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Review Paper-Development and Testing of Solar Stills

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Abstract - *Solar stills are the simple devices which are used to produce distilled water. These devices work on the simple principle of evaporation and condensation. As the name itself suggests that, these devices make use of solar energy which is abundant and available at free of cost in nature. The solar stills reviewed in this paper are having efficiency 30-40% and productivity is limited to 3-5 litre/m2/day. These solar stills are advantageous in many ways such as easy construction, dependent on renewable energy, maintenance free operation, lower unit cost of production. Researchers have been taking continuous efforts to improve efficiency and performance parameters of different solar stills, some of which are reviewed below.*

***Key Words*: Solar Still, Distillation, Solar Radiation, Brackish Water.**

1. INTRODUCTION

Water is a basic necessity of a man along with food and air. Fresh water resources usually available are rivers, lakes and underground water reservoirs. About 71% of the planet is covered in water, yet of all of that 96.5% of the planet water is found in oceans, 1.7% in the underground, 1.7% in glaciers and the ice caps and 0.001% in the air and vapor and clouds. Only 2.5% of the earth's water is freshwater and 98.8% of that water in ice and groundwater. Less than 1% of all freshwater is in rivers, lakes and the atmosphere. Distillation is one of many processes available for water purification, and sunlight is one of several forms of heat energy that can be used to power that processes. To dispel a common belief, it is not necessary to boil water to distill it. Simply elevating its temperature, short of boiling, hastens the distillation process it also can force unwanted residue into the distillate, defeating purification.

Desalination refers to the removal of salts and minerals from brackish water. Solar desalination is a technique to desalinate water using solar energy. There are two basic methods of achieving desalination using this technique; direct and indirect. Sunlight may provide heat for evaporative desalination processes, or for some indirect methods, convert to electricity to power a membrane process. . Solar distillation uses solar energy to evaporate water and collect its condensate within the same closed system. It can turn salt or brackish water into fresh drinking water (i.e. desalination). The structure that houses this process is known as a solar still and although the size, dimensions, materials, and configuration are varied all solar stills works on same principle.[1]

A solar still distills water, using the heat of the Sun to evaporate water so that it may be cooled and collected, thereby purifying it. They are used in areas where drinking water is unavailable. There are many types of solar still, including large scale concentrated solar stills and condensation traps (better known as moisture traps amongst survivalists).

fig.1.1 shows the diagram of conventional solar still. It consists of a basin with insulation, glass cover, distillate channel, water inlet and water drain. Initially basin is filled with brackish water and still is kept in sunlight.

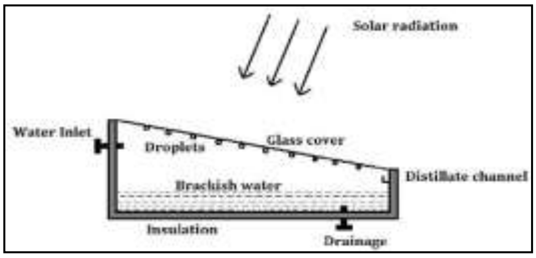

Figure 1.1 Schematic diagram of conventional solar still [2]

A proper insulation is provided from outside of a basin to avoid heat losses from water to surrounding. The basin is provided with the glass cover above it. As the solar radiations heats the water, water inside basin gets evaporated leaving behind the impurities. These water vapours are then condensed on the glass cover and collected through distillate channel and can be used for intended purpose. A water inlet port is provided to maintain a constant water level in the basin and a drain plug is used to remove impure water from the still. A conventional solar still works on a simple evaporation-condensation technique in a single basin.[3]

2.LITERATURE REVIEW

It is well known that the water problem, being either lack or pollution of it, has become very large in many areas of our planet, especially in desert, in traditionally dry regions and in modern industrial areas. Also, due to increase in population and industrial sectors in our surroundings, there is scarcity of clean and potable water. One-third of the global population (2 billion people) lives under conditions of severe water scarcity at least 1 month of the year.

Desalination is one of the methods used for purification of water in recent years. It is a process used to separate fresh water from brackish water; various methods are available for the production of the fresh water like multistage flash process, vapour compression process, reverse osmosis process, ion exchange and electro-dialysis process, etc. All these processes are used to produce fresh water but their production cost is higher for small amount of fresh water. On the other hand, we can use the solar still for the production of the fresh water or distilled water at low cost as solar energy is freely available to us. In any conventional simple horizontal solar desalination still, solar energy heats a mass of water at the basin, which acts as an evaporating zone and evaporates its surface water layer. By means of natural convection, the water vapour reaches the transparent glass's inner surface, which is at relatively lower temperature than the water vapour and inclined to the horizontal at an angle equal to the latitude of the place and condenses on it.

