European Journal of Sustainable Development (2022), **11**, 3, 367-375 ISSN: 2239-5938
Doi: 10.14207/ejsd.2022.v11n3p367

Solar still Design and Construction for its Implementation in Rural Communities in Mexico

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ABSTRACT
Water scarcity and sufficient energy sources without affecting climate change are complex problems facing humanity. Water purification, such as desalination using solar radiation as an energy source, is a mature technology method that provides economic savings in electricity, gas, and oil consumption, achieving good quality fresh water. Solar water distillation is an example of nature's purification mechanism through the water cycle. This paper presents a solar still design and construction with easily accessible, low-cost materials and simple manufacturing, which obtain the patent MX2020/070739. The energy evaluation and experimental results are also presented, verifying the device's technical feasibility. As a result, water production of 805/day was obtained, with a maximum solar irradiance of 980 W/m² and 36 °C ambient temperature and the efficiency during the test days was 38%. Using the distiller can benefit rural communities in Mexico by obtaining fresh water, achieving significant energy savings, and contributing to caring for the environment.

Keywords: Solar Irradiance, Solar still, Energy efficiency, Solar Technologies

1. Introduction

Throughout the existence of the human being, the world has been evolving at incredible speed: technological development, improvement of life quality, and the increase in the population have caused a rise in the energy demand that today is satisfied mainly using fossil fuels, leading to a situation of energy unsustainability and with a significant impact on the environment and people's health. The survival of humans and animals depends on freshwater availability. To meet growing freshwater needs, saline water must be converted into pure water.

1.1 The solar still

Solar desalination can be essential in solving water scarcity and excessive fossil fuel consumption (Kumar Nougriaya et al., 2020). Furthermore, solar stills are a promising technology for producing potable water using clean energy and are best suited for rural and remote areas (D'Cotha et al., 2021).

In the solar still, water is contained in an air-tight container enclosed by a transparent cover (generally closed from the top only). This transparent glass allows solar energy to heat the water to the evaporation level (which also kills all pathogenic bacteria).

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Evaporated water is condensed at the glass surface in an inclined position and is collected in a tray. A solar still fabrication is not complicated and consequently does not requires skilled work (Sanserwal et al., 2020). Solar stills can be natural or forced convection (Ghaffour et al., 2015). Many solar stills configurations can be found in the literature: double or single slope (Omri et al., 2005); cascade solar still (Ziabari et al., 2013); pyramid-shaped (Kabeel et al., 2020); vertical solar still (El-Sebaii, 1998); hybrid (the distiller can have an additional solar collector attached to improve its efficiency (Elbar & Hassan, 2020). Additionally, numerous publications on mathematical models with solar still efficiency prediction (Andrés et al., 2020) and papers that include experimental and theoretical research (Sharma et al., 2020, Kamal, 1988).

Moreover, some researchers analyze the optimal water basin depth (Tarawneh & Muafag, 2007) and evaluate the different building materials (Sanserwal et al., 2020); the water salinity concentration to distill (Hassan & Abo-Elfadl, 2017). Finally, the different climate effects on the produced water have been studied (Jubran, 2003, Panchal & Patel, 2017).

1.2 Water scarcity in rural communities in México

Two-thirds of the Mexican territory is desert or semi-desert, where the population and economic development are concentrated. Hence, groundwater depletion in big cities has resulted in the disappearance of springs, native vegetation, wetlands, lakes, river base flow, and local ecosystems (Jiménez Cisneros et al., 2010). On the other hand, the poorest communities with water availability do not have a hydraulic and electric infrastructure. In addition, conflicts over water have intensified (Oswald Spring Úrsula, 2018).

This paper presents a solar still design and construction, manufactured as a possible solution to water supply in rural populations in Mexico, built with accessible and inexpensive materials, long functional life, and easy operation and maintenance. The proposed solar still was registered at the Instituto Mexicano de la Propiedad Industrial, obtaining the patent in 2020, register number MX2020/070739.

2. Experimental Study

2.1 Experimental equipment

The solar still contains a double slope—the cover should have a high solar radiation transmissivity depending on the material's thickness. Also, the cover must present a low short-wave radiation transmission, promoting the greenhouse effect. This effect is achieved using standard or tempered glass, plastic materials such as acrylic, cellular polycarbonate, polyethylene, or any transparent cover with the mentioned properties.

