Asian Review of Mechanical Engineering
ISSN: 2249-6289 (P) Vol.7 No.1, 2018, pp.23-28

DOI: https://doi.org/10.51983/arme-2018.7.1.2437

A Review Paper on Techniques of Enhancing the Efficiency and Productivity of Solar Still

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***Abstract* - The present paper deals with a review on different techniques that improves the efficiency, productivity and performance of solar still. The different techniques are used separately to improve the performance of solar still. If we combine two or more different efficiency and productivity improvement techniques in a single unit of solar still then efficiency and productivity of solar still will absolutely improve. And the present work deals with effect of combining the two or more different efficiency and productivity improvement techniques that increases the performance of solar still.**
***Keywords:* Solar Energy, Thermal Energy Storage, PCM**

I. INTRODUCTION

Solar distillation is a relatively simple treatment of brackish (i.e. contain dissolved salts) water supplies. Distillation is one of many processes that can be used for water purification and can use any heating source. Solar energy is a low tech option. In this process, water is evaporated; using the energy of the sun then the vapour condenses as pure water. This process removes salts and other impurities. Solar distillation is used to produce drinking water or to produce pure water for lead-acid batteries, laboratories, hospitals and in producing commercial products such as rose water. It is recommended that drinking water has 100 to 1000 mg/l of salt to maintain electrolyte levels and for taste. Some saline water may need to be added to the distilled water for acceptable drinking water. Solar water distillation is a very old technology.

An early large-scale solar still was built in 1872 to supply a mining community in Chile with drinking water. It has been used for emergency situations including the navy introduction of inflatable stills for lifeboats. There are a number of other approaches to desalination, such as photovoltaic powered reverse-osmosis, for which small-scale commercially available equipment is available; solar distillation has to be compared with these options to determine its appropriateness to any situation. If treatment with polluted water is required rather than desalination, slow sand filtration is a low-cost option [12].

People need 1 or 2 litres of drinking water a day to live. The minimum requirement for normal life in developing countries (which includes cooking, cleaning and washing clothes) is 20 litres per day (in the industrialised countries 200 to 400 litres per day is typical). Yet some functions can be performed with salty water and a typical requirement for distilled water is 5 litres per person per day. Therefore $2m^2$ of still are needed for each person.

Solar stills should normally only be considered for removing dissolved salts from water. If there is a choice between brackish groundwater or polluted surface water, it will usually be cheaper to use a slow sand filter or another treatment device. If there is no fresh water then the main alternatives are desalination, transportation and rainwater collection. Unlike other techniques of desalination, solar stills are more attractive, the smaller the required output. The initial capital cost of stills is roughly proportional to capacity, whereas other methods have significant economies of scale. For the individual household, therefore, the solar still is most economic.

For outputs of $1m^3$/day or more, reverse osmosis or electro dialysis should be considered as an alternative to solar stills. Much will depend on the availability and price of electrical power. For outputs of 200 m^3/day or more, vapour compression or flash evaporation will normally be the least cost.

The latter technology can have part of its energy requirement met by solar water heaters. In many parts of the world, fresh water is transported from another region or location by boat, train, truck or pipeline. The cost of water transported by vehicles is typical of the same order of magnitude as that produced by solar stills. A pipeline may be less expensive for very large quantities.

Rainwater collection is an even simpler technique than solar distillation and is preferable in areas with 400mm of rain annually, but requires a greater area and usually a larger storage tank. If ready-made collection surfaces exist (such as house roofs) these may provide a less expensive source for obtaining clean water (see the Rainwater Harvesting Technical Brief) [12].

II. PERFORMANCE ENHANCEMENT

B. Selva Kumar *et al.* [1] analyzed the thermal performance of a "V" type solar still with charcoal absorber distilled water & collection output is estimated. The internal heat transfer and external heat transfer modes are studied. They observed that the overall efficiency of the still is 24.47%

without charcoal, 30.05% with charcoal, 11.92% with boosting mirror and 14.11% with boosting mirror and charcoal.

