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

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Abstract
The productivity of single-slope solar still is limited due to limited amount of solar energy absorbed, and that directly affected the evaporation process. For enhancing the evaporation in solar still, two ways are experimentally investigated. The first, a specially designed solar collecting tank is used to pre-heat raw water before it enters the basin of still. The second, two sizes of iron wicks are used to increase the area of solar absorbing element inside the still. The results show that the still productivity enhanced by 86.65 % and 72.53 % in different types of wicks, and about 48.83 % by solar collecting tank compared with conventional solar still.

Keywords: solar still, solar water distillation, evaporation enhancement, productivity enhancement, water preheat, single slope, distillation, distillate yield.

1. Introduction
In many communities without proper infrastructure or people who had to live in deserts and remote areas suffer a lack of potable water. Along with the availability of high density of solar energy the solar distillation might be the exact solution for such a problem. Producing a drinking clean water even from the salty or contaminated water is available by the use of solar still. Which evaporates the raw water and condenses it on a slop cool surface for collecting pure drinking water using only solar energy. Many methods for water desalination are used and solar distillation is one of them which costs no money rather needs no fuel. The only requirement is the solar still and space to install it.

Solar still produces pure water easily and with high purity, it could be used domestically, chemically, and also industrially. The water produced by solar still is limited by 2 to 4 liter per day per square meter (1). Therefore, attempts were carried out for increasing that amount by increasing evaporation rates with using different materials inside the solar still basin for either enhance thermal performance or heat storing. ElSebaii et al. (2) are used in their theoretical study a stearic acid as phase change material (PCM) to store solar energy during day time and increase still working time after the sunset. The results of the study show that adding PCM increases productivity by 83.3 %. Another study carried out by Sharshir et al. (3) stated the effect of enhancing thermal characteristics of water by adding nanoparticles to the raw water, like adding...
copper oxide micro flakes and graphite. It is cleared from the results that the productivity was enhanced by 53.9% when using copper oxide micro flakes and 44.9% when using graphite as a nanoparticle. While, Rajasekhar and Eswaramoorthy (4) studied the effect of mixing PCM for energy storing with nanoparticles for thermal performance enhancement. They used Paraffin wax and Aluminum oxide nanoparticles (Al₂O₃) and they found that productivity was enhanced by 45% when using PCM only and 66% when using Nano-PCM.

Adding specified materials to still basin may also enhance solar still performance due to increasing energy absorbing area or thermal contact area. Whereas, Hassanain (5) investigate experimentally the effect of water level changing and adding stainless steel and ceramic blackened balls on the solar still performance. The results prove that the solar still productivity decrease as the water level increases, also adding stainless steel and ceramic blackened balls increase productivity by 15.2% and 9.6% respectively. Haddad et al. (6) enhance the evaporation process by adding wick with vertical rotation for improving the heat transfer performance in the solar still basin as well as the total productivity. The experimental results show that the productivity increased to be 5.03 kg/m² in winter and 7.17 kg/m² in summer with increase of 51.1% and 14.21% respectively. El-Naggar et al(7) developed a solar still module equipped with a straight fins inside the still basin to enhance the heat transfer between the raw water and the absorber plate. The study shows increased in productivity by 13% compared with a conventional still working at the same conditions. While Estahbanati et al. (8) presented an experimental and theoretical study on the effect of installing internal reflector on the solar still inner walls. The results show that the efficiency increased by 18% when installing side walls IR and 22% when installing back wall IR, the productivity as well as increased by 65%, 22% and 34% in summer, winter and an entire year respectively compared to the conventional solar still. Bhargva and Yadav(9) used different types of materials (bamboo cotton, jute, wool, and cotton) in the still basin, which were led to increment in the productivity by 34.5%, 16.9%,37.8%, and 20.7% respectively. Also, in the same trend Rashidi et al. (10) conducted an experimental study with using reticular porous media for evaporation enhancement by increasing the absorption area. The results showed that the productivity increased by 17.35% compared to the still without the additives.

There are many studies presented to improve the solar still performance by using external parts for gained more energy which in turn enhances the evaporation process. One of them an experimental study presented by Gnanaraj et al. (11)which they used external mirrors to reflect the solar energy to still basin to increase the absorbed energy and then the evaporation rates. The results show that the productivity could be increased by 41%. Preheating input raw water to still basin will speed up evaporation time increasing by that the evaporation rates and thus the produced water. Ramanathan et al.(12)presented a modified model of solar still companied with a flat plate collector to increase the raw water temperature and the productivity increased by 25% compared to the model without collector.

