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Water Quality Enhancement Using PV-integrated Triple Slope Solar Still

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Abstract

Underground water and supply water of many local places are dirty and polluted, due to which good quality water is not supplied to houses. Humans use many techniques to enhance the water quality, but most need electricity to run. Solar distillation is one of the purification techniques that enhance water quality by using direct solar energy. This paper covers the experimental analysis of water quality enhancement using the Photovoltaic-Integrated Triple Slope Solar Still (PV-TSSS). Total dissolved solids (TDS), pH value, and Electrical conductivity (EC) were measured as 68 - 71 ppm, 7.3 - 7.4 pH, and 44 - 45 μS/cm, respectively, for enhanced water quality after solar distillation.

Keywords

Solar energy, Solar distillation, Water quality, Total dissolved solids, pH, Electrical conductivity

Introduction

Human beings are moving toward renewable energy because of the limited reserve of non-renewable energy sources, pollution, and global warming. Solar, wind, geothermal, and ocean power are the most common renewable energy sources. On the other side, one of the major issues confronting both underdeveloped and developing countries is the scarcity of safe drinking water. Water is one of the most essential sub-stances. It is a liquid that normally exists on the Earth's surface and is crucial for human use as well as habitats for plants and animals. And presently, fresh water is a major need of all living organisms. Basically, we know that water is a compound of oxygen and hydrogens, but in the water, a lot of elements are available, like minerals, metal contaminants, sodium (Na), calcium (Ca), potassium (K), magnesium (Mg), anions carbonate, sulfate (SO_4^{2-}), chloride (Cl^-), bicarbonate (HCO_3^-), and microorganisms. In drinking water, some of them behave hygienically for health on the basis of property and quantity. Kumar et al. showed a global result that is every year, 3.575 million people worldwide die as a result of water-related diseases [1].

Nowadays, there are many purification technologies available, and most of them are working with the help of electricity means dependent on fossil fuels. Solar distillation is the most effective technology for purifying water, with many advantages of using freely available solar energy. It is a simple technology that is less expensive than the other methods available. Solar distillation has no need for electricity, and it is very simple in construction and has no need for skilled operators as used in other types of purification technology.

Kumar et al. gave a survey that showed the limited use of renewable energy for desalination in a very limited number of cases. The share of total renewable

energy sources used for desalination in the world is only about 0.02 percent of the total energy used [2]. Patel et al. enhanced the water quality by removing Arsenic contaminants from Gomti river water, Lucknow, Uttar Pradesh, India, by experiment on modified double slope solar still with an activated adsorption bed [3]. Obtaining potable water through solar stills is one of the viable and cost-effective thermal applications that utilize solar energy. Desalination of brackish and seawater to provide the needed drinking water fulfills a basic social need [4]. Up to now, many designs have been developed with different specifications, and all the designs have been divided into two types. One is a passive type of solar still, which is a conventional method and uses only direct solar energy as an energy source, but another type is known as an active type which uses direct solar energy and some other heating source. Kumar et al. performed the experiment for single and double effect solar still for passive and active modes and found that in the passive and active types without water flow on the condensation surface; average outputs were 2.2 L/day and 3.9 L/day. Used flat plate collector to make an active type [5]. Pal et al. presented the work on modified basin type double slope solar still by adding multi wick the yield was enhanced and found cotton wick has a higher yield than jute wick by 9.4% [6]. Kumar et al. the cost analysis of triple slope solar still and given the first order differential equation of water temperature and given a theoretical yield was 10.3 L/m^2-day which is higher than all the passive type of model yield [7].

pH value

The concentration of hydrogen ions in water is indicated by pH. Water has a pH of 7.0 in its purest form. The pH should be between 6.5 and 8.5 for drinking purposes [8].

Total dissolved solids (TDS)

TDS are soluble inorganic salts and organic matter. In water, Na, Ca, K, Mg, anions carbonate, SO_4^{2-}, Cl^-, HCO_3^- are the major TDS elements. The ideal TDS for drinking water is less than 500 mg/L. and the maximum allowed limit is 2000 mg/L [8]. The TDS is an essential factor that indicates the amount of metal contaminants, minerals, organic components, and salt dissolved in water.

Electrical conductivity (EC)

EC is a measurement of the amount of dissolved material in water. The higher value of EC means a higher number of dissolved solids. It has a significant relationship with Na. The maximum allowed EC for safe drinking water is 3000 S/cm [8].

