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EXPERIMENTAL STUDY ON PERFORMANCE IMPROVEMENT OF A SINGLE BASIN SOLAR STILL WITH OMANI ROCK STONE BED

Mohammed Tarawneh, Rajendra Sethupathi and Senthil Ponnusamy
Karpagam University, Coimbatore, India
E-Mail: senth.ksa@gmail.com

ABSTRACT

In this work, an attempt was made for improving the performance of single basin solar still using Omani rock stone bed as an energy storage medium. The Omani rock stone bed would absorb solar energy during day time and would release the energy for vapourizing the seawater during night time. Two sets of experiments (one without rock stone bed and another with Omani rock stone bed) were conducted in this study. The productivity and thermal efficiency of the still in both cases were analyzed. It was observed that the use of Omani rock stone bed was able to produce 2.5 litres of daily yield and able to obtain 25% thermal efficiency, which are about 19% greater than the performance of the solar still with the absence of stone bed. The quality of fresh water was verified through water quality test and confirmed its suitability for the domestic use.

Keywords: single basin solar still, Omani rock stone bed, thermal efficiency, yield, water quality.

INTRODUCTION

The shortage of rainfall and the increase of population create water scarcity in many countries. In addition, the economic development and global warming also make a worldwide imbalance between supply and demand of fresh water. To meet out the demand of fresh water, most of seashore countries utilize various desalination techniques such as multi-effect evaporation, multi-stage flash distillation, thin film distillation, reverse osmosis and electro dialysis. The desalination techniques are energy intensive and costly towards operation and maintenance. Most of the existing desalination plants use fossil fuels as sources of energy. The use of conventional energy sources (hydrocarbon fuels) to drive these techniques has a negative impact on the environment [1-3].

Solar distillation is a most attractive, environment friendly and simple technique compared to other desalination techniques. It is well suited at the locations where solar energy is abundant. When saline or brackish or contaminated water is kept in a closed container under the open sky, it gets evaporated. The solar energy is used to accelerate the process of evaporation in the solar still [4-5]. The function of a solar still is to capture the evaporated water vapour by condensing it on a cool surface.

Solar stills are classified broadly into two categories namely passive and active solar stills. Passive solar stills require solar energy for evaporation of saline water whereas active solar stills require an additional thermal energy by external mode for faster evaporation [6-8]. The passive solar still is the most economical solar still to provide drinking water for domestic applications at decentralized level. This is due to the fact that it is simple in design and fabrication, easy to handle, long life and low production cost [9-12]. Passive solar stills are available in the different configurations like basin type solar still, wick type solar still, tubular solar still, spherical solar still, parabolic solar still; fibre reinforced plastic solar still, vertical solar still, cascade solar still, staircase solar still, etc. Out of them, basin type solar stills are widely used for domestic purposes in the arid and semi-arid areas due to their economic advantages like low investment cost, low maintenance cost and low production cost [13-15]. Numerous factors affect the performance of a solar still. The design factors such as absorbing material, absorbing area, condensing cover material, cover slope, cooling of cover, water depth, insulation material, insulation thickness, geographical position of the still, sun tracking system, etc and the climatic factors such as solar intensity, ambient temperature, wind velocity, etc affect thermal efficiency and the productivity of the solar still [16-18]. Generally, the production of fresh water by solar still is quite low. However, it can be improved with the proper control of most significant factors like absorbing material, water depth, condensing cover material, etc [19-20]. The objective of this study is to improve the performance of single basin passive solar still with Omani rock stone bed as energy storage medium.

PERFORMANCE OF SOLAR STILL

The performance of a solar still can be determined by its hourly yield of fresh water and its thermal efficiency.

Yield

The yield of a solar still indicates the amount of water produced by the still. The fresh water yield of the solar still can be measured with a measuring jar on hourly basis. Then, the overall yield can be calculated for a day based on the hourly yield of the soar still.

