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Experimental Analysis of Fresnel Lens-Based Solar Desalination Systems with Copper Receivers for Enhanced Thermal and Electrical Performance

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ABSTRACT

Solar desalination represents a breakthrough technology for creating sustainable freshwater because it meets both the water quality standards and technology efficiency requirements of modern times. The current desalination methods, which depend on fossil fuels, encounter major obstacles regarding their energy requirements and economical performance. The research investigates the improvement of solar desalination performance through coupling Fresnel lens technology with copper-based receivers to maximize thermal characteristics and power generation benefits. This research successfully unites Fresnel lenses of high performance with copper receivers to reach increased steam temperatures alongside power production during the same procedure. The research team performed experimental tests using a system that included four large Fresnel lenses in Sharjah, UAE. Under different operating settings, the system demonstrated its performance by measuring its flow rates together with ambient temperatures and recording the steam output values. The experimental data showed that bigger Fresnel lenses boosted the steam temperature beyond 1000°C as well as pushing pressure levels to 8 bar, which led to remarkable system efficiency benefits. The copper receiver system generated 775 mA DC electric current, which collectively enhanced the system's power efficiency. The tested combination of Fresnel lenses and copper receivers demonstrates an effective way to enhance solar desalination systems, according to observed experimental data. The dual-function technology combines desalination efficiency improvement with electricity production capabilities to establish a sustainable freshwater production method for arid regions. This investigation creates a basis for developing economical renewable desalination systems going forward.

1. Introduction

An escalating demand for freshwater arises because of accelerating population growth and expanding energy needs that generate serious social difficulties worldwide [1]-[3]. The planet possesses 70% water coverage, but just 3% of that water is drinkable fresh water, while the remaining 97% remains saline [4]-[7]. Human consumption solely relies on less than 1% of accessible freshwater, with the majority being trapped in ice caps and glaciers. Earth's water supply becomes rapidly depleted because of fast population expansion, which merges with industrial developments along with environmental soil pollution from climate change [8]-[10]. World Health Organization data shows that waterborne diseases become responsible for 80% of medical illnesses because they result in approximately half a million annual deaths within developing nations [11]-[14]. The projection shows that water scarcity will affect 30% of population centers throughout the world in approximately 10 years, yet severe water shortage conditions already exist in 50 water-scarce countries [15]-[17].

The escalating freshwater crisis has led to seawater desalination becoming an effective solution that secures a lasting freshwater supply [18]-[20]. Reverse Osmosis (RO) and Multi-Effect Distillation (MED) have evolved into established desalination methods that especially serve the Middle Eastern and North African arid regions. These methods require large energy consumption based on petroleum-fueled fossil fuels to operate, which produces both expensive operations and major environmental damage [21]-[24]. Implementing non-renewable energy sources poses a barrier to desalination operations due to limited power access and environmental sustainability objectives. Efficient and cost-effective renewable energy-powered desalination technologies need development to address current challenges in the industry [25]-[28].

Solar desalination technology has introduced new approaches that surpass conventional water desalination procedures [29]-[33]. Solar energy stands as the best power source for desalination operations because it gives numerous benefits, including its abundance and sustainability, while supporting environmental goals. The solar desalination technology includes direct and indirect systems as its main categories [34]-[37]. Water under direct solar desalination receives heat that leads to evaporation and then produces clean water through condensation. Solar power generates electricity as its source to operate reverse osmosis or multi-stage flash distillation processes within indirect systems. Solar technology used for desalination presents two techniques that minimize both operating expenses and power requirements better than procedures based on traditional fossil fuels [38]-[40].

Solar desalination systems with optical concentrators, particularly parabolic mirrors and Fresnel lenses, have become prominent in the solar desalination field. These concentrators send strong solar rays to thermal heatsinks, enabling quick temperature rises and speeding up the process of water vaporization [41]-[44]. Fresnel lenses provide better performance than standard parabolic reflectors because they boast lightweight design and affordable construction and achieve high optical efficiency. The devices work perfectly for maintaining small-scale water purification systems because they produce sufficient heat for desalination operations. Their operational effectiveness encounters restrictions through material reliability together with growth constraints and stepped control requirements in optical elements [45].

Existing examinations of solar mirror and Fresnel lens implementations in desalination setups demonstrated these systems produce inadequate temperatures for effective steam generation. The exploration of smaller Fresnel lenses proved insufficient for generating effective high-pressure steam from solar energy [46]. Researchers implement a fresh method by using four big Fresnel lenses instead of twelve smaller ones to receive twice the solar power rate for better desalination efficiency [47]. The design of the lenses and their arrangement seeks to reach maximum performance in evaporation and condensation processes, leading to better freshwater production. water desalination procedures [48].

Multiple barriers need attention before the proposed system can become fully operational [49]. The system function gets affected by environmental elements including cloud cover and dust accumulation which decreases the transmitted sunlight and minimizes optical power reaching the lenses. Financial budget constraints inhibit any further improvement of the system due to the study running on a self-funded basis [50]. The research results will advance solar desalination technology development by creating efficient and economical water solutions for water-stricken regions [51].

The remainder of the paper is organized as follows: Section 2 covers an exhaustive review of literature about current desalination methodologies along with solar power implementation, whereas Section 2.1 details both the design and methodology and experimental setup for the proposed technology. Performance assessment with efficiency evaluation follows in Section 3 before concluding with Section 4's summary and proposed research paths.

2. Methodology And Material

The flowchart in Fig. 1 outlines a systematic approach to developing a system for desalinating water using concentrated solar power. It begins with data acquisition, where essential information regarding solar radiation, water quality, and potential sites is collected. Next, the process moves to site identification and selection, ensuring that the chosen location is optimal for the research. Following this, a design for the solar desalination system is created. Once the design is finalized, the construction and assembly of a solar tracking system takes place, which is crucial for maximizing solar energy capture. Following assembly, the chart incorporates a decision point to verify the alignment of the tracking system with the sun; if not, it undergoes necessary adjustments. Once aligned, the Fresnel lens is mounted and adjusted to fit the system frame. Another decision point assesses whether the total dissolved salts exceed 500 mg/L; if they do, the system moves forward to full operational testing. Subsequently, the system undergoes experimental verification under varying operational parameters to assess performance. Finally, data collection occurs to gather insights from the tests, leading to the conclusion of the research with the end step. This structured approach ensures thorough evaluation and optimization of the desalination system's effectiveness.

