A technique used to improve the solar still performance for solar water desalination: A Review

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Abstract: Water is the basic necessity of life for survival. India has only less than 1% of fresh water available that used in domestic purpose, agriculture, industrial etc. In day by day due to increase the pollution of water the India survive lack of fresh water. Solar still is the simple method to convert the saline water converted into clean water. The main drawback with conventional basin type solar still is that the output is very law. In this review different methods are used to develop the various design of solar still for enhancement in productivity of solar still.

***Index Terms* - Phase Change Material, Solar Still, Distillate Output**

1 INTRODUCTION

A need for quality drinking water has become one of the prime demands for all living beings for their survival. Although the available water sources are plenty in nature on earth only 1% of water is readily available for drinking purpose and the remaining 97% of saline water, 2% in the form of glaciers and polar ice caps are unsuitable for drinking purpose. Animals and the human being need safer drinking water to avoid dehydration, as dehydration kills humanity faster than starvation. Water that apparently looks drinkable can contain harmful microorganisms, which could lead to illness or even death if consumed.

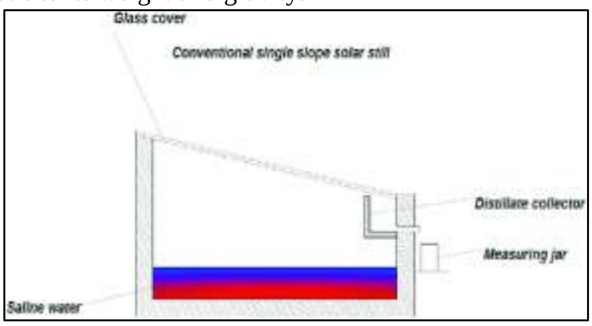
Due to rapid population growth and industrial developments, the need for quantum of drinking water has increased. So far, the possible natural way of getting drinking water is from rivers, lakes, wells, etc., which must be purified as they may contain harmful microorganisms and mineral contents. And the purification process involves namely sand filtration, chlorination and boiling. India comprising of 18% of total world population has only 4% of water sources available to serve for Indian community. Annual per capita of water available in the world has decreased from 6042 m3 during 1947 to 1816 m3 in 2001 and subsequently to 1545 m3 in 2011. The latest survey has predicted that, this water availability will be further reduced to 1340 m3 by 2025 and 1140 m3 by the end of 2050.

Moreover, as a major source ground water of 431 billion cubic meter as a major source for drinking and domestic purpose and nearly 690 billion cubic meter of surface water for irrigation purpose are utilized. Sources from Indian ministry of water resources, United Nations, UNICEF reported that nearly 90% of the water discharged from rivers does not meet the environmental norms. And nearly 65% of rainfall goes into the sea as waste. Beyond domestic and industrial sector, the next major user of water is the agricultural sector.

Solar desalination appears to be the easiest and cheapest method of producing potable water. For a very small scale of getting fresh potable water, solar desalination appears to be the best method. Majorly many review papers have concentrated only on the prospective design configuration. Basin type solar still is one of the breakthroughs of the 20th century where many researches are carried out to augment the fresh water production. For augmentation purpose, many used coupling methodologies with flat plate collectors and parabolic trough collectors, which makes the system cost uneconomical for people in the rural areas.

Basin type solar still

Basin type solar still is the most traditional and conventional method of getting fresh water utilizing solar energy. The schematic view of a conventional single slope single basin type solar still is shown in figure. Saline water is fed into the basin, and an inclined glass cover is placed over the basin. Solar radiation heats up the water inside the basin to make it evaporate from the top layer. The evaporated vapor inside the still rejects its latent heat through the cover for condensation to attain thermal equilibrium with surroundings. Since the cover is inclined, the condensed water makes droplets on the cover, and the droplets slide through it to the distillate collector due to the smooth cover surface. Also, there is a fact that the water forming larger droplets falls back into the basin itself due to its weight and gravity.



