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EVALUATION STUDY OF SOLAR WATER DESALINATION SYSTEM FOR SALINE TRACK AREA OF VIDARBHA REGION

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ABSTRACT

Performance of solar still was evaluated with evacuated tube collector by distilling four water samples collected from different location. The distillate yield from solar still depends on the temperature difference between the water in basin and inner glass cover. Higher the difference, the greater is the yield. The integration of evacuated tube collector with solar still increased the water temperature as well as distillate yield. The daily yield of 8 litre for 0.03 m water depth in basin was obtained in normal sunny days of summer season. The biological and chemical analysis of initial water sample and distillate water sample revealed that the distillate water was fit for consumption.

KEYWORDS: Distillate Yield, Evacuated Tube Collector, Solar Still, Water Depth

INTRODUCTION

Water is fundamental to human life on earth for survival and good health. Access to safe water is a major challenge in many communities in developing countries. As world population and social-economic growth, societies are challenged to provide fresh water to meet those needs for all of their people. Water is the basic necessity for human along with food and air. There is almost no water left on Earth that is safe to drink without purification. Only 1% of Earth's water is in a fresh, liquid state, and nearly all of this is polluted by both diseases and toxic chemicals. For this reason, purification of water supplies is extremely important.

Growing demands of freshwater resources are creating an urgent need to develop self sustained system to meet the demand of fresh water. Among the available purification technologies, solar desalination process proves to be a suitable solution for resolving this existing crisis. This renewable energy technology operates on a basic principle of solar water distillation (Tenathi *et al*, 2012). The sun’s energy heat increases the rate of evaporation. As the water evaporates, water vapor rises and condenses on the glass surface for collection. This process removes impurities such as salts and heavy metals as well as eliminates microbiological organisms. The solar distillation system in this paper includes evacuated tube collector (ETC) subsystem. Evacuated tube collectors utilize solar radiation to heat the work medium water.

MATERIAL AND METHODS

Location of Experiment

The experimentation was carried out at the Department of Unconventional Energy Sources and Electrical Engineering, Dr. PDKV, Akola. Akola is located at latitude 20.7°N and longitude 77.07°E. Akola has tropical savanna climate.

Experimental Set Up

In this experimental set up, a systematic diagram of a single basin active solar distillation unit is coupled with evacuated glass tubes (EGT) is shown in Figure 1, each of which contains an individual absorber tube covered with a selective coating to warm the water additionally prior to sending it to the solar still. An evacuated glass tubes are integrated with the single basin solar still. Inside solar still basin thermocouple fixed at basin liner and to inner glass cover. Because of inclined glass evaporated water particle can collect at the bottom of the glass.

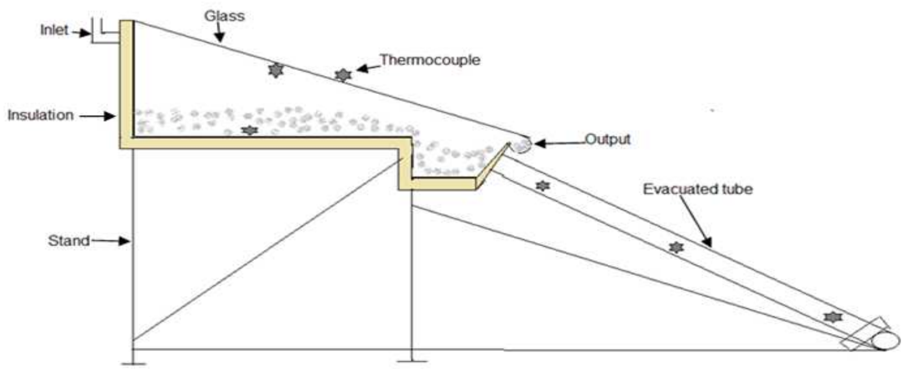

Figure 1: Systematic Diagram of Single Basin Solar Still Coupled with Evacuated Glass Tubes