Materials and Methods

Description of experimental setup

A 3-D model of PV-TSSS is shown in figure 1. It has three slopes of 25°, 15° and 15° for the south, east and west glass, respectively. Hence it is named PV-TSSS. The dimension of the rectangular base of the basin is 1.0 m x 2.0 m, in which polluted/brackish water is filled. There are three glass covers, on the east, west and south side. Glass covers are inclined at an angle of 15° to achieve a higher film type condensation rate.

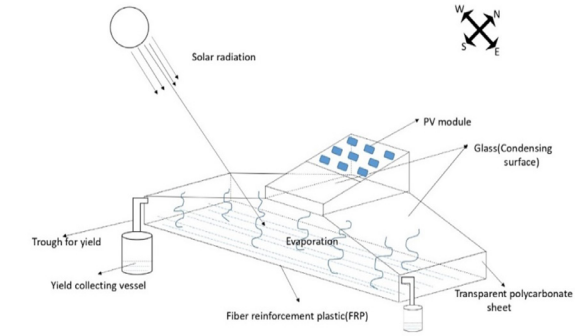

Figure 1: Schematic diagram of PV-TSSS.

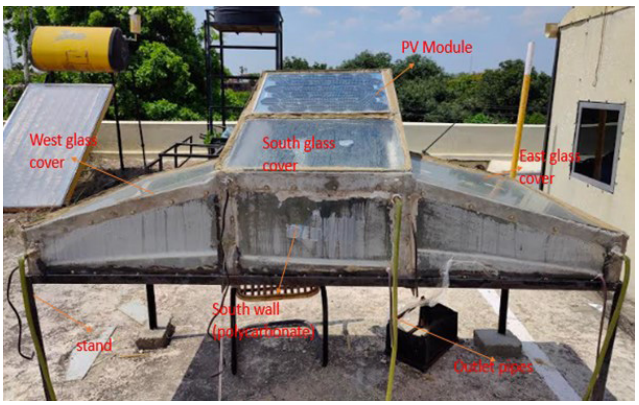

Figure 2: Pictorial view of PV-TSSS.

Condensed water from the glass cover and walls is collected through various troughs. At the end of each trough, an outlet pipe is provided for collecting condensed water. One inlet pipe is used for feeding brackish water into the basin through a hole in the north wall. Fiber-reinforced plastic (FRP) (5 mm thickness) is used as the material for constructing the solar still's base and north wall. East, west and south walls are transparent polycarbonate sheets (5 mm thick). A glass-to-glass PV



Figure 3: Digital TDS meter.

panel facing south is kept at 25° (equal to latitude of Prayagraj, UP). A glass-to-glass PV module is mounted on the setup to generate electric power. Design specifications of the setup have been shown in table 1.

Working principle

The amount of solar radiation that incident the solar still setup is transmitted through the glass and transparent Sheet (from the east, west, and south wall) into the still. The solar radiation is also transmitted through the brackish water to the basin surface, thus raising its temperature. With the collective effect of heat energy from glass, walls, and basin surfaces, water temperature increases and evaporates. The maximum amount of organic, inorganic compounds, and some metal contaminants are blocked from evaporating due to its high evaporation point. Water vapor mixes with air inside the solar still and raises its temperature. This causes a further increase in the kinetic energy of air molecules. When they collide with glass covers and walls, they release the latent heat of vaporization to undergo a phase change from vapor to liquid state. The condensate is collected in the collecting vessel placed outside the solar still at the east, west, and south walls. During the day, the incident solar radiation on solar still further increases the water's temperature and thus the evaporation rate to enhance the yielding. This process removes microorganisms and salinity to get potable water. Moreover, the use of solar PV makes the setup a multi-product setup, producing distilled water and electricity.

Results

The experiment was performed in the month of May to July 2022 in Renewable Energy Laboratory, Department of Mechanical Engineering, MNNIT, Allahabad, 211004, Uttar Pradesh, India.



Figure 4: Digital EC meter.

- Figure 6, figure 7 and figure 8 follows table 3, table 4 and table 5 for comparative analysis of water quality in the month May to July 2022, respectively.
- Solar distillation is processed by evaporation and condensation, and in evaporation, only water molecules get evaporated.
- Figure 6 and figure 7 show that the yield obtained by PV-TSSS has similar results of PH, TDS, and EC in different months. Means output yield quality are same and not dependent on climate change and input tap or brackish water quality.
- Sometimes water gets dirty and polluted due to mud mixing, pathogens generation and faults in water pipelines.

