be replaced by water cooling.

In known solar stills, there is no wind and the cooling of the condensation surfaces is usually poor. As a result, the yield of drinking water is relatively low, because none of the necessary components is optimally designed. Moreover, it can hardly be scaled up enough to produce sufficient drinking water for several people.

Here, a different approach is taken: hot water primarily has the task of generating wind. A concentric still is suitable to produce a larger amount of drinking water daily. After the physical basics and the structure have already been described[1][2], optimizations are discussed to reduce the technical effort and the construction costs.

Selection of the absorber

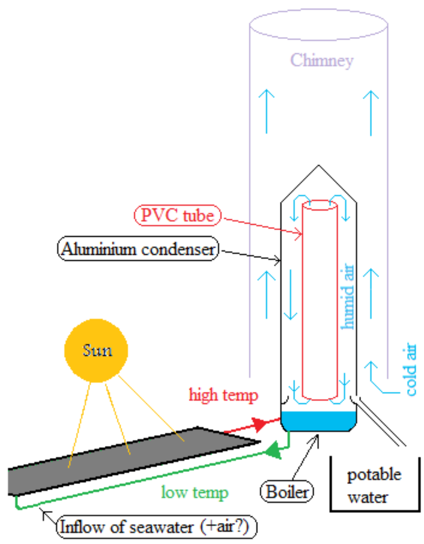
The absorber must collect electromagnetic radiation energy from the sun to heat water. The surface of the radiation collector should be as large as possible, dark and protected from the wind. Its *only* job is to collect "thermal energy". Optimal, but very expensive are vacuum collectors. Much cheaper are glass plates or transparent films to keep the wind away from the dark surfaces. If the absorber is made of metal such as copper, which has good thermal conductivity, it is sufficient to contact water-bearing pipes meandering with about 10 cm distance. Poorly conductive metals such as iron require closer spacing and should therefore be avoided. Hoses made of black EPDM (ethylene propylene diene monomer rubber), through which the water to be heated flows, are well suited and commercially available. Usually, a collector consists of many parallel, interconnected hoses that cover several square meters. Advantageous is the good transportability.

Large EPDM collectors have a positive side effect: since they contain much more water than the boiler, the average salt concentration increases slowly as the water evaporates. With a suitable volume ratio, it is sufficient to fill the system with seawater (4% salinity) before sunrise and to balance only the loss of water with other seawater during the day. By sunset, the salt content has

a) 19. May 2018, email: herbertweidner@gmx.de

increased significantly, then the entire liquid is drained. In simple systems, seawater can be refilled without preheating.

The connection to the boiler.



The water heated by the sun must be brought to the evaporator. You can save the costs and heat loss of heat exchangers by heating the salt water to be distilled directly in the collector. Then there is a single circulation for the entire amount of water. Every contact with metals should be avoided.

It is a good idea to mount the boiler higher than the highest point of the collektor. The heated water is directed from the top of the collector through a flexible EPDM hose or a PVC tube (red) to the boiler. After it has passed through and has become colder, it returns through a different tube (green) to the lowest point of the collector.

If the difference in height is sufficient, the difference in density of the warm and cooler water will create and maintain a circulation (without an energy consuming pump).

It is probably a good idea to inject air at the lowest end of the collektor. The air bubbles generate additional buoyancy and accelerate the circulation. As soon as the bubbles burst in the boiler, they increase the water surface and help to detach the vapor layer. The disadvantage may be that the escaping air entrains precious steam from the condenser. This can be avoided if the intake air is drawn from outlet of the condenser.

At the coolest point, the evaporated water is replaced by seawater. This can be monitored with a level sensor and does not have to be continuous.

The boiler

Its *only* job is to evaporate as much water as possible. Since this should be done at a relatively low temperature (well below 100 degrees and at normal atmospheric pressure), the surface must be as large as possible and the thin, saturated vapor layer above the surface must be constantly blown away by a strong wind. The surface of the water can be increased by air bubbles (The surface of the sea is never smooth and calm!).

The simplest construction of the boiler is a flat pan in which warm salt water is to evaporate. If the water - as shown in the diagram above - comes from the collector without a lossy heat exchanger, the boiler can be made of ceramic. This can help to prevent corrosion damage.

Undoubtedly, the amount of steam produced increases with the temperature of the water in the boiler. Low pressure is helpful, but expensive to produce. It is more important to constantly blow off the thermally insulating vapor layer above the water surface by a sufficiently strong wind. Remember: Without wind, much less water would evaporate from the relatively cool oceans.

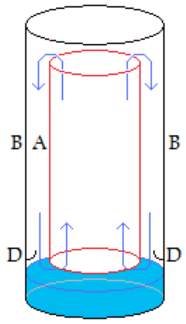
If there is a high demand for water, the area around the central boiler can be covered with collectors that supply warm water independently of each other. Depending on the position of the sun, some of them may lie in the shadow of the chimney. The condenser tower above the boiler should have the same diameter as the bottom pan. At any time, it may be withdrawn from the pan to check the function and interior structure.

