Experimental Investigation of a Single Slope Solar Still Performance- Evaporation Process Enhancement Using Evacuated Pipes

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Abstract. The single slope solar still productivity strongly depends on the amount of energy absorbed by the solar still basin plate. Therefore, increasing either the basin plate's absorption or enhancing the heat transfer with raw water will increase the pure water production rates. To improve the evaporation and the solar still thermal performance, custom-designed evacuated copper pipes with different diameters and water filling rates are experimentally investigated in this paper. Moreover, it has been noticed that pure water productivity is significantly affected as it improved by 90.09% when using a 15mm diameter pipe with a 50% filling ratio.

Keywords: solar still, distillation, evacuated tubes, solar still evaporation enhancement, solar still productivity

1. Introduction

The solar stills depend on solar radiation to convert the salty and contaminated water into drinking water based on the evaporation and condensation processes. Therefore enhancing any of these processes will improve the solar still productivity. Many attempts to evaluate the solar still performance in several methodologies. Meysam [1] used an external condenser filled with phase change material (PCM) for improving the condensation rates and simultaneously store the latent heat of condense vapor within the PCM for using it after the day time. The performance of the solar still was enhanced by 86%, and productivity records 6.555 kg/m² with a total efficiency of 50%. Adding internal mirrors for increasing the incidence of radiation and adding black painted metal balls was also investigated by Hassanain Ghani[2]. The study focuses on the effect of these parameters on different water depths. The results show that solar still productivity could be enhanced by 22.9% using internal mirrors, as well as productivity improved when using metal balls and decreasing water level. Pankaj Dumka et al. [3] investigate numerically and experimentally the effect of adding a magnetized ring of ferrite inside the still basin. the addition has a great effect on the evaporation process as well as the pure water productivity which improved by 49.22%. In contrast, Mohit Bhargva [4] studied multiple configurations to improve both the evaporation and condensation. Using an internal reflector to gain more energy, evacuated tube collector, heat exchanger, and external condenser. Different configurations were used to improve solar still performance. The experimental results show that the optimum configurations were combining the solar with an evacuated tube, internal reflector, and the external condenser. The improved
configuration was directly compared simultaneously with a conventional solar still with the same dimensions. The enhanced solar still productivity was 2259 ml/m² with an efficiency of 33.4%. Also, active ways are investigated using equipment that requires an external power source. Gnanaraj et al [5] improve the solar still by adding an external mirror for reflecting more radiation into the solar still basin. The increased radiation enhances the still performance by increasing the freshwater productivity by 41%. While, Z. Jaafar [6] study the effect of adding galvanized wick and using a special design solar collecting tank. Using the special tanks helps preheated the input water, which significantly affected the solar still productivity with 48.83%. While using the galvanized wick, improving the productivity by 86.65% using 25*25 mm grid. A. S. Abdullah [7] studied the effect of using a rotating drum inside the solar still basin to improve the evaporation process by increasing evaporation's surface. The drum was equipped with a heater and Nano-particles. An external condenser was also used to increase the condensation rates at the same time. A computational fluid dynamic (CFD) model was developed for estimating the results. The numerical and experimental results give excellent agreement for the solar still productivity. The drum was rotated with different speeds varying from 0.1 up to 4 revolutions per minute (RPM). The productivity increases as the drum speed increases, and the solar still productivity was enhanced by 350% when using an external condenser and drum rotating with 4 (RPM). Zakaria Haddada [8] Investigate experimentally the effect of using vertical rotating wick (VRW) or improve the solar still evaporation as well as the still productivity. The wick was black painted to increase the absorption, and it had a direct effect on the still performance, and the productivity increased by 14.72% and 51% in summer and winter respectively. A.E. Kabeel [9] Investigate experimentally the effect of using Nano-particles to improve the basin water thermal performance. Also, he used an external condenser to enhance the condensation rates in the solar still. The experimental results show that using Nano-particles is more efficient than using an external condenser. Nano-particle use was enhanced by 116%, while it improved by 53.2% by using an external condenser. Other researchers' studied enhancing the evaporation processes of conventional solar still. AK, Kaushal [10] suggested adding a floating wick and a heat exchanger for recycling the wasted heat. The design approaches productivity of 21% more than the conventional, while Mohit bhargva[11] studied combining the solar still with an evacuated tube solar collector to collect more energy. A heat exchanger was equipped in this experiment. The modified solar still performance was enhanced by 160% compared to the conventional solar still. Other methods are used to collect more energy like using an external reflector in the study presented by Lei Mu [12] and other Colleagues. The study investigated combining the reflector with a Fresnel lens for concentrating solar radiation on the absorbing plate. The evaporation presses and the productivity was significantly affected, and it recorded pure water productivity of 467% more than the conventional still. Corrugated basin solar still was also investigated by Z. M. Omara et al. [13] experimentally. The experiment conducted double metal wicks with internal reflectors together, and the freshwater productivity enhanced by 145% with an efficiency of 59%. Ramanathan [14] study the effect of enhancing the evaporation inside the solar still by using a flat plate absorber. Absorbing more energy increases the evaporation rates and improving pure water production by 25%.

2. Experiment set-up

The experiments included three separated single slope solar stills, each one contains a basin fabricated from a galvanized iron sheet of 1.5 mm thickness with an area of 1 m². All sides of the basin were 5 cm height. That iron basin mounted in a wooden frame, insolated with a 3 cm thick white cork for isolating the system and maintaining the collected energy within the solar still and minimizing heat losses. All the solar stills were covered with a 4 mm window glass with a transparency of 88% tilted with 32.1° and facing the south direction to receive the maximum solar radiation possible across the year, as shown in Figure 1.
3. Experimental procedures

All the experiments were conducted in May 2020 at the technical college's rooftop- Najaf /al-forat Al-Awsat technical university (32.5665 41.6256). A direct comparison was used to obtain accurate results by carrying out the experiment with three stills simultaneously and location to ensure that the three stills run at the same environmental conditions. Using 19 K-type thermocouples and a digital data logger are used to record the thermal data each hour from the beginning until the end of the experiment. The solar radiation and the produced pure water were also measured hourly using a digital solar meter and scaled cylinder.

