American Journal of Energy and Natural Resources (AJENR)

ISSN: 2835-9186 (ONLINE)

VOLUME 4 ISSUE 1 (2025)

PUBLISHED BY
E-PALLI PUBLISHERS, DELAWARE, USA

American Journal of Energy and Natural Resources (AJENR)

Volume 4 Issue 1, Year 2025
ISSN: 2835-9186 (Online)
DOI: https://doi.org/10.54536/ajenr.v4i1.4168
https://journals.e-palli.com/home/index.php/ajenr

Small-Scale Incinerator as Thermoelectric Power Generator

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Article Information

Received: December 09, 2024
Accepted: January 07, 2025
Published: March 13, 2025

Keywords

Power Generator, Renewable Energy, Seebeck Effect, Small-Scale Incinerator, Thermoelectricity

ABSTRACT

Waste management is a critical priority that requires attention from society, as electricity is essential for every household. The challenge of high electricity costs is exacerbated by a persistent electrical shortage stemming from limited energy sources. This study aimed to evaluate the acceptability of Small-Scale Incinerators as Thermoelectric Power Generators. Utilizing a descriptive and experimental research approach, the researchers developed small-scale incinerators designed to convert heat energy into electricity through the Seebeck effect. A descriptive research methodology was employed, wherein the researchers surveyed ninety respondents to assess the Small-Scale Incinerator based on factors such as affordability, appearance, durability, functionality, and safety. The findings indicated that 1 kilogram of biodegradable waste produced an output voltage of 0.010 volts with a recorded heat of 545°C, fully charging a twenty-four-volt battery in 685.71 minutes. In contrast, 3 kilograms yielded an output voltage of 0.030 volts at a heat of 650°C, fully charging a twenty-four-volt battery within 228.57 minutes, while 5 kilograms produced an output voltage of 0.050 volts at a heat of 820°C, fully charging a twenty-four-volt battery in 137.14 minutes. Overall, based on the performance of the Small-Scale Incinerator as a Thermoelectric Power Generator, respondents found it acceptable in terms of affordability, appearance, durability, functionality, and safety.

INTRODUCTION

Electricity is one of the most essential forms of energy, driving modern society and playing a fundamental role in daily life. Traditionally, energy sources such as coal, natural gas, oil, and nuclear power are converted into electricity for human consumption. However, rising temperatures in the Philippines have led to increased electricity prices, significantly affecting many Filipino families, particularly those in rural areas. This situation is compounded by an ongoing electrical shortage, making energy costs even more burdensome. The limited availability of reliable electricity sources has contributed to this persistent issue, highlighting the need for sustainable and cost-effective energy solutions.

The problem of waste management also contributes to this energy crisis. According to Coracero *et al.* (2021), only about 11% of waste in Metro Manila is recycled, with many individuals failing to engage in proper waste segregation due to perceived inconvenience. The construction industry, in particular, struggles with waste management due to financial constraints, generating an estimated 100 metric tons of waste annually. This waste typically ends up in landfills, creating environmental and economic challenges for organizations such as the Waste Management Office (WMO).

To address these concerns, Stauffer and Spuhler (2019) suggest that small-scale incinerators offer a viable alternative to traditional landfill disposal by combusting domestic waste and other refuse. This method reduces the harmful environmental impact of open burning, which generates hazardous pollutants, and facilitates of heat and energy recovery. However, effective waste management is essential before incineration, requiring proper segregation of organic materials and recyclables and safe disposal of potentially harmful ash residue that may contain heavy metals.

The conversion of heat into electricity through thermoelectric generators presents another promising solution. The Seebeck effect allows thermoelectric generators to directly transform thermal energy into electrical power. These generators offer several environmental benefits, including the absence of chemical products, silent operation, and long lifespans. They can be fabricated on various substrates such as silicon, ceramics, and polymers, making them versatile and position independent. However, for thermoelectric generation to be efficient, materials must exhibit high electrical conductivity and low thermal conductivity, which remains a key area of research in thermodynamics.

