Year around performance analysis of double basin solar still with evacuated tubes

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Abstract: Solar distillation is a simple technique to convert available brackish or saline water into potable water by use of solar energy. Solar still is a device in which solar distillation process occurs. But due to its lower distillate output, it is not used for industrial and domestic potable water need. Hence, the main aim of the present research work to test double basin solar still with Evacuated tubes annually and compared with other researchers work in terms of distillate output. From the one year analysis, it has been found that the, distillate output of present solar still found 12 liter per day and energy payback time and cost or potable water per day is around 117 days and 0.51 Rs.

Keywords: Double basin solar still, Evacuated tubes, cost of water per day, energy payback time

I. INTRODUCTION

Water is essential for the survival of all living things. Three quarters of the earth's surface is covered with water, and through a process called the hydrologic cycle it is distributed to most of the land masses. The hydrologic cycle is simply the evaporation and precipitation of water supplied from the oceans, surface water, and transpiration of plants. The evaporated water condenses into clouds, which are carried away by winds to different locations and eventually released in the form of rain or snow. The hydrologic cycle is continuously repeated and is powered from the solar energy, which causes water evaporation and moving the wind. As the water falls through the atmosphere, it may dissolve gases and accumulate fine particles such as soot and factories emissions. Reaching the ground, the water will pick up organic materials, minerals and clays. Surface water is highly affected by seasonal changes. The water temperature as well as the composition may vary considerably with time over the year.

During summer months, bacteria will grow more readily. In cold climate during winter months, the solid contents of surface water are increased due to ice formation. During autumn, decaying of organic matter such as leaves increases the organic matter concentration in the surface water. The transparent cover receives and transmits radiation into the still. Likewise, the condensation takes place along its lower surface. Also, it should suppress thermal radiation in the atmosphere. Glass is the best material to cover (Duffie et al. [1] since it has higher transmittance and less reflectivity. Also glass is opaque to thermal radiation. For higher latitude places, single slope still is preferable, and for northern Chemosphere the still faces south (Fath et al. [2]. The inclination of the cover is optimized to collect the accumulated condensate through drain before it drops down to the basin. The condensate mass accumulation depends on solar intensity and condensation rate. They also conducted indoor simulation experiments and found that the production rate is higher for 30° cover inclination. Glass temperature affects the condensation rate at its lower surface.

Lower glass surface temperature increases the circulation of air inside the still which enhances convective and evaporative heat transfer between basin water and glass. Also, cooler glass lower surface increases condensation. The glass cover temperature is reduced by continuous flow (Abu-Hijleh [3] or intermittent flow (Tiwari and Madhuri, 1985) of raw cooling water on the cover. The cooling water gains latent heat from condensing water and regenerates it in the basin. The second effect of evaporation and condensation takes place between the covers as shown in. Bassam A/K Abu-Hijleh et al. [4] result shows increase in production by 20%. Yousef and Mousa Abu-Arabi [5] results also show that, the use of the film-cooling increases the still efficiency up to 20%. Lawrence et al. (1989) had carried out research work on varying mass flow rate of water of upper side of glass cover to see its effect on distillate output and efficiency of solar still. They found that, enhancement of distillate output and efficiency was 9% and 5%, respectively, when the mass flow rate was 1.5 m/s. Wind velocity is also having its effect on the temperature of the glass. At higher wind velocity, due to higher convection heat transfer from the glass to atmosphere the productivity of the still is increasing (Yousef et al., 2004 and El-Sebaii [6] Tiwari and Rao [7] theoretically analyzed the effect of water flowing over the glass cover in a single basin still. The result shows the productivity is increased with flowing water over the glass cover. Also, the yield decrease when the water flow rate increases. Pr. K. Abdenacer and S. Nafila [8] had conducted lots of experiments on passive and active solar still based on water temperature and efficiency and found that, the active solar still always increased distillate output compared with passive solar still. Sebaii et al., [9] had fabricated passive solar still to find the optimum glass cover inclination.

