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Performance Study of a Water Desalination System Under Vacuum

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Abstract

Solar still is a device, which can produce fresh water from brackish or saline water. This paper presents an experimental analysis of a solar flash water desalination system under vacuum process to provide fresh water. In this study, a PCM based solar flash water type solar still is designed and constructed and then experimentally tested under vacuum condition. This is an active solar still which consists of a flat plate solar collector for preheating the brackish water, a vacuum type solar still for evaporation of fresh water, a pumping system and a PV system to operate the pump. A parametric investigation was performed to measure; internal basin water, PCM and glass cover plate temperature, internal pressure, product yield and thermal efficiency of the system. A Comparative analysis of the vacuum type solar still with the conventional solar still is also performed. Results show that under vacuum conditions the current solar still is capable to increase the evaporation rate up to 35% more than the conventional one. Therefore, the present solar still is more beneficial, cost effective and environment friendly among various non-renewable techniques available for removal of salinity.

Keywords: Solar still, Vacuum, PCM, Efficiency, Production rate.

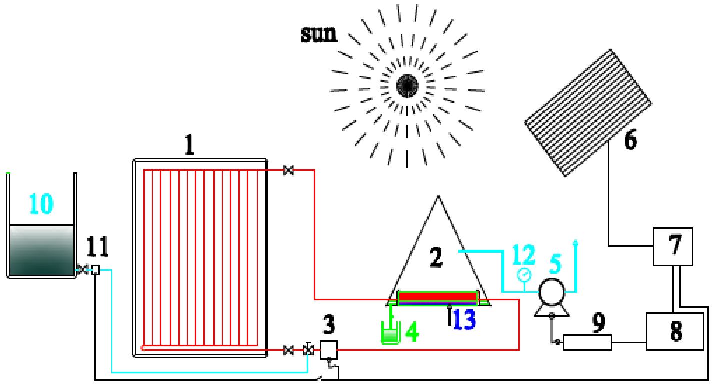
1. Introduction

Major recourses for fresh water are pond, lakes, river and underground water. Availability of fresh water on the earth is limited. It has been estimated that, more than two-third of the earth's surface is covered with water of which 97% of the earth's water of is salty and the 3% is fresh water [1]. Already lot of research works have been done to improve fresh water productivity using different techniques. World's water resources are depleting due to the increase in population and industrialization. As populations increase and sources of high quality fresh drinking water decrease using desalination processes to provide fresh water when other sources and treatment procedures are uneconomical or not environmentally responsible is becoming more and more common. Solar distillation is the use of solar energy to evaporate water and collect its condensate within the same closed system. Unlike other forms of water purification it can turn salt or brackish water into fresh drinking water .The structure that houses the process is known as a solar still and although the size, dimensions, materials, and configuration are varied, all rely on the simple procedure where in an influent solution enters the system and the more volatile solvents leave in the effluent leaving behind the salty solute behind [2]-[7]. Solar distillation differs from other forms of desalination that are more energy-intensive, such as methods such as reverse osmosis, or simply boiling water due to its use of free energy. A very common and, by far, the largest example of solar distillation is the natural water cycle that the Earth experiences. Therefore, development of suitable desalination technique may be appropriate option to the coastal population in Bangladesh. And the cost distribution of solar distillation is low from other [8]. Recently, various technologies have been developed to meet the increasing demand of potable water such as double slope solar still [13], providing low pressure inside the still basin [14], using Nano fluid and integrating the still basin with external condenser [15], enhancing the stepped solar still using internal and external reflectors [16], using a flat and ripped absorber in ''V" wick type solar still [17], floating cum tilted wick solar still [18], using a corrugated galvanized iron steel as an absorber in between the wick strips [19] and multiple porous blackened jute absorbers floated on the water basin [20]. Moreover, Huang et al. [21] studied the multi effect diffusion type solar still (MEDS) coupled with a vacuum tube solar collector. They showed that the 10-effect MEDS produces pure water ranged from 13.7 to 19.7 kg/day/m2 when the incident solar radiation ranges from 600 to 800 W/m2, respectively. For the 20-effect solar still, the productivity increases by 32% compared to the10-effect one. The literature review reveals that various options to improve the performance of solar stills have been investigated. However, a geothermal system integrated with a vacuumed solar still has yet to be explored in detail, especially for vacuum conditions. In this study, a closed-loop system will be integrated with a solar still to reject heat from the distilled water vapor into the ground to improve still performance [24]. (i) The vapor pressure and temperature inside the still can be reduced with a vacuum and, as a result, thermal losses from the vapor are reduced and the solar still can still produce condensed water even with low intensity of solar radiation. (ii) The vapor partial pressure inside the still can be reduced, which enhances the evaporation rate from the still. (iii) The low-temperature water exiting from the ground can enhance the condensation rate inside the condenser.