A notable example of renewable energy adoption is Goyal's (2023) initiative at Valenzuela City Technological College, where he developed a pinwheel-based wind power system. This system harnesses the natural movement of wind to generate electricity, providing an alternative to conventional energy sources. By integrating this wind-driven power system, Goyal aimed to promote sustainable energy solutions, reduce reliance on traditional power grids, and demonstrate the potential of wind energy in

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urban settings. This project enhances the college's energy efficiency and serves as an educational tool, showcasing the practical benefits of renewable energy to students and the surrounding community.

Similarly, De Lantar *et al.* (2024), in their study titled "Improvised Water Pressure Driven Power Source," explored an innovative approach to renewable energy by harnessing water pressure to generate electricity. The research focused on developing a system that effectively captures the kinetic energy from water flow or pressure and converts it into electrical power using a specially designed generator. This system was designed to operate in settings with consistent water flow, such as pipelines, irrigation systems, or small-scale hydro setups, making it adaptable for urban and rural environments. The study demonstrated the potential for sustainable power generation by utilizing water pressure as an energy source, particularly in areas with abundant water resources. Furthermore, the improvised water pressure-driven power source highlighted the feasibility of implementing cost-effective, environmentally friendly solutions to address the increasing electricity demand, offering an alternative to conventional energy systems while reducing reliance on fossil fuels. This initiative also provided insights into how localized energy generation can contribute to community energy efficiency and sustainability.

Building on these renewable energy strategies, Goyal (2023) also highlights the importance of policy interventions at Valenzuela City Technological College to reduce waste and electronic waste generation. A key aspect of these policies involves the development of products that assist in effectively managing waste, including using incinerators to generate electricity. However, it is essential that incinerators are only used for waste that cannot be reused or when extraction costs are prohibitively high. Furthermore, these incinerators should be situated in unpopulated areas to ensure safety.

Researchers at the college have also devised a strategy to minimize the amount of solid waste sent to landfills by introducing a Small-Scale Incinerator as a Thermoelectric Power Generator. This system offers a another safe and environmentally friendly alternative energy source for powering small household appliances, aligning with the college's sustainability and waste reduction commitment. Combining waste management strategies with renewable energy technologies like small-scale incinerators and wind power systems presents a sustainable solution to the Philippines' growing energy and waste challenges. Integrating such technologies helps reduce environmental impact and provides a practical means of generating electricity for communities facing energy shortages.

LITERATURE REVIEW

In line with Salamat (2014), the development of a thermoelectric module is proposed for low-voltage applications, such as computer radiators and LED lamps, aimed at creating a compact power bank for daily and emergency use, particularly benefiting Bulacan State University students and adventurers. Complementing this, Li and Zhao (2019) highlight the pressing need for improved municipal waste disposal amid economic growth and rising populations in China. Utilizing the PEST-SWOT framework, their analysis assesses the investment climate for waste incineration power, outlining opportunities and risks to assist developers. Together, these studies underscore the importance of innovative energy solutions and effective waste management strategies in addressing contemporary challenges.

Cui *et al.* (2015) developed an advanced detection technique leveraging ARM and DSP technologies to accurately identify trash-burning flame endpoints, with DSP handling image processing tasks and ARM regulating air volume and particle velocity based on these signals. In a related area, Kumar and Signh (2017) examined the influence of soluble ions in municipal incinerator ash on the strength and hardening of cement-stabilized materials, revealing that the incorporation of cement reduces maximum dry density while enhancing optimal moisture content over varying curing periods. Together, these studies highlight the integration of technology in waste management and the impact of incineration byproducts on construction materials, emphasizing the need for innovative solutions in environmental monitoring and material engineering.

