

Experimental Analysis of Desalination Unit Coupled with Solar Water Lens Concentrator

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Abstract. The main problem that the world faces in this scenario is shortage of potable water. Hence this research work rivets to increase the yield of desalination system in an economical way. The integration of solar concentrator and desalination unit can project the desired yield, but the commercially available concentrated solar power technologies (CSP) are not economically viable. So this study proposes a novel method to concentrate ample amount of solar radiation in a cost effective way. Water acting as lens is a highlighted technology initiated in this work, which can be a substitute for CSP systems. And water lens can accelerate the desalination process so as to increase the yield economically. The solar irradiance passing through the water will be concentrated at a focal point, and the concentration depends on curvature of water lens. The experimental analysis of water lens makes use of transparent thin sheet, supported on a metallic structure. The Plano convex shape of water lens is developed by varying the volume of water that is being poured on the transparent thin sheet. From the experimental analysis it is inferred that, as the curvature of water lens increases, solar irradiance can be focused more accurately on to the focus and a higher water temperature is obtained inside the solar still.

Keywords— Concentrated solar power (CSP), Water lens, Plano convex, Solar still, irradiance, Solar desalination unit

1. Introduction

Renewable energy is one of the fastest growing technologies and is recognized as a vital input to sustainability. Solar energy contributes a major role in wide range of applications like solar desalination, electricity generation, solar cooker, solar water heaters and solar pumps etc. The sun is a hot gaseous sphere with a blackbody temperature of 5762 K with a diameter of 1.39×10^9 m and is about 1.5×10^{11} m away from earth [1]. The sun's total energy output is 3.8×10^{20} MW which is equal to 63 MW/m² of sun's surface and only a tiny fraction of 1.7×10^{14} KW of the total radiation emitted is intercepted by the earth [1]. Solar desalination mimics natural hydrologic cycle, in which saline water

