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Performance study of single basin single slope solar still with pebbles of different diameters

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ABSTRACT

The performance of a single basin single slope solar still with sensible heat storage materials such as pebbles of different diameters with that of a conventional still were compared. Pebbles of diameters such as 2, 4, 6, 8, 10 and 12 mm were selected for the performance testing in the solar still. Two experimental stills of the same basin area have been fabricated and tested with pebbles of different diameters. The results showed that the productivity of smaller diameter pebbles was higher compared to the large diameter pebbles. The results showed that the use of 2 mm diameter pebbles produced 134 mL/d and 12 mm diameter pebbles produced 55 mL/d. The use of 2 mm diameter pebbles in the solar still increased the productivity by 27.27% more than the conventional still. It was also estimated that the payback period is less than the conventional solar still. The usage of pebbles as a sensible heat storage medium will improve the productivity of the solar still and will lead to exposure of various sensible heat storage materials in the near future.

Keywords: Pebbles; Productivity; Diameter; Solar still; Desalination

1. Introduction

Solar desalination is the process of converting the impure brackish water into potable drinking water using solar energy. Solar desalination methods have been used by the man kind for thousands of years. There are many methods of solar desalination, but the most common methods are distillation and reverse osmosis. Distillation is the process of converting the liquid into vapour form and then converting the vapour into liquid form, leaving behind the impurities. The process of distillation done using solar energy is called solar distillation or solar desalination. The devices used for solar desalination are known as solar stills [1,2]. Infact, solar stills were the first method that was used on a small scale to convert impure saline water to potable water. In the year 1872, in Las Salines, Chile, Caros Wison, a Swedish engineer supplied fresh water to workers at a salt peter and silver mine by the process of solar desalination. It operated for around 40 y and produced an average of 22.7 m^3 of distillate per day using the effluent from the mine as feed water. The main drawback of the solar desalination using solar stills is its low productivity. Normally, a solar still can yield 2.5 to 5 L/m^2/d of distillate.

Human beings need to drink fresh water to survive in this world. Our bodies contain approximately 60% water and humans cannot survive for more than a week, without fresh water, but they can survive for a month without food. Hence, fresh water is the basic need of the hour. The amount of water available on the earth's surface is about 1,386 million km^3, of the above; only 1% of water is fresh potable water. Nearly 97% of the water is in the form of oceans, which is too salty and 2% is in the form of ice-caps [3].

To stay healthy, humans need clean water. Countries need pure water for the development. They require pure water to run industries, schools, hospitals, etc. Everything we use such as food, cloths, things, etc., is made of some percentage of water. A scarcity of fresh water will lead to (i) slow or stop economic growth; (ii) affect agriculture; and (iii) degrade the quality of life.

A lot of research has been carried out to increase the productivity of solar stills. The use of reflectors [4], condensers [5], water heating systems [6–8], modifications in the absorber plate, type of stills, heat storage media, etc., are used to increase the productivity of the stills. Heat storage mediums can be either sensible heat type or latent heat type. Some sensible heat storage mediums are pebbles, bricks, gravel, etc. In this research, pebbles of different diameters were used in the solar still to increase the productivity of solar stills.

Nafey et al. [9] used black rubber of thicknesses 2, 6 and 10 mm and black gravel of different sizes such as 7–12, 12–20, and 20–30 mm. The use of black rubber with 10 mm thickness increased the productivity by 20% and the use of black gravel of 20–30 mm increased the productivity by 19%. Akash et al. [10] used black rubber mat, black ink and black dye and found that the productivity increased by 38%, 45% and 60% by the use of black rubber mat, black ink and black dye respectively. Sakthivel et al. [11] used jute cloth in the solar still and found that the productivity increased by 20%. El-Sebaii et al. [12] used sand as a sensible heat storage medium in a solar still and found that by the addition of 10 kg of sand the daily productivity increased by 4.005 kg/m^2. Abdallah et al. [13] used absorbing materials such as coated metallic wiry sponges, uncoated metallic wiry sponges and volcanic rocks in the solar still. It was found that the productivity of the coated metallic wiry sponges, uncoated metallic wiry sponges and volcanic rocks were 28%, 43% and 60% respectively. Kabeel et al. [14] conducted experiments on a modified solar power driven hybrid desalination system (SS-HDH). The efficiency of the modified system varied from 21% to 39%. The experimental work done in this paper is a part of the thesis of Prakash. [15].

