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Experimental Evaluation of Stepped Solar Stills Augmented with Magnets as Granular Porous Media

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Abstract: The provision of fresh, drinkable water is essential for human survival. Solar stills, devices that utilize solar energy to produce pure water, face the disadvantage of low productivity. This study proposes a novel solar still design aimed at enhancing thermal performance through the incorporation of stepped types and additional modifications, such as the integration of magnets, to further augment thermal efficiency. Experimental evaluations were conducted outdoors under the climatic conditions of Thi-Qar throughout the year 2023. The findings indicate that solar stills with the innovative stepped design achieved a productivity increase of 39.329% and 31.745%, respectively, compared to conventional designs. Furthermore, the inclusion of magnets resulted in an additional enhancement of 136.2% in productivity compared to the same design without magnets. Solar evaporation is highly regarded for passive water desalination due to its abundant resources, high efficiency, and lack of carbon emissions. Recent advancements have seen the development of bio-inspired solar evaporators that efficiently harvest solar energy and convert it into heat. However, challenges persist regarding the relatively low freshwater production rate and harvesting efficiency. Key areas for improvement include the absorption properties of the evaporator material and the evaporation efficiency of saline water. Water evaporation primarily occurs at the top surface of saline water, with the rate significantly influenced by the temperature difference between the evaporating surface and the surrounding atmosphere. To achieve a substantial temperature difference, broad-band solar absorbers with advanced microstructures have been designed to enhance solar absorptance and minimize heat loss via radiation on evaporating surfaces. Despite the development of sophisticated photothermal materials and evaporators, practical solar evaporation under simple fabrication processes remains elusive.

Keywords: Solar still; Desalination; Distiller; Renewable energy; Distillate yield; Magnet

1 Introduction

The huge rise in demand for energy has led to a shortage of conventional energy sources like fossil fuels, subsequently pushing people to hunt for elective sources of energy. With the sun being the ultimate source of energy, there's a need to tackle it for the feasible development of mankind. Sun-powered desalination has been in use for ages to filter raw water. Due to the progress in science and innovation, reasonable and effective sun-powered desalination gadgets were created for refining raw water utilizing sun-oriented control [1]. As one of the foremost imperative components of the earth, water is exceptionally vital for the existence of human life. It is available on earth in abundance, but very little of its availability comes from human use. Fresh and potable water is the most prominent issue at present. There are numerous variables which are dependable for the consumption of such less accessible freshwater. A few of them are expanding populations, industrialization, urbanization, transportation, etc. There's a need for water for different purposes like cooking, cultivating, drinking, and numerous more. Thus, safe water may be a huge challenge for current and future generations. Singh and Tiwari [2] determined whether spreading coal and metal chips within the basin of a still had any impact. Using the absorption materials (both with and without crystallization), Smith [3] reviewed absorption energy storage methods for single- and multi-effect distillers. Sodha et al. [1] conducted an extensive study of the usage of nanofluids in a still. Salman et al. [4] identified the application of servo-therm medium oil and sand (as materials for heat storage) under the liner of the basin. Mansour et al. [5] used paraffin wax as phase change material (PCM) in their study of passive water desalination through a concentrator and basin. They performed both an experimental and energy analysis. Various methods, including the use of nanotechnology, reflectors, storage materials, fans and fins for improving distillate output, were reviewed in detail by Mansour et al. [6]. For passive solar stills, Hamood et al. [7] discussed the effect of water depth on distillate yield and the internal heat transfer coefficient, whereas Mansour et al. [8] looked at the issue for active solar stills. Mustafa et al. [9] inspected how the distillate yield was affected by the solar still cavity characteristic length (aspect ratio from 1.94 to 2.67). Abdulhasan et al. [10] revealed a complete theoretical investigation of the impact of several climate conditions on a still's production. Utilizing stirrers controlled by a photovoltaic (PV) panel to create turbulence in the basin region, Dawwod et al. [11] evaluated the impact of cavity size on distillate output in a still. Sohani et al. [12] reported a hybrid solar distiller unit integrated with an air compressor using an artificial neural network (ANN) model. Many researchers and scientists have studied the relationship between magnets, magnetic fields, and water evaporation, and the results show that magnetization accelerates the rate of water evaporation. The study by Srivastava and Agrawal [13] shows that when water is subjected to a static magnetic field, the rate of evaporation increases due to alterations in the ions' hydration shells. Nashee and Hmood [14] investigated how water's physicochemical characteristics altered under a 0.5 T fixed magnetic field in a moving circulated system. It was found that water's surface tension was reduced by magnetic treatment. Furthermore, it was also determined that the magnetization leads to more hydrogen bonds being formed and that the mean size of water clusters increases compared to non-magnetized water. Sarbu and Dorca [15] experimentally demonstrated that the water evaporation amount may be greatly increased by using a wide gradient of magnetic field.

1.1 Background and Motivation

This section delves into the background and motivation behind this study. The shortage of fossil fuels and environmental considerations, such as greenhouse gas emissions, can lead to an energy crisis. According to the International Renewable Energy Agency (IRENA), energy consumption will increase by around 60% in the next 30 years, and alternative energy sources must be explored to cater to the needs of the population. One such alternative energy resource is solar energy, which is one of the most abundant resources on earth. The earth receives around 174 PW of solar energy, out of which around 30% is reflected back into space, and 47% is absorbed into the hydrosphere. The amount of solar energy absorbed by the earth is greater than the consumption of energy by humans. This energy can be harnessed for several applications, such as desalination using solar stills.

The earth has around 97% saline water, and only around 2% is useful freshwater, from which around 70% of the water evaporates and gets converted into water vapor. This vapor is again converted into freshwater with the help of cohesive capillary action, i.e., rainfall. Thus, the motive behind the solar still is to imitate the natural hydrologic cycle. Water is evaporated, and then this vapor is condensed into freshwater. Water is evaporated using solar energy, and the evaporated vapor is trapped under a glass cover, due to which the vapor cools down and is converted back into liquid water.

Water supplies are being polluted by industrial effluents. Existing techniques involve high operation costs and are not suited for small applications. Hence, there is a need to have a low-cost system that can operate in distributed applications. Solar stills do not require any complex technology and can be made using low-cost raw materials. A solar still shows the better facilities of natural drinking water sources in warm areas and rural environments.

1.2 Previous Studies on Solar Stills Augmented with Magnets

A stepped solar still (SSS) augmented with granular porous media of iron chips, magnetite powder, and a mix of both as porous media was fabricated to investigate the daily and hourly fresh water productivity after applying the magnetic field from 5 to 50 minutes at each hour from 9 am to 3 pm. The novel arrangement in the SSSs is five horizontal glass partitions on which only saline water is poured. In each partition, the fade and fixed magnets are arranged in separate experiments without their interference. A comparative analysis of all types of stills on all kinds of experiments has also been conducted. The findings indicated productivity in the range of 201.67-231.38 ml/h for the stepped still. Under the same conditions, the productivity was in the range of 383-740 ml/h, while applying the magnetic field for various durations and the still systems under experiments, yielded 242.20-273.94, 393.37-771.66, and 244.23-294.81 ml/h on the stills augmented with iron chips, magnetite powder, and a mix of both granular porous media, respectively. The best yield was observed during the 50-minute fixed magnetic field iron chips on a stepped still with a productivity of 771.66 ml/h, representing an increase of about 35.92% compared to a stepped still alone [16].