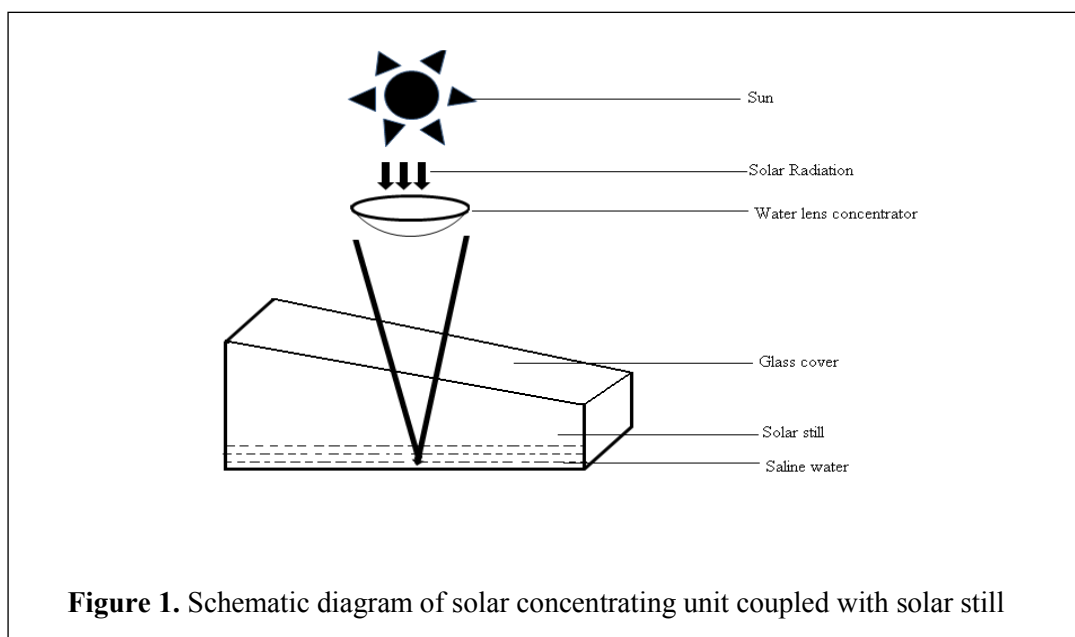


is evaporated using solar thermal energy and the resulting condensed water is collected as final product. In many parts of the world mainly coastal areas where plenty of underground water is available, but it is unfit for drinking because of high salinity content (2000 ppm to 3500 ppm) [2]. The saline water contains 28000 ppm of common salt, where maximum level of acceptance of salt content for human consumption is 500 ppm [2]. Thus solar desalination is a simple and widely accepted method to extract fresh water. The different types of solar still available are spherical, pyramid, hemispherical, double basin, tubular and hemispherical concentrator solar still[3]. In this research work, experimentation on single slope solar desalination unit integrated with water lens is mainly focused. A novel technology of water acting as lens is incorporated where solar irradiance passing through water gets concentrated on to the focal point where solar still is positioned to increase the distillate output. The ongoing research work by different researchers projected their idea on existing methods to increase the yield of distillate output are mentioned below.

The performance comparison on single basin solar still and an identical one coupled to a flat plate solar collector is done[4]-[5]. The results show that the coupled one has better performance than basin solar still. Different designs of single slope still to increase the productivity is carried out with an efficiency of 45% [6] . Akash, Bilal A *et.al.*[7] and Nafey A S *et.al.*[8] Studied the distillate yield variation of single slope solar still [9] by using different absorbing material like black rubber mat, black ink and black dye[10]. The performance evaluation of single and double basin double slope glass solar still is carried out with and without insulation, and the performance of still without insulation is 8.12% were as the performance of insulated still is 17.38%[11]. Elango T *et.al.*[12] done a performance comparison of solar still with water and nano fluids like Al_2O_3 , ZnO, Fe_2O_3 and SnO_2 and Al_2O_3 got a higher production of 29.95% . Samuel *et.al.*[13] and Murugavel *et.al.* [14]-[15] Suggested energy storage material to increase the yield of solar still and calculated payback period for cost effective energy storage material[16]. Prakash *et.al.*[17] conducted experimentation by changing the base material of solar still for same climatic condition and economical verification of the system is carried out. Digital simulation method and mathematical modelling of complicated solar still, by varying water depth, wind velocity and insulation were carried out by P.I Cooper [18]-[19].

This paper outlines the novel technology of single slope desalination unit coupled with water lens as concentrator. The result suggests that the productive capacity of the solar still can be increased to a measurable extent in an economical way by adopting this technique.

2.Description of the System



The experimental setup consists of mainly two parts[1]; (i) water lens and (ii) solar still. Water is the most commonly available transparent liquid on earth and can exist naturally in different forms and here water is a powerful weapon which acts as lens. For water lens a particular amount of water is poured over a thin transparent sheet, which is supported by a stand. The curvature of water lens is due to the elasticity of transparent sheet, and as whole forms the shape of Plano convex lens. Even though the water at the focal point gets heated up, the water that acts as lens maintains the initial temperature. That means water that act as lens allow the amount of solar radiation incident on it to converge at a focal point without absorbing thermal energy.

Furthermore, the solar desalination unit uses heat energy from sun to produce distillate output. In this experimentation process single slope solar still [20] is used. The solar still is constructed using mild steel material with copper coating at the bottom and a glass cover at the top. The unit is separated into two compartments where first one act as distillation tank and second one as collection tank. The entire system is coated with black paint to absorb maximum amount of heat. The solar radiation incident on desalination unit gets trapped inside the system due to the green house effect. The solar green house effect depicts that the glass cover has the property to capture the short radiation and won't allow long radiation to escape back. Due to this property the water starts heat up; it evaporates and gets condensed on glass cover. The solar radiation incident on earth surface can be concentrated through water that act as lens on to a focal point, were the solar desalination unit is placed. The water lens which focuses solar radiation on desalination unit increases the rate of evaporation through which the yield of the system can be increased. The simple schematic representation of solar concentrating unit coupled with desalination unit is shown in Figure 1.

