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Implementation of Solar Photovoltaic and Solar Dish Concentrator-Based Seawater Desalination System for Meeting Clean Water Needs - A Case Study in a Drought Prone Area in Indonesia

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***Abstract*—Water is an important resource for the survival of all living organisms. However, there are still many villages in coastal areas that lack clean water due to drought. This study explores the implementation of a solar desalination system using solar photovoltaic (PV) panels and a solar dish concentrator to address clean water needs in a drought-prone area in Indonesia. The system combines solar-generated electricity and concentrated solar heat to power a desalination device, converting seawater into potable water. During a seven-day trial, the device achieved an average boiler temperature of 405.9°C, enabling efficient water vaporization for desalination. The system produced 1300 ml of clean water every 30 minutes, totaling a daily yield of 23.4 liters under optimal sunlight conditions. The test showed a pH reduction from 8 (seawater) to 6.1 (desalinated water), moving the water into a safer range for human consumption. Additionally, electrical conductivity dropped from 36 milliseconds to 400 microseconds, indicating a significant reduction in salinity. These findings demonstrate the system's capability to produce clean water sustainably, supporting circular economy principles by reusing and optimizing renewable energy resources for water desalination in water-scarce areas.**

Keywords*—*Clean Water, Drought Area, Seawater, Solar Photovoltaic, Solar Dish.

I. INTRODUCTION

Water is an essential resource for the survival of all living organisms. Access to clean water has become increasingly critical, considering that each individual requires a minimum of 140-90 liters daily for basic needs [1]. In recent years, rapid population growth in urban and rural areas has led to a substantial increase in the demand for clean water [2-3]. Many communities in remote areas, particularly rural areas, often rely on natural water sources such as springs, rivers, and lakes [4-5]. These sources are frequently used without adequate treatment, posing a high risk of contamination from pollutants or pathogenic bacteria harmful to human health [6]. Furthermore, climate change causes longer and more intense dry seasons, further constraining the supply of clean water [7-8].

The issue of clean water scarcity is becoming increasingly concerning. Many regions, particularly coastal areas, are experiencing severe clean water crises [9-10]. These areas face substantial challenges in accessing clean water, with numerous villages across Indonesia struggling to obtain safe drinking water. The availability and accessibility of clean water for communities continue to deteriorate over time [11]. Given the extensive impact of this water crisis, it is crucial to devote serious attention to identifying effective solutions to address this pressing problem.

Natural water sources are increasingly diminishing, and the cost of obtaining processed clean water continues to rise [12]. For impoverished communities in coastal areas, purchasing clean water at high prices imposes a significant economic burden. This situation highlights the inequitable access to clean water resources, which should be a fundamental right for all individuals. Addressing the challenges of the clean water crisis requires innovation in water resource management [13-14]. Many communities are unable to treat seawater for safe use due to limited access to available technology [15-17].

Desalination systems are methods used to convert seawater into freshwater suitable for consumption [18-19]. This process involves the evaporation of seawater and the subsequent condensation of steam into clean water, leaving behind salt and other dissolved substances [20-21]. This study develops an innovative water treatment approach by implementing a Solar Desalination Machine, a desalination technology that integrates solar panel technology with a solar dish concentrator. This system is anticipated to serve as a solution for fulfilling clean water needs in communities, especially in regions facing similar challenges. The use of environmentally sustainable and efficient technologies is expected to enhance communities' access to clean water, making it more affordable and readily available.

II. LITERATURE REVIEW

Freshwater is becoming an increasingly scarce resource, especially in remote areas. This study aims to explore various seawater desalination technologies that leverage renewable energy. By analyzing the performance of solar-powered systems, it is intended to offer an effective and efficient solution to mitigate the issue of clean water scarcity. The first study evaluated the performance of a seawater desalination system powered by photovoltaic panels and innovative solar thermal concentration. This system used preheating of water with PV panels, integrating a thermal recovery system and a parabolic concentrator to improve the efficiency of the reverse osmosis (RO) process. Findings showed that using a preheating unit reduces the specific power consumption (SPCRO-PX) by 24.33–35.79% for brackish water and 18.69–22.87% for seawater. Additionally, the cost of freshwater can be reduced by up to 33.1%, making this technology an efficient option for applications in remote areas [22].

The second study developed a small-scale seawater desalination system using a combination of a parabolic dish and a solar still. The system consisted of a parabolic dish with a 1.46 m diameter and a solar still measuring 33x19x29 cm, positioned at the dish's focal point. The dish was coated with aluminum foil, providing 0.88 reflectivity to concentrate solar radiation onto the solar still. Testing results show that this system reduces pH by 7.28%, hardness by 99.29%, chloride by 98.75%, and total dissolved solids (TDS) by 99.79% from seawater. Although effective in purification, this system produced only a small amount of distillate (65 ml), indicating that further development is necessary to enhance its productivity [23].

