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Solar Stills : A review

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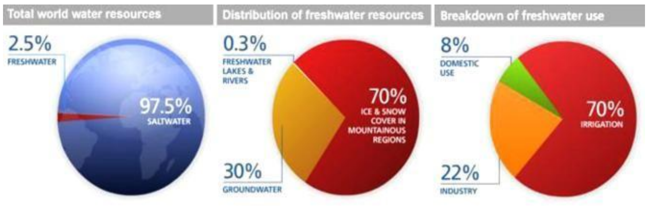
Abstract **Almost 70% of earth is covered by water but only 0.75% freshwater is available for domestic, agriculture and industrial purpose. With rapid growth of industries, population, agriculture production etc., demand for the pure or fresh water is increasing rapidly. This increasing demand of fresh water can effectively tackled by purification of available water. Solar desalination is an eco-friendly and economical way of obtaining the fresh water to cater the needs of rural population. Solar still is one of the simplest device to obtain freshwater from available brackish water, but limited by its productivity. This paper is a review of various design of solar stills. Now a days more attention is paid on developing the multi-effect solar stills to overcome drawback in single-effect solar still.**

Keywords — desalination, solar still, thermoelectric cooler, freshwater, multi-effect solar still.

I. Introduction

Water is the basic requirement for human being to live on earth. Over 70% of the earth is covered by water, but most of it is saline water, which is available in ocean and very small quantity of fresh water which is available in the rivers, lakes or other natural sources. With total global water reserves of
1.4 billion km3, around 97.5% of it is in oceans and the remaining 2.5% is fresh water present in ice-mountains, lakes, rivers and ground water. Due to rapid growth of industries, population, agriculture production etc., demand for the pure or fresh water is increasing rapidly, two third of the world population will face water scarcity by 2025 (UNEP, 2012).



Distribution of world water resource

As availability of fresh water is decreasing and demand of fresh water is increasing rapidly, it is necessary to obtain fresh water from available impure water. This rapidly increasing demand of fresh water can be effectively tackled by purification of available water.

II. Solar Desalination (SD)

These conventional methods of obtaining fresh or potable water are highly energy consuming processes, which requires thermal or electrical input. The conventional desalinations plants are operated by fossil fuels which contributes to pollution. Thus, many researchers are working on use of renewable energy for powering desalination units. Renewable energy commonly used for desalination plant is solar energy. Solar energy based desalination units are highly suitable for arid, semi-arid and remote regions where no electrical or other power supply is available.

The solar energy is used to heat the impure water to its saturation temperature, as water evaporates leaving behind the high concentration saline water. These water vapor rises & condenses on glass surface for collection. This process removes impurities such as salts, dust particles and heavy metals, as well as destroys microbiological organisms. The water obtained from this process cleaner than the purest rainwater. Use of solar energy/radiation to obtain fresh water is investigated for many years. Recently, more attention is directed towards improving the conversion efficiency of solar desalination system.

III. Solar Still (SS)

Solar still represents a natural hydrologic cycle on a small scale. The simple solar still is shown in **Error! Reference source not found.**. It consists of a basin made of some insulating material with basin liner from inner side which contains saline water, a glass or plastic cover sloping at an angle above the basin and meeting at the apex, creating a greenhouse like structure. The basin liner is generally painted black to maximize the absorption of solar radiation.

Solar radiation passing through glass cover produces the greenhouse effect that is which raises the temperature of the salty water present in basin. Water at the surface is evaporates, the water vapour rises in the still and reaches

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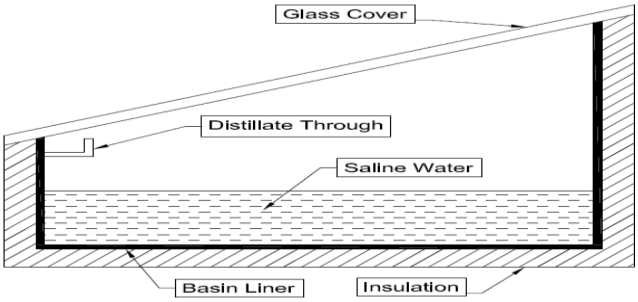
the sloping glass cover, where it condenses to liquid water and runs down the sides of the panels. The water is collected and drawn off to provide fresh water.



