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Assessing the Economic Viability of Solar Distillation Employing a Rotating Hollow Cylinder

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ABSTRACT

This study includes an experimental investigation of a conventional and improved solar still, both dual-tilt. The enhanced solar energy is coupled to a rotating hollow metal cylinder. The purpose of this study is to enhance the productivity of solar energy in the production of distilled water and reduce the production cost. The hollow cylinder enhanced the surface area needed for water to evaporate, while the thin layer of basin water in contact with the cylinder surfaces reduced the thickness of the layer of water to be heated. Adding an aluminium mesh layer to the surface of the rotating hollow cylinder caused the temperature of the basin water to rise, increasing the distilled water throughput from the still. This study included calculating the economic feasibility of the traditional and improved solar stills, as the cost of the traditional still is about 87 dinars to produce one litre, while the improved still costs 65 dinars to produce one litre.

1. INTRODUCTION

Renewable energy sources like the sun, ocean, sea, and wind provide clean power, and this method ensures that the energy reserves are refilled in a natural way. As environmental contaminants rise and the price of petroleum oil fluctuates constantly, renewable energy sources are becoming more important. Traditional power sources can now be surpassed by photovoltaic power. As an immediate transformation approach built on solar photovoltaics, solar power has great potential and various favourable features. It is especially useful in remote places and deserts. There is an abundance of water on our planet. The remaining 2.5% is brackish water, and just 2.5% is potable water. By using solar water distillation, the brackish water can be transformed into potable water. As simple, inexpensive, and environmentally friendly as a solar still can be. A solar water distillery operates by utilising the fundamental concepts of vaporisation and condensation. The solar water distillery uses the greenhouse effect to gradually increase the water's temperature as it passes through a glass surface, allowing the sun's rays to permeate the water and purify it. The vapour from the water is avoiding the harmful waste, leaving behind only microscopic organisms. Condensation forms on the cover's inside, which directs the water vapour into a collecting channel and, eventually, a contained vessel. Solar water distillation is a method that harnesses the sun's energy to convert salt water into drinkable water. Then, we use a solar still to generate potable distilled water, which consists of a traditional solar still and an enhanced solar still combined with a rotating hollow cylinder. In order to enhance efficiency, a layer of metal mesh is applied to the roller, followed by a layer of opaque black paint. The hollow cylinder is placed in a solar water distillation system. As the solar energy intensity increases, the rotation of the hollow cylinder also increases. Conversely, as solar energy intensity decreases, Environmental degradation has grown in economic significance since the emergence of climate change concerns. Water scarcity and environmental pollution are two issues that renewable energy-based desalination systems show promise for resolving. They require bigger installation areas and have higher expenses than fuel-based desalination, but they are not as productive. One way to purify salty, polluted, or brackish water is to use solar water distillation equipment. Since distillation uses solar energy, there is no cost associated with the fuel or electricity used. As a result of the declining concerns over climate change and emissions of greenhouse gases, to account for externalities caused by CO_2, SO_2, NOx, and PM, as well as various carbon-trading cost scenarios, fuel-based desalination cost values are changed. Recognising the environmental degradation costs of fuel-based desalination makes renewable energy desalination systems more economically viable, according to this analysis [1]. The process of theoretically solving the double-slope solar still using a rotating hollow cylinder: when compared to the optimised hourly efficiency of the modified solar still, which stands at 88%, the standard solar still falls short at 62% [2]. Results for all tests (total dissolved solids, pH, electrical conductivity, calcium, magnesium, nitrite, etc.) on distillate water from the solar water distillery have been superb. The pH levels, which fall within the range of 7 to 8.3, meet the requirements set by the standard [3]. Traditional power sources are now making way for photovoltaic power. Particularly in remote places and deserts, solar power has great promise and many desirable qualities as an immediate transformation system based on solar photovoltaic [4]. All four of the cylinders turned at the same time. The thermal performance of the distiller was also tested at 0.1, 0.2, 0.5, 1.0, 1.5, and 2.0 rpm for the cylinders. We also increased the temperature of the water in the basin using three electric heaters, which had a favourable effect on the evaporation rate of the pyramid solar still under study. Powering these electric heaters was a photovoltaic system [5]. The maximum thermal efficiency was 54.5% and 50% for the corrugated and flat discs' solar stills with wick, respectively, at 0.05 rpm. While conventional solar still had an efficiency of around 34% [6]. A modified solar still including a spinning drum significantly outperformed a control still in terms of productivity. Three methods for estimating heat transfer coefficients were used to build a simulation model of the altered still. An error analysis was carried out after the constructed model was calibrated and validated using real-scale data. While holding all other parameters constant, the calibrated model allowed for the systematic variation of crucial elements such as wind speed, solar radiation, brine water level and temperature, and rotational drum speed [7]. There is a fall in productivity from 1 rpm to 0.5 rpm when using a hollow cylinder in conjunction with a flat plate solar water collector, but the increase in productivity ranges from 146 to 260% at different revolutions per minute (rpm) from 0.5 to 10 rpm [8]. Wind speed, temperature, and sun radiation availability are some of the factors that can affect how effectively solar distillation works [9-15].