3. Method of Experimentation

The experimental analysis of solar still highlights the variation of distillate yield by comparing three different setups. The different experimental setup used are single slope solar still[20], single slope solar still[20] with insulation and insulated solar still integrated with water lens.

3.1. Single slope solar still

Single slope solar still[20] is constructed with a total area of 0.31 m² where distillation tank is 0.23 m² and collection tank is 0.081 m². A glass cover of 5 mm thickness was inclined at a tilt angle of 20° over the solar still for green house effect. The Figure 2 shows the experimental setup of single slope solar still.

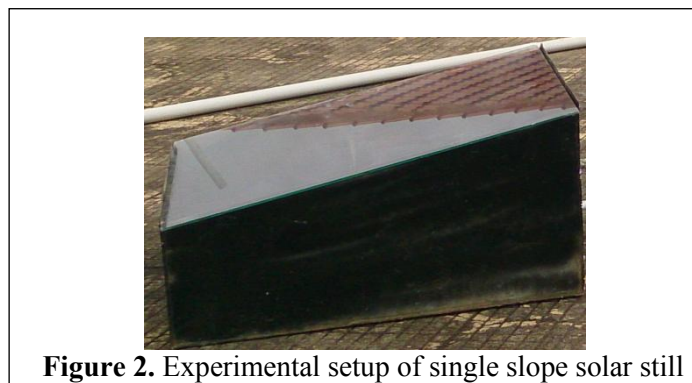


Figure 2. Experimental setup of single slope solar still

3.2. Single slope solar still with insulation

Single slope solar still [20] was insulated with polystyrene to reduce the conduction losses through bottom and sides, so that maximum heat will be retained inside the solar still. The Figure 3 shows the experimental setup of single slope solar still with insulation.



Figure 3. Experimental setup of single slope solar still with insulation

3.3. Insulated single slope solar still integrated with water lens

Water lens is an economical method to concentrate more amount of solar energy to the focal point compared to other CSP technologies. The maximum temperature obtained at the focal point of water lens was 514°C and water temperature at the focus was 95°C . As the solar irradiance passes through the water which act as lens more amount of solar energy can be concentrated at a point focus where a maximum temperature of 514°C was obtained with an average irradiance of 884.3 W/m^2 . The material used for water lens is thin transparent sheet of 0.4 mm thick, which is supported by a mild steel stand of 0.9 m diameter and 2 m height. The insulated single slope solar still is placed at the focus of water lens so that maximum amount of heat can be captured inside the solar still. Hence the rate of evaporation inside the solar still can be increased and the distillate output can be maximized in an economical way. The Figure 4 shows the experimental setup of insulated single slope solar still integrated with water lens.

During experimentation, three different quantities of water samples of 3l, 5l and 10l were tested and the testing was carried out in three different setups as mentioned above.