The still systems constructed on a mild-steel frame are lightweight. Their overall length, breadth and height are 2,300 mm, 450 mm and 780 mm, respectively. It is to be noted that the experimental setup can be expanded further by adding more glass boxes in series of 0.17m×0.17m×0.06m in size to increase the efficiency of the still [17]. Maximum productivity of 765 ml/h was observed in the still cavity after applying the magnetic field [18] on the first day of September. The maximum ambient temperature difference that was attained in the days of the experiment was about 24, between 25 to 47. Moreover, in the future, a detailed analysis of SSSs under flat plate and vacuum tube-type concentrators can be done to obtain more productivity.

2 Experimental Setup

The magnets used in this study are permanent ferrite ball magnets with a strength of 90 mT each. As shown in Figure 1, 504 spherical balls with an 8-mm diameter were arranged at each step. Thus, the total number of balls used is 50000 across the absorbent plate. These magnets provide a uniform magnetic field distribution in the saline water. They increase the wetted surface area needed for evaporation. In addition, they store thermal energy from the incident solar radiation (i.e., they work as sensible heat storage media). Moreover, they induce a magnetic field that magnetizes water to display this effect on the still's productivity [19].

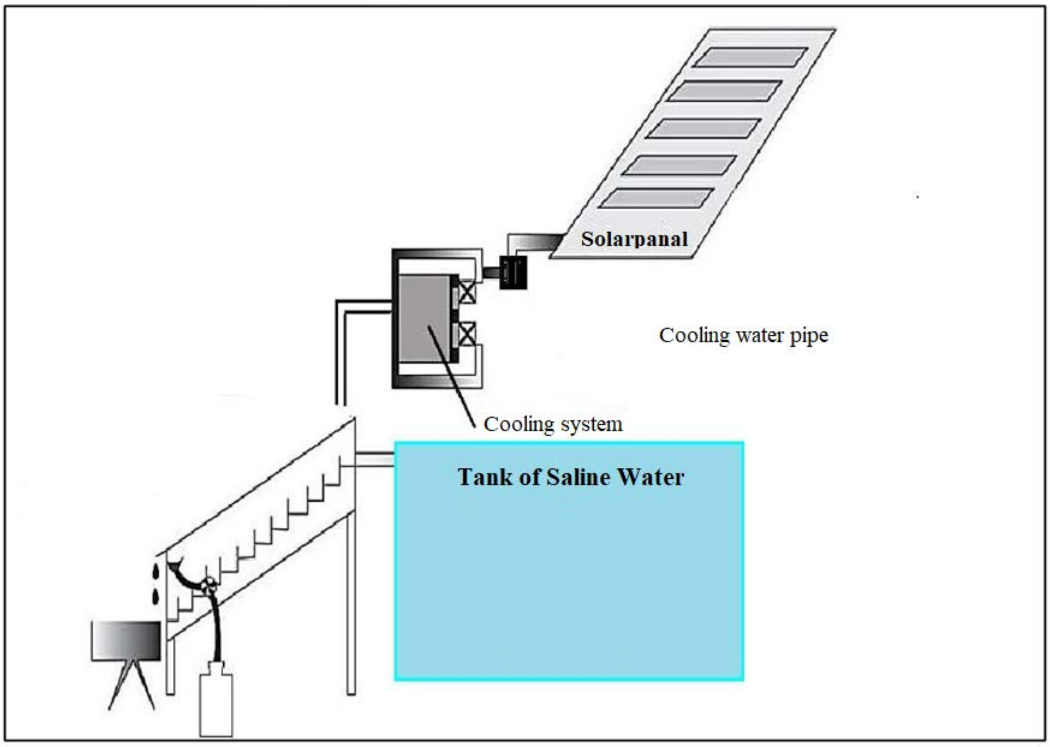


Figure 1. Schematic view of an experimental rig comprises stepped still, water cooling TER, and the PV solar panel

Figure 2 illustrates a schematic view and a photograph of the SSS designed and manufactured in this study. The basin is made of a 1.5-mm-thick copper sheet. A slightly inclined copper channel of 70 mm×50 mm×20 mm (length×width×height) was welded to the inner side of the basin front wall (upper edges) to collect the distillate water. The upper edges of the basin walls were tucked to provide support for the glass cover, while the welded lower and side joints were sealed with a layer of thermal silicon to avoid water leakage [20].

a) Still cover

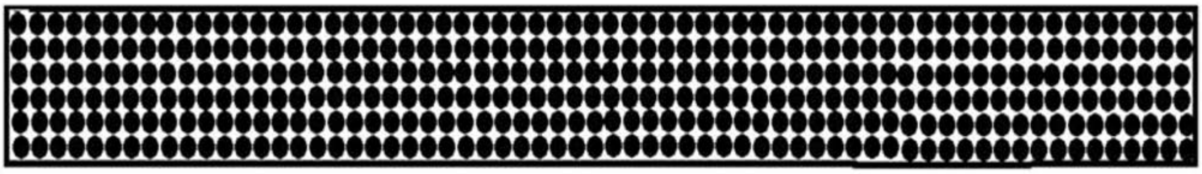
The still glass cover is identical to that used for the conventional still by the projected base area. The insulation is also similar to that used for the conventional still described in the next section.

b) Thermal-absorbing plate

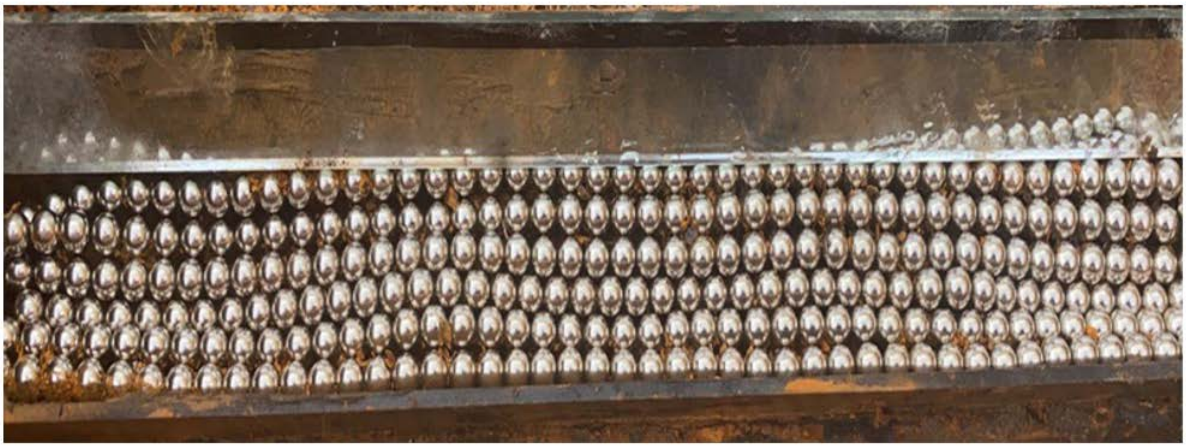
A copper plate of 710 mm×710 mm×1.5 mm (length×width×thickness) was fabricated from the solar energy absorber, which covers an area of $0.5\,\mathrm{m}^2$. The plate was bent into 10 steps of 700 mm×700 mm×20 mm (length×width×height), and was painted with a matt black dye to enhance its absorptivity to the incident solar radiation.

c) Water pump

A 6 W, 220-240 V, 50 Hz head water pump (type Aquarium Pump Q112) was fitted inside the still, as shown in Figure 2, to circulate the water internally and avoid heat loss. It has an 8-mm-diameter discharge port, and provides a maximum head and discharge of 90 cm and 500 l/hr., respectively. The pump delivers the saline water from the lowest step to the first one of the stills. The water flows and distributes evenly over the other absorber steps of the plate. This pump arrangement has an important advantage over the externally fitted pump because an external pump results in more heat loss even if the connecting pipes are insulated. As shown in subgraph (c) of Figure 2, the first supplies the saline water to maintain it at a constant level. The second is a discharge port, which is used for still-emptying and cleaning purposes.