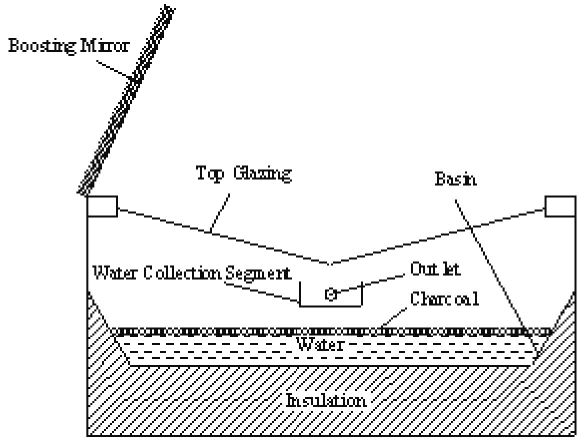

Fig. 1 Schematic diagram of "V" type solar still using a charcoal absorber and a boosting mirror.*[B.S. Kumar et al. / Desalination 229 (2008) 217–230]*[1]

In this experiment the performance of the still with the charcoal and boosting mirror is studied for the "V" type solar still. The presence of floating charcoal increases the absorption of radiation in the water and it results in increasing the evaporation rate. The boosting mirror concentrates the incident radiation over the basin area and it increases the evaporation and water collection.

Bharat Kumar Patil *et al.* [2] carried out an experimental investigation on a double slope single basin solar still using Phase changing materials like (paraffin wax) and Sensible heat storage elements like (black pebbles). By conducting experiments like black coated aluminum tray, with PCM, and with SHSE, the output obtained is observed to be 1100ml of distilled water when PCM (Paraffin wax) is used, 954ml when SHSE (Black Pebbles) is used and 795ml when black coated tray is used and black coated tray readings were kept as standard readings and remaining set of readings (with PCM and SHSE) were compared with standard readings and analysis is done by showing set of graphs and tables. Thus the percentage productivity observed in case of Paraffin wax and black coated tray is 30%, black pebbles and black coated tray is 18%, Paraffin wax and black pebbles is 13%.

B. N. Subramanian *et al.* [3] studied the important parameters affecting the performance of still such as depth of water, temperature of inlet water and water-glass cover temperature difference. The experimental results indicate that the still using waste heat recovery unit ensures low thermal losses, better heat preservation and improved rate of water evaporation. The results reveal that depth of water in the solar still is inversely proportional to the productivity of the still. The addition of finned-PCM heat recovery unit increased the inlet temperature of saline water closer to its saturated temperature which in turn reduces the amount of heat required to evaporate the water in the still and leads to a still with higher productivity and efficiency.

TABLE 1 COMPARISON OF COLLECTED DISTILLED WATER [BHARAT KUMAR PATIL ET AL. IJRMET VOL. 6, ISSUE 2, MAY - OCT 2016 ISSN: 2249-5762 (ONLINE)][2]

Type of Solar Still	Water output in ml	Percentage Productivity
Conventional Paraffin Wax (PCM)	795 1100	30%
Conventional Black Pebbles (SHSE)	795 954	18%
Paraffin Wax (PCM) Black Pebbles (SHSE)	1100 954	13%

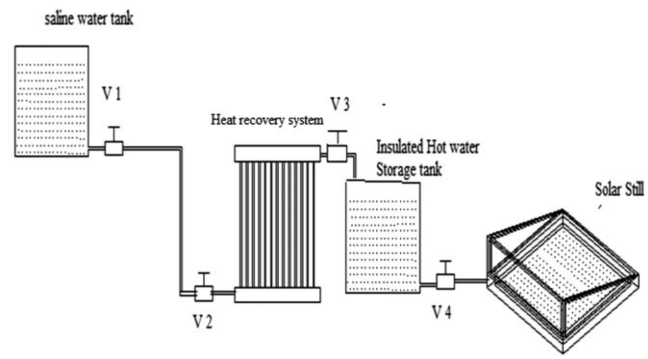

Fig. 2 Schematic of the experimental setup. *[B. N. Subramanian et al. /I J C T A, 9(37) 2016, pp. 545-553]*[3]

