Designing, fabrication and performance analysis of solar still for purification of water

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Abstract

Solar stills of four different capacities were fabricated and tested for water distillation. The distilled water production rate performance (PRP) was analyzed. The highest rate of PRP was recorded between 11.30 am and 12.30 noon in all the solar stills studied. It was 0.0287 L/m^2/hr in unit I, 0.0288 L/m^2/hr in unit II, 0.0279 L/m^2/hr in unit III and 0.0267 L/m^2/hr in unit IV. The study reveals that the solar stills. The pH of distilled condensate was 7.0 indicating neutral character. The TS, TDS, TSS, sulphates, phosphates and chlorides were reduced to zero after the solar distillation in all the four solar stills. It insures that the distilled water is 'Pure' water.

Key words: Solar still, solar energy, clean water, Distilled water, Sustainable technology.

1. Introduction

The need for safe, clean drinking water is increasing rapidly. The availability of clean portable water is a major problem faced by the humanity in last few decades all over the world. It is estimated that out of 1, 62, 000 of 5, 75, 000 Indian villages alone face the problem of brackish or contaminated water (Srinivas et al., 2010). The increasing pollution will magnify the problem of water scarcity. This scenario is not sustainable for the future of mankind. The scientific innovation and technological efforts can provide suitable solution. There is need of major development in the solar distillation as solution to this problem. Therefore, research and development of solar still is one of the ways to provide a sustainable source of potable water in Indian context.

The current water purification market amounts to more than 25 X10^6 m^3/d (Ettouney and Rizzuti, 2007) which has been mostly divided among the Multi-Stage Filtering (MSF) introduced in 1960 with the about 500 m^3/d unit capacities and Reverse Osmosis (RO) processes of about 75,000 m^3/d or more, commercialized in 1970 in many countries for the small needs (Al-Zubaidi, 1987) and evolved to large unit capacities. But, these technologies consume large amounts of energy to operate them. Energy consumption in the form of electric power has been currently rated at 5 kWh/m^3 for RO process and 4 kWh/m^3 for MSF (Borsani and Rebagliati, 2005). Furthermore, increasing demand for energy would result in the increased consumption coal, oil and natural gas for producing electric power and increase in the prices of these fossil fuels. Therefore, there is much scope for the solar thermal technologies to play crucial role in providing environment friendly technology and sustainable solution to the problem of pure water shortage.

2. Materials and Methods

The all materials required for the present investigation were collected from the local market. The solar still basins were fabricated from the local fabricator workshops in the Aurangabad city. The PVC pipes and U Channels for trough were purchased from the local market. The M-seal was used as sealing material to make the basin water-tight to control the evaporated water drops. Selected physical parts of solar still like still basin, transparent top, condensing arrangement, trough, insulation etc. were constructed and tested for solar distillation process. The rectangular plates were cut at the diagonals to prepare a tray shape and welded to form a water holding basin. The transparent glass sheet was selected for the top for providing passage of solar energy and side walls of solar still. The top rectangular rooftop of appropriate size was cut in transparent glass and fitted with M-seal. The trough of PVC plastic was cut in U shape and vertically placed to collect the condensate and facilitate the flow to the collection container or the measurement system. The other technical details are presented elsewhere (Jadhav, 2011).

The water is fed into the basin of the still. The basin water is evaporated by the heat of sunlight and triggered by greenhouse effect due to transparent top sheet. The pure water condenses at the top surface of the glass top. The droplets of condensed top slowly run down to the U channel due to slope which was collected as output. The solar stills were initialy filled with the feed water volume of 1500 ml, 1814 ml, 2104 ml and 2404 ml up-to the depth of about 2 cm. The still basin was kept in the sunlight generally at 10 am and the condensate measurement was carried out from 10.30 am leaving the condensate for about 30 minutes to ensure the trough cleaning process each time. The solar exposure, temperature and volumetric measurements were continued till 5.30 pm each time on the all days of experiment. The averages of 5 readings are considered for statistical mean. The Production Rate Performance (PRP), water conversion efficiency and percentage of the water purified is calculated. The qualitative and quantitative assessment of water was carried out using standard procedures (Trivedi and Goel, 1986).