2. EXPERIMENTAL SETUP

As seen in Figures 1 and 2, there are two types of solar stills: conventional and modified. The standard solar layout calls for a 0.05-metre-thick glass horizontal trough that is insulated. The length, breadth, and height of the basin are 1.32, 0.78, and 0.15 metres, respectively. One square metre is the overall footprint of the aquarium. The item is made of galvanised steel and then painted opaque black to maximise its solar energy absorption. An inclination angle between 0.9 and 32 degrees with respect to the horizontal was used to position a glass cover. The first step is to mount the glass tilt on top of the glass walls that are running vertically. To further secure it to the tub, a rubber gasket is then applied. A 0.004-meter-thick glass cover is included with the window panels. Millimeters are the specified units of measurement for this in the metric system. The bottom of the cup has a tube permanently attached to it so that the distilled water may be easily collected in the receiver. Both the inside and outside temperatures of the cover glasses. One way to characterize the appearance of a customized solar module is as an insulated container. We went with standard solar water dropper proportions for the bowl and cover glass. While modified solar still the process involves rotating a cylinder in a liquid while partially submerged. An opaque black has been applied to the cylinder, as seen in Figure 3. After that, an aluminum mesh is used to cover the empty cylinder. Every clip has a one-inch aperture diameter. Using quick screws, the aluminum layer is fastened to the cylinder's surface. The cylinder is subsequently coated with an opaque black as shown in Figure 2 for absorbed more solar intensity radiation this improvement aims to optimize the production process of the rotatable hollow cylinder, Locations of the thermocouples for modified solar still shown in Figure 4.

Figure 1. Conventional and modified solar still

Figure 2. Before and after painting the aluminum mesh with an opaque black for coated the rotating hollow cylinder

