An Experimental Investigation on the Performance of a Double Slope Single-Stage Solar Still tested in Cape Town, South Africa

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ABSTRACT

Desalination systems have emerged as an alternative solution to the global water crisis, with many countries using them to alleviate freshwater scarcity. Various types of desalination systems exist, including solar desalination, which is the focus of this study. This research aimed to design, construct, and test a Double Slope Single-Stage Solar Still (DSSSSS) under real environmental conditions in Cape Town, South Africa. The system incorporated an Evacuated Tube Solar Collector (ETSC) to enhance its performance. The DSSSSS was tested during day and night. The experiment took place in October and November 2023, during the spring season in South Africa. The water depth was maintained at 50 mm using a float valve, and a 220 V water circulation pump ensured continuous seawater flow between the basin and the ETSC. The system was tested for 12 days, the highest production obtained per day was 513 ml on a day when the maximum outdoor temperature was 30 °C. The minimum distillate produced was 140 ml on a day that had a maximum temperature of 22 °C and that was one of the coldest days during the testing period. A total of 2142 ml of distillate was produced during daytime and 1679 ml at night, amounting to 3821 ml over the testing period. Salinity and conductivity tests were conducted on both the raw seawater and the distillate to compare water quality before and after the purification process.

Keywords-seawater desalinations systems; double slope single-stage solar still; water purification; evacuated tube solar collector

I. INTRODUCTION

Fresh drinking water is a basic need for all living organisms. Accessing this resource is hard because 97% of Earth's water is seawater, which has salt concentrations of up to 30,000 ppm, 2% is frozen, and only 1% is freshwater [1]. Water scarcity is considered a global threat. Africa is one of the continents that experience water crisis with South Africa being amongst the countries that are faced with water scarcity. South Africa faces a severe water shortage due to its semi-arid climate, uneven distribution of water resources, and rising demand from urban growth, agriculture, and industry. The issue is worsened by droughts, outdated infrastructure, and environmental degradation. This scarcity leads to significant challenges, such as health risks, economic difficulties, and instability in societies, especially in underprivileged areas. Addressing the problem involves promoting water conservation, upgrading infrastructure, enforcing sustainable water management policies, and raising public awareness. Collaborative efforts are essential to ensure equitable access to clean water and long-term sustainability in the region [2, 3]. Between 2016 and 2018, Cape Town, South Africa, experienced what was reported as the most severe drought in a century, coming alarmingly close to exhausting its municipal water supply. The term "Day Zero" emerged, referring to the anticipated day when the city's taps would run dry, forcing residents to collect a daily ration of 25 L of water from communal distribution points. This crisis not only sparked widespread panic but also attracted significant international media coverage [4].

Considering that 97% of Earth's water is found in the oceans [5] and that South Africa has the third-longest coastline in Africa that stretches across two oceans, the seawater desalination technique could be a viable option for the water crisis. Seawater desalination is the method used to convert seawater from the Earth's oceans into water that is suitable for drinking [6]. Although this process proved to be a viable option for the water crisis, it comes with high energy demands. The global energy consumption for desalination is growing rapidly, having surged by 36.6% over a six-year span, from about 41 TWh in 2014 to 56 TWh in 2020. This demand was projected to rise to 345 TWh by 2040. Such a substantial increase in energy use for desalination is expected to increase climate pollution and global warming [7]. Alongside the environmental challenges, South Africa is also facing an energy crisis. This crisis, referred to as load shedding (defined as a controlled process of temporarily cutting off electricity in certain areas to prevent grid failure), has been marked by extensive nationwide power outages since it began in 2003. The situation has worsened significantly since May 2022 [8]. Peak loads and plant failures in the coal-fired generating units are the causes of loadshedding in South Africa. Technical issues cause plants to malfunction, resulting in unscheduled shutdowns or loss of load. This is a clear indication that operating desalination systems in South Africa could add strain to the country's power consumption [9].

Solar energy is freely available in nature and produces no carbon dioxide emissions, making it an attractive option for desalination [10]. Since these systems are highly energy-intensive, it becomes a challenge to use solar energy to drive them [11]. Solar desalination provides an alternative method that can be used to partially supply the world with potable water while utilizing low-cost energy, straightforward technology, and environmentally friendly practices. Solar desalination is an alternate strategy that can help ensure that there is always enough drinkable water available worldwide, which uses low-tech technology to harness free solar energy and encourages ecologically friendly behavior. Solar desalination is a dependable and sustainable water supply in rural or isolated places with moderate water demands [12]. Solar desalination systems are categorized into direct and indirect processes based on how solar energy is used to produce freshwater. In direct systems, solar energy is directly applied to seawater, combining energy collection and desalination in a single process. Indirect systems involve two sub-systems: one for collecting solar energy and the other for desalination. The solar energy can either be used as heat through thermal collectors or converted to electricity via photovoltaic panels to power a conventional desalination system [10]. Solar desalination systems refer to a device called a solar still. Solar stills are simple and cost-effective devices used to convert brackish or contaminated water into pure, potable water. They are designed to purify water using solar energy through the processes of evaporation and condensation. A solar still features a container with contaminated water and a transparent cover that captures solar heat, leading to the evaporation of the water. The vapor then condenses on the cover and is collected as purified water [13].

There are many types of solar stills, one being the Double Slope Single-Stage Solar Still (DSSSSS) which has received considerable attention and has been noted for its straightforwardness and potential for improved efficiency [14]. Its design features include two inclined covers that enhance the condensation and collection of distilled water. Authors in [15] stated that the performance of a solar still is influenced by several factors, including design and operational and climatic parameters. Design parameters cover aspects like the still type, insulation, cover material, tilt angle, and orientation. Operational parameters affect factors such as water depth, preheating of the feed water, salt concentration, and the use of dyes, wicks, or other heat-absorbing materials. Climatic parameters, which are less predictable, include solar radiation, ambient temperature, relative humidity, wind speed, and overall weather conditions.