M.E. El-Swify *et al.* [4] theoretically analyzed and experimentally tested a solar still of double exposure. It is compared experimentally with other identical stills without modification (ordinary L-type) during a complete year. The concept of planer reflectors is introduced in this modification. It is found theoretically that the double exposure still gained much more daily energy than that of the ordinary one in winter and summer. Experimentally, it is found that the double exposure solar still has 82.6% more daily yield than that of the ordinary one in winter time, and about 22% in summer time.

A simple modification introduced to the ordinary L-type solar still leads to a considerable increase of productivity of fresh water. This modification is represented by using the back glass cover and the inner sides of the ordinary L-type still as internal reflectors. The concept of using the internal reflectors instead of outside ones leads to:

1. Increase in evaporator temperature (water basin) without increasing the outer surface temperature of the upper glass cover, upper condenser, which is recommended.
2.The cooling effect of the back glass cover, back condenser, is improved due to the higher temperature difference as compared to the ordinary one.

A. K. Singh *et al.* [5] they carried out an optimization of the orientation for higher yield of a solar still in terms of the glass cover inclination. The effect of water depth on the hourly instantaneous cumulative and overall thermal efficiency and internal heat transfer coefficient has also been studied. Numerical computations have been made for Delhi Climatic conditions.

A.A. El-Sebaii *et al.* [6] was designed and fabricated a single slope single basin solar still with baffle suspended absorber (SBSSBA) using locally available materials. The model uses the lumped system of analysis in which the system is divided into several elements, each of which was treated as a lumped system by itself.

The effects of vent area and water depth of the upper and lower water columns on the daily productivity of the still were studied. Comparisons of the performance of the SBSSBA and the conventional unit, the single slope single basin solar still (SBSS), have been carried out. It is found that the daily productivity of the SBSSBA is about 20% higher than that of the conventional still (SBSS). A single basin solar still with baffle absorber plate (SBSSBA) was constructed and investigated. Experimental and theoretical investigations were made during the period 1996-1997.

Adding a suspended plate within the basin water of a conventional single basin still decreases the preheating time required for evaporating the still basin water. During the night, the lower water column acts as a heat source for the upper one; consequently, evaporation of basin water is continued even after sunset which improves productivity. From the obtained results it may be concluded that the daily productivity of the modified still was found to be around 18.5-20% higher than that of the conventional unit when Av=0 and Av=0.025 m^2, respectively. The optimum position of the baffle absorber was found to be in the middle of the basin water and with the lowest mass of the upper water with and without vents, respectively. Good agreement between measured and calculated results has been obtained. The present mathematical model overestimates the daily productivity of the still only by about 8%. The daily productivity of the still decreases with increasing Av, thus, it is advisable to use the baffle absorber without vents.

Mohammed Farid *et al.* [7] were designed and fabricated a single basin solar still having area of 1.5 m^2 from galvanized steel sheet with an inclined glass cover. The unit was insulated with Staropor. Efficiency of solar still was found to be independent of solar radiations. An increase in productivity was observed with increase in ambient temperature and decrease in wind velocity.

The following main conclusions were drawn from this experimental investigation:

1. For the condition of small diffused radiation, the still efficiency was found to be independent of solar radiation.
2. The diffused radiation is an important parameter in evaluating still production and efficiency.
3. Wind velocity and ambient temperature have opposite effect on still efficiency.
4. The hourly measurements are particularly useful in evaluating the effect of some parameters, such as ambient temperature, on still efficiency.
5. The significant increase of still production with the decrease of water depth in the still is in agreement with the results reported in the literature.

