CLIMATIC AND DESIGN PARAMETERS EFFECTS ON THE PRODUCTIVITY OF SOLAR STILLS: A REVIEW

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Abstract
We know that about 73% of the world covers water, out of which 90% of water is saltwater. This saltwater is not suitable for drinking and also for agriculture and industrial purposes. Due to increasing population and industrial growth, there in increasing need for fresh water. Thus there is a need to find an alternative technique that can replace the fossil fuels and non- renewable energy resources to satisfy these increasing fresh water requirements. Solar still is one such technique that can be used. Solar energy is used to remove the contaminants/impurities from water to supply fresh water in solar still. The parameters having an impact on the productivity of a solar still are: climatic parameters like wind velocity, ambient temperature, solar radiation intensity, relative humidity etc., design parameters such as water depth, condensing cover material and its thickness, insulation, slope or inclination of condensing cover etc. and the operational parameters includes feed water preheating, water salinity etc. The effects of various design and climatic parameters on the performance of solar still are discussed in this paper.

Index Terms: climatic parameters, design parameters, distillate output, solar still

I. INTRODUCTION

Water is the requirement of all life forms including plants, animals, and humans. About 73% of the world is covered by water, out of which 90% of water is saltwater. This saltwater is not suitable for drinking and also for agriculture and industrial purposes. Due to increasing population and industrial growth, there in increasing demand for fresh water. These increasing demands have created an imbalance between the supply and demand for fresh water. Besides this, energy consumption is another problem. The various desalination techniques are, such as reserve osmosis, electro-dialysis, carbon filtration, vapor compression etc. to incur fresh water. But, use of fossil fuels and non-renewable energy resources cause serious problems like global warming. Therefore, there is a need to find an alternative technique that can replace theses fossil fuels and non-renewable resources.

Solar still is one such technique that uses the solar energy to distillate the contaminated water. It uses free natural sunlight (solar radiations), available in an abundant form to purify contaminated water. It is an environmentally friendly technique that helps to substitute fossil fuels by solar energy. It has many advantages- it is environmentally friendly, consists of stationary parts, skilled manpower not required, fairly efficient in distilling water and easy to construct and maintain. But its major limitation is low productivity rate. It can give an output of only 2 to 5 liters per m^2 area per day. But still it can be used in remote areas where freshwater is insufficient, but solar radiation is abundantly available. Solar still schematic is shown in Fig. 1.

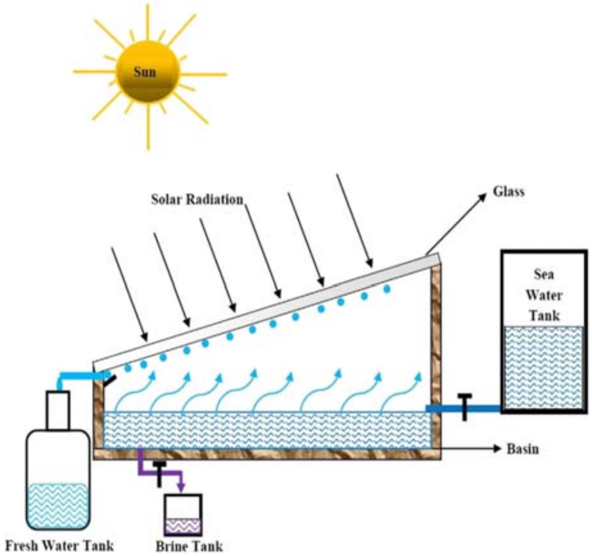

Fig. 1Schematic of a Solar Still [1]

A. Solar Still Working Principal

The working of solar still is based on - heating, evaporation, and condensation. The solar still basin is initially filled with saline water. As the solar radiation is incident on condensing cover of a solar still, these radiations are then absorbed by the salt water and until it warms the water up to its evaporation point. These evaporated vapors then rise up due to natural convection currents set inside the still and condense on the inner side of the cover. The resultant water vapour is separated from contaminants and impurities. The condensate then falls down due to gravity and pure water drops get collected in the condensate channel. The solar still working principle is shown in Fig. 2.

The performance of solar still is the amount of water distilled collected per day in the basin (liter/m^2/day).The productivity of solar still depends on the climatic, design and operational parameters. Climatic parameters are solar radiation intensity, wind velocity, ambient temperature, relative humidity, etc. The design parameters include water depth, insulation, cover material, its thickness and inclination, evaporation area. The operational parameters are feed water preheating, water salinity. This study focuses on effect of design and climatic parameters on the productivity of solar stills.