2.1. Design of a Concentrated Solar Power Water Desalination System (CSPWDS)

The geographical site location and weather conditions are important considerations for effectively utilizing the CSPWDS technology for water desalination. The CSPWDS plants need certain specific locational requirements. Availability of sunshine is one important condition. Since the input for heat production is the sunlight, the places that offer high intensity of sunshine are best suited for establishing such systems. The second important criterion is sufficient flatness of the locality. Open and flat terrain without any obstructions is required to set up the CSPWDS system.

The experiments conducted in desalination using FL are described in Fig. 2. FL has its characteristics used in our experiments as shown in Table 1. The sun is always on the FL and then on the receiver through the solar tracking device. The analysis of salt water is carried out through the passage of water from the salt water tank to the copper-based receiver inside a box covered with high-temperature glass, which will be detailed later. The specifications for 1 unit of Fresnel lens are given in Table 1.

In the concentrated solar water desalination systems (CSPWDS), mirrors or lenses are used to concentrate the sun’s light rays to provide the required heat energy to produce steam. The important components of a typical CSPWDS plant include mirrors or lenses, a tracking system, receivers, a heat storage system, a steam generator, and a condenser. The mirrors or lenses, also known as solar collectors, are used to concentrate the sun’s rays. The tracking system is functional to keep the collectors aligned toward the sun's direction, thereby increasing the solar output. The receivers are used to capture the concentrated solar rays, which will be used to heat the heating fluid to extend the operation time during the night. The condenser can be used in the CSPWDS system to condense the steam that is generated from the copper receiver to produce fresh water, as shown in Fig. 2.

These inlet and outlet pipes in Fig. 2 are isolated by insulating glass wool to reduce heat loss. The process of passing water through the pipes will produce dry steam. This is done by concentrating sunlight on it and then generating heat up to more than 800°C. This steam will branch into two paths after passing by a turbine. The first one will pass through a heat exchanger that condenses the steam and thereby produces fresh water. The second one will operate an electricity generator.

Table 1. Specification of fresnel

Lens. Specification	Value
Size	90 cm (height) × 67.5 cm (width)
Estimated power	8.9 W
Beam's type	Spot
Beam size at maximum power	4 ”nch (2.7" outer area 900 F)
Focal length	26 inches
Weight	12 lbs
Maximum climbed temperature	1790 F (IR thermometer)
Maximum temperature	2007 F
Material tested	Water = 12oz. boils 80 sec. Wood =flame 0.1 sec Zinc = melts .5oz –4 grams - 12 sec. * 3–1 grams - 7 sec Concrete = glow 15 sec. exposure, melt 35 sec Glass ” me¼”1" × 1/4" brown glass 17 sec