Table 1: Design specification of PV-TSSS.

Parameters	Specifications	Reasons
Location	MNNIT Allahabad, Prayagraj, India	Location Coordinates: 25.4358° N, 81.8463° E
Orientation	East-South-West	Optimum orientation for maximum solar radiation input
Body material (Base and north wall)	FRP	To serve as an insulator at the basin and at the north wall (0.04 W/m K) and act as an opaque surface.
Body material (East, West, and South wall)	Polycarbonate	To allow the solar radiation to pass through transparent material to maximize heat gain by water (88% transitivity), higher life and more robust than acrylic and glass material.
Basin area	2.0 m x 1.0 m	Optimal area to perform required output.
FRP sheet thickness	5 mm	As per market availability and good strength to sustain structure load.
Thickness of Polycarbonate sheet	5 mm	The optimum thickness for balancing heat transfer as compared to FRP sheet and transparency to allow solar Radiation.
Inclination angle of glass cover	15°	Optimal angle to prevent and maximize condensed water to fall back into the basin [9]
Color of the inside of north wall and basin	Black	To allow for the maximum absorption of solar radiation.
Inclination of PV module	25°	Latitude of the location at which setup is installed to get maximum exposure of the Sun
PV module rating	36 cells	18 V and 0.5 amp of DC



Figure 5: Digital pH meter.

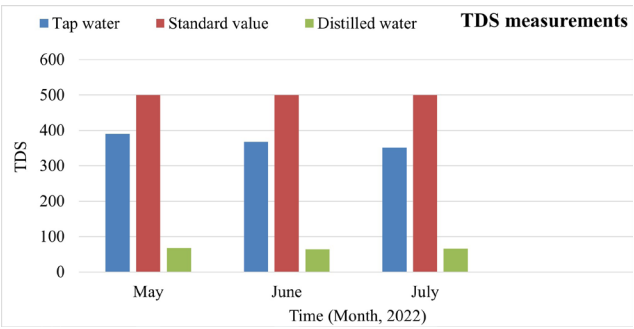

Figure 6: TDS comparison of tap water, distillate water, and standard value in May to July 2022.

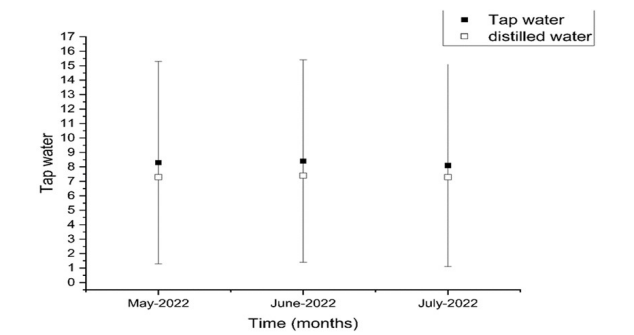

Figure 7: pH comparison of tap water, distillate water, and standard value in May to July 2022.

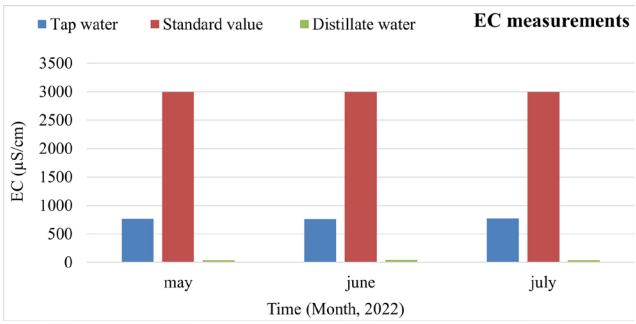

Figure 8: EC comparison of tap water, distillate water, and standard value in May to July 2022.

These factors sometimes show that the water quality is under the permissible limit, but it is not. That way, the use of solar distillation helps to block the maximum amount of additional dirtiness and organic, inorganic compounds and some metal contaminants from evaporating due to its high evaporation point.

- Finally, after condensation, the distilled water was obtained with a very low amount of TDS and EC.
- The quality test of basin water (tap water) and final distillate water for PV-TSSS under study are noted in table 2, table 3, and table 4 and further compared with its standard value. All the tests are examined under 20 - 25 °C.
- The pH of distillate water was lower than tap water in all the tests and under the permissible limit of standard value. It indicates that the removal of hydroxide ions (OH^-) is higher.
- The TDS value following the distillation process was discovered to be far below the standard limit, indicating that both organic and inorganic components had been successfully removed.
- And the EC of obtained distilled water is also lower than

Table 3: Quality parameters analysis of feed water and distilled water obtained from PV-TSSS (May 2022).