Authors in [16] aimed to improve the performance of a conventional solar still by comparing two double slope solar stills: a conventional and a modified version. The study evaluated the productivity, distillation efficiency, and exergy efficiency of both stills. The modified solar still featured a vacuum inside the chamber and used paraffin wax as a Phase Change Material (PCM) for energy storage. On the experimental day of October 14, 2020, from 10:00 AM to 6:00 PM, the modified still produced a maximum of 1300 ml of fresh water, while the conventional still yielded only 410 ml. Similar results were observed on the following day, October 15, 2020, with the modified still producing 1260 ml of fresh water compared to just 390 ml from the conventional still. In [13], two double-slope solar still designs were compared: a conventional solar still without fins and a modified design with parabolic fins as energy-absorbing elements. The study was conducted in Hyderabad, India (17.3850° N, 78.4867° E) from 9:30 am to 5:00 pm, with water depths ranging from 1 cm to 3 cm. The results indicated that the solar still with the parabolic finned basin achieved higher temperatures due to its increased rate of heat transfer. The desalinated water output was highest at a water depth of 1 cm, lowest at 3 cm, and intermediate at 2 cm. This suggests that the fins increased the contact area between the basin water and the absorber plate, improving efficiency. The 1 cm water layer, being thinner, facilitated greater heat transfer and thus enhanced desalination efficiency. The conventional still produced a maximum of 1180 ml of water per day, while the still with the parabolic finned basin produced up to 1250 ml per day, an increase of 70 ml [13].

Authors in [17] aimed to enhance the performance of a double slope solar still. Two solar stills were constructed and tested: a conventional solar still and a modified version. The traditional still, made of 1 mm thick galvanized steel, had basin dimensions of 1250 mm × 600 mm with a water depth of 10 mm. The modified still featured a larger condensation surface area compared to the conventional model, facilitating better heat exchange between the glass cover and the surrounding air. Additionally, reflective sheets were attached to the distiller's base and inner walls to redirect sunlight and provide extra heating to the basin. The external dimensions of the modified still were 1250 mm × 1100 mm × 400 mm. Both stills were tested simultaneously under the same weather conditions from February to July of 2014 in Baghdad, Iraq (latitude 33.33, longitude 44.43). The integration of internal reflector panels in the modified solar still increased water yield by approximately 18.5%. The modified design enhanced water temperature by reflecting solar radiation, which in turn increased the rate of vaporization. Moreover, the larger condensation area contributed to a higher rate of water condensation and overall productivity. In [18], a double-slope solar still was designed, constructed, and tested under Kenyan climatic conditions. The still had a basin area of 1 m² with a glass cover inclined at 15°. During the study, conducted in September and October 2016, the fabricated still produced 1.652 L/day.m^2. Authors in [19] carried out an experimental study aimed to increase potable water production using an Ultra-Modified Double Slope Solar Still (UMDSSS) under the climatic conditions of Lucknow (26◦30′ N, 80◦13′ E), U.P., India. The system was constructed with a combination of Fiber-Reinforced Plastic (FRP) and transparent acrylic sheets, featuring a basin area of 2 m². To boost water output, the modified double slope solar still was equipped with flat plate external reflectors, and experiments were conducted from June to December 2018, covering both summer and winter seasons. Observations were recorded from 07:00 to 19:00 daily. The external reflectors were used to enhance solar radiation on the glass cover, resulting in increased water distillation. During the experiments, the minimum potable water production was 7224 ml/day in summer and 5341 ml/day in winter at a 30° angle. In contrast, the highest water output recorded was 9157 ml/day in summer and 6630 ml/day in winter at a 60° angle.

The above mentioned solar stills show notable differences in potable water production due to the variations in design and climatic conditions. Generally, higher solar radiation and temperatures lead to greater water output. The differences in size and construction materials, such as FRP, acrylic sheets, and galvanized steel, influence the thermal properties and heat retention of the stills, affecting their efficiency. Additionally, various modifications, like the use of PCMs or reflectors, enhanced productivity by improving heat storage, solar radiation capture, and condensation, resulting in higher water output. Comparing the current DSSSSS to the previously discussed stills, the differences in production can likely be attributed to these factors. The literature also indicates that most solar stills are designed to operate only during daytime. This means that the performance of these systems is limited because they can only produce water in the presence of the sun.

Considering that the performance of solar stills highly depends on the conditions of the geographic location where they are installed, it was noted that, to the best of our knowledge, no published study has analyzed the performance of these designs under the Cape Town weather conditions in South Africa. This work presents and analyzes the performance of a DSSSSS under the Cape Town weather conditions. It further investigates the performance of the system even at night, when there is no sun available.

II. MATERIALS AND METHODS

The system was constructed as shown in Figure 1. The still was mainly made of galvanized iron sheets, steel tubing, and copper tubes. The water basin was made of galvanised sheets with dimensions of 1250 mm × 840 mm × 500 mm. The basin cover was a double slope made with steel, separated by two plates that created a gap that kept room-temperature cooling water to maximize the temperature difference between the saline water in the basin and the basin cover to enhance the condensation process.