Makarichi *et al.* (2018) provide a comprehensive review of the evolution of waste-to-energy incineration, transitioning from a focus on waste disposal to modern practices prioritizing energy recovery and advanced flue gas purification. This highlights significant advancements in waste management strategies. Complementing this, Goyal (2023) investigates the development of a wind-powered pinwheel aimed at reducing fossil fuel dependency, showcasing wind energy as a sustainable alternative that enhances national energy security. Utilizing a dynamo for electricity generation while mounted on a tricycle, this innovative design addresses energy needs and emphasizes the importance of renewable sources in a world with diminishing fossil fuel supplies. Together, these studies underscore the critical role of waste management innovations and renewable energy solutions in addressing contemporary environmental challenges.

Tait *et al.* (2020) examine waste incineration in Australia for waste reduction and electricity generation, highlighting health concerns associated with older technologies and the necessity for careful planning in modern incinerators. In parallel, Hooshmand *et al.* (2021) investigate thermoelectric generators, which can convert waste heat into electricity, emphasizing their development, efficiency parameters, and the design challenges they face in waste heat recovery applications. Enescu (2019) further elucidates the principles of thermoelectric energy harvesting, precisely the Seebeck effect, which transforms temperature gradients into electrical energy. These studies underscore the importance of innovative technologies, such as modern incineration and thermoelectric systems, in enhancing waste management and energy recovery while addressing health and engineering challenges.

Amine *et al.* (2020) explore thermoelectric effects, particularly the Seebeck and Peltier effects, which enable heat-to-electricity and electricity-to-heat conversion without moving parts. While these technologies face efficiency challenges that limit their application in areas like refrigeration and power generation, they promise reliable uses in space probes, lab equipment, and medical devices. Similarly, Fernandez (2021) notes a growing interest in waste heat recovery methods driven by environmental and economic pressures. Although historically used in space missions, thermoelectric generators are being considered for waste energy recovery, their low conversion efficiency raises concerns about potential energy losses when integrated with heat sources, prompting design enhancements to optimize performance. Together, these studies highlight thermoelectric technology's evolving role in addressing reliability and energy recovery challenges.

Research Questions

This study aims to determine the level of acceptability of a Small-Scale Incinerator as a Thermoelectric Power Generator as perceived by the respondents in terms of affordability, appearance, durability, functionality, and safety. Specifically, it seeks to answer the following questions:

1. What is the voltage output and temperature of the Small-Scale Incinerator operating as a Thermoelectric Power Generator while incinerating the following amount of waste:
   - 1 Kilogram;
   - 3 Kilograms; and
   - 5 Kilograms?
2. How long does the Small-Scale Incinerator as a Thermoelectric Power Generator fully charge the following battery:
   - 9V;
   - 12V; and
   - 24V?
3. What is the level of acceptability of a small-scale incinerator as a thermoelectric power generator as perceived by the respondents in terms of:
   - Affordability;
   - Appearance;
   - Durability;
   - Functionality; and
   - Safety?

MATERIALS AND METHODS

Research Design

This study aimed to determine the acceptability level of the Small-Scale Incinerator as a Thermoelectric Power Generator as perceived by respondents in terms of affordability, appearance, durability, functionality, and safety. The researchers utilized quantitative research, specifically employing descriptive and experimental research methods.

The descriptive research method involved distributing a survey questionnaire to ninety (90) individuals to gather comprehensive data on their perceptions regarding the acceptability of the power source. The survey assessed the power source in terms of affordability, appearance, durability, functionality, and safety.

Additionally, an experimental research design was employed. The researchers constructed a system that included the preparation of materials, analysis of the product's functionality, prototype construction, examination of its functions, preparation of a survey questionnaire, data collection and analysis, and interpretation of the results. The small-scale incinerator was tested with different amounts of waste, recording the heat and output voltage. It was also tested on its duration to charge 9-volt, 12-volt, and 24-volt batteries fully.

Research Participants

The researchers utilized a purposive sampling technique to select respondents, focusing on ninety (90) residents from three barangays in the 2nd district of Valenzuela City: Barangay Maysan, Barangay Parada, and Barangay Paso de Blas, with thirty (30) residents chosen from each barangay. These barangays were strategically selected based on their waste generation levels and potential receptiveness to alternative energy solutions. The purposive sampling ensured that the respondents were representative of the study's objectives, specifically targeting individuals with knowledge of waste management practices and energy needs, thereby enhancing the relevance and reliability of the findings.

