DEVELOPMENT OF A SOLAR THERMAL POWER GENERATOR USING WATER LENS-BASED THERMOELECTRIC TECHNOLOGY

Ketut Alit Adi Untara [1)], Nurul Kami Sani [*2)], I Wayan Darmadi [3)] , Kamaluddin [4)]
[1,2,3,4)] Physics Education, FKIP, Tadulako University, Palu City, Central Sulawesi, Indonesia.
[*]*Corresponding author*
e-mail: alit_fisika@yahoo.co.id [1)], nurulkamisani@gmail.com [*2)], darmadiuntad75@gmail.com [3)], kamaluddinuntad@yahoo.co.id [4)]

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ABSTRACT

Solar thermal power generation using thermoelectric technology offers promising potential for renewable energy use in Palu, Indonesia, providing a clean and sustainable source of electricity for low-power electronic devices. This approach not only reduces greenhouse gas emissions but also supports sustainable regional development by offering an alternative to fossil fuels, thus strengthening long-term energy resilience. Additionally, utilizing renewable energy can foster local economic opportunities and decrease energy import costs. This study employs a thermoelectric generator (TEG) that converts heat focused through water lenses into electrical power via the Seebeck effect. The system's performance depends on the temperature difference created between the heated and cooled sides of the thermoelectric module. Experimental results showed a voltage range of 0.1 V to 0.33 V, producing a current of about 0.001 A, with an output power of 1.0×10^{-4} W to 3.3×10^{-4} W. Though the current output supports low-power devices, further optimization is required to enhance efficiency. This research underscores the viability of water lens-based thermoelectric systems as an eco-friendly energy solution in solar-rich regions, presenting a potential pathway for sustainable energy generation.

Keywords: development; solar thermal power generator; thermoelectric water lens

INTRODUCTION

Addressing the twin challenges of climate change and the growing demand for energy underscores the urgent need to adopt renewable energy sources (Al-Shetwi, 2022). These sources not only reduce greenhouse gas emissions but also present the potential for sustainable and virtually limitless energy supplies. Among the renewable energy options, solar energy is particularly promising due to its widespread availability across the globe (Maslamani, Omer, & M. A, 2014; Zhu, Matsuura, Suzuki, & Tsuchiyav, 2014). Indonesia, as a tropical nation, has significant solar energy potential, capable of harnessing both sunlight and solar thermal energy as primary resources. This makes the development of efficient technologies for converting solar energy into electricity crucial for advancing sustainable energy solutions and meeting future energy demands (Indrayana, Dharmawan, Kumara, & Setiawan, 2024).

In particular, Palu, located in Central Sulawesi, Indonesia, benefits from abundant solar heat throughout the year, providing a unique opportunity to harness this renewable energy source. With the region experiencing consistently rising average temperatures, solar thermal energy presents a reliable, naturally replenishable resource that can be effectively utilized. By tapping into this abundant resource, Palu has the potential to meet its electricity needs sustainably, reducing reliance on fossil fuels that are becoming increasingly scarce and environmentally damaging. The use of solar thermal energy not only supports local energy independence but also contributes to global efforts in combating climate change, positioning the region as a model for renewable energy adoption in tropical areas (Lekbir, Meddad, Eddiai, & Benhadouga, 2019).

One of the innovative approaches to converting solar heat into electrical energy is through thermoelectric technology (Zhu, Matsuura, Suzuki, & Tsuchiyav, 2014). Thermoelectric devices have the ability to transform solar energy into a temperature gradient, enabling them to function as either coolers or heaters when integrated with photovoltaic arrays (Chen, Wang, Hung, Yang, & Juang, 2014; Champier, 2017). These devices can also convert solar thermal energy into electrical power, functioning as power generators (Maduabuchi, Ejenakevwe, & Mgbemene, 2021; Huda & Kumala, 2020). Harnessing solar energy to operate thermoelectric devices is considered an appealing approach to address the needs for cooling, air conditioning, and electricity generation, while simultaneously promoting energy conservation and environmental sustainability. Over the past few decades, considerable research has been conducted on solar-powered thermoelectric devices. This paper provides a comprehensive overview of the progress in solar-based thermoelectric technology (Wang, Lu, Chen, & Jia, 2023).

