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Solar-Powered Seawater Desalination: A Contribution To Provide Energy-Efficient Clean Water

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Abstract

This study focuses on developing a prototype for a seawater desalination system powered by solar panel. The desalination process is heated by a solar collector and 150 WP solar panel. The primary objective is to design, develop, and evaluate the prototype's efficacy, affordability, and scalability. The efficiency was measured by the quantity of freshwater produced per unit of solar energy. Of the three distillation tests, it was determined that the addition of a heater enhanced the performance of the system. However, the overall efficiency was limited due to the solar panel and collector's low heat output. A positive correlation was observed between irradiance and temperature, but incomplete evaporation indicated the need for additional research to optimize the process. The system consisted of a solar collector, a heater, and a distillation apparatus. Three distillation tests revealed that the addition of a heater improved the system's performance, resulting in a maximum achievable efficiency of 0.99% and the production of 16 ml of fresh water. This study demonstrates the potential for renewable energy sources to power seawater desalination and lays the groundwork for future sustainable desalination technologies despite its Limitations.

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Keywords: *Seawater; Desalination; Solar collector; Solar panel.*

Abstrak

Studi ini fokus pada pengembangan prototipe sistem desalinasi air laut dengan menggunakan panel surya. Proses desalinasi dipanaskan oleh kolektor surya dan panel surya 150 WP. Tujuan utamanya kegiatan ini merancang, mengembangkan, dan mengevaluasi kehandalan, keterjangkauan, dan skalabilitas prototipe. Efisiensi diukur melalui kuantitas air tawar yang dihasilkan setiap per unit energi matahari. Dari ketiga pengujian distilasi, ditentukan bahwa penambahan pemanas meningkatkan kinerja sistem. Namun, efisiensi keseluruhan cukup terbatas karena panel surya dan keluaran panas kolektor yang rendah. Korelasi positif diamati antara radiasi dan suhu, tetapi penguapan yang tidak lengkap menunjukkan perlunya penelitian tambahan untuk mengoptimalkan proses. Sistem terdiri dari kolektor surya, pemanas, dan alat distilasi. Tiga pengujian distilasi mengungkapkan bahwa penambahan pemanas meningkatkan kinerja sistem, menghasilkan efisiensi maksimum yang dapat dicapai sebesar 0,99% dan menghasilkan 16 ml air bersih. Studi ini menunjukkan potensi sumber energi terbarukan untuk menggerakkan desalinasi air laut dan meletakkan dasar bagi teknologi desalinasi berkelanjutan di masa depan meskipun memiliki keterbatasan.

Kata Kunci: Air laut; Desalinasi; Kolektor surya; Panel surya.

1. Introduction

Access to clean and safe drinking water continues to be a struggle for many regions of the world, especially in densely populated areas (United Nations Children’s Fund, 2017; Antar, et., 2012). The United Nations estimates that approximately 2.2 billion people cannot access safe drinking water (Ritchie et al., 2012) . Water desalination (WD) technologies successfully solve the potable water shortage, as seawater comprises nearly 97% of all accessible water resources (Mohamed et al., 2021). The Desalination of saltwater and brackish water is an up-and- coming solution to the world's water shortage issues. Over the past decade, this process has increased by 6.8% per year, resulting in annual production of 4.6 million m3/day of potable water (Eke et al.,(2020). Although plants with the most significant capacity are uncommon, they account for the most installed capacity. As of 2017, there are 18,500 desalination plants installed in 150 countries with a total capacity of 99.8 million m3/day, based on data provided by International Desalination Association (IDA) (Virgili,et al.,2016).

WD effectively removes dissolved salts to meet the rising demand for potable water (Zhang et al.,2020; Ibrahim et al., 2020). Seawater desalination solves this problem but requires much Energy (Al-Obaidi et al., 2022). Solar power can potentially provide a cost-effective, environmentally friendly means of generating electricity or thermal Energy for domestic use (Salameh et al., 2020; Al-Mamun et al., 2021). Solar Energy has recently become increasingly popular for powering desalination plants due to its sustainability and affordability (Xiang et al.,2020; Zhang et al., 2021; Yurtsever et al., 2019; Esmaeilion et al., 2021). Unfortunately, many solar-powered desalination devices are limited in efficiency, cost, and scalability (Pouyfaucon et al., 2018). Therefore, this study aims to develop a prototype of an efficient and cost-effective WD system that uses a solar collector and a 150 WP solar panel to generate the desalination process's heater. The proposed system aims to address the limitations of existing solar-powered desalination systems by offering a sustainable, affordable, and scalable alternative. The environmental impact of seawater desalination processes caused by burning fossil fuels will be mitigated using solar energy as an alternative (Al-Obaidi et al., 2022).

