Investigation of a small scale combined solar cooker desalination unit

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Abstract

Access to energy and to drink water represents the fundamental basis for decent life. Rural areas in structurally weak regions are primarily affected by the lack of these two goods. The use of solar cooker technology has shown how energy problems can be solved, by saving fuel cost and providing smokeless cooking. However, the problems of drinking water remain. The aim of this paper is to develop and investigate the productivity of a small scale multi stage desalination system working as an “add-on” unit in a 2,7 m² Scheffler solar concentrator. The whole system can be operated either as a solar cooker or as a sea water desalinator.

Key word : csp , desalination, multistage, low tech

1. Introduction

One of the water-related risks for the coming years is that the water resources are limited as the world's population and water needs continue to grow. Water scarcity has already affected every continent. By 2030, the UNO estimates that more than 40% of the world's population (around 2.3 billion people) will be living in areas facing high levels of water stress, especially in northern and southern Africa, as well as in South Asia and in Central Asia. To face these problems desalination is an alternative solution. However, it is an energy intensive process that requires expensive non-renewable fossil fuels. Since most people affected by water stress live in coastal areas with a high solar radiation, solar desalination can be considered as an ideal solution.

2. Desalination review

Water desalination is a process that separates dissolved salts (like sodium chloride) and other minerals from water to produce fresh water able to be drunk or for irrigation purposes. Desalination processes are divided into four technologies: thermal (MED, MSF), physical (RO), chemical (electrodialysis) and electric (flow-through electrodes). The worldwide desalination capacity is 88.6 million/m^3/day in 2016 and have known annual grow of more than 10 % in the last 10 years [IDA, 2016-2017]. Thermal desalination and reverse osmosis are technologies whose performance has already been proven for seawater desalination and dominate the global desalination market. Thermal technologies are mainly used in the Middle East combined to thermal power plant (using the exhaust heat of turbines) while membrane technologies are mainly used in Europe and the Asia-Pacific region.

a- On-grid desalination

Nearly all the worldwide desalination capacity is related to large scale on grid plants.

- **Revers osmosis**

RO plants (65% of the market in 2016) [Yoram Cohen, 2017] use electric pumps to apply pressure to push sea water through semi permeable membranes to separate dissolved solids form pure water. RO plants need complicated water pretreatment (filtering of particle in suspension) before reaching the membranes [COMMITTEE, November 2011]. The energy consumption of RO plants is proportional to the salinity of the inlet water. 3 to 5.5 kWh of electric energy is required to produce one cubic meter of fresh water [Energy Requirements Of Desalination Processes, 2013].

- **Thermal desalination**

Thermal desalination is a process using energy to evaporate seawater and subsequently condense it into pure water. There are two techniques to evaporate water; either to heat it up to the boiling point (100° C at 1 atm) or reduce the pressure with vacuum pumps or use of both them. These techniques are respectively MED (multi effect distillation), MSF (multi-stage flash) and MVC (mechanical vapor compression).
These plants are less sensitive to the quality and salinity of inlet sea water and need less consumable than RO plants; however, the energy consumption is higher 6.5 to 25.5 kWh/m^3 [Energy Requirements Of Desalination Processes, 2013]. Since the latent heat of vaporization is very high (2200 kJ at 100 °C) ,thermal desalination plant use several stages to recover this heat and use it to evaporate more sea water in successive stages. Up to 19 stages are used in industrial plant. The so-called gain output ration (GOR) measure the efficiency of thermal desalination plant and is defined as the amount of distilled water produced by one kg primary steam.
The value of GOR ranges from 1 to 10 kg/kg. [Tonner, 2008].

b- Off grid Desalination

Off-grid desalination plants can be divided in high-tech and low-tech technologies. High-tech desalination plants use reverse osmosis as described above with the singularity that the electricity supply is provided decentrally, either with fossil fuel (diesel generator) or with photovoltaic modules [Alkhatib, January 2014] or with a combination of both [A.Scrivani, 2005]. This configuration adds complexity to the RO plants: need of skilled personal, more consumable (fuel or battery), have a prohibitive cost and are not suitable for remote and structurally weak regions.

