Design and Implementation of Water Distillation System Using Solar Energy

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Abstract. An investigation of the solar distillation using a solar collector with a graduated absorbed surface has been utilized in order to improve the solar still performance. The solar collector is contained on a graduated absorbing surface with 25 steps. Absorbing surface made from copper plate and dye by a thermal black pigment to increase the solar absorption. The top of the solar collector is covered by a glass with 4mm of thickness. While, the other side surfaces of the solar collector are made from the transparent plastic with 6mm of thickness. Also, Aperture area of the solar collector was 0.4526 m². Experiments had been carried out in Baghdad (33.3° N latitude) during May in 2019 to investigate the performance of the still. The results appeared the maximum water production that reached up to 486 ml at the time interval between 12.30 and 1.00 pm, while the total thermal solar collector efficiency was 36%. The proposed method succeeded to reduce the TDS from 679 ppm to 39 ppm for inlet water and outlet pureed water respectively, and the volume distilled water production was 3696 ml for the time from 7.30 am to 4.00 pm.

1. Introduction

Water is one of the resources that potentially useful to all living beings. Often, water sources are brackish containing dissolved solids and a harmful bacterium, and therefore cannot be used for drinking. Distillation is one of the processes that can be used for water purification. Desalination refers to the process of removing salt and other minerals from water. The reason to distill the water in order to extract the fresh water from salt water which is suitable for human consumption or irrigation. Most of the researches in distillation were focused on developing the cost-effective ways of providing fresh water for human uses. Therefore, the solar distillation one of the most popular methods for water purification in the villages and far territory from the source of water purification nowadays [1-2].

2. Literature review

Various researches are carried out to improve the performance of the still. The basin area of the still, free surface area of water, inlet temperature of water, wind velocity, solar radiation and depth are some of the factors that effect on the productivity of the solar still. Abujazar et al. [3] done the efficiency evaluation of an inclined copper-stepped solar still experimentally. They pointed out that using of the inclined trays in stepped solar still increased the freshwater productivity up to 605 mL/m2l, wick type evaporator still and the efficiency of the still are improved by reducing the radiation losses from the
basin. Dubey et al. [4] designed a solar still with separated condensing chamber to enhance the rate of condensation and hence the productivity. Their performances in terms of energy and exergy efficiencies were compared with the conventional still. Dimri, et al. [5] done the theoretical and experimental analysis of a solar still with a flat plate collector under various condensing materials. Rashidi et al. [6] investigated the effect of Nano fluid on the productivity of a stepped solar still numerically. Also, they have optimized the geometry of steps. The results showed an enhancement of 22% hourly productivity. Nagarajan et al. [7] investigated the performance of an inclined solar still with and without baffles. The results showed that the freshwater productivity of the solar still with baffles was 1.68 times the freshwater productivity of the solar still without baffles. Suleiman [8] studied the effect of water depth on productivity, and their experimental results showed that a higher productivity of 6.7 L/day was obtained for a low water depth. Saettone et al. [9] designed and studied a stepped solar still with internal reflective walls, and attached a set of heat pipes. This technique has enhanced the solar still performance by 32.4%. Velmurugan, et al. [10] worked with an industrial effluent in a fin type single solar still and a stepped solar still separately. Velmurugan and Srithar [11] used asponge cubes in the still and acquired about 57.8% more yield than the conventional still. Zurigat and Abu-Arabi [12] modelling of the system along with the performance analysis was compared. Finally, the aim of present work is to investigate the performance of the new type of solar water distillation system using a gradual absorbed surface collector.

3. Experimental work

The experimental setup comprises of a transparent plastic box with dimensions of 73cmx62cmx45cm for length, width and high respectively with an inclination angle of 38.8° as shown in Figure 1. The top of the box was covered by a glass with 4mm of thickness. Therefore, the solar energy would be reaching the surface of absorbing plate through all aspects and from the top of the collector box. The surface of absorbing plate was design as shown in Figure 2. The surface of absorbing plate was made from copper plate with thickness of 1mm. The base area of the aperture area of the solar collector was 66cmx62cm, the maximum height was 30 cm and minimum height was 10 cm. Absorbing surface was reducing gradually from the maximum height to minimum height by 25 steps. Each step had a dimension of 2 x1 x62cm for width, height and length, respectively. As shown in Figure 3. The solar collector contained on three water ports. The first one used for flow of the brackish water into the solar collector, while the other two ports were used for water flow outside the solar collector (one for distilled water and the other for saline water).

