Design of Low Density Polyethylene Hemispherical with Wick Solar Still for Arid Regions

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Abstract: Deficiency of potable and irrigation quality water severely affects quality of life in arid and desert areas. This precarious situation can be at least partially mitigated by extensive use of solar desalination technology, which is technically well matured. Development of solar desalination relied on increasing efficiency, which needs to be shifted to appropriate design of the system. In this paper a novel design of low cost maintenance free hemispherical solar still is proposed for desalination in remote areas with low literacy rate. In field condition, hemispherical solar still of area 0.65m² is evaluated. Low Density Polyethylene (LDPE) sheet of 400 micron thickness replaces expensive and difficult to maintain glass and acrylic top cover. A separate arrangement is included for analyzing the wick effect in still. Various parameters are recorded. Distillate yield was typically found to be 2.2 liters/m², much less than 3.5 liters/m² but robustness of design and the low cost makes it more appropriate for remote areas.

Key Words: Hemispherical design, LDPE dome, Solar still, Remote area

1. Introduction

Availability of potable and irrigation quality water has been limiting factor in the development of remote arid and desert areas. Solar distillation technology has potential to increase the availability of potable and irrigation quality water, where brackish and/or saline water is available. However, focus in the development of solar distillation technology development has been on increasing the efficiency of the system. Design became complicated over the years with every attempt to increase the efficiency of the system. Maintenance of the system also became complicated and needed technical man power and materials not available locally. Rural community in remote areas needed systems, which are robust, easy to maintain and uses locally available material.

There are several designs of solar stills found in literature. Different techniques have been attempted to enhance the evaporation and condensation rates (Kalidas et al., 2008; Velmurugan and Srinath, 2011). Concept of integrating solar photovoltaic system (SPV) with solar thermal energy (STE), known as Photovoltaic Thermal (PVT) has been investigated by Kumar and Tiwary, 2008; Kumar et al., 2010; Singh et al., 2011. It has improved system performance without increasing complexities Waste heat utilization is also attempted by integrating the source with solar stills. The thermal and electrical energies from external collector are used to increase the basin water temperature and make the system self-sustain respectively. Yadav et al. (1996) had fabricated and tested simple asymmetric line-axis compound parabolic concentrating still. The performance of the inverted absorber solar still, a combined system of a slope solar still and a curved reflector under its basin, had been studied for various depths and climatic conditions by several researchers (Tiwary and Suneja, 1998; Abdul-Wahab et al., 2010). Present experimental study is based on an attempt made by designing a hemispherical solar still along with wick effect using a low density polyethylene sheet top covers.

High efficiency designs of hemispherical stills are made of glass or acrylic top-cover, which was difficult to replace if damaged. This difficulty is removed by forming a mesh of iron covered by Low Density Poly Ethylene (LDPE). Still’s efficiency and yield is recorded in field condition. Results indicated three grey areas - leakage, reduced solar insolation and reduced collection efficiency. Infield condition, LDPE and its interface with basin could not be made leak-proof. Besides, iron mesh reduced solar insolation. LDPE cover was also not very smooth for condensed water for sliding down to the outlet area. Hence good percentage of distillate dropped down to the basin. It affected overall distill water collection efficiency. 60% of conventional hemispherical yield could be only achieved. However, the design was robust since, it can be fabricated locally and can be easily maintained. Its local acceptability was found to be very high. It can be further improved to achieve even better efficiency in future designs without introducing any complications.

2. Design of Hemispherical Solar Still

A cross section representation of a hemispherical solar still with wick effect is shown in the Figure 1. The top cover of the solar still is made of low density polyethylene sheet of thickness 400 microns. Normally, plastic cover is more economical, user friendly and easy to replace. Iron rod of 5mm diameter is bent

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as parabolic shape and joined like an umbrella. This bent iron rod is welded on the circular ring of radius 96 cm. This formed the hemispherical basket type structure. Low density polyethylene sheet is pasted on the hemispherical shaped iron rod. To increase the collection efficiency of condensed distillate on the LDPE, iron mesh is kept above the LDPE. Such an arrangement allowed the iron mesh to remain in contact with ambient air. At the same time, iron mesh shielded the LDPE from damages from external sources, to a large extent. Another advantage of pasting the low density polyethylene at inner side avoids contamination due to rust formation of metal rod. The basin is made up of locally available wood. Dimension of the outer box was kept at 30cm (height) × 110cm × 110cm. The bottom of the enclosure is filled by sawdust of 10cm. The side gap between the enclosure and basin is also filled with saw dust. Distillate collection segment is separately shown in Fig. 1. Evaporated water is condensed at the top cover of the hemisphere and thereafter collected at the water collection channel. The outlet water is taken out through the tube fixed at four places.

2.1. Wick Arrangement

A separate arrangement is made to ascertain the wick effect in the present LDPE design. In this design, water storage basin is made up of stainless steel. Its diameter was fixed at 18cm and depth, 20 cm. An inlet is provided at the basin to maintain water depth in the basin, which is coated black from inside. The capacity of water stored in the basin was approximately 5 litters. The above mentioned water storage basin is attached with a metal sheet which covers the remaining entire surface with a slope 11°. This metal sheet acts as an absorber and it is coated black.