3. Results and Discussion

The fabricated units of four different capacities were successfully worked and solar distillation process was successful and capable to produce distilled water. The rate (quantity) of distilled water generated on hourly basis was relatively higher between 11.30 am to 12.30 pm (noon) in all solar still units. The distillation rate was decreased thereafter in all the units of solar stills due to the increased angle of solar radiation with decreased penetration inside the solar still chamber.

The volume of distilled water generated was 12.4 ml in the interval of 10.30 am to 11.30 am which increased to 20.30 during the next hour of exposure. The least volume of distillate was recorded between 4.30 pm and 5.30 pm. The results indicate that the distillation process was continuously taking place through out the time of exposure to the illumination of solar radiation from 10.30 am to 5.30 pm. The efficiency of distilled water production during the different time durations indicated that the efficiency was highest between 11.30 am and 12.30 noon. The efficiency during the period of first hour of exposure was 0.66% which reached dramatically to 1.74% with the net increase of 1.08%. The distilled water production efficiency was least during the 4.30 pm to 5.30 pm which accounted to 0.42% as net increase which is least among the observed results and the total distilled water production efficiency after 7 hours of exposure was 5.08% in solar still I.

The rate of distilled water production in unit II was 15.2 ml between 10.30 and 11.30 am. It was increased to 25 ml in the second hour of exposure between 11.30 am and 12.30 pm (noon) and found decreased subsequently thereafter for the next period of exposure. The percentage distillation after 7 hours of exposure was 6.63% of the water filled in the basin. The distilled water production efficiency in terms of solar energy absorption and vaporization leading to condensate was 5.21% from the initial volume of 1814 ml with the depth of 2 cm after the 7 hours of solar energy exposure.

The distillate volume in solar still unit II was least in the last hour of exposure between 4.30 pm and 5.30 pm. The cumulative distilled water production was just 15.2 ml after first hour, 40.2 ml after second hour and it was 92.4 ml after 5 hours. The cumulative distillation after 7 hours of illumination was 120.3 ml. About 0.84% water from the basin was collected after 1 hour of exposure, 4.20% was after 4 hours of solar illumination and 6.63% after 7 hours of solar illumination in solar still unit II. The results indicate that the production efficiency was just 0.66% after 1 hour and increased to 4% after 5 hours of exposure reaching to 5.21% after 7 hours of solar exposure.

The highest rate of distillation (28.5 ml/hour) was noticed in unit III between 11.30 am and 12.30 am which further decreased with the time of the day. The total cumulative volume of 138.9 ml was generated after 7 hours of solar exposure. The distilled water production efficiency in terms of solar energy absorption with subsequent vaporization and condensation was 5.13% from the initial volume of 2104 ml with the depth of 2 cm after the 7 hours of solar radiation exposure.

The distillate produced in solar still unit III was 18.9 ml in first hour, 22.8 ml during 3rd hour, 19.2 ml during 5th hour and just 11.5 during the 7th hour of exposure. The productions during 3rd and 4th hours of exposure were almost same, 22.8 ml and 22 ml respectively. The cumulative distilled water production after 2 hours in solar still unit III was 70.2 ml and was increased to 111.4 ml after 5 hours, 127.4 ml after 6 hours and finally to 138.9 ml after 7 hours of solar exposure.

The percentage of distilled water out of total quantity of water taken in the solar still unit III was 0.90% in first hour, 2.25% after 2 hours, 3.345 after 3 hours, 4.38% after 4 hours, 5.29% after 5 hours and 6.06% after 6 hours of solar exposure during the test time. The total of 6.60% water was collected from solar still after 7 hours of solar exposure from solar still unit III. The results indicate that the efficiency was just 0.70% in first hour. It was increased to 1.75% after 2 hours, 2.59% after 3 hours, 3.4% after 4 hours, 4.11% after 5 hours and 4.7% after 6 hours. The distillation efficiency after 7 hours of solar exposure was 5.13% in solar still unit III.