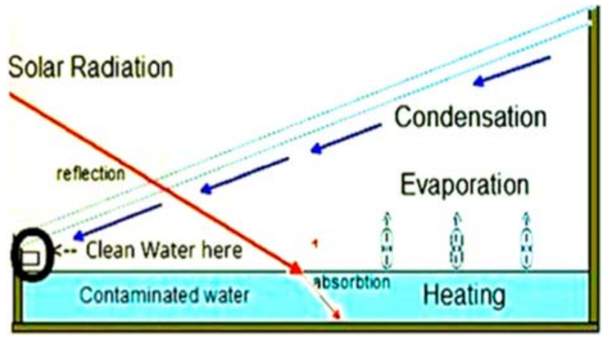

Fig. 2 Sketch of Solar Still Working Principle [2]

II. PERFORMANCE PARAMETERS OF A SOLAR STILL

A. Effect of Climatic Parameters on the Productivity of a Solar Still

1) Solar Radiation Intensity

The increase in solar radiation increases the distillate output [3]. The increased solar radiation increases the temperature difference between water mass and the condensing cover and hence increases the productivity of solar still. Solar still work on heating, evaporation, and condensation, therefore if solar radiation decreases, heating of water mass decreases which further reduces the evaporation rate and output of solar still. Therefore, the condensing cover material should be properly selected as it has a major role in the absorption process of solar radiation, thereby affecting the performance output of the system **[4]**.

Periodic Variations of Solar Radiation & Still Output is shown in Fig. 3. It was observed that the intensity of solar radiations is high from April to September and it is highest during May and June; hence the productivity of solar stills is high during these months [5].

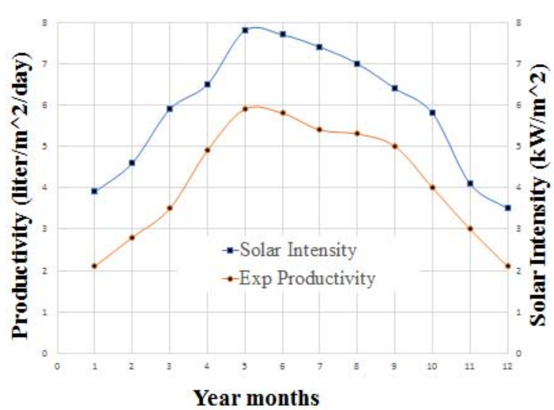

Fig. 3Periodic Variations of Solar Radiation & Still Output [1]

Fig. 4 shows that the solar still output is directly affected by solar radiation intensity **[6].**The maximum amount of solar radiations is obtained between 11:00 to 14:00 hours which increases output of solar still and exactly at 13:50 hours, a maximum output observed is 0.5 liters/m^2/hr.

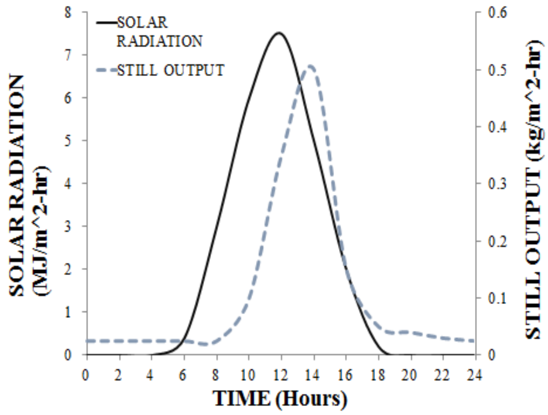

Fig. 4Effect of Solar Intensity on Still Output [7]

2) Ambient Temperature

It has been found out that, increase in ambient temperature increases the productivity of solar still (Fig. 5). The ambient temperature increases, the temperature difference water basin and condensing cove, thus increasing the evaporation rate and hence the output **[8]**. According to the work done by Hinai et al. **[9]**, it was observed that an increase in the productivity by 8.2% by increase in ambient air temperature by 10 °C - 12 °C.