(a)



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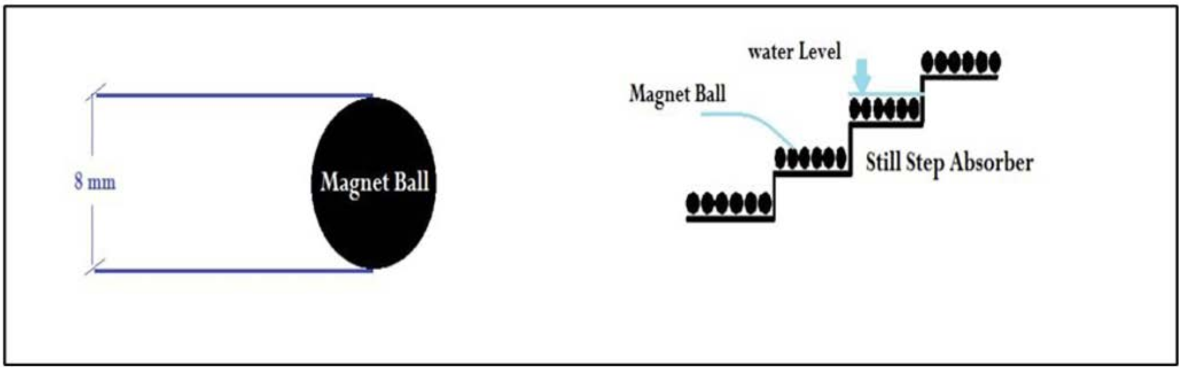


(c)

Figure 2. Schematic of magnetic balls arranged on still steppes: a) top view, b) side view, and c) plate of arranged magnets on the step

With an inclination of 31° with respect to the horizontal surface, the solar stills were covered with 4-mm-thick iron transparent glass. Throughout the tests, the first still (referred to as still 1: SSS) was maintained in its original form, while modifications were made to the second still (referred to as still 2: modified SSS). Figure 1 shows the permanent ferrite ball magnets, which have a diameter of 8 mm. Each magnet's magnetic field strength is 90 mT [21].

504 magnets were kept in the each stepped still, with a total number of 50000. The magnets were arranged in the basin tray (Figure 1) in such a way that an even distribution of magnetic field strength is possible. Both of the stills were oriented in the same direction, which is geographical south. Figure 2 depicts the schematic layout of stills 1 and 2, respectively.

The magnets have a dual effect because they are ferrous. After magnetizing the water, they operate as a storage medium for stored energy, leading to further increases in solar still efficiency. In both still 1 and still 2, five K-type thermocouples (K 7/32-2C-TEF) were placed in the basin to measure the temperature of the water, the atmosphere, and the inner and outer surfaces of the glass. A TM-207 solar power meter was used to measure incident solar radiation during the experiment. A graduated cylinder was used to measure distillate output [22].

All tests were carried out during a 10-hour period (8:00 to 5:00 p.m.). During the experiments, the following items were observed:

- Atmospheric temperatures, water, inner glass, basin, and outer glass.
- Incidental solar radiation intensity on slanted glass covers.

- Distillate output at a one-hour interval.
- Wind velocity.

3 Magnets

Permanent magnets were added to the basin to increase the surface area for evaporation and to store solar radiation as sensible heat due to their metallic and black-coloured nature. Moreover, it induces a magnetic field that magnetizes the water. The main purpose of adding the magnets is to investigate and explore the effect of the magnetic field on the still's productivity. The magnets are spherical-shaped with a diameter of 8 mm. They were arranged inside one of the trays in six columns, each containing 500 magnets. Figure 1 and Figure 2 illustrate the dimensions of the cross-section of the magnet and a photograph of the magnets inside the basin [23].

Experimental evaluations were conducted to compare the daily performance of a SSS with no media and granular porosity augmented with magnets. The experimental setup was placed in the open atmosphere, fully exposed to the sun's rays in the southeastern direction in Kottayam, India (latitude: 9.6598° N, longitude: 76.4418° E). The testing duration is eight working days on manufactured SSSs [24]. The constructed SSS, measuring 1 m×0.7 m, was tested alongside a still with no media (a solar still), which had a flat base at a 15° tilt angle. There are three different depths of the granular porous media in a SSS: 3.5 cm media depth (SSP1) with ongoing performance testing of 1.85 cm from transmittance of sunshine to evaporator surface; 6.5 cm media depth (SSP2) with ongoing performance testing of 4.85 cm from transmittance of sunshine to evaporator surface [25]; and 10.5 cm media depth (SSP3) with ongoing performance testing of 8.85 cm from transmittance of sunshine to evaporator surface up to 8.85 cm granular porous media. Fine sand with a mean diameter of around 0.42 mm was used as a granular porous medium. The magnets used in the assembled SSS (MSSS) are Neodymium Iron Boron (NdFeB) neocube magnets with dimensions of 2.5 mm×2.5 mm×5 mm. An equal magnetic field arrangement was used for this study. Totally, 17 magnets were used in SSSs, with 10 magnets on the evaporator surface and seven in the basin [9]. These magnets were arranged in a hexagonal position from the evaporator surface to the basin with a constant distance of 9.4 cm. The daily performance test evaluation ranged from March 28 to April 4, 2019. The SSS panel was placed on the roof side. The solar stills established in this study were aligned toward the southeast side (η=151°) concerning the earth's mounting because it has the highest projection of sun rays.

3.1 Experimental Setup

This section gives the specific setup for conducting the experimental evaluation, and discusses the configuration and arrangement of components necessary for the operation of the SSS augmented with magnets as granular porous media. The performance of the still without the magnetic field and with additional porous media (fine sand, coarse sand, and fiberglass beads) was compared to that of coated stills of similar design. Experiments were performed from 12:00 pm to 5:00 pm on March 20th, 21st, and 22nd, 2020. No alteration on these days was made in temperature, wind speed, or other meteorological conditions for the selected time periods.

