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Optimization of Single Slope Solar Still Geometry for Maximum Collected Solar Radiation

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Abstract

In future we will not only consume energy, we will also partly produce our own energy need. Solar energy has been proven to be a valid strategy for producing on-site renewable energy. Planning for integrating solar energy in buildings involves many players and decision-making. In this article, a process map defining which decisions regarding solar energy needs to be discussed in which design stage, is presented. With the help of this process map, more informed decisions should facilitate the implementation of solar energy in buildings. Our way of thinking about energy and buildings is changing; initially buildings were solely considered to be energy-consuming, future buildings will be need to consume less energy while producing part of their own energy [1]. One way to produce renewable energy on-site is by means of active solar energy. By doing so, It will reduce the impact on the environment and reduce the dependence on imported energy. Current legislation is already directing towards such energy efficient and energy producing buildings, with the European directive for the energy performance of buildings [2] as the clearest example.

Keywords: Solar energy, Solar Still, Solar Desalination, Building integrated Desalination.

INTRODUCTION

Distillation: Natural Process for Purifying Water

There are a number of processes that can be used to convert brackish water or saline water to fresh water. These include reverse osmosis, electro dialysis and distillation. Distillation is one of the simplest and widely used processes. More than 90% of the world's water desalination processes use distillation.

In the distillation process water is evaporated, leaving behind the impurities and microbiological organisms, thus vapour contains only fresh water molecules. The vapour should be condensed to get the fresh drinking water. The energy required for distillation can be provided by electrical energy or thermal energy. Since the vaporization of the water requires low temperature (around 100 °C), solar radiation energy can easily be used to achieve such low temperatures. The use of solar thermal energy for distillation is similar to the rain cycle of the earth. Solar radiation falling on earth causes evaporation of water, forming clouds, which then get condensed in the cooler regions and bring backwater to the surface. In this way, solar distillation is effective in removing many unwanted impurities as listed below.

Salts and minerals: Na, Ca, As, Fl, Fe, Mn, etc.
Bacteria: E. coli, cholera, etc.
Parasites: Giardia, Cryptosporidium, etc.
Heavy metals: Pb, Cd, Hg, etc.

Solar water distillation technology has a long history. Installations were built over 200 years ago, although to produce salt water rather than drinking water. Documented use of solar stills began in the sixteenth century. An early large scale solar still was built in 1872 to supply a mining community in Chile with drinking water. Mass production occurred for the first time during the Second World War when 2,00,000 inflatable plastic were made to be kept in life crafts for the US Navy. India is blessed with plenty of sunshine. Most of the country gets about 300 sunny days, resulting in daily solar radiation of about 4-7 kWh/m^2. Therefore, solar distillation technology can be implemented effectively. Design and implementation of solar distillation apparatus is easy and cost effective. In the application of solar energy, like conversion of brackish or saline water into fresh water, intermittent supply of solar radiation should not limit its use, as the fresh water is produced as and when solar radiation is available.

OPERATION OF SOLAR DISTILLATION

A solar still apparatus is built on the same principle as rainwater cycle consisting of two steps, evaporation and condensation. In this way, the basic principles of solar water distillation is simple yet effective. The sun's energy heats water to the point of evaporation. As the water evaporates, water vapour rises, condensing on the glass surface for collection. This process removes impurities such as salts and heavy metals as well as eliminates microbiological organisms. In the end, water is cleaner than the purest rainwater. A schematic diagram of solar distill is shown in the Figure 1