The water in the basin is heated by the solar energy directly received through the glass cover of the still and the solar radiation passes through the outer glass tube and fluid flowing through the absorber. Solar still has black painted basin of area of $1m^2$ filled with brackish water supplied to it from inlet (Figure 1).The evaporating basin is covered by a sheet of toughened glass having 4 mm thickness which allows the sun rays directed to basin. Angle of tilting the glass cover is 21 degree and 37 degree is EGT collector. A trough running along the bottom side of the glass cover ensures the collection of the potable water toward the collection vessel. The glass also holds the heat inside the still for continuing the evaporation of water inside the basin. An inlet pipe is fixed at the back side of the still for feeding the brackish water. Thermocouples (to measure the various temperatures of solar still) was used at different place. An Evacuated glass tube Collector (2100 mm long, 58 mm) has been used to evaporate the water which is inside the basin. Silicon rubber is used as sealant to prevent the heat losses between the solar still and evacuated glass tubes as well as leakage losses. The side walls and base of the solar still are insulated with polyurethane form having thermal conductivity of 0.016 W/m^2K of 5 cm thick. Depth of water level was maintained 3 cm during the period of investigation work.

Distillate Yield

The hourly distillate yield (kg/m^2h) obtained from solar still can be evaluated from known values of T_w and T_{gi} obtained as (Singh and Singh, 2015)

$$M_{ew} = \frac{h_{ew}(T_w - T_{gi}) \times 3600}{L}$$

Where,

h_{ew} = Evaporative heat transfer coefficient

T_w = temperature of water

T_{gi} = temperature of inner glass cover

L = latent heat of vaporization

Performance Evaluation of Solar Still

The performance of solar still was carried out with fixed water depth of and four sample of different location.

Table 1: Water Sample of Different Location before and After Distillation

Sr No.	Sample of Water		Location
	Before Distillation	After Distillation	
1.	Sample B1	Sample A1	C.A.E.T Akola
2.	Sample B2	Sample A2	Girls Hostel
3.	Sample B3	Sample A3	Shivni
4.	Sample B4	Sample A4	Mothiumri

Water Quality Analysis

Water is a universal solvent. It contains variable quantities of dissolved solids and gases. Sometimes, suspended and colloidal, organic and inorganic material occur as well.

Water is classified as hard or soft according to the concentration of Calcium and Magnesium ions. These ions are present in high concentration, the capacity of water to lather with soap is reduced and such waters are generally term as hard water. A soft water is one which produced lather easily soap. The standard value and methods were used for analysis of water given in table 2

Table 2: Different Methods and Standard Value for Measuring Water Quality Parameters

Sr. No.	Parameter	Standard Value		Method
		BIS	WHO	
1	pH	6.5 to 8.5	6.5 to8.5	pH meter
2	EC,dSm^{-1}	0.75 – 2.25	0.50	EC meter
3	TDS	500	500	Calculated from EC
4	Calcium,$meqL^{-1}$	3.8	3.8	Compleximetric titration method
5	Magnesium,$meqL^{-1}$	2.5	2.5	Compleximetric titration method
6	Sodium,$meqL^{-1}$	4.4	4.4	Flame photometric analysis
7	Potassium,$meqL^{-1}$	0.3	0.26	Flame photometric analysis
8	Chloride,$meqL^{-1}$	4.16	5.2	Mohr's titration method
9	Sulphate, $meqL^{-1}$	5.2	5.2	Turbidimetric method

Water Quality Indices and Suitability

After analysis of water samples for different parameters like total soluble salt, cations and anions, it is imperative to calculate some indices in order to assess the water quality and its subsequent effect on the soil. Important indices of water quality parameters are given below.