They performed studies to see best glass cover inclination during winter and summer. It was found that the optimum glass cover inclination was 33.3° N (Latitude of the place) for both summer and winter. M.K. Phadatare, S.K. Verma, [10] had evaluated the performance of a solar still with 4 mm plexiglass as a cover material to see the effect on the internal heat transfer coefficient and distillate output by varying the depth of brine. They found that, plexiglass of 4 mm thickness found an enhancement of distillate output by 2 cm brine thickness . Mahesana is located in Gujarat district and it has a good blessing of sun radiations. Hence, numerous number of researchers have done in Mahesana district on solar still [16-37]. (Panchal (2010, 2011, 2016a, 2016b), Panchal et al.

(2010), Panchal, Doshi et al. (2011), Panchal, Patel et al. (2011), Panchal and Shah (2011a, 2011b, 2012a, 2012b, 2013a, 2013b, 2013c, 2013d, 2014a, 2014b, 2014c, 2014d), Panchal, Thakar, and Thakkar (2014), Panchal and Patel (2016), Panchal and Mohan (2017) and Panchal and Sanjay (2017)).

The main aim of this present research work to investigate the performance of double basin solar still with vacuum tubes annually and compared its distillate output with other researcher work.

II. EXPERIMENTAL SET UP

Fig.1 Experimental set up of double basin solar still with evacuated tubes

Fig. 1 shows double basin solar still with evacuated tubes. . The overall size of the top basin used is 1000 mm *1000 mm *500 mm, and the upper basin is 1006 mm *1000 mm *500 mm. The lower basin is black coated to increase radiation absorption. Two window glass of 4 cm thickness provided in the present experimental set up. The lower glass cover is fixed at 8 mm above the basin bottom and upper cover was fixed at 10 cm above lower cover. An insulation of 5 cm in thickness was provided on all sides to reduce heat losses. Here polyurethane foam (PUF) with a thermal conductivity of 0.025 W/m2 K was used in the present experiment. The evaporated water in the lower basin and the upper basin was condensed by plane glass about 4 mm in thickness. The condensed water of the lower and upper basins was collected by measuring jar A silicone rubber sealant was provided to hold the toughened glass in contact with the still surfaces. A total of 4 holes was made on the lower and upper basins for the location of thermocouples. Here, 14 vacuum tubes were coupled with a hole about 6 cm in diameter in the lower side of the top basin. The inside pipe is coated with a selective coating of aluminum, nickel alloy compound (Al-N/Al) for better solar radiation absorption (>93%) and minimum emittance (<6%) The vacuum tubes were linked up to the still stand at an angle of 45° with respect to the horizontal axis. Rubber gaskets were provided to secure the vacuum tubes attached to the top basin of the solar still. The bottom part of the vacuum tube was connected to a sponge cloth to prevent breakage of vacuum tubes.

- Here, the main characteristic is the application of the double basin passive solar still is for the enhancement of distillate output. Compared with conventional passive solar still, it has following merits:
- The generated freshwater can quickly drip because of flow distance of the condensed water on the condensation surface is short and the inclination of condensation surface is large
- The condensation resistance of the water vapour is reduced due to water inside upper basin
- The area of condensation surface is increased, which leads to heat transfer efficiency of water vapour
- Lower basin is coupled to vacuum tubes, hence it continuous receives hot water from vacuum tubes, hence the distillate output of lower basin is higher.
- Latent heat of condensation of lower basin is utilized to evaporate water of the upper basin, which already receives solar energy, hence the distillate output of upper basin will also enhanced compared with conventional solar still.
- The total distillate output of present solar still will be summing of lower and upper solar still and it will be remains higher compared with conventional single basin passive solar still.