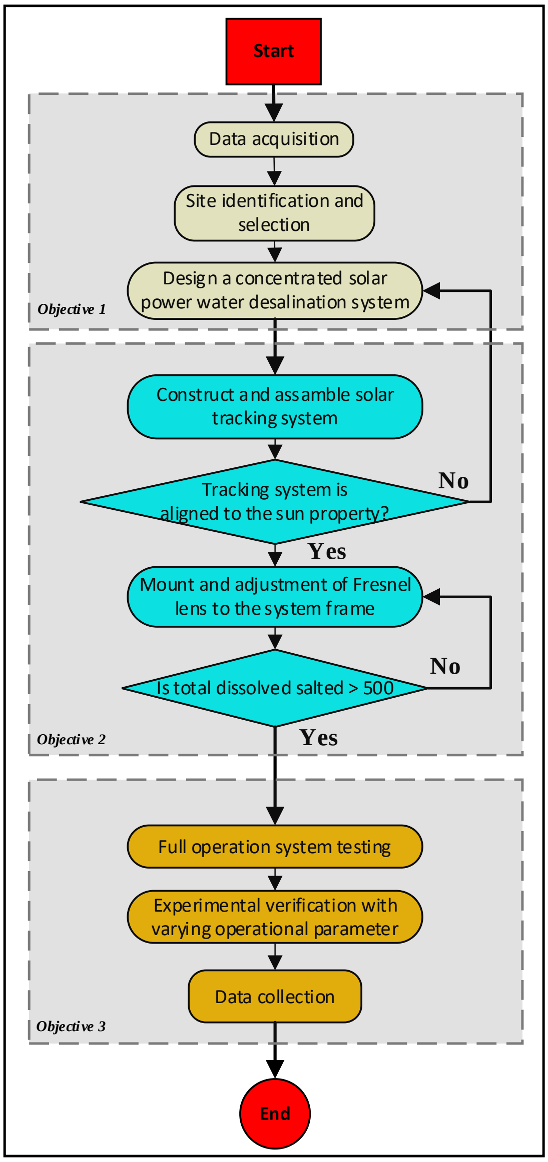


Fig. 1. Flowchart of overall research

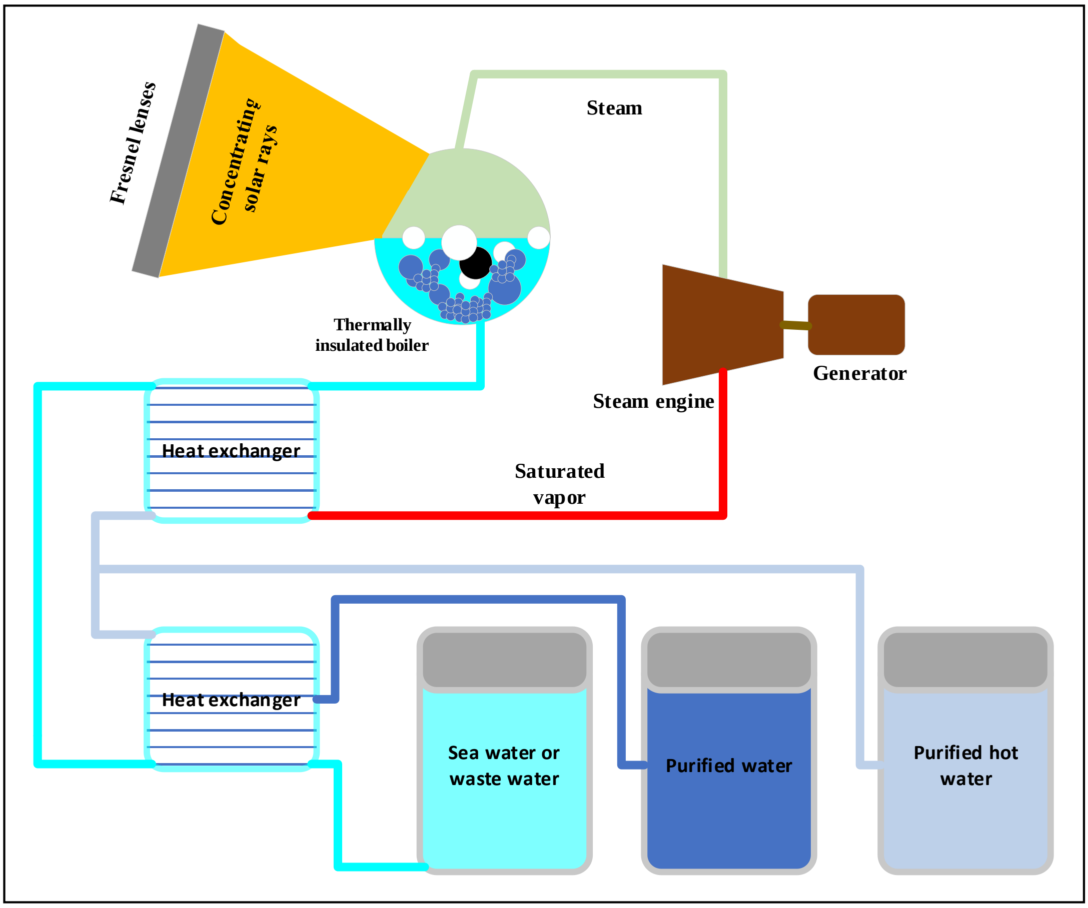


Fig. 2. Block diagram system of experiments conducted in desalination using FL

2.2. Working Mechanism of The Proposed CSPWDS

Table 2 shows the working process of the proposed system begins with aligning the tracking system to match the highest intensity of sunlight, determined by the geographical location on the map in terms of azimuth and altitude. Subsequently, water is stored in a special tank that is installed at a specified height. Due to the water column weight, water will flow through the system into the copper receivers. As the water reaches 100°C, it evaporates into steam. This steam is then directed into a turbine to generate the electricity, depending on the pressure that enters the turbine. The turbine rotates when the steam pressure entering the turbine exceeds 2.5 bar; otherwise, the system waits until the steam reaches the right temperature and then the required pressure needed to rotate the turbine and generate 24 V of electricity, driving the generator. The rotation of the turbine will result in steam condensation. The condensation water can be used for drinking, as depicted in Table 2. The subsequent section explains in detail the works that were done to complete the improved design of the CSPWD system.

2.3. System Design

The proposed system in this work consists of the following. The water tank capacity ranges from 50 to 150 ml; it has a check valve to prevent water from returning to the tank, an aluminum frame, a heat exchanger, copper-pipe receivers, angle valves, four Fresnel lenses, a steam turbine, and a small generator.

2.4. Fresnel Lens

The Fresnel lens is a cheap CSP device that is used in solar applications, especially in tropical weather, in water desalination, as shown in Fig. 3. The production rate of drinking water is directly proportional to the number of Fresnel lenses. The more Fresnel lenses used, the larger number of hot spots required. A multiple Fresnel lens system produces higher evaporation of feed water than using a single Fresnel lens because of the increased number of hot spots.

Table 2. Water-to-steam energy generation process with safety and quality controls

```
Start

  // Step 1: Water flows into the system
  Water will flow into the system

  // Step 2: Water passes through the receiver
  Water passes through the receiver

  // Step 3: Delay
  Wait for a short delay

  // Step 4: Check if steam is generated
  If Steam is generated then:

    // Step 5: Check if turbine pressure is greater than 2.5 bar
    If Turbine pressure > 2.5 bar then:
      Rotate Generator
      Stop
    Else:
      Stop
  Else:

    // Step 6: Check if focal point is very hot
    If Focal point is very hot then:
      Adjust Fresnel Lens

      // Step 7: Check if temperature is greater than 100 C
      If Temperature > 100°C then:

        // Step 8: Check if TDS is greater than 500 mg/l
        If TDS > 500 mg/l then:
          Direct water to Tank
          Stop
        Else:
          Stop
      Else:
        Stop
    Else:
      Delay
      Stop

End
```

Choosing the parameters for a Fresnel lens involves understanding both the application requirements and the optical properties of the lens itself. Applications such as magnifiers, projection systems, and solar concentrators use the Fresnel lenses depicted in Fig. 3. The optical parameters that need to be considered are focal length (f), which is the distance from the lens to the point where it focuses light, whereby it defines whether the lens will converge or diverge the light. The second parameter, lens diameter (D) of Fresnel lens, affects the amount of light it can capture and its overall size. A larger diameter generally improves light-gathering ability but may be less practical in terms of space. Typical lenses are made from optical-grade acrylic or polycarbonate. The choice of material affects the lens's durability, optical clarity, and cost.

A first prototype model shown in Fig. 4 consists of one Fresnel lens with concentric grooves that can focus the light source onto a single point, i.e., a focal point. Each lens used in the system is of dimension 850 mm × 1100 mm. Thus, the system occupies an area almost equal to 1 m × 1.2 m. In this system, the spot Fresnel lenses are used with concentric grooves so we can focus the light source onto a point and maximize the heat trapped rather than distributing it with a linear Fresnel lens. This design maximizes the efficiency and minimizes the area needed for the entire system. The frame plays a major role in providing a supporting structure to the entire system. A glass cover has been used to minimize heat loss and trap heat inside the enclosure.

By using aluminum, it was possible to reduce the frame weight by a factor of 20 compared to the case with a steel frame, as shown in Fig. 5 and Fig. 6. This great weight reduction allowed us to easily design an affordable tracking system with less need for electrical power. Moreover, with large Fresnel lenses, a temperature of over 1000 ºC at the focal point can be achieved. The capacity of the water tank used is between 50 and 150 ml, as shown in Fig. 7. The copper-pipe receiver is the main part of the system, which converts water into steam as shown in Fig. 8. It consists of copper pipe, a glass cover, pipe insulation, and a received wooden base. Copper receiver shown in Fig. 9.