Several researches are carried out to augment the performance of single basin solar still in the 20th century. Last decade many authors identified the change in geometry of the basin. Various integrations are made on the solar still for economic viability. There are several factors identified from the basin type solar still and discussed in brief by several researchers. The efficiency of the solar still depends upon the following important parameters: -

- Tilt angle of cover plate
- Depth of water

- Feed water flow rate
- Cover plate temperature
- Orientation of solar still
- Convective heat transfer from cover plate and side walls
- Design of structures and shapes
- Solar tracking
- Coating on basin
- External enhancement like heat pipe, coolers.
- Solar still is categorized in two classes as passive type and active type solar stills. Malik et al. (1982) [1] explored the researched the passive type solar desalination and later Tiwari et al. (2003) [2] investigated the position of both active and passive systems of solar distillation. They resolved that passive type solar stills are more cost-effective to deliver drinkable water in contrast to active solar stills. Among solar stills, the simplest and cheapest desalination systems are passive type single sloped and double sloped systems. Solar stills can to clean adulterated water comprising of salt present up to 10,000 ppm (part per million) [3]. Solar desalination is an economical, effective and environment friendly technology. The simplest and least expensive solar still is passive type solar still. The production of drinking water through passive type solar still relies on environment and some further constraints such as still body, positioning, slope of condensing glass cover, depth of water and vapor leak proofing [4]. Passive solar still further classified on the basis of type of glass cover used as single slope solar still and double slope solar still. But nowadays some new designs are also available that are used along with single slope and double slope solar stills.

There are several ways to improve performance of solar still. Utilization of dual slope solar still is one of them. Using dual sloped glass cover, condensation of evaporated water from basin increases which results in raised distilled water output. Other ways to increase distilled output are use of high conductive material as absorber plate, adding nanofluid in basin water, attaching wick material with absorber plate and utilizing extended fins for higher heat transfer.

The characteristics of solar still can be stated as follows.

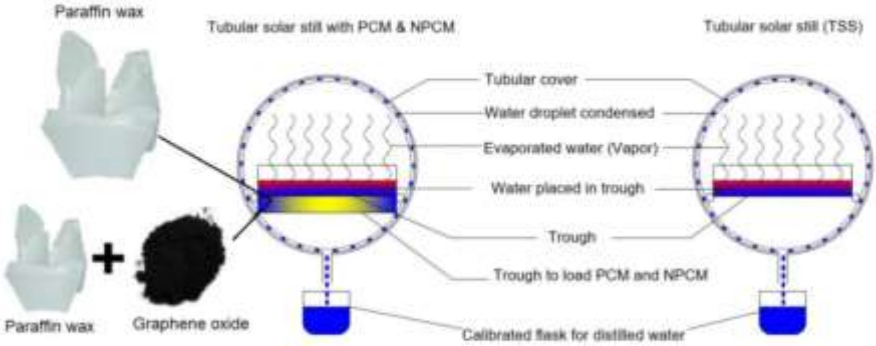
- The simple conventional solar still is more economical than active solar distillation system to provide drinking for the domestic applications.
- Single slope solar still collects more radiation as compared to double slope solar still.
- Lower condensing cover angle yield is more compared to higher condensing cover angle.
- Solar still productivity mainly depends on temperature difference between water and glass.
- The effect of water flow over the glass cover has a significant effect on the heat capacity of water mass in the basin.
- The still consist of a vertical conical shaped blackened cotton wick (representing absorbing/evaporating surface) with good capillarity is increasing the yield.
- Energy storage medium increases the solar still productivity and efficiency.
- The use of black paint raises the daily production and the efficiency of the solar still up to 10%.
- Solar still in grouping with greenhouses can be proposed to deliver theoretically practical system suitable for dry areas.
- The optimum flat plate collector slope is 20° and the glass cover slope is 15° for a active solar distillation system
- The active type solar stills are more appropriate for industrial appliances like distilled water for trading, extraction of essence from different seeds and green leaves, use in batteries, chemical laboratories etc.

