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THERMAL APPLICATION USING PYRAMID SOLAR STILL TO ENHANCE THE PRODUCING OF CLEAN WATER

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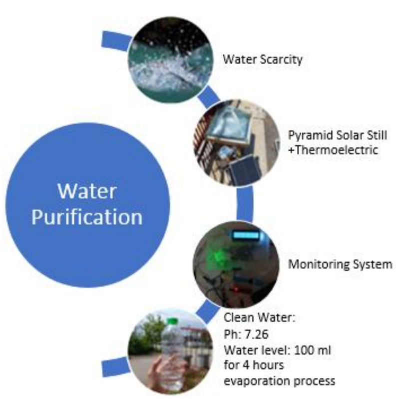
Graphical abstract



Abstract

Solar stills have become an environmentally responsible method of water purification in the context of tackling the urgent worldwide issue of water scarcity. Solar stills are a practical solution for areas with poor access to clean drinking water since they use the sun's limitless energy to filter contaminants from water. Standard solar still models have been used for this purpose, however their effectiveness and output quality frequently fell short of expectations. Consequently, there is a compelling need to investigate novel designs and technologies in order to improve the functionality of solar stills and the quality of the filtered water. This study examines solar stills as a means of removing contaminants from water within the context of water purification utilizing solar energy. The study specifically highlights a pyramid solar still's inventive design and evaluation because it deviates from regularly used standard models. This pyramid solar still has been designed in a special way, and a thermoelectric system has also been added to improve performance. Furthermore, real-time monitoring of critical water parameters is made possible by the integration of sensors like the DHT11. A heating plate has been added to the pyramid solar still to improve the evaporation process and increase efficiency. Under daylight and active heating, experimental results have proven its superiority, producing an amazing output of 100 milliliters of water with a pH level of 7.26. These empirical results highlight the pyramid solar still design's tremendous potential for increasing efficiency and enhancing water quality.

Keywords: Solar Energy, Pyramid Solar Still, Thermoelectric, Water Quality

Abstrak

Pegun suria telah menjadi kaedah pembersihan air yang bertanggungjawab terhadap alam sekitar dalam konteks menangani isu kekurangan air yang mendesak di seluruh dunia. Pegun suria ialah penyelesaian praktikal untuk kawasan yang mempunyai akses yang lemah kepada air minuman bersih kerana ia menggunakan tenaga matahari tanpa had untuk menapis bahan cemar daripada air. Model pegun suria asas telah digunakan untuk tujuan ini, namun keberkesanan dan kualiti keluarannya sering kali tidak mencapai jangkaan. Akibatnya, terdapat keperluan yang mendesak untuk menyiasat reka bentuk dan teknologi baru untuk meningkatkan kebolehfungsian pegun suria dan kualiti air yang ditapis. Kajian ini mengkaji pegun suria sebagai satu cara untuk menyingkirkan bahan cemar daripada air dalam konteks penulenan air menggunakan tenaga suria. Kajian itu secara khusus menyerlahkan reka bentuk dan penilaian inventif pegun solar piramid kerana ia menyimpang daripada model asas yang kerap digunakan. Pegun suria piramid ini telah direka bentuk dengan cara yang istimewa, dan sistem termoelektrik juga telah ditambahbaik untuk meningkatkan prestasi. Tambahan pula, pemantauan masa nyata parameter kritikal air dibuat bersepadu dengan penderia seperti DHT11. Plat pemanas telah ditambahkan kepada pegun suria piramid untuk memperbaiki proses penyejatan dan meningkatkan kecekapan. Di bawah cahaya matahari dan pemanasan aktif, keputusan eksperimen telah membuktikan keunggulannya, menghasilkan keluaran merangsangkan sebanyak 100 mililiter air dengan tahap pH 7.26. Keputusan empirikal ini menyerlahkan potensi besar reka bentuk pegun suria piramid bagi meningkatkan kecekapan dan meningkatkan kualiti air.

Kata kunci: Tenaga Suria, Solar Still Pyramid, Termoelektrik, Meningkatkan Prestasi, Kualiti Air

1.0 INTRODUCTION

Solar energy has played an indispensable role throughout human history, powering homes, businesses, and vehicles through solar panels. It is utilized for street lighting and water purification with solar stills. The integration of thermoelectric cooling and heating enhances solar still performance, improving efficiency and capabilities. This innovative technology contributes to reducing the carbon footprint and advancing sustainable solutions. While the World Health Organization (WHO) does not specify a specific pH standard for water, it recommends a safe pH range of 6.5 to 8.5 for drinking water based on their Guidelines for Drinking-water Quality. This range ensures minimal health risks [1].