Fig. 3. Fresnel lens (1 unit)

Fig. 4. First prototype of CSPWD system

Fig. 5. Four fresnel lenses in series

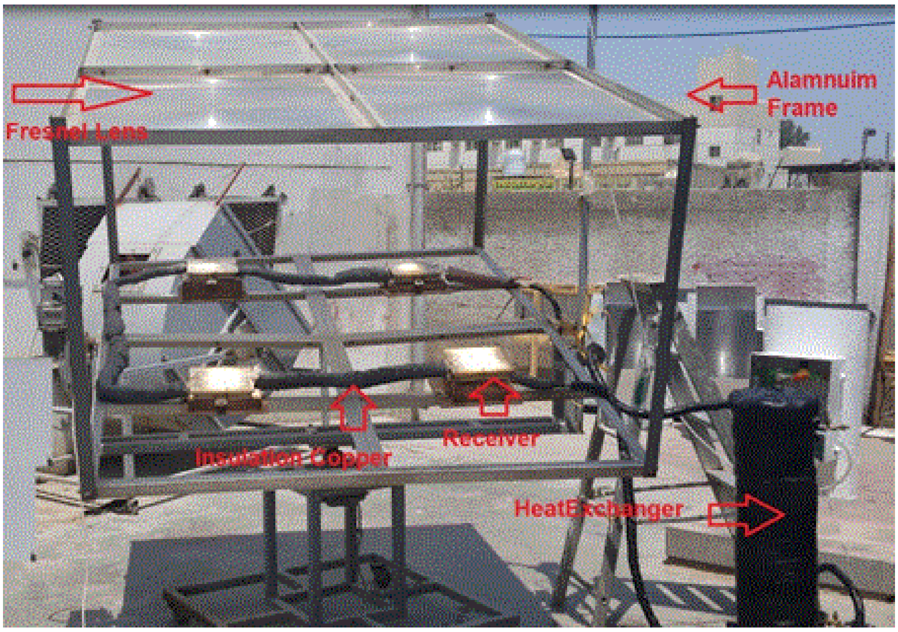


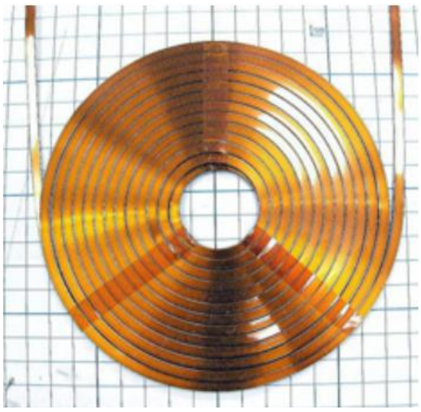
Fig. 6. Final prototype model with four large fresnel lenses and four copper receivers for CPWD system

Fig. 7. Water tank

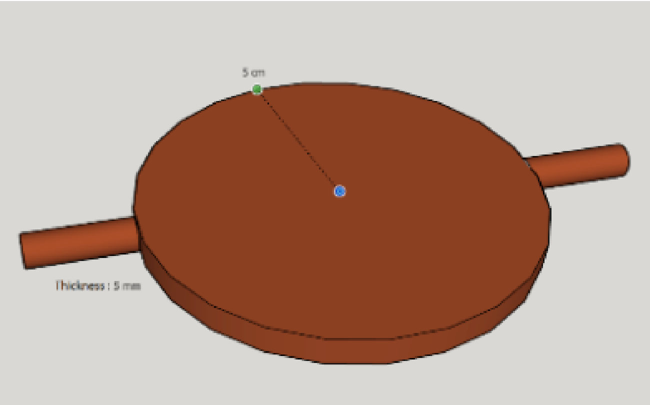
The proposed CSPWDS system uses two types of copper receivers. The system, consisting of four Fresnel lenses, employs four copper receivers to enhance their efficiency. Each receiver is located at the focal point of each lens. It is expected that the high thermal conductivity of copper improves the efficiency of the system over other affordable materials. However, one must insulate its base for the same purpose. The two proposed types of receivers are shown in Fig. 10. The first one is a spiral copper tube of diameter 5 mm, as shown in Fig. 10 (a) and the second one is a cylindrical shaped copper receiver of diameter 100 mm and thickness of 30 mm as shown in Fig. 10 (b). The third one is a practical receiver that was used in the research implementation as shown in Fig. 10 (c). Check valve is a device which is used to prevent water to return water to tank as shown in Fig. 10.

Fig. 8. Check valve

Fig. 9. Copper receiver



(a)



(b)

(c)

Fig. 10. Proposed copper receivers, (a) spiral copper tube and (b) solid round disc (c) insulated copper receivers

2.5. Cover Glass

The cover glass is used to enclose the receiver to minimize the heat losses and trap the heat inside the enclosure. The glass can also be painted black on the inside to prevent the heat from escaping, thereby creating a "greenhouse effect" as shown in Fig. 11.

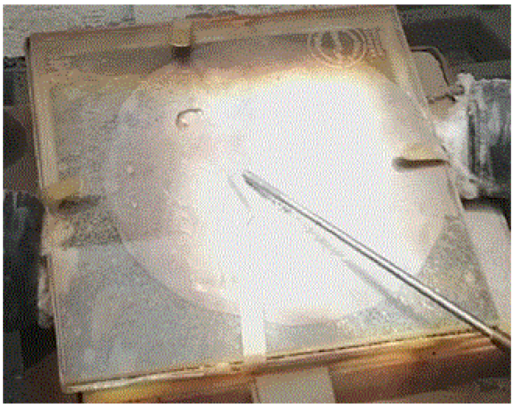


Fig. 11. Layout frame of cover glass

2.6. Heat Exchangers

Heat exchangers are devices that are capable of allowing heat to transfer between two fluids that are maintained at different temperatures without mixing, as shown in Fig. 12. These exchangers are used in a wide range of devices, such as heating and cooling systems, chemical processing, and power production plant facilities, as shown in Fig. 13.