![Figure 1. Solar distillation system](image)
A storage tank with capacity of 250 L used to supply the solar collector with brackish water. A gate valve was fitted on the water storage tank in order to control the mass flow rate of water that enters the solar distillation collector. The procedure of the solar distillation work is through the flow of brackish water inside the solar collector when the water is circling around the steps of the gradient surface. Then, the water will be evaporated due to heat absorption from the absorption plate. Finally, the evaporated water condenses as a result of its contact with surface of the glass and slips down to get out of the distilled water port. The remaining water will be very salty and coming from of the saline water port. The inlet and outlet water temperatures were measured by three thermocouples type- K (copper – constantan) with accuracy of ±0.5℃. Solar radiation intensity was measured by using a solar power meter type TES1333

4. Theory and calculations

Heat of evaporation can be calculated as follows:

\[ Q_d = m h_f \]  \hspace{1cm} (1)

Where

\( h_f \) Refers to enthalpy of evaporation of water and equals to 417460 J/kg [13].

Also, the mass of distilled water equal to:
md = Vρ \quad \text{(2)}

Where, ρ refers to the water density and equals to 1000 kg/m³. The heat energy of the distilled water is:

Q_d = \frac{V}{1000} \cdot h_f \quad \text{(3)}

The heat power of evaporation with respect to time interval is:

\dot{Q}_d = \frac{Q_d}{t} \quad \text{(4)}

The efficiency of the solar collector for distilled water is:

\eta_d = \frac{Q_d}{AI} \cdot 100\% \quad \text{(5)}

Where, A is aperture Area of the solar collector equal to 0.4526m². If the heat energy of saline water that outside the saline port use in other applications, so the heat power of the saline is:

\dot{Q}_s = \dot{m}c_p(T_s - T_b) \quad \text{(6)}

Where, \(c_p\) equal to 4180 J/kgK [13]. And the saline water flow through saline water port is:

\dot{m} = \frac{m}{0.5 \times 3600} \quad \text{kg/sec} \quad \text{(7)}

And, the total heat supplied by the solar collector is:

\dot{Q}_{\text{total}} = \dot{Q}_d + \dot{Q}_s \quad \text{(8)}

The total efficiency of the solar collector in case of using the heat power of saline water in other applications is:

\eta_{\text{total}} = \frac{\dot{Q}_{\text{total}}}{AI} \cdot 100\% \quad \text{(9)}

5. Results and discussions

Table (5.1) shows the reading data and the obtained results from 7.30 am to 4.00 pm at a time interval of 30 minutes for each reading at the volume flow rate 2.05 of ml/s. All these reading have taken in centre of Baghdad city with east into west with angle of tilted of 33° and along the day of 19 May 2019.

Table (5-1) measurements and results data along the day of 19 May 2019.

| Time (hr) | I [W/m²] | T_p [°C] | T_s [°C] | T_d [°C] | Tair [°C] | Vol [ml] | Q_d [W] | Q_s [W] | Q_total [W] | η_d % | η_total % |
|----------|----------|---------|---------|---------|----------|---------|--------|--------|------------|-------|----------|
| 8.00     | 567.7    | 30      | 54      | 39      | 31       | 5       | 1.16   | 8.36   | 9.52       | 0.45  | 3.71     |
| 8.30     | 688.9    | 31      | 57      | 41      | 32       | 20      | 4.64   | 12.1   | 16.74      | 1.49  | 5.37     |
| 9.00     | 765.8    | 32      | 59      | 45      | 33       | 50      | 11.6   | 15.69  | 27.29      | 3.35  | 7.87     |
Table 1: The hourly average values of solar radiation intensity and atmospheric temperature.