2 RESEARCH WORK

The production capacity of a simple type still is very less. This makes the system highly uneconomical. Numbers of methods are available to improve the effectiveness of the still. Depend on the methods used to enhance, the stills are passive and active type solar still. In active type of stills, additional condensers or collectors are used. In passive type stills either simple modification will be done inside the still or some materials are used in basin along with saline water. Enormous works have been carried out by researchers to improve the production capacity of the still by adopting different techniques.

Hitesh Panchal,Kalpesh Patel(2019) The use of various phase change material and they have potential to Increase distillate output.Phase change material are used to increase Distillate output not only during daytime but also Nighttime.

A.E.Kabeel(2020) Experimental study on tubular solar still using graphane oxide nanoparticles in phase change material for fresh water production for efficient results.



The evaporative heat transfer rate coefficient of tubular solar still, tubular solar still with pcm and pcm with nanoparticles are discussed here.

Its observed that the maximum EHTC occurs during afternoon. The yield is depending on the mass transfer during evaporation and depends on the temperature difference between glass cover and basin water. The influence of nanoparticles in the pcm enhanced the evaporation rate during sun shine, peak and off sunshine hours as compared to TSS-PCM and TSS-NPCM. The evaporative heat transfer rate is 43.66w/metre square at the average radiation 629 w/metre square.

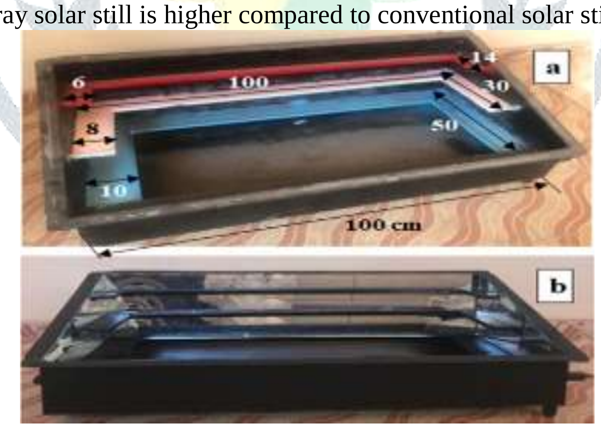
The increase in temperature of NPCM by 17% during the off-sunshine hours, the hourly fresh water yield is increased to about 20% as compared to TSS with pcm.

The tubular solar still with phase change material and nanoparticles are performed. The TSS with NPCM is improved the thermal conductivity compared to PCM without nanoparticles. The use of PCM with nanoparticle are improved the basin water temperature and evaporation rate.

A.S.Abdullah,F.A.Essa,Habib Ben Bacha,Z.M.Omara(2020) for improving the output of tray solar still used the phase change material with nanoparticles.

The tray solar still with paraffin wax as a PCM and copper oxide nanoparticles.

The total fresh water yield of the tray solar still is higher compared to conventional solar still.



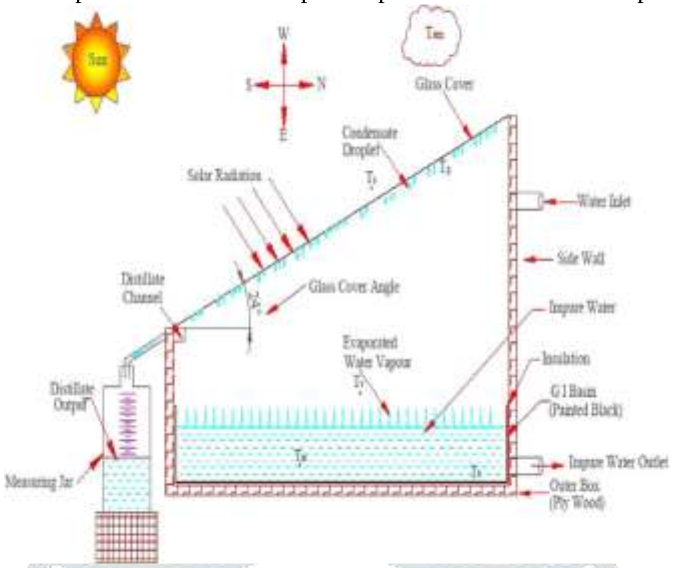
The tray solar still with internal reflector had a distillate more than the reference distiller. Its because of the high evaporation caused by the evaporative surface area of the tray distiller compared to that of the traditional distiller.