The third study investigated a solar-powered seawater desalination system utilizing a hyperboloid concentrator and helical copper coil. This system consisted of an evacuated tube collector (ETC), a parabolic dish concentrator (PDC), and a hyperboloid concentrator (HBC). The hyperboloid concentrator was specifically designed to collect radiation at wide incident angles without requiring tracking. Results showed that the system can produce high-quality drinking water with a salt concentration of 190 PPM from seawater with a salinity of 35.07 ppt within 3 hours, yielding 300 mL of pure water. The system's efficiency was improved by 30% compared to conventional PDCs, with a maximum output temperature of 109°C [24]. The subsequent study examined an innovative solar parabolic dish desalination system. This system incorporated a novel design for solar distillation installed at the focal point of the parabolic dish, and the study details both experimental and theoretical approaches. Modeled mathematically, the system demonstrated promising potential for small- to medium-scale desalination, especially in remote regions lacking freshwater resources. Findings indicated that the collector's optical efficiency and the size of the absorber plate significantly affect the volume of desalinated water produced, while other operational parameters, such as initial temperature and salinity, have a more limited impact [25].

These studies highlights the substantial potential of seawater desalination technology through innovative approaches. Each tested system demonstrated significant efficiency in reducing energy consumption and costs, offering promising prospects for meeting sustainable water needs in the future.

III. Methodology

The research methodology used in this study is Research and Development (R&D), which excels in fostering innovation, testing practical applications, and advancing technology through a systematic and structured research-based approach [26]. This method aims to develop and test seawater desalination technology powered by renewable energy. The study involves analyzing various systems that integrate photovoltaic panels and thermal concentration, with a primary focus on the efficiency of the reverse osmosis process.

This study also employs a quantitative approach to demonstrate the scientific value and measurement strength of the product by conducting result data analysis [27]. The data obtained are then analyzed to assess the impact of various operational parameters on efficiency and cost. The stages of this study consist of five stages as shown in Fig. 1.

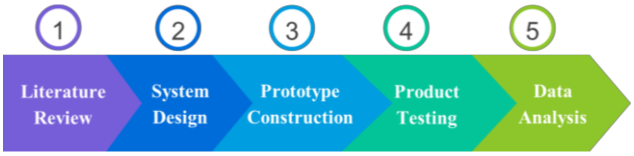

Fig. 1. R&D Methodology Stages

A. Literature Review

This study begins with a comprehensive literature review stage to establish a strong theoretical foundation. Journal papers and conference papers on renewable energy-powered desalination technologies were collected. These sources provided insights into existing systems' design and operational principles, highlighting innovations in solar energy utilization, thermal dynamics, and material selection. Particular attention was given to factors influencing desalination efficiency, such as integrating solar photovoltaic (PV) panels and thermal concentrators. The review informed the identification of best practices and technical challenges that guided subsequent stages of the research [28].

B. System Design

The design stage involved conceptualizing and modeling the desalination system, incorporating both solar PV panels and a parabolic dish concentrator. Computer-aided design (CAD) software was employed to create precise component models, ensuring optimal integration of system elements. Material selection prioritized components with high thermal conductivity and durability to withstand extreme temperatures typical of desalination processes. The design also emphasized modularity for ease of assembly and potential scalability for larger applications. The theoretical framework developed during this stage set the groundwork for practical implementation. In Fig. 2 there is a design of the product to be developed, namely solar photovoltaic and solar dish concentrator-based seawater desalination system for meeting clean water needs.

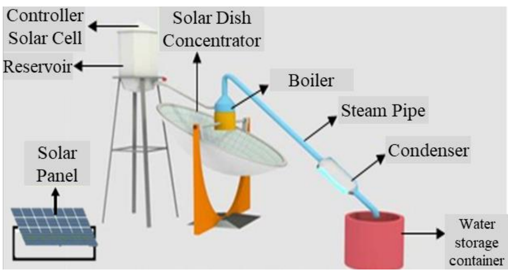

Fig. 2. Product Design

Each component has its function in the operation of this product. Completely, the function of each component can be seen in Table I.