The present study is focused on modeling of vacuum solar still and performance evaluation integrated with conventional solar still. Many attempts have been made to increase the productivity in this study, influence a PCM based solar flash water type solar still is designed and constructed and then experimentally tested under vacuum condition.

2. Methodology.

The proposed desalination system consists some main parts: glass cover vacuum chamber, solar collector, air compressor, pv module, water pump, inverter, battery, and two inch thick solid PCM under the saline water tray. As shown in Fig.1. In this vacuum type solar desalination system is initially internal basin filled with saline water by pumping from the ground tanks, creating a vacuum above the water surface in the unit with a vacuum pump. The vacuum pump is maintained by the solar controller of solar PV array. In a process, cool saline water is pumped through the vacuum chamber to continuous preheat it before enters a solar heater and flashes into a vacuumed chamber. The water vapor then condenses by losing its heat of condensation. As shown in fig.1. A rectangular shape solar collector with 3.5 fit length, 2.5 fit width and 2 inch depth is connected to the basin solar still. The bottom surface is made from highly selective material to maximize solar energy absorption. Copper tubes of 8 mm diameter are laid on the bottom surface. There are 10 parallel tubes spaced 2 inch apart and are covered by 4mm specular glass. Water circulates through the tubes and the heat exchanger in the basin in a closed loop. Then water circulation occurs by natural convection or by forced convection using a pump.



1. Solar collector
2. Vacuum chamber
3. 12v Dc Water pump
4. Fresh water
5. Air composer
6. Photovoltaic panel
7. Solar charge controller
8. Battery
9. Inverter (12v DC to 220v AC)
10. Saline water
11. Mini 12v Dc water pump
12. Vacuum gauge
13. PCM Materials

Fig.1. Schematics design of solar desalination system under vacuum

As shown in Figure 1, the vacuum pump will create suction (vacuum pressure Po) inside the still to enhance vaporization and drive the vapor to the condenser to prevent it from condensing on the glass. This will also reduce the glass temperature T_g .The energy balance on the water side at a certain instant of time is:

$$I_t\tau_g = (h_{rw} + h_{cw})(T_w - T_g) + h_e[p(T_w) - p(T_g)] \qquad (1)$$

The energy balance on the glass is:

$$I_t\alpha_g + (h_{rw} + h_{cw})(T_w - T_g) = (h_g - T_a) \qquad (2)$$

Where, I_t is the solar radiation at the tilted surface, τ_g is the glass transmissivity, α_g is the glass absorptivity, T_w is the water temperature, and T_g is the glass temperature. h_{rw} Is the radiation heat transfer coefficient from the water given as [25].

$$h_{rw} = \varepsilon\sigma[\frac{(T_w + 273)^4 - (T_g + 273)^4}{T_w - T_g} \qquad (3)$$

Where, ε is the emissivity and σ is the Stefan–Boltzmann constant. h_g Is the glazing heat transfer coefficient given as [25].

$$h_g = \varepsilon_g\sigma\frac{(T_g + 273)^4 - (T_a + 261)}{T_g - T_a} + 5.7 + 3.8 \qquad (4)$$

Where, V is the wind speed at the location and ε_g is the glass emissivity. [26]

The heat transfer may also be calculated as:

$$q = \varepsilon m_c c_c (T_w - T_{c.i}) \tag{5}$$

Where, c_c is the specific heat represents the outlet and inlet temperature of the fluid respectively.

3. Experimental analysis

Fig.2. (a) shows the experimental setup of triangular pyramid type vacuum solar distiller. Experiments were carried out from 9 am- 7 pm. At first saline Water entered to the internal basin from storage tank. The Solar water heater with flexible pipe maintain constant water level in the still. A small glass piece obstruction was fixed on the inside surface of the glass cover, to facilitate the deflection of the condensate return in to the collection channel, which in turn affixed with the still. The gliding water from the channel was transferred in to the measuring jar through the flexible piping. Here use a composer to suck air for a limited vacuum condition. Fig.2. (b) Shows the experimental setup of triangular pyramid type conventional solar distiller. Solar still uses solar irradiation as an energy source. The thermal radiation absorbed by the absorber plate increases the temperature of basin water. Due to the simplicity of the device, it has various applications in the industrial as well as in domestic sectors. The water filled in the basin gets evaporated by absorbing solar radiation and generates water vapor which comes in contact with the glazing cover and leads to the condensation. The condensate (condensed water) is accumulated at the down end of the inclined glazing cover.

