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Small-Scale thermoelectric incinerator prototype for sustainable waste management and power generation

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HIGHLIGHTS

- This study suggests a thermoelectric incinerator that tackles Indonesia's waste issue sustainably.
- CFD analysis enhances heat flow, improving the incinerator's combustion performance.
- High reduction, modular design, and flexible fueling make the suggested incinerator innovative.

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ABSTRACT

Indonesia faces a significant challenge in managing its waste effectively. Conventional incineration, while reducing waste volume, raises environmental concerns due to emissions. This research explores a novel approach by developing a thermoelectric incinerator prototype with a 10 kg/hour capacity. The incinerator aims to convert heat generated during waste incineration into electrical energy, offering an environmentally friendly alternative for waste management. The research involved designing and modeling the incinerator using Ansys Fluent 2021 R1 software. Incineration tests were conducted experimentally using 5 kg organic and 5 kg inorganic waste for 30 minutes. Critical parameters such as temperature distribution, moisture content, calorific value, combustion temperature, generated voltage, and ash production were analyzed. The analysis revealed good temperature distribution through Computational Fluid Dynamics (CFD) simulations, enabling the optimization of air and heat flow within the incinerator. Organic waste with a water content of 13.93% and a calorific value of 5327.76 cal/gram reached a combustion temperature of 181 °C. In comparison, inorganic waste (water content: 2.39%, calorific value: 10846.58 cal/gram) achieved a temperature of 210 °C. The maximum voltage generated was 2.1 V for organic waste and 2.2 V for inorganic waste. Notably, the incineration process was reduced by 72% for organic waste and 68% for inorganic waste, highlighting its effectiveness in volume reduction. This thermoelectric incinerator prototype offers several advantages: a high level of waste reduction, a modular design facilitating easy assembly and disassembly, and the ability to handle various types of waste as fuel.

1. Introduction

The waste problem in Indonesia is a complex and ever-growing issue. Conventional waste management methods, like landfills, are reaching capacity and pose environmental risks [1,2]. This necessitates a multi-pronged approach that includes waste minimization, recycling, and exploring alternative treatment options for non-recyclable waste [3]. One promising approach is the use of thermoelectric incinerators. These incinerators use waste as fuel to generate electricity through a thermoelectric circuit within the incinerator [4]. This technology offers an attractive solution as it converts heat generated during waste incineration into electrical energy, potentially reducing waste heat and greenhouse gas emissions associated with traditional incineration [5].

Thermoelectric incinerators have several advantages. First, this incinerator increases energy efficiency and reduces the environmental impact of the waste incineration process [6]. The heat from the combustion process is converted into electrical energy to reduce waste heat and greenhouse gas emissions. Second, thermoelectric incinerators can produce electrical power

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from waste [7]. It provides an alternative renewable energy source and helps reduce dependence on fossil fuels. Third, this incinerator can help save waste processing costs [8]. High waste management costs burden many parties [9]. Thermoelectric incinerators can help reduce this burden [10]. This incinerator is the right solution for managing coir and coconut shell waste [11]. This waste can be processed into electrical energy, so it does not pollute the environment and provides economic value.

Several studies have explored the application of Thermo Electric Generator (TEG) in incinerators. The performance of waste power plants using wood and plastic waste as fuel has been analyzed by Muhammad et al. [12]. Waste is burned in incinerators, and the heat from the combustion process is used to produce steam. The high-pressure steam is then used to spin a turbine and produce electricity. The research results show that wood waste is more effective than plastic in producing steam and pressure; high steam pressure produces higher turbine rotation and generator voltage, and a maximum voltage of 13.76 V is obtained with a steam pressure of 60 Psi and wood fuel [12]. TEG-powered incinerators can help solve the waste problem by converting waste into electrical energy. This technology offers an environmentally friendly solution for producing renewable energy. However, there are several weaknesses in this system, including the efficiency of energy conversion from heat to electricity still needs to be optimized, this system requires high initial costs to build a TEG-based incinerator, and regular maintenance and cleaning needs to be done to maintain system performance. TEG-powered incinerators have the potential to be an innovative solution to solve the waste problem and produce renewable energy. Wood waste has been proven to be more effective as fuel than plastic. Further research is needed to improve the system's energy conversion efficiency and power output.

Ardiatma et al. [13] designed and tested a smokeless incinerator with a thermoelectric power generator as an alternative solution to overcome waste and energy problems. The incinerator has two designs: 1 series and three series thermoelectric. The incinerator capacity is 0.01 m^3. The waste combines organic and inorganic waste, including plastic cups, plastic bottles, food wrappers, cardboard, vegetable waste, and dry leaves. The maximum combustion temperature during incineration reaches 345 °C. The design using one thermoelectric unit and three thermoelectric units arranged in series can produce electrical energy with a maximum voltage of 1.4 Volts in a series of 1 thermoelectric unit with a hot temperature of 125 °C and a cold temperature of 94 ºC with a temperature difference of 31 °C, and in a series with Using three thermoelectric units arranged in series is capable of producing a voltage of 4.7 volts with a heating temperature of 125 °C and a cooling temperature of 94 °C with a temperature difference of 31 °C. A 2.5-volt light bulb starts to light at 0.7 volts. Burning rate 3.74 kg/hour, charcoal yield 5.2%, and ash yield 17.2%. The effectiveness of smokeless waste incinerators assists in reducing domestic waste by 77.6%. This research has several advantages, including effectively reducing domestic waste, minimizing smoke and pollution, and producing electrical energy from combustion heat. However, in terms of incinerator capacity, it is still tiny. The voltage and electrical power produced are still low [13].

Nurjanah et al. [14] used 7 TEG chips to generate a voltage from the heat of the incinerator. TEG is connected in series and mounted on a heat sink. The heat from the incinerator is transferred to the heat sink, and the temperature difference between the hot and cold surfaces of the TEG produces an electrical voltage. The research results show that the maximum voltage produced by 7 TEG chips is 18.10 V at a temperature difference of 157 °C without load. The process of charging a 6V 4.5 Ah battery starts at a temperature difference of 130 °C with a voltage of 6.5 Vdc and a current of 265 mA. This system can produce electrical energy from incinerator exhaust heat, making it environmentally friendly and energy efficient. This system is relatively simple and easy to operate. The resulting voltage and current can be used to charge the battery. However, there are several weaknesses, including the relatively low voltage and current produced, the energy conversion efficiency from heat to electricity needing to be optimized, and the fact that this system requires a large heat sink to dissipate heat. This research shows that TEG can generate voltage from incinerator heat. This system has the potential to become a renewable energy source that is environmentally friendly and energy efficient. However, further research is needed to improve the system's energy conversion efficiency and power output [14].

The thermo-electric generator-waste heat recovery (TEG-WHR) system comprises a thermo-electric (TE) module, exhaust heat source, and heat sink. This system can potentially increase energy efficiency and reduce exhaust emissions on ships. Eddine et al. [15] discusses the Thermoelectric Generator - Waste Heat Recovery (TEG-WHR) system, which generally consists of a TE module, exhaust heat source, and heat sink. This system transfers heat from high-temperature zones (engine exhaust gases) to the TE hot junction. The heat is then dissipated to a low-temperature zone (for example, engine cooling water) via a TE cold junction. P-type (electron-deficient) and N-type (electron-excess) doped semiconductor elements are thermally connected in parallel and electrically in series. This research focuses on various applications of TEG systems for WHR systems. The TEG-WHR system can be used for multiple waste heat sources, such as engine exhaust gas, engine cooling water, industrial waste heat, and solar heat. The TEG-WHR system has several advantages, including high energy efficiency, environmental friendliness, and low maintenance costs. However, the TEG-WHR system also has several disadvantages, including high initial costs, low power output, and the need for a large heat sink [15].

