Design of Single Effect Solar Still for Water Purification

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ABSTRACT

A solar still is one technique that uses solar energy to distillate the contaminated water. It uses free natural sunlight (solar radiation), available in an abundant form to purify contaminated water. It is an environmentally friendly technique that helps to substitute fossil fuels by solar energy. The design of a specific solar still was done in this work. The designed solar still has the following components (i) top glass cover (ii) basin (iii) wall side, and (iv) stand. The basin has an area of 0.4225m^2. The upper side of the solar still has a height of 0.5m while the lower side has a height of 0.3m.The thickness of 3mm of galvanized steel was used for the construction of the solar still basin. The stand was constructed with a galvanized steel of 10mm thickness.

The still was also tested using different cover plate, pure glass top cover plate and HDPE top cover plate. The pure glass cover used had a better performance than High density polyethylene (HDPE) cover plate. The average Insolation during the experiment was 450w/m^2. The highest atmospheric temperature recorded in the experiment was 30ºC.

(Keywords: solar still, cover plate, distillate, design parameters, insolation)

INTRODUCTION

Solar energy can be used either for seawater desalination by producing the thermal energy required to drive the phase change processes or by generating the electricity required to drive the membrane processes [1]. Solar desalination systems are classified into direct and indirect collection systems. As their name implies, direct-collection systems use solar-energy to produce distillate directly in the solar collector, whereas in indirect collection systems, two sub-systems are employed. Conventional desalination systems are similar to solar systems because the same type of equipment is applied. The prime difference is that in the former, either a conventional boiler is used to provide the required heat or mains electricity is used to provide the required electric power, whereas in the latter, solar energy is applied [2].

Solar desalination on the other hand proves to be the most economical and viable techniques of purifying the saline water solution [3]. It uses the naturally available abundant supply of solar energy to evaporate the water and thus this method has zero operational cost [4]. The solar still is a very simple way of distilling water. It consists of a container whose inner surfaces is coated with black paint and is fitted with a glass cover. The container is filled with saline or brackish water to be purified. The solar radiation gets transmitted through the glass cover and is absorbed by the basin liner which in turn heats the water. The evaporated water gets condensed underneath the glass surface and is collected in a trough fitted along the length side [5].

Overview of Solar Stills

Solar stills are mainly classified into two categories, namely single effect and multi-effect stills [3]. Each of these stills are further classified as active and passive type depending upon the source of heat to evaporate water either directly through sun or using some external aid like solar collectors namely flat plate collectors, evacuated tube collector and concentrating collectors which are coupled to the desalination unit [3]. Much research has already been done in the solar stills and yet there is lot of scope for future studies in the development of solar stills for large scale economical production of fresh water.

The schematic representation of different processes of desalination is shown in Figure 1. An extensive and useful review on multi-effect solar stills has been presented by Rajaseeni-Vasanetal. [6]. The work of the authors was a valuable one which is giving an insight into the advantage of implementing various active techniques along with increase in the number of stages in order to enhance the rate of evaporation and condensation in comparison with simple conventional type solar still. As solar desalination is a growing research topic in the present health hazardous issues of lack of potable water, the present work aims at making an exhaustive survey of all there search done till recent past in solar stills primarily focusing on all the design and fabrication aspects of various systems [3].

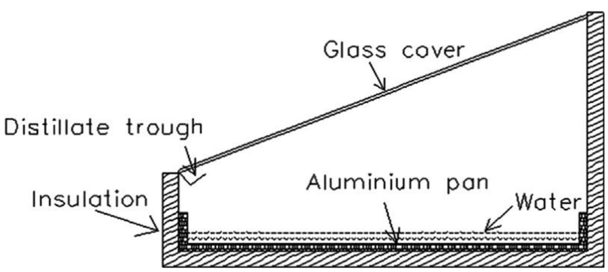

Figure 1: Single Slope Still [6].

History of Solar Desalination and Solar Stills

Aristotle described a process to evaporate contaminated water and condense it for drinking already in the fourth century B.C. [7]. Later on, the Arab alchemists in the 16th century documented this and Della Porta used wide earthen pots to heat up and evaporate water with use of solar radiation in 1589, see Figure 2 [8].

