Efficiency Enhancement Measures for Single Slope Solar Still – An Experimental Study

Nirupam Rohatgi*
Department of Mechanical Engineering,
Malaviya National Institute of Technology, Jaipur, India
* E-mail: nirupam.rohatgi@gmail.com

***Abstract*-The effect of various efficiency enhancement measures for single slope solar still has been studied experimentally. The experiments were carried out on a single-slope solar still with a basin size of 1.0 m x 0.8 m at Jaipur, India. Effect of internal mirrors, the quantity of water present in the basin, the presence of black dye in the water, the presence of foam and a bed of gravel on the distillate output during the sunshine and during the night and overall efficiency of the still were investigated. It was observed that for the cases without internal mirrors, mixing of black dye in the water and a bed of gravel had a positive effect on overall efficiency of the still, while the performance of still deteriorated due to use of yellow foam pieces. For the still with internal mirrors and plain water, the overall efficiency of the still increases by about 10%. However there was no benefit of using any of the above measures with internal mirrors.**

Keywords - Solar Still, Distillation, Potable water

I. Introduction

India has over 5.6 lakhs villages and out of that nearly 28% of villages have inadequate provision for potable water [1]. According to UNICEF, over one billion people are currently without access to improved water supply and another 2.6 billion have no form of improved sanitation services. Availability of drinking water is a major problem for the people living in arid or remote regions. The conventional distillation processes such as electrolysis, reverse osmosis, thin film distillation, multi-stage flash evaporation and multi-effect evaporation, are energy intensive techniques. However, in the regions where there is an abundant sun, solar energy can be used to obtain potable water from salty, brackish and used water. However, solar distillation is an attractive alternative because of its simple technology, simple maintenance and zero energy consumption.

A number of solar still plants and individual stills have been built around the world for quite some time [2]. Many innovative methods have been used to improve the efficiency of the stills and on one hand and many experiments have been done to fine-tune the parameters to enhance the efficiency of the still on the other hand.

Tiwari and Tiwari [3] suggested that the highest output and efficiency are obtained at lower depths of water in solar still basin.

Badran [4] observed that the productivity of a solar still depends upon the depth of water present in the basin; productivity decreases with the increase in the quantity of water in the basin and vice versa. The maximum temperature of water in the basin decreases with the increase in the quantity of water in the solar still basin, leading to lower evaporation and consequently lower output. He observed that there was a significant improvement in output of still with asphalt basin. Addition of a sprinkler with asphalt was found to be more efficient than the use of asphalt alone. The productivity of the still increased up to 51% when sprinkler was used along with asphalt basin liner in the still.

Bassam, Abu-Hijleh, and Rababah [5] found that the presence of sponge cubes can significantly increase the distillate output of solar stills.

Nafey, Abdelkader, Abdelmotalip, and Mabrouk [6] suggested that using black rubber in solar still basin improves productivity by 20% when the quantity of water present in the still was 60 l/m^2 and the glass cover angle was 15^0. They also observed that using black gravel of 20-30 mm size improves the distillate output by 19% when the quantity of brine present in the still was 20 l/m^2 and the glass cover angle was 15^0.

Ansari, Asbik, Bah, Arbaoui, and Khmou [7] studied a simple solar still with a heat energy storage system put under the basin liner of the still. They observed that energy storage enhances the productivity and the efficiency of solar still significantly. However, the phase change material (PCM) shall be selected on the basis of the maximum temperature of the water that can be reached by in the basin.

El-Bialy [8] compared the performance of a single-slope solar still with and without a floating absorber. Metallic and non-metallic floating absorbers made up of mica, stainless steel, aluminium, and copper were used. It was found that for all the investigated values of the mass of water above the floating absorber; the productivity of solar distiller with a floating absorber was found to be higher than that of the single basin solar distiller. He observed that floating absorber plate having the lowest value of thermal conductivity, i.e. a non-metallic material, mica gave the best performance.

Elango, Kannan, and Murugavel [9] studied the effect of mixing nano-fluids in basin water on the performance of a simple solar still. They chose three different water nano-fluids, i.e. Aluminium Oxide (Al_2O_3), Zinc Oxide (ZnO), and Tin Oxide (SnO_2). They observed that the still with Aluminium Oxide nanofluid had 29.95%, the still with Zinc Oxide nanofluid had 12.67%, and the still with Tin Oxide nanofluid had 18.63% more production than the still with simple water. The payback period of the still with nanofluid was found to be lesser than that of the still with simple water.