TABLE I. COMPONENTS IN THE PRODUCT

No	Components	Function
1	Solar Panel	Converts sunlight power into electricity.
2	Controller	Manages the electricity generated by the solar panel, Regulates the distribution of power to the other components, monitors system performance, and stores data for analysis.
3	Solar Dish Concentrator	Maximizes heat concentration to rapidly heat seawater for initiating the evaporation process and enhances thermal efficiency by utilizing concentrated solar energy.
4	Boiler	Holds seawater, optimize evaporation, and converts it into steam using the heat provided by the solar dish concentrator.
5	Steam Pipe	Transfers the steam generated in the boiler to the condenser and Insulated to minimize heat loss during the transfer process.
6	Condenser	Cools down the steam to convert it back into liquid form (desalinated water) and removes impurities and salts as the water transitions from vapor to liquid.
7	Reservoir	Stores seawater before it enters the boiler and controls the supply of seawater to the system.
8	Water Storage Container	Collects the desalinated water after the condensation process.

According to the design in Fig. 2, the operational process begins with seawater flowing from the reservoir into the boiler. A parabolic heat concentrator is used to collect and focus heat at the base of the boiler, thereby heating the seawater. Simultaneously, a solar panel generates electricity through the conversion of sunlight, providing supplementary heating to the water. The electricity generated is regulated to optimize energy usage. Within the boiler, seawater undergoes an evaporation process, producing water vapor that is directed through a steam pipe to a condenser. The condenser then cools the vapor, converting it into fresh water, which is stored in a designated container.

C. *Prototype Construction*

The prototype construction stage was constructed using components sourced based on the design specifications. The assembly included critical elements such as the parabolic concentrator, boiler, condenser, and solar photovoltaic panel. Electronic components were integrated to regulate temperature and optimize energy usage. Special care was taken to ensure the accuracy of assembly and compatibility of components, as these directly impact the system's efficiency and reliability. This stage translated the theoretical design into a tangible working system.

D. *Product Testing*

This device was developed to convert seawater into potable water. The initial testing stage was conducted under controlled laboratory conditions to evaluate the system's thermal performance, evaporation rate, and condensation efficiency. Key parameters such as boiler temperature and condensation rate were monitored and analyzed. Iterative adjustments were made to optimize performance, addressing any shortcomings identified during testing. This phase ensured that the system met the theoretical expectations before being exposed to real-world conditions.

Following successful laboratory testing, the prototype was deployed in a drought-prone coastal area to evaluate its real-world performance. Field testing was conducted in one of the villages that often experiences a shortage of clean water in Indonesia, namely Jepitu village, Girisubo district, Gunung Kidul regency, Special Region of Yogyakarta.

Fig. 3 shows the completed device that is currently being tested. Field testing involved measuring environmental variables, including solar irradiance, ambient temperature, and humidity, which could impact desalination efficiency. The system's ability to produce clean water sustainably under varying climatic conditions was assessed. Data collected during this phase provided valuable insights into the system's practicality, efficiency, and potential for broader application.

Fig. 3. Product Testing

E. *Data Analysis*

Data from both laboratory and field testing were analyzed statistically to determine the system's effectiveness and identify areas for improvement. Performance metrics, including daily water output, energy consumption, and desalination efficiency, were compared against previous studies and technologies. This analysis informed the final recommendations for system optimization and potential commercialization.

IV. RESULTS

This chapter presents a detailed analysis of the performance metrics and experimental findings from the implementation and testing of the solar desalination system. The results are categorized into key performance indicators such as thermal efficiency, clean water production, pH of water, and electrical conductivity [29].

A. *Boiler Temperature Analysis*

The desalination system was subjected to a seven-day operational trial under real-world conditions to evaluate its thermal efficiency. As shown in Fig. 4, the boiler consistently maintained an average temperature of 405.9°C, which is indicative of the system's high thermal performance. The integration of the solar dish concentrator was pivotal in achieving such high temperatures, enabling rapid and efficient vaporization of seawater. This consistent thermal performance underscores the system's reliability in harnessing concentrated solar energy for the desalination process.

Fig. 4. Device Temperature Check

B. *Analysis of Clean Water Produced*

The desalination device demonstrated a robust capability to produce clean water. Fig. 5 shows the clean water yield derived from the output of this product. With a production rate of 1,300 mL per 30 minutes, the system achieved a total daily output of approximately 23.4 liters under optimal sunlight conditions (9 hours of sunlight per day). This level of output highlights the system's potential to meet the daily water needs of small communities in drought-prone areas. The high productivity is attributable to the synergistic effects of thermal and photovoltaic energy inputs, ensuring consistent operation during daylight hours.

Fig. 5. Clean Water Produced

C. *Analysis of pH of Desalinated Water*

The pH test was conducted to compare the chemical properties of seawater from a beach in Jepitu village, Girisubo district, Gunung Kidul regency with the desalinated water output. The pH of the desalinated water was analyzed to assess its suitability for human consumption as shown in Fig. 6. The coastal seawater used for testing exhibited a pH level of 8, indicating alkaline characteristics. Post-desalination, the pH was reduced to 6.1, aligning closely with the recommended range for potable water. This significant pH adjustment demonstrates the system's capability to improve water quality effectively.