In 1872 a Swedish engineer made the first large scale solar desalination plant in Las Salinas, Chile, to provide thirsty railway- and mine workers. It was made of wood and glass and had a water surface of 4459 m^2 and a daily production of 22.7 m^3 [9].

The interest for simple distillation methods increased during the Second World War as many soldiers were stationed in remote areas without access to safe water and consequently saved many lives. This and the establishment of the US Office of Saline Water in 1953 resulted in the foundation of many solar stills programs and development. During the recent years the attention for small scale desalination plants for households and villages is increasing [9]. For the past two decades solar stills for households have been in use in several colonies on the US - Mexico border as a result of a joint project between El Paso Solar Energy Association, New Mexico University and Sol Aqua [10].

SOLAR STILL OPERATION

Water to be cleaned is poured into the still to partially fill the basin. The glass cover allows the solar radiation to pass into the still, which is mostly absorbed by the blackened base. This interior surface uses a blackened material to improve absorption of the sunrays.

The water begins to heat up and the moisture content of the air trapped between the water surface and the glass cover increases. The heated water vapor evaporates from the basin and condenses on the inside of the glass cover. In this process, the salts and microbes that were in the original water are left behind. Condensed water trickles down the inclined glass cover to an interior collection trough and out to a storage bottle. Feed water should be added each day that roughly exceeds the distillate production to provide proper flushing of the basin water and to clean out excess salts left behind during the evaporation process.

Manikandan et al, 2017 stated that if the still produced 3 liters of water, 9 liters of make-up water should be added, of which 6 liters leaves the still as excess to flush the basin [11]. The Figure 3 below showed the single effect solar still model developed. The model is similar to a model developed by Havard (2015).

