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Performance and Chemical Analysis of Distilled Saline Water Production Using Solar Distillation System

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Abstract: Solar powered distillation system has been the focus of great interest recently worldwide. The availability of fresh water resources and their quality is essential for poverty reduction in rural areas of numerous developing countries worldwide. In this paper a solar energy based distillation unit has been designed and analyzed.The analysis is based on experimental studies for composite climatic condition of Nagercoil, Kanyakumari District(latitude = $8^0$11N, Longitude = $77^0$29E). A distillation system which will convert the saline water into pure distilled water using solar energy. The designed distillation unit produces 2.3 liters of pure water from 20 liters of dirty water during eight hours with an efficiency of 41%.The chemical analysis of the distilled water and impure water was also carried out.
Keywords: Solar energy; Distillation; Saline water; Distilled Water; Single slope distillation system.

1. Introduction

Distillation is one of many processes available for water purification, and sunlight is one of several forms of heat energy that can be used to power that process. For people concerned about the quality of their municipally-supplied drinking water and unhappy with other methods of additional purification available to them, solar distillation of tap water or saline water can be a pleasant, energy-efficient option.Solar distillation of potable water from saline (salty) water has been practiced for many years in tropical and sub-tropical regions where fresh water is scare. However, where fresh water is plentiful and energy rates are moderate, the most cost-effective method has been to pump and purify.

Various research have been investigated in order to increase the distilled yield and productivity of fresh water from solar still in remote areas. Rural remote areas don't profit from well-established reverse osmosis desalination technology, hence integrated solar energy will be a boon for long run operation with less maintenance, less energy consumption and one time capital investment which is more economical[1]. Desalination of seawater and brackish water is now possible to meet the demand for potable water. Among the various methods, solar distillation is an attractive solution for isolated and remote area[2]. The selection of the appropriate renewable energy source powered desalination technology depends on variety of factors such as plant size, feed water salinity, remoteness, availability of grid electricity, technical infrastructure and the type and potential of the local renewable energy resource. Among the possible combinations of desalination and renewable energy technologies, solar and wind energy sources have been greatly exploited and found to be more promising in terms of economic and technological feasibility[3]. Design of solar still must be done very systematically to optimize the performance and to improve the productivity. Energy analysis and Instantaneous thermal efficiency are being considered as performance parameters for evaluation of solar still. However, Heat transfer losses and exergy analysis can be used in future for testing performances of different solar still[4].

The efficiency of the still has been calculated as 22.33% and the distillate output collected as 1.6 L/day [5] this trend also shown in the various researchers[6]. It was found that the average daily distillate outputs were 2.55 kgm^{-2} and 2.38 kgm^{-2} for the experimental still and conventional solar still respectively. In addition, the efficiency of the experimental solar still was 6.8% more than that of the conventional solar still. It can therefore be concluded that painting the internal surfaces of the walls of the still white improves the distillate output of the still[7]. The daily exergy efficiency, daily electrical exergy efficiency, the daily overall exergy efficiency and the daily overall thermal efficiency of the partially covered newly photovoltaic FPC active solar distillation system is higher than the previous distillation models [8].

It has been observed that for given parameters (water and glass cover temperatures and yield), the annual yield is optimum when the collector inclination is 20° and the still glass cover inclination is 15°[9]. Solar stills have a good chance of success in India for lower capacities which are more than 20 km away from the source of fresh water and where the TDS of saline water is over 10,000 ppm; A single sloped solar still receives more radiation than a double sloped solar still at low and high altitude stations; In active solar distillation system the optimum flat-plate collector inclination is 20° and the still glass-cover inclination is 15°, for maximum annual yield of the solar still[10]. The developed system is successful in reducing the excess chemical contamination of inlet water sample. It is observed that the values for chemical composition of distillate are well below the limits of drinking water standards. The chemical composition of distillate obtained satisfies the drinking water standards[11].