Thermal efficiency

The thermal efficiency (η) of a solar still indicates the solar energy utilized for making the fresh water during a particular time interval. It depends upon solar intensity (I), basin area (A_b), latent heat of water evaporation (H_L) and production rate of fresh water (m_w). It can be estimated from the ratio of the amount of energy

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used for the production of fresh water and the average solar intensity received in a day.

$$\eta = \frac{m_w H_L}{I A_b} \times 100 \quad (1)$$

where H_L is 2257 kJ/kg

EXPERIMENTAL SETUP

The passive solar still was fabricated with a basin made up of 5 mm thick fiber glass material. The basin was covered with glass cover which would act as a solar collector. The joining surfaces were tightly sealed with silica gel to make basin as the closed container. The provisions were made to supply seawater into the basin, to collect fresh water produced and to flush out the salt concentrated seawater from the basin. The basin was placed on a mild steel frame and was insulated with polyurethane foam to avoid heat loss from the sides and bottom of the basin. The inner side of the basin was painted black to absorb more heat during sun radiation. The schematic of the single basin passive solar still is shown in Figure-1. The specifications of the solar still are given in Table-1.

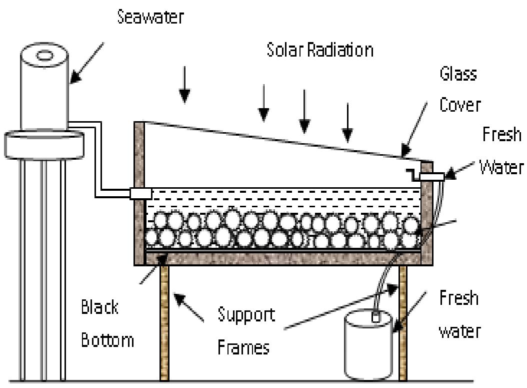

Figure-1. Schematic of the solar still.

Table-1. Specifications of the solar still.

S. No.	Geometrical parameter	Dimension
1	Length of the basin	1 m
2	Width of the basin	1 m
3	Area of the basin	1 m^2
4	Depth of basin in front side	0.20 m
5	Depth of basin in back side	0.62 m
6	Thickness of glass cover	5 mm
7	Glass cover area	1 m^2
8	Inclination of glass cover	22°
9	Insulation thickness	5 mm
10	Stone bed height	0.025m
11	Stone bed volume	0.025m^3

The basin of solar still was filled with fresh seawater to the depth of 50 mm. When the still was placed under the sun radiation, the incident solar radiation was transmitted through the glass cover. The seawater was thus heated and gave off water vapour. The water vapour was raised upwards and left the salt and other contaminates in the basin. The water vapour condensed on the glass cover and the condensate (fresh water) was collected in a storage container. The fresh water yield was measured using a measuring jar with an accuracy of 10 ml. The solar intensity was measured with a TES133 pyranometer with an accuracy of ± 1W/m^2. The experimental setup used for the conduct of experiments in this study is shown in Figure-2.

Figure-2. The experimental setup.

The experiments were conducted in Muscat, Oman (Latitude 23.617/Longitude 58.583). The experiment was started on first day 6.00 a.m. and completed on next day 6.00 a.m. Two sets of experiments were conducted in this study. First set of experiments were conducted using the experimental setup without the application of Omani rock stone bed for three consecutive days. Second set experiments were conducted using the same experimental setup with the application of Omani rock stone bed as energy storage medium for another three consecutive days.

First set of experiments were conducted using the solar still filled with 50 liters of seawater. The experiment was started on April 4th 2014 and completed on April 7th 2014. The solar still was placed with the tilted glass facing the sun (facing south) for all the experiments conducted. The solar intensity was recorded for one hour interval. The yield was measured in regular basis from the current day 6.00 a.m. to next day 6.00 a.m. Every day, the salts and other contaminants left in the seawater were flushed out and basin was filled with 50 liters of fresh seawater before

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starting the next experiment. The experiments were repeated on second and third day under the same experimental condition.