Hansen, Narayanan, and Murugavel [10] experimented with different wick materials and studied their effect on the performance of an inclined solar still. The material of the types of wicks explored was wood pulp, paper-wick, wicking water coral fleece fabric and polystyrene sponge. The wicks were placed on different absorber plate configurations such as flat plate, stepped plate and stepped plate with wire mesh. Water coral fleece material with a porosity of 69.67% was found to be the most suitable material for the wick.

Wettability of a surface determines the type of condensation, i.e., film-wise or drop-wise condensation. Zanganeha, Goharrizi, Ayatollahi, and Feilizadeh [11] studied the effect of nano-silicon coating on the distillate production of a single-slope solar still. They found that condensate production of a glass surface increased by 23% after nano-coating at a surface inclination of 50°. However, it was observed that at an inclination of 10°, the uncoated surfaces performed better.

In this paper some of the simple and cheap alternatives that may improve the performance of a single-slope solar still and wouldn't require skilled maintenance have been studied experimentally.

II. Working of a Solar Still

In a solar still, solar energy enters the solar still through a clear glazing surface such as a transparent glass or plastic sheet. A part of these radiations is absorbed by water depending upon the absorptivity of water. The part of the solar radiations that fall on the blackened surface is absorbed by the surface and in turn heat is transferred to water, water vapours and air present in the still. As the temperature of the water inside the solar still increases, it begins to evaporate. Warm vapours rise and condense on the underside of the glass cover. The condensed water accumulates as water droplets which slide to a trough due to gravity and collected in a storage tank. The water thus collected is as pure as distilled water as all impurities are left behind in the basin. The heat of condensation released by water vapours is lost to the atmosphere through the glass.

While condensation is a necessary process and heat of condensation is released to the atmosphere, a part of the heat is also lost to the atmosphere through walls and glass cover by conduction.

III. Experimental Set-up

The size of the solar still basin used for the experiment was 1.0 m x 0.8 m. The walls of the solar still were made of GI sheet (24 gauge) as GI is resistant to corrosion. The walls and the bottom of the still was double walled with insulation of 1" of Polystyrene (commonly known as "thermocol") placed between the walls to reduce the heat losses from the base and the side walls of the solar still. To improve the absorptivity of the solar still, inside surfaces of the solar still were painted with black epoxy paint as shown in Fig. 1. To reduce the heat loss from the outer surfaces of the still, outside surfaces were painted with white enamel paint as shown in fig. 1, and fig. 2. The basin was kept on a steel frame having a height of about 3 ft. An ordinary transparent glass of 5 mm thickness was placed at the top of the solar still from which solar radiation enters the still, as shown in Fig. 2. A layer of foam was placed between the glass cover and the top flat edges of the basin to prevent the leakage of water vapours from the joint. The orientation of the solar still was fixed so that it is facing south. The inclination of the glass was kept at 26^0, the same as the latitude of Jaipur. Due to the inclination of the glass cover condensed water droplets trickle down to the trough and collect in a storage tank.

Fig. 1: Solar still walls painted with black epoxy paint from inside

Fig. 2: Solar still with glass covering and outside walls painted white.

I. Observations

The present work discusses the effect of various efficiency enhancement techniques for single-slope solar still. The experiments were carried out on a single-slope solar still with varying water depth and other modifications such as the addition of black dye to water, use of foam on water surface and bed of gravel at the bottom of the basin. The above experiments were done with and without internal reflectors.

The incident radiations were measured with the help of a solarimeter placed on the glass cover. The sensor of the solarimeter was so placed that it was facing the Sun directly. The distillate output was measured with the help of a measuring cylinder. The experiments were done for three different quantities of water in the still, i.e. the amount of water in the solar still was kept at 10 litres, 20 litres and 30 litres for the experiment. At the end of every experiment, i.e. in the morning, the amount of water that had evaporated during the previous day was added the next day before the start of the experiment again.

II. Results and Discussion

A total of twelve sets of experiments were done by changing various parameters that affect the efficiency of the still.

IJSER

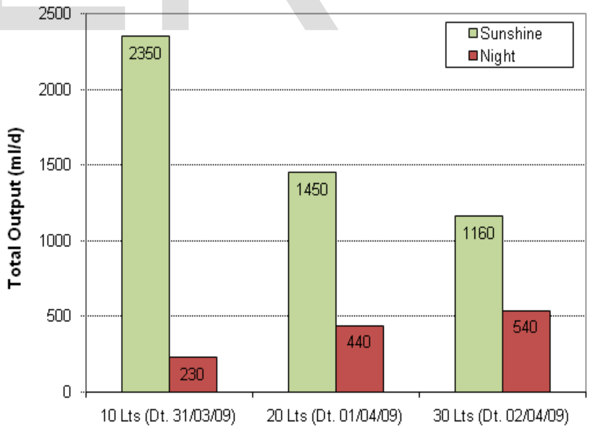

Fig. 3 Distillate Output during Sunshine and Night without Mirrors for different Water Quantities

Fig. 3 shows the effect of the quantity of water in the basin without internal mirrors on distillate output during the sunshine and the night. It was observed that while the day's output decreases with increase in water quantity, night's output increases. This is due to the fact that water has a large thermal mass. As the quantity of water in the still basin increases, the amount of heat stored in water increases which is released in the night leading to an increase in condensation of water vapours during the night.