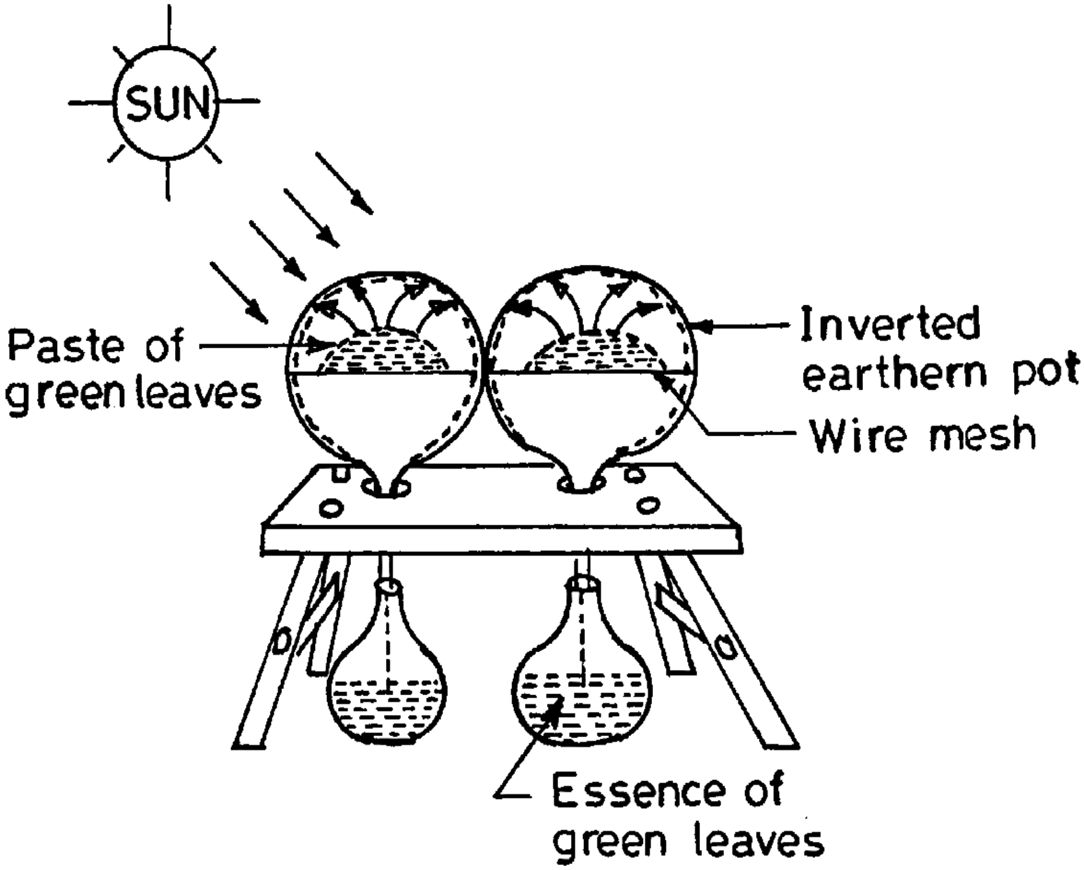

Figure 2: Solar Distillation by Della Porta in 1589 [8].

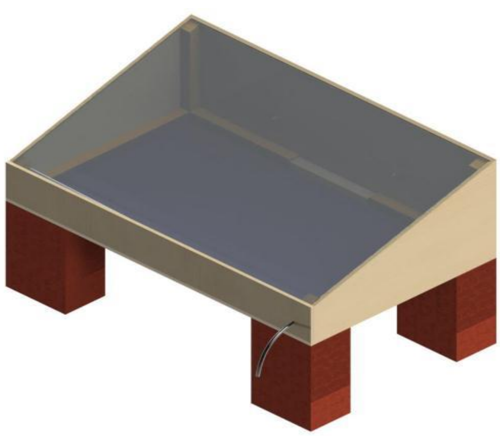

Figure 3: The Developed Solar Still Model [7].

MATERIALS AND METHOD

Assumption

The following assumptions are considered while designing single effect solar still [12]:

- The level of water in the basin is maintained constant level
- The condensation that occurs at the glass trough is a film type
- The heat capacity of the glass cover, the absorbing material, and the insulation material
- Vapor leakage in the still
- Temperature gradient along the glass cover thickness and in water depth.

- The heat capacity of the insulator (bottom and side of the still)

Material Selection

Cover Plate: The cover plate must allow transmittance of solar radiation and allow water droplets to form and slide down in the distillate production trough without falling back in the basin. Heat transfer through the cover plate increases when the thickness decreases and allowing more vapor to condensate. A.L. Ghoneyem, [13], showed that the production increased with decreasing glass thickness. Glass in 4 [mm] thickness is chosen as a cover plate material due to higher solar transmittance for various angles compared to plastic or thicker glass. Glass has high local availability, low price and can give a long operating life. The top cover was constructed using transparent glass material. The construction was based on the area obtained from design calculation, which is 0.4489 m^2.

Basin Material: The basin material will absorb the solar radiation that enters the still and must hence have high absorptivity values, withstand high temperatures and saline water without outgassing or harm the water quality. Galvanized iron covered with black paint will absorb the solar energy and right quality paint will not outgas. Havard (2015) in his research work showed that galvanized iron sheet is a good material for basin construction. The top cover was constructed using transparent glass material. The construction was based on the area obtained from design calculation, which is 0.4225 m^2. The dimensions are; Length is 650 mm, Breadth is 650 mm and Slope length is 300 mm

Insulation: The insulation material in the bottom and side walls of the still was chosen to be expanded polystyrene in 40 [mm] due to low thermal conductivity, low price and high local availability.

Walls: The walls will enclose the still, maintain robustness and a long operating life and is hence chosen to be galvanized iron sheets in 2 mm. Galvanized iron is resistant to saline water and will secure a stiff solar still. Havard 2015 also indicated that galvanized iron is resistant to salty water.

Legs: Since the walls are chosen to be of galvanized iron sheets it will ease the manufacturing and lower the cost to have legs with the same material. The legs will therefore also be of galvanized iron. The thickness of the stand was chosen to be 10 mm to be able to withstand the load it is been subjected to.

Distillate Production Trough and Hoses: The distillate production trough was chosen to be in galvanized iron, which will lower the cost and not affect the distillate water. The hoses in the still will transport both the saline and distilled water and must therefore not corrode or contaminate the water. Hoses were chosen to be in transparent polyethylene.

CALCULATIONS

Basin Area

The basin area is square with dimensions:

Length = 650 mm and width = 650 mm

$A = L x W = 0.65 x 0.65 = 0.4225 m^2$.