III. RESULT AND DISCUSSION

3.1 Hourly variations of solar intensity versus time for double basin solar still during summer and winter climate conditions

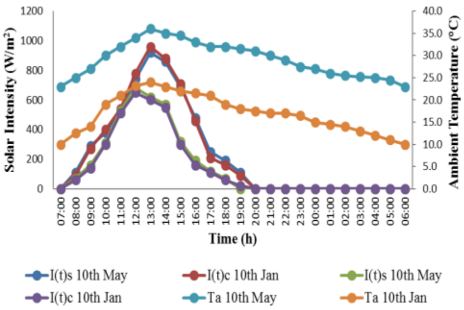

Fig.2. Hourly variations of solar intensity versus time during summer and winter conditions

Fig.2 shows that the hourly variations of solar intensity and ambient temperature on 10th May and 10th January. 2013. It shows that, solar radiation increases until it reaches its maximum value at mid-day, then it decrease again. This curve is observed in both summer and winter experimental days. The highest recorded value of solar intensities was 980 and 960 W/m^2 and 600 and 620 W/m^2 for vacuum tubes and solar still during 10th May and 10th January 2013. The maximum ambient temperature is found about 36 °C and 24 °C during 10th May and 10th January, 2013.

3.2 Lower and upper basin water temperature variations for Double basin solar still with evacuated tubes

Fig. 3 shows the variation of water temperatures of lower and upper basin during summer and winter experimental days of 10th May and 10thJanuary, 2013. It is shown that, maximum temperature of water inside the upper and lower basin remains higher during the summer experimental day compared with winter experimental day due to higher solar radiation and ambient temperature of the location. It is also shown that, water temperature increased during the day until it reaches its maximum value at 15:00 pm and then reduced slowly during summer experimental day and winter experimental day found maximum value at 14:00 pm and then reduced drastically compared with summer experimental day. The reason is the volumetric heat capacity of water inside lower and upper basin is responsible for the slow and drastic reduction in water temperature. Water temperature reaches its maximum value was 90.2 °C and 78.4 °C during summer experimental day and 63.2°C and 56.7°C. Climate condition always affects the temperature gained by passive solar still during summer and winter experimental day, hence summer and winter experimental day, maximum temperature achieved at 15:00 pm and 14:00 pm. It is also observed that, the lower basin water temperature remains high throughout the day during summer and winter experimental day, due to augmentation of vacuum tubes. During winter experimental day, temperature is found more than 60 °C during 14:00 pm. Generally, water temperature of passive solar still remains lower during winter, but here lower basin removes excess heat to the upper basin, hence water temperature remains higher during peak hours. It is a main benefit found in this arrangement of passive solar still.

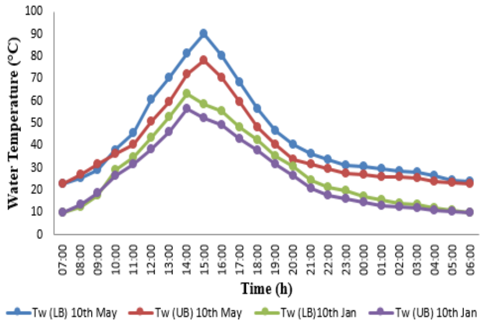

Fig.3: variations of water temperature inside lower and upper basin in Double basin solar still with evacuated tubes

3.3 Average hourly variations of water temperature in Lower and upper basin in Double basin solar still with evacuated tubes

Average water temperature is very important parameter for performance analysis of double basin solar still with vacuum tubes. Hence, individual justifications required for lower basin water temperature and upper basin water temperature. Most crucial basin of present passive solar still is "lower basin", due to augmentation it with vacuum tubes. Fig. 4 represents average water temperature of inside lower basin during July – 2012 to June - 2013. It is clearly found that, water temperature remains lower during early morning then it increases up to mid day hours then reduces slowly during off-sunshine hours for all experimental days. Higher and lower average water temperature is found during experimental days of May and January 2013 due to difference between the higher and lower solar intensity and ambient temperature. Average water temperature of monsoon experimental days is lies between the summer experimental and winter experimental days. It is also found that, after sunshine hours, water temperature inside lower basin is not changed drastically but slowly compared with lower basin due to its volumetric heat capacity.