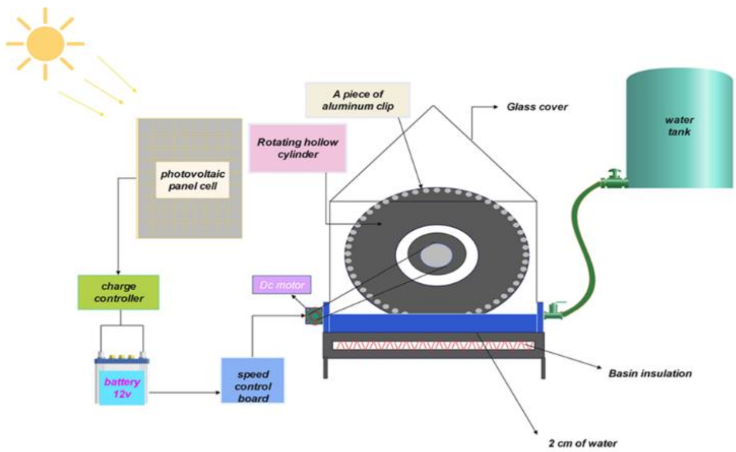

Figure 3. Modified solar still

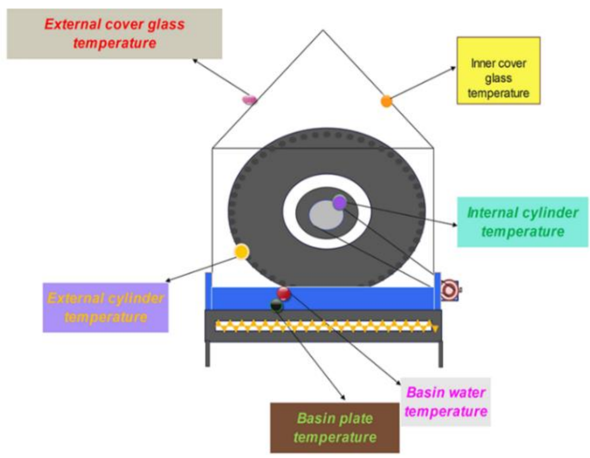

Figure 4. Locations of the thermocouples for modified solar still

2.1 Instruments used in experiment

2.1.1 The photovoltaic panel

This is the measurement of the chosen photovoltaic system: Measurements of this object are L = 1.48 m, W = 0.68 m, and H = 0.035 m. With 17.3 Ah of DC power, it can manage loads as high as 150 W. Offering power to the charge controller was its principal function. The photovoltaic system was tilted at 32 degrees to optimise the output of electrical power. Elements of the apparatus consist of four rectangular aluminium rods that are screwed together at 0.68 and 1.48 metre intervals. The mobility pedestal can be adjusted at various angles using a stationary pedestal. Four aluminium pieces joined at right angles form a rectangle that fits the dimensions of the fixed armrest; this is how the umbrella's supports are attached.

2.1.2 The controller for solar charging

A solar charge controller is an extra crucial component that must be included when using batteries. The lifespan of the batteries can be prolonged by avoiding frequent charging and discharging. The job of this is handled by the charge controller. When the battery is fully charged, the charge controller cuts power to the PV modules. When the batteries reach a certain percentage of discharge, the controller will cut power to the system. Full battery discharge is prohibited by most charge controllers. Having the charger on hand is crucial to the battery's extended operational life. The solar cell panel has it put behind it.

2.1.3 The battery

When sunlight wasn't an option, the DC motor's controller was powered by a 70 A heavy-duty calcium battery.

2.1.4 The DC motor controller

The velocity of the hollow cylinder was modified by a drive-control DC motor in accordance with the intensity of the light. The drive controller increases the rotational speed of the hollow cylinder as the intensity of the sun's radiation increases, and decreases it when the intensity decreases. Integrated into the actuator is a solar intensity sensor. Light-dependent resistors (LDRs), photoresistors, or photoconductive cells may be utilised in the construction of sun intensity sensors. Light regulates the value of a photoresistor. Photoconductivity is exhibited by a photoresistor through the reduction of its resistance as the intensity of the incident solar radiation increases. During the brightest hours of the day, the light-dependent resistor's (LDR) resistance decreases considerably, possibly to a few ohms. When darkness falls, their resistance can increase to 1 M2. Due to the fact that their sensitivity varies with the wavelength of the light, luminescent diode (LDR) devices are deemed nonlinear. The LDR sensor measures the radiation intensity of the sun as a high-precision integrated circuit. The solar intensity positively correlates with the output voltage of the sensor. It is not necessary to calibrate the LDR using external sources. In addition, the charge controller is tasked with supplying power to the drive controller, while a 50 KΩ standard variable resistance volume switch modifies the circuit's resistance to regulate the DC motor's power current and voltage.

3. THEORETICAL SETUP

3.1 The hourly efficiency of the solar stills

3.1.1 The hourly efficiency of conventional solar still

The results were divided by the daily average solar radiation I(t) (W/m^2) over the whole area A (1 m^2) and period Δt (3600 s) of the conventional solar still to obtain the hourly efficiency, $\eta h.c$. This was done by multiplying the hourly cumulative distillate water output $mewc$ by the average latent heat hfg at the average basin water temperature T_{bw} (℃) [16-21].

$$\eta h.c = \frac{mewc * hfg}{I(t) * Abp * \Delta t} * 100\% \quad (1)$$

where, the hourly cumulative distillate water output, $mewc$, for the conventional solar still in (kg/m^2 .hr), Abp is the basin plate area s (1 m^2) and hfg is the average latent heat in (J/kg) is obtained by:

$$h_{fg} = 103\,[2501.9 - 2.40706 * Tbw + 1.192217 * 10{-}3 * Tbw\,2 - 1.5863 * 10{-}5 * Tbw\,3] \quad (2)$$

where, T_{bw} is basin water temperature in (K).