Hiroshi Tanaka *et al.* [8] analytically investigated the effect of the vertical flat plate external reflector on the distillate productivity of the tilted wick solar still. They propose a geometrical method to calculate the solar radiation reflected by the external reflector and absorbed on the evaporating wick, and also performed numerical analysis of heat and mass transfer in the still to predict the distillate productivity on four days (spring and autumn equinox and summer and winter solstice days) at 30°EN latitude. They found that the external reflector can increase the distillate productivity in all but the summer seasons, and the increase in the daily amount of distillate averaged over the four days is predicted to be about 9%.

In this experiment they theoretically predicted the effect of a vertical flat plate external reflector for the tilted wick still on the solar radiation absorbed on the evaporating wick as well as the distillate productivity of the still at 30 EN latitude, and the results of this work are summarized as follows:

1. The averaged daily amount of distillate for four days (spring and autumn equinox and summer and winter solstice days) peaks when the angle of the still θ is 20E for the still with the reflector, and peaks at θ = 30E for the still without the reflector.

2. The average daily amount of distillate of the still with the reflector is predicted to be about 9% larger than that of the still without the reflector, and the vertical flat plate external reflector would be less effective for the tilted wick still than for the basin still.

Ragh Vendra Singh *et al.* [9] they done the thermal analysis of a solar still integrated with evacuated tube collector in natural mode. Performance has been predicted theoretically in terms of water and inner glass cover temperatures, yield, energy and exergy efficiencies during typical summer day of New Delhi (India). The variation of instant overall energy and exergy efficiencies has been found to be in the range of 5.1–54.4% and 0.15–8.25% respectively during the sunshine hours for 0.03 m water depth, which decreases with increase in depth.

Further, the system has been optimized for the number of evacuated tubes integrated and water depth in basin for nearly the same maximum water temperature attainable (≈94 °C) in each combination. The best combination among has been found by integration of 10 evacuated tubes with water depth of 0.03 m (total 52.5 kg water mass) in the basin. The respective daily energy and exergy efficiencies have been obtained as 33.0% and 2.5% and maximum along with daily yield of 3.8 kg/m^2.

The energy balance for each component of the integrated system in natural mode has been carried out with the following assumptions for simplification.

1. Solar distillation unit is vapour leakage proof,
2. Heat capacities of glass and basin material are negligible,
3. Temperature dependent heat transfer coefficients have been considered,
4. Side heat loss from the solar still is neglected,
5. There is no thermal stratification across the water depth,
6. Water temperature of ETC is an average of inlet and outlet water temperature,
7. Attenuation of solar flux within the water mass is considered in glass (α′ g), water (α′w) and basin (α′b), respectively.
8. Initial values of water and condensing cover temperatures have been used to determine the value of internal heat transfer coefficients

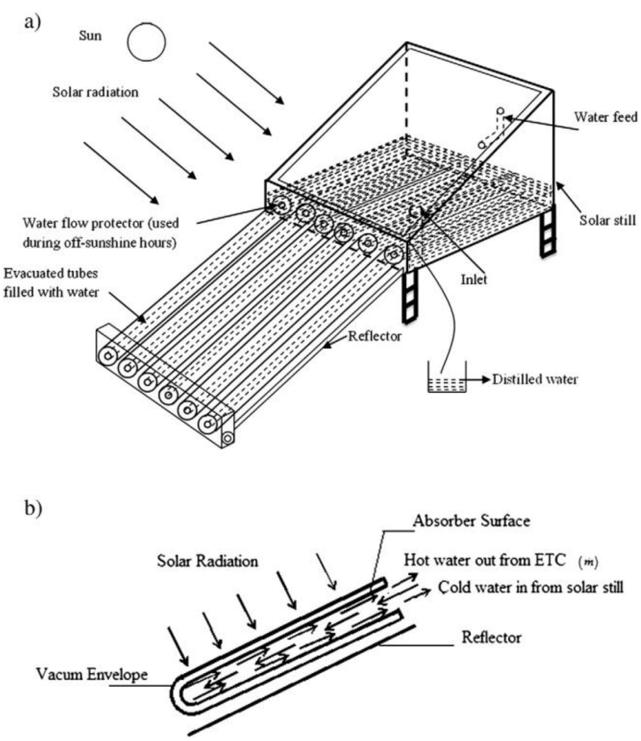

Fig. 3 a. Schematic diagram of EISS system in natural mode. b. Schematic diagram of thermo syphon process in single tube.*[R.V. Singh et al. / Desalination 318 (2013) 25–33]*[9]