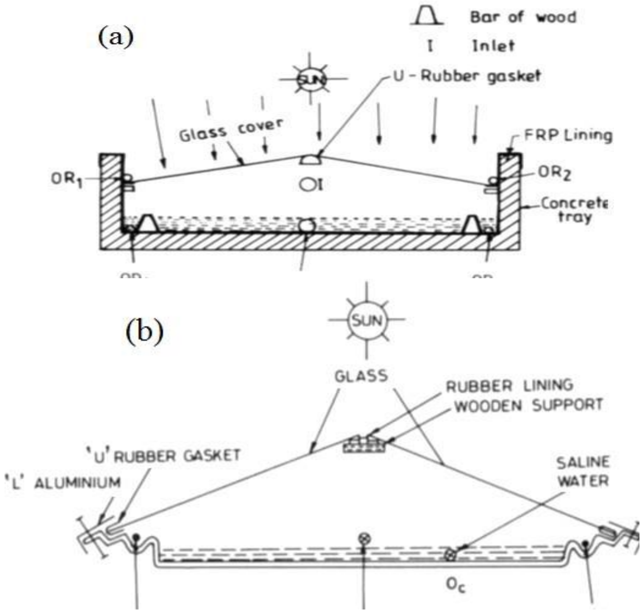
Simple Solar Still

Solar stills can produce 6 *liters of fresh water per day per square meter*. Because of low production rates, it is important to minimize capital costs by using very inexpensive construction materials. Efforts have been made by various researchers to increase the efficiency of solar stills by many ways. However, the latent heat of condensation can be used to preheat the feed-water, and this leads to an improvement in the efficiency.

IV. SINGLE EFFECT SOLAR STILL

Tiwari et al (1986) designed and studied the performance of three single basin solar stills with single slope FRP, double slop FRP and double slope concrete arrangement. They reported that the single slope basin still gives better performance than a double slope in winter, whereas the opposite result was observed in summer.

Maalej (1991) investigated the performance of single slope single basin solar still experimentally. He concluded that the best performance of solar still is achieved with high solar intensity, high insulation and low wind velocities. He achieved max 50% efficiency.



Cross-sectional view of double slope (a) concrete still with FRP lining

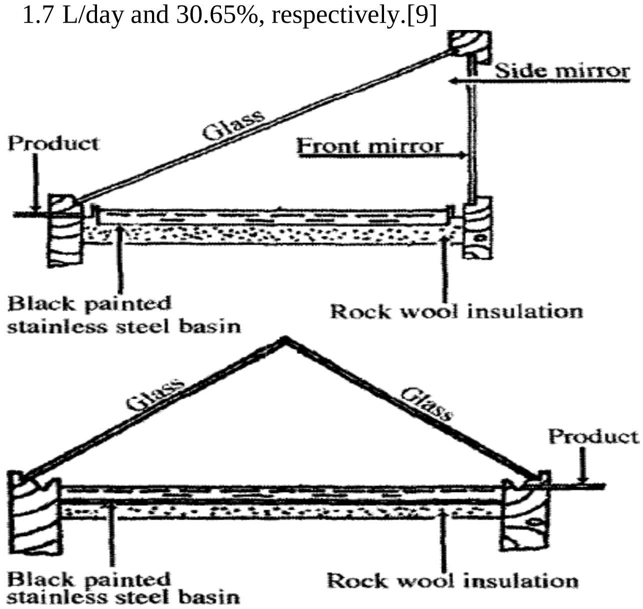
(b) FRP still

Tayeb (1992) tested four different designs of solar still. The stills had the same area of evaporation but different shapes namely inclined flat glass cover, a semi-sphere cover, a bi-layer semi sphere cover and an arch cover. Higher productivity is observed with higher ratio of condensation area to evaporation area.