On the other hand, research related to heat exchanger design for Thermoelectric Generators (TEG) has tested various shapes and dimensions, especially flat-shape (rectangular) and hexagonal (hexagonal). Flat-shape heat exchangers offer ease of implementation, such as in motor vehicle exhaust systems. The downside is heat loss on the short side of the heat exchanger. Hexagonal heat exchangers produce a more even hot surface temperature distribution but have limitations regarding TEG module accommodation and hot surface temperature.

Liang et al. [16] compared three heat exchanger configurations: triangular, rectangular, and hexagonal. Triangular heat exchangers have higher surface temperatures but are not used because they only allow a small number of TEG modules. Rectangular heat exchangers have a small width-to-height ratio to enable the placement of TEG modules on the short side. The research results show that a flat-plate heat exchanger's average hot surface temperature for the same inlet conditions is much higher (240 °C) than a hexagonal heat exchanger (120 °C). This is caused by the longer distance to the longitudinal axis in hexagonal heat exchangers. However, this design causes the surface temperature to decrease, but the temperature distribution becomes more uniform, similar to that of a hexagonal design [16].

Kim et al. [17] developed a high-performance hexagonal TEG that produces an electrical output of approximately 100 W with a pressure drop of 2.1 kPa [17]. In addition, Deng et al. [18] developed a heat exchanger design based on a hollow body to improve heat transfer even though it causes a higher pressure drop [18]. These studies highlight essential considerations in heat exchanger design for TEG. The flat-shape design offers ease of implementation but has the disadvantage of heat loss. The hexagonal design can overcome these shortcomings but has limitations regarding TEG module accommodation and hot surface temperatures. Further research is needed to optimize heat exchanger designs that balance heat transfer efficiency, TEG module operating temperature, and ease of implementation.

TEG-based incinerators are a promising technology for converting waste into electrical energy. The studies reviewed demonstrate the potential and challenges of this technology. Future developments could optimize incinerator and TEG designs to increase energy conversion efficiency. Integration of the TEG system with other systems, such as batteries and inverters, can produce an integrated power generation system. However, limitations exist in current thermoelectric incinerator designs, as identified in the literature review. A critical area for improvement is the capacity of these systems, with many having relatively small capacity that limits their overall impact on waste management. Additionally, research suggests a need to improve the efficiency of converting heat from waste combustion into electricity [19, 20].

Building upon this knowledge gap, this research aims to develop a prototype thermoelectric incinerator with a larger capacity, explicitly targeting 10 kg/hour of waste. Incineration tests were conducted experimentally using 5 kg organic and 5 kg inorganic waste for 30 minutes. Critical parameters such as temperature distribution, moisture content, calorific value, combustion temperature, generated voltage, and ash production were analyzed. The analysis revealed good temperature distribution through computational fluid dynamics (CFD) simulations with Ansys Fluent 2021 R1 software, optimizing air and heat flow within the incinerator.

2. Methods

2.1 Designed model

Figure 1 and Table 1 are a thermoelectric incinerator prototype design and description. The temperature distribution in the incinerator reactor was analyzed using Ansys Fluent 2021 R1. This research uses an incinerator to burn 5 kilograms of organic waste (dried leaves) and 5 kilograms of inorganic waste (polyethylene terephthalate plastic bottle waste) for 30 minutes by experimental testing. An evaluation was conducted to assess critical aspects of the process, including the spatial distribution of temperature, the quantity of moisture present, the inherent energy content of the fuel, the peak temperature achieved during combustion, the electrical power generated, and the amount of residual ash produced. The incinerator reactor has a reactor cover and water block on both the hot and cold sides to create a potential difference. The heat from the combustion process is converted into electrical energy by six thermoelectric Peltiers connected in parallel and series. The 5-watt lamp is used as a load to test the thermoelectric performance. A digital multimeter measures the resulting voltages. The smoke from combustion is released through the chimney.

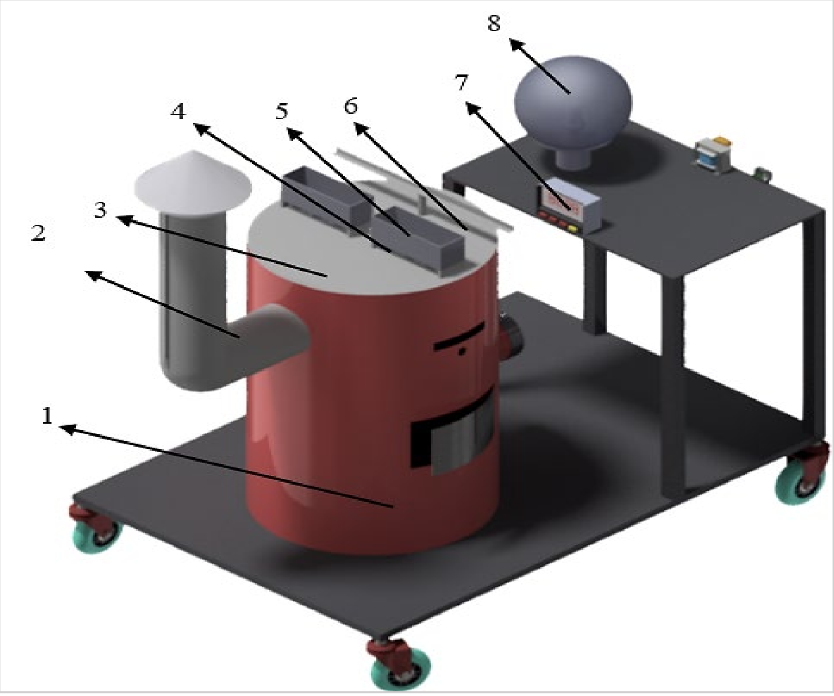

Figure 1: Thermoelectric Incinerator Prototype Design

Table 1: Parts Description

No	Part	Description
1	Incinerator reactor	This is the primary chamber where waste materials are introduced and undergo thermal decomposition (incinerating) at high temperatures.
2	Chimney	The chimney provides a designated path for the exhaust gases produced during incineration to exit the system safely.
3	Reactor cover	The reactor cover seals the incinerator reactor, preventing the escape of flames, smoke, and harmful fumes during operation.
4	Thermoelectric peltiers	These are solid-state devices positioned strategically within the system. They utilize the temperature difference between the hot incinerator reactor and the cooler water blocks to generate electricity through the thermoelectric effect.
5	Water blocks	These are heat exchangers located near the thermoelectric Peltier. Water circulation through these blocks absorbs heat, maintaining a cooler temperature on one side of the Peltier, which is crucial for efficient electricity generation.
6	Cable holder	The cable holder is an organized and secure pathway for electrical cables connecting the thermoelectric Peltier to the external circuit.
7	Digital Multimeter	This instrument measures various electrical parameters like voltage generated by the thermoelectric Peltier.
8	Lamp	The lamp could be connected to the electricity generated by the thermoelectric Peltier as a visual indicator of successful power generation.

2.2 Stages of simulating temperature distribution in the reactor incinerator

Temperature distribution in the reactor incinerator simulation was carried out through the Pre-Processing, Processing, and Post Processing stages.

2.2.1 Pre-Processing

In the pre-processing stage, there are several sub-stages, starting from creating geometry using Geometry, meshing, and determining the parameters used by Ansys Fluent 2021 R1.

2.2.1.1 This research geometry was created using the Space Claim facility in Ansys

The geometric design is made at a 1:1 scale, with a tube diameter of 590 mm, height of 920 mm, and thickness of 7 mm. Figure 2 shows the geometry of the incinerator reactor used in this research. After completing the model creation stage, proceed with the named selection stage to determine essential parts such as the inlet, output, and wall as showen in Figures 3-5.