One end of the wick from the water tank is spread circularly over the absorber and the other end of the wick is immersed in the water over the absorber. The sheet covers to a distance between water tank and wall of water collection segment. A separate outlet is provided for water collection. The photograph of hemispherical solar still with wick effect is shown in Figure 2.

2.2. Experimental setup

The performance of the still on clear sunshine days have been recorded from 09:30 HRS to 17:30 HRS. The basin is filled with 3.75 liters of saline water at 0930 HRS. Pre-calibrated thermocouples are fixed at the appropriate places and the readings are recorded. A thermometer with an accuracy of 0.1°C is used to measure the ambient temperature (Ta). The air temperature inside the still, wick temperature (Twick), water temperature inside the still (Twater), solar radiation (I), top cover temperature (Ts), and the amount of distilled water collected at the outlet are recorded. The distilled water collections are recorded at regular intervals. The efficiency of the hemispherical wick type solar still is calculated using,

$$\eta = \frac{M \times L}{I \times A \times t}$$

Where, M is the mass of distillate (kg), L is the latent heat of vaporization, A is the area of the still (m²), I is the solar radiation (W/m²) and t is the time (sec).

3. Results and discussion

Experimental data of hemispherical solar still with wick is recorded on typical normal sunny days. Variation of solar radiation (I), Water temperature (Twater), Wick temperature (Twick), ambient temperature (Tampl), plate temperature (Tplate) and amount of distilled water collection are recorded. Instantaneous efficiency and overall efficiency are computed from these recorded parameters.

Figure 3, curve (a) shows the variation of solar radiation with time. Morning radiation was recorded as 603.86W/m². Maximum value of solar radiation was recorded as 1086W/m². At 17:30 HRS, solar radiation was recorded as 220W/m². The average radiation received was 728W/M2. Fig 3, curve (b) shows the variation of ambient temperature with respect to time. The ambient temperature remained in the range of 30.4°C and 34°C. Condensation of water vapour is proportional to the temperature difference between top cover and wick or plate temperature. Variation of water
temperature, air temperature, plate temperature and wick temperature with respect to time are shown in Figure 4. Basin water temperature varied between 29.2 and 65.3°C. Similarly, the temperature variation for air inside the still, temperature of the absorber plate and wick temperature over absorber plate are recorded. It remained in the temperature range of 36-68.2°C (air), 40 - 81.6°C (absorber plate), and 31.1-71.3°C (wick). The difference between absorber temperature range and wick temperature range highlights the effect of wick.

Temperature variation of absorber (Fig. 4) reached a maximum value of 81.6°C and remained range bound in 72.6 - 74.7°C during the mid-sunshine hours. Hence, this temperature difference caused higher evaporation. The large temperature difference was observed between wick and basin water. The rise in wick temperature is only due to higher rate of absorption of radiation by the absorber. Higher absorber temperature, in turn, is an important parameter to stimulate more evaporation due to capillary rise through wick. Another advantage of this type of still is increased of surface area of the absorber due to 11 degree slope, which is extended to the entire perimeter of the basin. The hemispherical shape of the top cover also plays a major role in more condensation, because the surface area of the hemisphere is more than the single slope. It also facilitated increase in contact surface area for ambient air, resulting in increased condensation. The thickness of the sheet is also low. So the ambient air cools the cover quickly and supports for more condensation.

Figure 5, curve (a) shows variation of distilled water yield with time. The quantity of water collection is appreciable, given the simple design. This is because of increase in direct utilization of radiation absorption. The radiation received by the absorber and wick is immediately transferred for evaporation of moisture content of the wick. At the same time, the moisture level in the wick is retained to constant level by continuous supply of water from the water storage basin by capillary rise. Water collection from the still is 1.23L/day between 9.30 am and 5.30 pm and 0.2L is collected as yield rate during night. Total yield in 24 hours from the still was 1.43L/0.65m$^2$, i.e., 2.2L/m$^2$.

Fig. 5, curve (b) shows the instantaneous efficiency of the still with respect to time. The variation of the efficiency is in the range of 5.83% to 46.28%. The average efficiency of the still is 22.85%. Increase in efficiency with respect to time is due to wick effect. Thermal energy transfer is instantaneous and efficient. Wick temperature in the plate decreases slowly after sunset. It is evidently seen from the decrease in ambient temperature at 5.30 pm in Fig. 3. Temperature difference increases wick efficiency, which shows significant improvement in productivity. This type of still is designed with a low cost materials and is maintenance free. The LDPE sheet can be changed frequently. The LDPE sheet is more stable with UV radiation than other polymeric materials.

4. Conclusion

Hemispherical wick type solar still of area 0.65 m$^2$ was fabricated and tested in Coimbatore, India under actual field
condition. The designing cost of hemispherical low density polyethylene solar still is low to produce distilled water. The shape of the top cover and wick play a significant role to condense the water droplet and production of the distillate yield. The hemispherical shape formation for top cover arrangement of this type of still is difficult by using glass and other types of transparent acrylic material. The proposed still performance shows the significant result equal to conventional still. 22.85% efficiency is achieved from this still.

References