Solar energy systems, such as concentrated solar power (CSP) and photovoltaic (PV), have been evaluated for their ability to power both thermal and membrane seawater desalination processes, such as multistage flash (MSF) (Almerri et al., 2023), multi-effect distillation (MED) (Al-hotmani et al., 2019) [19], and reverse osmosis (RO)(Alsarayreh et al., 2020). Numerous studies have analyzed freshwater production's specific energy consumption and cost for various combinations of desalination processes and solar energy systems (Ali et al., 2017). Historically, thermal energy has been used for this purpose. Even in modern thermal desalination processes, such as multistage flash (MSF), multiple-effect distillation (MED), and thermal vapor compression (TVC), the fundamental concept of thermal desalination has been successfully adopted (Ali et al., 2021).

Recently, membrane techniques utilizing electrical energy have supplanted thermal Desalination in many regions of the world (Irena, 2012; Gude et al., 2010), primarily due to their lower energy consumption. A third category has also evolved based on the hybridization of thermal and membrane processes. MD and MSF/MED are examples of integration with RO. In addition to energy savings, membrane processes offer the benefits of compactness, lightweight, and high productivity, making them a perfect fit for process intensification strategies (Drioli et al, 2012; Drioli et al, 2011; Ahammad et al., 2008; Bernardo et al., 2010).Water production costs still favor fossil fuels, despite the potential to significantly reduce carbon footprints (Kim et al.,2022). Thus, more research and development or a carbon tax on fossil fuels are needed to make solar energy economically viable for desalination. This study aims to fill the "gaps" left by previous research and investigate the viability of using a solar collector and a 150 WP solar panel to power a desalination system for seawater. The proposed system will generate heat for seawater evaporation using a solar collector. Then, this vapor will be condensed into freshwater. The 150 WP solar panel will provide the necessary Energy to power the system, which will be modular and scalable to accommodate diverse requirements.

The primary objective of this study is to design, develop, and test a prototype of seawater desalination equipment that employs a solar collector and a 150 WP solar panel to generate the heater. The effectiveness, affordability, and scalability of the prototype were evaluated. The system's effectiveness was determined by the amount of freshwater produced per unit of solar energy, while its affordability was determined by its capital and operating costs. The system's scalability was evaluated based on its adaptability to diverse requirements and environments. Moreover, this study contributes to developing sustainable and cost-effective solutions to the global water crisis, especially in areas with challenging access to clean water. The proposed system has the potential to provide a research development for preparing a reliable source of freshwater using renewable energy, which could alleviate water scarcity and enhance the quality of life for millions of people worldwide.

2. Method

The evaporator is a device to process to be purified seawater. Separate solar panels power the solar collector and solar heater on the evaporator. The condenser functions as a conduit for condensing water vapor to direct it into the container containing pure water. In the meantime, the evaporator is responsible for the precipitation of salt solutions with a high concentration. To distill seawater, seawater will first enter an evaporator equipped with a valve, followed by an evaporator equipped with a solar collector and a heater. This process results in the evaporation of distilled seawater, which is then sent to the condenser. The condensed water vapor is then poured into the purified water vessel and the sediment crystallizes in the evaporator. The proposed system is depicted in Figure 1.