A stepped still made from sheet aluminum manufactured using the pouring method was used in the study. The apparatus has a basin area of 5940 cm^2 (L×W: 210 cm×28 cm), an overall length of 220 cm, a height of 123.6 cm, and a depth of 10 cm. It has four cascaded basins with different areas. The device was placed on the roof of a five-story building located in Pune (18° 32' N and 73° 51' E), India. On a bright sunny day, characteristically, the incoming solar radiation intensity decreases rapidly in the time period from noon until 3:00 pm and then remains almost constant. Therefore, the multi-basin solar still, which is easy to operate, was used to perform the experiments during these time periods of the day.

4 Results and Discussion

The effect of adding magnet balls to the stepped still on its performance was demonstrated. The use of the magnet balls is anticipated to improve the still's performance by enhancing its vaporization process. Figure 3 and Figure 4 demonstrate the water temperature and glass cover temperature, respectively, of the conventional stepped still and the modified stepped still with magnet balls. As for the water temperature, both conventional and modified stills show almost equal temperatures during the morning between 8:00 am and 9:00 am. Then a recognizable temperature difference between the two stills is observed. The still with magnet balls shows approximately 7°C higher than the unmodified still at all test hours. In general, the water temperature starts at the minimum in the morning and goes to its maximum value between 12:00 pm and 2:00 pm before it descends again to the minimum at the end of the day. This behavior is almost the same in both types. As for the glass cover temperature, the hourly temperature variation is almost identical in both stills, indicating a negligible effect of the magnet balls on the still's cover temperature.

Figure 5 shows the hourly yield of the conventional stepped still and modified stepped still with copper magnet balls. The results depict a significant improvement in the modified still's yield compared to the unmodified one. This could be attributed to the energy storage capacity provided by the magnet balls and the water magnetization effect, which reduces the water surface tension. The development percentage is varied during the day, with its maximum value being 195% at 1:00 pm.

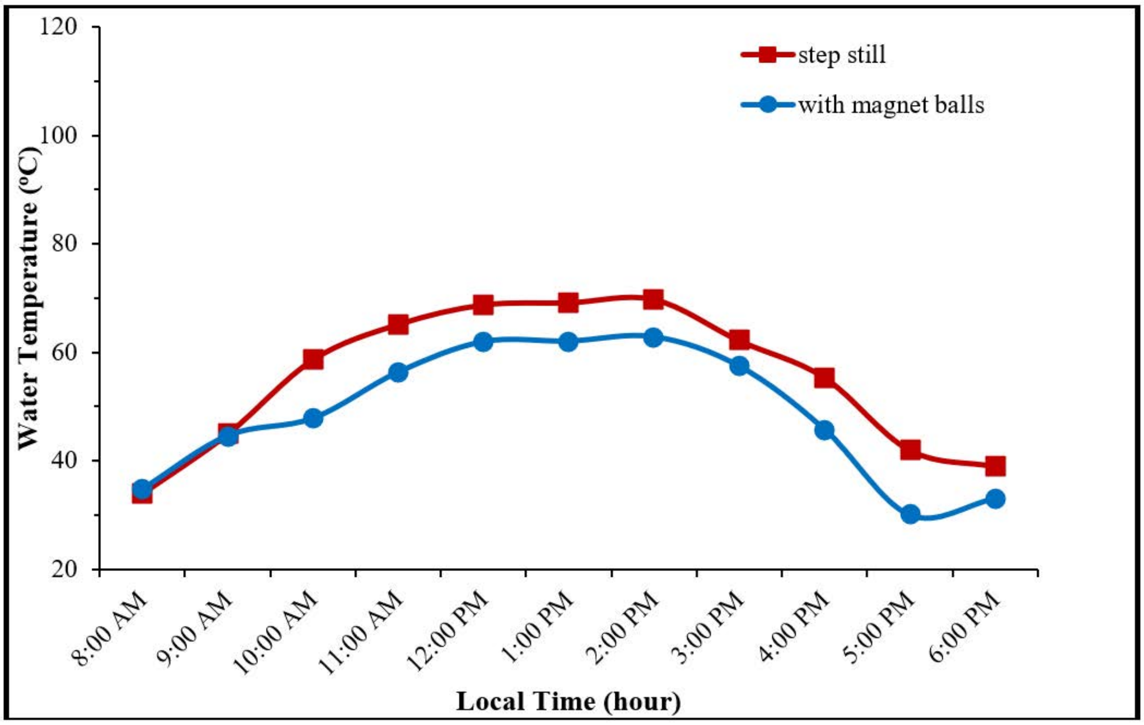


Figure 3. Hourly fluctuations of water temperatures in both modified stepped stills with magnet balls and conventional stepped stills

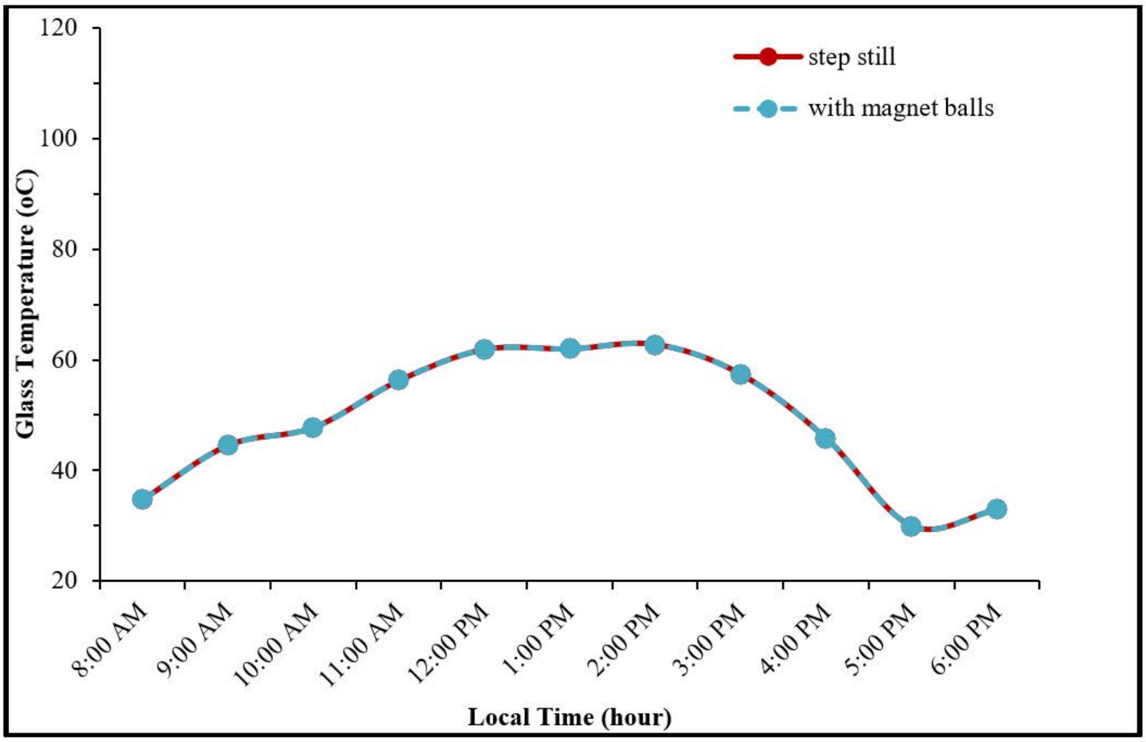


Figure 4. Hourly fluctuations of glass temperatures in both modified stepped stills with magnet balls and conventional stepped stills

