Journal of Global Engineering Research & Science (J-GERS)
Vol. 05, No. 01, June 2026, pp. 1-9
ISSN: 2830-5906, e-ISSN: 2830-5418, DOI: 10.56904/j-gers.v5i1.196

Effectiveness Analysis of Organic and Inorganic Waste Combustion in a Household Incinerator

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Article Info

Article history:

Received April 04, 2026
Revised June 05, 2026
Accepted June 25, 2026

Keywords:

Incinerator
Solid Waste Incineration
Waste Combustion
Thermal Treatment
Waste Volume Reduction

ABSTRACT

Waste burning is commonly practiced by communities in open areas, particularly within residential environments, often resulting in inefficient combustion and potential environmental impacts. This study aims to evaluate the combustibility of different types of household waste under open burning conditions and compare it with the performance of a proposed small-scale incinerator. The investigated waste types include wet leaf litter, dry leaf litter, food waste, plastic waste, and mixed waste, with variations in mass from 250 g, 500 g, and 750 g. Key parameters observed include combustion temperature, combustion duration, and burning behavior. The results indicate that moisture content and material composition significantly influence combustion performance. Wet leaf litter and food waste were classified as non-combustible under open burning conditions due to their high moisture content, which inhibits ignition. In contrast, dry leaf litter and plastic waste demonstrated good combustibility, achieving higher temperatures and longer combustion durations. Mixed waste exhibited moderate and inconsistent combustion characteristics due to its heterogeneous composition. In comparison, the proposed small-scale incinerator demonstrated superior performance, achieving a maximum temperature of 432°C and maintaining an operating temperature of approximately 421°C. Additionally, increasing the mass of waste generally led to longer combustion durations and, in some cases, higher temperatures. Overall, the findings highlight that open burning is less efficient for wet and mixed waste and may contribute to incomplete combustion and pollutant emissions. Therefore, pre-treatment methods such as drying and sorting, as well as the use of controlled combustion systems like incinerators, are recommended to improve combustion efficiency and reduce environmental impacts.

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1. INTRODUCTION

Waste has become a major problem in almost all countries, including Indonesia, with its volume continuously increasing in line with population growth. In general, waste can be defined as the residual output of a product or activity whose utility value has decreased, resulting in it no longer being reused and instead discarded [1]. Daily activities generate both organic and inorganic waste which, if not properly managed, will accumulate, produce unpleasant odors, and negatively affect cleanliness, safety, public health, and the environment [2]. Rapid population growth and urbanization in developing regions have led to a significant increase in municipal solid waste generation; however, this growth is often not matched by adequate collection and treatment facilities, resulting in environmental pollution and heightened public health risks [3].

Improper waste disposal further exacerbates environmental pollution, influenced by limited facilities, insufficient knowledge, and low public awareness. Generally, waste management is carried out through landfilling, recycling, or open burning. However, open burning is considered ineffective as it produces air-polluting smoke and is difficult to implement, especially during the rainy season. In addition to technical factors, waste management practices are also shaped by social and cultural habits that regard burning as an acceptable practice, despite its potential negative environmental impacts [4]. On a larger scale, the traditional use of waste incinerators is also associated with several challenges, including the potential emission of toxic pollutants such as dioxins that pose risks to human health and the environment [5], as well as technical issues such as high-temperature corrosion that may lead to material degradation due to prolonged heat exposure [6].

Therefore, more effective, affordable, and easily implementable waste treatment solutions are required. One potential technology is the incinerator, a waste treatment device that operates through combustion in a closed chamber at high temperatures ranging from approximately 300°C to 1,000°C, enabling significant volume reduction within a relatively short time and contributing to a substantial decrease in pollutant levels [7]. The process occurring within this device is known as incineration, a high-temperature waste treatment method that not only effectively reduces waste volume but also destroys toxic substances and pathogens while offering the potential for energy recovery through a waste-to-energy system [8]. This method has been proven to reduce waste volume by up to 90% and mass by up to 70%, while simultaneously enabling the conversion of thermal energy into electricity, thereby reducing dependence on landfills and supporting the waste-to-energy concept [9]. Furthermore, the implementation of small scale incinerators in community settings is considered more practical, as it minimizes harmful emissions compared to open burning and reduces the risks of pollution and health disturbances [10]. Small-scale incinerators are also designed to be more efficient and environmentally friendly through controlled high-temperature combustion systems [11]. Moreover, the development of automatic combustion control systems allows the process to operate more stably and optimally, including in the utilization of the generated thermal energy [12]. However, limited studies have compared the combustion behavior of different household waste types under open burning and small-scale incinerator conditions using temperature, combustion rate, and ash yield as performance indicators. Therefore, this study aims to evaluate the combustibility of different types of household waste under open burning conditions and compare it with the performance of a proposed small-scale scale incinerator.