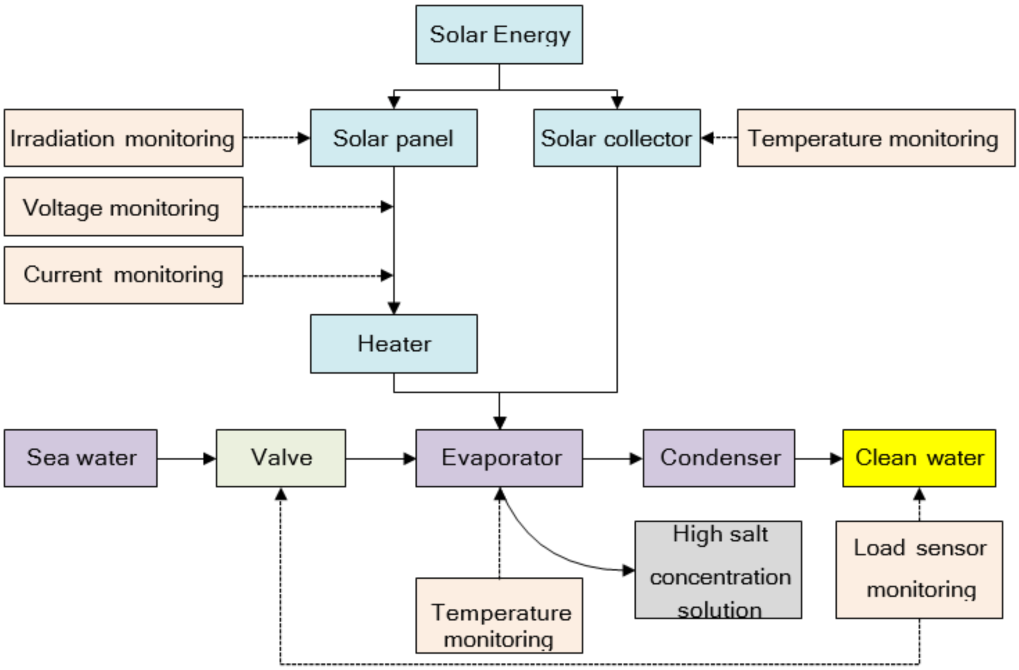

Figure 1. Seawater distillation proposed system.

2.1. Solar Panel Spesification

This study uses a 150WP polycrystalline solar panel to purify seawater. The solar panel has the following specifications: Vm = 18.72, Im = 8.01, Voc = 22.09, Isc = 8.76, and A = 0.9916 m2. The target of water to be purified is 2.5 liter, and the amount of purified water can be calculated. Assuming that the solar panel is exposed to maximum irradiation for four hours between 10:00 to 14:00, the solar panel produces approximately 600 watts of maximum power. The calculation shows 0.2596 kg of seawater can be purified per hour. During the four hours of maximum irradiation, it is possible to filter 1.038 kg of seawater, equivalent to 1.062 liter of vaporized water.

2.2. Solar Collector and Evaporator Glass

In this study, solar collectors made of copper pipes are used to collect heat to evaporate seawater. When sunlight hits the absorber on the solar collector, most of the heat energy is transferred to circulating water which flows through the copper pipes thereby helping to increase the temperature of the evaporator. The main components of the solar collector are the frame, cover, absorber, copper pipe, and insulator, as visualized in Figure 2. The cover reduces heat loss to the environment via convection, whereas the absorber absorbs heat from solar radiation. The copper pipe is a device for distilling seawater. The insulator reduces heat loss through conduction from the absorber to the environment, while the frame forms and supports the weight of the collector. The solar collector has the following specifications: a glass size of 0.27 m x 0.2 m x 3 mm, a collector height of 5 cm, a collector size of 0.27 m x 0.2 m, 50 mm bubble aluminum foil, T and L fittings of 0.5, and a 200 cm and 20 cm copper pipe.

Figure 2. Copper pipe with evaporator chamber.

The absorber is a thermally conductive plate that serves as the collector's primary component. In this study, the absorber comprises glass and copper riser pipes. The glass surface is colored black, as presented in Figure 3, to absorb solar radiation and retain heat more efficiently. Although glass is transparent to ultraviolet and visible light waves (the most prevalent forms of solar radiation), it is not evident to infrared light waves, which are responsible for the greenhouse effect. Thus, minimizing heat losses from the absorber's surface to the collector is possible. However, heat loss still occurs due to air convection between the absorber and the glass. The evaporator glass was made of clear glass with dimensions of 200 cm x 200 cm, a thickness of 3 mm, and a heat emissivity of 0.88. This glass is painted black to maximize its ability to absorb sunlight.