2. Methodology of Solar Distillation

The mechanism of solar distillation is as follows:

- The sun energy in the form of short electromagnetic waves passes through the transparent/opaque condensing cover (Glass/plastic/copper) and strikes at the blacked bottom surface of the still. This light changes its wavelength to long wave of heat which is added to the water kept in the sallow basin bellow the cover.
- As the water heats up it starts evaporating.
- These warm vapors start rising upwards towards the inner surface of the cooler cover plate. There these get condensed releasing their latent heat of condensation and forming a sheet of water on the under surface of the transparent cover.
- This condensed water than slips down the inner surface of the cover plate toward the distillate trough due to gravity.

3. Components of Solar Still

3.1. Still Basin:

It is the part of the system in which the water to be distilled is kept. It is therefore essential that it must absorb solar energy. Hence it is necessary that the material have high absorbtivity or very less reflectivity and very less transmissivity. These are the criteria's for selecting the basin materials. Kinds of the basin materials that can be used are as follows: 1. Leather sheet, 2. Ge silicon, 3. Mild steel plate, 4. RPF (reinforced platic) 5. G.I. (galvanised iron).

3.2. Cover plate:

The passage from where irradiation occurs on the surface of basin is top cover. Also it is the surface where condensate collects. The glass used having thickness of 3 mm and size is 500×200 mm.

3.3. Insolation:

The insolation used in between the basin and the plywood to reduce the heat loss due to conduction. The material used was thermocol and thickness of insulating material was 7 mm. Fig. 1 shows the experimental setup for single slope solar still.

4. Design of aSolar Distillation System

4.1. Design parameters

There are a number of parameters which affect the performance of a solar still. These were measured: Climatic Parameter: Solar Radiation, Ambient Temperature, Wind Speed, Humidity, Operational Parameters, Water Depth, Preheating of Water, Input Water supply arrangement [5].

Before proceeding further we would like to mention a few assumptions that we made for the design:

1. The system will serve a family of 5. The number is assumed to be the average size of a rural household. Data has also been confirmed with the census data.
2. Average requirement of water per person in a house is assumed to be around 1.5 liters/day. This gives the total water consumption to be around 7.5 liters/day. Also considering the requirement for cooking we roughly evaluate net water consumption per household is around 20 liters/day.
3. The solar constant equals 1.3 kW/m^2 but owing to losses incurred while passing through atmosphere we can consider the solar irradiation to be 1kW/m^2.

Fig. 1. Single slope solar still

Time taken for drop to come to channel = 1.3 hour
Time taken for drop to come out of channel = 0.6 hour
Amount of saline water poured initially = 20 liter
Amount of pure water obtained at the end of the exp. = 2.3 liter
Temperature of the condensate = 32°C
Specific heat of water = 4.2 kJ/kg
Latent heat of vaporization = Latent heat of condensation = 2260 kJ/kg

Manually operated vacuum pump is to reduce the air pressure inside the distillation chamber operating conditions of about 60°C to ensure low heat transfer losses. Conversion efficiency of solar distillation unit is assumed as 20%. The required area of the collector are calculated based on eqn. 1.

Aperture Area= Energy required for distillation of 20 liters of water / Solar energy Available per m^2 × Conversion efficiency (1)

$= (20 \times 4.2 \times (60-32)) / (1\ \text{kW/m}^2 \times 3600\ \text{s/hour} \times 6\ \text{hours/day}) \times (0.2) = 0.266\ \text{m}^2$
So 0.544 m^2 total area needed to distill 20 liters of water daily.

4.2. Distillation efficiency

Efficiency of the solar distillation system is given by eqn. 2.

Efficiency = (actual amount of pure water)/(theoretical amount of pure water)×100 (2)

4.3.Chemical analysis

Chemical analysis of impure (tap and saline) and pure (distilled) water which were used for the study was carried out for pH, electrical conductivity (EC), TDS (Mg^{2+}, Ca^{2+}, Na^{+} ions etc.)