2. METHOD

This study employed an experimental approach to evaluate the performance of the incinerator in combusting various types of household waste based on temperature, combustion rate, and ash yield parameters. The experimental setup utilized a custom-fabricated incinerator show in figure 1. The main body of incinerator consists of a cylindrical combustion chamber with a radius of 200 mm, and a vertical height of 490 mm. It's fabricated from high-grade refractory-lined mild steel to withstand high-temperature thermal degradation. For waste feeding, the chamber features a front entry door measuring 250 mm in width and 100 mm in height. At the top of the main chamber, an exhaust stack or chimney is installed with a height of 300 mm and a diameter of 150 mm to facilitate proper ventilation. To ensure optimal thermal performance, the incinerator is equipped with an automated auxiliary oil/gas burner mounted at the lower section of the main chamber to maintain stable combustion temperatures. The air supply system utilizes a controlled forced-draft configuration, introducing primary combustion air through the bottom intake manifold to maximize waste-to-oxygen contact. Additionally, a high-temperature Type-K thermocouple is strategically positioned in the upper zone of the primary chamber, just below the exhaust stack connection, to provide accurate, real-time temperature monitoring for safety and process control.

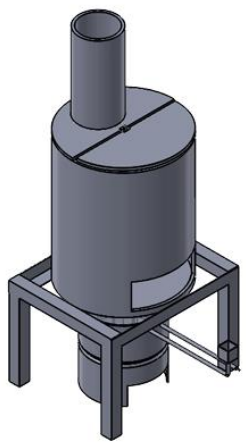

Figure 1. Custom Fabricated Incinerator

The research methodology employed in this study is illustrated in the flowchart shown in Figure 2. Prior to testing, the waste was classified into five categories: wet leaf litter (WLL), dry leaf litter (DLL), plastic waste (PW), food waste (FW), and mixed waste (MW). Each type of waste was prepared with mass variations of 250 g, 500 g, and 750 g. The combustion process was conducted using the designed incinerator, with heat supplied by a burner fuelled by waste oil. The combustion temperature was measured using a Type-K thermocouple positioned inside the combustion chamber, while the combustion time was recorded from ignition until the waste was completely burned.

The obtained data were then used to calculate the performance parameters. The combustion rate (CR), which represents the mass loss per unit of time, was calculated using Equation (1), where CR is combustion rate (g/hour), m_i initial mass (g), m_f is final mass (g) dan Δt is combustion time (second).

$$CR = \frac{m_i - m_f}{\Delta t} \tag{1}$$

while the ash yield was calculated as the percentage ratio of ash mass to the initial waste. where AY represents the ash yield (%) and m_{ash} is the mass of the residual ash remaining after complete combustion.

$$Ay = \left(\frac{m_{ash}}{m_i}\right) x100\% \tag{2}$$

The experimental results were analyzed comparatively to examine the influence of waste type and mass variation on combustion performance. In addition, temperature distribution was observed to evaluate heat propagation patterns and identify potential hotspot formation during the combustion process. This approach enables the identification of the most optimal waste type and operating condition in terms of combustion efficiency and thermal performance.