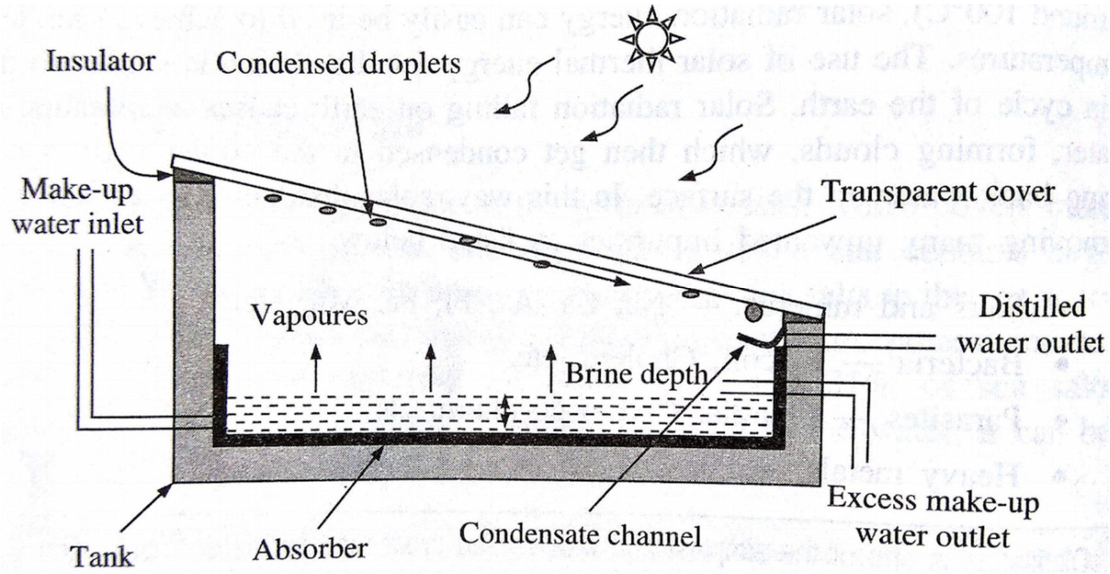

Figure1: Schematic layout of Single Slope Solar Still

A single basin solar still has a top cover made of glass. It has an interior surface made of a waterproof membrane. This interior surface uses a blackened material to improve absorption of the sunrays. The glass has a property to be transparent to visible light but opaque to ultraviolet and infrared light. Therefore, the glass cover of a solar still allows visible part of solar radiation to pass into the still, which is mostly absorbed by the blackened base, resulting in increase in basin temperature. Low temperature object radiates in the infrared region. Due to this, the basin radiates energy in the infrared region, which is reflected back into the still by the glass cover, thus, trapping the solar energy inside the still (glass cover absorbs infrared radiation and reradiates part of it back to the basin).

This is similar to a greenhouse effect. Due to this, the water heats up by about 10-20 ℃, resulting in increased rate of evaporation. The moisture content of the air trapped between the water surface and the glass cover increases. The heated water vapour evaporates from the basin and condenses on inside of the glass cover in the form of small droplets. The condensation at glass cover occurs due to lower ambient temperature outside the glass cover.

These drops of water flow into condensate collection channels on the sides, which can be collected externally. 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 through and out to a storage bottle. The long axis of the solar still should be placed along the East-West direction such that the glass sloping is facing towards the south.

Components and Specifications

Various components of solar still and their specifications are summarized in Table Refer to the still schematic given in above section.

System components	Specifications	
	Material	Purpose
Water basin/ Tank	Cement concrete or fiberglass	Container of saline water
Insulation	Polyurethane Foam, putty, tars	To prevent heat losses
Transparent cover	Glass or polyethylene	To transmit solar energy
Absorber	Black Butyl rubber, black polyethylene or ink or dye	To absorb the heat
Condensate channel	Aluminium, galvanized iron	To collect droplets of water
Make up water inlet	PVC pipe	To supply the saline water
Excess make-up water outlet	PVC pipe	To drain the water
Storage pot	Glass, Plastic	To store distilled water

Solar Still Design and Costing

Energy requirement and efficiency

The energy required to evaporate water is the latent heat of vaporization of water. The Latent Heat is the heat that is required by a substance to change its phase, from solid to liquid or liquid to gas or vice versa. The latent heat of evaporation of water is about 2260 kilojoules per kilogram. This implies that in order to produce 1 litre of water through distillation, heat input of 2260 KJ is required. In practice, one has to supply much higher amount of heat energy because the efficiency of the still will not be 100%.