The total quantity of distilled water produced per hour was higher in unit IV than other units. The maximum distilled water production of 31.2 ml /hour was observed in this unit between 11.30 am and 12.30 pm. The cumulative volume of distilled water after 7 hours of solar energy exposure was 159.9 ml and the distilled water production efficiency was 5.16% from the initial volume of 2404 ml with the depth of 2 cm. The distillate volume produced in solar still unit IV was 31.2 ml during this interval. The production was 25.4 ml in third hour of exposure, 22.4 ml in 4th hour, 21.3 ml in 5th hour, 19.5 ml in 6th hour and was minimum of 17.7 ml in 7th hour. The cumulative distilled water production was found increasing in first hour of exposure and the rate of increase was higher in second hour causing little reduction in the rate of increase thereafter in each subsequent hour of exposure.

The cumulative distillate generated was 52.6 ml after 2 hours, 79 ml after 3 hours, 101.4 ml after 4 hours, 122.7 ml after 5 hours and 142.2 ml after 6 hours. The total of about 159.9 ml distilled water was produced after 7 hours of solar exposure in solar still unit IV. The percentage efficiency of distilled water produced in solar still unit IV indicates that the distilled water produced in first hour of distillation was 0.93% which subsequently increased to 2.23%, 3.29%, 4.22%, 5.1%, 5.92% and finally to 6.65% after 2nd, 3rd, 4th, 5th, 6th, and 7th hours of solar exposure respectively.

The results reveal that the production rate performance (PRP) was highest in unit IV and lowest in unit I. It is obvious that the total area of solar exposure was higher in unit IV resulting into higher PRP than the other units with less solar exposure area in other units. The highest rate of PRP was recorded between 11.30 am and 12.30 noon in all the solar stills studied. It was 0.0287 L/m^2/hr in unit I, 0.0288 L/m^2/hr in unit II, 0.0279 L/m^2/hr in unit III and 0.0267 L/m^2/hr in unit IV. The results are graphically represented in Fig. 3 in a summarized for ease of comparison.

The comparisons for cumulative distilled water production in different units of solar stills tested in present study are summarized in Fig. 3. The date generated reveals that the cumulative distillation rate with respect to time of exposure was higher in the unit IV followed by unit III, then unit II and was least in unit I among the tested solar still units.

The distilled water production efficiency of different solar units during the solar irradiance is represented in Fig. 4. The results reveal that the distilled water production efficiency was marginally higher in the solar still having larger solar exposure surface area.

The assessment of distilled water from solar still indicates that the solar distillation of water is not only competitive with commonly supplied drinking water but also it is highly competitive with the bottled drinking water as it is free from all organic and inorganic impurities. It can be used for various purposes like in energy storage batteries, preparation of chemical solutions in laboratory analysis, pure solvent and other uses.

Removal of salts is compatible with distillation of common water by use of electrical distillation. The values of salts are zero and indicate that the removal of salts and metallic impurities are comparable with the bottled water in the market. The operation and maintenance is easier and no technical training is required for its use. Material of construction of solar still is readily available in local markets. Glass, stainless still and plastic are sufficiently durable and cost effective.

4. Conclusions

The solar still distillation is one of the simple methods to remove salts and other water impurities. It is concluded from the distilled water analysis that the water from solar still of any size is pure. The quantity of water distilled is relatively higher in the solar still of high surface area due to higher exposure to solar radiation.

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Table 1: Technical specifications of solar still units

Specification	**Dimensions of Unit I**	**Dimensions of Unit II**	**Dimensions of Unit III**	**Dimensions of Unit IV**
Basin area	750 cm^2	907 cm^2	1052.2 cm^2	1202 cm^2
Top Glass area	710.5 cm^2	869.4 cm^2	1020 cm^2	**1168 cm^2**
Glass thickness	2 mm	2 mm	2 mm	2 mm
Stainless steel thickness	1 mm	1 mm	1 mm	1 mm
Slope of glass	9^o	8^o	7.5^o	7.5^o
Upper side glass size (H X L)	10.5 cm X 24.5 cm	10 cm X 27 cm	10 cm X 29.5 cm	10 cm X 32 cm
Lower side glass size (H X L)	7.5 cm X 24.5 cm	7.5 cm X 27 cm	7.5 cm X 29.5 cm	7.5 cm X 32 cm
Side glasses ($H_1XH_2XL_1XL_2$)	10 cmX12.5 cm X28.7 cmX29 cm	7.5 cmX10 cm X31.5 cmX32 cm	7.5 cmX10 cm X33.5 cmX34.2 cm	7.5 cmX10 cm X35.5 cmX36.5 cm

The solar stills with simple geometry was designed in different sizes and fabricated. The technical specifications of four solar stills of different sizes designed, fabricated and tested are given in Table 1.