The transparent cover is placed on a plastic or metal base that contains the water to distill; this base would have a black coating to absorb the solar radiation.

The transparent cover and the absorber base are sealed to prevent evaporated water escape during the process. The cover inclination angle was established at 23° to avoid dripping condensed water into the salted water. The cover inclination depends on the experiment's location latitude. All the materials mentioned for constructing the distiller are easy to acquire and inexpensive. The double slope solar was still developed for domestic use; it can be scaled to larger dimensions or capacities if a ratio between width and length of 1:1.5 is maintained. Figure 1 shows the solar still in operation.

Figure 1. Solar still in operation

Legionella growth is reduced by removing and flushing infrequently used outlets, and calcium must be removed every 15 days. The pipes are as short and direct as possible also.

2.1.1 Solar still components

The double-cover solar still operates using natural convection or forced air convection. However, to operate forced convection, it uses a fan to drive air toward the condensation area (inclined lateral faces) and improve contact between the generated water vapor and the cold condensation surfaces, obtaining purified water and being drinkable. In addition, to have a secondary effect on the surface of the liquid, it improves the thermal exchange between the water and the surface that absorbs solar radiation, thereby increasing the vaporization capacity. The fan operates with an AC or DC motor, allowing a photovoltaic module in places where electricity is unavailable (Figure 2).

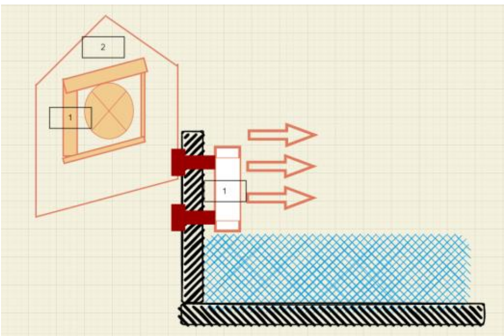

Figure 2. Solar still in operation with forced convection: 1) Fan, 2) Vertical wall for fan support

Inside the solar still, a float valve was located at one of the lower rear ends of the base body. This valve is interconnected to a container located outside, which contains the salt water; when the water level in the solar still is deficient, the valve opens and allows the amount of water necessary to continue the process; At that moment, the valve closes, keeping the water level constant. All components inside the solar still are plastic. Figure 3 shows the location of the float in the solar still.

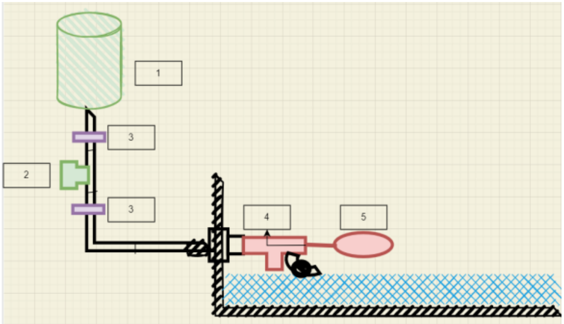

Figure 3. Detail of the location of the float concerning the solar still: 1) Saltwater container, 2) Container shut-off valve, 3) Union nuts for container separation, 4) Water level control valve, 5) Float for opening/closing of the water inlet valve.

Between the float and the salty inlet water in the external container, there is also a filter to avoid impurities that could block the mechanism of said valve. Furthermore, the inclusion of the float with the fan improves efficiency compared to a similar one operating only with natural convection and facilitates the operation of the solar still. Figure 4 shows a side and front image of the double slope solar still design.

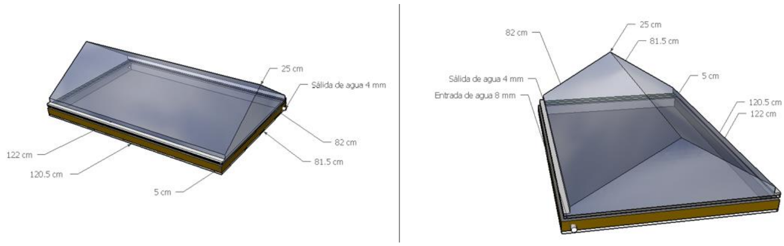

Figure 4. A side and front image of the double slope solar still design

2.2 Experimental methods.

The salty water is placed in the absorber container, adequately oriented towards the equator, and exposed to solar irradiance. The water increases its temperature until the evaporation begins; when the saturation conditions are reached, vapor water begins condensing due to heat transfer to the colder cover wall. The condensate is recovered in a channel leading the distilled water outside for storage. The concentrated brine is deposited in the black tray, and if required, the process can be continued until crystallization to obtain the dissolved salt.