Malaysia experiences a tropical climate characterized by high humidity and hot temperatures. Putrajaya stands as the warmest and rainiest region, while Kelantan boasts the coldest temperatures. February is recommended for travel due to lower rainfall, whereas October to December witnesses the highest precipitation. Nonetheless, the decline in rainfall at the Melaka Dam between 2015 and 2019 poses challenges in accessing clean water, significantly impacting the daily activities, hygiene, landscapes, and health of rural consumers [2-3].

According to the study, evaporation is intensified by higher temperatures and is affected by weather conditions such as sunlight, warmth, and humidity [4]. Solar water distillation employs solar energy to purify water through the process of evaporation and condensation, effectively separating impurities [5]. Condensation takes place when gas molecules lose energy and transition into a liquid state, influenced by factors like temperature, pressure, and the presence of condensation nuclei. Water purification encompasses the removal of unwanted substances from water, including chemicals, pollutants, solids, and gases, making it suitable for various applications [6]. Common methods include filtration, sedimentation, distillation, and biological processes like slow sand filters and activated carbon [6]. These processes are vital in ensuring the availability of clean and safe water for drinking, industrial use, medicinal purposes, and more. A comprehensive understanding of the principles and techniques behind evaporation, solar water distillation, condensation, and water purification is crucial in meeting diverse water needs.

The solution for the recent problem is the development of Pyramid Solar Still. Pyramid solar stills, available in two primary types (Triangular Pyramid Solar Still and Square Pyramid Solar Still) differentiated by their basin shapes [7], offer a unique advantage over conventional single slope solar stills. Unlike their counterparts, pyramid solar stills do not require frequent adjustments to track the sun. They efficiently capture maximum solar radiation throughout the day without the need for constant repositioning [8]. This is facilitated by the design where one side of the cover receives direct and intense solar radiation, while the opposite side remains cooler. The temperature contrast between the water surface and the cover promotes condensation on the cooler sides, facilitating water purification within pyramid solar stills [9].

In the study, several parameters were examined, including heat transfer through electromagnetic waves, which can lead to absorption, reflection, or transmission. Convection involves fluid movement driven by density variations, while conduction is the direct transfer of heat through molecular contact until thermal equilibrium is reached [10]. The thermoelectric effect harnesses alloy metals with different electron densities to convert temperature differences into electrical voltage or vice versa, resulting in the SEEBECK, Peltier, and Thomson effects [11]. To maximize sunlight absorption, pyramid solar stills are most effective when inclined between 0 and 30 degrees, with lower inclinations enhancing capture and equatorial latitudes benefiting from the higher path of the sun [12]. Other factors such as local climate, design conditions, and operational factors play a significant role in the effectiveness of solar stills. Cloudy conditions can reduce evaporation rates, and the design of the solar still, whether it is a wick or basin type, impacts its performance [13].

In light of Malaysia's tropical environment and irregular rainfall patterns, the main goal of this study is to address the problem of water scarcity in that country. In areas where water resources are running low, the study aims to investigate and apply cutting-edge technologies Pyramid Solar Stills in particular to improve water filtration and offer a long-term answer to the urgent need for clean water. Through the use of a multidisciplinary approach that incorporates concepts of thermoelectric effects, solar energy use, and heat transfer physics, the research aims to enhance the effectiveness and potential of Pyramid Solar Stills for water purification. Additionally, taking into account the various climates in Malaysia, it seeks to examine the effects of environmental elements on the operation of these solar stills, including temperature and humidity. In addition to advancing our knowledge and comprehension of solar distillation and water purification techniques, this research will help mitigate water-related problems and provide important insights into ecologically friendly and sustainable practices. The study's ultimate goal is to offer a reliable and flexible response to the region's growing need for clean water in the face of fluctuating climatic conditions and limited water supplies.