The ideal basins used for the distillation have shallow and wide structure with the black painted inner surface; wide structure for larger surface area and black paint for trapping utmost extent of solar energy. The painted surface is baked in the sun to make it free from the toxicity of color otherwise the toxic volatiles will also evaporate with the water. For the collection and condensation, the transparent glass cover is used. If the temperature difference between glass cover and basin plate temperature increases then the distilled output increases. The glass cover keeps the radiation inside the still and produces greenhouse effect.

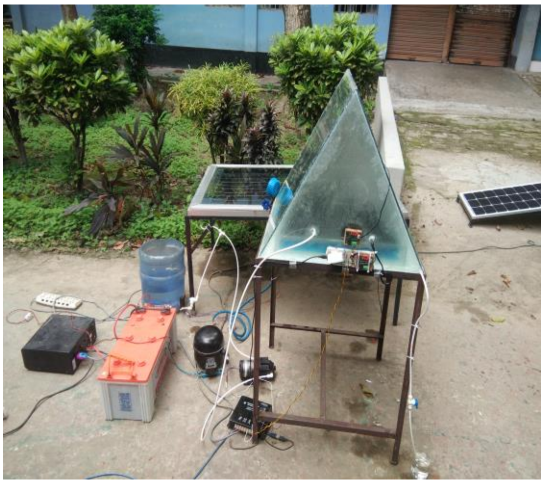


Fig.2. (a)

"Solar desalination system under vacuum condition"

Fig.2. (b)

"Solar desalination system without vacuum condition"

4. Result and discussion

Figure 3(a) and 3(b) shows the comparison ambient temperature of the analytical and experimental results and the figure also shows the experimental result for a conventional and vacuum type solar still. The result of the analytical model enhanced solar still with the vacuum pressure condition. It is evident that the analytical result is in close agreement with the experimental data.

The performance of a solar still mainly depends on the various factors such as depth of water, inclination, water mass and ambient conditions. Thus various experiments were conducted on the still with and without vacuum on different setup. Fig. 3(a) represents the hourly variation of ambient temperature with solar intensity maintaining without vacuum condition and Fig. 3(b) show the same parameters when vacuum is created within the system. It is obvious from the figures that the maximum values are obtained in the afternoon. The average temperature variations for PCM, glass plate and basin water were 49.29 °C, 46.79 °C, and 49.29 °C respectively without maintaining the vacuum condition and with vacuum condition the pervious values were 49.26°C, 42.41°C and 52.02°C respectively.

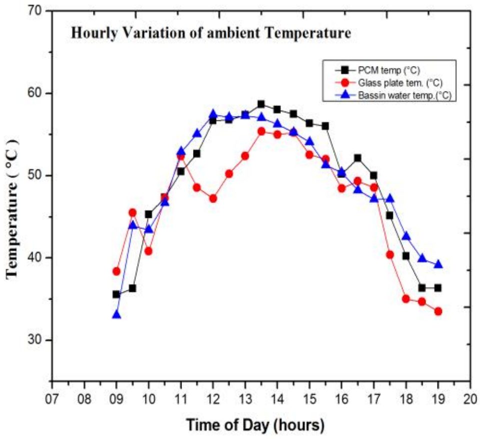


Fig.3. (a) maintaining without vacuum condition

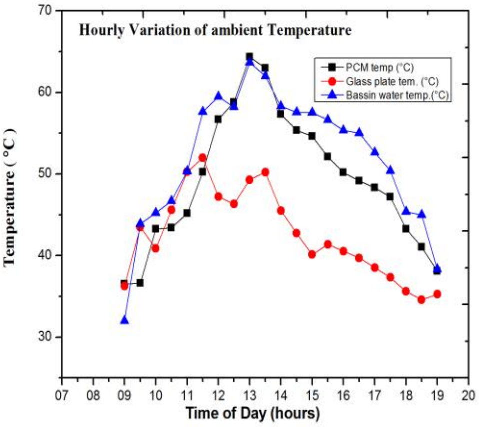


Fig.3. (b) maintaining with vacuum condition

The hourly variation of basin water temperature, glass plate temperatures and PCM temperature were shown in Fig. 3(a) and Fig.3 (b) with internal basin area of 60.96 cm² and 5.08 cm water depth. And the hourly yield 99 ml/60.96 cm² and 119 ml/60.96 cm from basin brackish water. It is clear the basin liner temperature is very close to the PCM temperature at the starting time. After 12:00 pm the temperature of PCM remains constant due to its melting point. With the increase in solar intensity the PCM temperature is increased. During evening it releases its heat to water. It is obvious that the temperature of basin water is decreasing during that time due to the ambient condition. It is observed that the maximum value of solar radiation causes higher evaporation rate of water in the basin. The accumulate yield of solar still is maximum under vacuum conduction. The maximum yield was found to be 990 ml/day (without vacuum) and 1190 ml//day (under vacuum).