Table 2: Results of five tests for the performance analysis of solar stills

Exposure Time (Min)	**Water Distilled (%) in Unit I**	**Water Distilled in Unit II (%)**	**Water Distilled in Unit III (%)**	**Water Distilled in Unit IV (%)**	**Production Efficiency η (%) of Unit I**	**Production Efficiency η (%) of Unit II**	**Production Efficiency η (%) of Unit III**	**Production Efficiency η (%) of Unit IV**

10.30 am	0	0	0	0	0	0	0	0
11.30 am	0.83	0.84	0.90	0.93	0.66	0.66	0.70	0.72
12.30 pm	2.19	2.22	2.25	2.23	1.74	1.74	1.75	1.73
13.30 pm	3.34	3.22	3.34	3.29	2.66	2.53	2.59	2.55
14.30 pm	4.35	4.20	4.38	4.22	3.46	3.30	3.40	3.27
15.30 pm	5.15	5.09	5.29	5.10	4.10	4.00	4.11	3.96
16.30 pm	5.85	5.92	6.06	5.92	4.66	4.65	4.70	4.59
17.30 pm	6.39	6.63	6.60	6.65	5.08	5.21	5.13	5.16

Table 3: Physico-chemical parameters of feed-water and solar distillate in all four units

Physico-chemical characteristics	**Feed-water (Before distillation)**	**Solar distillate (After solar distillation)**
pH	6.6	7.0
Total Solids (mg/L)	1332	00
Total Dissolved Solids (mg/L)	880	00
Total Suspended Solids (mg/L)	452	00
Sulphates (mg/L)	254	00
Phosphates (mg/L)	176	00
Chlorides (mg/L)	233	00

The quality of water was tested before feeding to solar still distillation unit to insure the feed-water quality and the distilled water from solar still was tested after collecting the distillate to insure the quality. It is observed that the pH of the water before distillation was slightly acidic. The pH of distilled condensate was 7.0 indicating neutral character. The TS, TDS, sulphates, phosphates and chlorides were reduced to zero after the solar distillation in all the four solar stills (Table 3). It insures that the distilled water is 'Pure' water.

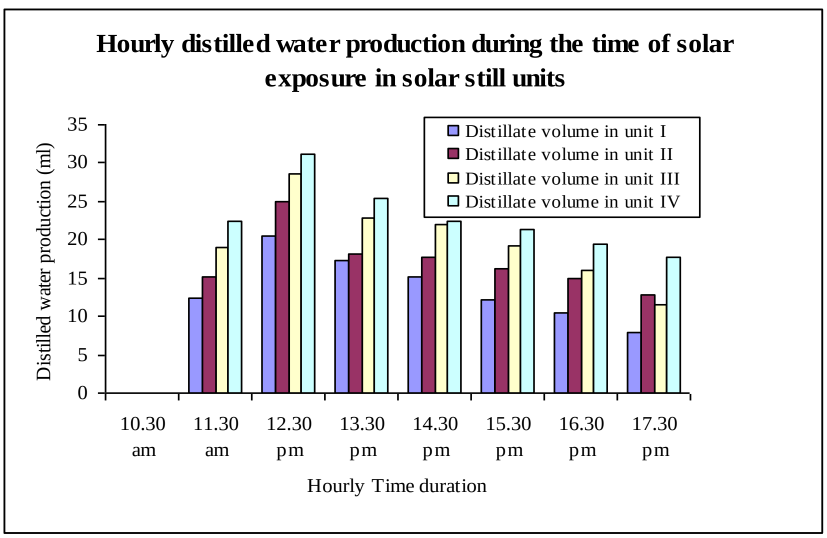

Fig. 1: Hourly distilled water production during the solar exposure of solar stills.