5. Results and Discussions

Experiments were carried out from January to April 2014 and the results for various parameters recorded for some typical days in the mentioned period are given here.The hourly variation of various parameters like solar radiation, ambient temperature, temperature of water in solar still, yield of distillation water for the experiments carried out for different depths of water in solar still, and yield of distillation water for the experiments carried out for different inclination angle for solar collector for typical days in March-April 2014. The amount of sunshine hours was around 10 which was an average of the daily sunshine hours during the duration of data collection.The daily average insolation was about 820 W/m^2. The ambient temperature during the project duration ranged from 29°C to 43°C with the highest temperatures always observed around 11:30-14:00 hrs.

The variation of solar radiation and the ambient temperature of solar distillation unit for the climatic parameters of study area as given in Fig. 2. It can be observed that the maximum solar radiation of 910 W/m^2 is reached in the month of May. The maximum ambient temperature of 43°C was observed at 11.00-14.30 hrs.

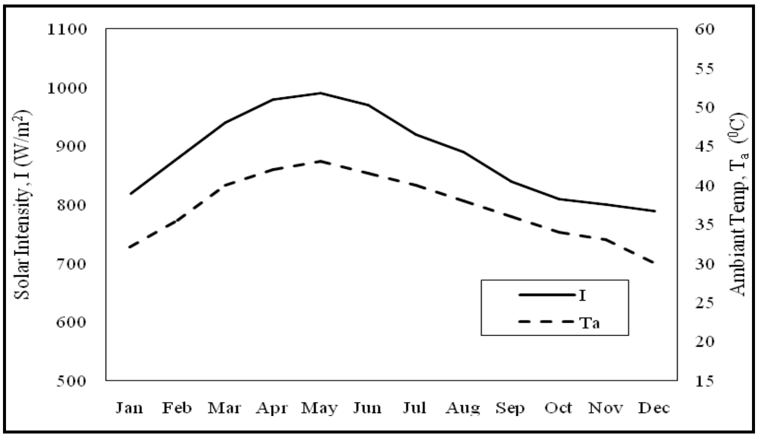

Fig. 2. Monthly variation of solar intensity at the still glass cover and ambient temperature

The effect of water depth on the monthly and annual yield is shown in Fig. 3. This shows that the annual yield decreases with an increase of water depth due to the storage effect. Where it was observed that, there is a decrease in distilled yield when the water mass increased to 0.1 m. The average yield in the still was found to be 3250kg/m^2-year at the least water depth (0.02m), whereas the distilled water yield decreases with higher water depth.

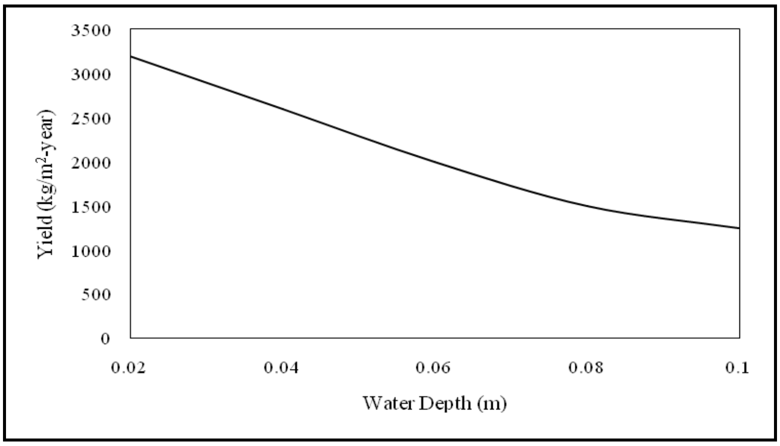

Fig. 3. Effect of water depth on the yearly yield for an active solar distillation system

The annual yield for an active distillation system for different collector inclinations for a given solar still cover inclination is shown in Fig. 4. One can conclude that the yield is maximum at 22°. Hence the computation for annual yield was extended with varying still cover inclinations for 5° and 55° inclination of the glass cover. However, the optimum inclination for annual yield in this case is 22°.