3.1.2 The hourly efficiency of modified solar still

The hourly efficiency, $\eta h.m.$, for the modified solar still was calculated by multiplying the cumulative distillate water output $mewm$ by the average latent heat hfg at average basin water temperature T_{bw} (in degrees Celsius). The resulting value was then divided by the daily average solar radiation I(t) (in watts per square metre) over the entire area A (in square metres) and the time period Δt (3600 seconds) of both the modified solar still and power consumption of the DC motor P_{motor} (2.16 W).

$$\eta h.m = \frac{mewc * hfg}{I(t) * Abp * \Delta t + (Pm * \Delta t)} * 100\% \quad (3)$$

3.1.3 The daily efficiency of conventional solar still

The conventional solar still's daily efficiency, $\eta D.c.$, was calculated by adding together the hourly efficiency and dividing it by the total number of hours of effective distillate water production:

$$\boldsymbol{\eta D.c} = \frac{\sum_{i=1}^{n} \boldsymbol{\eta h.c}}{\boldsymbol{n}} \quad (4)$$

where, n is the number of effective distillate water producing hours.

Table 1. The fixed cost of materials used in conventional and modified solar still

Seq.	Material	Fixed Cost (ID /m^2)	
		Modified	Conventional
1	Sheets of galvanized iron	85000	85000
2	Glass frame and cover	45000	45000
3	Insulation	20000	20000
4	Sheet aluminum	12000	-----
5	solar photovoltaic panel	90000	-----
6	DC-motor	15000	-----
7	DC motor driven by a controller	50000	-----
8	Battery	50000	-----
9	Other	25000	30000
10	Total fixed cost	392000	180000

3.2 The daily efficiency of modified solar still

By adding up the hourly efficiency and dividing it by the total number of hours of effective distillate water generating theoretical, the modified solar still's daily efficiency, denoted as η$D.m.$, was determined.

$$\boldsymbol{\eta D.m} = \frac{\sum_{i=1}^{n} \boldsymbol{\eta h.m}}{\boldsymbol{n}} \qquad (5)$$

3.3 Economic probability of solar water stills

3.3.1 Economic probability of conventional solar still

In Iraqi dinar (ID), the entire fixed cost (F) of a typical solar still is around 180,000 ID, as shown in Table 1. If you want to know how much distillate water production costs on average, variable cost is consist from operation cost and maintenance cost, you have to assume that the total cost (Y) and variable cost (X) are determined in this way [8]:

$$Y = F + X \qquad (6)$$

Y = 180,000+180,000*0.3*305*20 = 1260,000
1260,000/14444.12 = 87ID

With a variable cost (X) of 0.3*F each year and a predicted solar still lifetime of 20 years, the total cost (Y) is 1260,000 ID. The experimental results show that, with a 2 cm water thickness in the basin, the minimum average daily cumulative distillate water output is 2367.89 ml/day. Assuming that there are an average of 305 bright days per year in Kirkuk, Iraq, calculate the cost of producing one liter of a certain product using a typical solar still. In the long run, the solar still will produce 14444.12 liters of distillate water, which is equal to 2367.89×305×20. So, 87 ID per lit is the price of one liter of typical solar still fuel, which is 1260000 divided by 14444.12.

3.3.2 Economic probability of modified solar still

Table 1 shows the total fixed cost of the modified solar still, which includes several components such as the photovoltaic panel and battery: The value of F is 392,000 ID points. Let us pretend the sun still has a lifespan of twenty years. Plus, since we're going to assume that X is 0.3*F every year, we can calculate Y as follows: 2744000 ID = 392,000 + 0.3 * 392,000 * 20. At a basin water thickness of 2 cm, the experimental test findings show that the minimum average daily cumulative distillate water output is 6893.9 ml/day. Pretend that solar stills run for 305 days a year. A modified solar still has a total distillate water output of 42052.79 liters (6893.9×305×20) during its lifetime. Thus, 65 ID per liter is produced by one liter of adapted solar still, which is 2744000 divided by 42052.79.

4. RESULTS AND DISCUSSION

As shown in Figure 5, the air velocity fluctuates during the day, indicating that the air velocity is not constant.

As shown in Figure 6, the month of November experiences higher temperatures. This can be attributed to the higher intensity of solar radiation during the month, as well as the lengthier number of daylight hours in November.

As shown in Figure 7, the elevated temperature during the month of November results in a greater intensity of solar radiation.

The amounts of distilled water produced by the conventional and modified solar stills in October 2023 are displayed in Figures 8 and 9, respectively. Since the sun's rays are more intense in October than in November and December, each solar still produces more distilled water in that month. This is because October is the peak month for solar radiation. On the other hand, September has an average disparity of 34.12% for the upgraded solar still, and December sees an average disparity of 69.51%. In October, the difference rate in a traditional solar still is approximately 29%, and in December, it increases to 46.7%. The reason being that October's higher ambient temperature and less efficient solar still system will cause condensation rates on the glass cover of the still to be lower than December's.