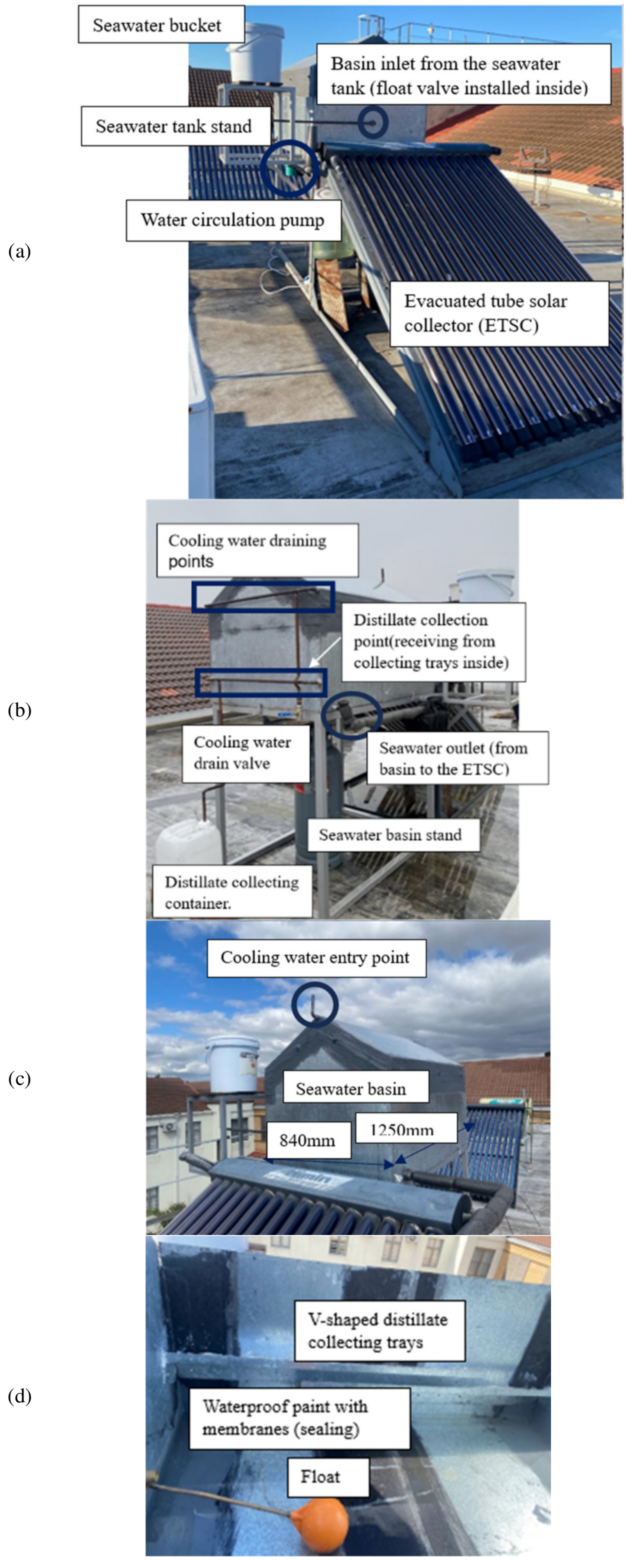

Fig. 1. Solar still (a) overview including the ESTC, (b) seawater piping, (c) basin measurements, (d) inside the water basin.

The cooling water between the basin cover was controlled and refilled manually in the cooling water entry point shown in Figure 1(c) and the drained through the cooling water drain point shown in Figure 1(b). The water was filled through the cooling water entry point. This changed once the temperature rose. The water temperature was not monitored using any devices. The water was drained through the drain valve shown in Figure 1(b). The seawater tank was the primary source of the seawater and was elevated by a frame stand made of steel tubes to allow the water to flow by gravity as shown in Figure 1(a). Seawater was transported from the primary tank to the basin using 15 mm copper piping, the inlet point of the basin had a float valve installed to keep a consistent seawater level of 50 mm inside the basin (Figure 1(d)).

The seawater basin was placed on a frame stand made of galvanized steel tubes as shown in Figure 1(b). The seawater flow from the basin went through an outlet point to the solar collector passing through a water circulation pump. The manifold connection between the basin and the solar collector was incorporated with the circulation pump to maintain a continuous flow of the seawater within the entire system. Figure 1(a) shows the solar collector manifold and the circulation pump. The solar still was incorporated with the Evacuated Tube Solar Collector (ETSC) to maximize its efficiency by keeping the water in the system at a high temperature even after the sun sets and thus keeping the distillate production going for longer. This specific type of solar collector was selected due to its availability and mainly due to its ability to store energy and therefore extend the distillate production after sunset. Seawater passed through the solar collector manifold going back into the basin at a higher temperature. Once the water in the basin was heated, the evaporation process began with the steam rising directly to the basin cover and the condensation process took over as the steam cooled down. The water droplets that formed on the cover began flowing to the V-shaped collecting trays attached to the basin along both 1250 mm sides shown in Figure 1(d). The trays were placed at an angle to allow the water to flow freely, directing it to the copper piping outside the basin, which then carried the distillate to the collecting tank shown in Figure 1(b). The distillate was subsequently gathered from this tank.

The solar irradiance was measured using the instrument in Figure 2 and transmitted to the console display unit in Figure 3. The temperatures of the inlet and outlet points of the system were monitored during the testing process. The temperature data logger that was used was the 12-channel BTM-4208SD data logger. The tests were conducted using the K-type sensor setting. The K-type sensor has temperature range from -100°C to 1300°C. The temperature logger could be operated using either 8 × 1.5 V batteries or a direct current (DC) adapter for power. The battery option was used for the tests. Four K-type thermocouples were used as shown on Figure 4. The thermocouples were attached to the surfaces of the inlet and outlet points using an insulation tape and then connected to the T1-T4 ports of the data logger. A memory card was used on the data logger to store the temperature data which were exported to a computer on Excel for processing. Figure 14 shows a graphical representation of thermocouple temperature data collected on 25 October 2023, during both day and night time.

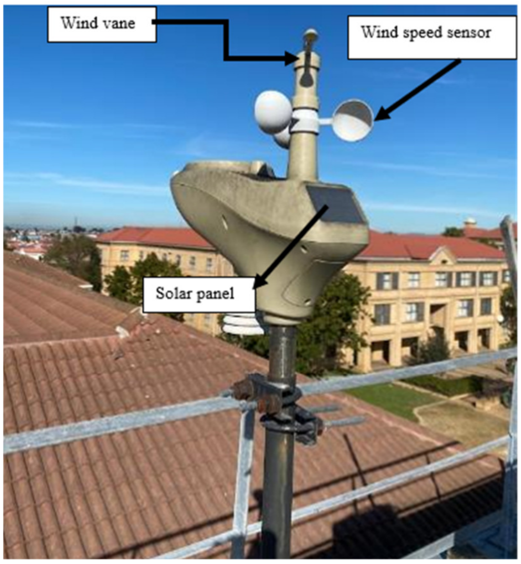

Fig. 2. HP2000 wireless weather station.

Fig. 3. Weather station display unit.