The second set of experiments was conducted by placing 25 kg Omani rock stones of 5 mm size, in the solar basin. Fifty liters of seawater was filled in the basin, which created a water column above the stone bed. The experiments were started on 8th April 2014 and completed on 11th April 2014. The solar intensity was recorded for every one hour interval. The fresh water yield was measured on hourly basis. The end of each day, the concentrated salt and other contaminants in the seawater were flushed out and fresh seawater of 50 litres was filled into the basin before starting of next experiment. The performance of the solar still was estimated based on the measured solar intensity and yield.

RESULTS AND DISCUSSIONS

Solar intensity

Solar intensity is the amount of solar radiation received in the experiment days. Solar intensity in the first set of experiment days from April 4th 2014 to April 7th 2014 and second set of experiment days from 8th April 2014 to 11th April 2014 are shown in Figure-3 and Figure-4. It was observed that the radiation from the sun increased continuously from 6.00 a.m. and reached the maximum about mid of the day. Then, the solar radiation started to decrease and the trend continued upto the sunset. A same trend was observed in all the experimental days.

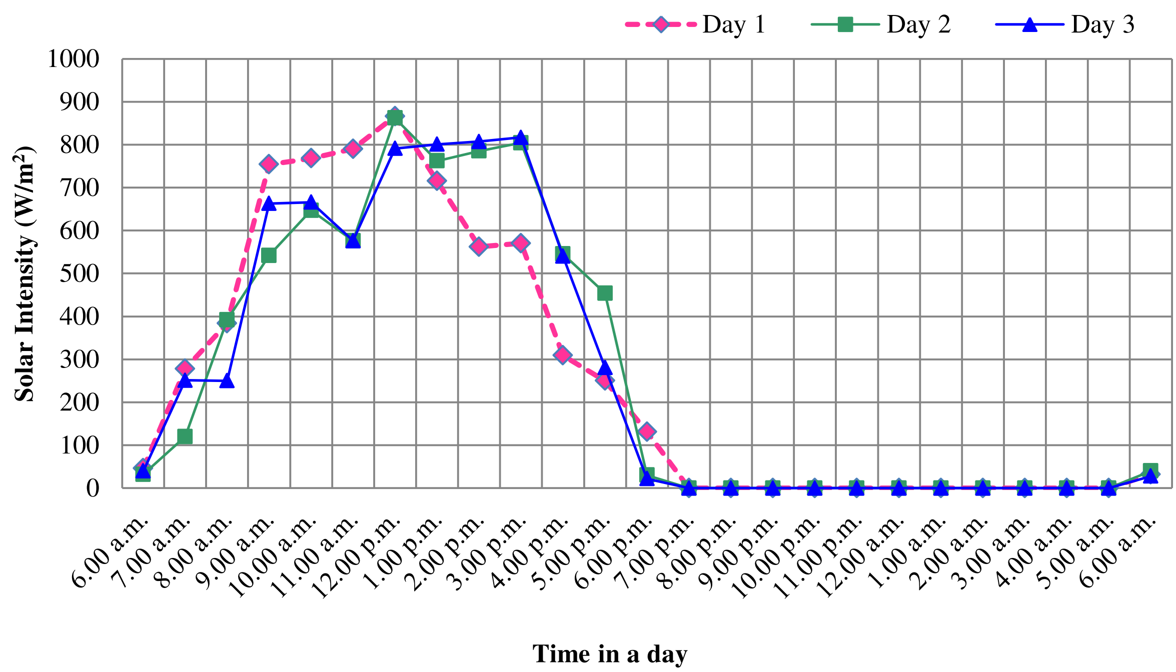

Figure-3. Solar intensity in the first set of experiment days.