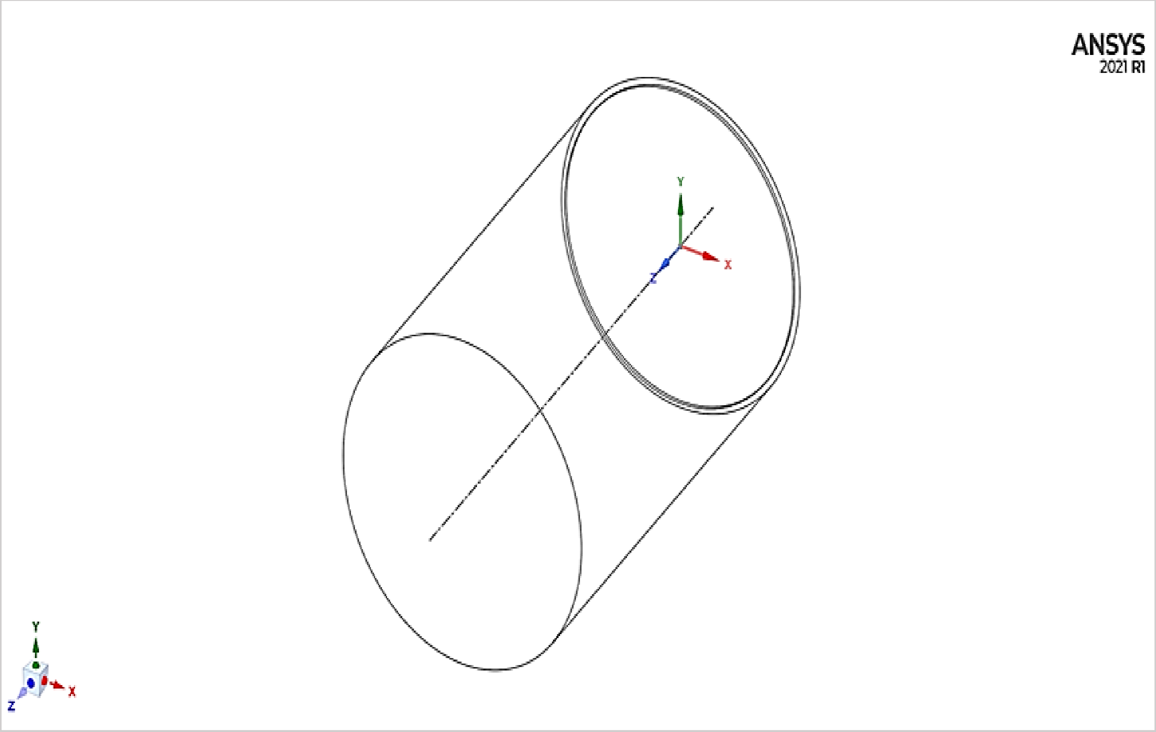

Figure 2: Geometry of Incinerator Reactor

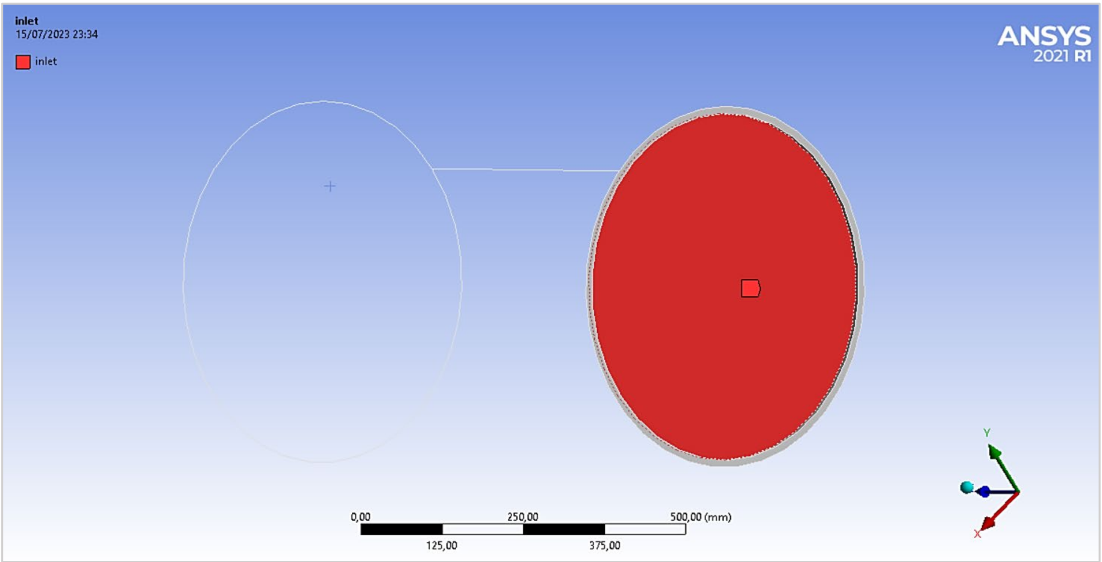

Figure 3: Inlet

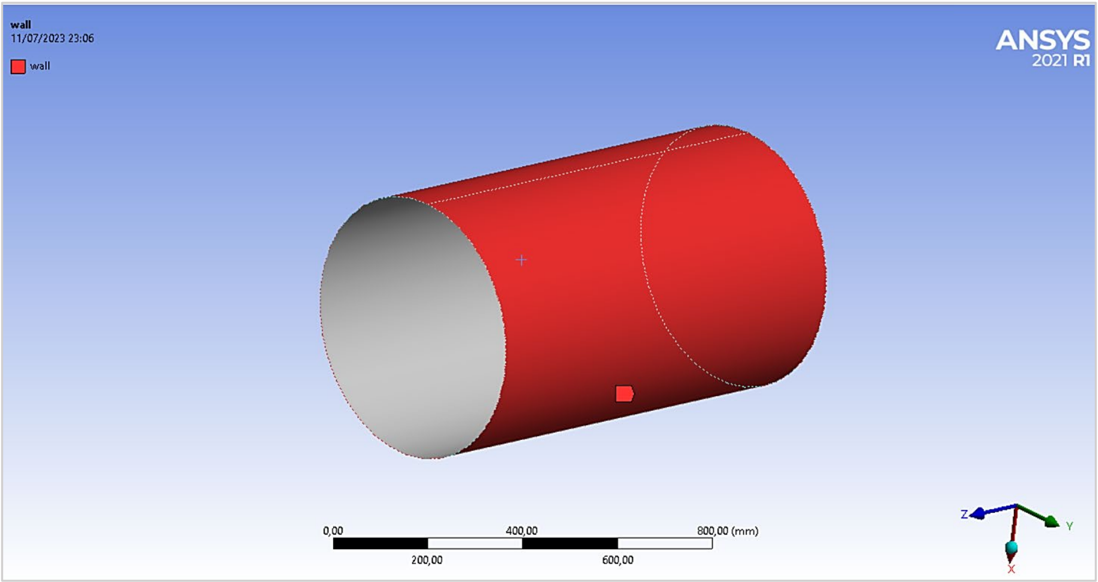

Figure 4: Wall

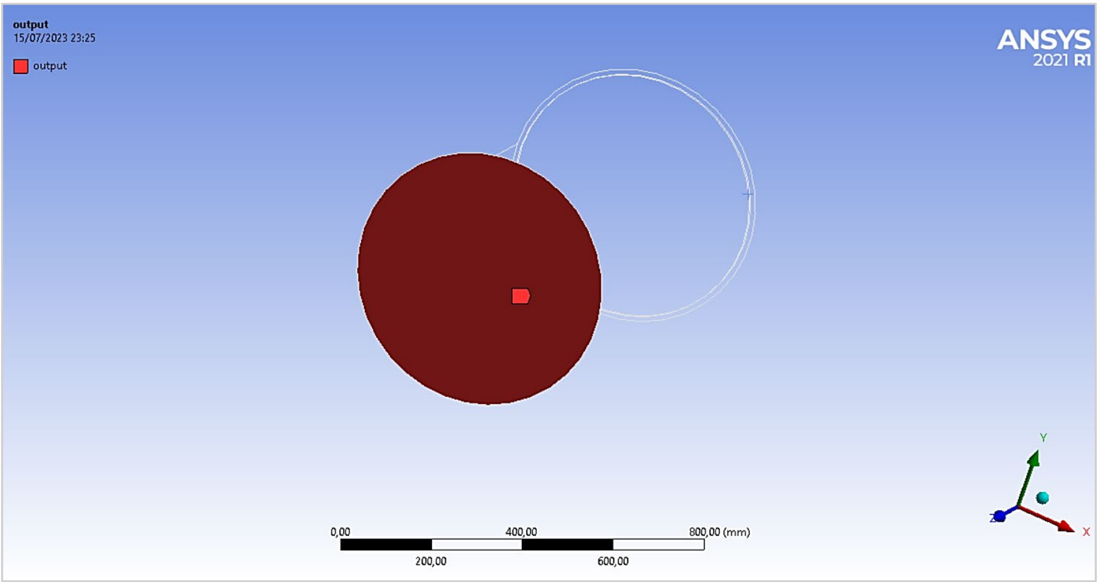

Figure 5: Output

2.2.1.2 Meshing

The independent test is crucial to determine the optimal number of cells for the simulation flow. While increasing the number of cell meshes improves result accuracy, computational time also increases significantly. Figure 6 showcases this test, ensuring mesh refinement has minimal impact on numerical outcomes through the Courant number (ratio of timestep to fluid transit time across a cell). Figure 7 and Table 2 show the mesh results and details of the properties.

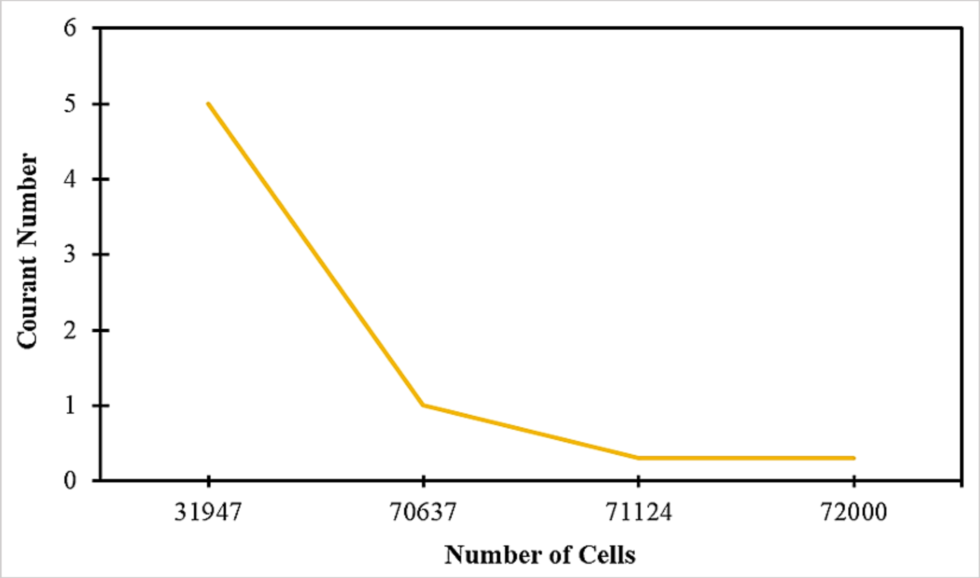

Figure 6: Courant Number during Mesh Testing

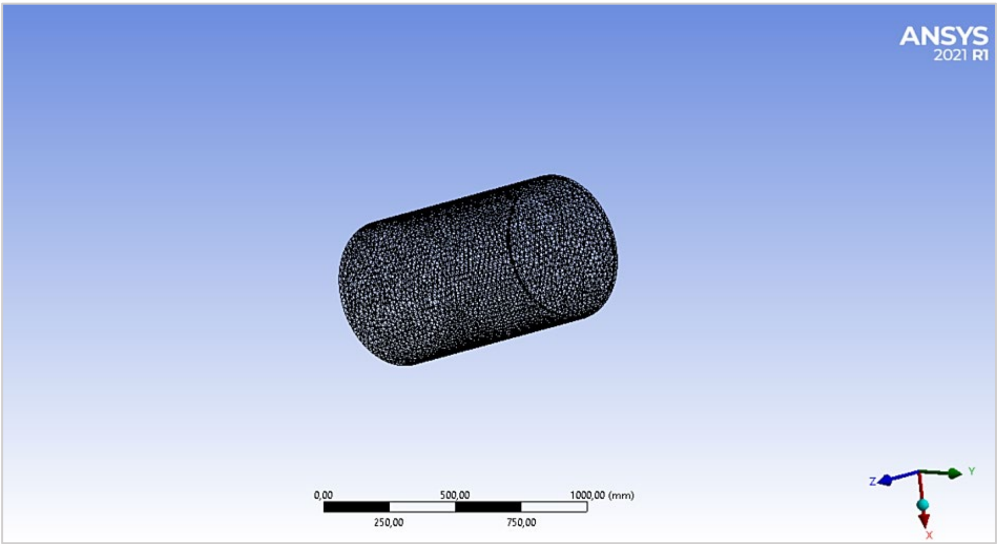

Figure 7: Meshing

Table 2: Mesh Properties

No	Geometry	Mesh Size	Mesh Type	Number of Nodes	Number of Cells
1	Inlet	25 mm	Tetrahedral	13510	71124
2	Wall	25 mm			
3	Output	25 mm			

2.2.2 Processing

2.2.2.1 The governing equations

The governing equation for temperature distribution analysis in an incinerator reactor is the energy equation derived from energy conservation. This equation for the transfer of thermal energy within the reactor due to:

- Convection: Movement of the hot combustion gases within the reactor.
- Conduction: Heat transfer through direct contact between the hot gases and the reactor walls.

The energy equation can be written in various forms depending on the specific assumptions made. A transient (time-dependent) analysis and viscous effects are shown in Equation 1.

$$\frac{\partial T}{\partial t} + \left(\frac{u \cdot \partial T}{\partial x}\right) + \left(\frac{v \cdot \partial T}{\partial y}\right) + \left(\frac{w \cdot \partial T}{\partial z}\right) = \alpha \cdot Laplacian\ (T) + Q_v \quad (1)$$