The aim of this research is to investigate the effect of raw water preheating by the means of new model solar collecting tank and adding different types of wicks to improve the overall solar still productivity.

2. Experimental Setup

For experimental investigation of the effect of raw water preheating and wick adding, three single slop single basin solar still have been built up on the rooftop of Communication Department at Najaf Engineering Technical College/ AL-Furat Al-Awsat Technical University
located in Najaf / Iraq (31.97°N, 44.36°E). The first still is used as a conventional solar still, the second is modified into a solar collecting tank and the third one is modified into a wick design. All components of the stills, which will describe below, are constructed, from a materials available in the local industrial zone, and fixed inside a 25mm thick wooden frame for support and insulate. The Schematic diagram of the conventional solar still and pictorial view of the modified stills are showed in figures 1 and 2 (A and B).

Figure 1: Schematic view for the solar still 1. Raw water tank. 2. Level tank. 3. Wooden frame. 4. insulation cork. 5. basin liner. 6. Raw water. 7. water vapor. 8. condensed water drops. 9. Glass cover. 10. pure water collecting tray. 11. pure water collecting tank

Figure 2 (A): pictorial view of solar collecting tank
2.1. Basin Liner

The basin is designed according to the standard solar still dimensions with a basin area of 1 m² of galvanized iron metal sheet with 1.5 mm thickness and edges of 100 mm height for containing water without leakage. The basin is painted with anti-rust paint as a first lining, and for absorbing a maximum available energy all the basin painted with a second lining of high-temperature resistance black paint to withstand the high working temperature.

2.2. Glass Cover

For allowing maximum energy to enter solar still and reaches the still basin. A 6 mm window type glass with a transmissivity of 0.88 is used to cover the solar still tilted with an angle of 32° with horizontal. The glass cover is mounted and fixed on the wooden frame by rubber silicon to prevent vapor leakage.

2.3. Insulating Material

The four inside walls of the wooden frame are insulated with a white cork of 30 mm thickness and 0.045 W/m.°C thermal conductivity. Also, the underlie of the still basin is insulated to ensure maximum energy gained.

2.4. The Distillate Channel

For collecting the water condensate from the lower edge of the glass cover a U shape 1000 mm length and 3 mm thick a PVC channel is used. It is fixed inside to collect the water and delivered it from the still to the graduated flask.

2.5. Solar Collecting Tank

In order to enhance the evaporation process more energy must be absorbed by raw water, and as the still basin area is limited therefore a modified tank is suggested to be built with a surface area of 0.176 m² and 7.04L capacity. The tank is tilted with the same angle of the still glass cover and mounted on the side of the still. Also, it is painted with black paint for more energy absorption.

The tank constructed from galvanized iron sheet of 2 mm thickness with (1100 x 160 x 40 mm) and covered by 4 mm window glass with a gap of 4 mm to avoid heat losses by convection with the ambient as shown in figure 2. In order to avoid vapor loss from the still pure
water transparent output hose. It is revolved in a way that creates a static pressure to prevent any vapor from getting out while allowing the pure water to flow normally as shown in figure 3.

The tank is manufactured with side glass tube for level monitoring and to be sealed perfectly with 5 valves to control the water and airflow in and out. A special feeding mechanism is introduced in the developed tank to control the exact water level inside the still basin. As the tank is sealed and the only passage for air to inter the tank is the still feeding pipe designed to barely touch the basin water surface, therefore whenever the water inside the basin is in wanted level the air gap is closed and no water will pass to the solar still until the water level drops allowing the air to inter the tank again as shown in figure 4.

![Still output pipe](image)

![Proposed feeding mechanism](image)

**Figure 3: still output pipe (pure water)**

**Figure 4: proposed feeding mechanism**

### 2.6 Galvanized Wick

For enhancing the solar still performance two types of wicks are proposed to be used inside the solar still basin to increase the solar absorbing area.

The two wicks are made of galvanized iron with the specific heat capacity of (0.46 KJ/kg.k) and thermal conductivity (79.5 W/m.k) and with outer dimensions of (800 mm x 800 mm) and (4 mm) wire gage for both of the two wicks. The inner dimension of the first wick grid is 25 mm x 25 mm while it was 50 mm x 50 mm in the second wick and as shown in figure 5 A and B.
2.7. Measuring Devices
2.7.1. Wind Speed
A digital anemometer type (AM-4206M) is used to measure the wind speed hourly, the range of speed reading varying from 0.4 to 30 m/s with an accuracy of (±1.8% N+2d).