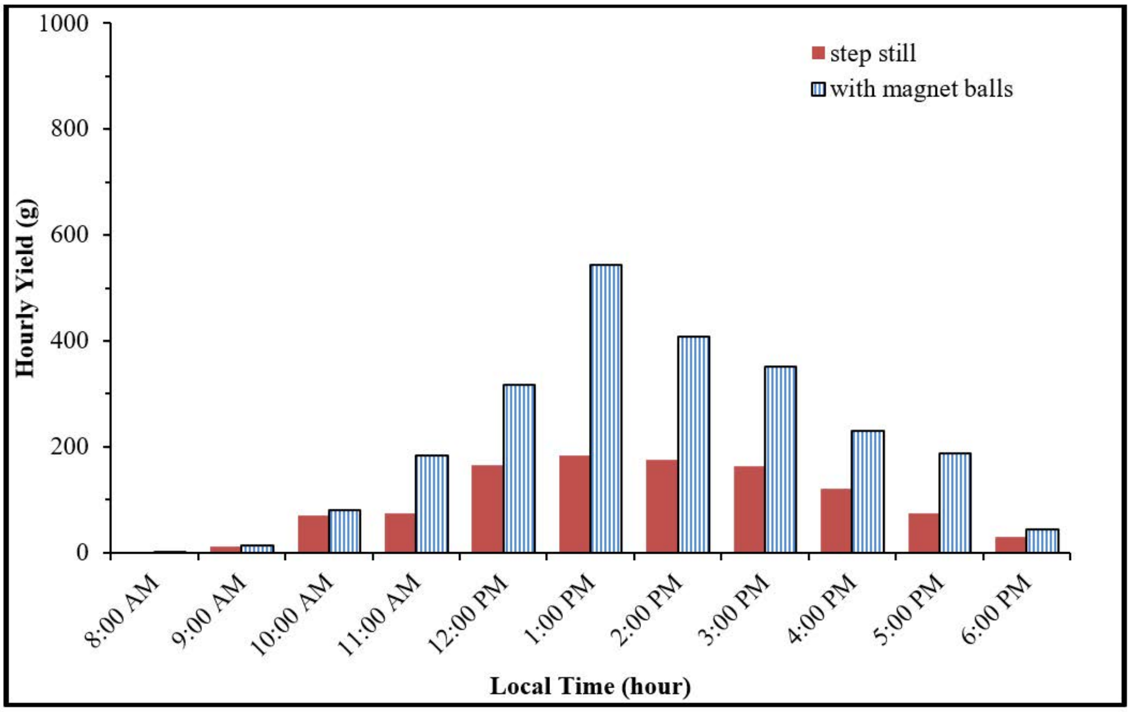


Figure 5. The hourly yield of the SSSs using magnet balls

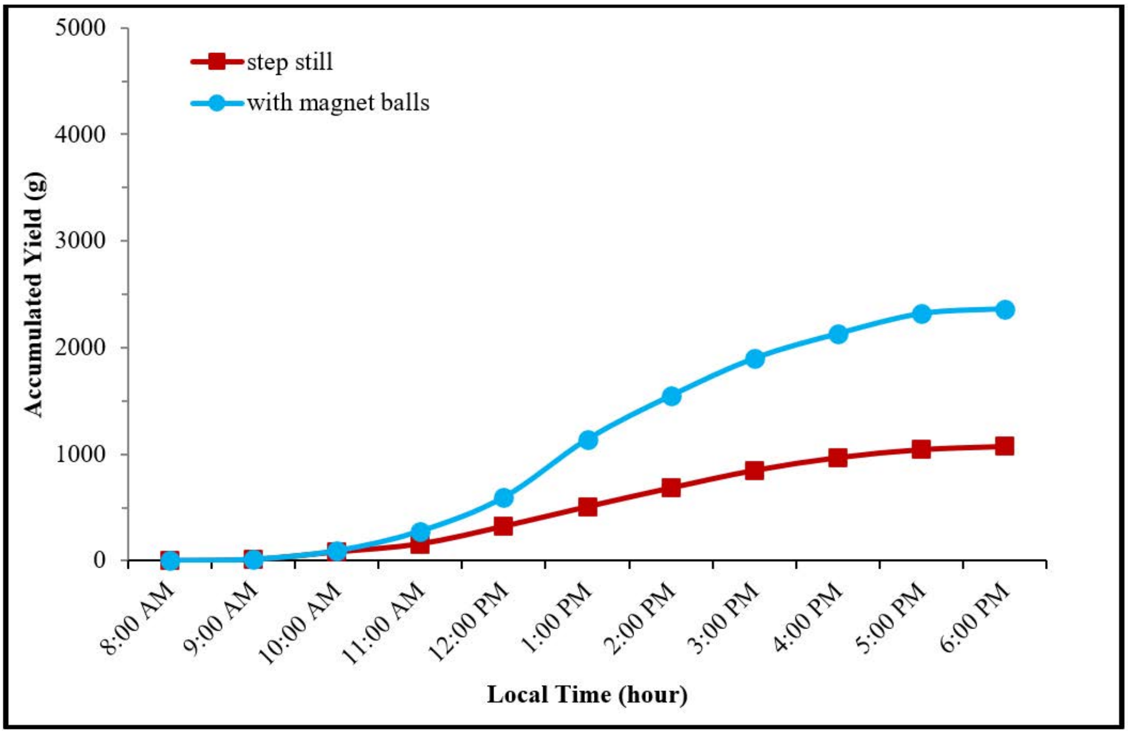


Figure 6. The accumulation yields of both modified stepped stills with magnet balls and conventional stepped stills

The hourly accumulated yield of the two stills is shown in Figure 6. A very minor yield is observed at the beginning of the day due to the low solar intensity. However, it evolves remarkable during the day and continues even after the sun sets because of the stored solar energy in the magnet balls. The reduction in ambient temperature in the evening also plays an important role in improving the yield. The stepped still with magnet balls shows an accumulated yield of 2361 gm compared to 1072 gm for the conventional stepped still, which signifies 120% development. The daily productivity of the stills is demonstrated in Figure 7, with a significant improvement in the modified stepped still's productivity being observed.

Figure 8 shows the instantaneous efficiency of the conventional stepped still and the modified stepped still with magnet balls. No difference between the two stills' efficiency is identified between 8:00 am and 11:00 am. Then the modified stepped still demonstrated improved efficiency between 11:00 am and 5:00 pm. The percentage of improvement is around 300% at each hour of the day.