Fig. 4 shows overall efficiency without internal mirrors for 10 litre of water without any dye, full yellow foam or foam pieces. Full yellow foam of area 0.8m x 1.0 m and yellow foam pieces were used on the surface without internal mirrors for 10 litres of water. It is evident from the chart that yellow foam sheet as well as yellow foam pieces decrease the efficiency of solar still. The overall efficiency decreased by 22% when yellow foam sheet was placed on the surface of the water and the overall efficiency decreased by 10% when yellow foam pieces were placed on the surface of the water. The drop in efficiency occurs because foam doesn't let the solar radiation reach water and the bottom of the still where they must ideally be absorbed. It was assumed before the experiment was done that foam will increase the rate of vaporization water by increasing the surface area of water and thus increase the distillate output. However the results were found otherwise. Foam leads to increase in vapour temperature because it doesn't let the radiations reach the water in the basin. Although it appears that the rate of vaporization depends on water temperature, actually it primarily depends on the rate of heat added to the water; the rise in temperature is only a subsequent effect of heat addition. So from the experiments it is evident that at least light coloured foams don't increase the overall efficiency of the still. It is suggested that the effect of black coloured foam may be investigated.

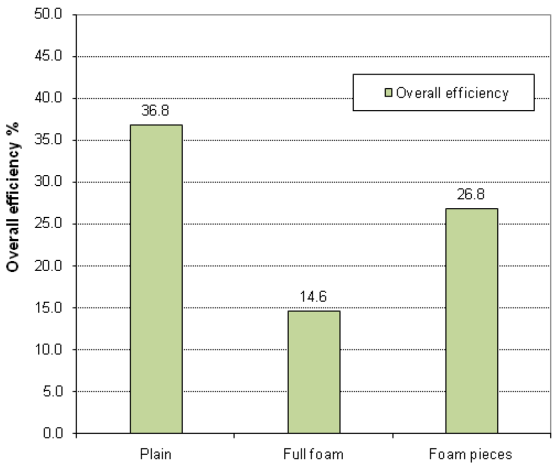

Fig. 4 Overall efficiency without Mirrors for 10 litres Water Quantity

Fig. 5 shows the effect of internal mirrors on the overall efficiency of the still for different quantities of water present in the basin of the still. It is evident from the results that the overall efficiency with the use of internal mirrors is significantly more than that without internal mirrors. With the use of internal mirrors overall efficiency increases by 8% for 10 litre of water; it increases by 10% for 20 litres of water and it increases by 5% for 30 litres of water in absolute terms. This is because internal mirrors reflect solar radiations falling on vertical sides to water and the blackened base below the water. Thus radiations falling on the vertical walls which would either increase the temperature of the vapours or be lost through side walls by through conduction are reflected back to the basin where they are absorbed and transferred to water in the basin.

Fig. 5. Overall Efficiency with and without Mirrors for Different Water Quantities

Fig. 6 shows overall efficiency with and without mirrors for 10 litres of water for different modifications such as the addition of black dye to water and spreading a bed of gravel in the basin. From the figure, it is evident that without mirrors overall efficiency increases by 6% while with internal mirrors overall efficiency remains same due to the addition of black dye as compared to clear water with internal mirrors. Black dye increases the absorptivity of basin water which increases the temperature of water and increases productivity. It is evident that mixing black dye in basin water improves still's performance significantly when internal mirrors are not used. However the effect of black dye on still performance is insignificant when mirrors are used. It also shows overall efficiency with and without mirrors for 10 litres of clear water and bed of gravel in clear water. Overall efficiency without internal mirrors and bed of gravel (total wt. of gravel = 6 kg, and the approximate size of gravel = 2 cm) in basin increases by about 5%. This can be explained by the fact that the gravel surface is not black and therefore during the day time part of solar radiations falling on the gravel surface is reflected back by the gravel. This result in a decrease in day's output, while heat stored by the gravel during the day is released during the night increasing night's output. The net effect of the two opposing phenomena when no mirror is used is that overall efficiency increases. However when internal mirrors are used, solar radiations reflected back by the gravel increases while surplus heat stored by gravel during the day remains same and the net effect of the two opposing phenomena is that overall efficiency decreases by 4% as compared to plain water with internal mirrors.

