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Performance analysis of solar still using sensible heat materials for saline water

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ABSTRACT

Natural water resources are polluted in large extent that affects human and other living organisms. Therefore, water purification has gained an important attention in recent years. Among the various methods adopted for water purification, solar still is a device used to purify the saline and polluted water. Various sensible heat materials such as charcoal, pebbles and gravels are used in the solar still. These materials are used to increase the rate of evaporation and to enhance the performance of solar still. The experimental results proved that the sensible materials that were using the combination of charcoal with gravels resulted in high yield. From this experiment, the rate of discharge for combination of pebbles with gravels, pebbles with charcoal and gravels with charcoal are 200%, 240% and 290%, respectively.

Keywords: Charcoal; Gravels; Pebbles; Sensible heat materials; Solar still

1. Introduction

Water is a natural resource and a vital aspect of any living organism in the world. Water scarcity has become one of the main problems in recent decades. In addition, there are various health problems in recent years due to water pollution. So, technical efforts are essential to handle the pollution issues. Solar energy is one of the renewable abounded pollution free energy. Solar still is working under the principle of distillation process. The saline water is converted into pure water using solar energy that is called as solar desalination process.

The solar energy is stored in the solar still by active and passive system. In active system, some external thermal sources are used where as in passive system those thermal sources are not used in the solar still. The major objective is to enhance the yield of purification water using some sensible heat storage materials. Abdel-Rehim et al. [1] suggested that the solar heat energy collection and storage of solar energy in the solar desalination process improves the solar still production. Several experiments were conducted using solar energy concentrator with simple heat exchanger and the fresh water productivity was increased by an average of 18%.

Abhat [2] proved that the solar heat absorbing material increased the production rate of solar still. The solar still efficiency is increased by using the low-temperature phase change materials. Various low-temperature phase change materials are analyzed with solar still for improving the effectiveness of solar still. Ackermann et al. [3] evaluated about the solar collectors in the solar still. The design of solar collectors plays a vital role to increase the collection of the solar radiation and conducted a computational investigation of the effects of internal fins on solar collector panels in the solar still. Zhang et al. [4] designed a concrete based solar still to increase the thermal energy storage of solar desalination process and to improve the performance of solar still. Fath [5] conducted many experiments about the solar thermal energy storage technologies of latent heat thermal energy storage and sensible heat storage systems. The latent heat thermal energy storage systems have many advantages over sensible heat storage systems including a

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large energy storage capacity per unit volume. Kumar [6] designed various models of solar still and conducted experiments for increasing the production rate of solar still. Lacroix [7] had investigated about the latent thermal storage system experimentally. The latent thermal energy storage system analyzed with shell-and-tube type of heat exchanger with PCM filling inside the solar still and also increased the solar still performance. Lafdi et al. [8] suggested that the carbon material increased the thermal conductivity in solar desalination process. Graphite foams infiltrated with phase change materials as alternative materials for space and terrestrial thermal energy storage applications. Carbon materials can have thermal conductivities as high as 470 W/m K, and also used in the thermal energy storage systems. Mehling and Cabeza [9] suggested that the latent heat storage is more than the sensible heat storage.

Mettawee and Assassa [10] evaluated the thermal conductivity of latent heat storage in the solar desalination process .The thermal conducting materials such as metal fins; metal beads and metal powders are high thermal conductivity property and improve the solar still effectiveness. Naim and Abd El Kawi [11] suggested the non-conventional solar stills with energy storage elements of solar desalination process. They designed a simple solar still with a phase change materials such as paraffin wax and paraffin oil as the energy storage media to make use of its latent heat of fusion for storing the excess solar energy at noon.

This stored energy could be used to evaporate the water during off sunshine hours in the evening and night. This resulted in the average daily still yield of 2.5 kg/m^2 with 15% improvement in the production. Sopian et al. [12] evaluated the solar collectors and the collector materials. Several experiments were conducted by the insertion of porous media and also increasing the thermal efficiency of the systems. The evaluation of double-pass solar collector with porous–non-porous materials is improving the thermal efficiency of the solar still desalination process. Stritih [13] presented several heat transfer experiments in rectangular phase change materials. The insertion of high-thermal conductivity materials were high thermal conductivities and the heat transfer is improved and increased the efficiency of the solar still. Tian and Zhao [14] discussed about the latest developments and advances in solar thermal applications, providing a review of solar collectors and thermal energy storage systems. Various types of solar collectors are reviewed and discussed, including both non-concentrating collectors and concentrating collectors. These are studied in terms of optical optimization, heat loss reduction, heat recuperation enhancement and different sun-tracking mechanisms. Various types of thermal energy storage systems are reviewed and discussed, including sensible heat storage, latent heat storage, chemical storage and cascaded storage and the design criteria of the solar still, material selection and different heat transfer enhancement technologies for improving the performance of solar still desalination process.

Velmurugan et al. [15] suggested that the sensible heat storage materials are increasing the solar still production rate. The sensible heat storage materials placed along with solar still basin and absorption of solar energy was more and improved the solar still performance. The design of fin type solar still with sensible heat storage materials such as pebbles, coals and sand increased the productivity of the solar still.