Top cover

The top cover was constructed using transparent glass material. The construction was based on the area obtained from design calculation, which is 0.4489 m^2.

$A = L x W = 0.65 x 0.65 = 0.4489 m^2$

Expected Output of a Solar Still

Practical Action Technology UK, gave an approximate method of estimating the output of a solar still which is given by:

$Q = E x G x A / 2.3$

where:

Q = daily output of distilled water (liters/day)

E = overall efficiency

G = daily global solar irradiation (MJ/m^2)

A = aperture area of the still (i.e., the plan areas for a simple basin still (m^2)).

In a typical country the average, daily, global solar irradiation is typically 18.0 MJ/m^2 (5 kWh/m^2). A simple basin still operates at an overall efficiency of about 30%. Hence the output per square meter of area is:

Q = 0.30 x 18.0 x 1/2.3
= 2.3 liters (per square meter)

Performance varies between tropical locations but not significantly. An average output of 2.3 to 3.0 liters/m^2/day is typical, the yearly output of a solar still is often therefore referred to as approximately one cubic meter per square meter, $1m^3/m^2$/year.

RESULTS AND DISCUSSION

Testing of the Solar Still

Figure 4 showes the temperature different between water and pure glass used as the top cover and High-Density Polyethylene (HDPE) used as cover plate. The temperature difference in the both cover plate increased from the 8 am when the experiment started to about 2 pm, then the temperature decreased from 3 pm to 4 pm when the test for day 1 terminated. This is similar with the work done by Prachi et al (2017) which state that the maximum amount of solar radiations is obtained between 11:00 to 14:00 hours which increases output of solar still [16].

The first temperature difference recorded for day 1 was 2.5°C for HDPE and 2.7°C for pure glass. At middle of the experiment which is about 12 noon the temperature difference measured was 6.5°C for HDPE and 6.9°C for pure glass. Also at the end of the experiment the recorded temperature difference between water and cover plate is 6.3°C for HDPE and 6.6°C for pure glass. This result indicated that pure glass is better used as a transparent cover plate for solar water distillation. The maximum atmospheric temperature recorded during the experiment was 30ºC while the minimum atmospheric temperature recorded was 24ºC. Sengar et al. (2012) stated that in winter, maximum inside temperature reached in solar still was 63.8ºC where ambient temperature and solar radiation were found as 540 W/m^2 and 30.3ºC [15].