| Time (h) | Solar Radiation (W/m²) | Air Temp (°C) |
|----------|------------------------|---------------|
| 9.30     | 816.6                  | 33            |
| 10.00    | 852.3                  | 34            |
| 10.30    | 899.7                  | 36            |
| 11.00    | 903.3                  | 39            |
| 11.30    | 915.6                  | 39            |
| 12.00    | 926.4                  | 41            |
| 12.30    | 938.9                  | 43            |
| 1.00     | 945.6                  | 45            |
| 1.30     | 932.1                  | 44            |
| 2.00     | 897.3                  | 42            |
| 2.30     | 856.1                  | 40            |
| 3.00     | 759.4                  | 39            |
| 3.30     | 622.7                  | 38            |
| 4.00     | 521.2                  | 36            |

Figure 4 shows the solar radiation intensity and the temperature distribution (inlet brackish water, outlet distilled water, outlet saline water and ambient air) along the day time from 8.00 am to 4.00 pm. All the different temperatures of the component of solar still and ambient air temperature increased with time until reaching the maximum values of 1.00 pm due to increasing in solar radiation intensity which reached the maximum values of 1.00 pm, where in this case, an increasing in the absorb solar radiation by the collector exceeded the losses to the atmosphere. After 1.00 pm, the temperature decreased due to decreasing in the solar radiation intensity. Where, in this case, the losses from solar collector became larger than the absorb solar radiation.

Also Figure 4 shows that the curve of solar radiation decreased sharply after 1.00 pm due to the cloud that appeared at that time. While, the temperature of distilled water and saline water decreased gradually and this due to absorbed plate worked as a heat storage.

Figure 5 shows the thermal efficiency of the solar distillation collector along the intervals of the day time from 7.30 am to 4.00 pm, where, the time intervals was equal to 30 minutes. Figure 6 shows that both of the distilled water efficiency and total efficiency are increased towards the day time to 1.00 pm, and then decreased due to behaviour of the solar radiation intensity along the day. Also, Figure 6
shows that the total thermal efficiency greater than the distilled water efficiency due to higher outlet water temperature which is used in other thermal applications. The highest value of the distilled water efficiency and total thermal efficiency are 26% and 36% respectively for time interval between 12.30 pm and 1.00 pm due to highest solar radiation intensity at that time.

![Figure 5. Productivity of distilled water with time](image1)

![Figure 6. variation of solar collector efficiency with respect to time](image2)

**6. Conclusion**

An investigation of the solar distillation using a solar collector with a graduated absorbed surface has been utilized in order to improve the solar still performance. Experiments had been carried out in Baghdad (33.3° N latitude) during May in 2019 to investigate the performance of the still. The following conclusions are extracted from this investigation:

1. The values of solar distillation collector efficiency and production of distilled water reached the maximum amount at 1.00 pm.
2. The volume of distilled water production by the solar collector was 3696 ml, which equivalent to 8166 ml/m² through the time between 7.30 am to 4.00 pm.
3. The maximum values of efficiency of the solar collector for both of the distillation and total thermal are 26% and 36% respectively.
Nomenclature

| Symbol | Description | Units |
|--------|-------------|-------|
| A      | Aperture Area of The Solar Collector | m²   |
| Cp     | Specific Heat Capacity | J/kgK |
| hf     | Enthalpy of Evaporation of Water | J/kg |
| I      | Solar Radiation Intensity | W    |
| m      | Mass of Water | kg   |
| ĥ      | Distilled Water Mass Flow Rate | Kg/sec |
| Q      | Heat Energy | J/kg |
| Ĥ      | Heat Power | W    |
| T      | Temperature | °C   |
| t      | Time | sec |
| V      | Distilled Volume | ml |
| ρ      | The Water Density | Kg/m³ |
| η      | Efficiency | -    |

Subscripts

| Symbol | Meaning |
|--------|---------|
| b      | Brackish |
| d      | Distilled |
| s      | Saline |

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