where , T: Temperature, t: Time, u, v, w: Velocity components in x, y, and z directions (obtained from the Navier-Stokes equations), α: Thermal diffusivity of the gas mixture, $Laplacian\ (T)$: Laplacian operator, representing diffusion in all directions, Q_v: Volumetric heat source (represents heat generation due to combustion)

2.2.2.2 Determining in general

Starting from the pressure-based solver type, absolute velocity formulation with time transient.

2.2.2.3 Models

Modeling uses energy and viscosity with SST k-omega.

2.2.2.4 Defining materials

The incinerator reactor (wall) material uses steel. Meanwhile, the reactor cover (output) uses aluminum. The selection of steel for the reactor incinerator and aluminum for the reactor cover is based on the optimal material properties for each part's operating conditions and functionality. Steel is chosen for its high mechanical strength, thermal resistance, and corrosion resistance. Aluminum was chosen because it is light, corrosion-resistant, and has high thermal conductivity. The material's properties are from the Fluent database shown in Table 3.

Table 3: The Materials Properties

	Properties		
Materials	**Density (kg/m^3)**	**Specific Heat (J/kg K)**	**Thermal Conductivity (W/m K)**
Steel	8030	502.48	16.27
Aluminium	2719	871	202.4

2.2.2.5 Boundary conditions

The inlet boundary condition specifies a flow velocity of 5.1 m/s and a temperature of 723 K. At the reactor cover (output) boundary condition, convection heat transfer is modeled with aluminum as the wall material and the surrounding temperature is set to 300 K. Reactor incinerator (wall) are modeled with convection heat transfer, using steel as the wall material and a surrounding temperature of 300 K.