III. EXPERIMENTAL PROCEDURE AND ANALYSIS

The main aim of the experiments conducted for this research study was to maximize the distillate production from the system while reducing losses. The knowledge obtained in the process of completing the literature review relating to factors that affect the production of solar stills was implemented to achieve the best possible results. This experiment was conducted in Cape Town, South Africa (latitude 33.9249° S, 18.4241° E respectively) at CPUT's Bellville Campus. The system design shown in Figure 1 was tested during day and night between 07:00 to 19:00 and 19:00 to 07:00, respectively, from October to November 2023 (spring season in South Africa). It was deemed practical to conduct the tests during this period, given the knowledge that solar irradiance significantly impacts the efficiency of solar stills.

After the DSSSSS's construction process was completed, the system was moved to the roof of CPUT's Mechanical Engineering Department for testing. The assembly of the system was completed on the top of the roof and then placed in position. Prior to placing the cover on the basin, the basin was filled with tap water and monitored for leaks in the piping and water basin. No leaks were detected on the piping, however, minor leaks were detected on the basin. These leaks were sealed using silicone on the outside and waterproof paint with membranes on the inside of the basin as shown in Figure 1. Leak tests were conducted until no further leaks were detected.

(a)

(b)

Fig. 4. (a) The temperature data logger, (b) surface thermocouple.

The seawater used for the experiment was collected from the shoreline of Sunset Beach in Milnerton, Cape Town, South Africa. Because it was collected from a sandy and polluted ocean, it was filtered before filling the system with a polyester cross-knit cloth as shown in Figure 5. This process was completed to prevent sand and other solid particles from causing build-up or blockages in the system. The saline water tank was also cleaned to remove any foreign particles that might block the system and affect the distillate production. The seawater was then poured into the seawater 20 L bucket. This bucket was placed at an elevated height to the basin and the seawater was transported to the basin using the force of gravity through 15 mm copper piping. A float valve was installed at the inlet of the basin from the seawater bucket and was positioned at a water depth of 50 mm. Seawater was then transported to the solar collector through copper piping with a water circulation pump installed on the line.

Fig. 5. Seawater filtering.

Water circulation was conducted between the seawater bucket and the basin, and again between the basin and the solar collector. Once the water heated up, the evaporation process began, and the vapor rose to the basin cover that was positioned at the latitude angle of the testing area where the vapor changed to water droplets (condensation). The water basin was incorporated with four collection trays inside. The water droplets ran down the cover and fell into the collecting trays that were placed at an angle to allow free flow of the distillate water to the copper piping that delivered the distillate to the collecting container. The distillate produced was then collected every morning and evening at 07:00 and 19:00, respectively. The collection process was completed using the collection jar and the distillate was kept in sampling containers that were labelled with dates.

IV. RESULTS AND DISCUSSION

The results discussed in this chapter were collected for a period of 12 days during the above specified day and night periods. The distillate production, the quality of the distillate, and the ambient conditions in which the system was tested were considered and will be analyzed.

A. Daily Weather Conditions – Solar Irradiance and Wind Speed

Solar irradiance and windspeed are two of the most crucial factors that influence the productivity of solar stills [20]. These parameters were recorded during the experimental process to track the weather for all the testing dates. This section discusses the weather conditions for the testing period. Graphs representing the hourly average solar irradiance versus time and the hourly average wind speed versus time for the 12-day testing period were plotted with the Origin software. The discussion on weather conditions is divided into three parts i.e., days with the highest, moderate, and lowest solar irradiance.

1) Days with the Highest Solar Irradiance

The first, third, eleventh and twelfth days were the ones with the highest irradiance during the testing cycle with a daily average of 370 W/m^2, 467 W/m^2, 455 W/m^2, and 411 W/m^2 respectively for daytime. The daily solar irradiance average during nighttime ranged between 0 – 9 W/m^2 for the entire testing cycle.

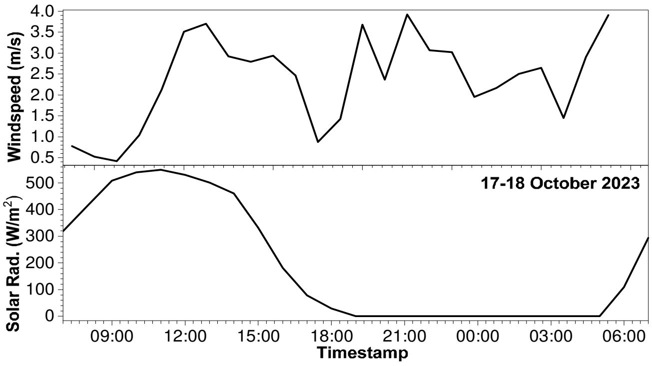

Fig. 6. Solar irradiance and wind speed vs time (day 1).

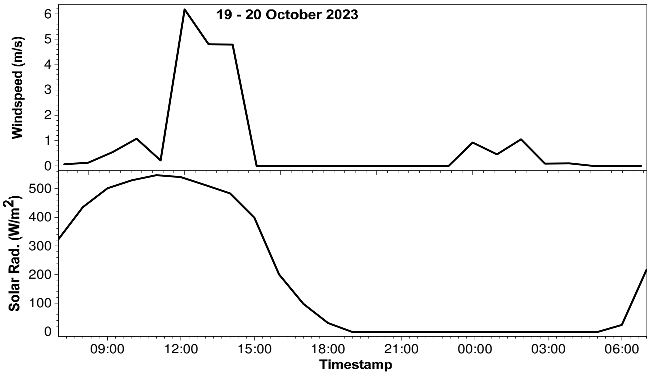

Fig. 7. Solar irradiance and wind speed vs time (day 3).

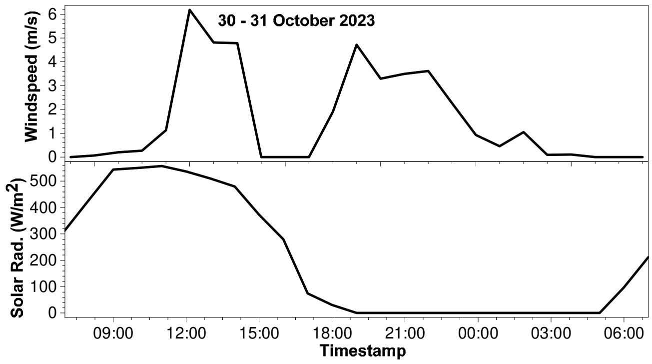

Fig. 8. Solar irradiance and wind speed vs time (day 11).