Figure 3. Evaporator glass.

2.3. Heater Coil

The heater was installed as an additional heating element on the solar collector's underside to expedite seawater's evaporation. The heater's output will be adjusted to match the solar panels. The power of the heating element is calculated using Ohm's law. The heater's power output is estimated to be 149.95 W based on the maximum voltage and maximum current that the solar panel can produce, which are 18.72 V and 8.01 A, respectively. The coil's resistance is 2.337 Ω, with a wire length of 1.256 m, as presented in Figure 4.

Figure 4. The heater coil mounted on the pipe.

2.4. Testing Procedure

In this study, we developed a prototype system for seawater desalination powered by renewable Energy. The system consisted of a solar collector, a solar panel, and a heater. We conducted various tests to evaluate the performance of the system. To ensure the accuracy of the data collected, we conducted tests on the sensors used in the system. We tested the ACS712 30A current sensor, the DC voltage sensor module, the DS and NTC temperature sensors, the irradiance sensor, and the weight sensor. For each sensor, we recorded the readings under different conditions to ensure its proper functioning. The calibration of the sensors used is presented in Figure 5 and Figure 6.

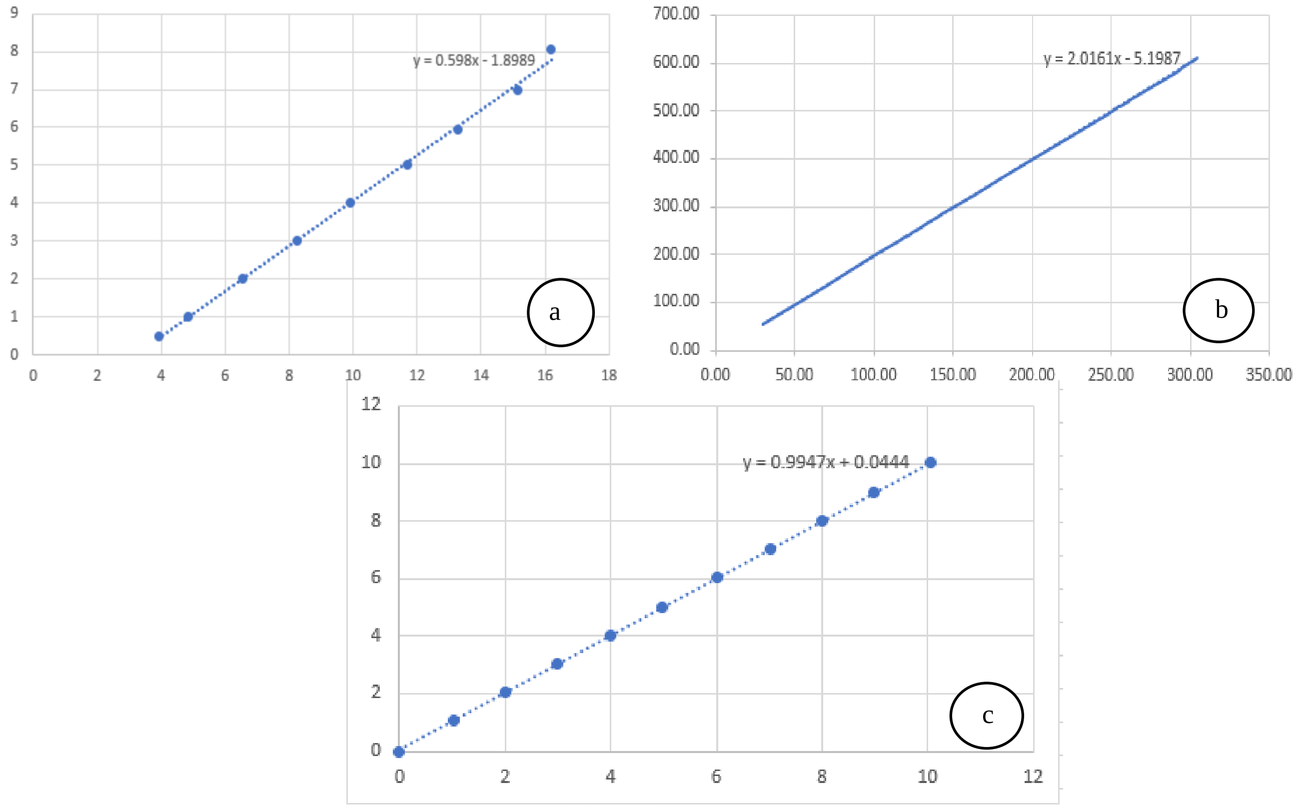

Figure 5. Calibration data for ACS712 30A Sensor (a), Irradiation Sensor (b), and Voltage Sensor (c).