The total freshwater yield of the reference and tray distiller with reflector was 2200ml and 3450ml respectively with an improvement percentage of 57% for tray distiller compared to the reference still.

The tray solar still evaporation rate and condensation rate are improving when nanoparticles is used because the heat transfer coefficient is better when nanoparticle are used.

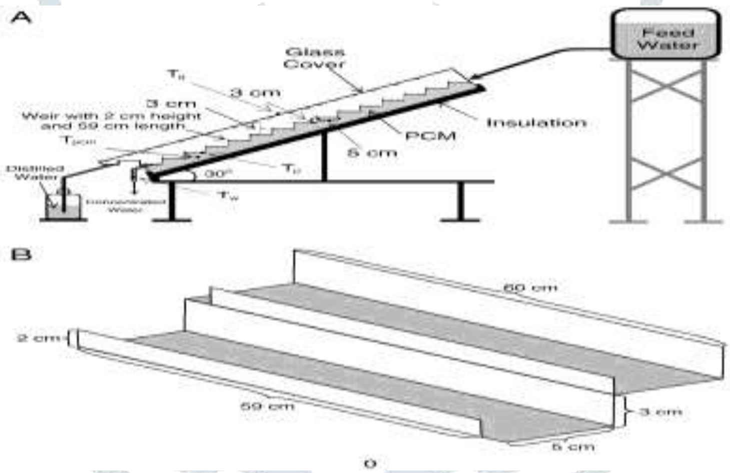
For a given cover material and thickness, when the solar incidence angle is in the lower range, transmittance is higher and the reflectance is lower. For a lower glass thickness, the absorption is lower (Duffie and Beckman 1991) [5]. The inclination and direction of inclination of the cover depend on the latitude of the place (Tiwari et al 1994, Singh et al 1995) [6] [7]. For lower latitude places double slope facing north and south direction still is preferred. Since, for lower latitude regions, the sun rays are close to normal on south facing cover for a part of the year. For remaining part of the year, sun rays are close to normal on north facing cover. The cover with inclination equal to latitude angle will receive the sun rays close to normal throughout the year.

But for the solar still, the cover inclination helps to collect the condensate water using collecting tray at the bottom. If the inclination is less, there is a possibility of fall in drops to basin before it reaches the tray. The condensate mass accumulates when it slides down along the bottom surface of the cover. The surface tension should equalize the weight of the condensate during sliding down. The rate of accumulation of condensate mass depends on rate of evaporation and condensation. Rate of evaporation depends on intensity of solar radiation. Hence, the angle of inclination is optimized with early average variation of solar azimuth angle and solar intensity of the place. Solar still with cover plate inclination from 10 to 50 was tested (AboulEnein et al 1998) [8]. Tiwari (2005) [9] conducted indoor experiments on experimental still with various cover plate slopes and found that a higher yield was obtained with an increase in temperature for a 30° slope compared to 15° and 45° slopes of the condensing cover.



For places with latitude higher than 20, single slope still is preferable. For north latitude places the single slope still with south facing cover and for south latitude places, still with north facing cover are used (Fath et al 2003) [10]. If the double slope still is used for higher latitude places, only one side of the cover will receive the sun rays and other side will be on the shadow side for sun rays.

M. a. F. T. Dashtban(2011) Thermal analysis of a weir-type cascade solar still integrated with PCM storage for improving performance of solar still.



Designed a weir cascade solar still with latent heat thermal energy storage system to improve the productivity. They used18 kg mass of paraffin wax (2 cm thickness) as heat storage system. The daily theoretical productivity was found to be 6.7 and 5.1 kg/m2. day, for the still with and without PCM, respectively. The results showed that the productivity of the still with PCM was, theoretically, 31% higher than that of the still without PCM.

E.-S. A. a. E.-B. E. Aboul-Enein S(2019) Investigation of a single-basin solar still with deep basins for Experiments with deep basin reveal that, the productivity of the still decreases with an increase in depth of water.