Research Instrument

This study utilized a researcher-designed survey questionnaire validated by experts in the field of Electronics. This questionnaire comprised a series of questions aimed at collecting essential information regarding the respondents' profiles and inquiries related to the level of acceptability of the Small-Scale Incinerator as a Thermoelectric Power Generator.

Part 1 evaluates the demographic profile of the respondents. Part 2 includes questions about the level of acceptability of the Small-Scale Incinerator as a Thermoelectric Power Generator in terms of affordability, appearance, durability, functionality, and safety. Part 3 assesses the respondents' perspectives, suggestions, and recommendations for enhancing the Small-Scale Incinerator as a Thermoelectric Power Generator.

Data Gathering Procedure

The study underwent ethical scrutiny by the Valenzuela City Technological College Ethical Review Committee. Upon receiving confirmation and clearance from the Ethical Review Committee, a formal letter was submitted to the College Dean of Valenzuela City Technological College office, seeking authorization to conduct the research. Subsequently, the researchers made initial contact with the Barangay Chairperson of Barangay Maysan, Barangay Parada, and Barangay Paso de Blas to briefly introduce and explain the study. The College Dean issued an endorsed letter to the Barangay Chairpersons, approving the study's execution.

Before conducting the survey, the researchers developed a Small-Scale Incinerator as a Thermoelectric Power Generator and tested its functionality to ensure effectiveness and reliability. The prototype was meticulously designed, constructed, and subjected to a series of tests to evaluate its ability to convert waste into usable energy through thermoelectric technology. The researchers began by incinerating 1 kilogram of biodegradable waste, which produced an output voltage of 0.010 volts at a recorded heat of 545°C, fully charging a twenty-four-volt battery in 685.71 minutes. In contrast, 3 kilograms yielded an output voltage of 0.030 volts at a heat of 650°C, fully charging a twenty-four-volt battery within 228.57 minutes, while 5 kilograms produced an output voltage of 0.050 volts at a heat of 820°C, fully charging a twenty-four-volt battery in 137.14 minutes.

Respondents who expressed a desire to participate in the study must complete an informed consent form before its commencement. This process ensured that participants fully understood the research's purpose, scope, and potential implications. Before conducting the survey, the researcher provided clear explanations regarding the study's objectives, procedures, and participants' rights, including the right to withdraw at any point without any consequences. By signing the informed consent forms, participants acknowledged their voluntary participation and understanding of the study, ensuring ethical compliance and fostering transparency between the researcher and respondents.

After completing all the necessary forms, the researcher proceeded with the survey. Thirty respondents from each barangay with knowledge of and experience using incinerators were selected to participate in the survey. All gathered data were tabulated, computed, and analyzed using Real Statistics. Subsequently, the data were interpreted and presented.

Data Processing And Statistical Treatment

The researchers utilized descriptive statistics such as weighted mean and percentage analysis. All were computed using Real Statistics as part of the statistical treatment and data analysis. The total number of respondents who agreed that a small-scale incinerator could be utilized as a thermoelectric power generator was determined through percentage analysis. The weighted mean was used to evaluate the acceptability of the small-scale incinerator as a thermoelectric power generator based on affordability, appearance, functionality, durability, and safety. The researchers also utilized the ohm's law and power law to calculate the voltage output and temperature of the small-scale incinerator as a thermoelectric power generator.

Ethical Consideration

The study underwent an ethical review by Valenzuela City Technological College, and researchers obtained approval from the college president and local Barangay Captains before proceeding. Informed consent forms were provided to all respondents before the survey. Respondents' privacy, anonymity, and dignity were protected per the Data Privacy Act, ensuring no harm was inflicted. Additionally, all sources and ideas, including those not initially conceived by the researchers, were cited correctly, thus avoiding any instances of plagiarism.

RESULTS AND DISCUSSIONS

Table 1: Quantity of waste is required to operate the small-scale incinerator as a thermoelectric power generator.