Three specific tests were conducted in the experiment involving seawater distillation. Initially, we utilized a solar collector as the sole energy source to heat and distill seawater. Second, we conducted tests with a solar collector and solar- powered heater. Thirdly, we tested a heater powered solely by a solar panel. The tests were conducted between 8:00 and 12:00 to observe the variation of solar radiation throughout the testing period. We recorded the time required to distill seawater, the necessary temperature to purify seawater, and the quantity of distilled seawater.

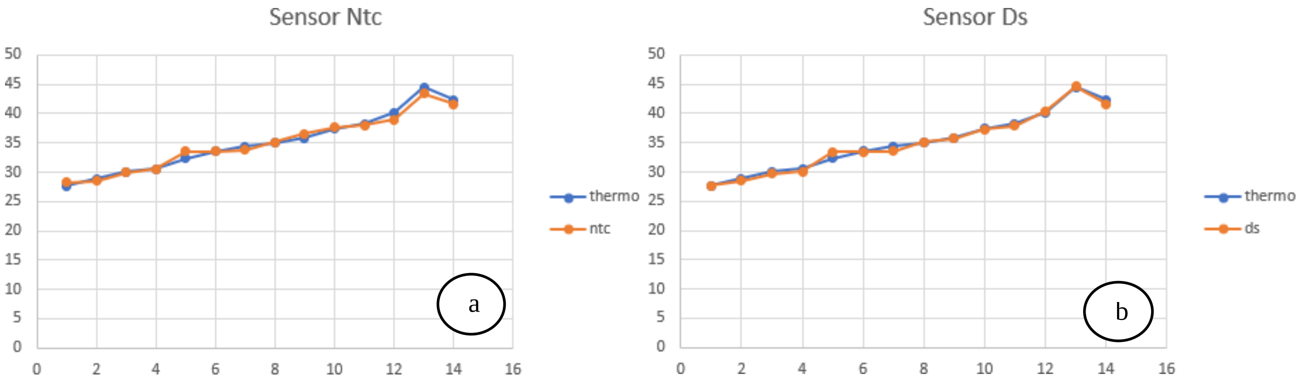

Figure 6. Calibration data for NTC sensor (a) and Ds18b20 Sensor (b).

3. Results and discussion

Clean water is essential for human survival. In some regions, however, access to clean water is minimal and expensive. Using a seawater distillation system is one way to circumvent this issue. The distillation system separates water from salt and other minerals. In this research, we tested three distinct types of distillation systems. The first test was conducted by evaporating water using a solar collector as a heat source. We utilized a solar collector with a flat mirror reflector and a porous absorber material. During the test, we monitored the temperature and rate of clean water production at each stage of the distillation procedure. The second test was conducted utilizing a hybrid system comprised of a solar collector and a coil heater powered by solar panels. Using a coil heater as an additional heat source is anticipated to accelerate the distillation process and increase the amount of pure water produced. The third and final test was conducted utilizing only the coil heater, not solar panels, or a solar collector. In this test, clean water's temperature and production rate were measured and compared to previous test results. In this article, we provide recommendations for the best seawater-to-purified-water distillation system based on the results of our tests. It is hoped that this research will aid in discovering solutions to the problem of clean water supply in regions with limited access to clean water.