Sodium Absorption Ratio, SAR

It is calculated to indicate the sodicity or alkalinity hazard of water

$$SAR = \frac{Na^{+}}{\left[\frac{Ca^{2} + Mg^{2}}{2}\right]^{\frac{1}{2}}}$$

Where concentration of cations is in meq per litre. Based on the values of SAR, water can be rated into different categories of sodicity as under

Table 3: Suitability Class for SAR

Suitability Class	SAR, Rating
Safe	Less than 10
Moderately safe	10 – 18
Moderately unsafe	18 – 26
Unsafe	More than 26

Residual Sodium Carbonate, RSC

This index is important for carbonate and bicarbonate rich water. It indicates their tendency to precipitate Ca^+ as $CaCO_3$.

$$RSC = (CO_3^{\ 2-} + HCO_3^{\ 2-}) - (Ca^{2+} + Mg^{2+})$$

Where concentration of both cations and anions is in meq per litre. Sodicity hazard of RES, water can be rated into different categories of sodicity as under

Table 4: Suitability Class for RSC

Suitability Class	RSC, Rating
Safe	Less than 1.25
Moderately safe	1.25- 2.50
Unsafe	More than 2.5

RESULTS AND DISCUSSION

A solar still coupled with evacuated tube collector was designed and fabricated for distillation of water as per the designed specification as given in Table 5

Table 5: Design Specification of Solar Still Coupled with Evacuated Tube Collector

Sr. No.	Particular	Specification
1	Collector area, m^2	2.10
2	Area of basin, m^2	1.00
3	Area of glass cover, m^2	1.04
4	Angle of inclination of glass, °	21.00
5	Width of basin, m	1.00
6	Number of tube	10.00
7	Length of tube, m	2.10
8	Outer diameter of tube, m	0.058
9	Inner diameter of tube, m	0.048
10	Area of tube, m^2	0.19
11	stand height, m	1.25

Performance of Solar Still

The solar still coupled with evacuated tube collector was evaluated at full load conditions. Temperature of water in the basin, glass cover inner surface, glass cover outer surface and water temperature in evacuated tube were recorded with the help of calibrated thermocouple in combination with digital temperature indicator. The results obtained from experiments are summarized as follows:

Performance of Solar Still for Sample 1

Figure 2 shows the variation of temperature and solar radiation with respect to time for sample 1.It has been observed that as intensity of solar radiation increased the temperature also increased and it was found to be maximum of about 43˚c at 14.00 h (Ganadason et al, 2011).

Average temperature of evacuated tube was found to be 68.08˚C with corresponding average ambient temperature of about 39.25˚C and solar radiation of about 541.72 W/m^2. As temperature in evacuated tube were measured to determine the useful energy from the collector, similarly the temperature of inner glass surface and outer glass surface was found to be in the range of 36.1 to 87.5 ˚C and 35.1 to 81.9, respectively. The temperature of water in the basin was found to be in the range of 38.8 to 91.70˚C as it is the temperature which is responsible for evaporation of water in the basin (table 6) (Badran, 2011).

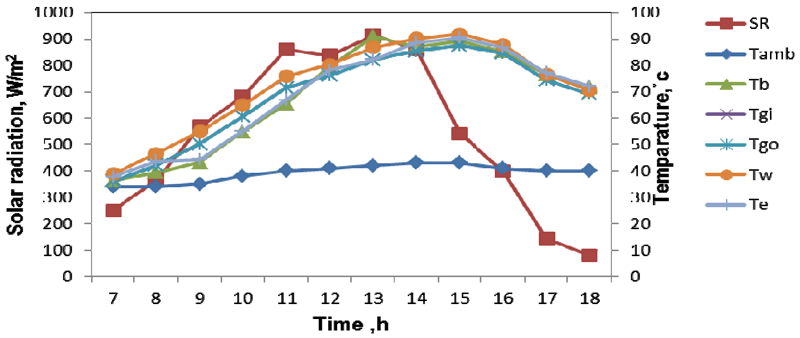

Figure 2: A Hourly Variation of Temperature and Solar Radiation with Respect to Time for Sample 1