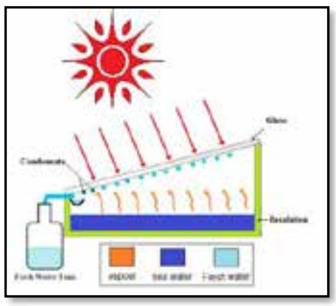


Figure 1 : solar still

Low-tech desalination plants work with the solar still principle, here an enclosed and insulated greenhouse is filled with sea water and exposed to the sun. As the infrared rays can penetrate the green house and not escape it, a thermal accumulation occurs, and saline water is heated up and evaporate. Then the water vapor condenses on the sloped inner side off the glass cover and trickles down to a fresh water tank. To increase the productivity of fresh water, different shapes of solar still have been investigated [Bhattacharyya, 2013] (spherical, single slope, double slope, pyramidal, hemispherical, etc). As solar still have a GOR of one (latent heat is not recovered), the yield is directly proportional to the solar radiation and cannot exceed the daily insulation divided by the latent heat of evaporation. In the practice a fresh water production between 2 and 6 $Liter/m^2/day$ has been reported [Bhattacharyya, 2013]. The largest solar still plant was in operation from 1872 to 1912 in the Atacama Desert in Chile, providing fresh waters for silver mine. The plant was 4,700 square meters big and produced 23.000 Liter fresh water per day representing an average of 4.9 $Liter/m^2/day$. Solar still are low-tech desalination devices with no need for consumable or high skilled personal for operation and maintenance. However, they have a low productivity (no recuperation of latent heat) and need specific dedicated place and infrastructure.

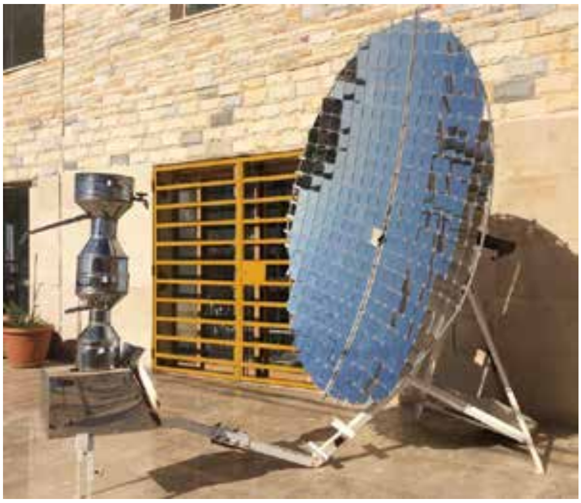
3. System description

- **System requirement**

The system is planned for zones with restricted access to energy for cooking and to fresh water and where solar radiation is available. This may be the case either for remote areas or for areas of natural or man-made disasters. The desalinator should not require a dedicated space, consumable and specific skill to be operated and shouldn't contain moving parts. The system must be affordable and repairable on site. And finally, the productivity of the desalinator must be higher than the productivity of conventional solar still.

- **Solar concentrator**

The used solar device is a fix focus point focal solar concentrator (called Scheffler concentrator). The surface of the mirror is 2.7 m^2 and the effective optical surface 1.9 m^2. Depending of the season the nominal thermal power is between 0.7 kW and 1 kW



The fix focus technology enables the position of divers heat receiver: direct cooking, oven, dryer boiler etc with no need for flexible pipe or. More than 28,000 m^2 were installed in India in 2013 (Singhal, 2015).

- **Desalinator**

The desalinator is made with two modified essential oil distiller (made with stainless steel). Each distiller is composed of lower part (cylindrical tank) where the sea water is filled and subsequently heated. And an upper part in which the produced vapor condenses along the conical form and flows to the outlet pipe where fresh water is collected (see top of figure 3). In order to condense, the vapor need to be cooled. This "cold" is provided by cooling water filled on the top of the upper part surrounding the cone where the latent heat is released. Two distillers are assembled together (one over the other). The lower distiller is called first stage and the upper one second stage. The third stage is open (atmospheric) and used as cold source to drive the process. The dimensions of the distiller were chosen in such a way that it was integrable to the concentrator. The diameter of the first stage will set in the focal point. And the height of both distillers so that no shadow will be projected on the reflecting mirrors.

Figure 2 : Distiller

- **Operation**

The desalination unit work discontinuously, in the beginning of the process cold sea water is filled in the three stages (dark blue in figure 4). Than heat is supplied on the bottom of the first stage until the contained sea water boils and start to evaporate. The primary vapor rises and come into contact with the bottom wall of the second stage. The bottom of the second stage has a conical shape to increase the heat exchange surface and allows the condensate to trickle down to the channel where primary fresh water is collected and flows out through an evacuation pipe. As the primary vapor come in contact with the cold cone, the vapor condensates and releases the latent heat to the sea water contained in the second stage. This secondary sea water is heated up and after a while starts to evaporate, rises, comes into contact with the cold bottom wall of the atmospheric stage, condenses and trickle down. Finally, distillated water is collected in the channel of the second stage. The sea water contained in the third stage receives the latent heat of the secondary vapor, is heated and evaporates to the atmosphere. To reduce the heat losses, the desalinator is insulated with heat resistant foam (not shown in the figure).