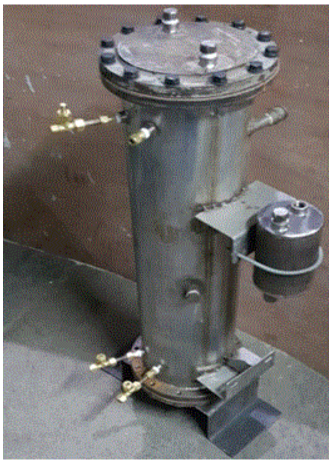


Fig. 12. System heat exchangers

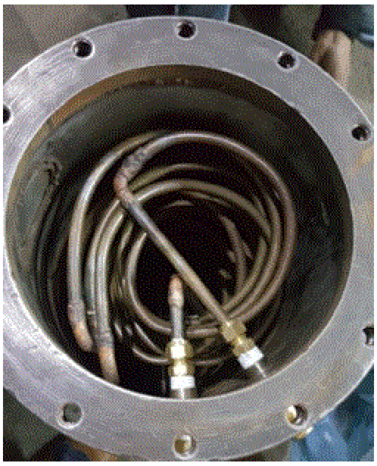


Fig. 13. The inside of the system heat exchangers

The main Basic Heat exchanger equation applies to all types as follows (1):

$$\Delta T_m = \frac{\left((T_1 - t_2) - (T_2 - t_1)\right)}{\ln(T_1 - t_2)\,(T_2 - t_1)} \tag{1}$$

Where,

Q : is Heat Transfer Rate (kJ/h) or (BTU\h)

A : is Heat Transfer Area (m^2) or (ft^2)

ΔT_m : is logarithm of the mean Temperature difference (kJ/h.m^2. °C) or (BTU/h°F); and

U : is Overall Heat transfer coefficient (Celsius or Fahrenheit)

2.7. Fresnel Lens Basics

Fresnel Lens: A Fresnel lens is an optical device designed to capture and focus light efficiently, originally developed for use in lighthouses to research light over long distances. It consists of a series of concentric, thin rings that reduce the amount of material needed compared to a traditional lens while maintaining a similar focusing capability. The geometry of these rings allows for precise control of light refraction, enabling the lens to concentrate light into a narrower beam. The size of a Fresnel lens directly impacts its light-gathering ability; larger lenses can collect more light, which is crucial for applications requiring significant intensity, such as solar energy collection or illumination. The effectiveness of a Fresnel lens is not solely dependent on its diameter but also on the configuration and spacing of its concentric rings, which determine its focal length and efficiency in focusing light. Consequently, the selection of lens size and design is critical in applications where optimal light concentration is necessary, such as in solar desalination systems, where maximizing solar energy capture directly influences the efficiency of water evaporation and subsequent desalination processes.

2.8. Solar Radiation

Solar radiation is the electromagnetic energy emitted by the sun, characterized by a spectrum that includes visible light, ultraviolet, and infrared wavelengths. This energy reaches the Earth's surface, typically quantified in watts per square meter (W/m^2), which serves as a standard measure of solar irradiance. A Fresnel lens enhances the utilization of this solar radiation by concentrating sunlight onto a smaller area, effectively increasing the intensity of the solar energy at the focal point. The lens achieves this through its unique design of concentric grooves, which refract incoming sunlight, redirecting it towards a common focus. By focusing the sunlight, a Fresnel lens can greatly increase the energy at the focal point—often much higher than the normal sunlight—making it more effective for things like solar heating systems or solar panels. This increased intensity can lead to higher temperatures for thermal processes or improved electrical output for solar panels, making Fresnel lenses a valuable component in solar energy harvesting technologies.

3. Heat Transfer and Experimental Results

This research explains the system analysis and experimental results of the proposed desalination system. It is divided into four sections. The system operation parameter and experimental result, the electricity generated using the Fresnel lens and steam turbine, and presentation analysis of the result of the Fresnel lens system. The analysis of the real results from the desalination system aims to find the best design by understanding how well each part works, including the Fresnel lens, heat exchanger, copper pipe receiver, system insulation, steam turbines, and small generators, as shown in Fig. 14.

3.1. The Specifications of Glass Used in the System

Concerning flow rate influence, Table 3 illustrates a systematic increase in flow rates from 0.09 to 0.15 liters per minute. Notably, as the flow rate increases, there is a corresponding rise in both useful energy input (QU) and thermal efficiency (Qu/J). This evidence suggests that higher flow rates positively impact the efficiency of the solar desalination process. On the other hand, the ambient and steam temperatures show that the relationship between ambient temperature and steam temperature is evident in the data. As the local time progresses, there is a general upward trend in both temperatures, reflecting the influence of solar radiation on the heating process. Moreover, wind speed is a crucial factor affecting the thermal efficiency of the system. Instances where wind speed is higher, such as at 12:30, show a decrease in thermal efficiency. This result indicates that increased wind speed may contribute to heat losses, impacting the overall performance of the solar desalination system. The values of heat capacity (CP) remain constant throughout the experiment. Such behavior suggests that the system maintains a consistent ability to store and transfer thermal energy, ensuring stable performance under changing conditions. The variation in thermal efficiency over time provides valuable insights into the system's performance throughout the day. Peaks in thermal efficiency correspond to optimal conditions, while decreases may be attributed to factors such as weather conditions and wind speed.

Fig. 14. Four fresnel lenses are arranged in series in the field location, Sharjah UAE

Table 3. Specifications of glass

Specification	Value
Heat resistance temperature	1823 F
Chemical temperature	450 F
Size thickness	02 inch to 0.125 inch
Pyrex Glass temp	450 F to 914 F
Pyrex Size thickness	0.02 inch to 2.25 inch
Pyrecrem glass	1300 F to 1427 F
Pyrecrem thick	0.2 inch
Quartes Glass	1700 F to 2200 F
Pyrex Glass temp	450 F to 914 F
Pyrex Size thickness	0.02 inch to 2.25 inch
Tempered Glass temp	450 F
Tempered Size thickness	0.125 inch to 1.0 inch
Vycro Glass temp	1700F to 2200 F
Vycro Size thickness	0.125 inch to 0.75 inch

The heat transfer equation in Joules is calculated from the following (2):

$$Q = mC_p\Delta T \quad (2)$$

Where:

Q : Heat energy transferred, in Joules (J)

m : Mass of the liquid being heated, in grams (g)

Cp : Specific heat capacity of the liquid, in Joule per gram degree Celsius (J/g°C); and

ΔT : Change in temperature of the liquid, in degree Celsius (°C)

Now since it is known that power is the rate of change of energy, then received power by the Fresnel lens is found from:

$$P = \frac{Q}{t} = \frac{mC_p\Delta T}{t} \quad (3)$$

If the time taken to increase the temperature from an initial value, T_o, to a final value, T_f is measured, the incident energy and power can easily be calculated. Thus, the gained output ratio is then found using (3).