Figure 4. Experimental setup of single slope solar still with insulation

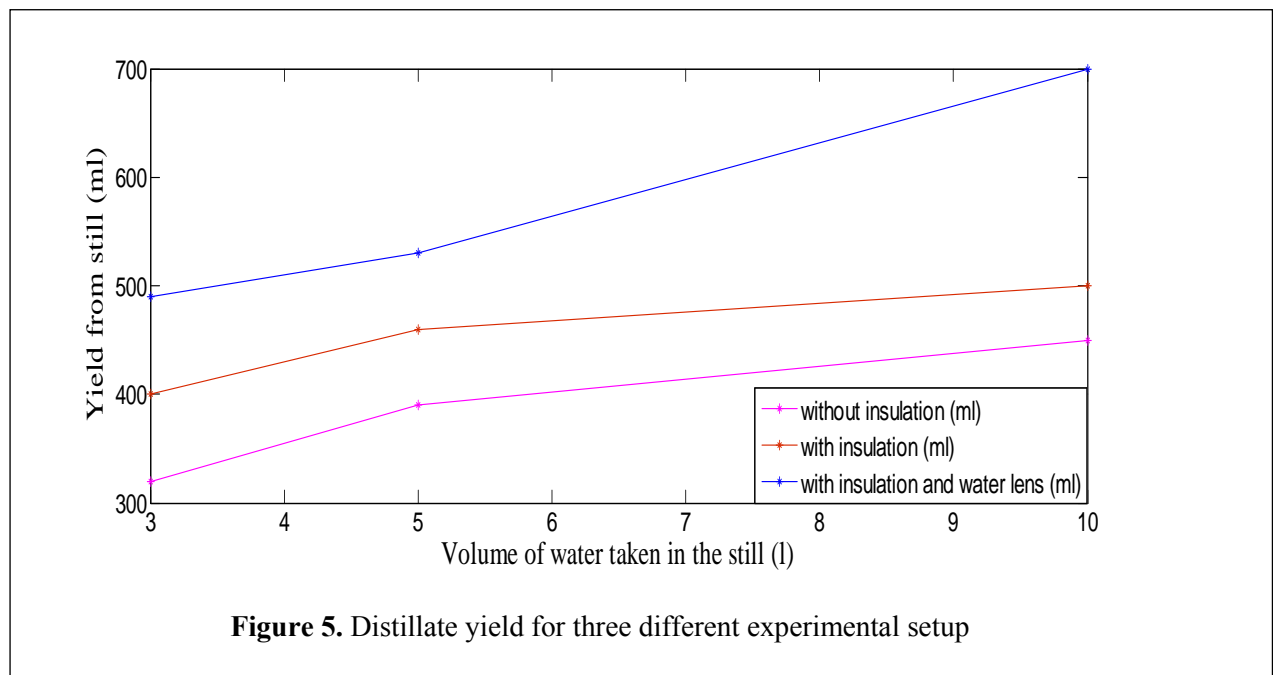
4. Results and Discussion

Table 1 shows that as the curvature of water lens increases from 5l to 10 l the time taken to heat, 1l of water decreases from 20 minutes to 8 minutes. That is as the curvature of water lens increases up on adding water the solar irradiance can be focused more accurately so that more heat will be trapped inside the solar still within short period of time. Hence the rate of evaporation inside the solar still can be increased in a faster rate.

Table 1. Volume of water used to increase the curvature of water lens

Volume of water used as lens (litre)	Time taken to heat the water to 60°C (minutes)
5	20
7	16
9	12
10	8

The experimentation on single slope solar still was conducted with three setups as mentioned in Figure 2, Figure 3 and Figure 4 with 3l, 5l and 10l of water was tested in each one. The Figure 5 shows the variation in distillate yield with respect to each litre of water for three different set ups. Single slope solar still with an average irradiance of 839W/m², insulated single slope solar still[18] with an average irradiance of 868.6 W/m² and insulated single slope solar still[18] integrated with water lens with an average irradiance of 884.3 W/m² were obtained during experimentation. Here the maximum yield of 700 ml was obtained from 10l of water for an insulated single slope solar still integrated with water lens. Hence Figure 5 shows that integrated system can give better yield and with the help of water lens the entire model of desalination system become simple and economical.



The Table 2, Table 3 and Table 4 shows the effect of initial and final water level for three different setup. As the quantity of water increases the distance between the glass cover and water surface decreases, hence the evaporative losses can be reduced. And the depth of water is reducing from initial level to final level steeply for an integrated system compared to other two setups mentioned in Figure 2 and Figure 3 which shows that rate of evaporation is higher for integrated system and similarly the evaporative losses can be reduced as the quantity of water increases.