The trends depicted in Figures 6-9 show the average hourly solar irradiance and wind speed versus time (7 am to 7 am) on these days. In the morning, the sunlight is still low, it then increases as the day progresses and reaches its peak at noon and shortly afterwards decreases until the sun sets. The highest solar irradiance reached on the testing cycle days was 549 W/m^2, 546 W/m^2, 558 W/m^2, and 578 W/m^2, respectively. The peak was reached between 11:00 and 12:00 for all the days during which the tests were conducted. The wind speed trend fluctuates during the day. The surface temperatures of all the inlets and outlets of the seawater within the system were measured, however, no surface temperatures were recorded for the days with the highest solar irradiance due to a problem experienced with the data logger batteries.

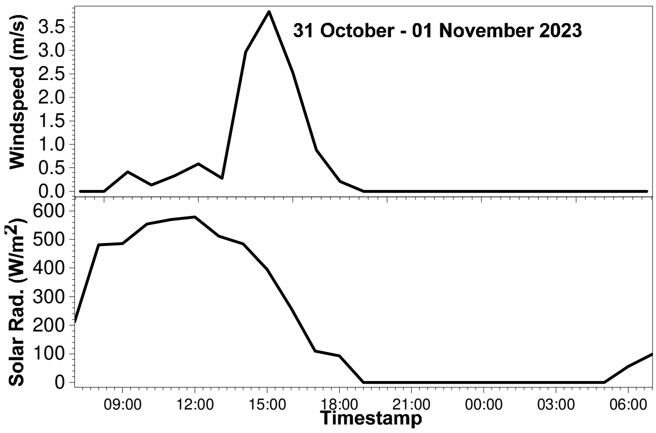

Fig. 9. Solar irradiance and wind speed vs time (day 12).

2) *Days with Moderate Solar Irradiance*

The fifth, sixth, seventh, and ninth days of the testing cycle were those with moderate solar irradiance with an average of 327 W/m^2, 384 W/m^2, 318 W/m^2, and 335 W/m^2 respectively. The trends in Figures 10-13 show the average hourly solar irradiance and wind speed versus time on these days. The highest solar irradiances reached on these four days were 489 W/m^2, 544 W/m^2, 501 W/m^2 and 528 W/m^2, respectively. The peak was again reached between 11 am and 12 pm on all days.

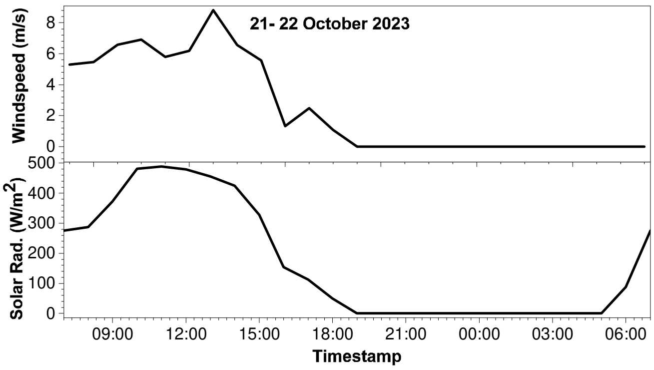

Fig. 10. Solar irradiance and wind speed vs time (day 5).

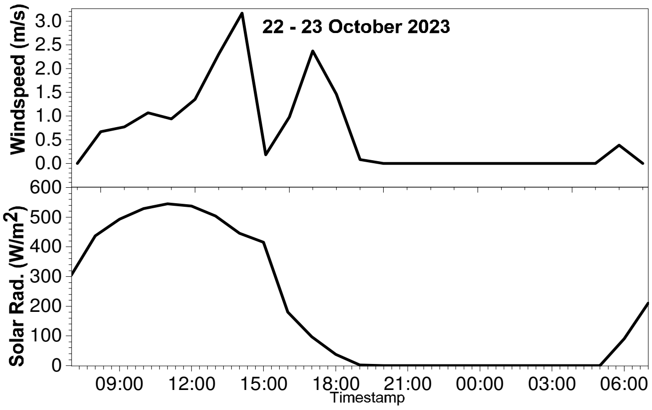

Fig. 11. Solar irradiance and wind speed vs time (day 6).

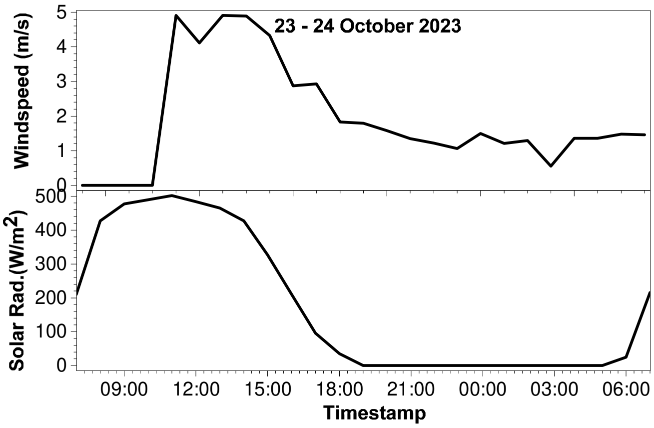

Fig. 12. Solar irradiance and wind speed vs time (day 7).

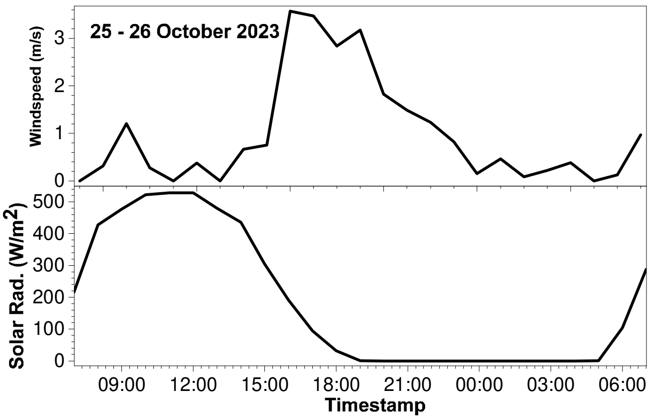

Fig. 13. Solar irradiance and wind speed vs time (day 9).