In 2017, S. Varun raja et al. made an attempt to find out effect of water capacity on internal and external heat transfer for a solar distillation system.

The performance analysis is achieved by energy balance of the still. Fig.2.1 shows the energy transfer processes for various components in the still, which have a direct effect on the output. For simplifying the analysis, the following assumptions are considered:

- No vapour leakage in the solar still.
- Level of water in the basin is maintained constant.
- System is in a quasi-static condition.
- Condensation that occurs at the glass cover is a film type.
- Heat capacity of the absorbing material is negligible.
- Heat capacity of the glass cover and the insulation material are negligible.

The construction of Single basin solar still is shown in fig.2.1 the basin is made of galvanized iron sheet of 0.5 × 1 m2 with height of 288mm, and 1.4 mm thickness. The inner surface of basin is painted with black paint to absorb the high amount of solar radiation incident on them. The condenser of still is made of glass with 4mm thickness and inclined at an angle 10° with horizontal. Glass covers have been framed with wood and sealed with silicon rubber bush.

The impure water filled in the basin, absorbs the solar radiations. Due to this, the water temperature increases. This increase in temperature causes evaporation of water. The vapours start moving upward and gather around the inner surface of the glass cover. As the temperature of the glass cover is below the temperature of the water vapours, the vapours start to condense on the glass. The inclination of the glass causes the water droplets to flow down towards distilled water collector.

During the experiment; ambient temperature, water temperature, basin temperature, solar radiation intensity, inner wall temperatures, outer wall temperatures, bottom side temperature and wind velocity was measured every 60 minutes. The hourly productivity of fresh water is collected in a container. The daily productivity is obtained as a summation of day and night productivity.

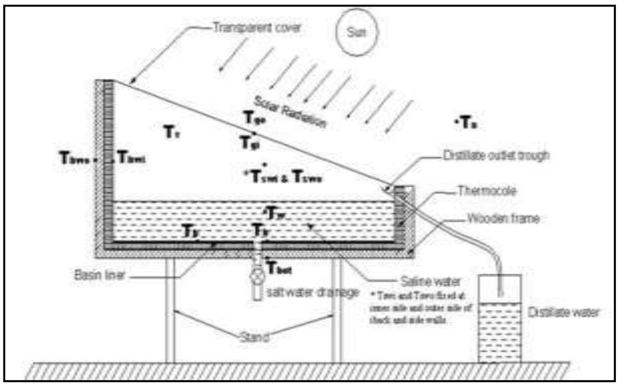

Figure 2.1 Schematic diagram of experimental setup of conventional solar still. [4]

In this study, following conclusions can be obtained:

• In lower levels gives more yields from 9.00hrs to 13.00hrs, then productivity decreases till evening whereas higher water levels starts its productivity slowly from 9.00hrs – 13.00 hrs. and then steadily increases till the end of the day's experiment. Between 18.00hrs and 9.00hrs (next day), the productivity is more in higher water levels than the lower water levels. As the water depth decreases from 60mm to 10mm the productivity increased by 12%.

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• The largest temperature (83.9°C) of the solar still is recorded at inner wall surfaces and is almost constant for all water levels and the next largest temperature is recorded at vapour side (78.8°C). The lowest temperature is recorded at the bottom side of the still (32.2°C).

• The maximum hourly yield (0.320 kg/hr.) is obtained from lower water depth (10mm) between 12hrs-13hrs and the lowest maximum hourly yield (0.204 kg/hr.) is from higher depth (60mm) at 16hr-17hrs. The maximum hourly yield of solar still is based on the capacity of basin water which is started from middle afternoon for lower levels and vice versa. [4]

In 2017 Mohommad Al-harahsheh et al. enhanced the solar still by using external solar collector and Phase Change Material (PCM).