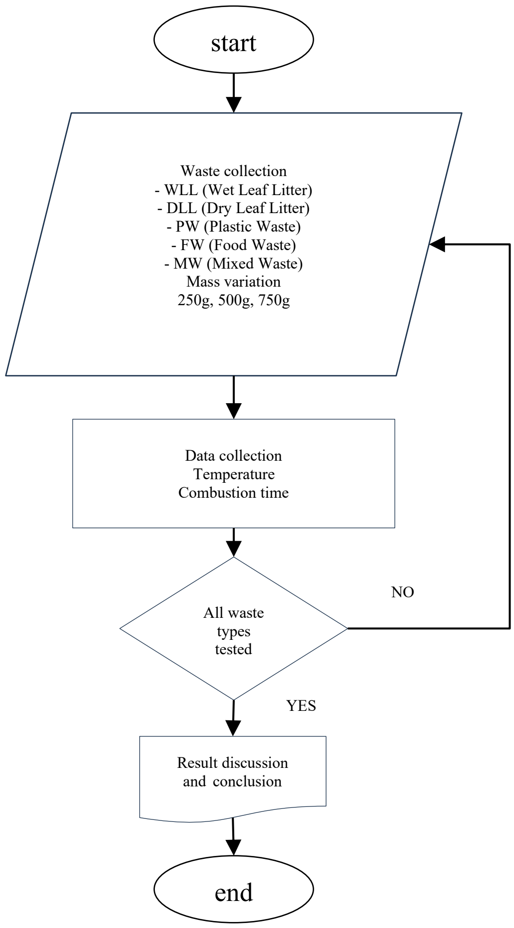

Figure 2. Research Flowchart

3. RESULTS AND DISCUSSION

3.1 Conventional Waste Burning in the Environment

Waste burning is commonly carried out by communities in open areas, usually within residential yards. In evaluating the performance of this device, combustion measurements were conducted under typical community conditions to compare conventional open burning practices with combustion using the proposed incinerator. The results of the data collection for conventional community burning are presented in Table 1.

Table 1. Combustibility of Different Waste Materials under Open Burning Conditions

Waste Categories	Weight (g)	Temperature (°C)	Time (s)	Description
Wet leaf litter (WLL)	250	-	-	Difficult to ignite
	500	-	-	Difficult to ignite
	750	-	-	Difficult to ignite
Dry leaf litter (DLL)	250	146	306	Combustible
	500	151	498	Combustible
	750	188	486	Combustible
Plastic waste (PW)	250	159	282	Combustible
	500	164	438	Combustible
	750	169	558	Combustible
Food Waste (FW)	250	-	-	Difficult to ignite
	500	-	-	Difficult to ignite
	750	-	-	Difficult to ignite
Mixed Waste (MW)	250	137	534	Combustible
	500	129	606	Combustible
	750	143	924	Combustible

Table 1 shows that under open burning conditions, wet leaf litter (WLL) and food waste (FW) are classified as difficult to ignite, as they fail to ignite under the tested conditions. This behavior is primarily attributed to their high moisture content, which absorbs a significant portion of the supplied heat energy and inhibits the temperature from reaching the ignition point. In such cases, the presence of water necessitates an initial evaporation phase before combustion can occur, rendering these materials unsuitable for direct burning without prior drying. In contrast, dry leaf litter (DLL) is categorized as combustible and exhibits favorable burning characteristics. As the mass increases from 250 g to 750 g, both the combustion temperature (from 146°C to 188°C) and combustion duration (from 306 s to 486 s) increase. This trend indicates that larger quantities of dry biomass can sustain combustion for longer periods and achieve higher temperatures due to increased fuel availability and improved heat retention. The absence of moisture plays a crucial role in enhancing ignition and overall combustion efficiency [13].

Plastic waste (PW) is also identified as combustible, demonstrating relatively stable combustion temperatures ranging from 159°C to 169°C, along with increasing combustion durations as the mass increases (from 282 s to 558 s). This behavior is associated with the high calorific value of plastic materials, which supports sustained heat generation during combustion. However, it is important to note that open burning of plastics poses significant environmental risks due to the potential release of toxic emissions. Mixed waste (MW) is likewise classified as combustible, but it exhibits less consistent combustion behavior. The recorded temperatures fluctuate between 129°C and 143°C, while combustion time increases substantially with mass (from 534 s to 924 s). This variability suggests that the heterogeneous composition of mixed waste, which consists of both combustible and non-combustible or high moisture components, leads to uneven burning performance.

Overall, the results indicate that moisture content and material composition are the primary factors influencing combustibility under open burning conditions. Dry and homogeneous materials tend to burn more efficiently, whereas wet or mixed waste require pre-treatment, such as drying or sorting, to enhance combustion performance [14]. Additionally, increasing the mass of waste generally results in longer combustion durations and, in many cases, higher temperatures due to sustained heat generation. Furthermore, inefficient combustion processes have the potential to generate harmful pollutant emissions, such as particulate matter and persistent organic compounds, which may adversely affect human health and ambient air quality in the surrounding areas.