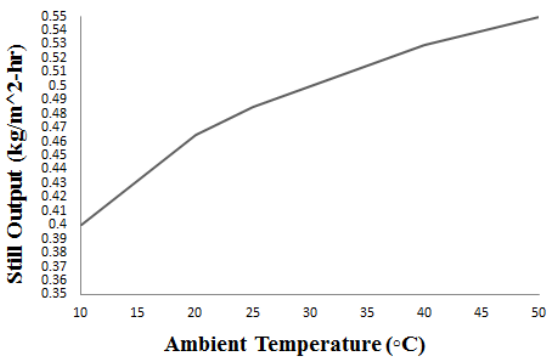

Fig. 5Variation of Ambient Temperature vs Solar Still Output [7]

3) Wind Velocity

As the wind velocity increases, the coefficient of heat transfer from the condensing covers to the surrounding increases. This increases the temperature difference between water mass and cover, which in turn enhances the natural circulation of air inside the still. Blowing winds increases the production rate by lowering the temperature of the cover and thus increasing the condensation rate **[10].** Hence, the upper surface temperature of the cover is important as it greatly affects the solar still output.

The daily output of a solar still is observed to increase as wind speed increases to a certain velocity [11]. The effect of wind speed on solar still productivity is shown in Fig. 6. The maximum daily yield was obtained at minimal heat capacity of basin water. El-Sebaii **[12]** showed the effects of wind speed on the output of active and passive type stills and concluded that the output increased with the wind velocity.

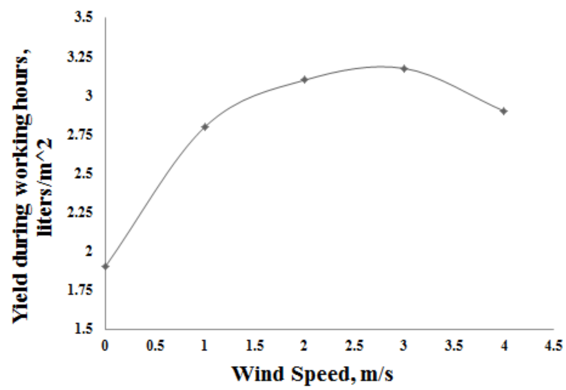

Fig. 6Wind Speed vs Solar Still Output [2]

4) Relative humidity

Relative humidity is a meteorological parameter, it cannot be controlled but it also has an effect on the solar still output. Koffiet al. **[13]** studied that variations in humidity were noted from 40% up to 65% as illustrated in Fig. 7. Also, it has been found that increase in relative humidity leads to the increase in solar still distillate output **[14], [15].**

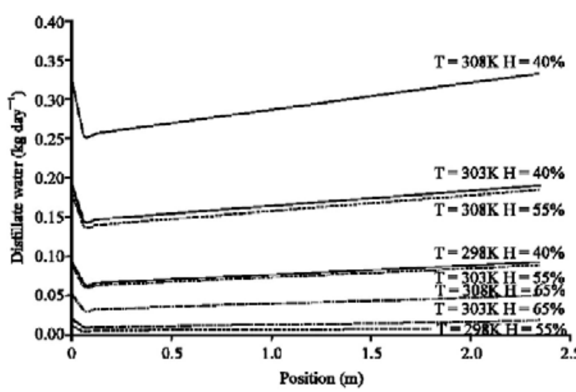

Fig. 7Relative Humidity vs Solar Still Productivity [7]

B. Effect of Design Parameters on the Productivity of Solar Still

1) Evaporation Area

The increase of evaporation area increases the rate of evaporation in a solar still, i.e., solar still output is directly proportional to the surface area of a solar still **[16]**, shown in Fig. 8.

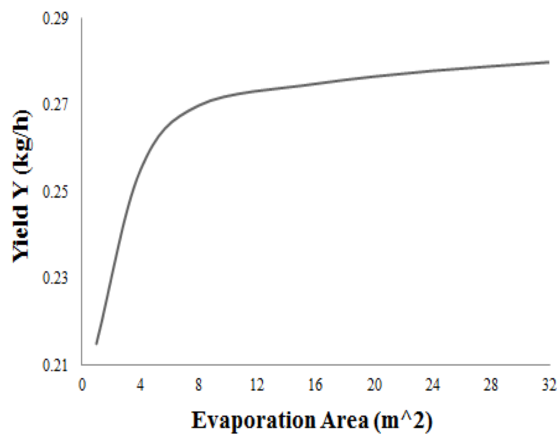

Fig. 8Variation of Evaporation Area on Solar Still Output [7]

Stepped solar still enhances the evaporation rate by increasing the evaporation area. The evaporation area is increased by using wicks, jute cloth, sponge, rubber or some other similar items **[17], [18]**. The total output was improved by about 80% by using sponges, fins, and wick. Another study was done by Velmurugan et al. **[19]**, who used fins, sponge, and pebbles in stepped solar stills with to increase the evaporation area. It was noticed that there was an increase in water mass temperatures and hence increase in evaporation rates. The results showed that the still yield was increased in comparison to the conventional stepped solar stills. This is because pebbles increase the volumetric capacity that helps to retain a huge amount of thermal energy in the still basin.