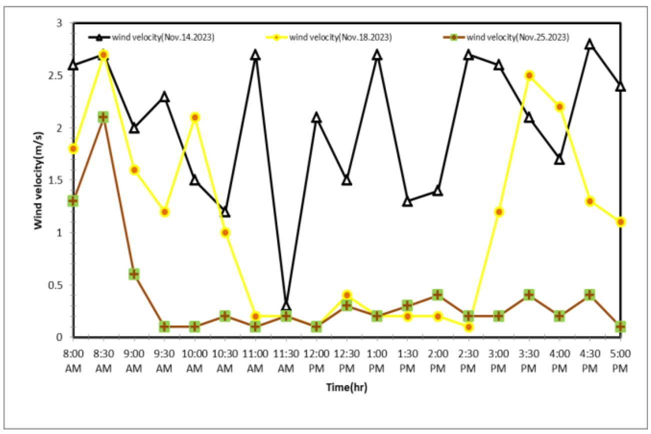

Figure 5. Relation between time and wind velocity for November, 2023, Kirkuk, Iraq

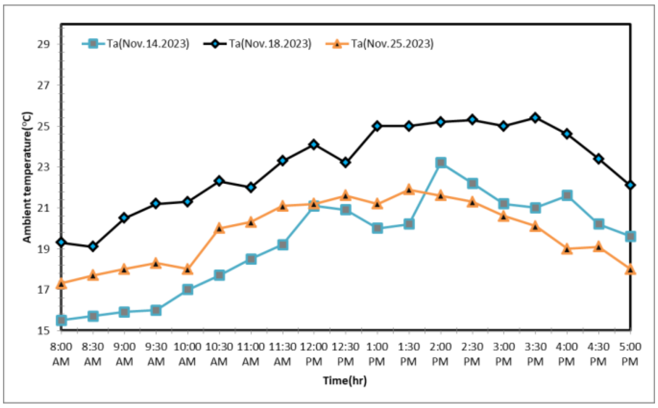

Figure 6. Relation between time and ambient temperature for November, 2023, Kirkuk, Iraq

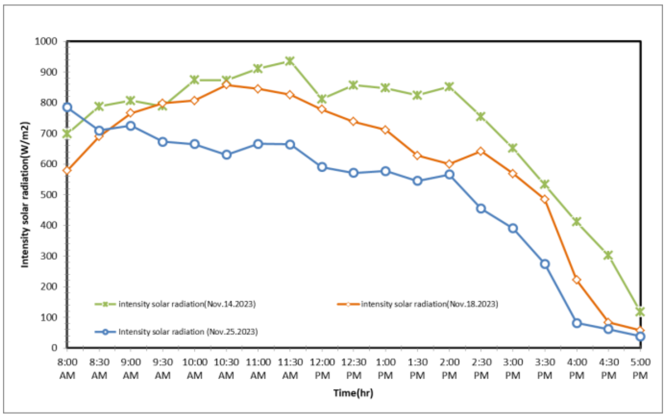

Figure 7. Relation between time and intensity solar radiation for November, 2023, Kirkuk, Iraq

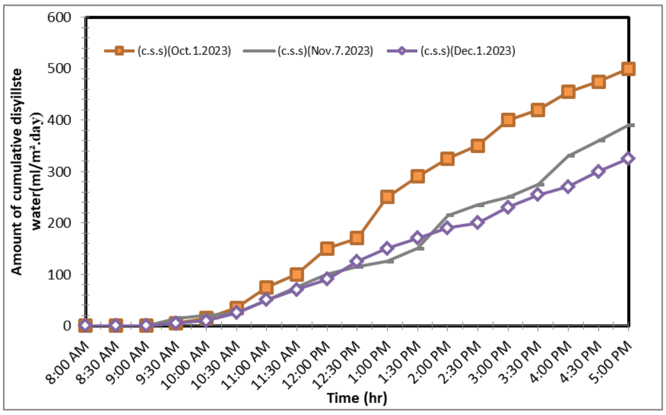

Figure 8. Relation between time and amount of cumulative distillate water for conventional solar stills at (2cm water depth) for different month, 2023, Kirkuk

Even if productivity is higher in October compared to December, Figures 10 and 11 show that efficiency is higher in December. Simply put, less sunlight reaches the distillery basin in the month of December, leading to this effect. Because efficiency is proportional to both the quantity of water generated and the strength of the incident solar radiation, falling in October improves efficiency in December. More so, the distilled water production goes more in December because the temperature drops compared to October, which improves the water vapor condensation on the inside of the glass cover.