Table 6: Variation of Temperatures and Solar Radiation with Time for sample 1

Time (h)	T_{Amb} (^{0}C)	T_b (^{0}C)	T_{gi} (^{0}C)	T_{go} (^{0}C)	T_e (^{0}C)	T_w (^{0}C)	Solar Radiation (W/m^2)
7.00	34	36.2	36.1	35.1	37.60	38	250.6
8.00	34	39.5	42.1	37.7	41.00	46.2	363.2
9.00	35	43.2	50.2	40.3	43.23	54.2	567.6
10.00	38	54.7	60.7	55.1	54.50	64.4	683.0
11.00	40	65.4	71.5	61.3	65.83	74.9	860.6
12.00	41	79.4	76.1	69.9	76.10	79.8	836.8
13.00	42	90.8	82.1	72.4	82.10	85.8	913.7
14.00	43	87.0	85.4	72.7	88.17	89.2	862.4
15.00	43	89.1	87.5	74.9	90.30	91.6	542.0
16.00	41	85.2	84.6	81.9	87.30	87.1	397.3
17.00	40	76.5	74.3	60.8	78.40	76.2	142.8
18.00	40	71.6	69.2	58.0	18.00	70.5	80.6
Average	**39.25**	**68.22**	**68.32**	**60.01**	**68.08**	**71.49**	**541.72**

Figure 3 shows the variation of daily distillate output with wind speed. The distillate output increased as wind speed increased. As wind speed increased water temperature in basin and glass temperature decreased because of heat was removed more rapidly from still cover by convection. Hence temperature difference increased with increase in wind velocity therefore distillate output increased as wind velocity increases during a day and distillate yield decreased with wind velocity during night because of increase in heat losses due to wind. Due to increase in wind velocity cover temperature was decreased and the distillate yield increased. The wind velocity was found to be in the range of (0.3 to 4.2 m/s) with corresponding increase in distillate yield of about 913 ml (EI-Sabaii, 2000).

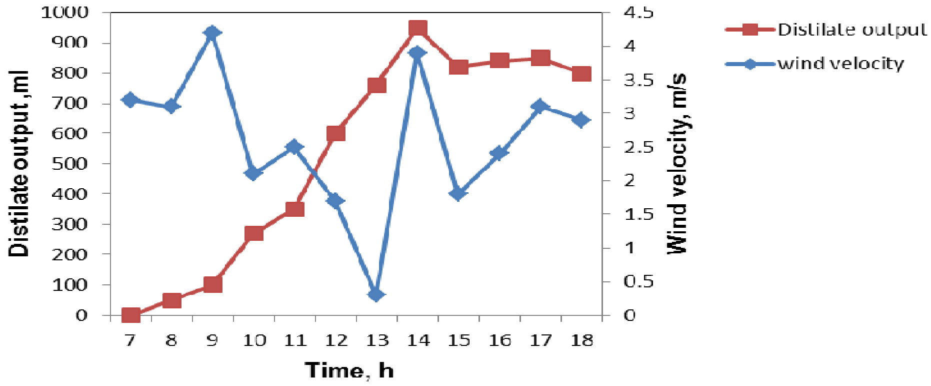

Figure 3: A Variation of Daily Distillate Yield and Wind Speed with Respect to Time for Sample 1

Table 7 depicted that the wind velocity was found be maximum at 14 h (3.9 m/s) with corresponding distillate yield of about 930 ml. During early hours the wind velocity the wind velocity was found to be maximum (4.2 m/s) with corresponding distillate yield of 100 ml. This was due to the time lag between evaporation and condensation process (Arora *et al*, 2011). Total distillate yield was found to be 8.30 liter for sample 1 in 24 hours

Table 7: Variation of Ambient Temperature, Wind Velocity, Solar Radiation and Distillate Yield with Time for Sample 1

Time (h)	T_{Amb} (^0C)	Wind Velocity (m/sec)	Solar Radiation (W/m^2)	Distillate Yield (ml)
7.00	34	3.2	250.60	0
8.00	34	3.1	363.20	50
9.00	35	0.3	567.60	100
10.00	38	2.1	683.00	270
11.00	40	2.5	860.60	350
12.00	41	1.7	836.80	600
13.00	42	4.2	913.70	760
14.00	43	3.9	862.40	950
15.00	43	1.8	542.00	820
16.00	41	2.4	397.30	840
17.00	40	3.1	142.80	850
18.00	40	2.9	80.60	800
Average	**39.25**	**2.6**	**541.72**	**Total yield = 8.30L**

Figure 4 shows the variation of distillate yield and solar radiation with respect to time. Performance of still mainly depends on the intensity of solar radiation absorbed by absorber plate and hence increased in distillate yield due to increased difference between temperature of water and glass cover temperature. It was observed that performance of still directly affected by solar radiation particularly at 14 h when maximum production was observed i.e 950 liter with corresponding maximum solar radiation of 862.4 W/m^2. Increased in solar radiation resulted in increase of water mass temperature, hence it would cause evaporation at faster rate. Therefore, the decreased solar radiation intensity would lower the system distillate yield. The solar radiation curve followed the same path as that of the distillate yield (Al-Hinai et al, 2002).