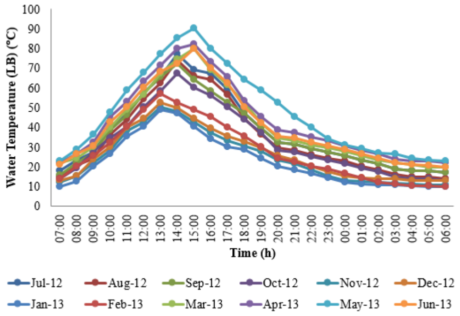

Fig. 4: Average hourly variations of lower basin water temperature double basin solar still with evacuated tubes

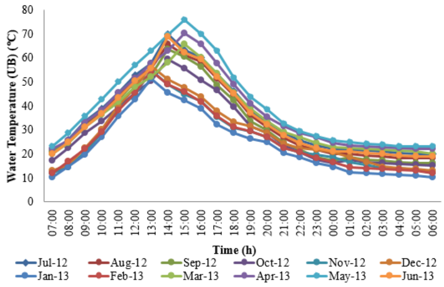

Fig. 5: Average hourly variations of upper basin water temperature double basin solar still with evacuated tubes

Fig.5 represents average temperature variations of upper basin during summer and winter experimental days. Upper basin received solar radiation from top and excess heat from lower basin, hence its average water temperature during summer and winter experimental days remain higher compared with conventional passive solar still. Due to higher water temperature inside top basin, performance of upper basin is also higher compared with ordinary passive solar still due to higher water temperature inside it. Higher upper basin average water temperatures found during May 2013 and lower during January, 2013. Remaining average experimental days water temperatures found between above two months.

3.4 Hourly variations of distillate output of lower and upper basin during summer and winter climate conditions of double basin solar still with evacuated tubes

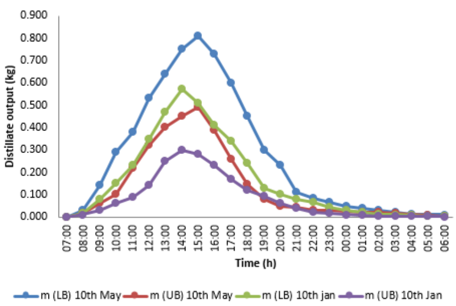

Fig. 6: Hourly variation distillate output for lower and upper basin of double basin passive solar still

during summer and winter experimental days

Fig. 6 represents the hourly variation of distillate output for lower and upper basin of the solar still during the summer and winter experimental day. It is found that, higher water and lower glass cover temperature difference found higher distillate output inside passive solar still. Here, lower basin is attached with vacuum tubes and received lower solar radiation passing through the upper basin glass cover and hot water through vacuum tubes, hence distillate output remains higher compared with upper basin. In normal passive solar still, distillate output increased from morning to midday due to better availability of sunrays and then decrease due to unavailability of sunrays. But in this still, after sunshine hours, due to the higher heat capacity of water, lower basin acts as a heat reservoir and maintains higher water temperature for distillate output and also release the latent heat of condensation to upper basin for producing distillate output. Hence, not only lower basin, but also an upper basin produces the distillate output after sunshine hours. During summer experimental day, maximum water temperature gained between 15:00 pm and 14:00 pm and winter experimental day gained between 14:00- 15:00 pm due to the climate condition effect on distillate output. Lowest ambient temperature and climate condition gained peak distillate output early and summer gained during after midday (15:00 pm to 16:00 pm). It is also demonstrated that, after sunshine hours (after 17:00 pm) distillate output is decreased drastically in passive solar still due to absence of solar radiation. But, here same condition is found during winter climate condition, but not in summer. In winter climate conditions, it is demonstrated that, after 17:00 pm there is a marginal gap between the output of lower basin and upper basin, but there is a big gap between the output of lower and upper basin in summer climate condition. The reason is, during summer climate condition, the temperature of water remains higher, and hence the storage effect is considerable due to 30 kg water in the lower basin and hence, the distillate output remain higher during summer climate conditions compared with winter climate conditions.