2.0 METHODOLOGY

The two primary hardware circuits in this project are the heating module and the water container made of aluminum that will be attached to the solar still to heat the raw water to the desired temperature. The heating module merely serves to support the primary heating element, which is direct sunlight, rather than being the main heating source itself. Temperature sensor block diagram in Figure 1 will be used to track the water's temperature.

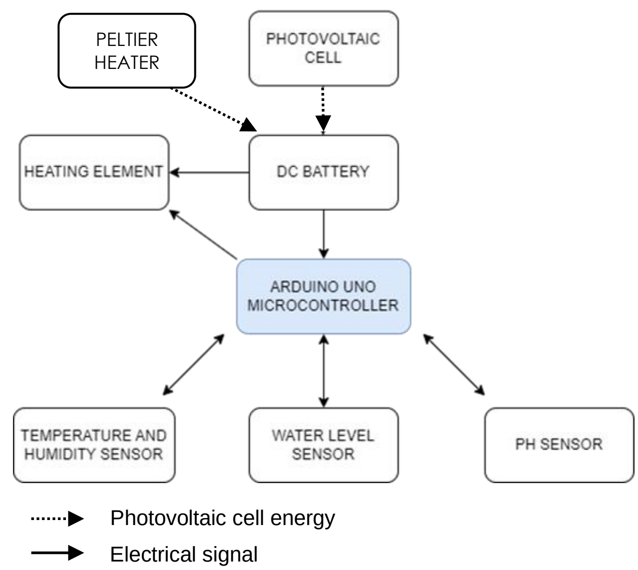


Figure 1 Circuit Block diagram

In addition to solar radiation, Peltier heaters are used to generate heat and raise the water's temperature in order to support the thermal performance that sunlight is not capable of achieving. The Peltier effect is a phenomenon that occurs at the junctions of these materials. When the electric current passes through the junctions, it causes one side of the device to absorb heat energy from the surroundings (the cold side) while the other side releases heat energy (the hot side). This creates a temperature gradient across the device, with one side becoming cold and the other side becoming hot.

The tilt angle of the solar glass continues to have a significant impact on the efficiency of solar stills. The location's geographic latitude, the direction of the cover, and their combined elements define this specific angle. An important factor to take into account is how the cover's inclination lines up with the latitude angle. This is because it is expected that coverings positioned this way will get year-round solar radiation characteristic of that latitude. Because of the direct connection between solar radiation intensity and evaporation, this alignment is essential. As a result, changes in the sun's azimuth angle and solar intensity are reflected in modifications to the angle of inclination [14].

The effect of the angle of the condensing surface on productivity was investigated by applying a study by Kabeel *et al*. [12] at Tanta City, Egypt using square pyramid solar stills. The scientists built three identical square pyramid solar stills, with glass cover angles of around 30° to 50°. Their research showed that when the glass cover angle went above the latitude angle, the yield of pyramid solar stills decreased. In this project, angle of 44° is considered which follows the range in [12].

Different designs are available for the solar still, and each has pros and cons of its own. The design that was selected for this project has a pyramid shape with a square base, standing about 30 cm tall, with base measurements of about 60 cm by 60 cm. Glass that is clear is the material used in construction. With a few minor modifications, the chosen proportions are taken from earlier research, notably [15]. The height has been cut in half in comparison to the measurements given in [15], and the breadth and length have been lowered from 70 cm to 60 cm. Using the pyramid-shaped solar still's lower height to its advantage, this innovation seeks to increase the production of water droplets. The inclined cover of the solar will still be about 44° since the height is angled to trap water vapor, which then swiftly falls to the edge of the solar still to the base. Figure 2 displays the glass pyramid design measurement.