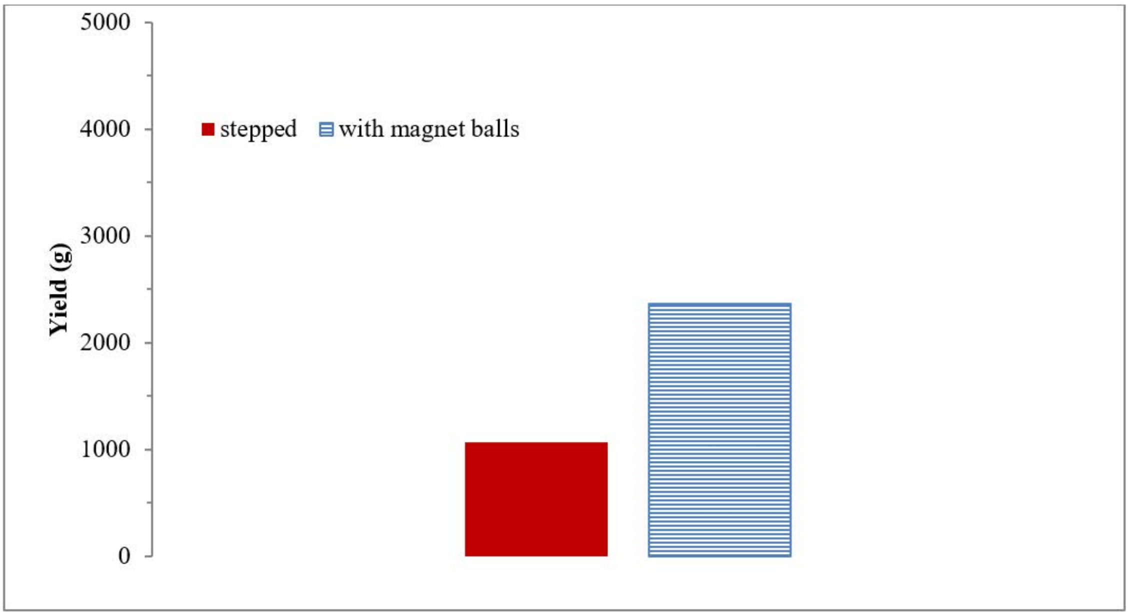


Figure 7. The daily yield of both modified stepped stills with magnet balls and conventional stepped stills

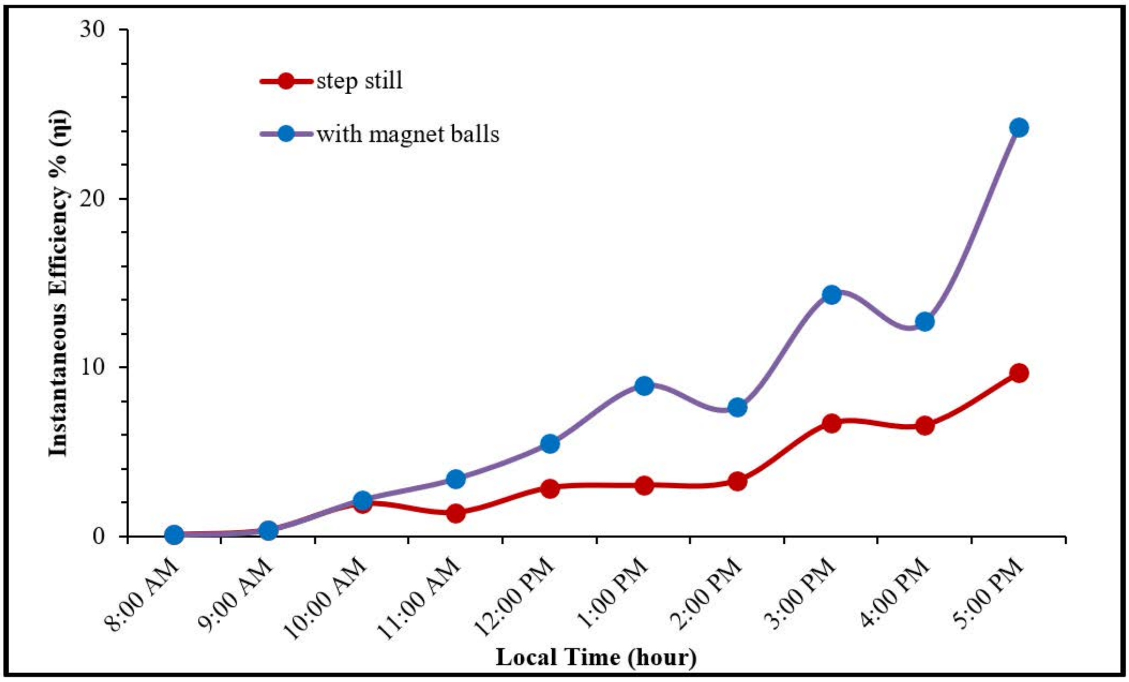
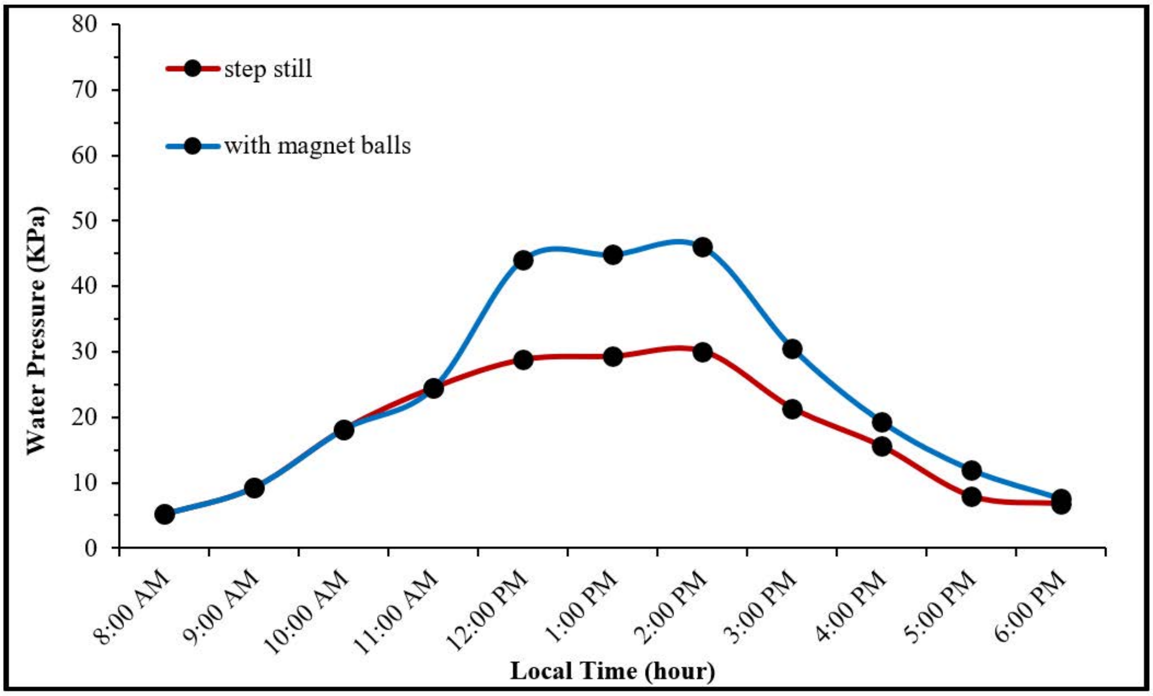