Parameters	Tap/underground water (MNNIT, Prayagraj)	Distillate water	Standard value for drinking water (BIS 2012)
TDS value (mg/L)	391	68	Below 500
pH value	8.3	7.3	6.5 - 8.5
EC value (µS/cm)	770	44	Below 3000 (at 25 °C)

Table 2: Specifications of TDS, pH, and EC digital meter.

Instrument name	Model name	Accuracy	Range	Resolution
Digital TDS meter	HM DIGITAL aquapro water tester (TDS)	±0.2%	0 - 5000 ppm	1 ppm
Digital pH meter	HM DIGITAL PH-80	±0.2 pH	0 - 14 pH	0.1 pH
Digital EC meter	HM DIGITAL aquapro water tester (EC)	±0.2%	0 - 9999 µS	1 µS

Table 6: Water quality comparison of solar distillation and some other traditional techniques.

Purification technology's	TDS (ppm)	pH	EC (µS/cm)	Comments
Solar distillation (PV-TSSS)	350 to 390	7 to 7.5	39 to 48	Produces comparatively cleanest water
Boiling	Not effected	6 to 6.5	Not effected	Remove bacteria and some chemicals by vaporization
Filtration (slow sand)	145	7.8	239	Filtration helps to block the solid particles and minor changes in quality
Reverse osmosis (RO) [10]	Below 50 ppm	5 to 7	0.05 µS/cm to 200 µS/cm	Removes ions, unwanted molecules, and larger particles

Table 4: Quality parameters analysis of feed water and distilled water obtained from PV-TSSS (June 2022).

Parameters	Tap/underground water (MNNIT, Prayagraj)	Distillate water	Standard value for drinking water (BIS 2012)
TDS value (mg/L)	368	64	Below 500
pH value	8.4	7.4	6.5 - 8.5
EC value (µS/cm)	772	48	Below 3000 (at 25 °C)

Table 5: Quality parameters analysis of feed water and distilled water obtained from PV-TSSS (July 2022).

Parameters	Tap/underground water (MNNIT, Prayagraj)	Distillate water	Standard value for drinking water (BIS 2012)
TDS value (mg/L)	352	66	Below 500
pH value	8.1	7.3	6.5 - 8.5
EC value (µS/cm)	766	39	Below 3000 (at 25 °C)

tap water and under the standard value. This signifies the effective removal of dissolved solids (metal contaminants).

- PV-TSSS has a higher yield as compared to single and double slope solar still is 10.3 L/m^2-day (theoretical). The average yield obtained in May, June, and July 2022 was 8.7 L/m^2-day. This amount of yield value was near to theoretical value, and error was obtained due to a minor leakage problem. And power production of 9 W obtained from the PV Module.

Discussion

In this study, the water quality measurement of distilled water of PV-TSSS from May to July 2022 was done and found to be near to the same result in the quality of water.

- The experiment is focused on TDS, pH, and EC value parameters for water quality measurements and found that all the values obtained after the distillation process are under the permissible limit of the standard value of drinking water (BIS 2012).
- The pH value of distillate water was 7.3 - 7.4, and for tap water was 8.1 - 8.4.
- TDS value of distilled water was 64 - 68 mg/L, and EC was 39 - 48 S/cm.
- PV-TSSS produces the cleanest form of water, and the produced distilled water can be used in batteries, hospitals, research laboratories, and in chemical processing.
- The low value of TDS and EC also indicates the high removal of organic, inorganic, and dissolved solids contaminants and a low amount of minerals and Ca. So to obtain healthy water, some addition of minerals and ca is needed.
- Water quality comparison of solar distillation and some other traditional techniques has been shown in table 6.

Acknowledgments

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Conflict of Interest

There are no conflicts of interest.

Credit Author Statement

Rahul Patel, Abhay Kumar, and Ashutosh Kumar: Conceptualization, Experimentation, Writing - original draft preparation, Writing - review and editing; Rahul Dev, Vineed Narayanan, and Supriya Yadav: Data analysis, Writing - original draft preparation, Writing - review and editing, Supervision. All the authors read and approved the manuscript.

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