3.1. Performance of Solar Collector

The outcome of a distillation process that is powered solely by the sun and uses a solar collector as the only source of heat is determined by the amount of heat absorbed by the solar collector from solar radiation. Table 1 presents the findings obtained from the tests. At first, the water temperature was the same as inside the pipe, which was 32.77.43°C. During this experiment, the highest temperature the water ever reached was 81.56 °C. However, because thewater temperature did not reach 100 °C, which is the point at which it begins to boil, the evaporation process was not finished. Then, Figure 7 illustrates the relationship between the amount of irradiation and the temperature. According to the graph, the value of the irradiation increases in direct proportion to the rise in water temperature. At an initial irradiation of 110 watts/m^2, the chart shows that the temperature was approximately 30 °C when it was first measured. The system's temperature gradually increased as the amount of irradiation it received raised. In this experiment, the water reached its highest temperature of 81.56 degrees Celsius when the solar collector was irradiated 292 W/m2.

Table 1. Distillation test data using a solar collector

Time	Glass Temperature (°C)	Water Temperature (°C)	Environment Temperature (°C)	Irradiation (Watt/m^2)	Q_{in} (Watt)
08.00-08.30	30.01	32.77	31.45	110	61
08.30-09.00	33.45	35.84	31.98	125	69
09.00-09.30	38.93	42.90	35.02	177	97
09.30-10.00	49.68	55.64	36.94	188	104
10.00-10.30	61.33	73.46	46.29	177	97
10.30-11.00	69.23	79.90	51.13	521	287
11.00-11.30	71.29	80.27	51.22	525	289
11.30-12.00	73.10	81.56	52.03	517	284
			Average value	292	161

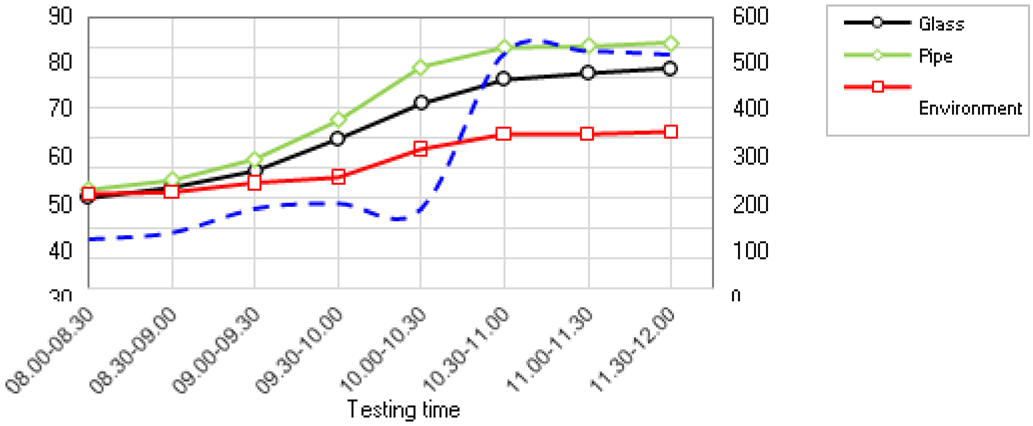

Figure 7. Irradiation and temperature characteristics during the testing time using a solar collector.

3.2. Performance of Hybrid Solar Collector and Heater

On the second experiment, the goal was to determine the outcomes of solar-powered distillation using a solar collector and a heater. The results of the tests are summarized in Table 2. The tests were carried out from 08.00 to 12.00, and the initial temperature of the water was 37.76 °C, which was also the pipe temperature when the tests began. Because the water did not reach its boiling point of 100 °C during this test, the highest temperature that could be achieved for the water was 80.55 °C. This is because the vaporization process was only partially successful. Moreover, Figure 8 illustrates the relationship between irradiation and temperature clearly and concisely. The value of the irradiation increases which in turn causes an increase in the temperature of the water. Based on the information gathered, the panel power and collector heat were at their peak between 11:30 and 12:00, reaching 66.19 and 281 watts, respectively, with irradiation of 513 watts/m2 during that time. It can be seen from Figure 7 that the initial temperature of the system ranged from 30.13 °C to 37.76 °C, and the irradiation was 391 watts per square meter. The system's temperature continued to rise gradually as the irradiation continued to rise until it reached its maximum temperature of 80.55 °C at the pipe, 67.36 °C at the glass, and 39.62 °C in the environment.

Table 2. Distillation test data using a solar collector and heater.