A 500 g of salty water was tested through the system that consists of four large Fresnel lenses. The initial temperature of the water was $T_o = 25^oC$. The temperature was raised to $T_f = 115^oC$ in 5 minutes, and only 100 g of water were consumed in this phase. The experiment took 15 minutes to completely evaporate the total 500 g of water. Hence, the received energy and power by the four lenses can be calculated as follows. The energy needed to raise the temperature of the 500 g of water from $T_o = 25^oC$ to $T_f = 100^oC$ is (4):

$$Q_1 = 500 \times (100 - 25) \times 4.184 = 156{,}900\ J \quad (4)$$

The energy to convert the 500 g from water at $T = 100^oC$ to steam at $T_f = 100^oC$ is (5):

$$Q_2 = 500 \times 2260 \frac{J}{g} = 1{,}130{,}000\ J \quad (5)$$

The energy to convert the 500 g from a steam of T = 100oC to steam at Tf = 115oC is (6):

$$Q_3 = 500 \times 2.03 \times (115 - 100) = 15{,}225\ J \quad (6)$$

The total energy is (7):

$$Q_t = Q_1 + Q_2 + Q_3 = 1{,}301{,}225 \quad (7)$$

Hence, the received power of the system is (8):

$$P_t = P_1 + P_2 = 868 + 1735 = 2603\ W \quad (8)$$

One of the biggest limitations from an engineering perspective is the difficulty in modeling the complete system into a set of equations. For high theoretical efficiencies, it can be assumed that the receiver does not absorb any heat but fully transfers it to the working fluid.

3.2. Chart Interpretation

In a chart comparing Fresnel lens size with solar radiation and electrical power, typically the following components: X-Axis (Horizontal) which represents the size of the distance from Fresnel lens and Y-Axis (Vertical) which could represent the amount of solar radiation concentrated by the lens, often measured in watts or energy density (W/m²) as shown in Fig. 15. Electrical power of the lens, often measured in watts or energy density (W) as shown in Fig. 16.

3.3. Lens Size and Solar Concentration

A larger Fresnel lens can collect and focus more solar radiation due to its greater surface area. This means it can potentially concentrate more solar energy. Smaller Fresnel Lenses: A smaller lens has less area to collect light, so it focuses less solar energy compared to a larger lens. Before Concentration: The chart may show the baseline solar radiation level (incident solar radiation) before the lens focuses it. After Concentration: It will also show the increased intensity of solar radiation at the focal point of the Fresnel lens as shown in Fig. 15. This value is higher because the lens

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concentrates the light into a smaller area. As the size of the Fresnel lens increases, the concentrated solar radiation may increase linearly or predictably, demonstrating a direct correlation between lens size and solar energy concentration, as illustrated in Fig. 16. There could be diminishing returns if the lens size becomes excessive relative to the area being focused, due to practical limits in focusing efficiency or losses in the optical system. As shown in Fig. 16 Larger Fresnel lenses are more efficient at concentrating solar radiation, which can be useful for solar thermal applications or solar power generation. When designing a system that uses Fresnel lenses, understanding this relationship helps in selecting the right size lens for the desired concentration and energy output PLED as shown in Fig. 17 and Fig. 18.

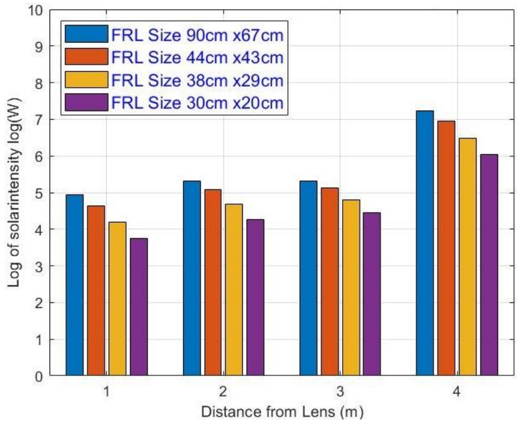

Fig. 15. Effect of fresnel lens on solar intensity power

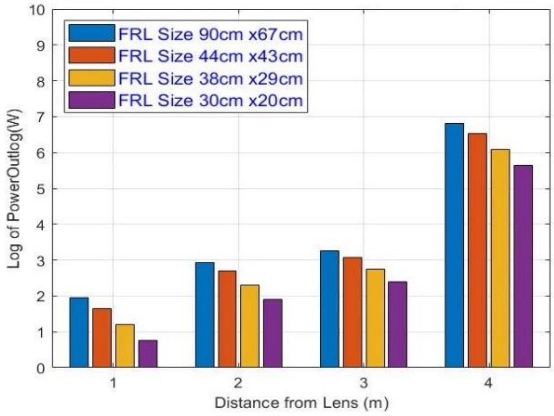

Fig. 16. Effect of fresnel lens on electrical power

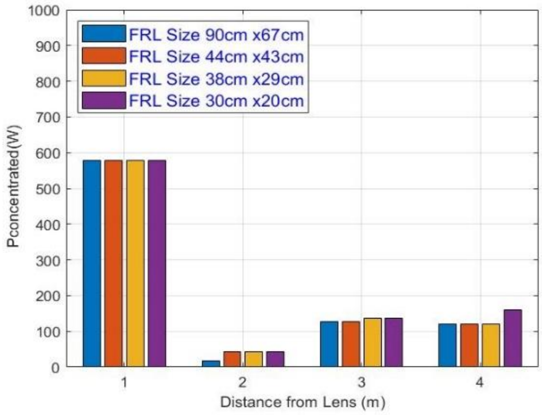

Fig. 17. Effect of fresnel lens on $P_{concentrated}$

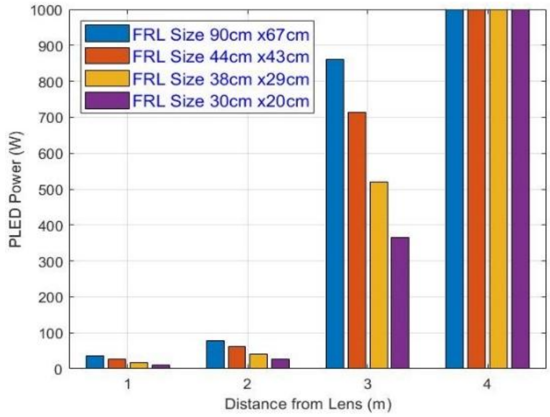

Fig. 18. Effect of fresnel lens on PLED

Table 4 encapsulates the experimental results of our solar desalination system, offering a detailed snapshot of its performance under varying conditions. The data highlights the influence of flow rates, ambient and steam temperatures, wind speed, and heat capacity on the system's efficiency. This analysis serves as a foundation for refining and optimizing the solar desalination process, paving the way for the development of more effective and sustainable freshwater production systems.