Al-Hayeka and Badran (2004) investigated the two designs of solar still namely asymmetrical greenhouse type (ASGHT) with mirrors and the symmetrical greenhouse type (SGHT) Figure 11. They observed that ASGHT with mirrors had more productivity and efficiency than SGHT. They also observed that decreased depth of water and the addition of dye improved the productivity of both stills.[8]

M. Ali Samee et al (2007) designed and tested the simple single basin solar still with the basin area basin area of 0.54 m2. They reported the productivity and efficiency of still as

1.7 L/day and 30.65%, respectively.[9]



Schematic diagram of the (a) ASGHT (b) SGHT

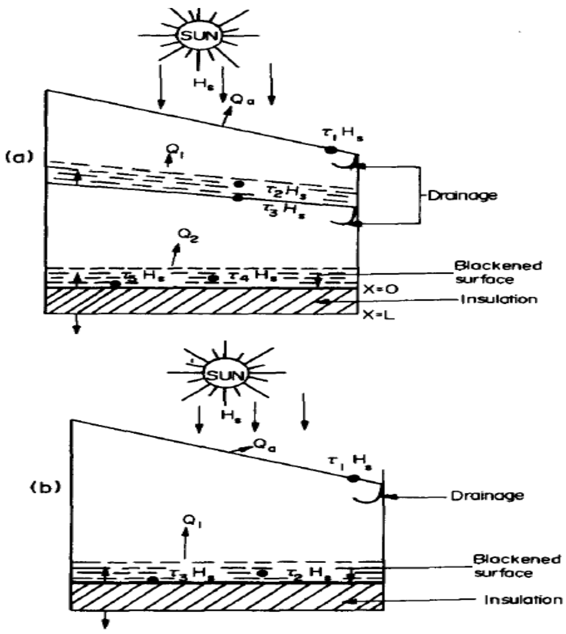
Tiwari A. and Tiwari G. (2006) investigated the effect of water depths on heat and mass transfer in a passive single slope solar still in summer conditions. The solar still had tested for the different five water depths from 0.04m to 0.18m. They reported that, the highest output and efficiency are observed at lower water depth

Kumar and Bai (2008) studied the performance of solar still with enhanced condensation. Tubes carrying water are attached to walls to enhance the condensation. The daily production rate of 1.4 L/m2.day and 30% efficiency was observed during the experimentation.

V. MULTI EFFECT SOLAR STILL

Sodha et al (1980) performed periodic analysis and experimentation on single slope double basin solar still to evaluate its performance. They reported 36% higher productivity than single basin solar still and productivity increases rapidly with increasing thickness of insulation till 4cm and then increases slowly.

Mahdi (1992) performed transient analysis for performance prediction of multi basin solar still. The effect of the number of basins on the daily productivity of the still was analyzed. It is observed that productivity increases with increase in no. of basins but for more than three basins improvement is not significant.



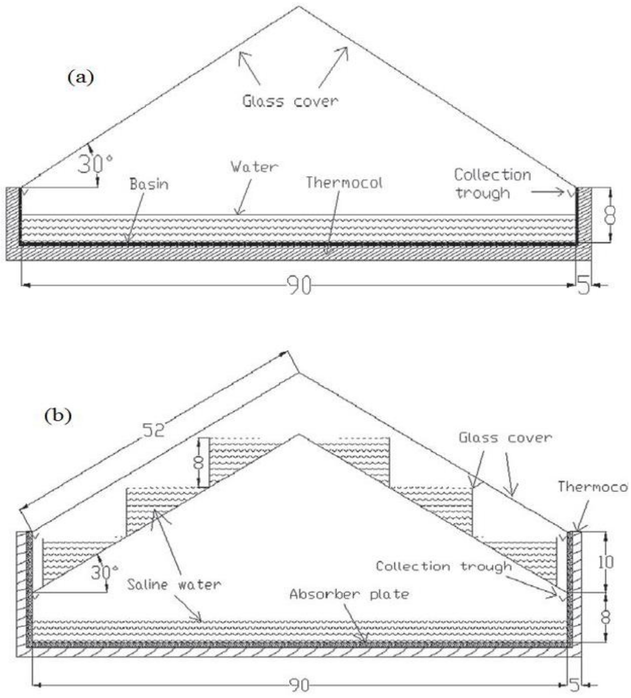
Schematic sketch of solar still (a)Double basin; (b)Single basin

Al-Karaghouli and Alnaser (2004) did the performance analysis of single and double basin solar still, with and without insulation. The basin area for all stills was kept same. They reported, addition of insulation has significant influence on productivity, efficiency is increased between 2% to 8% by adding the insulation. Also productivity of double basin solar still was 8% and 13% higher than single basin still with and without insulation respectively.[14]