3.5 Hourly Variations of Average Distillate Output for Lower Basin inside double basin solar still with evacuated tubes

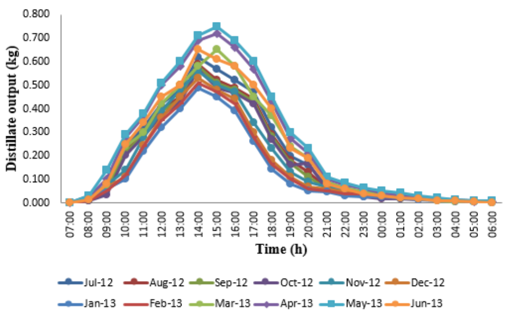

Fig. 7: Hourly variations of average distillate output of lower basin inside double basin solar still with evacuated tubes

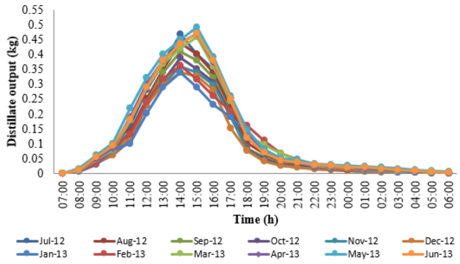

Fig. 8: Hourly variations of average distillate output of upper basin inside double basin solar still with evacuated tubes

To see the overall performance of Double basin solar still with evacuated tubes , the average distillate output of lower and upper basin play an important role. Figs. 6 and 7 represent hourly variations of distillate output of lower and upper basin during a one year time period of July 2012 to June 2013. It clearly shows similar curve trends for increment and decrement in distillate output for lower and upper basin. It is also shown that, average maximum distillate output gained during the month of May, 2013 and lower during the month of January, 2013 for lower and upper basin

3.6 Comparison of average distillate output of lower and upper basin of double basin solar still with evacuated tubes

Table 1 represents the average daily and monthly distillate output of lower and upper basin for performance analysis of solar still with constant depths of water inside lower and upper basin during July 2012 to June 2013. It is shown that, there are total 292 sunshine days in entire year during July-2012 to June 2013. It is also representing that, average daily distillate output of lower basin is found 5.23 kg and upper basin is 2.89 kg. Hence, total average daily distillate output of solar still is 8.13 kg.

Table 1: Average Daily and Monthly Distillate Output of Lower and Upper basin of double basin solar still with evacuated tubes during July 2012-June 2013

Month of Year	No of clear sky days	Average daily distillate output of Lower basin (kg)	Average daily distillate output of Upper basin (kg)	Average Monthly distillate output of Lower basin (kg)	Average Monthly distillate output of Lower basin (kg)	Average daily distillate output of DBSWVT (kg)
Jul-12	25	5.4	2.7	135	14.58	8.1
Aug-12	23	5.1	2.95	117.3	15.045	8.05
Sep-12	22	4.9	2.9	107.8	14.21	7.8
Oct-12	20	4.80	2.87	96	13.776	7.67
Nov-12	22	4.71	2.8	103.62	13.188	7.51
Dec-12	23	4.6	2.5	105.8	11.5	7.1
Jan-13	17	4.4	2.1	74.8	9.24	6.5
Feb-13	20	4.8	2.6	96	12.48	7.4
Mar-13	31	5.9	3.1	182.9	18.29	9
Apr-13	30	6.1	3.32	183	20.252	9.42
May-13	31	6.3	3.62	195.3	22.806	9.92
June-13	28	5.8	3.32	162.4	19.256	9.12
Average	292	5.23	2.89	129.99	15.38	8.13