A. A. A.-G. F. A.-H. a. A. F. El-Sebaii(2019) Thermal performance of a single basin solar still with PCM as a storage medium for efficient desalination of solar still. The results of the study showed that the productivity at daylight decreased as the mass of PCM increased; but overnight productivity and day productivity were increased significantly with the increase of PCM mass due to the increased amount of the stored heat within the PCM.The evaporative heat transfer coefficient is increased by 27% when using 3.3 cm thickness of stearic acid beneath the basin liner.

The heat transfer through the cover plate increases with decrease in thickness and increase in thermal conductivity. Experimental results show that a solar still with glass cover plate of 3 mm thickness gives about 16.5% more production than the cover with 6 mm glass thickness (Abdulrahman Ghoneyem and Arif Ileri 1997) [11]. Glass is the preferred material for cover, since it has higher solar transmittance for various angle of incidence and long service life. The glass surface wets with condensed water and allow film condensation at the bottom surface that results in less loss in transmittance. The other cheap transparent plastic materials do not possess the above required qualities (Malik et al 1982) [12]. Dimri et al (2008) [13] strongly justifies using glass as a condensing cover for solar still.

The function of the basin is to receive the entire radiation passing into the still through the cover with minimum reflectance loss and conduction loss to surrounding. It has to store the excess energy during the sun shine day time to release the energy when the radiation is not available during day time due to clouds and in night (Malik et al 1982) [12]. The evaporation of water depends on the natural convection circulation of air mass inside the still, which is the function of temperature difference between the water and the glass. This temperature difference is the driving force for the circulation of air (Cooper 1979) [14]. Also, the evaporation rate of water depends on the area of exposure of the basin water with air mass in circulation inside the still (Kwatra 1996) [15].

The basin water depth is having significant effect on the productivity of the still. Investigations show that the water depth is inversely proportional to the productivity of still (Cooper 1979, Rajesh Tripathi and Tiwari 2005) [9] [14] . Experiments with deep basin reveal that, the productivity of the still decreases with an increase in depth of water during daylight and the reverse is the case of overnight production (Aboul-Enein et al 1998) [16].

As water depth increases the volumetric heat capacity of the basin, reduces the water temperature for given solar radiation input. But the temperature and production rate are uniform and will not be affected by sudden solar intensity variation due to cloud passing for a short period of time. The heat stored in the water mass is released during the absence of sunshine and production continuous even during night (Tiwari and Tiwari 2006) [17]. For a shallow basin still, the volumetric heat capacity of water is less and the temperature of water will be high. This will increase the evaporation rate and productivity of the still. But any change in solar radiation will have immediate effect on water temperature and production.

Some black materials can store more amount of heat energy and increase the volumetric heat capacity of the basin in addition to increasing the basin absorption. Glass, rubber and gravel are such materials having these properties (Nafey et al 2001, Abdel-Rehima and Ashraf Lasheen 2005). Experimental results show that black rubber with 10 mm size increases the productivity of the deep basin still by 20% and black gravel with 20-30 mm size increases the productivity of a shallow basin still by 19%.

The productivity of solar stills may be improved by using storage systems. These storage systems could be sensible or latent heat systems. This adopted method utilizes the heat dissipated from the bottom of the still. The latent heat thermal energy storage systems have many advantages over sensible heat storage systems including a large energy storage capacity per unit volume and almost constant temperature for charging and discharging modes. Recently, many papers have appeared concerning the use of PCMs as storage media integrated with some solar thermal energy systems; such as that considered the use of phase change materials as storage media in solar stills [18].

Recently, many papers have appeared concerning the use of phase change material (PCM) as storage media integrated with some solar thermal energy systems for the purpose of fresh water production during the night and improve the productivity of the systems.

