Performance Evaluation of Solar Still

Papi Reddy Peddireddi

August 30, 2022

PERFORMANCE EVALUATION OF SOLAR STILL

PAPI REDDY

ABSTRACT

Solar desalination is becoming increasingly viable particularly in a country like India that receives sufficient sunshine throughout the year and has long coastline. Solar still, a common device used for this purpose, is simple in principle and operation but suffers from low productivity. The objective of this work is to bring out the importance of different parameters affecting still performance and thereby improve the performance of the still. Thus, starting from 2.2 l/m^2 of average water produced in a day in case of a basic still geometry, final design of the still containing a passive condenser and fitted with a mirror produces 4.5 l/m^2 of water, which is higher than that reported in literature for the given geographical region.

Keywords: *solar still, desalination, minimum depth, passive condenser, mirror*

1. INTRODUCTION

Rapid industrialization together with population growth has resulted in an increased demand for freshwater. Presence of large volume of sea water provides both challenge and opportunity to obtain freshwater through the process of desalination. Though sea water desalinization involves a very high capital cost, it is becoming increasingly viable owing to the severe water shortage that 70% of the world population will face by 2025 and also because about 50% of the people live within 200 km of the sea coasts. If desalination is carried out using conventional fossil-based energy, the recurrent consumption not only makes the scheme expensive but also causes environmental pollution. On the other hand, for a country like India, in the tropical and sub-tropical regions, daily solar radiation is more than twice the global average [1]. Hence, solar desalination proves to be an attractive means of producing clean water using solar power. This forms the motivation behind the present work.

Solar desalination involving phase change can be of different types (multistage flash, multi-effect distillation, humidification-dehumidification, passive vacuum desalination, solar still, etc.). The present work focuses on the use of solar still which works based on the principle of greenhouse effect. In this approach, radiation from the sun evaporates water inside a closed chamber, covered with transparent sheet made of polymer or glass at a temperature higher than the ambient temperature. The water vapour, thus formed, condenses on the inside surface of the cool transparent top and produces droplets of water which are collected through channels outside the still. Figure 1 shows the working of a typical solar still.

Performance of solar stills are greatly affected by many factors, including the depth of water in the basin, thermal insulation and vapour leakage, shape and material of the still and climatic conditions like solar radiation, wind speed and ambient temperature. The main drawback of the conventional solar still is its very poor productivity (about 2-4 l/m^2 of water produced per day as mentioned by Kalogrirous [2]), and hence many efforts towards better designing of stills have been made in the past to improve the productivity. Al-Hayek and Badran [3] had used symmetrical and asymmetrical solar stills and found that the productivity of asymmetrical solar still is about 20% higher than the symmetrical one. They have also observed that, as long as depth of water is low, depth of water plays no significant role. Aybar et al. [4] had studied the performance of inclined solar water distillation system which produces fresh as well as hot water. It was found that the distillate output increased by 23% when black wick was used instead of the bare bottom plate. However, the hardness of the freshwater increased in the presence of wicks in comparison to the bare plate. Kabeel [5] had used basin type solar still with concave wick surface for evaporation and other sides of the pyramidal-shaped still for condensation and recorded an output of 4 l/m^2 in a day. Hansen et al. [6] have produced the maximum distillate of 4.28 l/day for a period of 12 hours using water coral fleece whose performance was found to be superior to other wick materials tested.

Literature survey discussed above shows that there has been a continual improvement as different design approaches have been pursued. However, it is also clear that there is scope for improvement of the design and operation of single solar still by systematically studying the different design options on a basic solar still design. This approach, which seems missing in the existing literature, is expected to bring out relative importance of different parameters in increasing the efficiency of the solar still and is likely to help arrive at a superior design. This forms the main objective of the present paper. Another objective of the work is to develop a low-cost, fully passive solution so that it can reach a larger section of the population, particularly in developing countries.

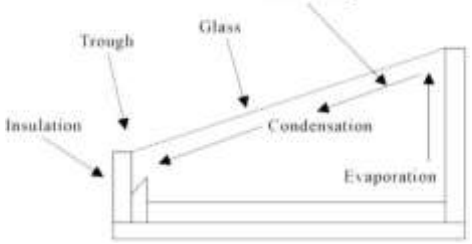

Fig. 1: Schematic of a simple basin-type solar still

In the next section, details of the experimental set up and methodology have been explained. That is followed by the presentation of results and discussion of the significance of the observed and measured data in Section 3.