This method employs thermoelectric modules to transform temperature differences directly into electrical current. In this process, solar heat is absorbed by the thermoelectric material, and the temperature gradient between the hottest and coolest regions of the module generates an electric potential (Rowe, 1999). By leveraging this principle, the abundant solar heat available in Palu can be harnessed to produce clean and environmentally friendly electricity, offering a sustainable energy solution (Bhukesh & Kumar, 2023). Electricity produced by thermoelectric-based solar thermal power systems can be utilized to power low-energy electronic devices. In the current digital age, the demand for electronic devices, ranging from communication tools to household appliances, continues to grow. Harnessing electricity from renewable sources not only reduces dependence on fossil fuels but also mitigates their adverse environmental effects, contributing to a more sustainable and eco-friendly energy landscape (Xie, et al., 2024).

By integrating the abundant solar heat in Palu with thermoelectric technology, a sustainable power generation system can be developed to meet long-term energy needs (Bateman, 1961). This approach offers an effective solution to reduce reliance on finite fossil fuel resources while simultaneously minimizing negative environmental impacts. As solar energy is a renewable and widely available resource, utilizing it to generate electricity can significantly contribute to sustainable energy practices, particularly in regions like Palu that experience consistent sunlight throughout the year. Thermoelectric-based solar power systems present a promising opportunity to harness renewable energy, particularly solar heat, in Palu. By employing this technology, clean and sustainable electricity can be generated to power low-energy electronic devices. The use of such systems not only reduces greenhouse gas emissions, thus benefiting the environment, but also supports the achievement of sustainable development goals by providing a reliable and eco-friendly energy source (Ayachi, He, &

Yoon, 2023; Liu, et al., 2024). This technology could play a crucial role in addressing energy needs while contributing to a greener, more resilient future.

Thermoelectric-based solar power systems present a promising opportunity to harness renewable energy, particularly solar heat, in Palu. By employing this technology, clean and sustainable electricity can be generated to power low-energy electronic devices (Pradana & Widyartono, 2020). The use of such systems not only reduces greenhouse gas emissions, thus benefiting the environment, but also supports the achievement of sustainable development goals by providing a reliable and eco-friendly energy source. This technology could play a crucial role in addressing energy needs while contributing to a greener, more resilient future (Xia, Zhang, Meng, & Yu, 2020; Yang, et al., 2024).

As a result, establishing thermoelectric-based solar power generation in Palu can be a key strategy to provide a sustainable energy source, decrease reliance on fossil fuels, and bolster long-term energy security. Moreover, utilizing renewable energy can foster local economic growth, lower energy import expenses, and improve regional energy autonomy (Umam, Budiarto, & Wahyuni, 2017). In response to these opportunities, *Development of Solar Thermal Power Generation Using Thermoelectric Water Lens* has been launched to explore and apply this innovative solution.

METHOD

The method employed in this study is experimental, with data analysis using a qualitative approach along with mathematical calculations. This section outlines the planning for the *Development of a Solar Thermal Power Generator Based on Thermoelectric Water Lens*. The research procedures include a literature review, device design, device fabrication, device testing, functionality testing, data collection, and report preparation. In general, this section describes how the study was conducted.