2) Water Depth

It was observed that solar still yield decreases with increasing water depth. When water depth increases, the volumetric heat capacity of water also rises. This tends to decrease the water mass temperature, thus lowering the temperature difference between water mass and condensing cover, further lowering the output of the still **[20], [21]**. The evaporation rate of solar still is in inversely proportion to the depth of water in the still basin. Therefore, in order to obtain high distillate output, the depth of water in the still should be kept at an optimum level.

In a study carried out Khalifa et al. **[22],** changing water depths i.e., 1, 4, 6, 8 and 10 cm were tested for their effect on the distillate output. It was observed that, with the increase in water depth the output was reduced to 46%. But, during the night, the production output was found to increase with increasing water depth and thereby aided to the total production.

Furthermore, in a study, optimal depth of 4 cm was found to give an optimum solar still output. Moreover, it is recommended to have water depth ranging from 2 to 6 cm **[9]**, as shown in Fig. 9.

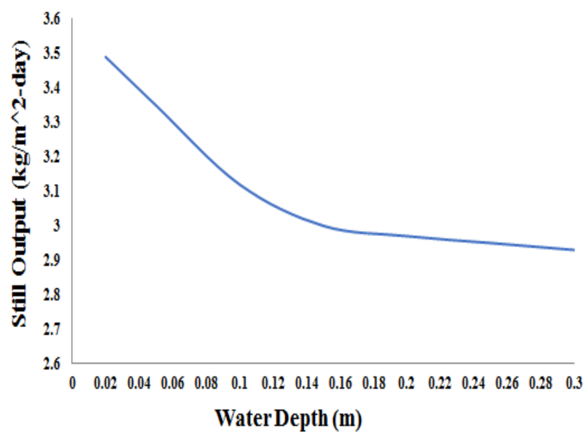

Fig. 9 Results of Distillate Output for Varying Water Depth [7]

3) Condensing Cover Material, Thickness, and its Inclination

Condensing cover material helps to increase the efficiency of solar still. The cover should be able to absorb the maximum amount of solar radiations incident on it and should reflect the only minimum of these radiations. It should be able to transmit as many radiations as possible to heat the water in the basin in order to enhance the condensation.

It has been observed that copper gives higher distillate output due to its high thermal conductivity as compared to glass & plastic [23] as shown in Fig.10.

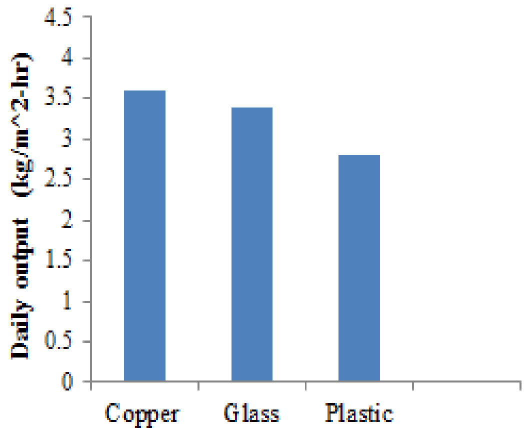

Fig. 10 Daily Output for Various Condensing Cover Material [2]

The effect of various thicknesses of glass cover that range from 2mm - 6mm for passive type solar still and for solar still accompanied with flat plate collector is shown in Fig. 11.

The slope of the condensing cover is directly effect on the solar still productivity. The cover angle should be sufficient such that the amount of condensed water runs easily to the condensate channel without reflecting back too much of the received solar radiations. A suitable cover angle facilitates easy flow of water drops into the channel, thus maximizing the absorption of solar radiation and also helps to insulate the exterior surface of the cover to reduce heat losses. it is favourable to keep the condensing cover angle between 20° to 45° to achieve maximum solar still output [22,24,25].