2. EXPERIMENTAL SET UP AND METHOD

It has been mentioned in the previous section that several factors affect the performance of the solar still. Of these, some parameters like solar radiation, ambient temperature and wind speed are natural and hence ambient temperature and wind speed are monitored during the experiments. Other factors which affect the performance can be broadly linked with the geometry and construction of the still. Some of these parameters are the still size, shape and inclination angle, choice of bed material, depth of water, presence of condenser or a reflecting surface. For the ease of fabrication, flat, rectangular solar still was chosen as the test bed. Modifications are then added to this still to study effects of other parameters/design features.

A single-basin, glass-walled solar still has been designed and fabricated as shown in Fig. 2(a). The base is formed by an 8 mm thick square sheet of glass, which gives the still a footprint of 0.64 m^2. Below the plate, an 18 mm thick plywood board was used to support the base plate as well as to provide insulation. The top cover was made of a 4 mm thick glass plate placed at an inclination of 13° with the horizontal, corresponding to the latitude of Chennai as suggested by Sukhatme and Nayak [7] for ensuring maximum incident solar radiation. The top cover was supported by 6 mm thick vertical glass plates on all sides and RTV silicone sealant was used to prevent leakage. The collection channel was made of glass as well and was inclined at an angle of 5° so as to speed up the condensate collection and avoid tendency for water droplets to re-evaporate. The condensate is collected in a container placed atop a weight sensor and periodic readings are taken to determine the amount of water collected. Experiments were conducted between 9 am and 5 pm in the months of February till April when the ambient temperature varied between 34.4° C and 39.2° C and the wind speed was in the range of 0.8-5 m/s. Further details and exact daily variations of temperature and wind speed are given in the report by Pednekar [8]. The measured parameters recorded were air temperature near the top plate, basin water temperature, ambient air temperature and water mass collected. LM 35 sensors were used to measure the atmospheric temperature as well as the top cover and DS18B20 was used for recording water temperature. All temperature information was stored in a data logger.

Initially experiment was carried out with (a) charcoal and (b) sand bed to determine which one ensures a higher temperature rise. Figure 3 shows that charcoal had a higher temperature rise (peak temperature reached is 84° C, in the dry condition) in comparison to sand (76° C). Thus, in all other experiments reported in this paper, a charcoal bed was used. This geometry is termed as the "basic geometry" of the solar still in this work. Effect of condenser has been shown to be important in literature and a solar still fitted with a passive condenser was used in some of the experiments (Fig. 2(b)). In some experiments, a mirror was fitted with the solar still to reflect the incident sunlight on the water (Fig. 2(c)).