Fig. 19 illustrates the relationship between the final steam temperature and local time based on the measured data listed in Table 3. No measures have been taken outside this time period since the solar temperature is not sufficient to produce steam at the required high temperature, which is necessary to perform saltwater desalination.

It is observed from Fig. 19 that the output temperature of the water (Tempout) is increased with the time start 10.00 am morning till 12.00 pm reach maximum, then the temperature is decreased. For example, when the time 12.00 pm, the temperature measured is 120 degrees Celsius.

Table 4. Experimental results

Local time	Flow rate (liter/ minute)	Ambient temperature (ºC)	Steam temperature (ºC)	Wind speed (m/s)	CP	QU /joules	Qu/J
10:30	0.09	44.50	95.00	12.20	4.182	105595.5	105595.5
10:45	0.10	45.10	96.00	10.80	4.182	106431.9	106431.9
11:00	0.11	44.80	100.00	12.60	2.03	1130000	1130000
11:15	0.12	45.10	110.00	12.20	2.03	10150	1352177.4
11:30	0.13	44.80	116.00	14.80	2.03	16240	1358267.4
11:45	0.15	44.60	117.00	13.00	2.03	17255	1359282.4
12:00	0.15	45.10	119.00	12.80	2.03	19285	1361312.4
12:15	0.15	44.80	119.00	12.50	2.03	19285	1361312.4
12:30	0.15	44.60	119.00	18.4	2.03	19285	1361312.4
12:45	0.15	44.50	115.00	15.8	2.03	15225	1357252.4
13:00	0.14	44.50	115.00	16.6	2.03	15225	1357252.4
13:15	0.13	44.50	115.00	17.6	2.03	15225	1357252.4
13:30	0.12	44.50	115.00	16.9	2.03	15225	1357252.4
13:45	0.11	44.50	112.00	18.7	2.03	12180	1354207.4

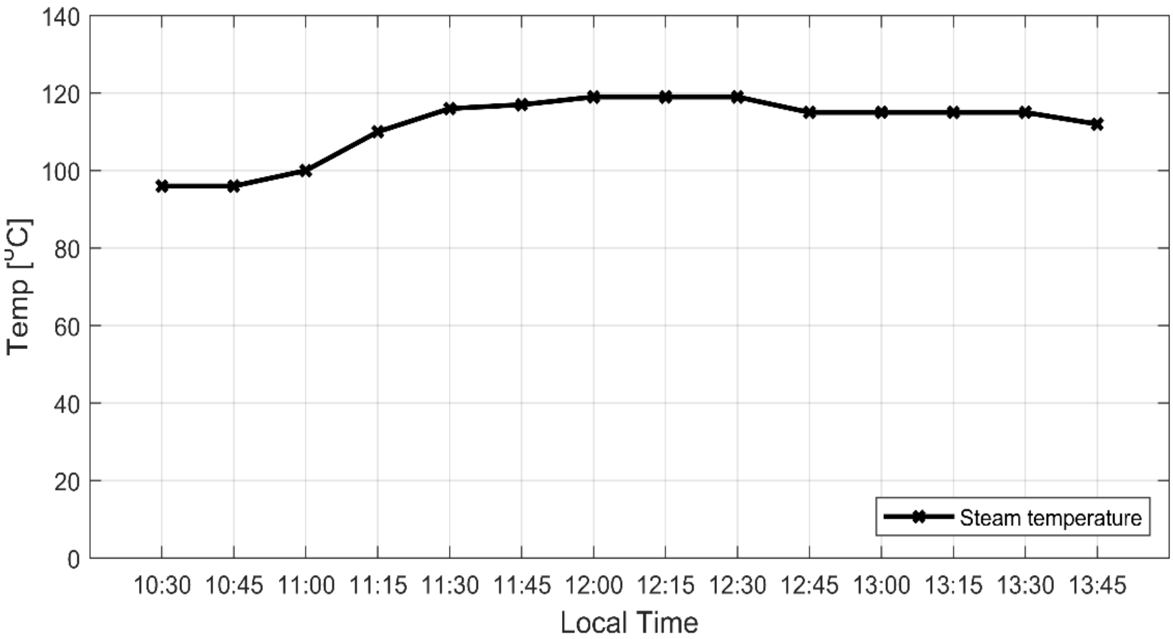

Fig. 19. Output steam temperature (TempOut) versus local time (hours)

It is observed from Fig. 20 that the energy is increased with the increasing of the Tempout starting from 10.00 am (morning) until 11.00 am, reaching maximum energy, and then the energy stays at the same value. For example, at 11.00 pm, the temperature is 120 degrees Celsius, energy Qu=1352477 joules and stay Qu=1360000 joules approximately.

It is observed from Fig. 21 that the flow rate is increased with the increasing of Tempout starting from 10.00 am in the morning until 12.00 pm, reaching the maximum flow rate. The flow rate stayed at the same value after 12.45 pm. The flow rate remains at the same value as the flow rate; this value is given a constant mass flow, which provides a constant flow rate of the resulting fluid even if the measured volume changes due to pressure or temperature changes. After that, the flow rate drops, and the liquid can't be turned to steam due to low pressure.