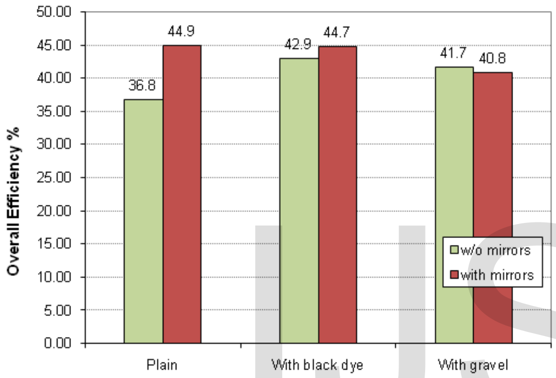

Fig. 6 Overall Efficiency with and without Mirrors for 10 litres of Water

In one of the experiments without mirrors and water quantity of 10 litres, it was observed that about 660 ml of water vapours were lost while 2240 ml of water vapours were condensed. Thus a total of about 30% of water vapours escaped from still without being condensed. This is a significant loss and if this leakage is plugged properly, an increase in efficiency of solar still by about 10% can be attained.

III. Conclusions

A total of twelve sets of experiments were carried out during the study by changing various parameters that affect the efficiency of the still. Following conclusions can be made from the study:

1) The overall efficiency for 10 litres, 20 litres and 30 litres of water without mirrors is nearly the same and it is about 35%.

2) The overall efficiency of the solar still for different water quantities is maximum for 10 litres and 20 litres of water with internal mirrors. It is nearly equal to 45%. Thus the use of internal mirrors increases the overall efficiency by about 10% as compared to that obtained without internal mirrors.

3) With internal mirrors in use the overall efficiency of solar still for 10 litres of water using different efficiency enhancement arrangements is maximum for plain water. With internal mirrors in use there is no benefit of the addition of black dye, while the addition of a gravel bed reduces the overall efficiency of the still by about 4%.

4) Without the use of internal mirrors, the addition of black dye in basin water increases the overall efficiency by about 6%; bed of gravel (total wt. of gravel = 6 kg, and approximate size of gravel = 2 cm) in basin increases the overall efficiency by about 5%; while placing a yellow foam sheet in water basin decreases overall efficiency by about 22%.

5) About 30% of distillate output escapes as water vapours from the still without being condensed. This can be prevented by designing a leak-proof still that can be done at a nominal extra cost.

IJSER

References

[1] Hikmet S. Aybar, FautEgelioglu, U. Atikol, "An experimental study on an inclined solar water distillation system," Desalination, vol. 180, 2005, pp. 285-289.

[2] E. Delyannis, "Historical background of desalination and renewable energies," Solar Energy, vol. 75, 2003, pp. 357-366.

[3] Anil Kr. Tiwari, G.N. Tiwari, "Effect of water depths on heat and mass transfer in a passive solar still: in summer climatic condition," Desalination, vol. 195, 2006, pp. 78-94.

[4] O. O. Badran, "Experimental study of the enhancement parameters on a single slope solar still productivity," Desalination, vol. 209, 2007, pp. 136-143.

[5] Bassam A/K, Abu-Hijleh, Hamzeh M. Rababah, "Experimental study of a solar still with sponge cubes in basin," Energy Conversion and Management, vol. 44, 2003, pp. 1411-1418.

[6] A.S. Nafey, M. Abdelkader, A. Abdelmotalip, A.A. Mabrouk, "Solar still productivity enhancement," Energy Conservation & Management, vol. 42, 2001, pp. 1401-1408.

[7] Omar Ansari, Mohamed Asbik, Abdallah Bah, Abdelaziz Arbaoui, Ahmed Khmou, “Desalination of the brackish water using a passive solar still with a heat energy storage system,” Desalination, vol. 324, 2013, pp. 10-20.

[8] E. El-Bialy, “Performance analysis for passive single slope single basin solar distiller with a floating absorber - An experimental study,” Energy, vol. 68, 2014, pp. 117-124.

[9] T. Elango, A. Kannan, K. Kalidasa Murugavel, “Performance study on single basin single slope solar still with different water nanofluids,” Desalination, vol. 360, 2015, pp. 45-51.

[10] R. Samuel Hansen, C. Surya Narayanan, K. Kalidasa Murugavel, “Performance analysis on inclined solar still with different new wick materials and wire mesh,” Desalination, vol. 358, 2015, pp. 1-8.

[11] Peyman Zanganeh, Ataallah Soltani Goharrizi, Shahab Ayatollahi, Mehrzad Feilizadeh, “Productivity enhancement of solar stills by nano-coating of condensing surface,” Desalination, vol. 454, 2019, pp. 1-9.

IJSER