Time	Glass Temp.(°C)	Pipe Temp. (°C)	Environ- ment Temp. (°C)	Voltage(V)	Current (A)	Irradiation (Watt/m2)	Power (Watt)	Qin (Watt)
08.00-08.30	34.81	37.76	30.13	11.17	3.98	391	44.68	215
08.30-09.00	41.35	51.98	32.65	11.88	4.24	423	50.42	233
09.00-09.30	45.25	62.28	34.32	11.95	4.44	439	53.10	241
09.30-10.00	53.36	69.43	35.30	12.47	4.60	463	57.45	255
10.00-10.30	63.23	75.66	36.48	12.71	4.97	496	63.12	273
10.30-11.00	67.03	79.70	38.74	12.85	5.08	508	65.30	279
11.00-11.30	67.36	80.55	39.14	12.73	5.17	511	65.84	281
11.30-12.00	67.11	80.21	39.62	12.59	5.26	513	66.19	282
				Average value		468	58	257

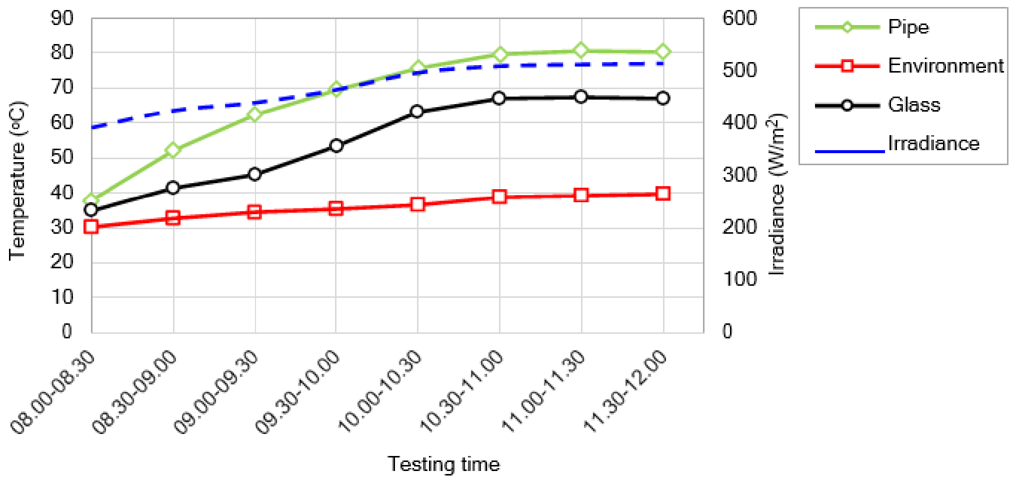

Figure 8. Irradiation and temperature characteristics during the testing time using hybrid solar collector and heater.

3.3. Performance of Heater

The third experiment, which aimed to determine the outcomes of solar-powered distillation using a heater, was carried out between the hours of 8:00 and 12:00. The solar panel absorbed the sun's rays as they passed through it. These rays were used as a source of heat in the distillation process. The panel was then connected to the heater in a line of sight. The examination outcomes are shown in Table 3. Then, Figure 9 illustrates the relationship between irradiation and temperature clearly and concisely. The value of the irradiation increases which in turn causes an increase in the temperature of the water. Based on the information gathered, the panel power and collector heat were at their peak between 11:30 and 12:00, reaching 66.19 and 281 W, respectively, with irradiation of 513 W/m2 during that time. It can be seen from Figure 9 that the initial temperature of the system ranged from 30.13 °C to 37.76 °C, and the irradiation was 391 542 W/m2. The system's temperature continued to rise gradually as the irradiation continued to rise until it reached its maximum temperature of 80.55 °C at the pipe, 67.36 °C at the glass, and 39.62 °C in the environment. It is clear to see that the irradiation was at its highest between the hours of 9:00 and 9:30, reaching a value of 542 W/m2. The amount of irradiation that hits the solar panel at any given moment is directly proportional to the amount of power produced by the solar panel. The initial temperature of the system was 37.18 °C in the air, 40.10 degrees Celsius on the glass, and 42.21 °C on the pipe. The temperature in the system eventually reached 63.03 °C on the pipe as it continued to rise.

Table 3. Distillation test data using a heater.