The PCM is used to store solar thermal energy collected by the system at daytime as latent heat, to provide heat during night time thus continuous operation. Water in the basin and the PCM were heated by direct solar radiation and by hot water flowing through a coil heat exchanger, fixed in the basin, heated by a solar collector. The produced water vapor from the basin condensed on the inner side of the water cooled double-glass cover. The condensate was withdrawn as fresh water. The effect of hot water circulation flow rate, cooling water flow rate, and basin water level on the amount of fresh water produced were studied. The production rate of desalinated water was proportional to the increase in ambient temperature and hot water circulation flow rate. There also is an optimum value of cooling water flow rate (about 10 ml/s) at which the unit productivity was the highest. Additionally, as the water level in the basin increased the productivity decreased. The unit was capable of producing 4300 ml/daym2, of which about 40% was produced after sunset. The economic evaluation reveals that such units are feasible mainly in remote areas.

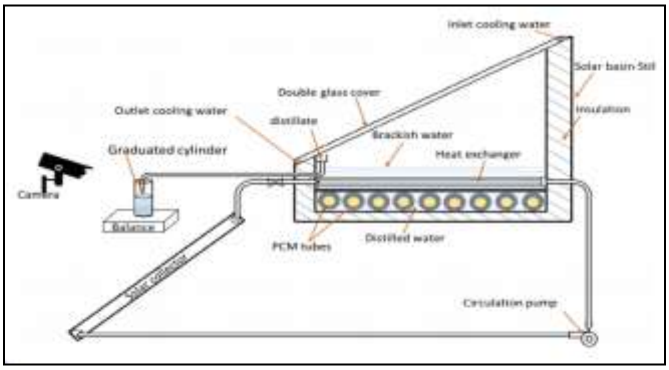

Figure 2.2 Schematic diagram of an experimental setup of solar still with PCM. [5]

It consists of four main parts: solar basin, solar collector, double glass cover, and tubes filled with PCM (Sodium Thio-Sulfate Penta Hydrate (STSPH)) immersed in distilled water. It is made from stainless steel and painted black to improve absorption of the solar energy. Water to be distilled is placed at the bottom of the basin to a certain level. The basin has a double glass cover made of two glass layers placed 1 cm apart. Coolant water is passed through the double glass cover to lower the inner glass temperature. Lowering the glass temperature, increases vapor condensation and increases the driving force between the evaporation and condensation processes taking place in the same chamber. The condensate slips on the inner glass surface and falls into an inclined tray attached to the inner glass and ends in a collection tube, and then it is withdrawn as fresh water. Every tube was filled with the PCM material (Sodium Thio-Sulfate Penta Hydrate (STSPH)). This inorganic salt was selected to be used in this study as PCM material because of several attractive features including its high latent heat of fusion per unit volume, small volume change at melting point, availability and low cost compared to other competitive PCM materials.

The operation of the unit involves two processes heat charging and heat discharging. The heat charging involves heating water in the basin directly from solar irradiation and storing energy in the PCM during daytime and the heat discharging involves extracting energy from the PCM to heat the water during night time. Thus, achieving continuous operations during the 24 hours period. During the charging process, throughout the daylight, water in the basin is heated by two means: directly by the absorbed solar energy passing through the glass cover and by the heat received from the solar collector. As the water basin temperature increases from an initial value often around the ambient temperature to the melting temperature of the PCM and beyond, energy is stored in the PCM as sensible heat first with the PCM being in the solid phase, then as latent heat, and possibly as sensible heat. At the same time, as water in the basin is heated, evaporation takes place.

Therefore, PCM is a good material to supply energy during night time period without any change in thermal behavior. Also, the productivity is higher, compared to other stills. The PCM is more effective at lower masses (lower level) of water in the basin. Changing the level of water affects the unit productivity. Generally, the water production is around 4300 ml/daym2 approximately. [5]

In 2018, Kuldeep H. et al study a comprehensive review on the pyramid solar still both experimentally and numerically

The main objective of the pyramid solar still is to increasing productivity of conventional solar still. The pyramid solar still has attractive advantages over the conventional solar still and other types of solar still. Hence, it required lot of research and study for the development of the pyramid solar still.

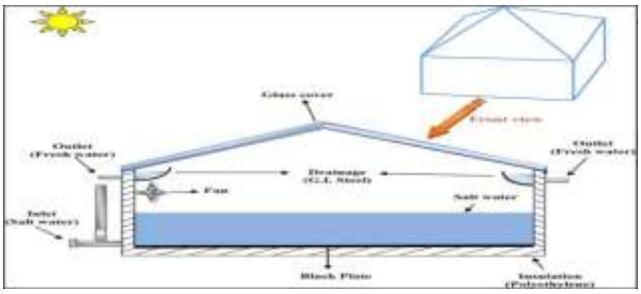

Figure 2.3 Schematic diagram of active pyramid type solar still. [6]