3.2 Temperature Measurement

To evaluate the performance of the device, the combustion temperature produced by the incinerator was measured using a thermocouple. The experiment was carried out under no-load conditions (without waste) to determine the baseline combustion temperature generated by the unit. This approach is important because measuring under no-load conditions allows researchers to isolate the thermal characteristics of the incinerator itself, without interference from varying waste compositions. By establishing a baseline combustion profile, it becomes possible to assess the efficiency of the chamber design, ignition system, and airflow management. These findings provide a foundation for further studies under loaded conditions, where the influence of different waste types on combustion stability and temperature can be compared against the baseline data.

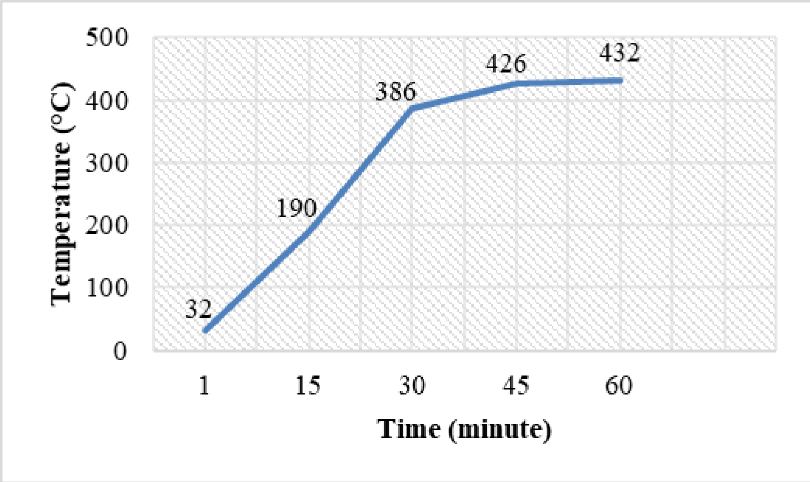

Figure 3. Temperature in combustion without waste

The combustion profile shown in the figure 3 that highlights three distinct phases of incinerator operation. In the first 15 minutes, the rapid rise from ambient temperature to nearly 200°C reflects the ignition and early combustion stage, where fuel-air mixing and chamber design play critical roles. Between 15 and 30 minutes, the temperature climbs sharply to almost 400°C, indicating vigorous combustion and strong heat release. After 45 minutes, the curve begins to plateau, stabilizing around 430°C, which suggests the system has reached a thermal equilibrium point. From a research perspective, this stabilization is significant because it demonstrates the incinerator's ability to maintain continuous combustion without excessive fluctuations. The maximum temperature achieved demonstrates the system's ability to sustain stable combustion at around 430°C, which is already effective for processing low-calorific and non-hazardous materials. This steady performance highlights the incinerator's reliability and efficiency in maintaining continuous operation. Moreover, the consistent thermal profile provides a strong foundation for future enhancements, including improved insulation, secondary burners, and optimized airflow control, which could elevate the system to meet even stricter environmental and safety standards. In this way, the current research not only confirms the incinerator's capability for safe and efficient waste treatment but also opens promising opportunities for development. The stable combustion curve shows that the design principles are sound, and with targeted improvements, the system can evolve into a more advanced solution capable of handling a wider range of waste types while aligning with international best practices.

3.3 Combustion Rate and Ash Yield

The combustion rate experiment was performed using five waste categories representing the dominant components of typical household waste.