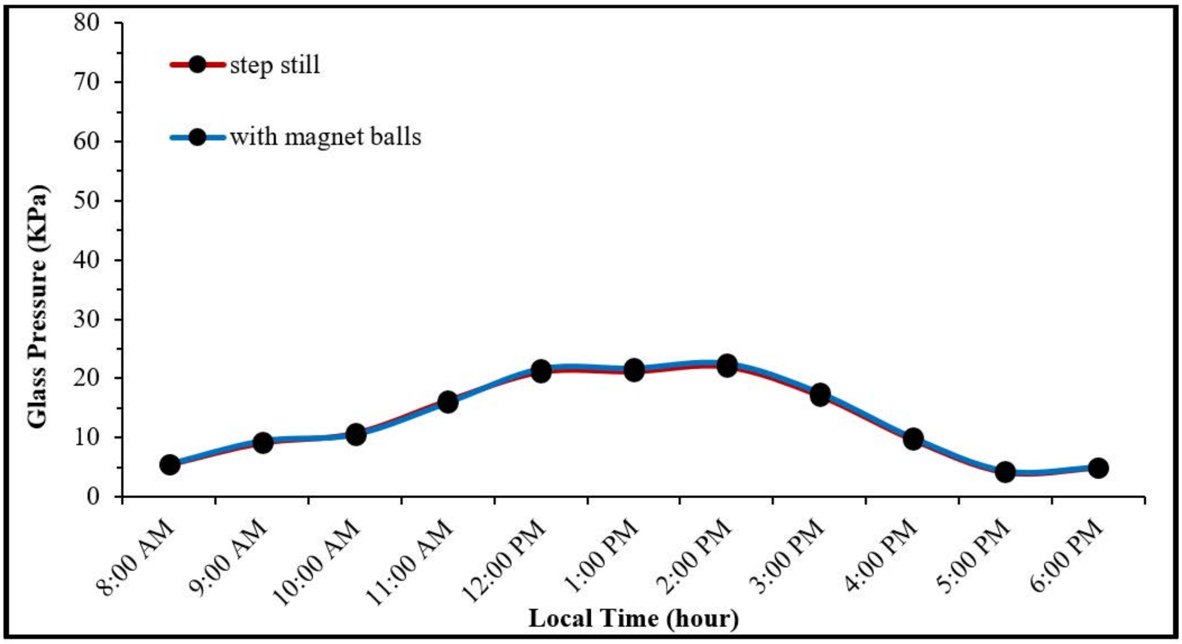
Figure 8. The instantaneous efficiency of both modified stepped stills with magnet balls and conventional stepped stills (1/4/2022)

Figure 9 illustrates the hourly pressure variation inside the stepped stills measured at two locations: the basin water and the glass cover. Subgraph (a) of Figure 9 shows the pressure in the basin water of the conventional stepped still and the modified stepped still with magnet balls. The results show constant pressure development, approximately the same pressure trend and a very minor pressure difference between the two still types from 8:00 am and 11:00 am.

Then the modified still exhibits a significant increase in pressure between 12:00 pm and 2:00 pm compared to the unmodified still, maybe due to the reduction in the surface tension of magnetized water. At 1:00 pm, the pressure in the modified still is 44.8 kpa, which is 53% higher than the pressure in the conventional stepped still. After 2:00 pm, the pressure in both stills descends to its minimum value at the end of the day. The pressure declination rate is higher in the modified still. Subgraph (b) of Figure 9 shows the stills' pressure measured at the glass cover. The pressure at both stills has the same value and hourly variation, indicating no effect of the added magnet balls on the pressure at the glass cover.



(a)



(b)

Figure 9. The pressure inside the stepped stills measured at two locations: (a) the basin water and (b) the glass cover

Figure 10 demonstrates the hourly $h_{conv.}$ variation of the conventional stepped still and the modified stepped still with magnet balls. The results show a significant improvement in the $h_{conv.}$ due to the magnetization effect. Both still types show a linear increase in the convective heat transfer coefficient from 8:00 am to 10:00 am. Then the unmodified still demonstrates constant $h_{conv.}$ value till 2:00 pm when it starts to decline. On the other hand, the $h_{conv.}$ of the modified still keeps increasing till 12:00 pm when the maximum value of 3.8 $W/m^2 \cdot K$ is reached. This maximum value represents 46% development relative to the unmodified still.

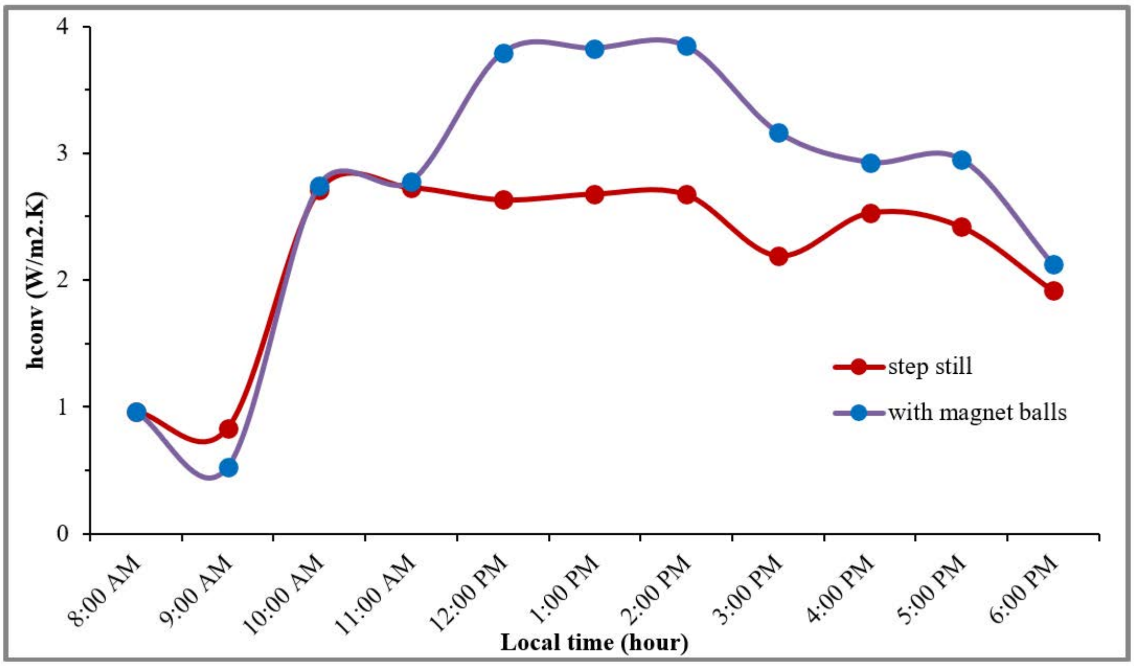


Figure 10. The heat coefficients for convection heat transfer in both modified stepped stills with magnet balls and conventional stepped stills