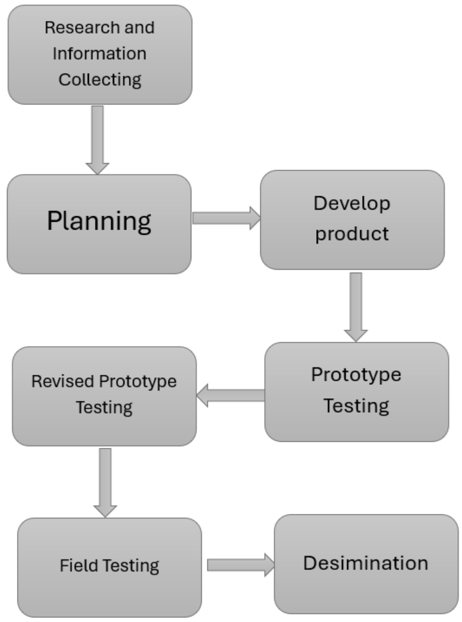

Figure 1. Research Planning Flowchart

The development method involves using a variety of materials and procedures. The main materials include solar heat, thermoelectric modules, water, clear plastic, support pipes and plates, as well as a voltmeter and ammeter. The process begins by creating a convex lens with a diameter of 20 cm from clear plastic, followed by calculating the lens's focal distance. The lens and thermoelectric modules are then positioned according to the calculated focal distance. This process is repeated with lenses of varying diameters, including 40 cm, 60 cm, 80 cm, and 100 cm. Additionally, different arrangements of thermoelectric modules are tested, both in series and parallel configurations, to measure the resulting electrical energy and power output. Finally, the electricity generated is used to power low-energy electronic devices. This approach allows for an in-depth analysis of how changes in lens size and thermoelectric setup impact the system's efficiency and energy output.

The focal distance of the lens is determined using a measuring tape, which is used to directly measure the distance from the center of the lens curvature to the focal point (f) in centimeters. This step is essential for ensuring the correct positioning of the lens relative to the thermoelectric modules, as the focal point plays a critical role in concentrating solar heat onto the thermoelectric material. By accurately measuring the focal distance, the efficiency of the system in harnessing solar energy can be optimized. This setup enables the conversion of solar thermal energy into electrical energy through the thermoelectric modules, which rely on the temperature difference between the heated and cooled surfaces to generate electricity.

To calculate the electrical energy and power produced, measurements of the voltage (V) and current (I) flowing through the load circuit are taken. These measurements are carried out on both series and parallel configurations of thermoelectric modules to evaluate which setup provides the highest energy output. The resulting electrical energy (E) is determined using the formula **E = VIt**, while the electrical power (P) is calculated using **P = VI**. By experimenting with different configurations and measuring these parameters, the study aims to identify the optimal system design that maximizes energy generation for low-power electronic applications. This process ensures that the solar thermal power generator is both efficient and practical for real-world use.

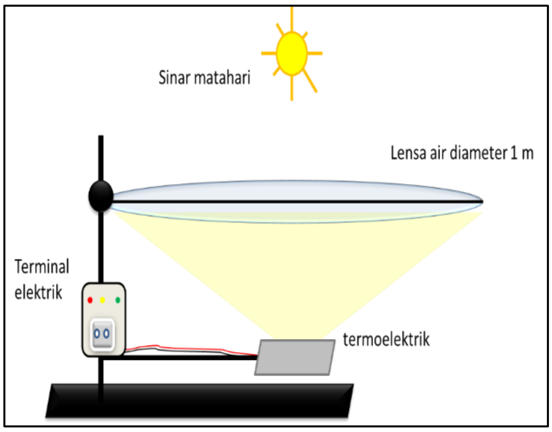

Figure 2. Design and Development of a Solar Thermal Power Generator Based on Thermoelectric Water Lens

RESULTS AND DISCUSSION

The primary objective of this study was to develop a solar power generation system using thermoelectric technology, incorporating convex lenses made from clear plastic and water. This system harnesses solar thermal energy by focusing sunlight with convex lenses, which is then converted into electrical energy through thermoelectric modules. The interaction between solar energy, thermoelectric effects, and lens optics forms the foundation of this renewable energy solution. The combination of these technologies is particularly well-suited for providing power to low-energy electronic devices.