Heat could be lost due to conduction, convection and radiation. There are several possible heat loss paths in solar still, such as heat could be lost due to vapour leakage, heat loss at the bottom and sidewalls of the still through conduction, heat loss due to radiation, heat loss due to convection from the glass cover, heat absorbed by the cover, etc. The overall heat loss could be 40 to 60%. Based on this information, the efficiency of solar still could vary in the range of 30% to 45%.

Design of the solar still

Design of the solar still is very simple. One aim of the calculation is to find out how much distilled water we will get per day from one square metre area and how much total area is required to fulfill our requirement. Following assumptions can be taken into account:

1. Latent heat of water evaporation – 2260 kJ/kg
2. Density of water – 1 kg per litre
3. Efficiency of Solar still – 0.30
4. Average daily solar radiation on a given location – 6 kWh/m^2- day
5. Amount of distilled water required per day – 15 litres

Step 1: Useful solar radiation
Daily available solar radiation = 6 kWh/m^2-day
Useful solar radiation = Daily solar radiation x solar still efficiency
= 6 x 0.3 = 1.8 kWh/m^2- day
Step 2: Litres of distilled water produced per day per square metre
Latent heat of water evaporation = 2260 kJ/kg
Number of litres of distilled water produced per square metre per day efficiency of the system

$$= \frac{Useful\ solar\ radiation}{Latent\ heat\ of\ water\ evaporation}$$

$$= \frac{6480}{2260}$$

= 2.86 litres/m^2-day
Step 3: Total area of the solar still to fulfill the requirement
Total distilled water requirement per day = 15 litres/day
Total area of the solar still to fulfill family requirement

$$= \frac{Total\ daily\ Requirement}{Number\ of\ litres\ produced\ per\ day\ per\ square\ metre}$$

$$= \frac{15}{2.86}$$

= 5.23 m^2

Alternatively the total solar distill area required to fulfill daily requirement can be calculated using following formula

$$A= \frac{Q\ X\ 2.26}{G\ X\ E}$$

Where,

A- total distill area required
Q- total distilled water required per day
G- daily solar radiation in MJ/m^2- day
E- efficiency of solar distill in decimal

Economics of Solar Still

Payback period can be calculated using the calculation for distilled water used in battery maintenance. According to the calculations shown in section 1.11 a solar distill with 30% efficiency will produce about 2.86 litres per day per square metre if the daily solar radiation is 6 kWh/m^2-day.

Calculation of payback period for solar distill unit
Daily-distilled water production per unit area
= 2.86 litre/day
Cost of manufacturing of solar distill for one square metre area
= Rs 1500/m^2
Cost of distilled water in the market
= Rs 10/litre
Worth of distilled water produced everyday
= 2.86 x 10 = Rs. 28.6/day
The number of days required to recover the cost of solar distill

$$= \frac{Cost\ of\ manufacturing}{Cost\ gain\ per\ day}$$

$= \frac{1500}{28.6} = 52.31 = 53$ days

Thus, it can be seen that the payback period for solar distill is within 2 to 3 months.

Maintenance and troubleshooting

Some precautions must be taken for the good performance of solar still. They are as follows:

1. *Cleaning the basin and flushing:* As water evaporates from the solar still basin, salts and other contaminants are left behind. Over time, these salts can build to the point of saturation if the still is not properly maintained and flushed on a regular basis. Properly operating a still requires about three times as much make up water as the distillate produced each day. If the still produced 2 litres of water, then 6 litres of make up water should be added. The additional 4 litres water leaves the still as excess make up water. The excess make up water flushes the still basin through the overflow to prevent salt buildup.
2. *Cleaning the glass and condensate channel:* The glass cover must be cleaned periodically to remove the dust from the cover, which otherwise absorbs some part of the solar radiation reducing the efficiency of the solar distill. Care must be taken to avoid the breakage of glass, which may lead to vapour leak. Condensate channel also must be cleaned periodically while draining out the basin water. Glass can be cleaned with distillate itself or any other available cleaning solution.