2. Experimental setup

The experimental set-up of a single basin single slope solar still basin made up of black lime stone to increase the absorption of solar radiation. The top of the basin is covered with 4 mm thick white glass cover with 45° slope angle.

The main aim of the experimental setup is to utilize the maximum solar energy and to improve the performance of the still. The height of the lower side is 0.170 m and higher side is 0.340 m. Effective area of the black lime stone basin is 0.540 m × 0.385 m. Body of solar still is joined into silicon paste free from leakage of vapour from the basin to atmosphere.

The yield from the still is collected at the outlet end of basin. The sensible heat storage materials are placed inside the solar still basin.

Fig. 1 shows that the collection of pebbles, Fig. 2 shows that the collection of gravels and Fig. 3 shows that the collection of charcoals. In conventional solar still, there are no sensible materials used and the amount of distillate obtained was 1190 ml/m^2/d.

Fig. 1. Pebbles.

Fig. 2. Gravels.

Fig. 4 shows that the complete experimental setup of single basin and single slope solar still fabricated with black lime stone for absorbing and storing more solar radiation as energy absorbing materials.

3. Working principle

Solar still is working under the principle of desalination process. Fig. 5 shows that the working principle of solar still. In this process, the pure water is produced without salt contents from the salty water. The stored solar energy is used to evaporate the saline water and the vapour is condensed and collected as soft and safety drinking water.

The solar still yield is depending upon the following factors. They are 1) Depth of the solar still basin saline water 2) The slope angle of the solar still top glass cover 3) The energy storage materials. When decreasing the depth of water in the solar still basin, the production rate of solar still is increased and increasing the depth of basin water, the production rate is decreased. The production rate also depends on the intensity of solar radiation.

Fig. 3. Charcoals.

Fig. 4. Solar still with sensible heat materials.

4. Results and discussion

The solar still effects and energy storage materials are considered as a good mechanism to enhance efficiency. The data obtained for three combinations of sensible heat materials have been studied and analyzed. Table 1 contains the pH and TDS value of saline water (test water) and yield water (good water) of solar still.

Table 2 shows the variation of basin water temperatures for pebbles with gravels, pebbles with charcoal and gravels with charcoal.

Fig. 6 shows that the graph between time and basin water temperature for three basins sensible heat materials.

The gravels with charcoal are used as energy storage material; the maximum temperature is obtained 86°C. The pebbles with charcoal are used as energy storage material; the maximum temperature is obtained 80°C. The charcoal and gravels are used as energy storage material; the maximum temperature is obtained 86°C. The experimental results proved that charcoal and gravels are proved with the maximum basin water temperature.

Table 3 contains discharge of pebbles with gravels, pebbles with charcoal and gravels with charcoal. Fig. 7 shows that the yield rate of three basin energy storage materials. The pebbles with gravels are used as basin energy storage materials; the maximum discharge of the still is 490 ml.

The pebbles with charcoal are used as basin energy storage materials; the maximum discharge of the still is 560 ml.

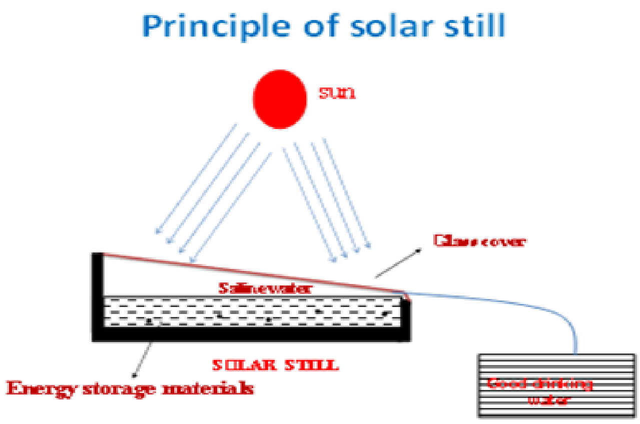

Fig. 5. 2D diagram of solar still principle.

Table 1
Properties of saline and yield water

S. no	Property	Test value	
		Saline water	Yield water
1	pH	7.5	7.1
2	TDS (ppm)	820	40

Table 2
Basin water temperature

Time	Without energy Material °C	Pebbles with Gravels °C	Pebbles with Charcoal °C	Gravels with Charcoal °C
9 am	35	47	51	54
10 am	38	52	58	62
11 am	43	59	63	69
12 am	47	69	72	77
1 pm	52	73	76	82
2 pm	53	76	80	86
3 pm	47	70	75	79
4 pm	40	62	67	71
5 pm	38	57	62	66
6 pm	36	56	59	62

Table 3
Discharge rate of yield water

Time	Without energy material (ml)	Pebbles with gravels (ml)	Pebbles with charcoal (ml)	Gravels with charcoal (ml)
9 am	–	–	–	–
10 am	60	130	180	220
11 am	150	330	390	460
12 am	220	440	490	570
1 pm	250	470	540	630
2 pm	210	490	560	670
3 pm	140	340	410	500
4 pm	90	180	270	390
5 pm	50	130	190	280
6 pm	30	90	130	190