Table 2. Effect of initial and final water level for single slope solar still

Volume of water taken in still	3l	5l	10l
Initial water level	2.0cm	3.4cm	6.3cm
Final water level	1.3cm	2.7cm	5.5cm

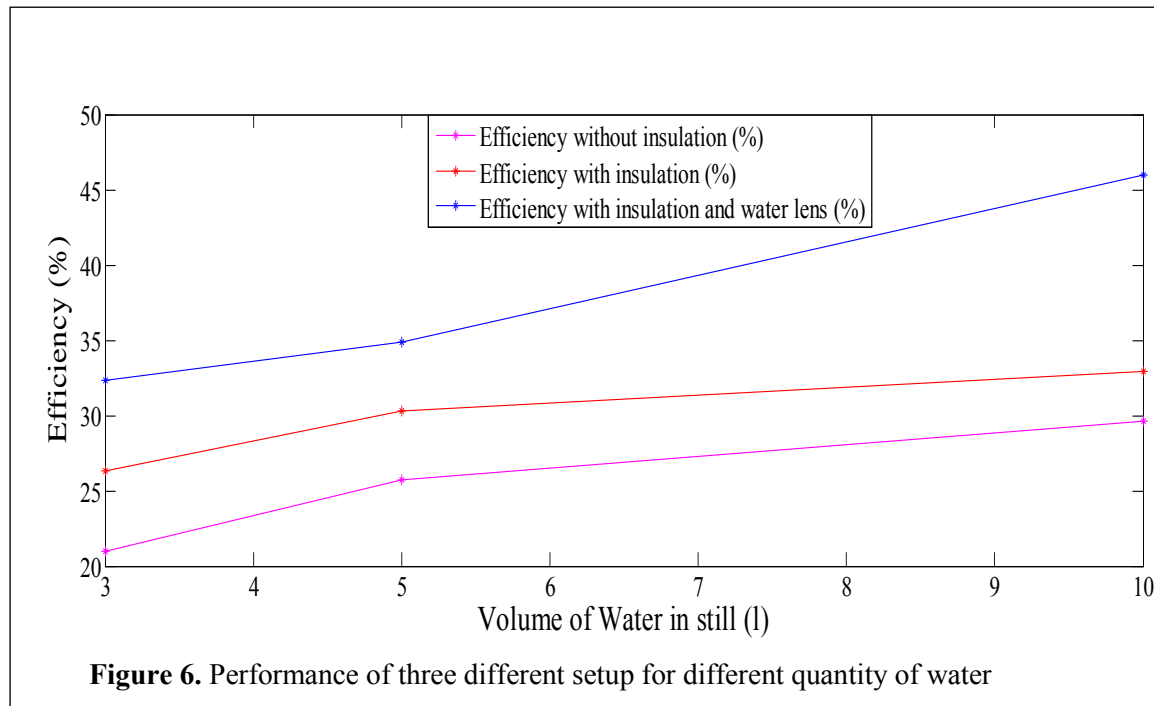
Table 3. Effect of initial and final water level for single slope solar still with insulation

Volume of water taken in still	3l	5l	10l
Initial water level	2.0cm	3.4cm	6.3cm
Final water level	1.1cm	2.2cm	5.0cm

Table 4. Effect of initial and final water level for insulated single slope solar still with water lens

Volume of water taken in still	3l	5l	10l
Initial water level	2.0cm	3.4cm	6.3cm
Final water level	0.8cm	2.0cm	4.4cm

Figure 6 shows that the maximum efficiency for insulated solar still integrated with water lens is 46% compared to single slope solar still where efficiency is 21%. The efficiency is higher for an integrated system where novel technology of water lens is used. Hence by incorporating water lens the yield of the system can be increased in a measurable and economical way.



5. Conclusion

Since the scarcity of portable water is increasing day by day desalination using solar thermal energy is a best option to be adopted in this present era. The water lens is an eco friendly approach to concentrate abundant amount of solar energy and the maximum temperature obtained at the focus was 514°C . From the present work, it can be inferred that, as the curvature of water lens increase the time required to heat the water decreases. The experimental analysis of solar desalination unit integrated with water lens can increase the performance of the distillate output more economically. The experimentation reveals an excellent efficiency of 46% with a higher yield of 700ml for this integrated system. The future works involves the incorporation of pre-heater tank and sprinkler with the above mention experimental setup, thus to study the influence on rate of evaporation.

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