Environmental conditions were monitored daily at a meteorological station in the Faculty of Engineering of the Universidad Autónoma de Campeche (solar irradiation, ambient temperature, and relative humidity). In addition, the solar still was instrumented with type K thermocouples located at strategic points inside and outside the solar still (glass cover, water contained in the black tray, base, and wall of the black tray) and insulation).

3. Results and Discussion

The test period was carried out during a year to study the solar still thermal behavior and efficiency. However, some sunny days were chosen to present the typical climatological data.

3.1 Climatic parameters

Table 1 presents the measuring device's technical specifications used to obtain the efficiency of the solar still, according to the manufacturer's data.

Table 1. Technical specifications of the measuring devices

Variable	*Description*	*Model*	***Error Maximum***
Solar irradiation	Pyranometer brand LI-COR	LI-200R	Azimuth: < ± 1% on 360° a 45° elevation
Relative Humidity	NRG Systems	RH-5X	± 3%
Ambient temperature	NRG Systems	110S	± 1.1°C
Wind direction	NRG Systems	Series #200P	± 3°
Anemometer	Wind sensor	P2546C-OPR	± 0.3 m/s

Figure 5 shows a weather condition on a typical experimental day during the test period. In Figure 6, the solar irradiance reached 800 W/m², the wind velocity was 0.62 m/s and the maximum ambient temperature was 38.97 °C (figure 6).

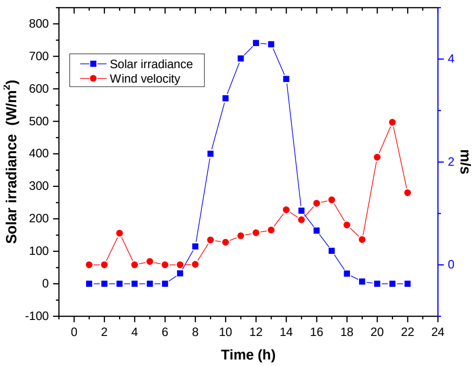

Figure 5. Solar irradiation and wind velocity during the sunniest day of the test period

3.2 Thermal characterization

The maximum temperature in the black tray was reached at 1 pm (77.5 °C); this temperature is an average of the different sensors located at the base and side walls of the tray. The water to be distilled achieved a maximum temperature of 70.1 °C. Besides, the inside solar still air remained constant for approximately three hours (60 °C). This constant temperature was observed also in ambient temperature (57 °C). In the case of the insulation (polyurethane foam), a maximum temperature of 46.96°C was measured; finally, the maximum ambient temperature measured at the weather station was 38.97 at 1 pm, too—figure 6 shows the solar still temperature evolution.

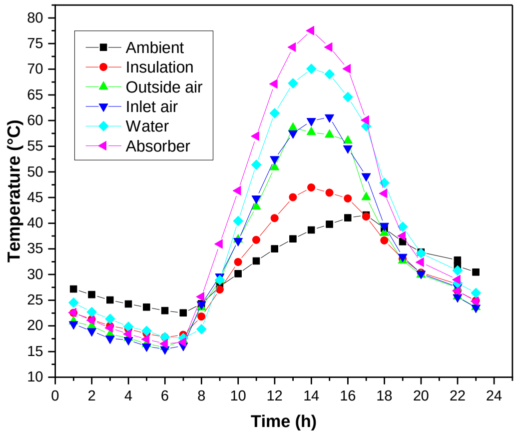

Figure 6. Temperatures inside and outside of the solar still.

Figure 7 shows the double slope temperatures analysis: a) outer cover and b) inner cover. It can be see the temperatures uniformity. In the first case, it reaches 46.85 °C; in the second case, the maximum temperatures reached in the lower lateral faces (77 °C), and at the peak of the cover, 59 °C.