Rajaseenivasan et al (2013) did comparative study of double slope single and double basin solar stills. The double basin solar still, upper basin was divided into three stepped compartments. They studied the effect of depths of water, different wick materials, porous material and energy storing materials. Maximum productivity of 5.68 L/m^2.day was observed for double basin solar still with mild steel pieces as energy storing material.[15]

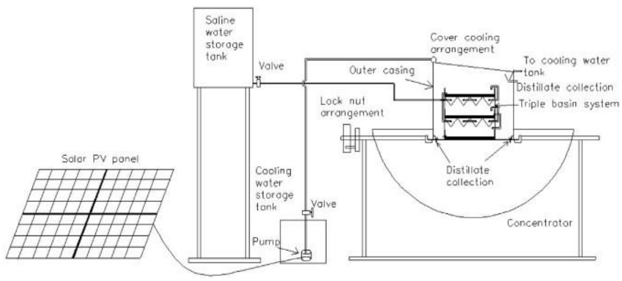
Feilizadeh et al (2015) investigated effect of the amount and mode of input energy to an active multi-stage (four stages) solar still. Indoor experimental setup was developed, to simulate energy absorbed by solar collectors an electrical heater controlled by PLC was used. They reported the freshwater production is a quadratic function of CBA ratio.[16]

Elango and Murugavel (2015) studied effect of water depth on productivity f single and double basin double slope solar still. They fabricated both the stills using glass, which had same basin area. Tested these stills for water depth of 1cm, 2cm, 3cm, 4cm and 5cm under insulated and un- insulated conditions. To maintain stagnancy of water in upper basin, equally spaced seven vertical glass strips of 0.05 m height and 0.003 m thickness were provided at both slopes. It is observed that double basin, lower water depth and insulation gave better performance.[17]



Schematic diagram of double slope solar stills (a)Single basin; (b)Double basin

Srithar et al (2016) developed and experimentally tested triple basin solar desalination (TBSS) with cover cooling and parabolic dish concentrator (PDC) as shown in fig. Four triangular hollow fins were attached at the bottom of the upper and middle basin to place energy storage materials. The cover cooling reduced galss temperature upto 8°C, which increased distillate output by 30% as compared to conventional TBSS. . The configurations were tested with empty fins and fins filled with river sand and charcoal as energy storage materials. The daily productivity upto 16.94 L/m^2.day was obtained with TBSS with CC, PDC and charcoal in fins. [18]



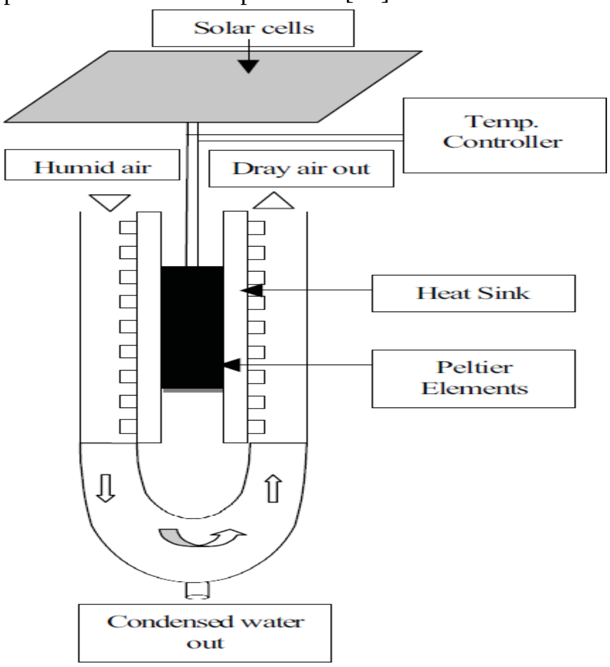
Schematic of the experimental setup for TBSS with CC and PDC

Kalbasi et al (2018) formulated mathematical model to predict performance of single and double basin solar still and validated it using experimentation. They reported 14 % and 16% decrease in productivity of single and double effect respectively, by increasing the water depth from 1cm to 3cm. Also, the yield from multi basin still increases with number of stages, but beyond optimum number stages productivity is not improved.