Amount of Waste Biodegradable	Temperature	Voltage Percentage
1 kilogram	545 °C	0.010V
3 kilograms	650 °C	0.030V
5 kilograms	820 °C	0.050V

Table 1 presents the quantity of waste required to initiate the operation of the small-scale incinerator as a thermoelectric power.

As presented in the table, the results of the Small-Scale Incinerator as a Thermoelectric Power Generator indicated that the system's voltage output increased with the amount of biodegradable waste incinerated. When 1 kilogram of biodegradable waste was burned, the incinerator achieved a temperature of 545 °C, resulting in a voltage output of 0.010 V. With 3 kilograms of waste, the temperature rose to 650 °C, and the voltage output increased to 0.030 V. Finally, incinerating 5 kilograms of waste produced a temperature of 820 °C and a voltage output of 0.050 V. These findings illustrate a direct relationship between the quantity of waste burned and the heat and voltage generated, emphasizing the system's potential scalability for energy production based on available biodegradable waste. However, the low voltage output suggests the need for further optimization to enhance the efficiency and practicality of the generator.

The findings from the Small-Scale Incinerator as a Thermoelectric Power Generator closely aligns with the insights of Sofi'i *et al.* (2024), who emphasized the escalating waste management crisis and the potential of thermoelectric incinerators as a sustainable solution. The study established a direct correlation between the volume of biodegradable waste incinerated and the heat and voltage generated, with larger waste quantities yielding increased energy output. This supports the concept articulated by Sofi'i *et al.* (2024) in which thermoelectric incinerators convert waste combustion heat into electrical energy, thereby providing the dual benefit of waste reduction and energy generation. Although the incinerator in this study produced relatively low voltage outputs, it demonstrates the feasibility of the technology as a scalable solution to waste and energy challenges, underscoring the necessity for further optimization to enhance efficiency and practicality, akin to the sustainable alternatives proposed for addressing global waste issues.

Table 2: The duration required for the Small-Scale Incinerator to function as a Thermoelectric Power Generator for the complete charging of batteries.

Battery	1 kilogram of Waste	3 kilograms of Waste	5 kilograms of Waste
9V	257.14 mins	85.71 mins	51.43 mins
12V	342.86 mins	114.29 mins	68.57 mins
24V	685.71 mins	228.57 mins	137.14 mins

Table 2 demonstrates the duration required for the Small-Scale Incinerator to function as a Thermoelectric Power Generator for the complete charging of batteries.

The results of the study demonstrate how the battery's performance is affected by the amount of biodegradable waste incinerated using the Small-Scale Incinerator as a Thermoelectric Power Generator. Specifically, the duration of battery operation decreases as the waste quantity increases, regardless of the battery's voltage rating. For a 9V battery, the incineration of 1 kilogram of waste provided 257.14 minutes of operation, while 3 kilograms yielded 85.71 minutes, and 5 kilograms only 51.43 minutes. Similarly, for a 12V battery, 1 kilogram of waste resulted in 342.86 minutes, 3 kilograms in 114.29 minutes, and 5 kilograms in 68.57 minutes of operation. The trend was consistent for the 24V battery, which operated for 685.71 minutes with 1 kilogram of waste, 228.57 minutes with 3 kilograms, and 137.14 minutes with 5 kilograms. These findings suggest that while increasing the waste quantity generates more heat and voltage output, the energy production efficiency decreases over time due to the system's limitations in sustaining power for extended periods. This emphasizes the need for further system refinement to improve energy storage and conversion efficiency, making it more practical for continuous power generation.

The results of the study on the Small-Scale Incinerator as a Thermoelectric Power Generator complement the findings of Relleta *et al.* (2024) regarding the development of waste-to-energy systems. Both studies highlight the potential of thermoelectric generators (TEGs) to convert heat from waste combustion into electricity for energy storage. In the present study, while increasing the quantity of biodegradable waste generated more heat and voltage, the duration of battery operation decreased, indicating limitations in sustaining power efficiency over time. Similarly, Relleta *et al.* (2024) observed the performance of their system by incinerating biomass waste, achieving a peak voltage of 12.45 V, and storing the energy in a lithium-ion battery.