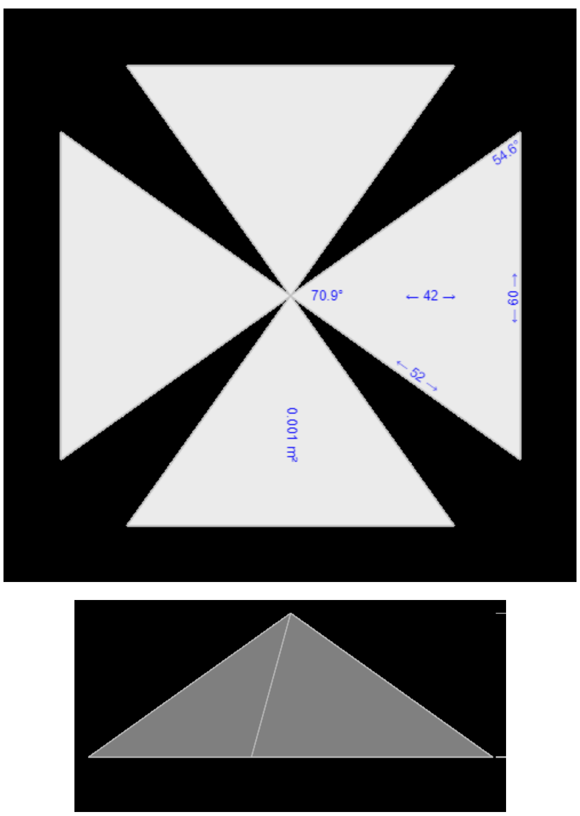


Figure 2 Pyramid Glass cross section

There are many different designs in the realm of solar stills, and each has its own advantages and disadvantages. Envision the solar base remaining in the shape of a pyramid, measuring around 30 cm in height, 60 cm in breadth, and 60 cm in length. This specific configuration required careful consideration due to the task at hand. The solar still maintains an angled stance at a 30° inclination to ensure that water vapor finds its ideal path, easily condensing and cascading towards the edges, finally reaching the base. The solar still's body, which was ingeniously built from galvanized steel and strengthened with wooden blocks, functions effectively as a container for gathering and utilizing solar thermal energy. The Solar Still's structural layout is depicted in Figure 3.

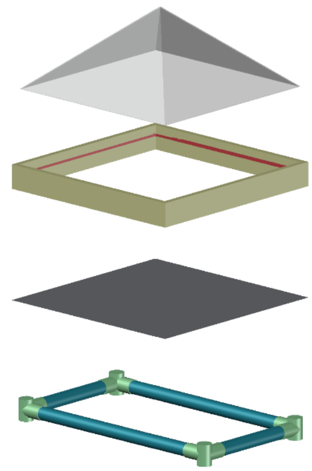


Figure 3 Prototype 3D Structure

Temperature, water level, humidity, pH, and a heating plate sensor are just a few of the many environmental variables that can be tracked and controlled by the trainer that is being used. While the temperature sensor is used to measure the outside temperature, the water level sensor makes it easier to evaluate the liquid levels inside a prescribed container. Additionally, the humidity sensor is intended to monitor the surrounding air humidity, and the pH sensor is useful in determining a liquid's basicity or acidity. Precise control over the heating plate and precise temperature modulation are made possible by the integration of an Arduino microcontroller. Utilizing the information gathered, the Arduino controls the heating plate's functioning by processing data from the several sensors. These monitoring system is follows our previous works in [16-17]

An analog pH meter that is specifically made for this purpose can be used to determine the pH of a solution and determine whether it is acidic or alkaline. A wide voltage supply range of 3.3–5.5V is supported by the inbuilt voltage regulator chip. There is very little jitter in the output signal after hardware filtering. Using this pH sensor makes it easier to quickly assemble a pH meter and determine the pH of various aqueous solutions with accuracy. The prototype of sensor circuit is shown in Figure 4.