Multiple Effect Solar Still

To improve this low efficiency, multiple effect solar still (MES) have been studied in many groups [6-8]. In MES, water evaporates on the first wick condenses on the condensation surface of second plate, which has second evaporating wick on its opposite side. Therefore, the latent heat of condensation can be reused to evaporate the water in the second wick. (Fig. 1) By staking multiple layers of the condensation-evaporation plate, the heat of condensation can be reused multiple times to increase its efficiency. By stacking 11 layers, Tanaka et al. [6] obtained more than 10 litter per m^2 per day under sunlight about 20MJ/(m^2 day), which is comparable to higher than 3.5 tons per year.

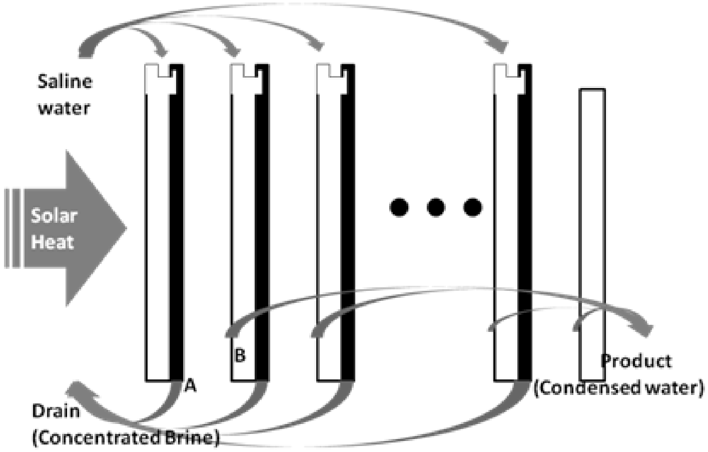

Figure: 2 Concept of multiple effect solar still: Saline water dripping through wick(A, Black) evaporates and condenses on the condensing plate (B, White), while concentrated brine drains to waste. The latent heat emitted during the condensation process heat the next wick for evaporation.

The system cost may include not only the Multi Effect Still itself, but also the installation cost which includes land, labour and structure material. This installation cost, especially the land cost, is almost linearly proportional to the size of the system. Therefore, if we install many Multi Effect Stills in separate bare land, substantial amount of budget would be required.

We can overcome this problem, by installing Multi Effect Still as part of building component. Since Multi Effect Still has panel shape, which can be positioned vertically or diagonally, it can be placed on the wall or rooftop. This is similar concept to Building Integrated Photovoltaic in solar power generation. Similar to photovoltaic panels in Building Integrated Photovoltaic, Multi Effect Still panels may replace concrete or tiles of outdoor structure of buildings, walls or fence facing sunny direction of the location.

Cost of land and installation may not make big matter in this "Building Integrated Desalination", since such cost is already required for making the same structure even without Building Integrated Desalination. Only the additional cost is required to add water supply and drain line to the structure, which might be partially compensated by the saved cost of the building material.