2. Experimental analysis

2.1. Pebbles of different diameters

Experiments were conducted in a still at the University College of Engineering Villupuram, (11.9547°N, 79.5277°E) Tamil Nadu, India. The experiments were conducted during the month of April 2021. The depth of water used was 3cm and the mass of pebbles used was 3 kg for all the experiments. The diameters of the pebbles used are 2, 4, 6, 8, 10 and 12 mm. For each diameter of pebbles, the readings were taken for 3 d. The maximum sunshine day values of solar radiation, wind velocity and atmospheric temperatures were considered for the analysis.

The readings were taken for every 1 h interval from 6 A.M. in the morning to 6 A.M. the next day. The incident radiation was measured by a PV type sun meter. The wind velocity was measured by a digital anemometer and the ambient temperature was measured by a mercury thermometer.

The temperatures of the saline water, absorber plate and the inner glass cover were measured using the K-type thermocouples with multi-channel digital display unit. The basin and the glass cover must be cleaned at regular intervals to prevent salt deposition and dust. The schematic diagram of the single basin single slope solar still is shown in Fig. 1, and the photographic view of the different diameter pebbles used is shown in Fig. 2.

3. Results and discussions

3.1. Different diameter pebbles

The graphs show the changes of climatic conditions on the days of experiment, even though the experimental days were different. Figs. 3 and 4 show the variation of solar radiation and the atmospheric temperature of the maximum sunshine days of the experimental period with the solar still. Fig. 5 shows the variation of saline water temperature, and it reaches a maximum of 58°C for 2 mm diameter pebbles. The smaller diameter pebbles have a

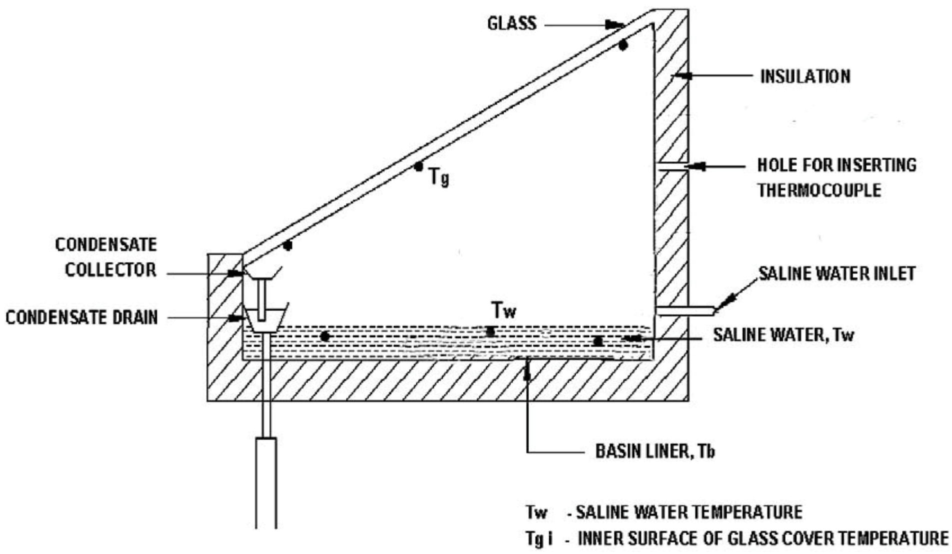

Fig. 1. Schematic diagram of the single slope single basin solar still.

Fig. 2. Schematic diagram of the different diameter pebbles used in the still.