The three solar stills thermal performance were experimentally investigated for 100% and 50% filling ratio under three cases, 15 mm copper pipes, 7mm copper pipes (as in figure 2), and conventional still without adding pipes.

The first comparison was between the solar stills with 15 & 7 mm pipes with the conventional still. The copper tubes were evacuated using two-stage evacuated pumps. After that, it filled partially with 50% of its original volume with water using a custom design feeding mechanism, as in figure 3.

Another experiment was also conducted using the same pre-mentioned configuration. With 100% pipes filing to study changing the pipes contained water on the solar still thermal performance and freshwater productivity.
4. Results and discussion

4.1. Effect of solar radiation

The experimental investigation covers several parameters that directly affected the solar still performance, such as solar radiation, ambient temperature, basin water, vapor, and glass cover temperatures. The first experiment was conducted using a 100% water filling ratio, and as it was noticed that the temperatures of the basin water and vapor rise as the solar radiation rises and continue rising until reaching its peak value at 01:30 PM, while the solar radiation reaches its maximum value at 11:30 AM. As in figure (4-6)

![Figure 4. variation of temperature and solar radiation with time for conventional solar still](image1)

![Figure 5. variation of temperature and solar radiation with time for solar still equipped with 15 mm diameter copper pipe](image2)
Another experiment was also conducted for the same copper pipes with 50% water filling to investigate reducing the trapped water and increasing the evacuated area on the thermal performance. As shown in figures 7 and 8, both the vapor, water, and glass cover temperatures started to rise with the rise of radiation incidence, reaching its maximum value at 12:30 PM.

4.2. Effect of using evacuated pipes

Using evacuated copper pipes filled with 100% positively affects the thermal performance inside the solar still. It is shown in Figures 9 and 10 the temperatures for both vapor basin water of conventional solar still is slightly more in the first hour, due to the needed energy to be absorbed by the basin plate and the black painted copper pipe. After that, the temperatures of them both start to overcome vapor and water temperatures in the conventional solar still and reach the maximum value at 1:30 PM with a temperature difference of 9.8 °C and 4.6 °C for 15 mm, 7 mm pipes respectively. Simultaneously, basin
water temperature differences were recorded as 7.5 °C and 3.7 °C for 15 and 7 mm pipes respectively. After that, the temperature starts to drop until the end of the experiment.

As for the 50% filing ratio, an experiment was conducted for the three solar stills at the same environmental conditions. Adding evacuated pipes was also positively affect the thermal performance of the solar still. Both vapor and basin water temperatures start to rise with the rise of solar radiation. The difference between stills equipped with 15 or 7 mm diameter with conventional solar still was quite a few at the beginning of the experiment. The temperature difference starts to grow with time due to the rise of incidence radiation and the partially filled pipes' additional effect. As shown in Figures 11 and 12.

4.3. Daily productivity

As expected, the accumulative freshwater productivity in both solar stills improved by 15 and 7 mm evacuated pipes was significantly enhanced during the experiment. The accumulative productivity in the still with 100% filling ratio was not at its best values at the first hours of the experiment due to the
large amount of energy needed to raise the trapped water temperature inside the copper pipes. In comparison, it requires less energy when the filling rate is 50%. The accumulative pure water productivity rises along with the experiment time until reaching its maximum value at 1:30 and 2:30 for 100% and 50% filling ratio, respectively, as shown in figures 12 and 13.

Using evacuated pipes with a diameter of 15mm has more effect than using 7 mm pipes due to the increase in tarped water amount. The productivity was enhanced by 46.77% and 19.93% when using 15 and 7 mm pipes respectively. Moreover, as it is obverse in figures 13 and 14, using copper pipes with a 50% filing ratio has more effectiveness than the 100% filling ratio. Moreover, the accumulative pure water productivity records enhance by 90.09% and 27.83% for 15 and 7 mm pipes respectively, compared to the conventional solar still.

![Figure 13. Productivity variation with time for the three types of stills at 100% filling ratio](image1.png)

![Figure 14. Productivity variation with time for the three types of stills at 50% filling ratio](image2.png)

**Table 1:** The accumulative pure water productivity for the three solar stills

| Solar still with copper pipe | 15 mm pipe | 7 mm pipe | Conventional |
|-----------------------------|------------|-----------|--------------|
| 100% filling                | 2.68 L/m².day | 2.19 L/m².day | 1.826 L/m².day |
| 50% filling                 | 4.03 L/m².day | 2.71 L/m².day | 2.12 L/m².day  |

5. Conclusion

The main parameter of this study focuses on improving the solar still thermal performance. To achieve that particular purpose, two different diameters of evacuated pipes filled different water levels. Two improved solar stills compared to a reference conventional still working under the same conditions. The experimental results that added evacuated pipes significantly affected the solar still thermal performance and pure water productivity. Based on the above discussion, some conclusions could be conducted from this study and as below.

1- Adding black painted evacuated pipes significantly affect the solar still productivity.
2- Increasing the evacuated pipe diameter enhancing the solar still productivity by 27.8% when using 7 mm pipe, while it was 90.09% using 15 mm pipe.
Reducing the water filling ratio, enhancing the solar still thermal performance and productivity, and the enhancement was improved from 46.77% up to 90.09% when using 100% and 50% filling ratios.

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