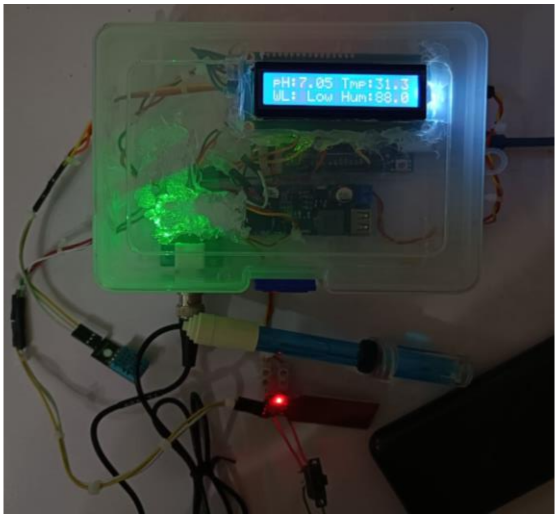


Figure 4 Monitoring kits for Pyramid Solar Still

The entire system works in unison to produce clean water with the necessary capacity and to keep the air pH at the right level. The key components of this integrated system are an Arduino Uno microcontroller and a Pyramid Solar Still, which are fitted with a variety of sensors including temperature, water level, humidity, and pH. With its distinctive shape, the Pyramid Solar Still effectively uses the processes of evaporation and condensation to purify water. Precision in the purifying process is ensured by the sensors' ability to monitor environmental variables in real-time. By measuring the ambient air temperature, the temperature sensor maximizes the efficiency of the Pyramid Solar Still by controlling the heating plate. By accurately measuring liquid levels, the water level sensor improves operating effectiveness. Meanwhile, by keeping an eye on atmospheric humidity, the humidity sensor increases the adaptability of the system. In order to produce water that is within the recommended pH range for safe consumption, the pH sensor is essential in measuring the acidity or basicity of the water being treated. The experiment has been done in Durian Tunggal, Melaka, Malaysia and the result is collect in between April to May 2023.

3.0 RESULT AND DISCUSSION

An assessment of a pyramid solar still's performance would normally entail determining how efficient the device is in terms of producing water per unit area, producing water at a consistent rate, and producing pure water. The amount of water produced per still area can be used to calculate the still's efficiency. This is commonly expressed in liters of water per day per square meter of still surface area. More water is produced per unit area when the efficiency is better. By calculating the volume of water produced during a specific time period, such as a day or an hour, the rate of water production can be ascertained. More water is generated in a shorter amount of time when the production rate is higher.

A. Daylight Test

In accordance with the guidelines established for carrying out this test, rainwater must be collected in an aluminum tray with the precise measurements of 25 centimeters in length, 30 centimeters in width, and 7 centimeters in depth. The pH level of the rainwater that has been collected is then thoroughly checked and analyzed. This standardized process is necessary to guarantee the consistency and homogeneity of the test conditions across different experimental settings. By using an aluminum tray with the aforementioned measurements, a controlled environment is created for the assessment of the pH values of rainwater. By following these exact guidelines, scientists can ensure the correctness and dependability of the data collected during the evaluation of rainwater quality, enabling strong and scientifically solid conclusions in the context of environmental research and water quality study. The quality of the rain water is Alkaline with 9.07pH and have little dusk particle forming inside the water. The test has been done on Afternoon from around 1.00 pm-5.00 pm. The specification for the Raw water is show in Table 1.

Table 1 Raw water specification

Parameter	Value
Water Source	Rain Water
Raw Water Quality	9.07pH
Turbidity	Have Dusk Particle
Amount of water	5 Liter

Approximately four hours were spent on the first test. After the distillation process, the water is free of impurities and has a higher-grade pH of 7.25 with less than 100 ml of water collected. After an hour, the formation of water droplets begins, and they continue to grow over the next few hours at an average temperature of 34.75°C and humidity of 64.75 percent. The tests do not need thermal support from a heater; instead, they simply employ radiation from the sun's direct rays. The outcome of the examination is documented in Table 2. A comparison of the surrounding temperature, water temperature, and humidity is shown in Figure 5.

Table 2 Daylight Monitoring Result and Graph Without Heater

Parameter / Time	1.20pm	2.20pm	3.20pm	4.20pm
Waterdrop forming	None	Low	Medium	Medium
Environment Temperature	35°C	36°C	34°C	34°C
Humidity	61%	62%	68%	68%
Heater Support	None			
Water Collected	Less than 100 ml			
Water Quality	7.45pH			