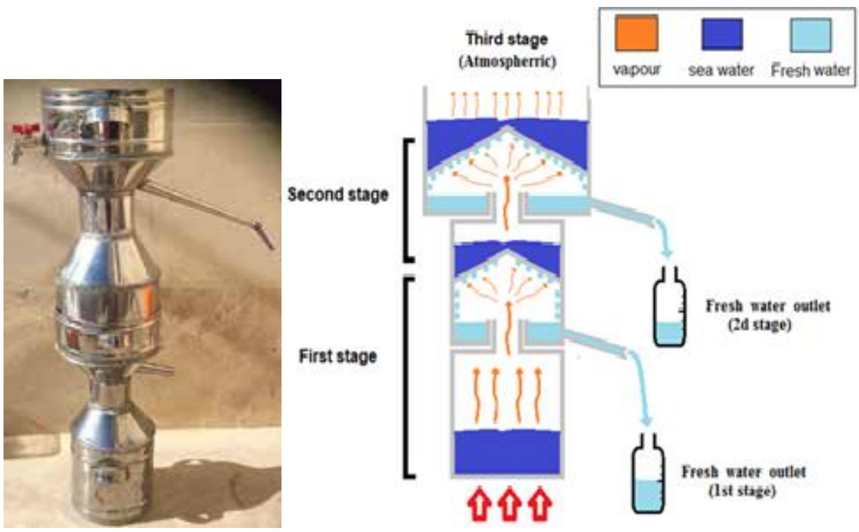


Figure 3 : two stage sea water desalinator. Real picture (Left) and schematic (Right)

4. Experimentation and results

To investigate the performance of the desalinator under constant and measurable conditions, the tests were first performed with gas burner as heat sources. The gas consumption can be measured by the weight difference of the gas bottle. As the desalinator works discontinuously, a precise quantity of sea water must be filled in each distiller stages. A great quantity of water will increase the thermal inertia of the system and more water will be heated than evaporated. Low quantities of sea water will cause an overheating; the vapor will not condense and will escape from the outlet pipe in form of gas and fresh water will not be collected. The purpose of the experimentation is to find the sea water ratio between the first and second stage corresponding to the maximal GOR. Tests were carried out with different quantity of sea water in the first and second stage and the gas consumption was limited to 200g (+/- 100g). The result of the experimentation with different sea water quantity is shown in figure 4.

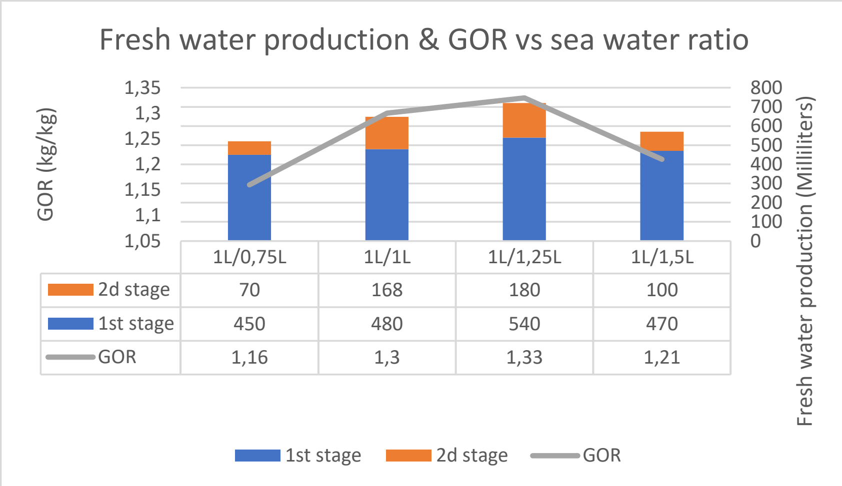


Figure 4: Sea water ratio vs fresh water production

The experimental result shows a nonlinear dependency between the sea water ratio (first stage to second stage) to the fresh water productivity as well to the GOR. A maximum output is given for sea water volume of one liter in the first stage and 1.2 liter in the second stage. A higher amount of sea water (1 liter first stage /1.5 liter second stage) decrease the productivity of fresh water (mainly in the second stage). This can be explained that the latent heat of the primary vapor is more used to heat the sea water in the second stage than to evaporate it. A lower volume of sea water in second stage decreases also the production of freshwater. As primary vapor is not cold enough to condensate, the primary vapor escapes outside and gives the latent heat to the atmosphere (and not to the second stage).

Conclusion

The design and the experimentation of double stage solar desalination unit has been successfully achieved. A gained output ratio (GOR) of 1.3 have been reached. However, the temperature of the collected fresh water condensate is still high and can be used to preheat seawater and increase the GOR. In this case a continuous desalination is needed.

The design of desalination unit is vertical which make it impractical. A better and compact design in ableing the implementation of a third enclosed stage can be developed.

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