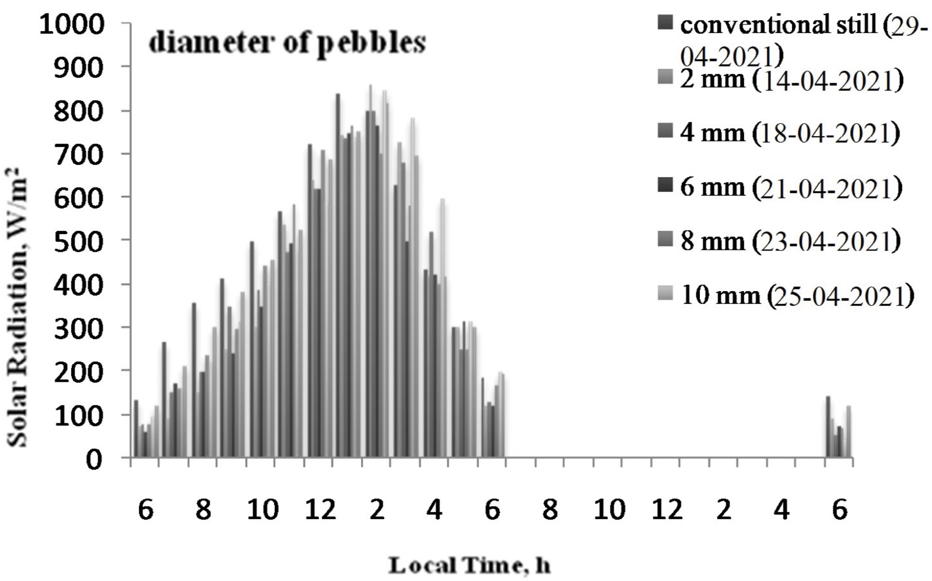

Fig. 3. Variation of solar radiation.

large surface area, and hence more thermal energy can be conducted and heated sooner than the large diameter pebbles. It was found that the temperatures were higher for the smaller diameter (i.e., 2 mm) pebbles than the larger ones (i.e., 12 mm) due to the increase in the surface area for the smaller diameter pebbles. Fig. 6 shows the variation of productivity for the different diameter pebbles used in the still. It shows that the productivity is higher for the smaller diameter pebbles when compared to the larger diameter pebbles. The productivity is maximum upto 2,200 mL/m^2/d for 2 mm diameter pebbles. Fig. 7 shows the cumulative productivity of the different diameter pebbles used in the still. The still with 2 mm diameter pebbles had a maximum productivity of 2,200 mL/m^2/d and the still with 12 mm diameter pebbles had a minimum productivity of 1,795 mL/m^2/d. Fig. 8 shows the percentage increase in the productivity of the solar stills for different diameter pebbles. The still with 2, 4, 6, 8, 10 and 12 mm diameter pebbles gave 27.27%, 23.99%, 20%, 16.01%, 11.84% and 10.8% respectively more productivity than the conventional still. The properties of pebbles and some of the sensible heat storage mediums are given in Table 1. The comparisons of previous works are shown in Table 2.

4. Economic analysis

The payback period of the experimental set up depends on the overall cost of fabrication, maintenance cost, operating cost, and cost of feed water. The cost of feed water is negligible.

The cost of making the two stills is the same. The cost of the pebbles of any diameter is only Rs. 10/kg. Only 3 kg

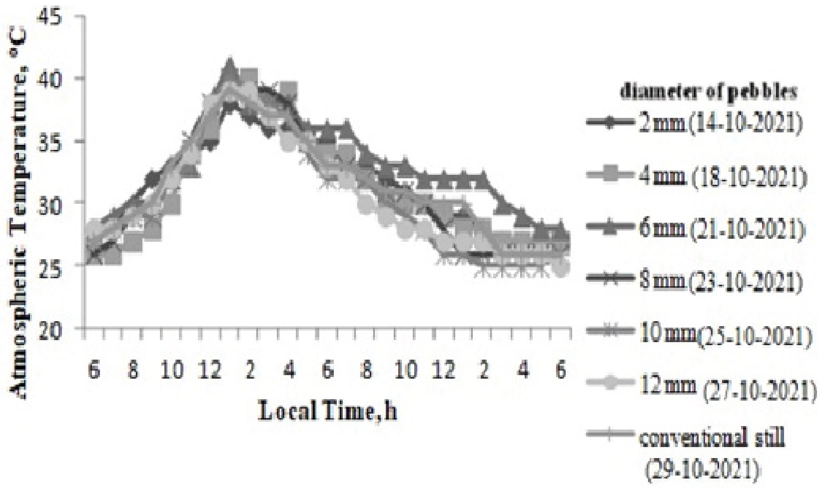

Fig. 4. Variation of atmospheric temperature.