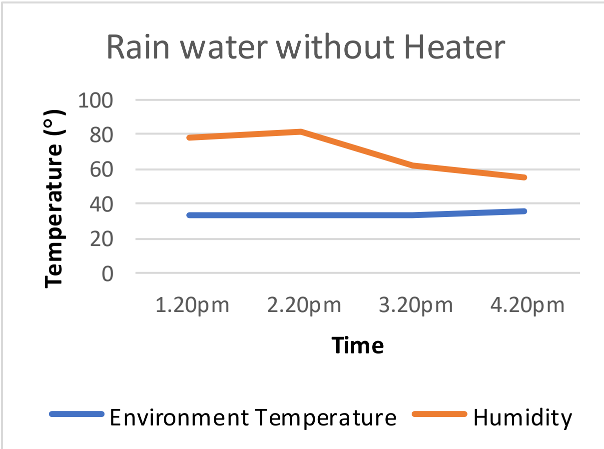


Figure 5 Rain water without heater

To heat the water for the second run, a Peltier system has been put at the bottom of a galvanized tray inside the solar still. The water type and volume are the same as in the prior experiment. After the distillation process, the water is free of impurities and has a higher pH of 7.26 after about 100 milliliters of water are collected and the result is tabulated in Table 3. After an hour, the formation of water droplets begins, and they continue to grow over the next few hours with an average temperature of 33.7°C and humidity of 64.25 percent. The solar still's water temperature is kept at an average of 43.6 °C by the heater. The tests do not need thermal support from a heater; instead, they simply employ radiation from the sun's direct rays. Figure 6 shows a comparison of the humidity, water temperature, and environment temperature.

Table 3 Daylight Monitoring Result and Graph with Heater

Parameter / Time	10.30am	11.30am	12.30pm	1.00pm
Water Drop forming	None	Low	Low	High
Environment Temperature	32.8°C	33.2°C	33.8°C	35°C
Humidity	78%	62%	62%	55%
Heater Support	Yes			
Water Temperature	32°C	41°C	49.1°C	52.3°C
Water Collected	100 ml			
Water Quality	7.26 pH			

B. Night Test

Similar to the daytime test, the tap water has been gathered for the nighttime test and placed into an aluminum tray measuring 25 cm by 30 cm by 7 cm. The tap water has an alkaline pH of 7.23 and contains a small amount of developing dusk particles. Without receiving any assistance from Heater, the test was conducted overnight. Table 4 displays the specifications for the raw water.

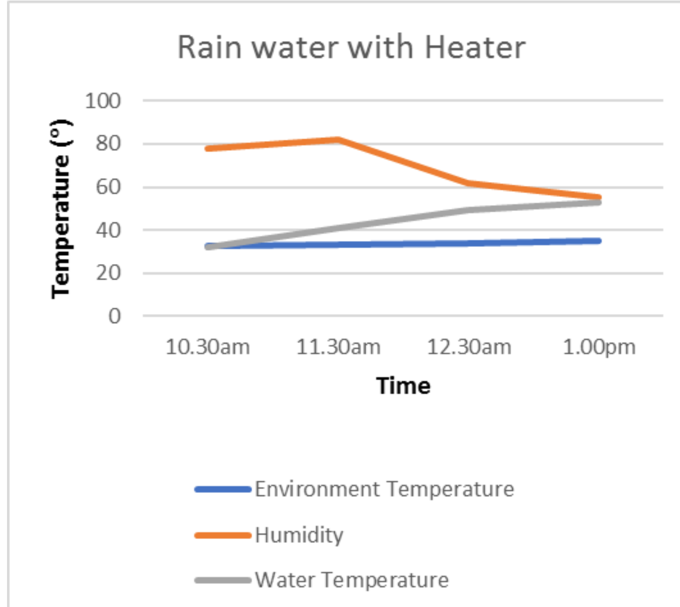


Figure 6 Rain water with heater

Table 4 Raw water specification

Parameter	Value
Water Source	Tap Water
Raw Water Quality	7.23 pH
Turbidity	Clear
Amount of water	5 Liter

It took almost four hours to complete the first test. Poor water drop formation on the glass is one of the distillation process' byproducts, making it impossible to collect the water. The evaporation process is produced by the extremely low temperature. At an average temperature of 32.15°C and humidity of 80.25 percent, the formation of water droplets begins after one hour and continues for the next few hours. No solar light or thermal support from a heater is used in the testing. The test results are recorded in Table 5, and Figure 7 displays a comparison of the temperature and humidity.

Table 5 Night Monitoring Result and Graph without Heater

Parameter / Time	8.30pm	9.30pm	10.30pm	11.30pm
Water Drop forming	None	None	None	Low
Environment Temperature	32.8	32.4°C	31.9°C	31.5°C
Humidity	78%	79%	82%	82%
Heater Support	None			
Water Collected	None			
Water Quality	None			