The basin area of 0.96 m × 0.96 m × 0.15 m was kept same for the all three models. In the double basin still, upper most pyramid shape glass cover and glass cover which form the upper basin acts as condensation surface. Similarly, in triple basin solar still, additional condensation surface was provided by the two glass sheets forming the upper and middle basins. Sides of pyramid shaped cover were inclined at an angle 45°. The observations are noted on hourly basis for the solar intensity, wind velocity, distillate output and temperatures of ambient, inside glass surface, basin and water. the effect of forced convection on the performance of pyramid solar still and found that approximate 25% increase in fresh water production for forced convective system (with fan) in compare to free convection. The fan creates continuous turbulence of air lying on water surface which takes evaporated water vapor away from the water surface which results in faster evaporation rate.

Following results are observed in this design:

- Pyramid shaped solar still is more efficient over conventional solar still.
- Pyramid type solar still eliminates the requirement of tracking mechanism and reduces the shading effect of side wall.
- Various parameters like water depth, glass cover temperature, ambient air velocity, inlet saline water temperature; movement of water vapor inside the solar still and materials of various components (Basin, Insulation and Transparent cover) has significant effect on the performance of still. Hence, all parameter must be optimized for the maximum performance
- Quantity and quality of saline water (in terms of depth of water) affects the performance of pyramid solar still as similar as that for conventional solar still.
- In case of forced convective heat transfer in pyramid solar still, daily distillate production increases with increase in the Reynolds number and wind velocity.[9]

In 2018, Mehrnaz Naroei et al. investigated the influence of photovoltaic thermal collector to stepped solar still experimentally and numerically.

The fresh water production efficiency of stepped solar stills is higher than the basin solar stills. Because in stepped solar stills, the thickness of water layer is less and the evaporation rate is much higher by connecting the PVT water collector to stepped solar still, following observations can be observed:

- The PVT water collector provides the electrical power needed to pump saline water in stepped solar still.
- The PVT water collector by preheating the water at the entrance to the stepped solar still would lead to the increase of the saline water temperature and improving the fresh water production efficiency.

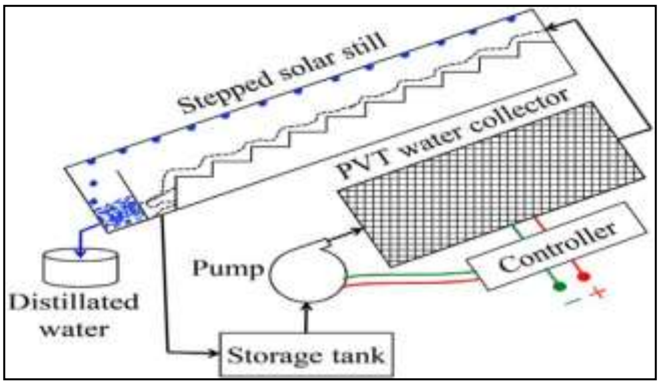

Figure 2.4 Schematic diagram of experimental setup of stepped solar still with PVT water collector. [7]

A schematic diagram of stepped solar still connected to PVT water collector and its components are shown in Figure.2.4

According to Figure.2.4, water is pumped into the PVT collector and then preheated by receiving heat from the PV cells. Pre-heated saline water evaporates by receiving solar radiation in the stepped solar still. Evaporated steam is condensed on glass cover and fresh water is produced. In addition to supplying pumping power, the PV cells provide extra power for other uses.

The experimental setup includes stepped solar still, PVT water collector, pump, storage tank and other equipment. In the stepped solar still, the absorber consists of six steps. Each step has a length of 58cm, width of 13cm and height is 5cm. So, the absorption surface area and effective evaporative surface is 0.63m2 and 0.45m2 respectively. Condenser glass has a thickness of 5mm and an area of 0.52m2. PVT water collector is a 90W silicon mono-crystalline PV module connected to a solar collector. PVT water collector surface is equal to 0.77m2.

In this experiment it is observed that, connecting the PVT water collector to stepped solar still increases energy efficiency by more than 2 times and a 20% increase in freshwater productivity. PVT water collector in stepped solar still in addition to providing electrical power of pumping, can supply about 1.06kW/day electric power during day for other uses. [7]

3. CONCLUSION

In the world of competition and energy crises, solar still proves the best option to meet the growing need of potable water, as it utilize the renewable, unlimited, pollution free and free of cost solar energy. So many researches have been carried out in this field for continuous innovative and efficient revolution.

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