a. System operates in quasi-steady state regime during the day,
b. Water level in the basin of solar still is kept constant.

The following conclusions have been drawn;

1. Natural circulation rate increases up to 44 kg/h in an individual tube when the radiation is at its peak and at high basin water temperature (80.0 °C).
2. The integration of ETC with solar still increases the water temperatures as well as yield. The daily yield obtained is 3.8 kg/m2 for 0.03 m basin water depth. The yield decreases further with increase in water depth.
3. The variation of instant overall energy efficiency of the system has been found in the range of 5.1–54.4%, while exergy efficiency in the range of 0.15–8.25% between 9:00 and 15: 00 h. The evaporative fractional exergy dominates over the radioactive and convective fractions at most of the time.

The maximum daily energy and exergy efficiencies have been found to be as 33.0% and 2.5% respectively. To make the system efficient, the combination between the size of ETC and basin water depth needs adjustment. Smaller size of ETC with 10 number of tubes is preferable than a single unit the larger size ETC integrated.

Kazuo Murase *et al.* [10] they have made Experimental and numerical analysis of a tube-type networked solar still for desert technology Experimental data measured in our laboratory using infrared lamps showed the effectiveness of the method for productivity, the design of the basin tray and thermal efficiency up to 12.5%. A large number of artificial huge ponds as salty water reservoirs are in the first step scattered about desert areas. Natural evaporation of brackish water or seawater in reservoir by solar radiation produces available effects for humidification around the areas. Secondly, our developed tube-type solar stills connected between the reservoirs constitute the network of pipelines for salty water transportation.

The still pipelines between reservoirs are spaced throughout the plantation. Our concept for desert plantation proposes that the lower half part of the still is buried underground. The distilled water condensed inside the tube is not collected in a tank but flows directly underground through a drain at the bottom of the tube. A conventional roof-type still needs insulation at the bottom of the still. However, a tube-type still generally has an air gap between a basin and the bottom of a tube, which allows for the underground setting.

A tube-type solar still was proposed as an integrated device for a conventional still and a water distributor applicable to our concept for desert plantation. The still has the following merits:

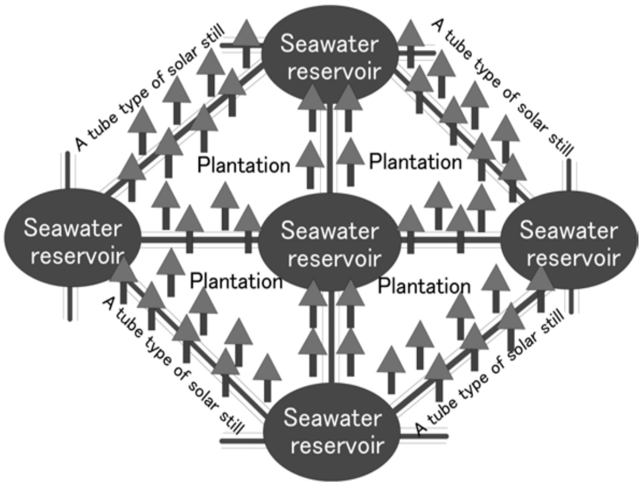

Fig. 4 Conceptual view of a desert plantation. *[K. Murase et al. / Desalination 190 (2006) 137–146]*[10]

1. The still may be immediately set up at the plantation area like a pipeline connected with brackish or seawater ponds so that it supplies directly distilled water into the ground by penetration.
2. Metal-free materials, e.g., vinyl chloride, are easily utilized for inhibiting corrosion by salty water.
3. The experimental data show that higher water level contributed to stable performance with thermal efficiency up to 12.5%.
4. The numerical simulations revealed that the heat convection is within the still. The tube basin produced a larger convection area over the basin and restricted the vapour circulation under the basin than a conventional flat basin. The tube basin provides the possibility of a still without insulation. Therefore, it is possible to set up the lower half of the underground for our concept.
5. The system is very simple but practical as one of the most suitable technologies for desert plantation.