Figure 12 shows the efficiency of both traditional and modified solar stills. It is noted that the efficiency of the modified solar distiller is lower compared to (Hussein) (without the presence of collector) because the productivity is high and the intensity of solar radiation is high. Therefore, the efficiency of the current work is lower. However, when comparing the efficiency of an improved solar distiller with the efficiency of (Hussein) in the presence of a working collector. To heat the water in the solar heater before it evaporates, thus productivity is higher, which reduces efficiency. Therefore, the current work efficiency is higher than Hussein's efficiency.

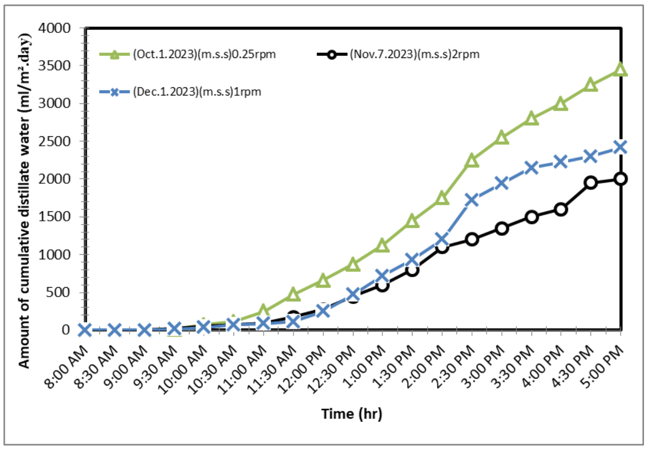

Figure 9. Relation between time and amount of. cumulative distillate water for modified solar stills at (2cm water depth) for different month, 2023, Kirkuk, Iraq

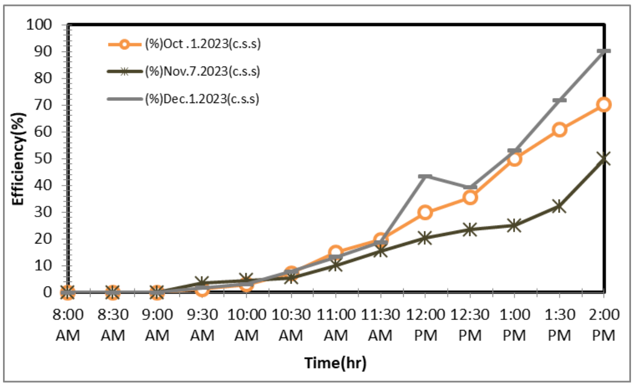

Figure 10. Relation between time and efficiency for conventional solar stills for different month, 2023, Kirkuk, Iraq

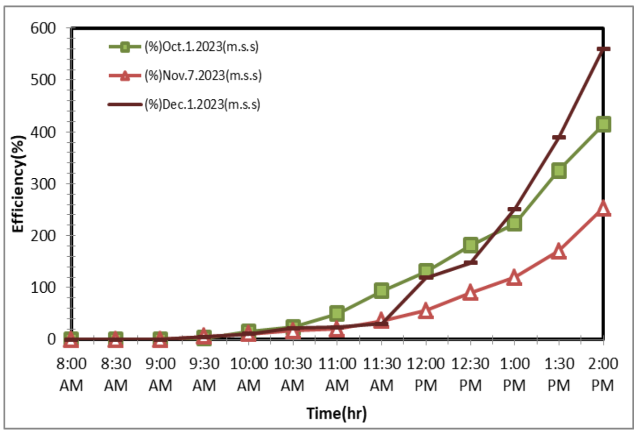

Figure 11. Relation between time and efficiency for modification solar stills for different month, 2023, Kirkuk, Iraq