2.2.2.6 Solution

The solution method, initialization, and run calculation are determined at this stage. The type of solution method used in this research is shown in Table 4. The simulation will calculate the solution to the governing equation for each point in the simulation domain.

Table 4: Solution Methods

No	Solution Methods	Types
1	Pressure-velocity coupling	SIMPLE
	Spatial Discretization	
	a. Gradient	Least Squares Cell-Based
	b.Pressure	Second Order
2	c.Momentum	Second Order Upwind
	d.Turbulent Kinetic Energy	Second Order Upwind
	e.Spesific Dissipation Rate	Second Order Upwind
	f.Energy	Second Order Upwind

2.2.3 Post processing

The post-processing stage in numerical simulation converts numerical data into useful information:

a. Visualization converts data into an easy-to-understand format, such as graphs and diagrams.
b. The analysis extracts essential information from the visual data.
c. Interpretation connects the results of the analysis to actual physical phenomena.

2.3 Electricity

The thermoelectric used is TEG SP1848 27145 SA. with an output max of 4.18 V and 699 mA. Size: 40 mm x 40 mm x 3.4 mm, see Figure 8.

Based on Table 5, the 100 °C thermoelectric heat source was used to shorten battery charging time. With this setup, each thermoelectric unit generated 4.18 V and 669 mA. The total output was significantly amplified since six units were connected in parallel.

Figure 8: TEG SP1848 27145 SA

Table 5: Open circuit voltage and current from thermoelectric temperature variations

Temperature (°C)	Open Circuit Voltage	Current
20	0.97 V	225 mA
40	1.8 V	368 mA
60	2.4 V	469 mA
80	3.6 V	558 mA
100	4.18 V	669 mA

3. Results and discussion

3.1 The numerical results

3.1.1 Temperature distribution

This research successfully modeled the distribution of temperature (affecting electrical energy) for the distribution of thermoelectric output electrical energy. The CFD simulation on the incinerator aims to determine the flow direction, flow speed, and temperature distribution in the incinerator reactor. The air resulting from burning waste that flows in the combustion chamber experiences changes in temperature and speed [19]. The following is the incinerator reactor geometry's YZ plane temperature contour.

When combustion occurs in an incinerator reactor, a temperature distribution pattern emerges with the highest temperature found in the inlet area, which is the starting point of combustion. This temperature will then flow throughout the reactor room. The condition that occurs in Figure 9, temperature distribution at 10 seconds contour visible in the incinerator reactor, is said to be in the preheat phase with a temperature of 723 K. Because it is still in the preheat phase, the condition of the combustion chamber, which is not close to the combustion point is still at room temperature, namely 300 K. So it can be said that new heat transfer occurs around the preheat area.

In Figure 10, the temperature distribution contour appears at 33 seconds. The heat flow movement in the reactor flows from the heat center to all spaces in the reactor. The reactor walls experience heat transfer by convection caused by hot air flow from combustion. Furthermore, in Figure 11, the temperature distribution contour appears at 64 seconds. Heat transfer has occurred maximally in the reactor. All outer reactor walls experience heat transfer by conduction caused by the flow of hot combustion air, which spreads throughout the combustion chamber with a temperature of 723 K and a temperature on the output wall of 395 K to 412 K.