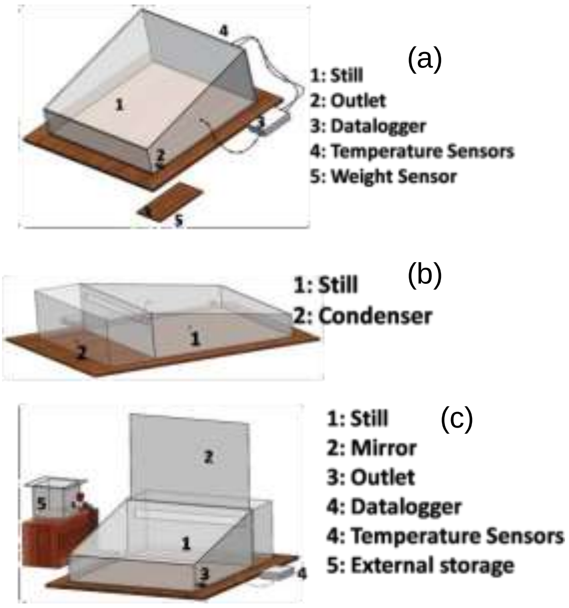

Fig. 2: Different designs of solar still

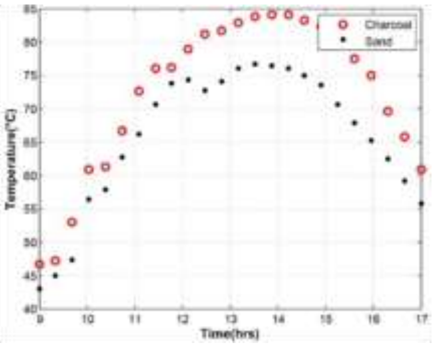

Fig. 3: Bed temperature in case of charcoal and sand

3. RESULTS AND DISCUSSION

It is shown in literature that, at the same solar radiation condition, lowering of water depth inside the basin results in increased evaporation [9] but, as mentioned earlier, Al-Hayek and Badran [3] had suggested that the influence of water depth is not significant. Hence, in this work, at first a suitable water depth is arrived at (Fig. 4). Fig. 4(a) shows the diurnal variation of productivity for 5 mm depth of water. Also shown is a comparison with theoretical prediction calculated on the basis of the work by Dunkle [10]. Since the effect of charcoal is not considered, the theoretical estimation underpredicts the behaviour. From Fig. 4(b) it is clear that there is ~9% and ~16% deterioration when depth is increased from 5 mm to 7 mm and 9 mm respectively. Hence in the remaining work, depth is maintained at 5 mm. The reason for improved behaviour at a water depth of 5 mm is clear from Fig. 5 which shows the difference between water temperature and that at the top surface. It is seen that though the temperature difference is same at the beginning of the experiment, lowest water depth of 5 mm reaches highest temperature fastest, while 7 mm one takes 2 hours longer time to reach similar temperature and that for 9 mm never reaches the levels attained by the other two depths.

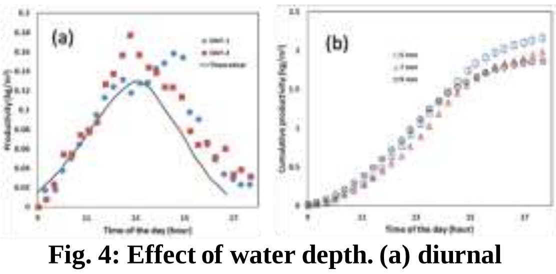

Fig. 4: Effect of water depth. (a) diurnal variation of productivity at 5 mm depth, (b) comparison of cumulative productivity for different depths

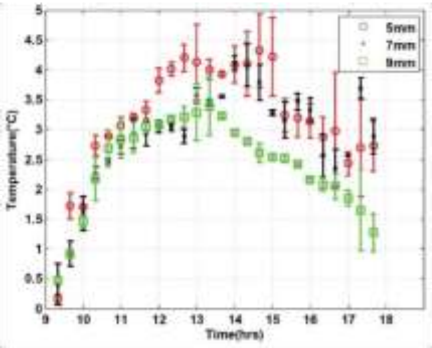

Fig. 5: Difference between temperature of water and that on the top plate for different depths of water

The next design enhancement attempted was the introduction of a condenser. Yeh et al. [11] have shown that significant improvement could be achieved by reducing still pressure and by continuous removal of water vapour. However, this implies sacrificing the concept of passive basin still and hence, in the present work, a passive condenser shown in Fig. 2(b) was used. Condenser used in the present work occupies 35% of the still volume and no attempt was made to optimize the geometry. Figure 6 shows the effect of un-cooled and cooled passive condenser and Fig. 6(a) shows a typical performance of an un-cooled condenser. It is clear that though cooled passive condenser is ~5% more effective than un-cooled one, the un-cooled device itself registers a ~54% improvement over the basic still.

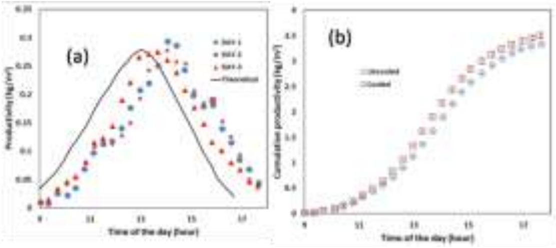

Fig. 6: Effect of condenser. (a) diurnal variation in case of un-cooled condenser, and, (b) comparison between un-cooled and water-cooled condenser

Effect of introducing an external mirror was found to increase productivity by ~21% but it also adds to the complexity and hence merely adding a mirror to the basic still is not an attractive option. Hence, a flow from an external storage was brought in to maintain the depth of water (Fig. 7(a)) and also the water-cooled condenser was utilized (Fig. 7(b)). It is seen that there is a significant improvement over the basic model and this fact is brought out clearly in Fig. 8. A comparison with Fig. 5 shows that, whereas for the base geometry the temperature difference is 4.5°C, in case of mirror with condenser and external water storage shows a difference of 9°C. Figure 9 shows an overall comparison of different design modifications and it shows that the highest production of water is about 4.5 l/m^2, which is higher than that obtained by Hansen et al. [6] using wick.