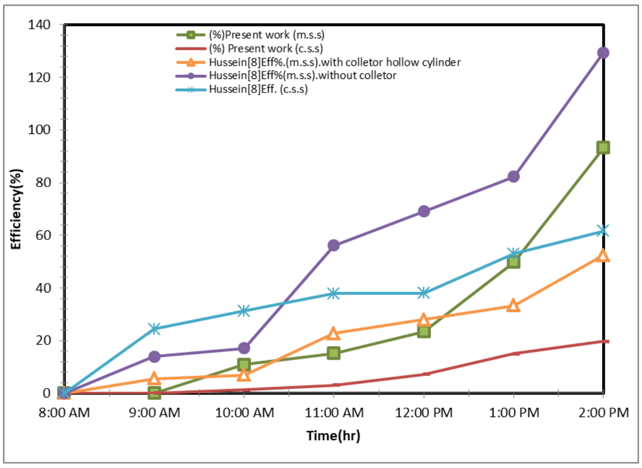

Figure 12. Relation between time and efficiency of various models of solar stills in Kirkuk, Iraq, in 2023

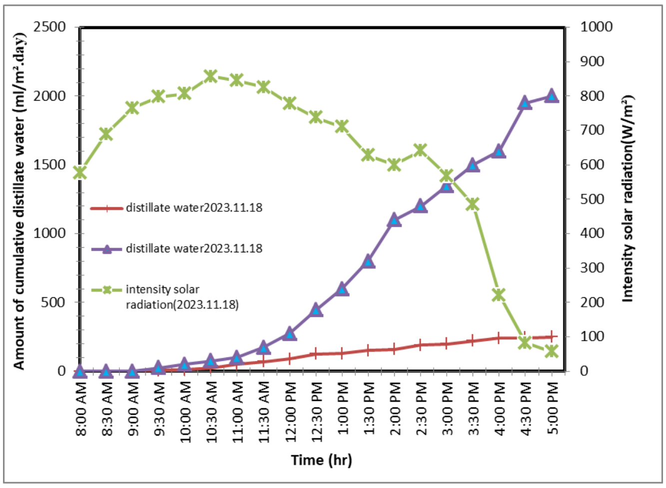

Figure 13. The relationship between the quantity of cumulative distillate water produced by the conventional solar still, modification solar still and solar

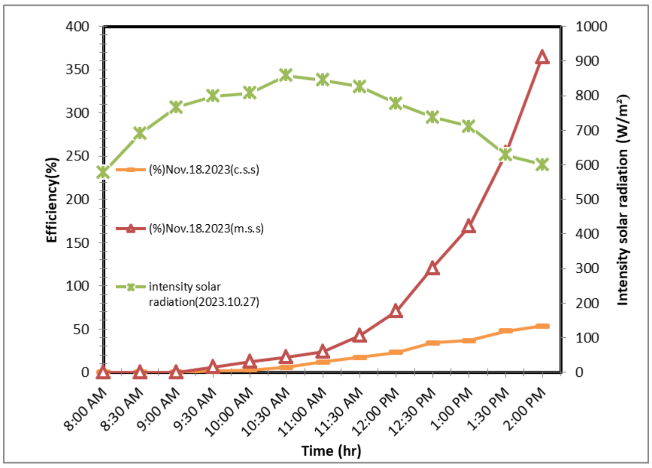

Figure 14. Variation of solar radiation and efficiency for the conventional and modification solar still for November, 2023, Kirkuk, Iraq

The solar radiation intensity in October 2023 and the cumulative quantity of distilled water produced by the conventional and modified solar stills are depicted in Figure 13. It is observed that the cumulative volume of distilled water for both solar stills is greater in October as a result of the elevated ambient temperature and the increased intensity of solar radiation in that month. Consequently, condensation rates on the glass cover of the solar still are expected to decrease during October.

The efficiency of the conventional and modified solar stills, as well as the solar radiation intensity in November 2023, are illustrated in Figure 14. The decrease in efficiency of both solar stills during the month of November can be attributed to two factors: the elevated ambient temperature in November and the heightened intensity of solar radiation in November. While these factors contribute to an increase in productivity, they ultimately result in reduced efficiency.

5. CONCLUSION

1. The study also included a cost-benefit analysis of the two solar still designs; whereas the modified solar still costs 65 ID to produce one litre, the conventional solar still costs around 87 ID.
2. Covering the spinning hollow cylinder with an aluminium mesh layer increases the solar still's productivity. October saw a production of 500 ml from the regular sun still and 3450 ml from the modified solar still operating at 0.25 rpm.
3. Because of the low temperatures and weak sun radiation, December is the most efficient month. So, December is a month of low output and great efficiency.
4. An augmentation in the intensity of solar radiation results in a concomitant enhancement in the still's productivity.

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