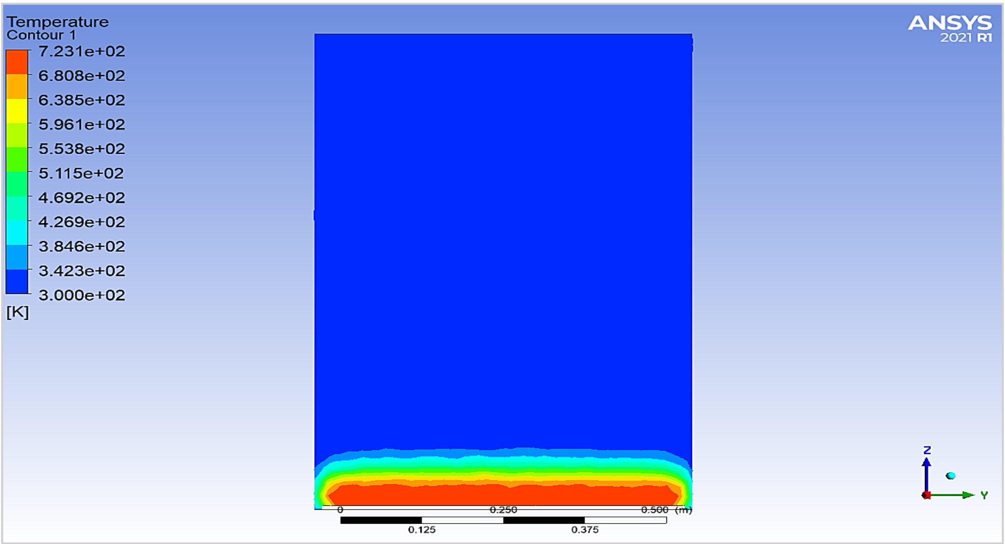

Figure 9: Temperature Distribution at 10 Seconds

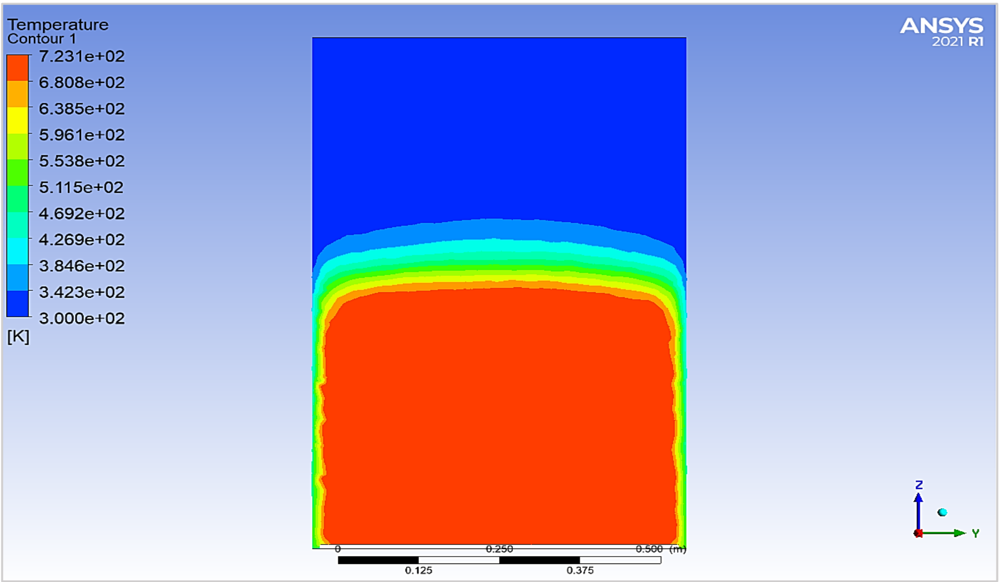

Figure 10: Temperature Distribution at 33 Seconds

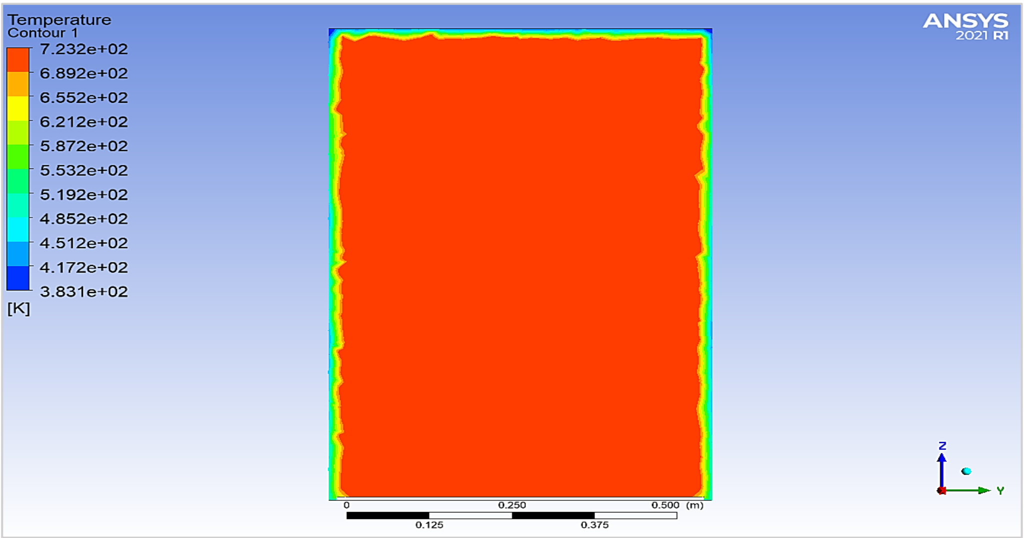

Figure 11: Temperature Distribution at 64 Seconds

Airflow and heat flow dynamics within the incinerator reactor were revealed through the simulation results as combustion begins, see Figure 12, and the air velocity peaks in the inlet area, reaching 5.1 m/s. This high velocity initially concentrates around the burning point, but as combustion progresses, Figure 13, heat flow dominates, spreading from the center outwards. This flow encounters the reactor walls, generating turbulence at the outlet. By the end of the process, as shown in Figure 14, the air velocity has been distributed across the entire chamber, with variations ranging from 2.55 m/s at the top to 3.825 m/s near the center. The continuous interplay between combustion and turbulence ensures sustained hot air circulation within the reactor [20].

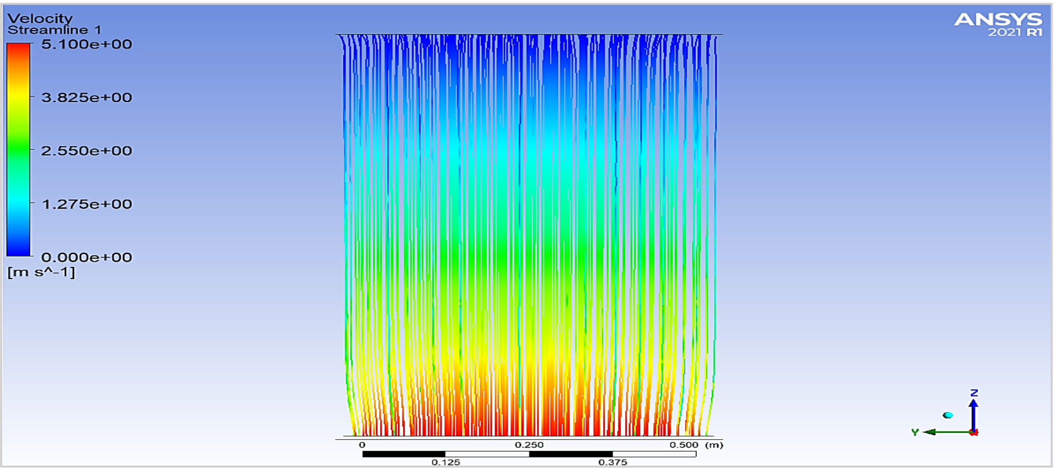

Figure 12: Velocity Streamline at 10 Seconds

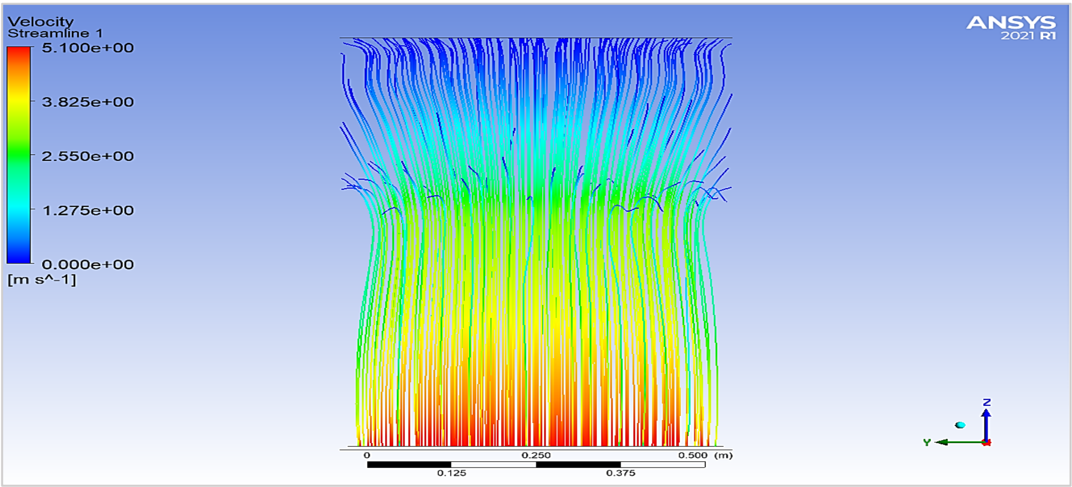

Figure 13: Velocity Streamline at 33 Seconds

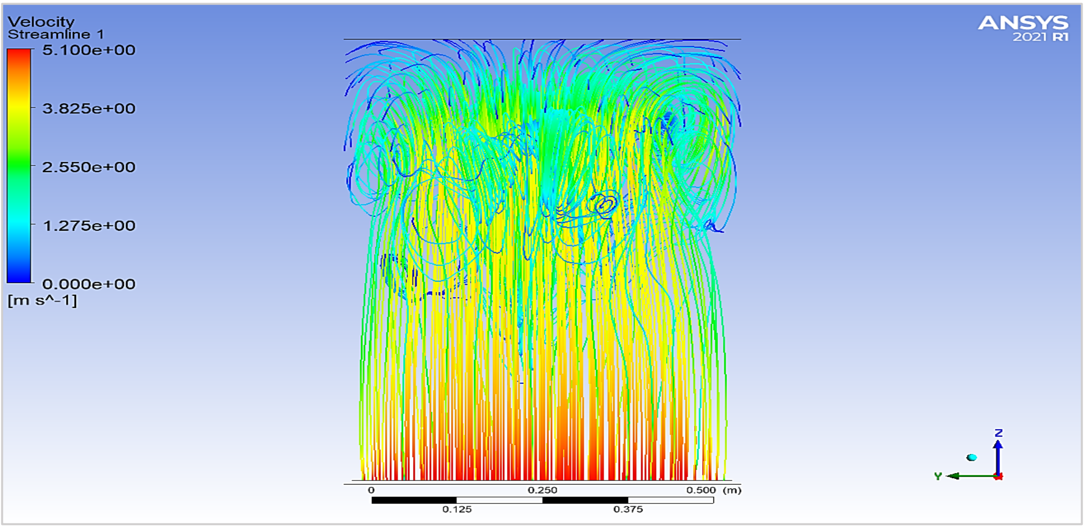

Figure 14: Velocity Streamline at 64 Seconds

3.2 The experimental results

3.2.1 Water content

The waste used in this experiment consisted of two types, namely organic waste and inorganic waste. The organic waste is dried leaves, while the inorganic waste is used in Polyethylene Terephthalate (PET) plastic bottles. The results of testing the water content of the two types of waste can be seen in Table 6. The loss-on-drying method tested water content with a Sartorius MA 30 moisture analyzer.

Table 6: Water content of organic and inorganic waste

No.	Waste Type	Water Content (%)
1	Organic	13.93%
2	Inorganic	2.39%

3.2.2 Calorific value

The calorific value of waste was tested using a digital bomb calorimeter. The results of testing the calorific value of waste are presented in Table 7.