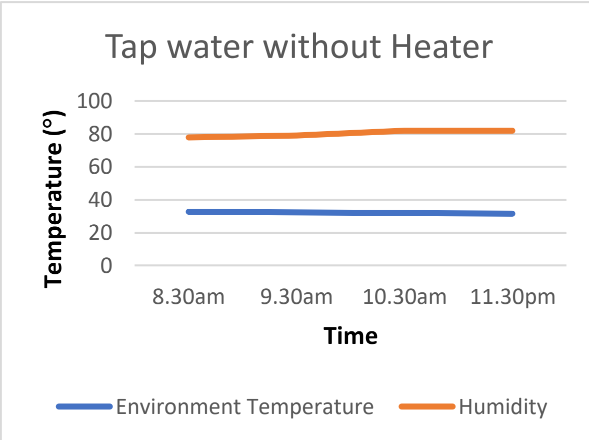


Figure 7 Tap water without heater

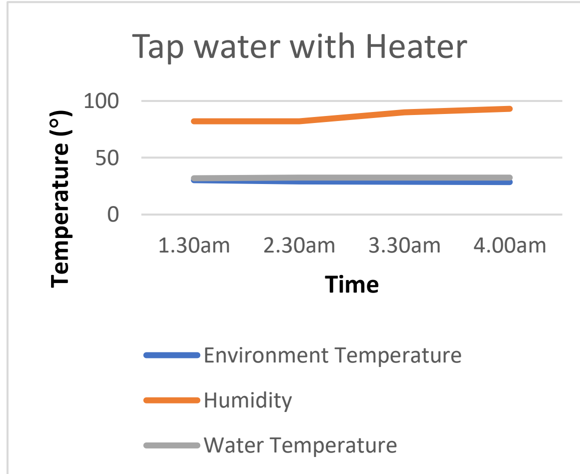


Figure 8 Tap water with heater

It took almost four hours to complete the second test. The process of distillation results in low water droplets appearing on the glass, making it impossible to collect the water. This is due to the extremely low temperature required to initiate the evaporation process. After one hour, water drop formation begins, and it continues to increase over the course of the next few hours with an average temperature of 29.15°C and humidity of 86.75 percent. The heater keeps the water in the solar still at an average temperature of 32.45 °C. The only thermal energy used in the experiments is from the supporting heater; no solar radiation is present. Table 6 and Figure 8 show a record of the test outcome.

Table 6 Night Monitoring Result and Graph with Heater

Parameter / Time	1.30am	2.30am	3.30am	4.00am
Water Drop forming	None	Low	Low	Low
Environment Temperature	30.3°C	29°C	28.8°C	28.5°C
Humidity	82%	82%	90%	93%
Heater Support	Yes			
Water Temperature	32.°C	32.6°C	32.6°C	32.6°C
Water Collected	None			
Water Quality	None			

A second heater can be installed to help speed up the evaporation process; in general, quicker rates of evaporation are encouraged by higher temperatures and lower humidity. Moreover, keeping humidity levels higher guarantees that there is enough moisture in the air to allow it to condense into liquid. However, without the essential heat energy from sunshine, distilling water at night becomes a difficult process. Therefore, in order to maximize the effectiveness and efficiency of the evaporation and condensation processes in order to obtain distilled water, the installation of additional heating mechanisms in conjunction with suitable environmental conditions becomes essential.

Table 7 Summary of the Daylight and Night Test

	Daylight Test with Heater 10.30 am - 1.30 pm	Daylight Test without Heater 1.20 pm - 4.20 pm	Night Test with Heater 1.30 am - 4.00 am	Night Test without Heater 8.30 pm - 11.30 pm
Forming of Water Drop	High	Medium	Low	Low
Volume of Water	100ml	<100ml	None	None
Output pH Level	7.26 pH	7.45 pH	None	None
Avg Environment Humidity	64.25°C	64.75%	80.25%	86.75%
Avg Environment Temperature	33.7°C	34.75°C	29.15°C	32.15°C
Avg Water Temperature	43.6°C	None	32.45°C	None

The Daylight test with a supporting heater is clearly more effective at producing distilled water than the other three tests, as shown by the results in Table 7. This test, which collected a volume of water approximately 100 ml with a pH of 7.26, showed noticeably faster water drop production and an overall higher water collection rate. The enhanced performance can be explained by the Pyramid solar still's constant temperature, which is maintained both inside and outdoors, and by the presence of ideal humidity levels.