Heat Energy and Thermoelectric Conversion

Heat energy, in the context of this study, refers to the energy transferred between objects or systems that exhibit a temperature difference. The flow of heat occurs through three main mechanisms: conduction, convection, and radiation. In conduction, heat is transferred directly between objects in physical contact.

Convection involves the transfer of heat via fluid motion, such as air or water, and radiation enables the transfer of heat through electromagnetic waves, including infrared radiation, without requiring a medium.

The thermoelectric module in this study was activated by the temperature difference induced by the focused solar radiation. Thermoelectric materials, typically composed of semiconductors with high electrical conductivity and low thermal conductivity, are capable of converting thermal energy into electrical energy through the Seebeck effect. This effect occurs when a temperature gradient between two points on a material leads to the movement of charge carriers from the hot side to the cold side, generating a voltage difference. The efficiency of this conversion is influenced by the temperature differential between the hot and cold sides of the thermoelectric module, which was enhanced by applying water to cool the cold side of the module.

Optical Focus and Lens Design

The convex lens used in this study was constructed from clear plastic and water, with varying diameters to assess their impact on the focal length and energy conversion efficiency. Convex lenses focus light by refracting it toward a single focal point, and the focal length depends on the curvature of the lens and the refractive index of the material. In this experiment, the lenses were tested under direct sunlight, and the focal distance was measured. The results revealed that the lens, when filled with water, focused sunlight to a point 100 cm away. At this focal point, the thermoelectric module was placed, allowing it to absorb the concentrated solar energy and convert it into electrical power.

Thermoelectric Power Generation

The focused solar radiation heats the hot side of the thermoelectric module, creating a temperature difference between the hot and cold sides. The cold side was kept cooler by applying a thin layer of water, facilitating the temperature gradient required for the thermoelectric effect. The voltage generated across the thermoelectric module ranged from 0.1 V to 0.33 V, depending on the intensity of the absorbed heat. The current produced by the module was measured to be approximately 0.001 A, resulting in a power output ranging from 1.0×10^{-4} watts to 3.3×10^{-4} watts.

Although the power output was relatively small, it was sufficient to power low-energy electronic devices, such as mobile phone chargers and small electronic gadgets. This demonstrates the potential of using solar thermal energy focused by water-filled convex lenses for sustainable energy generation. However, the relatively low output highlights the need for optimization, such as using larger lenses, increasing the number of thermoelectric modules in series or parallel configurations, or improving the efficiency of the thermoelectric materials used.

This study demonstrates the potential of utilizing a solar power generation system based on thermoelectric technology, with convex lenses made from clear plastic and water, as a sustainable solution for generating low-power electricity. The results confirmed that by focusing solar energy through the convex lenses and converting the heat to electricity via the Seebeck effect in thermoelectric modules, we can produce a small but measurable amount of electrical power. While the energy output in this study was relatively modest, it highlights the feasibility of using solar thermal energy, especially in regions with abundant sunlight like tropical areas, for renewable power generation. The observed electrical output, although low, was sufficient to power small electronics such as mobile phone chargers, which suggests that the system could be a practical and inexpensive solution for providing power to low-energy devices.

One of the key findings of this research is the importance of the temperature differential between the hot and cold sides of the thermoelectric module. The design of the system, which utilized water to cool the cold side of the thermoelectric module, played a crucial role in enhancing the efficiency of the energy conversion process. The Seebeck effect, in which a temperature gradient generates a voltage difference, directly links the efficiency of the thermoelectric conversion to the effectiveness of heat dissipation. In this study, the power output ranged from 1.0 x 10^{-4} watts to 3.3 x 10^{-4} watts, and the potential difference ranged from 0.1 V to 0.33 V, with a current of about 0.001 A. These findings are consistent with previous studies that show how small-scale thermoelectric generators can provide power in situations where other renewable energy sources may not be feasible, such as in off-grid locations or remote areas with limited access to electricity (Cotfas, Enesca, & Cotfas, 2024; Elsheikh, et al., 2014; Xi, Luo, & Fraisse, 2007). Thermoelectric devices are capable of harnessing solar thermal energy and waste heat to generate electricity, making them an environmentally friendly option (Baskar, Maridurai, & Arivazhagan, 2022). As a result, they have gained significant attention as a sustainable and versatile energy source that can fulfill various power demands. Additionally, thermoelectric devices offer a clear advantage when integrated into cogeneration systems, as they can simultaneously produce both electricity and useful heat, enhancing overall system efficiency (Indrayana, Dharmawan, Kumara, & Setiawan, 2024; Rokhim, Endahwati, & Sutiyono, 2023).