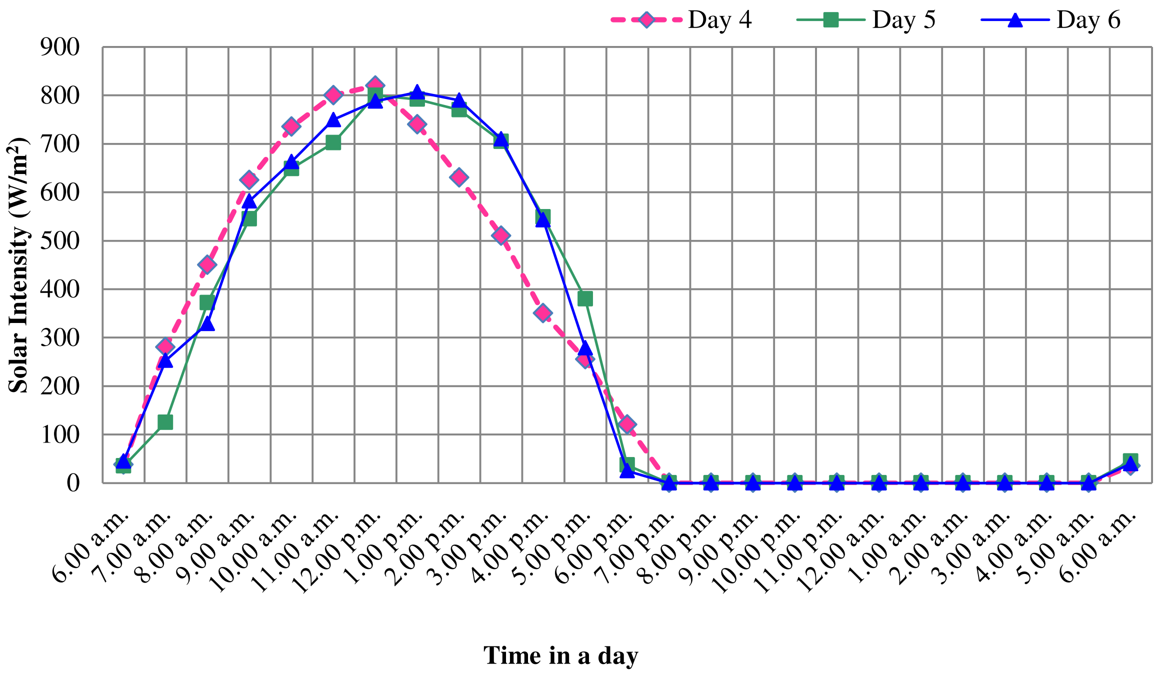

Figure-4. Solar intensity in the second set of experiment days.

Yield

Figure-5 shows the hourly yield of the solar still with the absence of Omani rock stone bed. The hourly yield measured for the three days was noted to be a similar pattern of the amount of solar intensity. The hourly yield increased as the solar intensity increased during the day. The solar intensity reached its maximum about mid of the day but the yield reached its maximum about 2.00 p.m. It was due to the time lag between the energy supplied for vaporization and condensate collected. During the time from1.00 p.m. to 2.00 p.m., the reduced solar intensity increased the temperature difference between the seawater and glass cover, and resulted in more condensation of water vapour. During evening and night (non sunshine period) hours also, water production was continued because of the energy stored in the seawater, but the rate of production was very minimal compared to the sunshine period.

Figure-6 shows the variation of yield of solar still with Omani rock stone bed. The energy stored in the stone bed was given to the seawater during late evening hours, which increased the yield of the still. There was a steep increase in yield of the still till 12.00 p.m. and there was a steep decrease in yield of the still after 2.00 p.m. The increase and decrease in the yield of the still exactly followed the variation of solar intensity during that period. It was observed that hourly yield was around 0.21 litre during the time from 11.00 a.m. to 12.00 p.m. and reached maximum (0.26 litre) at 2.00 p.m. As the solar intensity received by the still was increased, the yield was also increased. The increase in the yield was due to the increase of solar intensity. The solar intensity increased the temperature difference between water surface and glass, and increased the water vapour formation.