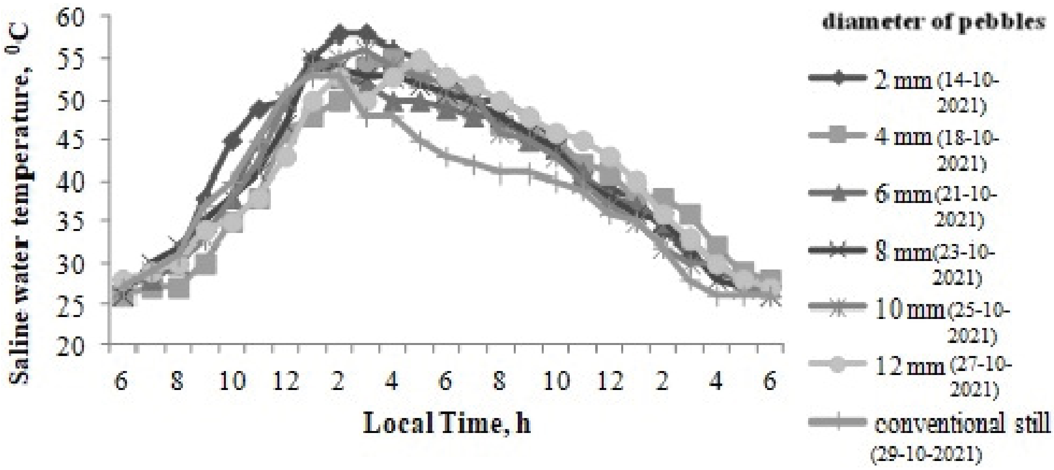

Fig. 5. Variation of saline water temperature.

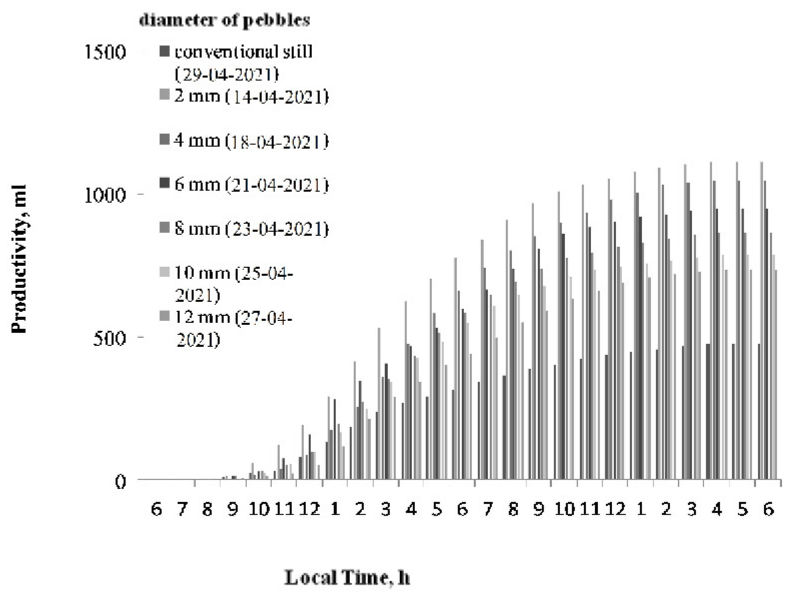

Fig. 6. Variation of productivity (different diameter pebbles).