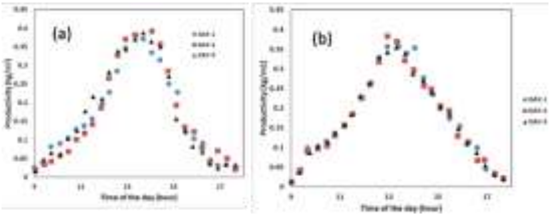

Fig. 7: Effect of mirror-fitted with the basic still geometry. (a) only external storage is added, and, (b) external storage and water-cooled condenser used

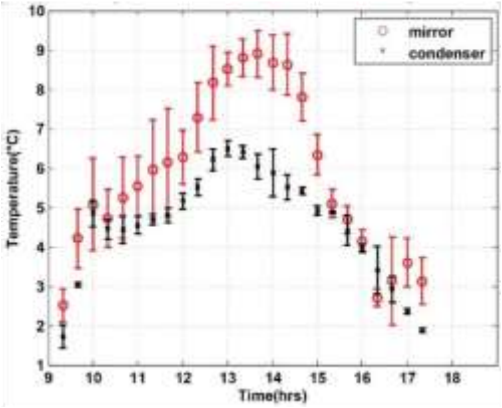

Fig. 8: Temperature difference between water and top plate in case of a mirror-fitted solar still and a mirror-fitted solar still where external storage and water-cooled condenser is used

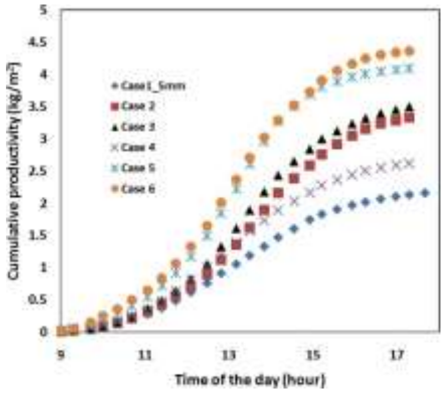

Fig. 9: Comparison of cumulative productivity for different cases reported in this paper

4. CONCLUSIONS

Conventional solar stills used for desalination suffer from low productivity and efficiency. In this paper a systematic experimental work is reported where roles played by different parameters and functional units like the depth of water, passive condenser, mirror and external flow are clearly brought out. It is shown that the basic solar still employed here is capable of producing 2.2 l/m^2 of water and the final recommended design can produce 4.5 l/m^2, which perhaps is higher than the highest productivity reported at least in this part of the world. For better utilization of solar energy it is provided arrangement to turn the solar still as per movement of sun.

5. ACKNOWLEDGEMENT

The authors thank Ms. Sonal Shandilya for rendering the drawings of the solar stills.

6.
REFERENCES

[1] Kalogirou, S., 1997, Energy, 22, 69-81.

[2]Al-Hayek, I. and Badran, O.O., 2004, Desalination, 169, 121-127.[

3]Aybar, H.S., Egelioglu, F. and Atikol, U., 2005, Desalination, 180, 285-289.

[4] Kabeel, A.E., 2009, Energy, 34, 1504-1509.

[5] Hansen, R. S., Surya Narayanan, C., Murugavel, K. K., 2015, Desalination, 358, 1-8.

[6] Sukhatme, S. P. and Nayak, J. K., 2008, Solar Energy: Principles of Thermal Collection and Storage, Third Edition, McGraw Hill, India.

[7] Pednekar, A. M., 2016, Performance evaluation of the different designs of the solar still", Dual Degree Project Report, Engg. Des. Department, IIT Madras, India.

[8] Tarawneh, M.S.K., JJMIE, 1(1), 23-29.

[9] Dunkle RV. Solar water distillation; the roof type still and a multiple effect diffusion still, International Developments in Heat Transfer, ASME. In: Proceedings of International Heat Transfer Part V. University of Colorado; 1961. p. 895.

[10] Yeh, H.-M., Ten, L.-W. and Chen, L.-C., 1985, Energy, 10(6), 683-688.