The Condenser

The only task of the condenser is to cool the steam, to effectively extract the condensation energy and release it to the environment. In a solar still, wind must be generated somehow without external energy, if possible. Therefore, the condenser is designed to internally generate strong wind.

Since the entire system can not store energy, the condenser must dissipate as much energy as the collectors supply. Usually the condenser has a smaller *inner* surface than the collectors. This results in a high power density passing through the wall of the condenser. Therefore, the material must have a high thermal conductivity in order to transfer the high condensation energy of water to the outer surface. Glass is not a good choice. Since the condensed water contains no salt, the condenser should be made of metal, aluminum should be ideal. The condensation surface should be mounted vertically, so that the drops of distilled water flow down quickly into the gutter (D). All requirements are best met by a long, vertical aluminum tube that is air-cooled outside. To realize an effective countercurrent exchange, steam and cooling air must flow in opposite directions. But humid air (the vapor to be condensed) rises, heated air also. The direction of one of the two currents has to be reversed.

It is easier to divert a small volume of steam than the much larger amount of cooling air. Here, a simple method is proposed to generate a wind over the water surface without additional expenditure of energy. This wind is necessary to blow off the saturated vapor layer above the water surface. Only then, new vapor can be formed over the liquid.



A vertical pipe (A) with open ends inside the metal condenser (B) does the job. Warm steam rises inside this tube, outside the steam is cooled, its density increases and it sinks downwards. The taller the condenser tower and the greater the temperature difference between the water in the boiler and the (average) temperature of the condenser, the faster the steam will circulate. The vertical pipe (A) should be made of thermally poorly conductive material such as plastic. PVC is cheap and tasteless.

The inner surface of the PVC pipe should be smooth to keep the flow resistance low. It may be advantageous to make the outer surface of the PVC tube helical in order to to extend the residence time of the steam in the vicinity of the cooled condenser. A rotating and turbulent airflow may also better blow the vapor layer off the water surface. A possible support from bursting air bubbles has already been discussed above.

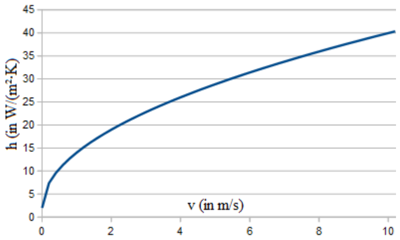
The outer surface of the condenser must be *well* cooled and must have cooling fins. The normally horizontal air flow is certainly not enough, it should be replaced by a *strong* vertical flow, which can be generated by a sufficiently high chimney.

Cooling the condenser

For illustration, the values of a small desalination plant are calculated: The collector consists of 20 m² EPDM mats, which lie nearly flat on the ground and have no wind protection. At an air temperature of 35º and a water temperature of 50º at the outlet of the EPDM mat, the efficiency of the collector is estimated at 30 %. The sun heats the contained water inside the collector with the thermal power $P = 20\,m^2 \cdot \frac{1000\,W}{m^2} \cdot 0.3 = 6000\,W$.

The condenser has to transfer as much power to the cooling air and needs a sufficiently large cooling surface. An enlargement of the surface by cooling fins improves the heat transfer to the passing air. A laminar air flow cools much worse than a turbulent flow. This can be created and reinforced by cooling fins on the outside. Since the condenser must not be warmer than the ambient air, the heat radiation can be neglected and the outside does not have to be darkened. The heat energy must be dissipated by air cooling.

We choose an aluminum tube with diameter = 40 cm and length = 300 cm, closed at the top. The inner condenser surface (no cooling fins!) has a surface area of 3.8 m², resulting in a heat flux of 1600 W/m². Water cooling would be appropriate and would reduce the overall volume. In dry areas, however, water is valuable. To dissipate the condensation energy by air cooling, the outer surface of the condenser must be significantly increased.



With air cooling, the heat transfer coefficient *h* (in W/(m²·K) depends strongly on the wind speed *v* (in m/s). The formula $h \approx 12 \cdot \sqrt{v} + 2$ describes its influence with sufficient accuracy. The diagram shows that you should not do without forced wind cooling. Electrically powered fans should be replaced by the natural draft of a chimney. Now, we assume that the air speed in a sufficiently high chimney is 8 m/s. Furthermore, we expect the outer wall of the condenser to be no more than 3º warmer than the ambient temperature (35º) and much colder than the exit temperature of the collector (50º or higher). Then one can calculate the necessary cooling surface *A* of the condenser with the formula $A = \frac{P}{h \cdot \Delta T} = \frac{6000\,W}{36\,(W/m^2/K) \cdot 3\,K} = 56\,m^2$.

That's the minimal *outer* surface of the condenser, requiring additional cooling fins. The picture shows a suitable structure. However, the finned heat exchanger surfaces must be cleaned regularly, because dust settles on the exchange surfaces and deteriorates the heat transfer. In order not to throttle the air speed too much, it is advantageous to increase the distance between the cooling fins and to mount additional cooling surfaces further up in the chimney, connected via heat pipes. The entire cooling surface of the condensers exceeds the total area of the solar collectors by far!

[1] H. Weidner, A Proposal for an Improved Solar Still, 2016
[2] H. Weidner, An Effective Concentric Solar Still, 2016