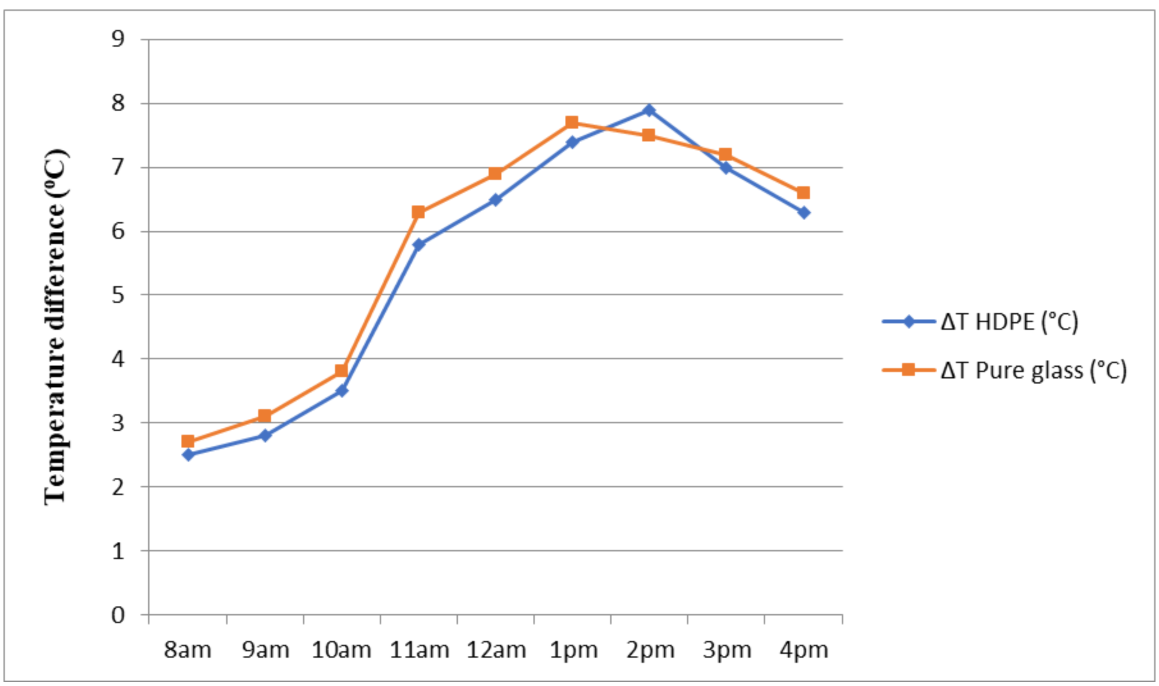

Figure 4: Temperature Difference Between Water and Glass Against Time for Day 1.

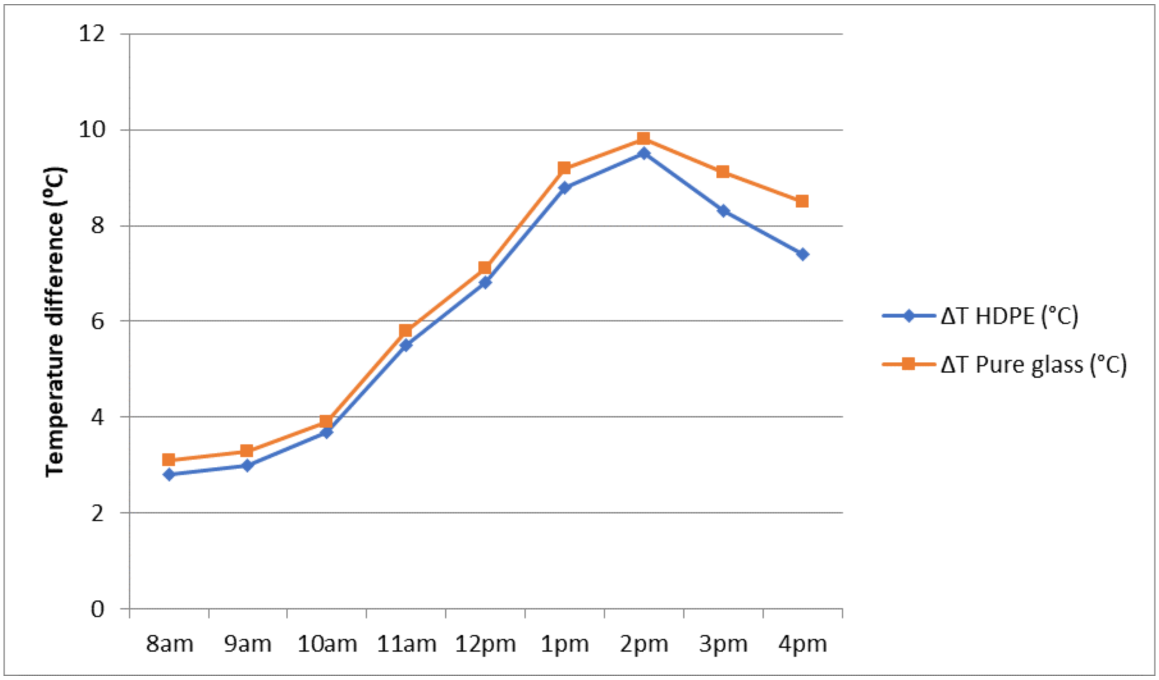

Figure 5: Temperature Difference Between Water and Glass Against Time for Day 2.

Figure 5 is the experiment conducted on the second day to ascertain the performance of top cover plate used for the solar still design. The experiment was conducted from 8 am to 4 pm and the temperature difference between water and the two top cover plate were recorded. The temperature difference between the cover plates at the day 1 was 2.8°C for HDPE and 3.1°C for pure glass. Also at interval of 4 hours it was recorded that the temperature difference is 6.8°C for HDPE and 7.1 for pure glass. The day 2 of the test period also showed very clear difference in temperature for the two top cover plate used by 4 pm. It was concluded that pure glass gave a better yield when used as transparent cover than HDPE.