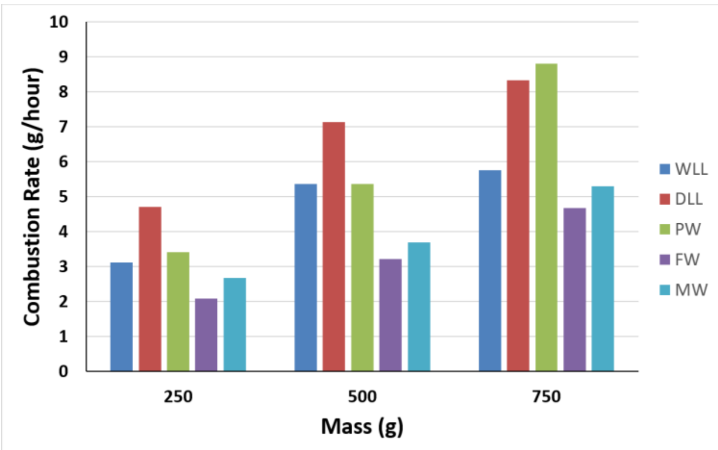

Figure 4. Combustion rate result for different waste categories

The combustion rate results for different waste categories at varying masses (250, 500, and 750 g) are presented in Figure 4. Overall, the results indicate a consistent increase in combustion rate with increasing mass for all waste types. At 250 g, DLL exhibits the highest combustion rate (4.71 g/hour), followed by PW (3.42 g/hour) and WLL (3.125 g/hour), while FW shows the lowest rate (2.08 g/hour). As the mass increases to 500 g, the combustion rates rise significantly, with DLL maintaining the highest value (7.14 g/hour), followed by both WLL and PW (5.37 g/hour), MW (3.7 g/hour), and FW (3.22 g/hour). At the highest mass of 750 g, PW becomes dominant with the highest combustion rate (8.8 g/hour), slightly surpassing DLL (8.33 g/hour), while WLL (5.76 g/hour), MW (5.3 g/hour), and FW (4.68 g/hour) remain comparatively lower. From a performance standpoint, the variation in combustion rates can be attributed to the physical and chemical properties of each waste type. DLL consistently shows high combustion rates due to its low moisture content and higher combustibility, allowing for more efficient burning. PW demonstrates a significant increase at higher masses, likely due to its high calorific value and sustained combustion once ignition is achieved. In contrast, FW consistently records the lowest combustion rates across all masses, which can be explained by its high moisture content that inhibits efficient combustion and requires additional energy for water evaporation. WLL shows moderate performance, as its moisture content is higher than DLL but lower than FW, while MW reflects averaged behavior due to its heterogeneous composition. These findings suggest that waste composition and moisture content play critical roles in determining combustion efficiency, with dry and high-calorific materials yielding superior combustion performance, particularly at higher mass inputs.

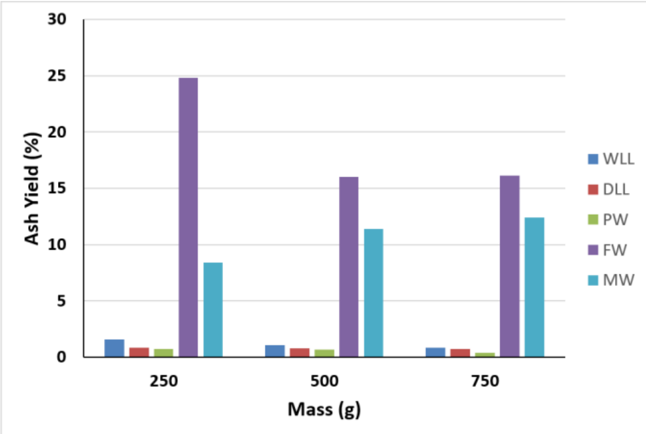

Figure 5. Ash Yield result

The ash yield results presented in Figure 5 show that food waste (FW) and mixed waste (MW) produce significantly higher ash residues compared to other waste categories across all mass variations. For FW, the ash yield is extremely high at 24.8% for 250 g, then decreases to 16% at 500 g and slightly increases to 16.1% at 750 g. Similarly, MW exhibits relatively high ash yield values, increasing from 8.4% (250 g) to 11.4% (500 g) and reaching 12.4% (750 g). This indicates that both FW and MW contain a considerable amount of non-combustible or inorganic material, which remains as residue after the combustion process. From a thermal and material perspective, the high ash yield in FW can be attributed to its inherent composition, which includes organic residues rich in minerals such as salts, calcium, and other inorganic compounds. Additionally, the very high value observed at 250 g suggests possible influences such as high moisture content, incomplete combustion, or contamination (e.g., bones, soil, or other impurities) that contribute to residual mass. In contrast, MW shows a more consistent increasing trend with mass, reflecting its heterogeneous composition, which combines both low-ash materials (e.g., plastics) and high-ash components (e.g., organic waste). The gradual increase in MW ash yield with mass indicates that larger quantities may enhance the accumulation of non-combustible residues and reduce combustion uniformity. Overall, FW demonstrates the highest ash production due to its composition and combustion characteristics, while MW reflects a combined behavior that depends strongly on the proportion of its constituent materials.