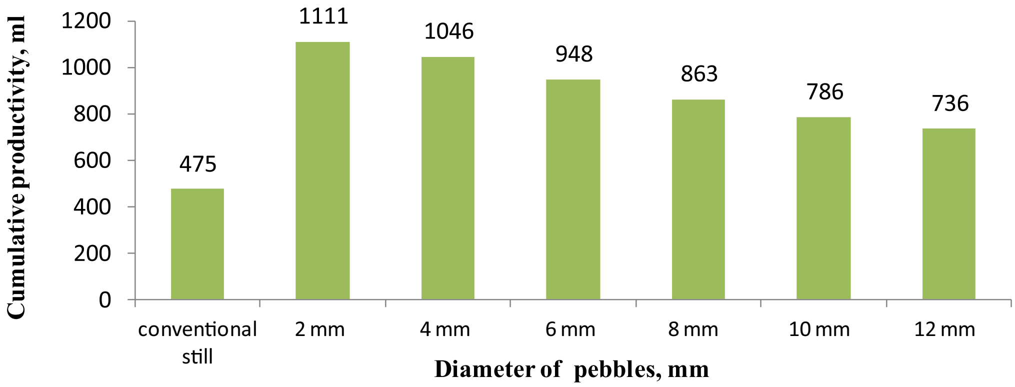

Fig. 7. Cumulative productivity for different diameter pebbles.

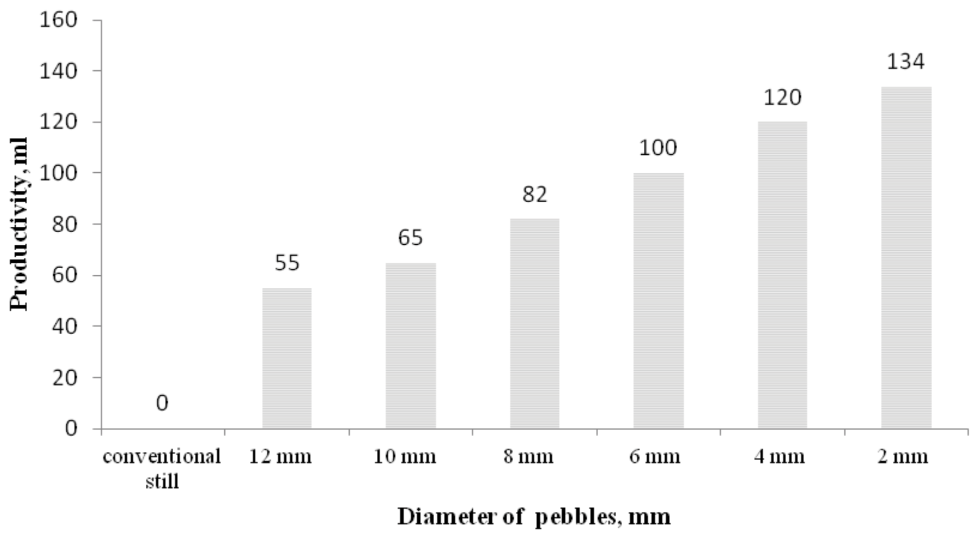

Fig. 8. Percentage increase in productivity for different diameter pebbles.

Table 1
Properties of sensible heat storage mediums

Material	Density (kg/m^3)	Specific heat (kJ/kg K)	k (W/m K)	$\alpha \times 10^6$ (m^2/s)	$b \times 10^{-3}$ (J/m^2 ks$^{1/2}$)
Pebbles	2,200	0.710	1.8	1.15	1.68
Slag	2,700	0.836	0.57	0.25	1.13
Soil (clay)	1,450	0.880	1.28	1.00	1.28
Soil (gravel)	2,040	1.840	0.59	0.16	1.49
Brick (dry)	1,800	0.840	0.5	0.33	0.87

for each diameter of pebbles were used. Hence, the cost of pebbles was Rs. 30 for each diameter of pebble. Hence, the system cost of the conventional still was Rs. 4,000 and for the still with pebbles, it was Rs. 4,030. The economic analysis of the system is shown in Table 3. The system with 2 mm diameter pebbles yields 27.27% more productivity than the conventional still. The payback period of the still with 2 mm diameter pebbles is 3.05 y, which is less than the payback period of 4.16 y for the conventional still.