The parallel findings underscore the scalability and potential of waste-to-energy systems while also pointing out the need for optimization in energy storage and system efficiency. Both studies address the issue of waste management and energy generation but highlight areas for improvement, such as enhancing battery performance and refining the energy conversion process. Additionally, Relleta *et al.*'s inclusion of an activated carbon filter and a wireless monitoring system offers insights into incorporating additional features for monitoring and environmental safety, which could be considered in future iterations of the Small-Scale Incinerator to make it more practical and sustainable.

Table 3: The Level of Acceptability of Small-Scale Incinerator as Thermoelectric Power Generator

Indicators	Average Weighted Mean	Verbal Interpretation
Affordability	4.13	Acceptable
Appearance	4.23	Acceptable
Durability	4.20	Acceptable
Functionality	4.42	Acceptable
Safety	4.34	Acceptable
Grand Weighted Total	4.26	Acceptable

Table 3 presents the Summary of the Level of Acceptability of a Small-Scale Incinerator as a Thermoelectric Power Generator.

The indicator "Affordability" achieved an average weighted mean of 4.13, categorized as acceptable. This suggests that the cost of the small-scale incinerator was reasonable and within an acceptable range. The indicator "Appearance" obtained an average weighted mean of 4.23, also categorized as acceptable, indicating that its design and aesthetics met the respondents' expectations. The indicator "Durability" received an average weighted mean of 4.20, interpreted as acceptable, reflecting that the incinerator was perceived as sturdy and capable of withstanding regular use. The indicator "Functionality" achieved an average weighted mean of 4.42, interpreted as acceptable, indicating that the incinerator effectively converted waste into energy. The indicator "Safety" secured an average weighted mean of 4.34, which is acceptable, suggesting that the incinerator was considered safe for use. These results indicate that the respondents view the small-scale incinerator as a thermoelectric power generator.

The overall acceptability of the Small-Scale Incinerator as a Thermoelectric Power Generator, as perceived by the respondents, yielded a general weighted mean of 4.26, denoted as "Acceptable." This confirms that the system was deemed acceptable in terms of affordability, appearance, durability, functionality, and safety, demonstrating its potential as a practical and reliable waste-to-energy solution. This aligns with the broader context discussed by Li *et al.* (2015), who highlight the growing promise of thermoelectric power production as an environmentally favorable and effective technology. The complexities and barriers in thermoelectric systems, such as material thermal resilience and interface reliability, the results of this study show that the Small-Scale Incinerator holds potential as a sustainable and practical waste-to-energy solution. The overall grand weighted mean of 4.26 further confirms the incinerator's viability, suggesting that it is a promising technology, consistent with advancements in thermoelectric devices and their increasing applicability.

CONCLUSIONS

Based on the study's findings, it was determined that 1 kilogram of biodegradable waste produced an output voltage of 0.010 volts with a recorded heat of 545°C, fully charging a twenty-four-volt battery in 685.71 minutes. In contrast, 3 kilograms yielded an output voltage of 0.030 volts at a heat of 650°C, fully charging a twenty-four-volt battery within 228.57 minutes, while 5 kilograms produced an output voltage of 0.050 volts at a heat of 820°C, fully charging a twenty-four-volt battery in 137.14 minutes. Overall, based on the performance of the Small-Scale Incinerator as a Thermoelectric Power Generator, respondents found it acceptable in terms of affordability, appearance, durability, functionality, and safety. These results highlight the potential of the system to provide an efficient method for converting biodegradable waste into electrical energy, offering a sustainable solution for waste management and energy production. The implications of this study suggest that further optimization of the system could enhance its energy output and efficiency, making it more practical for widespread use. Additionally, the positive reception regarding its affordability, appearance, and safety indicates that the system is well-received by potential users, reinforcing the feasibility of integrating small-scale thermoelectric incinerators into various communities as an alternative energy source.

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