Avesahemad S.N. Husainy has studied Hygienic drinkable water is a basic necessity for man along with food and air. Fresh water is also required for agricultural and industrial purposes. Most water sources are contaminated by industrial waste, sewage and agricultural runoff. The higher growth rate in world population and industries resulted water in a large acceleration of demand for fresh water.

The natural source can meet a limited demand and this leads to acute shortage of fresh water. Hence, there is an issue to essentially treat the salt and contaminated into purified water. There are several methods to convert impure water into potable water for drinking, but out of them thermal method is economically viable. In this paper experimentation were carried out on two different setups of double slope single basin solar still with and without thermal energy storage by phase change material.

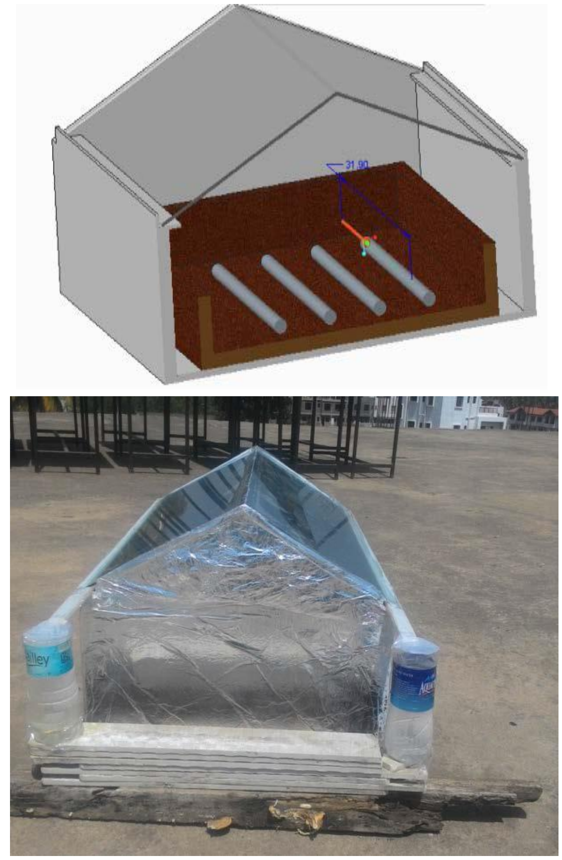

Fig. 5 Experimental Setup Using Latent Thermal Energy Storage

From this experimentation it was observed that, solar still continues to produce the fresh water by converting mud water. The distillate production is said to be increased to 10-25% with PCM. The energy storage materials in the still store considerable amount of heat during noon hours and release the stored heat to the basin water in the late afternoon hours when radiation is low, and are found to influence the temperature of the solar still components considerably.

III. CONCLUSION

The following result is made from the experimental study:

1. "V" type solar still with charcoal absorber is an efficient technique to improve efficiency of Solar Still.
2. Double slope single basin solar still using Phase changing materials like (paraffin wax) and Sensible heat storage elements like (black pebbles) is efficient technique to improve efficiency of Solar Still.
3. Solar still of double exposure also helps to improve efficiency of Solar Still.
4. The glass cover inclination of Solar Still is also affect the efficiency of Solar Still.
5. Single slope single basin solar still with baffle suspended absorber improves the productivity of solar still.

6. A tube-type networked solar still is also improves the effectiveness of solar still.

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