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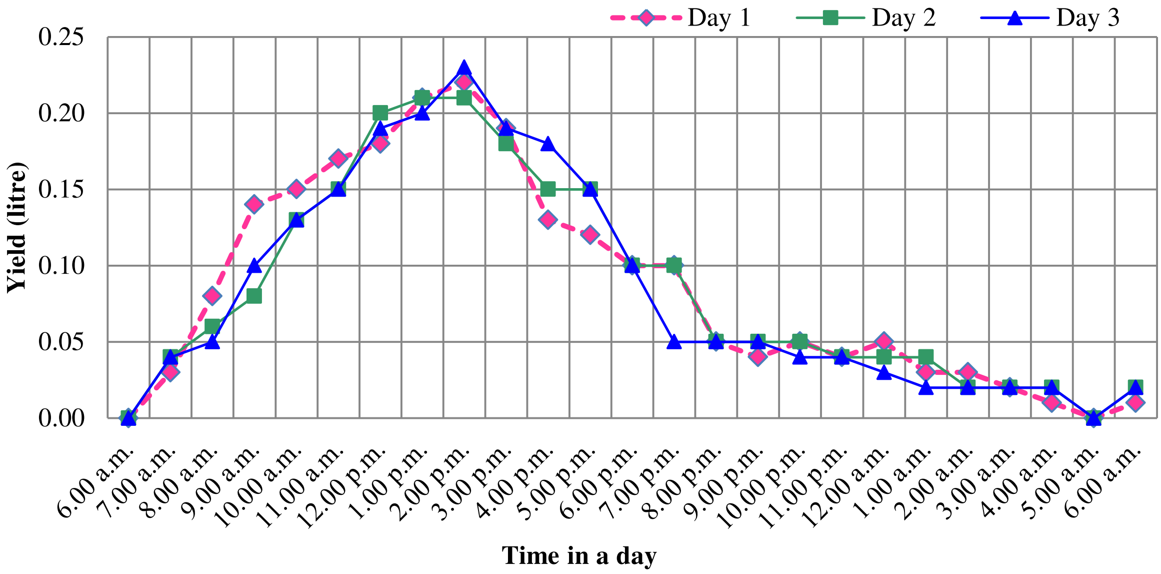

Figure-5. Variation of yield (without stone bed).

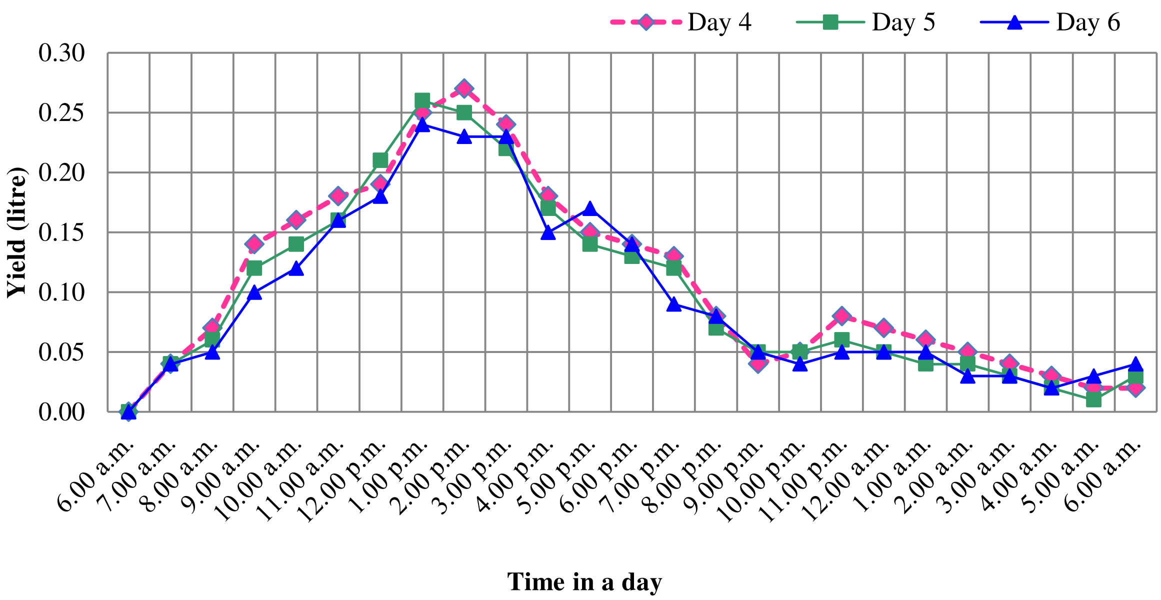

Figure-6. Variation of yield (with stone bed).