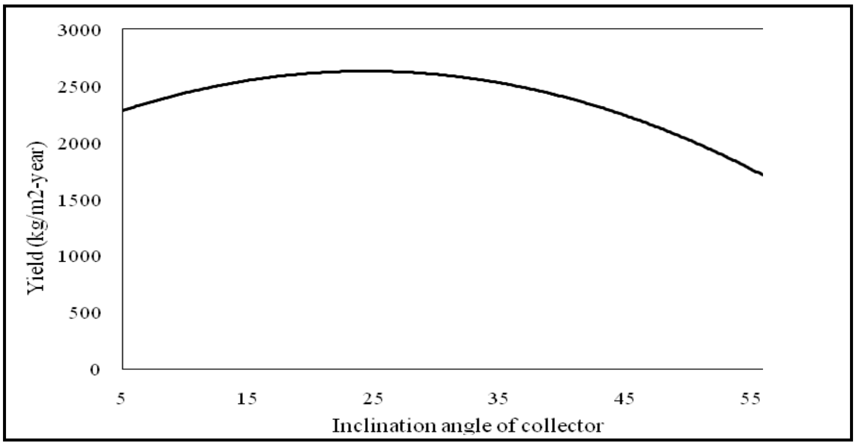

Fig. 4. Effect of collector inclination on the yearly yield of an solar distillation system

Table. 1. Chemical analysis of saline and distilled water samples

Chemical Property	Tap Water	Saline Water	Distilled Saline Water
pH	7.74	9.8	7.10
EC (dS/m)	4.6	34.1	0.52
TDS (ppm)	660	38790	81
Na^{+} (ppm)	421	10752	91
K^{+} (ppm)	2.1	392	1.6
Ca^{2+} (ppm)	1.08	409	0.6
SO_4^{2-} (ppm)	21	2668	2.4
Mg^{2+}(ppm)	2.6	1278	1.1
CO_3^{2-} (ppm)	4.8	210	0.36
HCO_3^{-} (ppm)	18	72	21
Cl^{-} (ppm)	110	18971	18

Chemical analysis of tainted (tap and saline water) and pure (distilled saline water) water which were used for study was carried out for pH, EC, TDS (Mg^{2+}, Ca^{2+}, Na^{+},SO_4^{2-} ,K^{+}, Cl^{-} ions etc.) illustrated in Table 1. As can be observed from the table, chemical analysis of pure (distilled) water had a reduction in the pH, EC and various ions like Mg^{2+},Ca^{2+}, Na^{+},SO_4^{2-} ,K^{+}, Cl^{-}, Carbonate, Bicarbonate etc. compared with the saline water.

Efficiency of solar assisted distillation unit was observed as 41% in November and 59% in May. The plant gives maximum efficiency at 22° slope in summer season and at 35° slope in winter season.

6. Conclusion

Solar distillation is a promising way of meeting potable water demand in remote areas. In this work, solar distillation system was designed and fabricated and experimentation was done. The following conclusions were enlisted on the above discussions made. Efficiency of solar assisted distillation unit was observed as 41% in winter and 59% in summer seasons. On the basis of the results and discussion, it was observed that for maximum annual yield, the optimum collector inclination for a flat plate collector is 22° slope in summer season and at 35° slope in winter season. The maximum distillate yield obtained for basin area of 0.544 m^2 for water depth of 0.02 m for the time period 11:00–14:30 h. The yield decreases as the depth of water in the coupled system increases. The reduction in distillate yield of the coupled system for water depth of 0.06 and 0.04 m compared to 0.02 m is 37.5% and 18.75% respectively.

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