From table 4.4 it was observed that solar radiation was found to be low during late hours with corresponding distillate yield of about 800ml. It was observed that due to the increase in solar radiation the temperature of water in the basin increases until the intensity of radiation decreases. Therefore the distillate yield was maximum during late hours as compared to earlier. This results were found to be in agreement of (Yadav, 2015). The solar radiation was found to be in the range of 80.6 to 913.7 W/m^2 with corresponding distillate yield of about 8.30 liter.

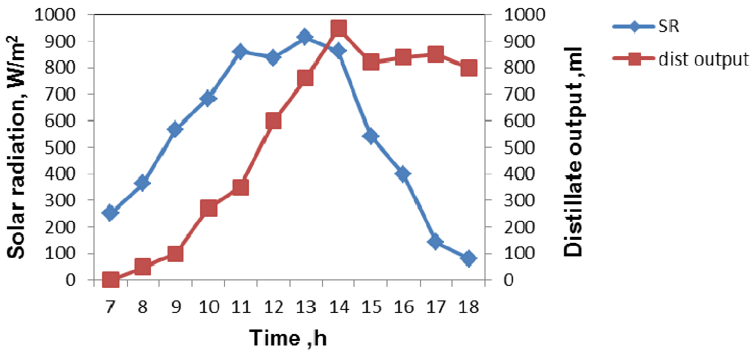

Figure 4: A Variation of Distillate Yield and Solar Radiation with Respect to Time for Sample 1

Figure 5 shows the variation of ambient temperature and distillate yield with respect to time. Due to increased in ambient temperature production rate of solar still increased with temperature difference between basin and inner glass cover surface of about 5^{0}C. The peak value of ambient temperature was found to be 43°C with corresponding distillate yield of about 950 liter because of sudden rise in ambient temperature. The ambient temperature was found to be in the range of about 34 to 43 $^{\circ}$C (table 7). Similar results were observed by (Nafey *et al*, 2000).

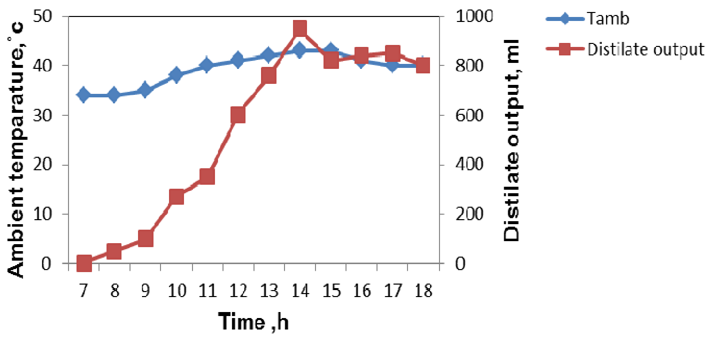

Figure 5: A Variation of Ambient Temperature and Distillate Yield with Respect to Time for Sample 1

Water Analysis

Chemical analysis of impure and pure water which were used for study was carried out for pH, EC, TDS, $Mg^{2+,}$ Ca^{2+}, Na^{+} ions etc. The data obtained during the experimentation is presented in Table 4.3. It was observed from the table no, the chemical analysis of pure (distilled) and impure (saline or tap) water has shown reduction in the pH, EC and various cations like $Mg^{2+,}$ $Ca^{2+,}$ Na+, and anions Cl-, carbonate, bicarbonate etc. in the pure water.