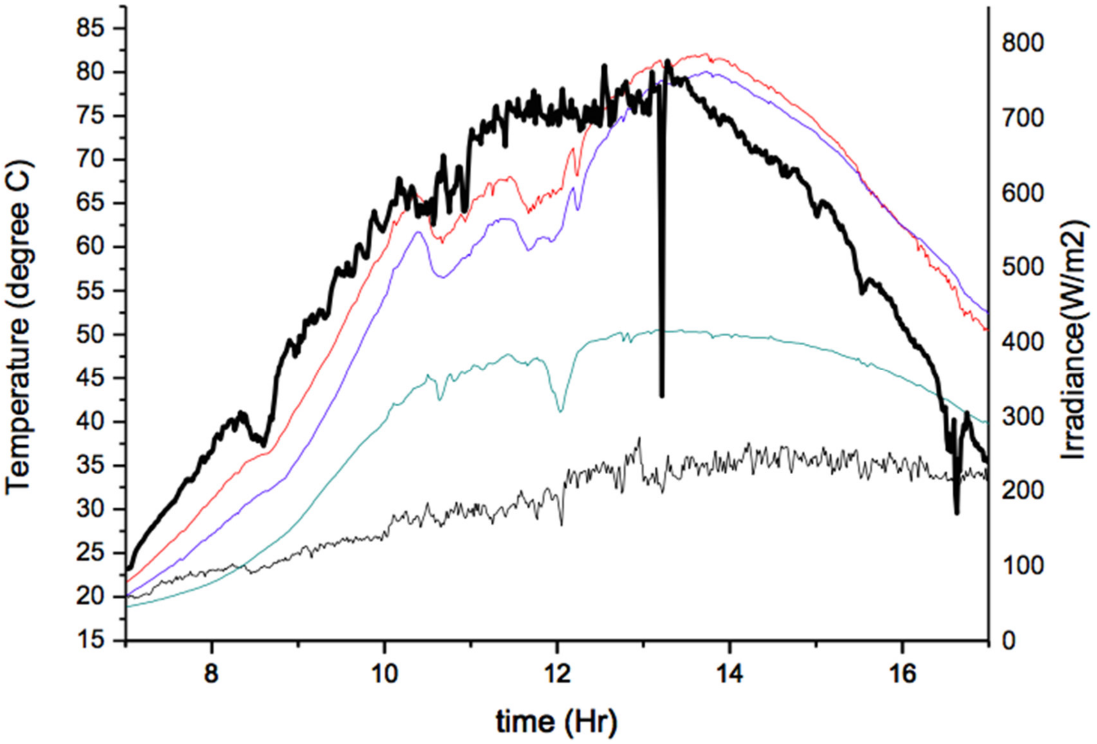

Figure: 3 Irradiance and temperature inside of black insulating plate

Figure 3 represents the solar irradiation and the temperatures with the system measured at New Delhi, on May 29th, 2016. Since each layer is cooled by evaporating water, it takes some time to heat up the layers by solar heat. Therefore, there is some right shift of the layer surface temperature graph from the solar irradiance graph. Adding proper amount of water is very important to operate the system efficiently. Deficient feeding may cause drought of evaporation wick, lowering the efficiency and failure of the system. Too much feeding may cause loss of heat so that large portion of water drained out even before evaporation occurs. Tanaka et al. [6,8] suggested around 1.6~2 for optimum feeding rate to evaporation rate ratio. In other words, the ratio of drain to the condensate should be in the range of 0.6~1. For proper water feeding, automatic flow controller was initially planned for the MES system. However, unfortunately, it was not ready at the time of measurement. Therefore, water was supplied under manual control, which was not very successful. Total solar energy on the active area during the period was calculated to be 1.38MJ by integrating the irradiation curve (6.31MJ/m^2) multiplied by the active area (0.219m^2). During the period, the MES system produced 283g of fresh water. Therefore, performance of 205g/MJ was calculated. In other word, under condition of 20MJ/m^2/day, the system may produce about 4.1 litters per square meter daily. This is less than half of the expected value (more than 10 litter per square meter daily) described in above introduction. However, considering that this is a preliminary test, and we used MES with only 6 layers on current measurement instead of 10, there would be some room for further improvement.

Conclusion and Future Work

It can be a practical solution to supply fresh water to isolated societies that cannot afford huge costs of Mass-Desalination Plant. Low cost multiple effects solar still could be a plausible way to realize. Some primitive test was done for the Multi Effect Still system. Further improvement on performance and cost down would be developed and tested soon. Since each water deficient country has its own specific environmental condition as well as specific social and economic requirements of water desalination, collaboration with researchers in such countries would be helpful to speed up the development Actual field test with improved prototypes in such countries should be done in future.

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