Table 7: Calorific Value of Organic and Inorganic Waste

No	Waste Type	Sample Mass (g)	Initial Temperature (°C)	Final Temperature(°C)	Temperature Difference (°C)	Calorific Value (cal/gram)
1	Organic	1	25.8	27.8	2	5327.76
2	Inorganic	1	26.2	30.26	4.06	10846.58

3.2.3 Incineration temperature of organic waste

The burning process uses organic waste that has been dried for one day. Figure 15 shows the temperature rise from 69 ºC to 181 ºC from the 5th to the 25th minute. In the 30th minute, the temperature decreased to 158 ºC. This decrease can be attributed to fuel depletion and moisture content. As the organic waste burns out, the heat production diminishes, leading to a temperature drop. When organic waste burns, it releases heat and stores it in chemical bonds [21]. As the waste depletes, there's less fuel to break down and release heat. This decline in heat production can't keep up with the heat lost to the environment, causing the temperature to drop. Even after drying, organic waste can still contain moisture. This moisture absorbs heat energy for evaporation during combustion, reducing the available heat for raising the temperature. Even after drying, moisture remaining in organic waste significantly reduces the achievable incineration temperature. Water's high heat capacity demands more energy to raise its temperature than organic material. Furthermore, during combustion, the water absorbs heat as it transitions from liquid to vapor (evaporation). This heat absorption for evaporation reduces the available heat to raise the overall temperature within the incinerator. Additionally, moisture effectively lowers the amount of usable fuel, as only the organic portion contributes to heat generation [22].

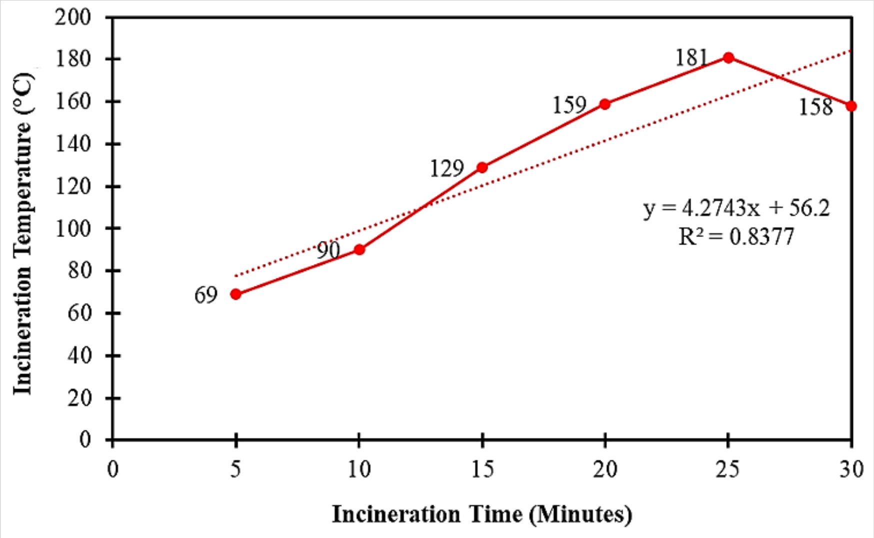

Figure 15: Incineration Temperature of Organic Waste during Experimental Tests

3.2.4 Incineration temperature of inorganic waste

Inorganic waste demonstrably achieves a higher and more sustained combustion temperature than organic waste, as shown in Figure 16. The temperature rise from 68 ºC to 210 ºC between the 5th and 25th minutes, followed by a minimal decrease to 198 ºC at the 30th minute, highlights this advantage. This disparity can be attributed to several key scientific principles:

3.2.4.1 Absence of Significant Moisture Content

Unlike organic waste, which often retains moisture even after drying, inorganic waste typically has minimal water content. This is a crucial factor as water possesses a high specific heat capacity. A high specific heat capacity signifies greater energy is required to raise the water temperature than an equal organic material mass [23]. During organic waste combustion, a portion of the heat released is used for water evaporation, a phase change requiring latent heat of vaporization. This energy is not available to increase the overall temperature within the incinerator.

3.2.4.2 Combustion Efficiency

Moisture in organic waste effectively reduces the amount of usable fuel. Inorganic waste, lacking significant moisture, offers a higher effective fuel content, leading to a more efficient combustion process and a higher achievable temperature.

3.2.4.3 Calorific Value

Different materials possess varying inherent energy content, known as calorific value. Inorganic materials have higher calorific values than organic materials, see Table 7. This implies that inorganic waste releases more heat energy during combustion per unit mass, contributing to a higher peak temperature within the incinerator.

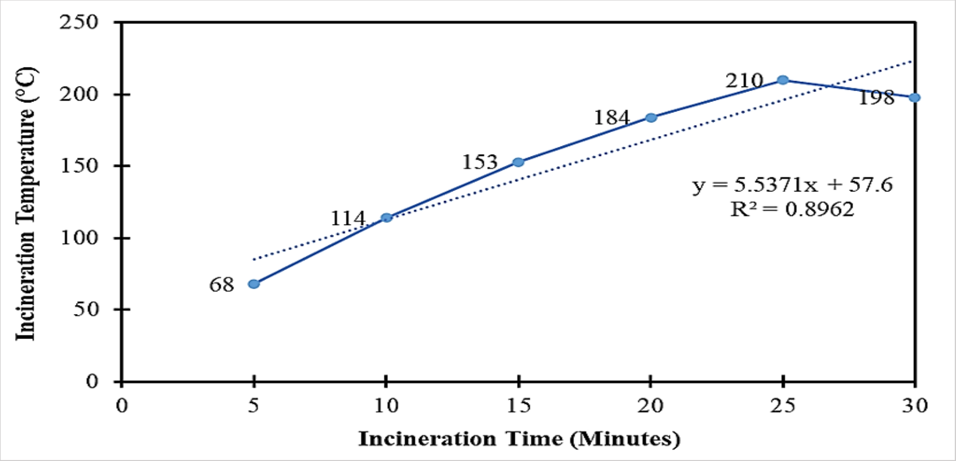

Figure 16: Incineration Temperature of Inorganic Waste during Experimental Tests

3.2.5 Organic waste incineration voltage

Figure 17 shows the relationship between temperature and voltage produced in the combustion process using an incinerator. At the 5th minute, with a temperature of 69 ºC, the resulting voltage is 0.7 V. The voltage continues to increase as the temperature increases. In the 25th minute, when the temperature reached 181 ºC, the resulting voltage came to 2.1 V. After that, the voltage decreased in the 30th minute to 1.6 V as the temperature dropped to 158 ºC. Voltage is obtained by utilizing heat from the combustion process to heat the hot side of the thermoelectric. The cold side of the thermoelectric is cooled with a water block to produce a temperature difference. This temperature difference creates a potential difference, which makes an electric current. The light connected to the thermoelectric circuit turns on starting at the 25th minute and continues to light for 5 minutes afterward. This shows that the light can turn on when the voltage reaches 2.1 V.