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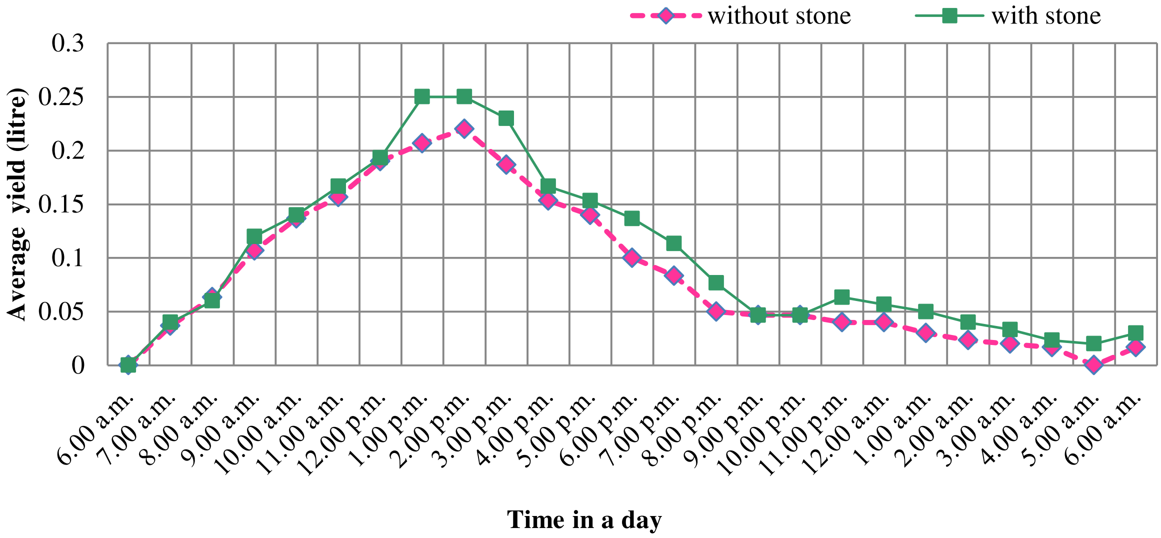

Figure-7. Comparison of average yield.

Figure-7 shows the average fresh water collection for both cases. It was observed that the solar still with stone bed produced more fresh water compared to the conventional still (without the stone bed) throughout the day. It was due to the fact that more energy was absorbed from sun radiation and stored by the stone bed and the same energy was made use of more fresh water. Also, lesser temperature differences between the water surface and atmosphere caused the less heat loss. i.e. more utilization of heat for water vaporization and storage of energy in the stone bed. It was observed that the fresh water collection rate was maximum about 2.00 p.m. in the both cases. The heat stored in the water and stone bed was utilized for the evaporation of seawater, hence fresh water yield was more in the still with the stone bed compared to the still without the stone bed.

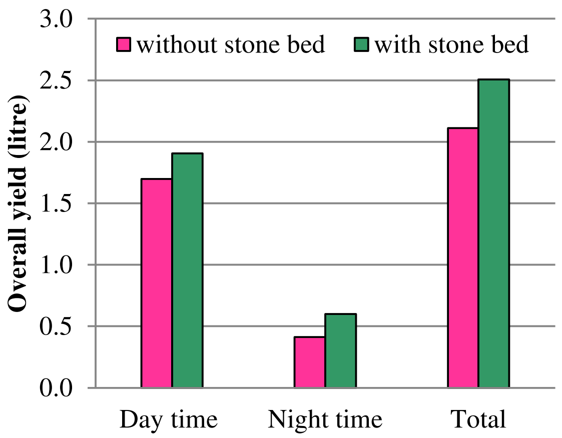

Figure-8. Comparison of overall yield.