Table 8: Chemical Properties of Water Before and After Distillation

Sr. No.	Parameter	Before Distillation				After Distillation			
		B1	B2	B3	B4	A1	A2	A3	A4
1	pH	7.02	7.03	7.31	7.23	7.01	6.98	6.99	6.88
2	EC	1.49	1.50	2.40	3.04	0.03	0.04	0.04	0.06
3	Na^{++}	24.43	25.40	65.46	92.0	00	00	0.98	0.98
4	TDS	953.60	960	1536	1945.6	19.2	25.6	25.6	38.4

Table 8: Contd.,

5	Ca + Mg	28.0	22.00	31.60	60	3.6	5	4	2
6	Cl-	22.00	24.00	40.00	48	2	2	5.4	5.7
7	HCO_3	4.66	5.22	6.52	6.9	0.04	0.04	0.12	0.12

The data presented in table no 8 indicated the values obtained for cations and anions during the course of investigation. Based on the data it was observed that the considerable amount of contains Ca +Mg was found in the range of 22 to 60meqL^{-1} before distillation while it was reduced to 2 meqL^{-1}after distillation, which was followed by sodium 24.43 to 92 before distillation and 0 to 0.98 meqL^{-1}after distillation. Similarly, in respect of anions It was observed that bicarbonate was found to be in between 4.66 to 6.9 meqL^{-1}before distillation and 0.13 to 0.27 meqL^{-1} after distillation. The chloride was 22 to 48meqL^{-1} and 0.04 to 0.12. meqL^{-1} before and after distillation respectively.

In case of total dissolved solid, it was reduced to 19.2 and 38.4 after distillation which was in the range of 953 to 1946 ppm for before distillation. The electric conductivity of impure water sample was found in the range of 1.49 to 3.04 dSm^{-1}which was reduced remarkably to 0.03 to 0.06 dSm^{-1}showing the significance of adopted methodology for getting good quality distilled water.

CONCLUSIONS

The distillate yield from solar still depends on the temperature difference between the water in basin and inner glass cover. Higher the difference, the greater is the yield. The integration of evacuated tube collector with solar still increased the water temperature as well as distillate yield. The daily yield of 8 litre for 0.03 m water depth in basin was obtained in normal sunny days of summer season. The distillate yield were found to be 8.38,8.23,7.45,8.25 ml for sample 1,2,3 and 4 at corresponding average wind velocity of 2.6,1.43,1.94,2.8 m/s, respectively thus the productivity increased with the increase in wind speed. Chemical analysis suggest that the distilled water fit for human consumption.

REFERENCES

1. Al-Hinai H., Al-Nassri M. S.,Jubran B.,(2002). Effect of climatic, design and operational parameters on the yield of a simple solar still, Energy conversion management 43: (1639-1650).
2. Arora S., Shobhit C., Udayakumar R. and Ali M. (2011) Thermal analysis of evacuated solar tube collectors. Journal of Petroleum and Gas Engineering Vol. 2(4): 74-82
3. Badran O. (2011) Theoretical analysis of solar distillation using active solar still.Int. J. of Thermal & Environmental Engineering Vol. 3(2):113-120
4. El- Sebaii A. A. (2000). Effect of wind speed on some designs of solar stills, Energy conversion management 41 :(523-538).
5. Gnanadason M. K., PalanisamySenthil Kumar, Sivaraman G. (2011) Design and Performance Analysis of a Modified Vacuum Single Basin Solar Still.Smart Grid and Renewable Energy, 2: 388-395
6. Nafey A. S., Abdelkader M., Abdelmotalip A., Mabrouk, (2000). Parameters affecting solar still productivity, Energy conversion management41:(1797- 1809)
7. Singh P. and Singh J. (2015) Performance Evaluation of Single Basin Solar Still. World Academy of Science,

Engineering and Technology International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering Vol. 9(10)

8. Tenthani C., Madhlopa A., and Kimambo C. Z. (2012) Improved solar still for water purification. Journal of sustainable energy & environment 3 :111-113

9. Yadav S. and sudhakar K. (2015), Different design of solar still: a review, Renewable sustainable energy review 47 :(718-731).