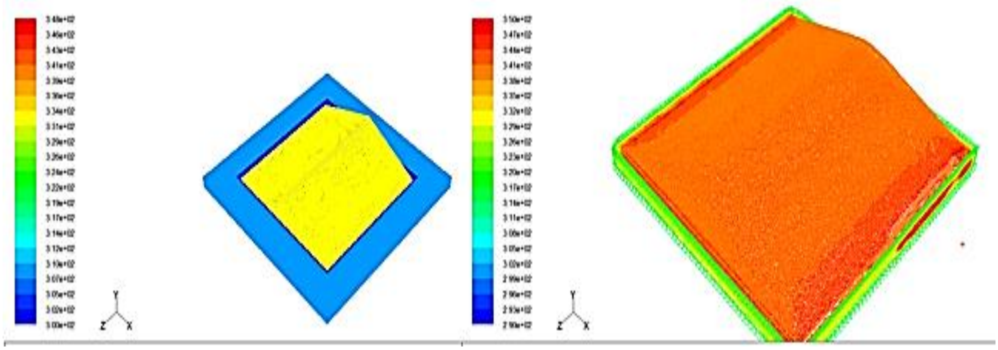

Figure 7. Temperatures in the glass cover. Images made in the Fluent program, de la compañía ANSYS [www.ansys.com], (scale in °K).

Figure 8 shows the freshwater production (every hour). The output water average obtained was 0.8 l.

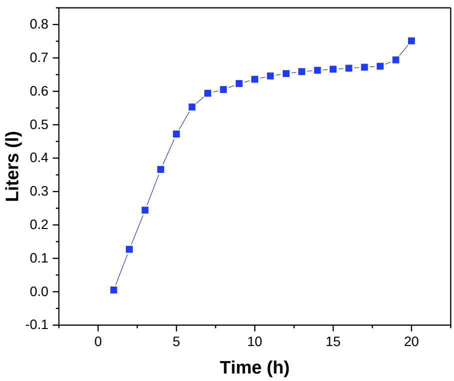

Figure 8. Fresh water production in one day of the test.

Figure 8 shows the freshwater obtained during the five consecutive days that were taken as a reference concerning the energy received in the collector (irradiation per area of the collector by the factor 0.814 derived from the attenuation of the glass cover).

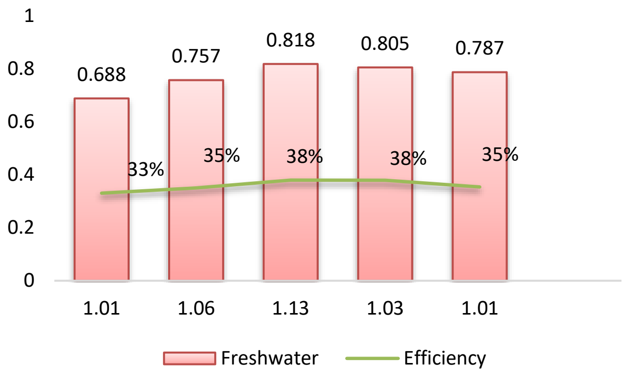

Figure 9. Freshwater production as a function of solar energy received in the solar still.

6. Conclusions

Solar distillation as a desalination method is a process that requires large solar areas to obtain moderate volumes of water. However, solar still technologies have many advantages as the null use of fossil fuels or electricity, becoming an attractive system for application in rural areas, representing a technology to be used in areas with high solar irradiation.

Solar performance is a function of the geometry and materials properties. For the construction of the double house solar still, it was determined that the best angle for the double house is 23°C. Moreover, due to the optical material behavior in manufacturing the covers, it was determined to choose a 3.0 mm thick glass because it is economical, accessible, and easy to obtain. Additionally, it presents high visible and infrared transmission and good chemical stability to weathering. The cover glass used has a transmission of 81.4% in the visible region. The maximum efficiency obtained in the solar still during the test days was 38% with 0.805 l/day.

The proposed solar still has a self-feeding preheated water system with solar thermal energy, facilitating its operation and improving its productivity.

To promote double slope solar stills application in rural communities and possible scaling to large areas, and considering the results obtained, it is suggested: the water volume required by a five members family and determine from first proportionality principles the optimum absorber needed area produce the freshwater volume necessary.

The proposed solar still was registered with the Mexican Institute of Industrial Property, obtaining the patent in 2020, register number MX2020/070739.

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