2.7.2. Temperatures
The temperature at different locations along the solar still must be measured and recorded individually. To accomplish that six calibrated K-type thermocouples are used for each solar still to measure the temperature of basin water, vapor and glass cover. Also, four additional same type thermocouples are used to measure the temperature of input water of conventional solar still, ambient, modified tank surface and modified tank output water. All thermocouples are connected to a 32 channel Applent (AT-4532x) data logger and data is recorded and exported in an excel sheet for further analysis.

2.7.3. Solar Radiation
The main parameter that directly affects the solar still performance is solar radiation. A digital solar radiation type (TM-207) is used to measure the exact solar radiation fallen hourly, with the same tilt angle of the glass cover (32°), the accuracy of the used device was (± 5%, ± 10 W/m2).

3. Experimental Work Methodology
The solar still models orientation were from east to west facing the south direction for gain as maximum energy as possible. The solar radiation fell on the front glass passing into the enclosed system and absorbed by the basin plate which contains raw water. As the raw water temperature increased it start to evaporate. As the saturated vapor touches the inner glass cover (with low temperature) it starts to condensate forming a pure water film or droplets sliding on the glass inner side. All the condensed water collected via a special collector for being used. The experiments are done in sunny, cloudy, and partially cloudy climate and the results are measured for the sunny days.

The solar collecting tank experiment is done for the modified solar still with the conventional with a water depth of 20 mm on the 27th January 2020 in the previously mentioned
location. An experiment was done on the 3rd March 2020 to study the effect of adding wicks, three stills are used contain 25*25 mm grid wick, 50*50 mm grid wick and the conventional with the same water depth for all.

4. Results and discussions
All the experiments are done on single slop solar stills that constructed from the same materials, dimensions, location, also ate the same time for obtaining accurate results. The measuring devices are tested and calibrated to provide precise readings. The study is done from 8:30 AM to 4:30 PM.

4.1 Effect of Modified tank
As the solar still performance is strongly depending on the solar radiation intensity and the ambient temperature. Thus, experimentally investigate the effect of adding a modified tank that collects more solar energy with a surface area of 0.176 m².

Figure 6 represents the change in solar intensity during the experiment which varied with time to reaches up the maximum value of 1136 W/m² at hour of 12:30 and then decrease to 108 W/ m² at hour of 4:30 which represent the end of the experiment. Figure 7 illustrates the variation of inlet raw water temperature to the still with time. From the figure the temperature of the input water of the modified still reaches 52.9 °C while it was 16.5 °C conventional one. Also, it’s obvious that increasing the input water temperature effects directly on the basin water temperature, as shown in figure 8 whereas the basin water temperature at the peak time was 58.7 °C and 50.2 °C for the modified and conventional stills respectively. Due to the increase in basin water temperature, the productivity increased dramatically as shown in figure 9 where it was 2.1 L/m². day for the modified still and 1.45 L/m². day for the conventional.
4.2 Effect of Adding wicks

The solar irradiance is the main parameter that control the solar still productivity. Figure 10 shows the daily amount of solar radiation and its variation with time. The productivity is depending on the evaporation rates which related to the amount to the energy absorbed and transferred to the raw water.

The heat transfer inside the still between the water and absorbing plate is determined by the heat transfer coefficient, temperature differences, and the total surface area, increasing the surface area would increase the amount of energy transfer. Therefore adding wicks will help to increase the thermal contact area as well as the heat transferred to the raw water.

Figure (11) shows the differences in water temperature with time caused by adding wicks. As its obvious the temperature has different values correspond to the thermal contact area and the maximum temperature for the water inside the basin occurred when using a 25*25 mm grid wick. The evaporation rates also increased as shown in figure (12), whereas the maximum temperature reached 80.1, 69.9, and 58.2°C when using 25*25, 50*50 mm grid wick and without using wicks respectively. Figure (13) represents the relationship between productivity with time for the three solar still models, where it was 3.16, 2.921 and 1.693 L/m² day when using 25*25, 50*50 and without using any wicks respectively.
5 Conclusion

The main objective of this study is to increase the productivity of the single basin single slope solar still by means of enhancing the evaporation process. All the experiments are done in the city of Najaf /Iraq (31.97° N, 44.36° E) on the rooftop of Communication Department at Najaf Engineering Technical College/ AL-Furat Al-Awsat Technical University. The comparison was done between modifying and conventional stills with the same dimensions, specifications. Also, at the same time for each enhanced parameter and the experimental results showed that the following

1- Raw water pre-heating using solar collecting tank is a very efficient way to enhance the solar still performance
2- Using metal wicks increase the thermal contact area affecting the solar still performance
3- Using 25*25 mm grid wick is more efficient than the use of 50*50 mm grid wick with the same outer dimensions

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