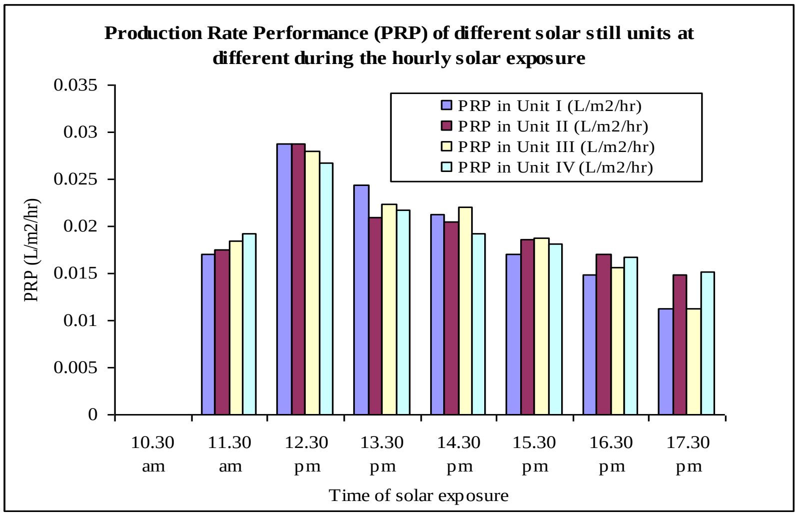

Fig. 2: Distilled water production rate performance of solar stills during the exposure.

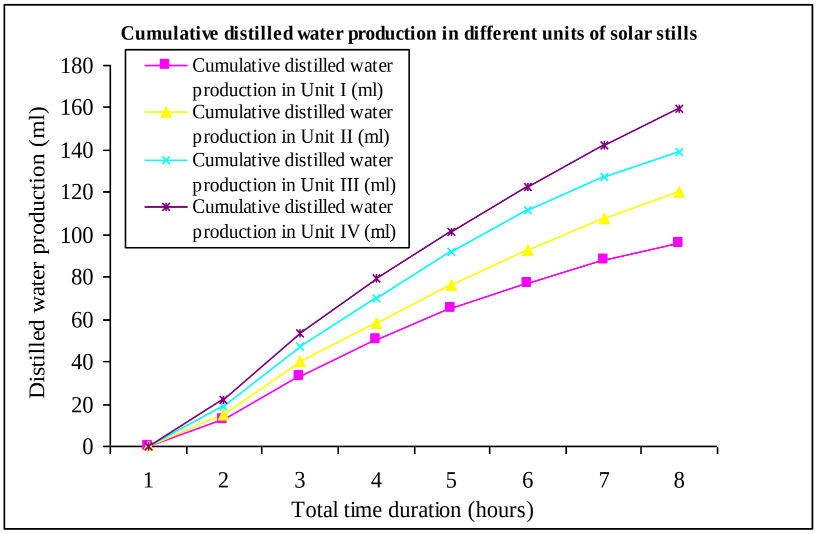

Fig.3: Average of cumulative distilled water production in different units of solar stills.

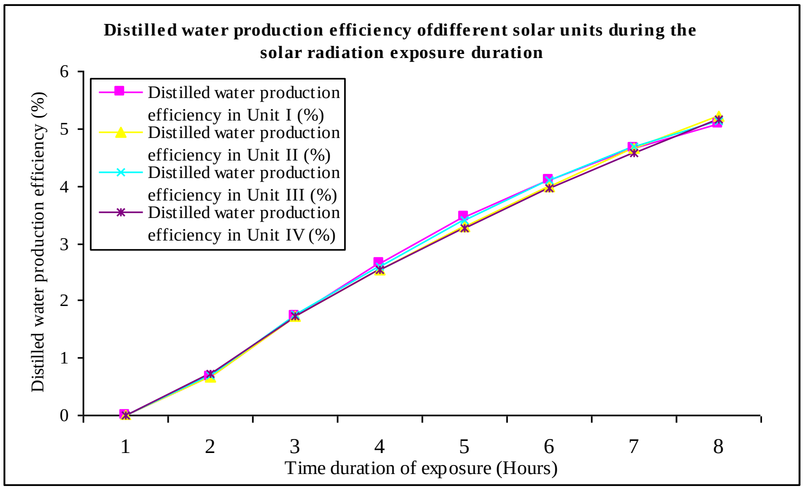

Fig.4: Distillation efficiency of solar stills during the solar energy exposure.