The surface temperatures of all the inlets and outlets of the seawater within the system were measured, however, not all the days could be recorded due the already mentioned challenge experienced with the data logger batteries. On day nine, the data logger was operational for the full duration of testing period, i.e. 7 am to 7 am the following day. These thermocouple surface temperatures for day nine are discussed below. The newly designed DSSSSS was incorporated with surface thermocouples on the four seawater inlets and outlets to monitor temperature . The thermocouples were connected with the above discussed 12-channel BTM-4208SD data logger. The data logger was powered with eight AA 24V batteries, which resulted in multiple disturbances in the data logging process. On 25 October 2023, data were obtained for both day and night time testing periods and Figure 14 is a graphical representation of that data. It can be noted that the temperatures increased and reached a peak around noon due to the increase in solar radiation, whereas a decrease can be noted during the late afternoon. Authors in [21] designed, manufactured and tested a hybrid photovoltaic thermal (PVT) double slope active solar still and noted that the temperatures of both the water and cover reached a maximum around noontime. It can also be noted from the trend in Figure 14, that temperatures started increasing after 5 am due to the sunrise. The T1 (outlet from the basin) and T3 (outlet from the solar collector) temperatures were slightly higher compared to those of T2 (inlet to the solar collector) and T4 (inlet to the basin from the solar collector). Although, the piping from the basin to the solar collector and from the solar collector to the basin were covered with insulation material, the graph in Figure 14 clearly shows that heat losses incurred. Although the insulation material minimizes heat losses, the fact that it does not completely prevent them can be clearly noted.

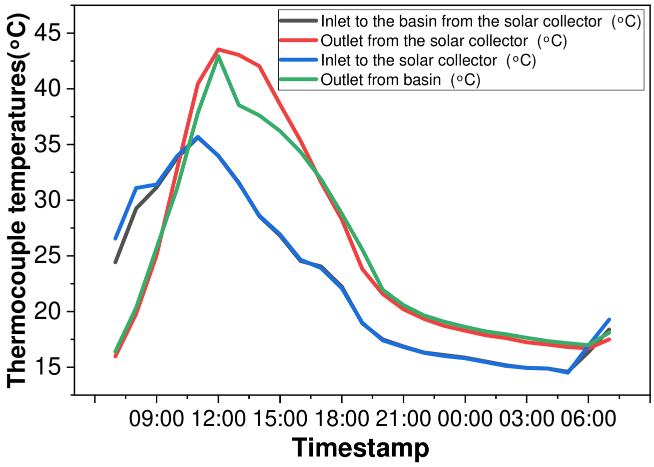

Fig. 14. Thermocouple temperatures vs timestamp.

3) *Days with the Lowest Solar Irradiance*

The second, fourth, eighth, and tenth days of the testing cycle were the days with the lowest solar irradiance with an average of 299 W/m^2, 187 W/m^2, 196 W/m^2, and 308 W/m^2 respectively. The trends depicted in Figures 15-18 show the average hourly solar irradiance and wind speed versus time (7 am to 07 am) on these days. The highest solar irradiance reached on these days were 512 W/m^2, 363 W/m^2, 460 W/m^2, and 538 W/m^2 respectively. The peak was reached between 11 am and 12 pm for all the days on which the tests were conducted. The surface temperatures of all the inlets and outlets of the seawater within the system were measured, however, no surface temperature data was recorded for the days with the lowest solar irradiance owing to the previously indicated problem experienced with the data logger batteries.

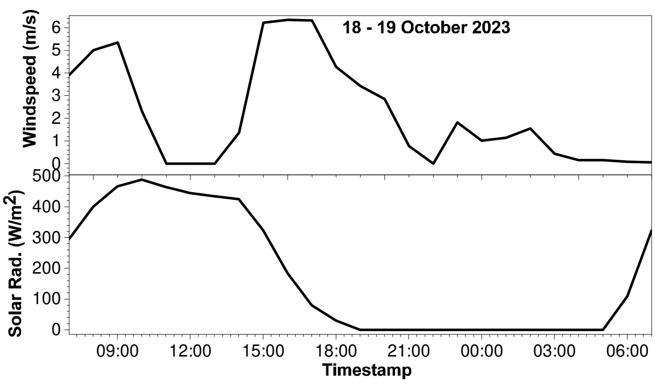

Fig. 15. Solar irradiance and wind speed vs time (day 2).

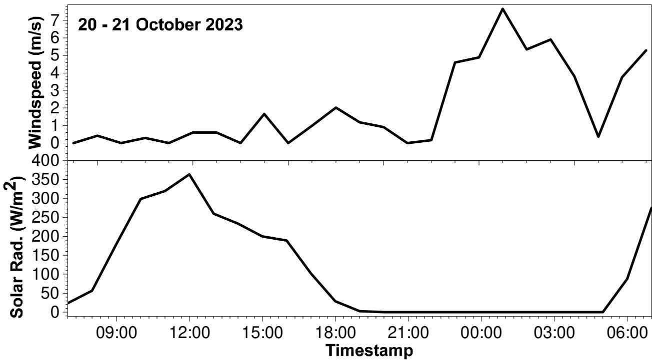

Fig. 16. Solar irradiance and wind speed vs time (day 4).