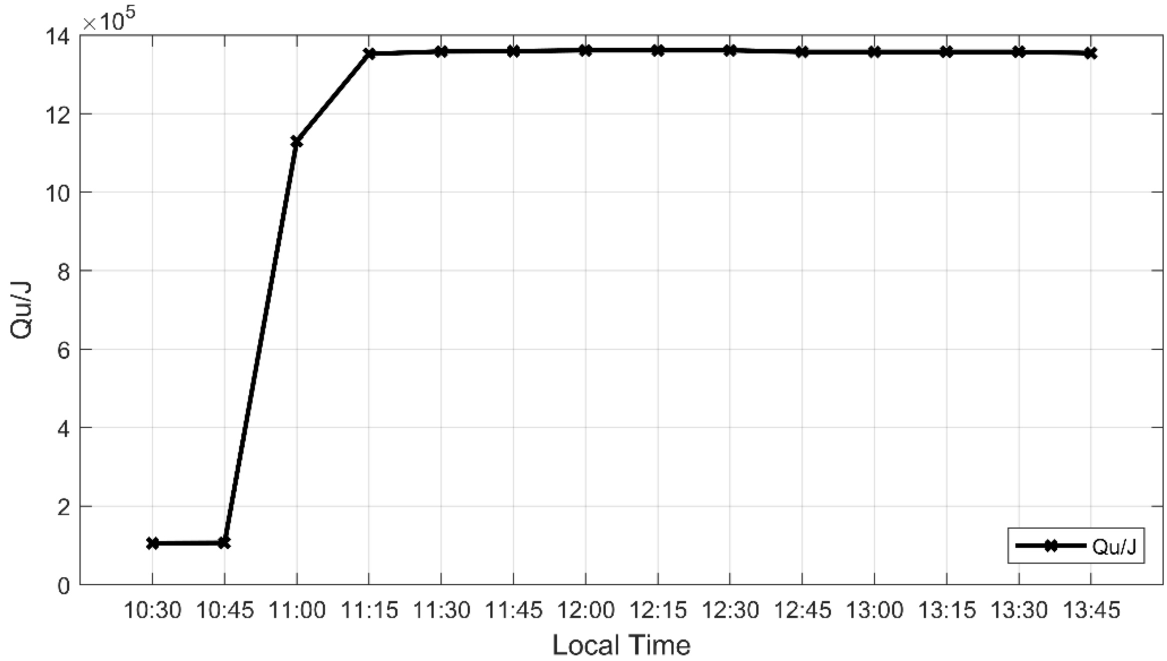

Fig. 20. Output temperature in relation to Qu

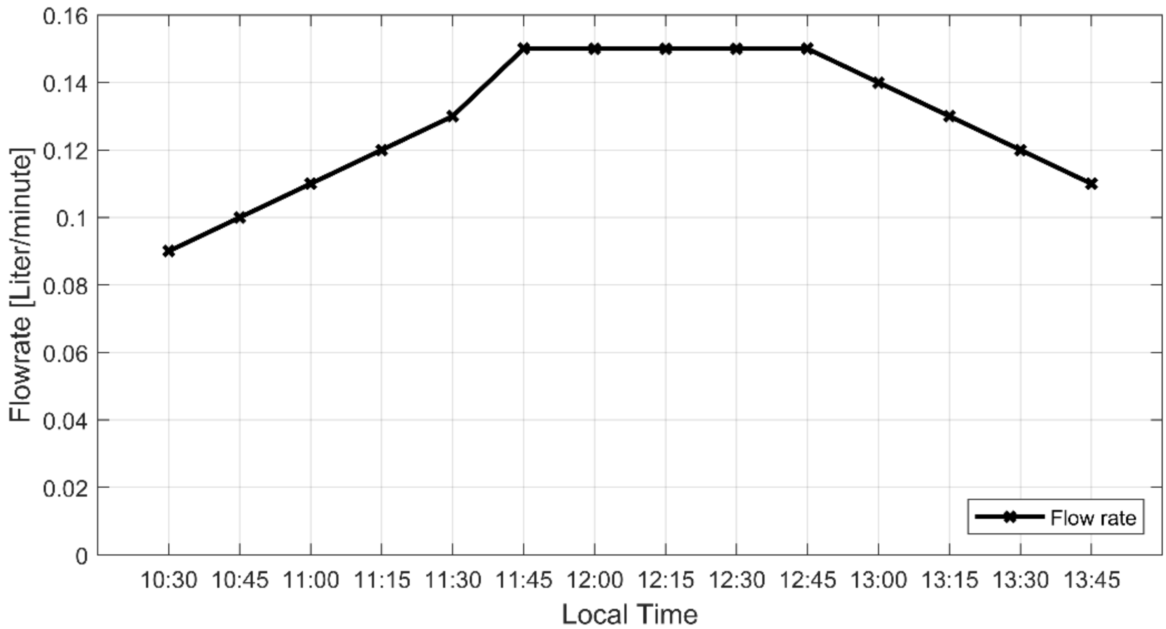

Fig. 21. Flow rate versus time

4. Conclusion

Worldwide freshwater demand continues to grow because population increases and water scarcity problems become more severe. The extensive coverage of seawater across Earth's surface becomes impractical for direct consumption due to its high salinity content, therefore requiring proper desalination solutions. Classical desalination methods require costly procedures that make them unfeasible for regions with limited resources. The research evaluates solar desalination systems powered by Fresnel lenses and copper receivers as a sustainable and economical desalination method.

The study reached its essential three objectives, which advanced the development of solar desalination technology. Traditional desalination system performance received an enhancement through the use of Fresnel lenses in place of reflective mirrors, which simultaneously enabled the development of new technology. Larger Fresnel lenses enabled the researchers to reach steam temperatures above 1000°C that resulted in raising steam pressure to about 8 bar. This upgraded system surpassed regular mirror-based systems because it operates at much higher temperatures, exceeding 70°C. The fusion of Fresnel lenses and copper receivers advances small-scale solar desalination technology by creating an efficient system that produces water and electrical power at the same time.

The second objective aimed to identify proper operational parameters that included flow rates together with environmental variables for the system. The peak steam temperature was confirmed to appear during local noon hours. Experimental data revealed the ideal copper receiver dimensions as 7 mm outer diameter and 6.12 mm inner diameter. Similarly, molten sand provided efficient insulation of the copper receiver, and rubber insulation on the copper pipes effectively helped sustain temperature equilibrium. The discovered details help the system designers to create improvements for future operational efficiency.

An electric current of 775 mA successfully operated an LED lighting system, indicating that the dual functionality of the system was achieved. The research shows Fresnel lenses act as a viable means to enhance both pressure levels and quality standards of steam to achieve efficient water desalination and power generation. Research shows that Fresnel lenses produce steam beyond what mirror-based systems achieve, which thus creates new opportunities for more economical and environmentally friendly desalination solutions.

The findings from this research indicate that solar desalination systems are crucial in areas without power grids and where water is scarce, as they provide both fresh water and electricity, improving security in both areas. The integrated system functions for both water purification and power generation purposes, thereby establishing sustainable water and electricity services specifically for households distant from centralized power grids.

Future development strategies will enhance the system's operational efficiency. When the system incorporates larger Fresnel arrays and integrates with photovoltaic panels, it will achieve additional efficiency benefits. Improving the system's reliability and extending its lifespan necessitate better solutions to mitigate environmental factors that contribute to dust accumulation and solar radiation variability. To assess the overall adoption potential, researchers must investigate the economic feasibility of scaling up the technology for rural and isolated locations. This research demonstrates the effective implementation of Fresnel lenses and copper receivers in solar desalination systems, resulting in improved electrical power generation and heat efficiency. These advancements signify a major breakthrough in the field, offering promising avenues for more sustainable and cost-effective future desalination solutions.

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