VI. USE OF THERMOELECTRIC MODULE (TEM)

FOR PRODUCTION OF FRESH WATER

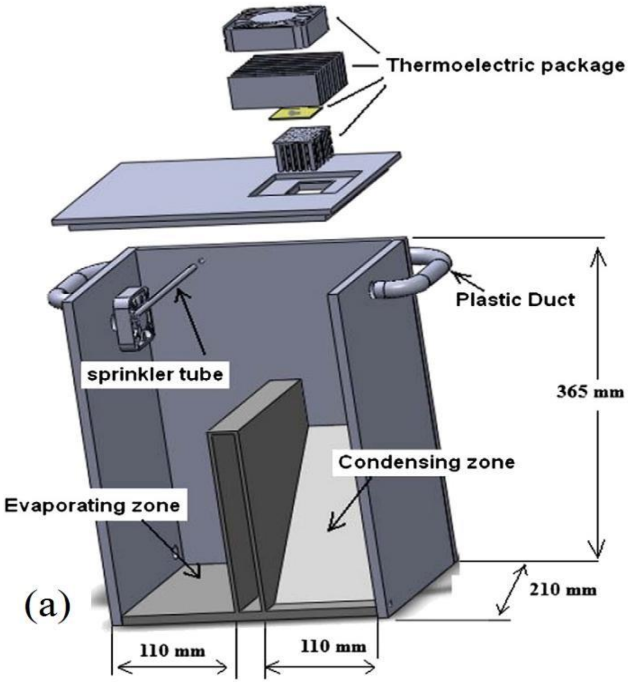
Atta (2011) developed and tested a solar water condenser using thermoelectric coolers for high humidity environments such as places close to the sea, where moisture can be condensed from the ambient air. The main components of the solar PV/battery thermoelectric dehumidifying system are the PV cell, the thermoelectric refrigeration system and the cooled object. **Error! Reference source not found.** shows the schematic of the setup used. The moisture air is pumped first into the hot side of the Peltier element to increase the air temperature which increases the moisture holding capacity of air, then pushed to the cold side to condense the moisture. The condensed water falls into a reservoir to be used for irrigation. Applying the system in high humidity see area produced 1L of water per hour. [21]



Block diagram of the built water condensation

Esfahani et al (2011) developed and tested a portable solar still with thermoelectric cooling (TEC). To improve performance of still developed, they used some techniques such as using a solar collector, a wall covered with black wool and water sprinkling system to increase evaporation rate. The still was made using plexiglass.[22]

Ravindran (2012) used TEM to improve productivity of simple solar still. He reported increase in distillate output from 0.7L to 1.2L, without and with TEM, which is approx. 58% improvement.[23]



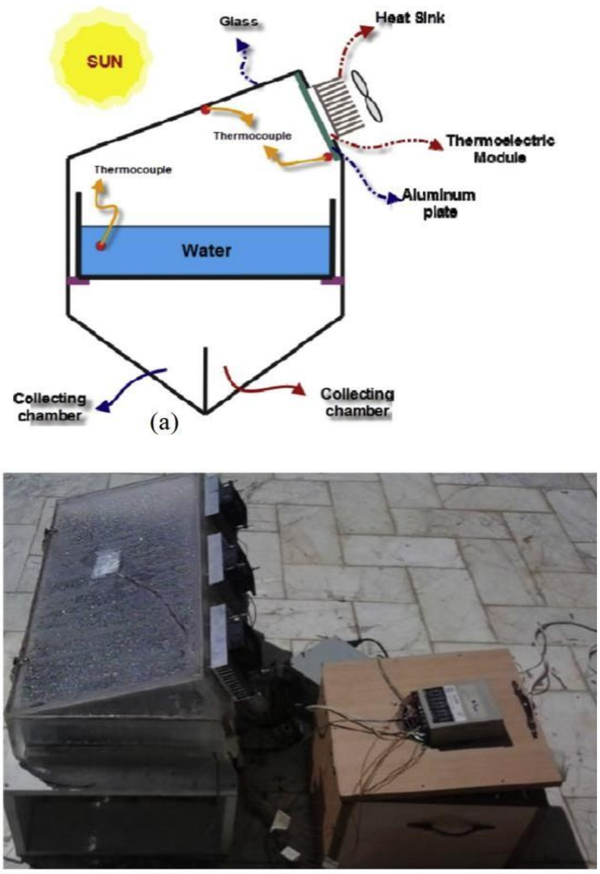
Portable solar still using TEM

Dehghan (2015) developed a thermodynamic model and performed exergic analysis of thermoelectric assisted solar still. The results are compared with experimental results. It is found that the highest exergy destruction happens in the thermoelectric module, which is 63.4% followed by basin- liner (20.7%) and the saline water (15.1%) and glass cover (0.8%).[24]