5. Conclusions

- Studies on the performance of the still with different diameters of pebbles compared to the conventional still were conducted.
- It showed that the still with smaller diameter pebbles gave more productivity than the larger diameter pebbles. This is due to the increase in surface area when smaller diameter pebbles are used.
- Also, the use of pebbles is cost-effective. The use of 2 mm

Table 2
Comparison of previous works

Sl.no.	Author(s) and place	Modifications	Specifications	Month/year of experiments	Observation
1.	Radhwan [16] Saudi Arabia	Stepped still with latent heat thermal energy storage	Absorber: stainless steel sheet Phase Change material (PCM): Paraffin wax	2003	Productivity was 4.6 L/m^2.
2.	Abdallah et al. [13] Jordan	Various absorbing materials used in the still	Basin volume: 69.3 × 69.3 × 69.3 cm^3	2007	Productivity of coated and uncoated metallic wiry sponges and black rocks were 28%, 43% and 60% respectively.
3.	Tabrizi et al. [17] Iran	Integrating basin solar still with a sandy heat reservoir	Basin area: 0.41 m^2 Material: galvanized iron sheet	2009	Productivity is increased by 75% than the conventional still.
4.	Kabeel et al. [18] Egypt	Hot air injection and PCM in the still	Still basin: 0.6 m × 1.2 m Absorber plate: Material: copper Dimensions: 0.54 m × 1.14 m	July 2015	Productivity is increased by 108% more than the conventional still.
5.	Deshmukh et al. [19] India	Single basin still with sand and servo-therm oil	Still basin: 0.5 m^2	May 2014	Productivity is increased by 42.30% and 39.37% for servotherm oil and sand compared to the conventional still.
6.	Faegh et. al. [20] Iran	Solar still with external storage and PCM	PCM: Paraffin	2017	Maximum productivity and daily efficiency was found to be 6.555 kg/m^2 d and 50% respectively.
7.	Rafiei et al. [21]	Oil based nano fluids used in the still	Dish concentrator with conical cavity receiver was used as heat source	2020	Productivity of Cu/oil nanofluid was higher compared to other nanofluids.
8.	Present work	Single basin still with pebbles of different diameters	Basin area: 0.5 m × 0.5 m	April 2021	Productivity of 2 mm diameter pebbles is 27.27% more than the conventional still.

Table 3
Economic analysis (for different diameter pebbles)

Factors	Conventional still	Still with 2 mm diameter pebbles
Fabrication set up	Rs. 4,000	Rs. 4,030
Yearly usage	300 d	300 d
Productivity/day	1.6 L/m^2/d	2.2 L/m^2/d
Total production	300 × 1.6 = 480 L/y	300 × 2.2 = 660 L/y
Total cost saved	480 L × Rs. 2/L = Rs. 960	660 × Rs. 2/L = Rs. 1,320
Payback period	4.16 y	3.05 y

diameter pebbles in the still increases the productivity by 27.27% more than the conventional still.

- The thermal conductivity, temperature diffusivity, heat diffusivity, and climatic conditions play a vital role in improving the performance of solar stills.
- The cost analysis shows that the payback period of pebbles with a 2 mm diameter is 3.05 y, which is less than that of the conventional still.
- The use of sensible heat storage materials as pebbles would be a novel work in this research, resulting in the exposure of many more sensible heat storage materials to increase the productivity of the solar still.

Author's contribution

Prakash perumal (Assistant Professor) conducted all the experiments and wrote the manuscript.

Symbols

dt	—	Time interval, s
h	—	Heat transfer coefficient, W/m^{2}K
h_{fg}	—	Enthalpy of evaporation at T_w, J/kg
$I(t)$	—	Solar flux on the collector, W/m^2
m	—	Mass, kg

m_c	—	Condensate, kg/m^2
P	—	Partial pressure, N/m^2
Q	—	Heat transfer, W
T	—	Temperature, °C
U	—	Side heat loss coefficient from basin to ambient, W/m^{2}K

Greek

ε	—	Emissivity
α	—	Absorptivity
σ	—	Stefan-Boltzmann constant, W/m^{2}K^4

Subscripts

a	—	Ambient
b	—	Basin
c	—	Convective
e	—	Evaporative
g	—	Glass
r	—	Radiative
w	—	Water
s	—	Surface
eff	—	Equivalent
loss	—	Side loss

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