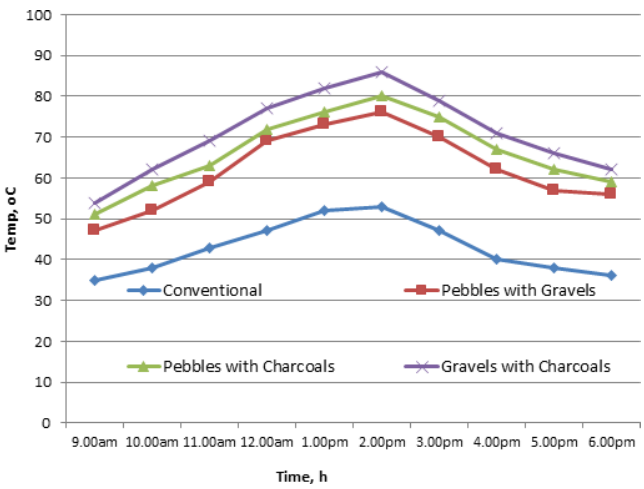

Fig. 6. Basin water temperature distribution.

The charcoal and gravels are used as basin energy storage materials, the maximum discharge of the still is 670 ml. The result showed that the still using gravels with charcoal are used as energy storage materials, gave highest production rate.

Fig. 7 shows the graph between time and yield rate of various sensible materials. The maximum solar still discharge rate of yield is 670 ml/d and the yield rate was more in the time of 2.00 pm

Fig. 8 shows the cumulative range of three energy storage material. The pebbles with gravels are used as basin material, the yield of solar still is 2600 ml. When the pebbles with charcoal are used as basin materials; the yield of solar still is 3160 ml. Alternatively, when gravels with charcoal are used as basin materials; the yield of solar still is 3910 ml. The results showed that the gravels with charcoal are proved with the highest productivity due to its natural black colour and porosity.

Table 4 shows that the cumulative yield variation of solar still for different sensible heat storage materials such as pebbles with gravels, pebbles with charcoal and gravels with charcoal.

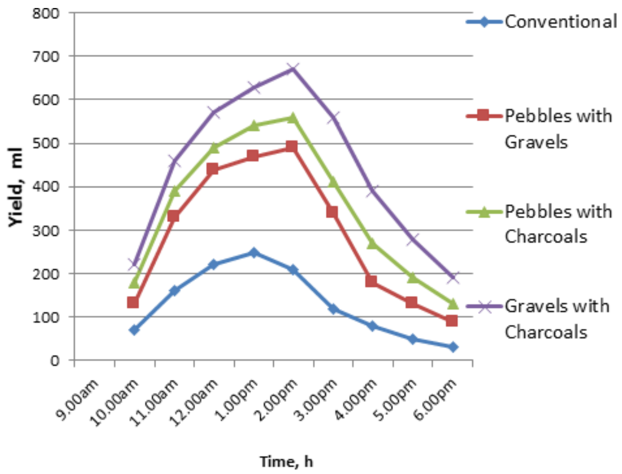

Fig. 7. Yield rate of sensible heat materials.

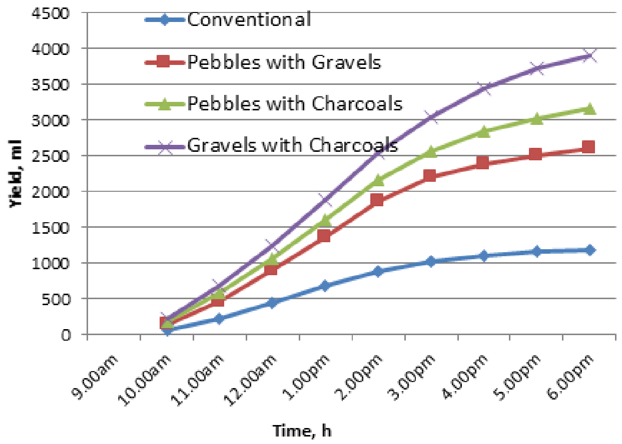

Fig. 8. Cumulative yield range of different sensible heat storage materials.

Table 4
Cumulative day yield of solar still

Time	Without energy material (ml)	Pebbles with gravels (ml)	Pebbles with charcoal (ml)	Gravels with charcoal (ml)
9 am	–	–	–	–
10 am	60	130	180	220
11 am	210	460	570	680
12 am	430	900	1060	1250
1 pm	680	1370	1600	1880
2 pm	890	1860	2160	2550
3 pm	1030	2200	2570	3050
4 pm	1110	2380	2840	3440
5 pm	1160	2510	3030	3720
6 pm	1190	2600	3160	3910

5. Conclusion

In this paper, the solar still with three various sensible heat materials performance were analyzed in the process of converting saline water into good drinking water. From the experimental results, solar still with the combination of gravels and charcoal as energy storage material gave maximum amount of productivity comparing to the rest of energy storage materials.

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