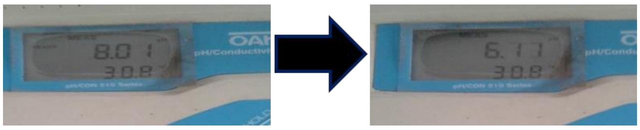

Fig. 6. pH Level Test

D. *Analysis of Electrical Conductivity of Water*

Electrical conductivity (EC) measurements were conducted to evaluate the desalination system's effectiveness in reducing salinity. According to Fig. 7, the raw seawater showed a high EC value of 36 mS/cm, indicative of elevated salt content. After processing, the desalinated water's EC value was markedly reduced to 400 µS/cm, reflecting a substantial decrease in dissolved salts. The results confirm that the system successfully produces water with low salinity, suitable for domestic and agricultural use.

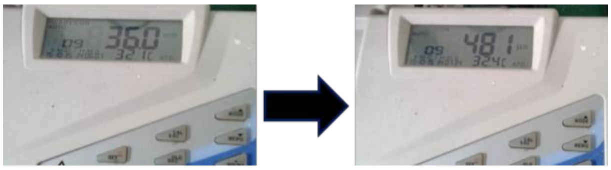

Fig. 7. Electrical Conductivity of Water Test

E. *Sustainability Contribution*

The system's reliance on renewable solar energy aligns with the principles of environmental sustainability and the circular economy. By utilizing solar power for both electrical and thermal processes, the system minimizes its carbon footprint. The modular design further enhances its scalability and ease of deployment, making it suitable for diverse geographical settings. In addition, this study makes the following key contributions, such as:

1) *Novel Integration of Technologies*

It presents a desalination system that integrates a solar photovoltaic panel with a solar dish concentrator to harness both electrical and thermal energy for efficient seawater desalination. This system also reduces energy costs compared to traditional desalination methods, offering a sustainable and economical solution for water-scarce regions.

2) *Demonstration of High Performance*

The system's performance metrics were benchmarked against similar solar desalination technologies discussed in the literature. The boiler's average operating temperature of 405.9°C is higher than many existing systems, which typically achieve maximum temperatures around 300–400°C. Then, the daily yield of 23.4 liters exceeds the productivity of smaller-scale systems, such as those utilizing standalone solar stills or parabolic concentrators, which often produce less than 10 liters per day. On the other hand, through rigorous testing, this study also provides detailed analyses of pH reduction, salinity levels, and electrical conductivity, highlighting the significant improvements in water quality achieved by the system.

3) *Sustainability Emphasis*

By leveraging renewable solar energy and minimizing waste, the system aligns with circular economy principles, offering a scalable and environmentally sustainable solution to address clean water scarcity. Moreover, field application in a drought-prone area underscores the system's reliability and adaptability to varying environmental conditions, making it a viable option for other similar regions.

V. CONCLUSION

The solar desalination system developed in this study has demonstrated significant potential for addressing clean water needs in drought-prone regions. The system's integration of solar PV panels and a solar dish concentrator enabled it to achieve high thermal efficiency, with an average boiler temperature of 405.9°C and a notable daily output of 23.4 liters of clean water. The desalinated water's pH level was reduced from 8 to 6.1, and electrical conductivity dropped from 36 milliseconds to 400 microseconds, ensuring the water met safety standards for human consumption. Moreover, the system embodies the principles of sustainability by utilizing renewable energy sources, minimizing resource waste, and providing a cost-effective solution for water production. Its modular design allows for scalability and ease of implementation in various settings, especially in communities with limited access to clean water.

Field testing that was conducted in one of the villages in the coastal area that often experiences a shortage of clean water in Indonesia, namely Jepitu village, Girisubo district, Gunung Kidul regency, Special Region of Yogyakarta can validate the system's capability to perform efficiently under real-world conditions, demonstrating its robustness and adaptability. These results highlight the feasibility of deploying such systems to alleviate water scarcity challenges in other drought-prone and coastal regions worldwide.

Future research could focus on further enhancing the system's efficiency, exploring advanced materials for improved thermal conductivity, and integrating smart monitoring technologies for automated operation and maintenance. Additionally, socio-economic studies on community acceptance and cost-benefit analyses would provide valuable insights to support the large-scale adoption of this technology. The findings of this study reaffirm the potential of renewable energy-powered desalination systems to play a pivotal role in achieving sustainable water resource management, addressing the urgent needs of water-scarce communities, and contributing to global efforts in tackling water insecurity challenges.

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