However, several factors contributed to the relatively low power output observed in this study. First, the efficiency of the thermoelectric materials used in the module plays a significant role in the system's overall performance. Although the thermoelectric materials used in this research showed promising results, further investigation into high-efficiency materials with better thermoelectric properties is necessary. Specifically, materials with higher Seebeck coefficients, lower thermal conductivity, and high electrical conductivity would substantially increase the power conversion efficiency. Additionally, increasing the number of thermoelectric modules used in series or parallel configurations could improve the overall output.

Another limitation of this study was the size and configuration of the convex lenses. The lenses used in this research had a limited diameter, which restricted the amount of solar energy that could be concentrated onto the thermoelectric module. By using larger lenses, more sunlight can be focused on the module, which would enhance the thermal energy available for conversion to electricity. Additionally, the lens material (clear plastic and water) can be optimized for higher refractive indices, which could further increase the concentration of solar energy at the focal point. The current setup could benefit from exploring lens materials that have higher optical clarity and durability under prolonged exposure to sunlight.

Despite these challenges, this study lays the groundwork for future advancements in solar thermoelectric systems. The integration of solar thermal energy and thermoelectric conversion technologies presents a promising renewable energy solution that can be used in various applications, from powering small electronics to off-grid solar power systems. As the efficiency of both thermoelectric materials and lens optics improves, this technology could become a practical and cost-effective energy solution for low-power applications in the future.

Furthermore, the integration of thermoelectric technology with solar thermal energy holds promise for a variety of future applications . For example, thermoelectric devices can be used in thermally powered cooling systems (thermoelectric coolers), or in monitoring and controlling the temperature in industrial processes. Research into the development of new, high-efficiency thermoelectric materials and improved lens designs will be crucial to scaling up this technology. These advancements could make solar thermal-powered thermoelectric systems more efficient, reducing reliance on fossil fuels and contributing to global efforts to combat climate change.

In conclusion, while the initial results show that the proposed system is capable of generating electricity from solar thermal energy, the power output can be enhanced through further optimization of the system design, materials, and configurations. This approach provides a promising direction for future research aimed at developing efficient and sustainable energy systems that harness renewable sources like solar power. The combination of thermoelectric technology and solar thermal energy holds great promise for contributing to the global shift toward renewable energy and reducing dependence on non-renewable resources.

Future research should also focus on integrating additional components to enhance the system’s efficiency. For example, incorporating a heat exchanger to optimize the heat dissipation process at the cold side of the thermoelectric module may increase the temperature gradient, improving the thermoelectric conversion efficiency. Furthermore, the design of a tracking system for the lens that can follow the sun’s position throughout the day could ensure that the system maximizes the amount of solar radiation focused onto the thermoelectric modules.

CONCLUSION

The development and application of thermoelectric technology in this system provides a renewable solution to power low-power electronics. The principle behind this energy conversion is rooted in well-established thermodynamic effects, such as the Seebeck effect, which plays a central role in converting thermal gradients into electrical voltage. With improvements in the design of the lens and thermoelectric module configuration, it is anticipated that the system's power output could be significantly increased, making it viable for a broader range of applications, including off-grid solar power generation and low-power household appliances.

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