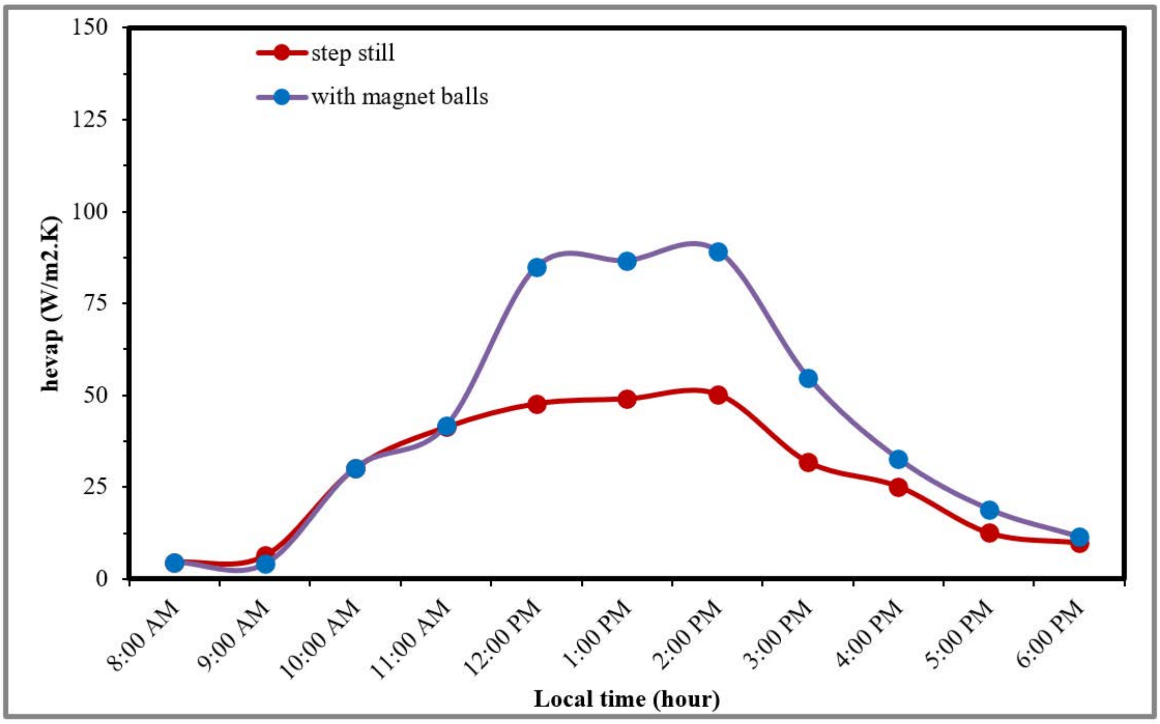


Figure 11. The heat coefficients for evaporation heat transfer in both modified stepped stills with magnet balls and conventional stepped stills

Figure 11 presents the hourly variation of the $h_{evap.}$ value of the modified and unmodified stepped stills. A remarkable improvement in the $\mathrm{h_{evap.}}$ is recognized in the modified still, which is attributed to the magnetization effect. Both stills show an increase in the $\mathrm{h_{evap.}}$ value between the start of the test and 11:00 am. Then the unmodified still shows constant $\mathrm{h_{evap.}}$ value between 11:00 am and 2:00 pm. While in the modified still, the $\mathrm{h_{evap.}}$ keeps increasing to its maximum value (85 $\mathrm{W/m^2 \cdot K}$) at 12:00 pm. This represents a 75% development relative to the unmodified still.

The investigation was conducted with the aim of determining the effect of magnets on water production from a SSS augmented with granular porous media in desert-like conditions. The experimental performance was dogged out for a stepped still filled with iron granular media, kept under the influence of magnets, and compared with the sole effect of magnets upon the still without medium, the sole granular media effect upon the solar still without magnets, and an empty still. The empirical observations persist from January 15th to February 13th, 2020, with daily mean water production of 1.69 $\mathrm{kg/m^2}$, 1.35 $\mathrm{kg/m^2}$, 1.22 $\mathrm{kg/m^2}$, 1.06 $\mathrm{kg/m^2}$, and 0.46 $\mathrm{kg/m^2}$, respectively. Moreover, the performance of a SSS filled with iron porous media was investigated in addition to the previous experimentation to enhance water production. The porous media increased daily mean water production by 29.67%, 61.15%, and 194.79% compared to the conventional still, the still with magnets, and the sole media effects on the still without magnets. The augmentation increased the overall productivity of SSS by up to 11.76%. The overall efficiency of a solar still with granular media is 292.42% higher than that of a conventional still. The granular media effect was 3.81% with an increase of 1 g and 10.95% in 5 g. The highest mean annual water productivity for the media increased from 5% to 15% and then declined to over 15%. Moreover, the empirical observations are also supported by 3D numerical simulations.

The outcomes of the investigation can be summarized as follows: The developed solar still, with a gross area of 1.10 m×0.85 m and its components, is suitable for the use of domestic water and agricultural practices in regions with base water contamination. The SSS with an internal slope of 30° is more productive and efficient as compared to the flat still. The water temperature in the SSS supplied with solar reflectors is higher than that of the conventional solar still. The annual productivity and efficiency of SSS are 3.53 $\mathrm{l/m^2}$ per day and 50.07%, respectively. During the period of experimentation, convection heat losses were reduced due to the design of the stepped still. Hot water was supplied to the SSS from an axial flow rough pipe heat exchanger system. The SSS with stepped inlet and outlet tanks reduced the first-pass hot water temperature in the distribution tank (0.85 m×1.20 m) by 12.69°C compared to the conventional still (0.85 m×0.85 m) which enhanced the performance of the solar still. The stepped still with a low basin depth (15 cm) did not affect productivity and efficiency during the hours of experimentation compared to that with a high basin depth (25 cm). By applying the porous media, daily productivity can be enhanced by 200-220% due to vapour diffusion.

5 Conclusion

Two solar stills were tested experimentally under the weather conditions of Thi-Qar, Iraq. The conclusions are as follows:

a) The solar still with stepped design enhanced its productivity even more by adding the magnets inside the still's basin. The daily productivity enhancement of the SSS with magnets was 136.2%, compared to the same still designed without the magnets. The enhancement was caused by the magnets, which increased the surface area for evaporation and induced a magnetic field within the basin.

b) The solar still's performance is extremely sensitive to climate parameters. The solar radiation has the dominant effect on the passive solar still because it is the only source of energy provided to the system. Thus, the yield is increased by increasing the solar radiation.

The experimental and economic analysis of a SSS augmented with magnets and fine gravel as granular porous media was undertaken. This study explored the effects of the incorporation of magnets in the solar still on the performance of the still, which has not been attempted so far, to the best of the author's knowledge. The experimental data indicates an improvement of about 42% in the productivity of the solar still with the incorporation of magnets over the still without porous media. A hybrid still with both magnets and fine gravel resulted in the highest productivity, with an increase of about 69% over the still without porous media. The use of magnets in stepped solar stills can produce potable water, particularly in barren lands and deserts. The use of solar stills can also be used in military sectors and on-site water restoration plants due to sewage, brine, oil-water downing, etc., and can also produce pharmaceutical water with enhanced quality.

The analysis of a tilted SSS with and without granular porous media was conducted. The experimental configuration uses a hybrid still with sand and stones in granular porous media with water in the basin. To increase heat absorption, the still was painted black from the inside. The economic analysis gives an insight into its field installation. The experimental data indicates that the use of tilted SSS could enhance water yield up to 157.4%, and conventional single-basin stills have not been designed so far. Water depth plays a major role in yield, which increases yield even under less solar intensity.

Future Work

a) The solar still could be coupled with magnets with nanofluid.

b) Different shapes and arrangements of magnets could be used.
c) A magnetic field outside the still could be applied to make the magnets rotate to create movement inside the still.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflict of interest.

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