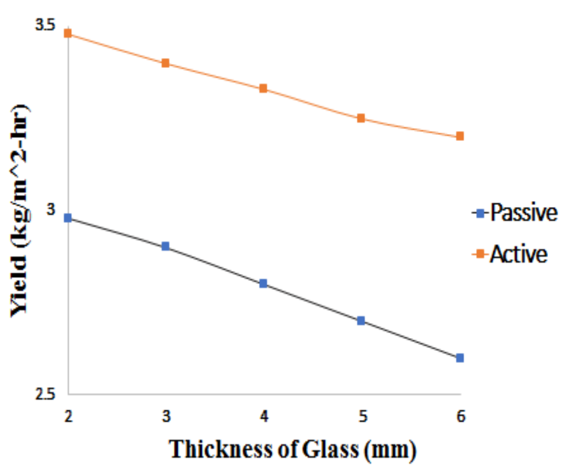

Fig. 11 Output of Different Glass Cover Thickness [2]

4) Thermal Storage Materials and Additives

As the temperature of the air inside the still rises, the air volume on the top of basin water reaches the condensing cover due to buoyancy forces caused by density variation due to the difference in temperature between the cover and water surface. The production capacity improves as thermal capacity of a solar still system increases for various solar intensities. The production capacity also increases when the latent heat of condensation is recovered **[26]**.

The condensing cover must permit the transmission of solar radiation and release as much heat as possible to the surrounding to ensure condensation. Thus, increase in the thermal capacity increases water mass temperature in the basin and thereby enhances the evaporation efficiency. **[27, 28].**

The various materials that can be used for the base of a solar still can be plastic, metal sheets, copper, aluminium or steel with high thermal capacity [29]. The thermal conductivity of steel (k = 48 W/m-K) is low as compared to aluminium (k = 200 W/m-K,) and copper (k = 400 W/m-K, respectively). But, steel is usually preferred due to its low cost even if its thermal capacity is relatively low. Some other materials such as concrete cement, galvanized iron sheets or fiber reinforced plastic (FRP), black polycarbonate can also be used as a basin bottom for the solar still. These materials act as absorbents for solar radiation and as non-adsorbing materials for water, thereby increasing the basin temperature in order to improve the productivity.

5) Insulation

Insulation is another important parameter that affects the solar still productivity. Insulation is provided with the aim that it absorbs maximum solar radiation that is required to evaporate water and for the thermal energy transfer. It is usually provided at the bottom or side walls, but bottom insulation is important. This is because it helps to prevent the loss of heat to the environment. It is observed that 6 cm-thick insulation layer can increase the productivity up to 80% due to a higher still temperature **[30]**.

Various insulating materials such as air gap, glass wool, hay, sawdust etc. can be integrated with stepped or conventional solar still. It has been observed that, the productivities were higher by 74%, 82%, 126%, and 130%, respectively for solar stills provided with insulation than the productivity of non-insulated solar still. Hence insulation is necessary for solar still productivity.

III. CONCLUSION

The climatic parameters include solar radiation intensity, ambient temperature, relative humidity, wind velocity etc. which are obviously not under our control. Whereas the design parameters include the evaporation area, water depth, condensing cover material and its thickness, cover angle etc. which can be easily controlled and hence can help to increase the productivity of solar still.

- Solar still productivity increases with increased solar radiation.
- Still output is proportional to the ambient temperature.
- Wind velocity also has direct proportion with the solar still output. Blowing winds increase solar still distillation by lowering the temperature of the cover and hence increases the rate of condensation. Hence, any wind obstacles near solar still cover has a negative effect on its output.
- The productivity of solar still increases with the increase of evaporation area.
- Solar still productivity decreases with the increase in the water depth because as the water depth increases, the volume of water and hence the volumetric heat capacity of water increases, thus lowering the evaporation rate.
- Condensing cover material should be transparent, less sensitive to reflection and should have high thermal conductivity. Copper, glass, plastic, and steel are most preferred materials.
- The lower the thickness of condensing cover, greater is the transmissivity and absorptivity of incoming solar radiation and hence higher solar still productivity.
- It is favorable to keep the condensing cover angle between 20° to 45° to achieve maximum solar still output.
- Materials such as concrete cement, galvanized iron sheets or fiber reinforced plastic (FRP), black polycarbonate can also be used as a basin bottom for the solar still which act as absorbents for solar energy.
- Insulation is provided with the aim that it absorbs maximum solar radiation that is required to evaporate water and prevent the loss of heat to the environment. An air gap, glass wool, hay, sawdust etc. can be used as insulating materials.

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