Fig.4. (a), Shows that hourly compression of fresh water production under vacuum vs. without vacuum condition. The maximum product yield found by vacuum condition at afternoon in (12:00 -13:00) pm. Also Fig.4 (b) shows that comparison of total productivity of fresh water at10 hours in the date of 05 July 2019 Fri Day.

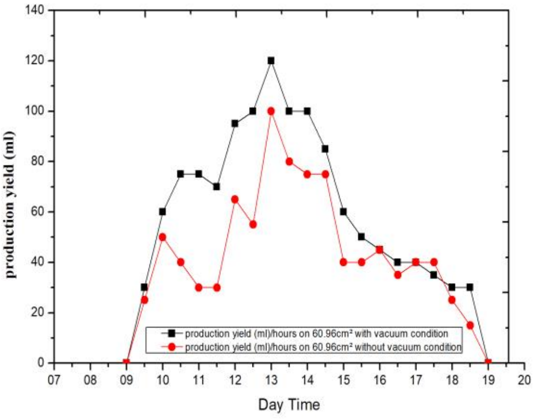


Fig.4. (a) Production rate Vacuum VS. Without vacuum

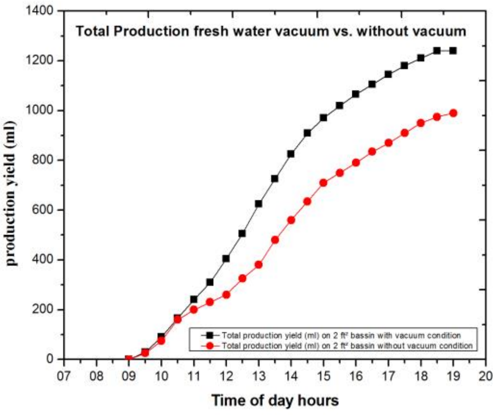


Fig.4. (b) Production Fresh Water Vacuum VS. Without vacuum

5. Error analysis

Evaluation of the system performance needs several parameters to be measured during the experiments. These parameters are the inside saline water temperature, the outer glass cover temperature, the surrounding temperature, the vacuum pressure inside the basin, the total solar radiation and the amount of output distilled water. The Temperature Sensing using DS18B20 Digital Sensors were used to measure all temperatures inside and outside the solar still. The DS18B20 is a small temperature sensor with a built in 12bit ADC. It can be easily connected to an Adriano digital input. The sensor communicates over a one-wire bus and requires little in the way of additional components. A 500 ml glass jar was used to measure the hourly productivity. According to the accuracy of each measuring instrument, the estimation of the uncertainty in measurements has been calculated using the procedures explained by Kline and McClintock [23]. It has been carried out that the maximum uncertainty in the measurements does not exceed 2.5%.

The experimental error analysis indicated the implication of the error in measured parameters on the uncertainty of the results. Detailed analysis of the various experimental parameters was carried out using the differential method according to Moffat [29]. Summary of the uncertainty values of the experimental parameters is listed in

Table 1. Uncertainties involved in measurement of parameters.

Parameter	Temperature	Measuring jar
Accuracy	±1.0 °C	1% full scale
Fluctuation	<±1.0 °C	<1% full scale
Uncertainty	±1.0 °C	1%
Minimum value measured	33 °C	One fourth of the jar
Uncertainty %	5%	4.0%

Table 1 gives the uncertainty in the measurement of different parameters. These values are based on the accuracy of each measuring instruments and the fluctuations observed in the measured values.
The daily efficiency of the solar still is calculated as:

$$\text{Efficiency} = P_d \times L / A_b \sum I_{(t)} .dt$$

The uncertainty in daily efficiency is thus estimated to be ±7%

6. Conclusion

In this experiment a triangular pyramid type solar still is designed and constructed to evaluate the performance under vacuum and without vacuum condition. The maximum hourly productivity is 120 ml/60.96 cm² basin of vacuum type solar still, working hours between 12:30 -1 P.M and then decreases at 6 P.M. At the night time after 6 P.M it slightly increases which means that the PCM is giving its latent heat to water in the basin and enhances the productivity at night. The productivity is predicted for the present unit and it is around 1240 ml/day. From the present experimental results of the solar still under different conditions following conclusions were drawn.

- The productivity of fresh water from solar still was higher at vacuum condition compared to conventional one.
- The efficiency of solar still was increased by 35% under vacuum condition.
- Also it is found that the effect of PCM plays an important factor of the solar still.

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