3.7 Economic analysis of double basin solar still with evacuated tubes

Table 2: Fabrication cost of Double basin solar still with evacuated tubes

Details of component	Quantity	@ Materials	INR
Mild still Plate	36 kg	R_{MS} = Rs. 78/kg	2808
Evacuated Glass Tubes	14	R_{EGT} = Rs. 200/pic.	2800
Silicon Seal	14	R_{ss}= Rs. 50/pic.	700
EGT Cap	14	R_{cap}= Rs. 50/pic.	700
Glass cover(Glass thickness 5mm)	1.043 m^2	R_{glass} = Rs. 190/m^2	198
Glass Tray(Glass thickness 5mm)	1.5 m^2	R_{glass} = Rs. 190/m^2	285
Thermocouple wire (K- Type)	30 m	$R_{k\text{-}type}$ = Rs. 35/m	1050
Sealant	4 m	R_{selant}= Rs. 25/m	100
Fiber reinforced plastic	2.3 m^2	R_{FRP} = Rs. 180/m^2	414
Stand	1	-	200
Manufacturing cost	-		1300
Total			10555

Before supply any new passive solar still in market, its economic analysis plays important role. Here, economic analysis shows capital cost of Double basin solar still with evacuated tubes, cost of potable water produced and payback time. Hence, Table 2 represents the capital fabrication cost. It is shown that, total capital cost is found 10555 INR. Table 3 represents annual cost of potable water produced by solar still and it is found 0.51/kg INR and Table 4 represents the payback period of solar still is 117 days.

Table 3 : Annual cost of water produced in solar still

Particular	Cost INR
Principal cost (P)	10555
Salvage Value (S) (10% of principle value)	1055.5
Life of still (n)	20
Interest rate (i)	10%
Capital Recovery Factor (CRF)=	0.106079
Sinking Fund Factor (SFF)=	0.006079
Annual First Cost = (CRF*P)	1119.666
Annual Salvage Value (SFF*P)	64.16647
Annual Maintenance Cost (Rs. 0.15* Annual Cost)	167.95
Annual Cost /m^2 = Annual first cost + Annual maintenance cost- Annual salvage value	1223.45
Annual Distillate output of solar still	2374.69
Annual cost of distillate output per kg = Annual First Cost/Annual Yield	0.5152

Table 4 : Energy payback time of solar still

Fabrication cost	10555
Operating cost	Rs 5/day
Maintenance cost	Rs 5/day
cost of feed water	Rs 1/day
Cost of distilled water	Rs 12/kg
Annual distillate output of present solar still	8.13 kg/day
Cost of water produced /day	97.56 INR
Subsidized cost given by government sectors is taken as 4%,	
Net Profit = cost of water produced - operating cost-Maintenance cost- cost of feed water	480 INR
Payback period = (Investment - Subsidized cost)/(Net Profit)	117 Days

3.8 Comparison of double basin solar still with evacuated tubes with other researchers work.

Table 5 : Comparison of present solar still with other researchers work

Sr. No.	Name of Researcher	Type of attachment with passive solar still	Increase in distillate output (%)
1	Dev and Tiwari, (2012)	Evacuated tube collector coupled with passive solar still	32%
2	Sampathkumar Karuppusamy (2012)	Evacuated tube collector with granite gravel	59.78%
3	Xiong. *et al*. (2013)	Multi-effect passive solar still integrated with evacuated tubes and corrugated sheet	90%
4	Z. M. Omara et al. (2013)	Evacuated tubes with wick materials	108%
5	Present work	Double basin solar still with vacuum tubes	225%

Generally conventional passive solar still received 2.5 kg average distillate output. Hence, Table 5 represents comparison of present work with other researchers work on passive solar still in terms of percentage increase in distillate output.

IV. CONCLUSION

From the present research work, following points are concluded:

- Present double basin solar still with evacuated tubes found impressive distillate output during daytime and night time.
- Present solar still has fabrication cost around 10555 INR.
- It can be obtained about 0.5152 Rs/kg of water from present solar still.
- It can be obtained energy payback time around 117 days.
- Present solar still increased distillate output of water around 225% compared with conventional passive solar still.

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