Time	Glass Temp. (°C)	Pipe Temp. (oC)	Environ-ment Temp. (^oC)	Voltage (V)	Current (A)	Irradiation (Watt/m^2)	Power (Watt)	Q_{in} (Watt)
08.00-08.30	42.21	40.10	37.18	12.71	4.50	479	60.18	42.21
08.30-09.00	48.69	44.12	40.43	14.04	5.01	538	70.49	48.69
09.00-09.30	57.19	49.65	49.39	14.17	5.03	542	71.25	57.19
09.30-10.00	63.03	55.33	50.47	13.31	4.69	497	63.26	63.03
10.00-10.30	62.63	56.75	46.63	11.63	4.04	424	50.55	62.63
10.30-11.00	61.58	59.27	47.81	12.52	4.41	465	57.65	61.58
11.00-11.30	61.19	56.82	46.01	12.41	4.36	459	56.65	61.19
11.30-12.00	61.12	56.04	47.20	13.49	4.78	509	65.41	61.12
				Average value		489	61.93	489

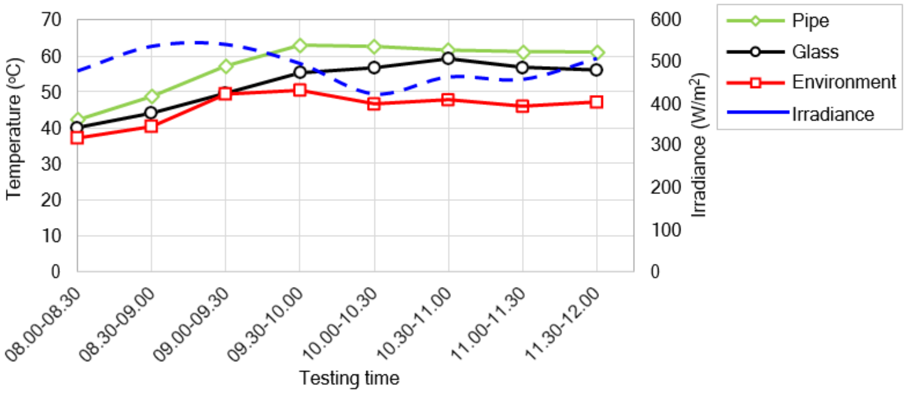

Figure 9. Irradiation and temperature characteristics during the testing time using heater.

Finally, the results of each distillation test are summarized in Table 4. Testing with a solar collector yielded 5 milliliters of pure water. Because the output power of the solar panels and the heat that can be absorbed by the solar collector is not enough to boil seawater, the efficiency of this device is very low. The amount of water that is purified as a result is meager. The low level of effectiveness of this research tool can be attributed to the water in question. And when the process of purifying seawater is compared to the distillation process used in this study, which utilizes a solar collector and heater and has an efficiency of 0.99% and can produce as much as 16 mL of fresh water, it is possible to say that the addition of a heater can increase the efficiency of the process.

Table 4. Distillation efficiency.

Evaporation Methode	Distillation Result(ml)	Q IN (Watt)	Q USE (Watt)	η (%)
Solar Collector	5	160.8	0.82	0.4
Hybrid (Solar collector and heater)	16	264	2.63	0.99
Heater	4	61	0.65	1.08

4. Conclusion

This study focused on solar energy distillation of seawater. The analysis purified seawater using a solar collector, a heater, and a distillation system. The system's effectiveness was evaluated by conducting three distillation tests and analyzing the results. The results demonstrated that adding a heater to the solar collector improved the system's performance. The maximum achievable efficiency was 0.99%, and the total freshwater produced was 16 mL. However, the system's overall effectiveness was low due to the limited heat available from the solar panel and collector to raise the boiling point of the seawater. The relationship between irradiance and temperature was positive, with greater irradiance resulting in higher temperatures. However, in none of the tests, the water reached the boiling point, indicating that the evaporation was incomplete. Solar Energy as a heat source for water distillation is feasible, but further research is required to optimize the process and increase its efficiency. In conclusion, this study demonstrates the feasibility of utilizing solar energy for seawater desalination and lays the groundwork for future research and development of sustainable desalination technologies.

5. Authors' Declaration

Authors' contributions and responsibilities - The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

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Availability of data and materials - All data are available from the authors.

Competing interests - The authors declare no competing interest.

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