The water temperatures for the conventional and wire wick solar stills were 64 °C and 51 °C, respectively, at the precise time of 14:00 in the study cited as [15]. Interestingly, these temperatures are marginally higher than those found in the present study. It is important to note that the results published in [15] were obtained without the use of a heater. This comparison highlights how effective the pyramid-shaped solar still used in this study is because it shows that it can still create clean water when a heating element is added, even at a lower water temperature. According to this research, adding a heater improves the pyramid-shaped solar still's efficiency and lowers the water temperature required for efficient distillation.

Over the course of an hour, the initial high temperature in the distillation process progressively drops, resulting in ideal circumstances for effective evaporation. This temperature trend helps to improve the process of evaporation. At the same time, the humidity increases gradually every hour, which is helpful in speeding up the condensation process. Table 7 demonstrates that as humidity rises, there is a sufficient amount of moisture in the air to encourage the transformation of vapor into liquid. As illustrated in Figure 9, a successful distillation process necessitates the meticulous coordination of the heating and cooling phases, guaranteeing the production of highly concentrated water droplets and the intended purifying result.

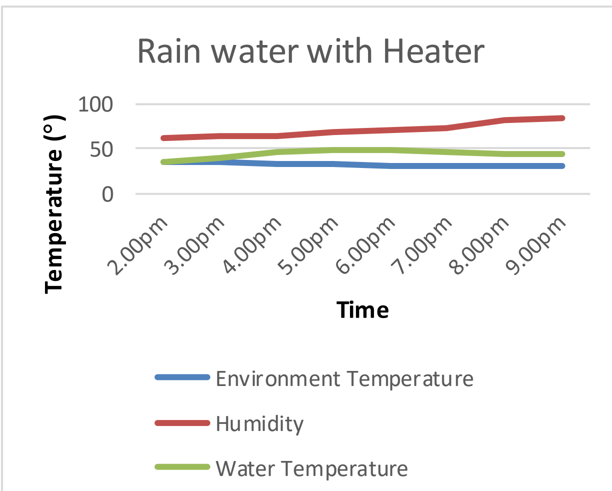


Figure 9 Heating and Cooling test Graph

The pyramid solar still experiment demonstrated how temperature and humidity have a big impact on the processes of evaporation and condensation. Sufficient humidity promoted effective condensation, and higher temperatures increased the rate of evaporation. For maximum efficiency, humidity and temperature must be balanced. This is because high temperatures with low humidity prevent condensation, while low temperatures with high humidity prevent evaporation. In pyramid solar stills, the relationship between temperature and humidity must be optimized to optimum water output. These results offer important new information for future studies and development aimed at raising the efficacy and efficiency of solar still technologies.

4.0 CONCLUSION

The pyramid solar still with thermoelectric heater added to its conceptual framework is a combination of two different technologies: thermoelectric heater and solar still. Utilizing solar radiation to cause water to evaporate, the solar still then gathers the condensed water vapor, acting as a filtration system for the water. Simultaneously, the electrically powered thermoelectric heater is smoothly incorporated into the solar still equipment to maximize its performance and increase the water output rate. The main benefit of combining a thermoelectric heater with a solar still is the increased control it provides over the process of producing water. By carefully using the thermoelectric heater, the system raises the interior temperature of the still, which accelerates the evaporation process and increases the amount of water produced. This is especially helpful in areas with lower solar radiation or in cloudy weather when there may not be enough solar energy. Research results demonstrate the effectiveness of the pyramid solar still when heated during the day, leading to much better water quality results. Compared to conventional models, the pyramid solar still design has the potential to improve output quality and operational efficiency, as demonstrated by the production of 100ml of water with a pH of 7.26. In addition, hot, humid weather is known to affect the productivity of the pyramid solar still. This is demonstrated by trials in which the still produced more than 100 milliliters when operating in ideal conditions with 70% humidity and 30 degrees Celsius for a continuous duration of four hours. As a backup heat source, the pyramid solar still makes sure that water evaporation continues even when there is little sun exposure. This feature is especially helpful in areas where the sun's intensity varies during the day or the weather fluctuates. As a result, the pyramid solar still with a thermoelectric heater is a more reliable and efficient option for systems that purify and distill water. This ground-breaking device combines solar power with electric heating to provide an improved method of purifying water while addressing the difficulties caused by fluctuating solar rays. The cost-effectiveness and practicality of this integrated system, however, depend on a number of factors, including the demands of the current water purification application, the availability of electricity, and certain environmental considerations.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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