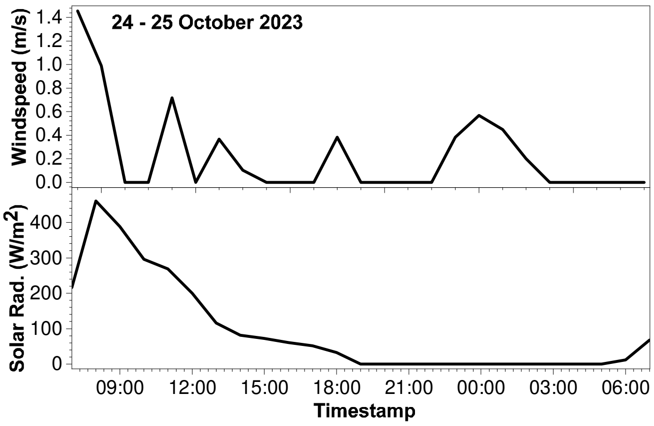

Fig. 17. Solar irradiance and wind speed vs time (day 8).

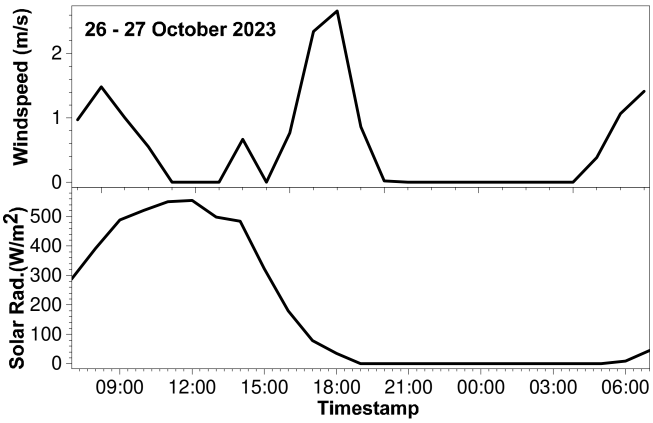

Fig. 18. Solar irradiance and wind speed vs time (day 10).

B. *Day Time Experimental Results*

The tests were conducted from 17 October 2023 at 7 am to 31 October 2023 at 7 pm, South African time. Data were collected only for 12 days because from 27 to 29 October the system was not operated due to the rainy weather. Figure 19 is a representation of the distillate production collected during the daytime for these 12 days vs the average solar irradiance for these days. The minimum and maximum distillate production for the daytime collection was 53 ml and 325 ml respectively. It should be noted that the maximum production was not achieved on one of the days with the highest average solar irradiance, even though the minimum production was achieved on one of the days with the lowest average solar irradiance. The system was made with a steel cover with a hollow area within that held water to cool the hot water in the basin. The cooling water had to be changed by hand, however, the system was not monitored continuously throughout the day. It was observed that on extremely hot days, the water's temperature inside the cover quickly increased, which slowed down the cooling effect that the cover was meant to provide. Then, especially on extremely hot days, the condensation rate dropped, and the amount of distillate produced decreased. This observation clarifies why the day with the maximum sun irradiation did not yield the most production – the intense heat hindered the production process.

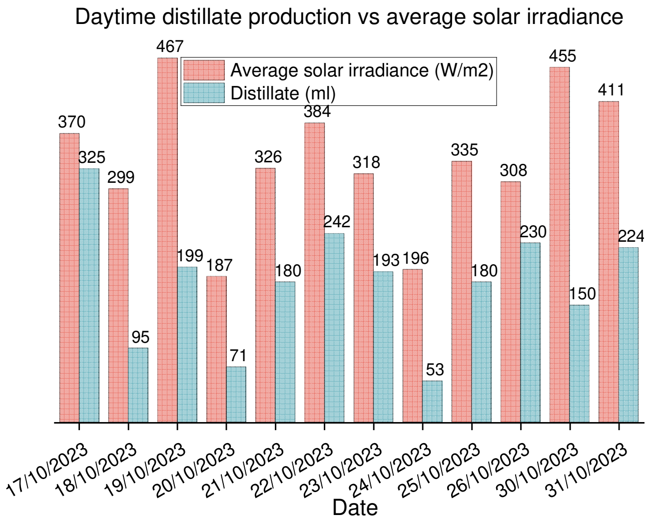

Fig. 19. Day time distillate production vs average solar irradiance.

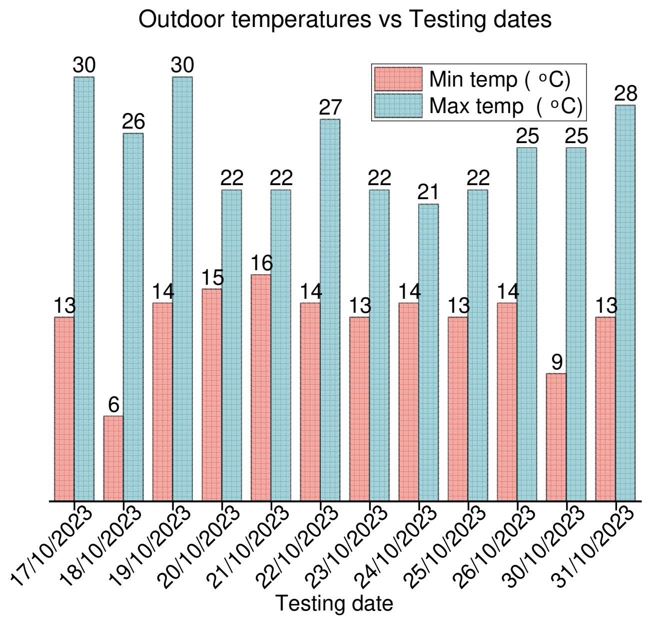

Fig. 20. Outdoor temperature vs testing dates.

Figure 20 is a representation of the minimum and maximum temperatures for the 12-day period during which the tests were conducted. It can be noted from Figures 19 and 20 that on high-temperature days the production level was high and vice versa for the low-temperature days, as is expected for solar stills.

C. Night Time Experimental Results

Figure 21 shows a representation of the distillate production collected during the night time periods for the 12 days vs the average solar irradiance for those days. The three lowest production nights were experienced on 20 October (69 ml), 26 October (94 ml) and 25 October (111 ml) respectively, with the maximum temperatures for those days being 22 °C, 25 °C, and 22 °C, respectively. The three highest production nights were 19 October (219 ml), 22 October (218 ml) and 17 October (188 ml), and the maximum temperatures for those days were 30 °C, 27 °C, and 30 °C, respectively. It can be noted that minimum and maximum production was achieved on nights that had the lowest temperature and the highest days temperatures. Even though during the night, the temperatures were significantly low, the ETSC kept the water in the system warm for a longer period and, therefore, extended the production hours. ETSC tubes are made from material with a high-temperature resistance and excellent solar irradiation transmittance. The vacuum created within the tubes works as an insulator, reducing heat dissipation to the surroundings [22]. This process is the reason the system continued operating with no solar irradiation available, thus, using ETSCs for nighttime production proved to be a great benefit since heat losses are minimized but still occur at a slower pace after sunset.