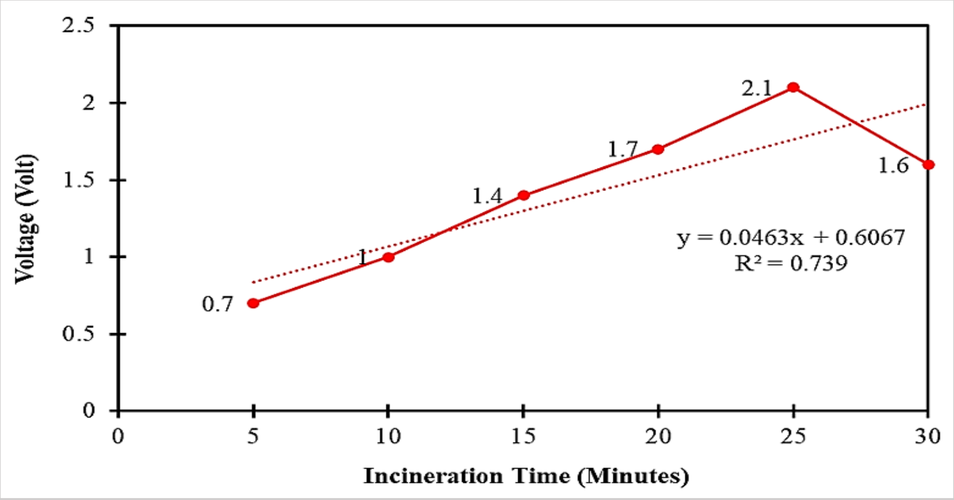

Figure 17: Organic Waste Incineration Voltage during Experimental Tests

3.2.6 Inorganic waste incineration voltage

Figure 18 compares the voltage produced in the combustion process using inorganic and organic waste. At the 5th minute, with a temperature of 68 °C, combustion with inorganic waste has a voltage of 0.9 V. This voltage continues to increase as the temperature increases. In the 25th minute, when the temperature reached 210 °C, the resulting voltage came to 2.2 V. After that, the voltage decreased slightly in the 30th minute to 2.1 V. Compared to inorganic waste, the voltage produced by organic waste is lower. At the 5th minute, with the same temperature (68 °C), the voltage produced was only 0.7 V. This voltage continued to increase until it reached 1.8 V at the 25th minute (temperature 181 °C) and then dropped to 1.6 V at 30 minutes (temperature 158 °C). The reduction in voltage during combustion with inorganic waste is not very significant compared to organic waste because the heat produced in the combustion process is still stored in the incinerator tube. The light connected to the thermoelectric circuit turns on starting at the 25th minute and continues to light for 11 minutes. This indicates that the light will remain on if the voltage exceeds 2 V.

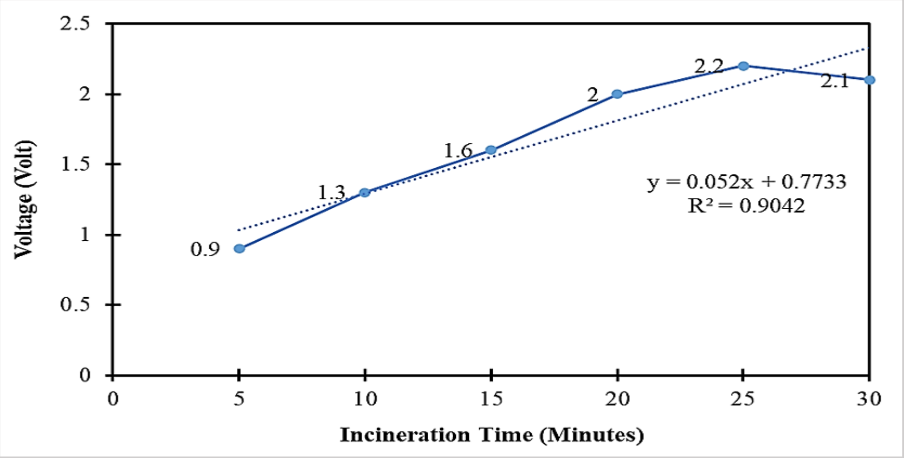

Figure 18: Inorganic Waste Incineration Voltage during Experimental Tests

3.2.7 Ash yield

Burning 5 kg of organic and inorganic waste in an incinerator reactor produces different ash results. From 5 kg of organic waste, 1.4 kilograms of ash remains (28%), indicating that 72% of the mass has been converted into heat energy and gas. Meanwhile, 5 kg of inorganic waste produces 1.61 kilograms of ash (32%), indicating that 68% of the mass has been converted into heat and gas energy. Both types of waste show a somewhat effective combustion process. Organic waste produces less ash, indicating a higher mass conversion efficiency into heat and gas energy. Several factors, such as waste composition and water content, can cause this. Dried leaves contain more water and volatiles (13.93%), so they burn more efficiently and produce less ash. Additionally, dried leaves with high water content have less ash.

Table 8 presents a comparison of current research incinerators with previous research. The latest incinerator innovations offer several advantages over previous models. Based on prior research on thermoelectric incinerators, the scale and efficiency of converting heat into electricity have not been optimal [11,12,13]. The heat from combustion is converted into electrical energy through the Seebeck effect. Thermoelectrics are practical and space-saving but have lower conversion efficiency.

Table 8: Comparison of current research with previous research

No	Incinerator Type	Fuel	Incineration Temperature (°C)	Voltage (V)	Incineration Time (Minutes)	Ref.
1	Thermoelectric	Organic waste 2.5 kg	125	4.7	40	[13]
2	Thermoelectric	Organic waste 1 kg	300	18.10	40	[12]
3	Thermoelectric	Coconut fibre and shell 2 kg	78	12.4	30	[11]
4	Thermoelectric	Organic waste (dried leaves) Inorganic waste (PET) 5 kg	181 210	2.1 2.2	30	Current research

The prototype incinerator presented in this research offers a superior solution for waste management. Its advantages include:

- Combustion capacity: 10 kg/hour, effectively processing moderate waste.
- Waste reduction: 72% for organic and 68% for inorganic waste, demonstrating the effectiveness of incineration in reducing waste volume.
- Space-saving: The modular design, which is easy to assemble and disassemble, makes it ideal for limited areas.
- Fuel flexibility: It can utilize various fuel types, such as organic, inorganic, and biomass, making it more adaptable.
- Environmentally friendly: Flue gas emissions meet quality standards, minimizing air pollution impacts.

Despite these advantages, one drawback is the lack of a water circulation system in the cold side water block. Further development is needed to address this limitation and optimize the incinerator's performance.

Overall, the latest incinerator innovation has the potential to become an efficient, environmentally friendly, and flexible waste management solution suitable for various scales and conditions.

4. Conclusion

This research investigated the feasibility of a 10 kg/hour capacity thermoelectric incinerator prototype for waste management in Indonesia. The prototype demonstrated the potential to convert waste heat into electricity, with Computational Fluid Dynamics (CFD) simulations (Ansys Fluent 2021 R1) aiding in optimizing temperature distribution and air/heat flow. Experimental incineration of organic and inorganic waste mixtures (5 kg each) revealed the influence of waste properties on performance. Organic waste (13.93% water content, 5327.76 cal/gram calorific value) reached a combustion temperature of 181℃. It generated a maximum voltage of 2.1 V. Conversely, inorganic waste (2.39% water content, 10846.58 cal/gram calorific value) achieved a higher combustion temperature (210 ℃) and voltage (2.2 V). Both waste types exhibited significant volume reduction (72% organic and 68% inorganic), highlighting the prototype's effectiveness. Moreover, the higher water content in organic waste limits its combustion temperature and voltage generation compared to inorganic waste, which has a lower water content and higher calorific value. This research demonstrates the potential of the thermoelectric incinerator prototype for waste management. The prototype offers advantages such as high waste reduction, modular design, and the ability to handle various waste types. Further research is recommended to optimize design for efficiency, investigate scalability, and analyze economic viability for large-scale applications.

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Author contributions

Conceptualization, Y. Sofi'i.; data curation, R. Hidayatulloh.; formal analysis, R. Zaroby.; investigation, M. Budiman.; methodology, G. As'adi.; project administration, R. Hendaryati, resources, A. Rahmandhika.; software, Suwarsono.; supervision, Y. Sofi'i.; validation, Sudarman.; visualization, W. Nugroho.; writing—original draft preparation, R. Hidayatulloh, G. As'adi, M. Budiman, and R. Zaroby.; writing—review and editing, Y. Sofi'i. All authors have read and agreed to the published version of the manuscript.

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Data availability statement

Not applicable.

Conflicts of interest

The authors of the current work do not have conflict of interest

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