Figure-8 shows the overall yield obtained in the day time and night time for both cases. It was noted that the overall yield was more during day time due to the direct utilization of the maximum available solar energy in the day time. In the night time, the fresh water was formed due to the heat stored in the water in the conventional still and energy stored in the stone bed. The day time and night time yield were noted to be high in the case of solar still containing the stone bed, because more heat energy from solar radiation was utilized for making the fresh water.

Thermal efficiency

The thermal efficiency of the still was calculated based on the average yield using the Equation (1). Figure-9 shows the overall thermal efficiency of the solar still. The efficiency of the still with the stone bed was noted to be 25% whereas the efficiency of the still without stone was noted to be 21%. The efficiency of the solar still was improved by 19% with the help of Omani rock stone bed as the energy storage medium. The increase of overall efficiency was due to reduction of energy loss by the still and larger temperature difference maintained between the basin seawater surface and inner surface of the glass cover.

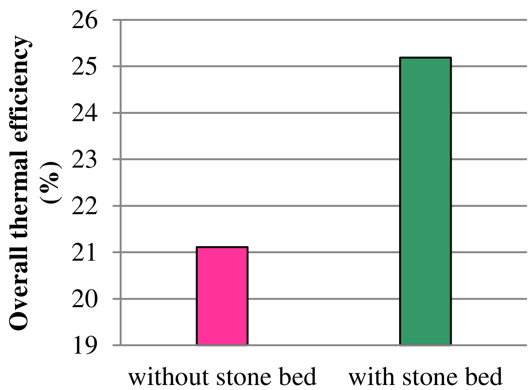

Figure-9. Comparison of overall thermal efficiency.

Water quality analysis

The fresh water samples were tested for analyzing their quality. From the test results given in the Table-2, it was observed that the fresh water obtained from the solar still were found with good quality in comparison with Omani standard for un-bottled drinking water. It is evident from this analysis that the distilled fresh water is suitable for human consumption.

Table-2. Water quality analysis.

Analysis Item	Unit	Omani standard	Distilled water
pH	-	6.5-8.5	6.75
Chloride	mg/l	≤250	3.91
Flouride	mg/l	0.6-0.8	0.74
Nitrate	mg/l	≤50	0
Sodium	mg/l	≤200	3.79
Sulphate	mg/l	≤250	4.43
Sulphide	mg/l	≤0.05	0
Total hardness	mg/l	≤200	19.65
TDS	mg/l	120-600	140
Calcium	mg/l	≤30	4.35
Potassium	mg/l	≤30	1.39
Magnesium	mg/l	≤30	2.10
Sodium	mg/l	≤200	3.79
Lead	mg/l	≤0.01	0.001
Copper	mg/l	≤2	Nil
Iron	mg/l	≤1	Nil

CONCLUSIONS

The performance of single basin passive solar still was improved using Omani rock stone bed as an energy storage medium in this study. The rock stone bed absorbed the excess energy available in the basin water during the sunshine and gave the energy back to vaporize the seawater during the non sunshine period. The heat stored was utilized for vaporization of the hot water present in the basin until the stone temperature reached equilibrium temperature with the basin water. The solar still with the rock stone bed utilized the higher amount of solar radiation during the day and increased the fresh water yield from 2.1 litres to 2.5 litres and thermal efficiency from 21% to 25%. Hence, the overall performance of the solar still was improved by 19% compared to the conventional solar still. The uniqueness of the solar still is the use of natural stone bed for storing the heat and releasing the same for the distillation throughout the day. This solar still can be used anywhere in the world, because the rock stone bed can be easily prepared with locally available stones.

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