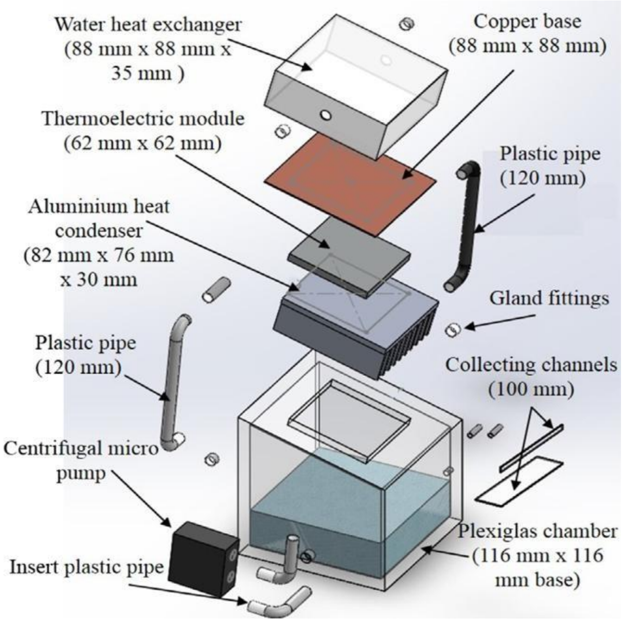
Rahbar et al (2016) designed, fabricated and experimentally tested a novel asymmetric solar using TEC to investigate effect of TEM on performance of solar still. Productivity with TEM is approx. 3.2 time more than that of the glass surface, though size of TEM is 2.8 smaller than glass surface.

Shafii et al (2016) developed and experimentally tested a solar still equipped with evacuated tube collectors and thermoelectric modules (TEM). The TEMs are used to generate electricity from temperature difference between condensing hot vapors and cold ambient air, which is used to drive small fan for inducing forced convection in still. The electricity produced by TEM is used to drive fan leads to 14% increase in daily yield of still.

Joshi et al (2017) developed and experimentally tested a thermoelectric fresh water generator (TFWG). The fresh water is produced by condensing the moisture form ambient moist air. The maximum 0.24L fresh water is generated in 10 hours using 10 TEM. [27]



Asymmetrical solar still with TEM (a) Schematic views; (b) Photograph



Assembly drawing of thermoelectric distillation system

Rahbar et al (2017) performed exergic analysis of double slope single basin solar still with thermoelectric heating module (TEM). Thermoelectric modules are used as heater to increase the water temperature and improve the performance of the still. The use to TEM improved yield of still when solar intensity decreased.[28]

Al-Madhhachi and Min (2017) designed a system to effectively use hot and cold side of TEM simultaneously for production of fresh water. They reported 28.5ml (678mL/m^2) average water production over a period of 1 hour and specific energy consumption of 0.00114 kW h/mL.

VII. CONCLUSIONS

Many investigation has been carried out by researcher and scientists to improve the performance of solar desalination system by considering various design parameters (condensing cover material, its thickness and inclination, water depth in basin, type of solar desalination system), climatic parameters (solar radiation, wind velocity, humidity, ambient temperature,), operational parameters (salinity of water) which affect the production rate of solar still. The main problems in solar desalination systems are relatively low productivity, low conversion efficiency and large area requirement. There is scope to enhance productivity (distillate output) of solar desalination system. Literature shows that the performance of the solar still can be enhanced by

- lowering water depth in basin
- increasing the number of basin (upto 3 basins)
- utilizing the heat released by condensation in effective way
- lowering the temperature on condensing surface.
- concentrating the solar radiation

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