The bar chart below showed the distillate produced for a period of 3 days using the difference top cover plate. The day 1 produced a total of 3350 ml of distil water. The HDPE top cover plate produced 1500 ml and pure glass cover produced 1850ml in day 1. This is similar to the result obtained by Arunkumar et al (2012) which stated that distillate output of the concentrator-coupled single slope solar still was 2600 ml/m^2/day while that from the tubular solar still was 4500 ml/m^2/day.

The distillate produced in the day 2 was slightly higher than the first day. This may be due to high solar radiation recorded in day 2. The total distillate produced in the day 2 was 4700 ml in it the HDPE top cover plate produced 2200 ml and pure glass produced 2500 ml. This evidence also supported the already established fact that pure glass is better used as transparent cover plate than HDPE.

CONCLUSION

The fresh water requirements in the world are increasing every day due to fast growth in the world population. The world population is over 7 billion with the majority of this population concentrating in the Asian countries. The demand for good quality water from this enormous population is overwhelming making scientist to think of alternative method of good water supply apart from natural rainfall and underground water. This is because the growth in industries in the world today have polluted some of the natural water supply, hence the need for water distillation.

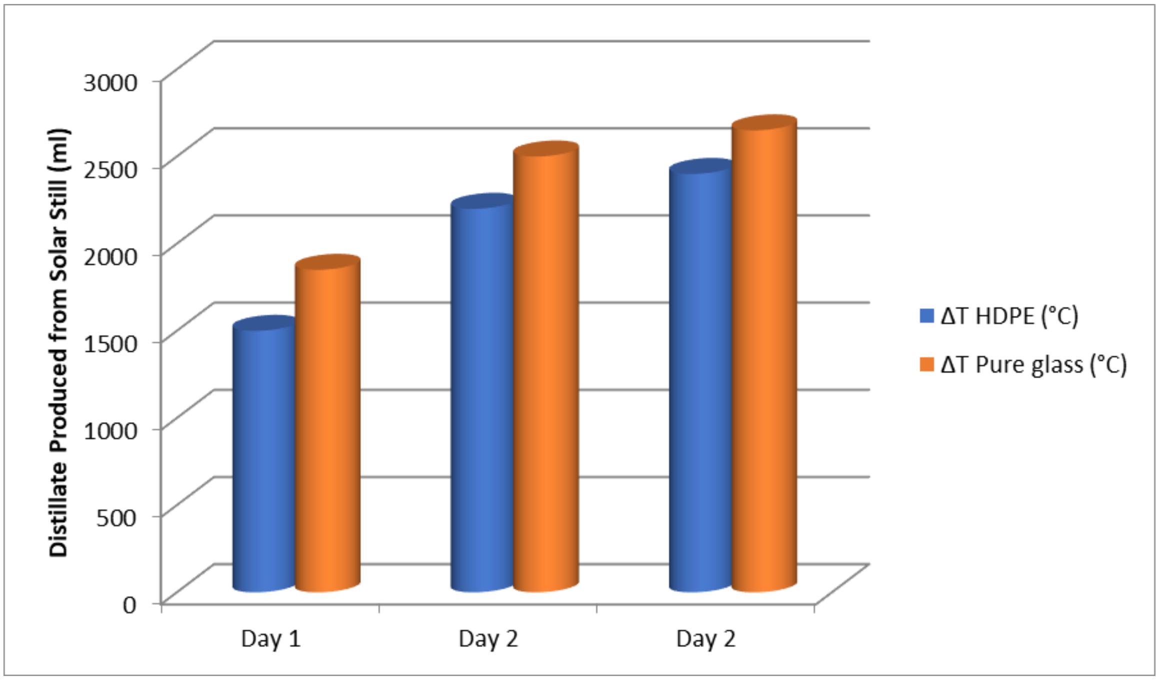

Figure 6: Daily Distillate from Different Glass Cover Plate.

This work centered on the design of single effect solar still for production of distillate water. The design comprises step by step component design. The basin part of the solar still has an approximate area of 0.423 m^2. The area of top cover plate is slightly greater than the basin area by 0.0264 m^2. The total distillate produced on the first day of test run of the solar still was 3350 ml.

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