Al-Hamadani and Shukla [19] examined a single slope solar still with myristic acid as phase change material (PCM), the melting point and latent heat of myristic acid is 50-54 ℃ , 177 kJ/kg respectively. The daily productivity and efficiency were affected by mass of PCM and basin water under indoor simulated condition. Basic energy balance equations are modelled to expect the temperatures of water and glass, daily distillate output and efficiency of the single slope solar system with PCM. It was found that daily productivity and efficiency of the system increased with the higher mass of PCM and lower mass of basin water, but daily productivity was reduced when the amount of PCM exceeds 20 kg. The new solar still with PCM has increased the day distillate output by 35-40 % and the night distillate output by 127%.

Swetha and Venugopal [20] have added a heat reservoir under the linear of a single slope solar still using Lauric acid with (41-43) ℃ melting point as (PCM) and sand as sensible heat storage. It was observed from numerical calculations that 36% increase in collection of fresh water when the still used Lauric acid and 13% increasing when the still used sand as heat reservoir.

Kantesh [21] used bitumen (melting point:54 ℃) as PCM to enhance the productivity of single basin double slope solar still and to store the solar thermal energy in the form of latent heat. The efficiency of the solar still without PCM was about 25.19% while in presence of PCM (Bitumen) it was 27.%.

El-Sebaii [22] presented a mathematical model for single basin solar still with and without PCM under the basin liner of the still. Numerical calculations were carried out using stearic acid as PCM (melting point: 52℃), on a typical summer day. The effect of mass of the PCM on the daylight productivity, overnight productivity, daily productivity and efficiency of the still for different masses of basin water was studied. The results of the study showed that the productivity at daylight decreased as the mass of PCM increased; but overnight productivity and day productivity were increased significantly with the increase of PCM mass due to the increased amount of the stored heat within the PCM. During discharging of the PCM, the convective heat transfer coefficient from the basin liner to basin water is doubled; thus, the evaporative heat transfer coefficient is increased by 27% when using 3.3 cm thickness of stearic acid beneath the basin liner. Therefore, on a typical summer day, a value of day productivity of 9.005 L/m2 /day with a daily efficiency of 85.3% has been obtained compared to 4.998 L/m2 / day when the still is used without the PCM.

Ramasamy and Sivaraman [23] have designed a cascade solar still with and without PCM for water purification. The system mainly consisted of stepped absorber plate connected with PCM sub-system and single slope glass plate. Paraffin wax was used as Latent heat storage material due to its feasible general and economic properties. The hourly productivity is slightly higher in the case of solar still without PCM during sunny days. The maximum obtained total productivities were 1.85 and 1.680 l/day for 0.76 m2 area of still without and with use of PCM, respectively. The disadvantages of using PCM are corrosion when in direct contact with metal piping or housings. It was concluded that the inclined solar stills have higher efficiency than conventional solar stills due to smaller air gap, but the total productivity with PCM was less than that without PCM, so the latent heat storage enhanced the productivity just at night hour but it is not good for this system. The performance of still mainly depends on water flow rate and solar intensity.

Dashtban and Tabrizi [24] designed a weir cascade solar still with latent heat thermal energy storage system to improve the productivity. They used18 kg mass of paraffin wax (2 cm thickness) as heat storage system. This heat storage system was placed under the absorber basin plate to keep the operating temperature of the still high enough to produce distilled water during the lack of sunshine, especially at night. Theoretical models were also developed for the still with and without PCM, and the calculated results were compared with the experimental data. Moreover, other important parameters affecting the performance of the still were investigated, such as water level on the absorber plate and distance between water and glass surfaces. The daily theoretical productivity was found to be 6.7 and 5.1 kg/m2. day, for the still with and without PCM, respectively. The results showed that the productivity of the still with PCM was, theoretically, 31% higher than that of the still without PCM.

3 Conclusion

Maintaining minimum water depth in the basin increase the productivity of solar still. The increase in depth of water decrease the still productivity.

Latent heat storage material is enhancement in performance of solar still.

The heat energy from the sun may be stored using absorbing material and phase change material. The still can produce distillate during off-shine hours. Paraffin wax and stearic acid may be used as pcm.

Phase change material with nanoparticle is improved the output of solar still. The nanoparticle are enhancing the thermal properties of pcm.

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