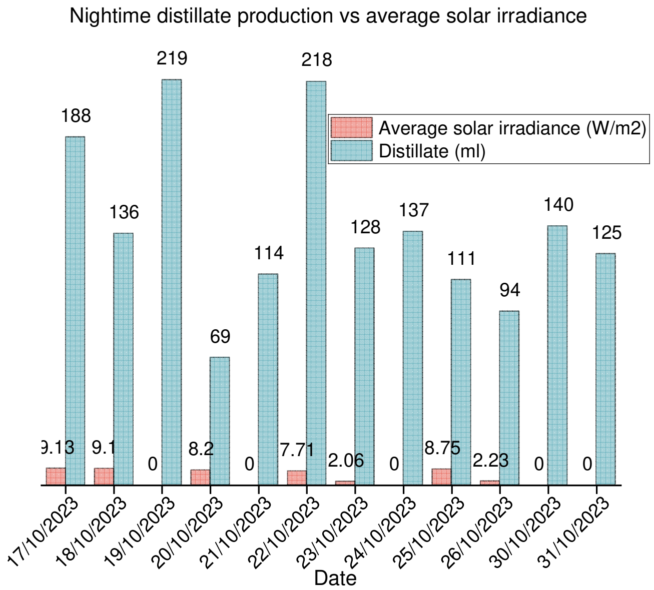

Fig. 21. Night time distillate production vs average solar irradiance.

D. Day Time vs Night Time Production

The graph presented in Figure 22 shows the comparison between day and night distillate production collected from the newly designed DSSSSS incorporated with the ESTC. There are differences between night and day time distillate production, the highest and lowest percentage differences were 61.3% on the 24 October 2023 and 2.8% on 20 October 2023. It was noted that on some days, production was higher during the night time compared to daytime. By leveraging ETSC technology, the experiment demonstrated the feasibility and effectiveness of utilizing solar energy for distillation processes, even during non-daylight hours. This finding emphasized the potential of ETSCs to enhance overall productivity and efficiency in solar-powered distillation systems. Additionally, a comparative analysis carried out in [23] revealed that ETSCs offer distinct advantages, especially during colder seasons, ensuring a more consistent output of thermal energy. This assertion was validated by the experiment's results, wherein nighttime distillate production occasionally surpassed daytime production levels on certain days.

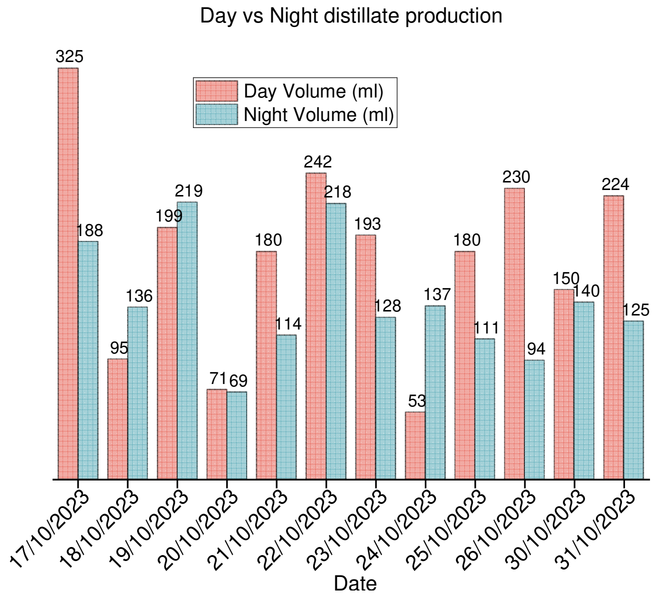

Fig. 22. Day and night distillate production.

V. CONCLUSION

This study was based on a new design for a DSSSSS incorporated with an evacuated tube solar collector tested in Cape Town, South Africa. Multiple experiments were conducted on the DSSSSS, however, this proposed design provides a unique approach to improve the production of single-stage solar stills. The system used the force of gravity to transport water from the seawater tank to the basin and a 220 V circulation pump to maintain a continuous flow between the basin and the solar collector. The DSSSSS was incorporated with a cover that contained cooling water to increase the condensation rate of the system.

The experiment on the DSSSSS was run for 12 days, from 17 October to 1 November 2023. The system was tested during both day and night times. The total distillate produced during the experiment period was 3821 ml, of which 2142 ml were produced during the day time and 1679 ml during the night time.

The cooling water on the basin cover proved to be more effective in the mornings and evenings. During the day when the outdoor temperature was high, the water within the cover became warmer and, since the DSSSSS was not monitored continuously throughout the day, when the water temperature increased it stopped serving its purpose of cooling, or rather, increasing the temperature difference of the water inside the basin and the cover to speed up the condensation process. However, in the morning when the water was still cold, it served its purpose. In the evenings the water in the cover was still warm after sunset, thus, the heat from the basin cover and the solar collector kept the distillate production going for longer during the night.

Incorporating a solar collector (evacuated tube type) proved to be very effective for the DSSSSS, especially during night time because it was noted that the system continued to produce distillate even after sunset. It was noted that on 19, 20, 22, and 30 October 2023, the night production almost equaled the day distillate production, with the difference being 9.1%, 2.8%, 9.9%, and 6.7%, respectively. On these days, the system performed at almost the same capacity during daytime and nighttime under completely different weather conditions, while on 18 and 24 of October, the night time production surpassed the day time production. The newly designed DSSSSS manufactured and tested for the purpose of this research study performed quite effectively during the day and exceptionally well at night, considering that there was no solar radiation during the nighttime period.

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