3.4 Fuel Consumption

The fuel consumption test was conducted using the actual calculated capacity during the combustion process. The use of an incinerator as a combustion method is considered more effective than open burning because it can reach high temperatures of approximately 500–1,000°C, allowing waste to be reduced to ash within a relatively short period under a more controlled process [13]. The fuel used in this system consists of used waste oil and water. Waste oil serves as the primary fuel, generating the main flame during the combustion process. Meanwhile, the water produces steam that assists in enhancing fuel atomization and projecting the flame, resulting in a more stable and larger combustion zone. Table 2 presents the fuel consumption characteristics of the system.

Table 2. Fuel Consumption

Waste Oil (Liter)	Water (Liter)	combustion time (min)	Oil Consumption (Liter/s)	Water Consumption (Liter/s)
0.75	1.5	105	0.000119048	0.000238095

Table 2 presents the fuel consumption characteristics of the incinerator system using a combination of waste oil and water during the combustion process. The results show that a total of 0.75 liters of waste oil and 1.5 liters of water were consumed over a combustion duration of 105 minutes. The corresponding consumption rates were calculated as 0.000119048 liters/s for waste oil and 0.000238095 liters/s for water, indicating that the water consumption rate is approximately twice that of waste oil. This ratio suggests a controlled fuel–water mixture, which is essential for maintaining stable combustion and supporting atomization within the burner system. From a performance standpoint, the relatively low fuel consumption rate indicates that the incinerator operates efficiently in terms of energy usage while sustaining the combustion process for an extended period. The use of water alongside waste oil likely contributes to improved combustion characteristics, such as better fuel dispersion and temperature regulation, which can help prevent excessive flame temperatures and reduce the risk of thermal damage to the system [15]. Additionally, the longer combustion time (105 minutes) reflects the system's capability to maintain continuous operation with minimal fuel input. Overall, these results demonstrate that the integration of waste oil and water as a fuel source is effective in achieving stable, efficient, and controlled combustion within the incinerator system.

3.5 Effectiveness of Combustion Comparison

This combustion comparison analysis was conducted to evaluate the effectiveness of the incinerator by comparing it with typical community waste burning practices, which are usually carried out in household yards or designated local burning areas. Table 3 presents a comparative analysis between an incinerator-based combustion system and ordinary (conventional) combustion across several categories of waste, focusing on temperature, combustion time, and effectiveness. Overall, the incinerator demonstrates a significantly higher and more consistent combustion temperature (421°C across all tests), which directly influences its ability to process a wider variety of waste materials. In contrast, conventional combustion operates at much lower temperatures (ranging approximately from 129°C to 169°C where applicable), leading to incomplete or inefficient burning for certain waste types. For wet leaf litter, the results clearly show that conventional combustion is ineffective, as the material cannot be burned at all. The incinerator, however, successfully combusts the material, although it requires increasing time as the mass increases (288 s for 250 g up to 474 s for 750 g). This highlights the incinerator's capability to handle high-moisture waste, which is typically difficult to ignite and sustain in open burning conditions. In the case of dry leaf litter, both methods are capable of combustion, but the incinerator performs much more efficiently. The combustion time is significantly shorter, with time savings ranging from 114 to 222 seconds. This indicates that even for easily combustible materials, the higher and stable temperature of the incinerator accelerates the oxidation process.

Table 3. Comparison of Incinerator Combustion with Conventional Combustion

No	Category	Weight (g)	Incinerator		Ordinary combustion		Combustion Time Comparison	Description
			Temp (°C)	Time (s)	Temp (°C)	Time (s)		
1	Wet leaf litter	250	421	288	-	-	-	Difficult to ignite
		500	421	336	-	-	-	Difficult to ignite
		750	421	474	-	-	-	Difficult to ignite
2	Dry leaf litter	250	421	192	146	306	114	Faster in 114 second
		500	421	276	151	498	222	Faster in 222 second
		750	421	324	188	486	162	Faster in 162 second
3	Plastic waste	250	421	264	159	282	18	Faster 18 second
		500	421	336	164	438	102	Faster 102 second
		750	421	306	169	558	252	Faster 252 second
4	Food waste	250	421	462	-	-	-	Difficult to ignite
		500	421	588	-	-	-	Difficult to ignite
		750	421	576	-	-	-	Difficult to ignite
5	Mixed waste	250	421	336	137	534	198	Faster 198 second
		500	421	486	129	606	120	Faster 120 second
		750	421	528	143	924	396	Faster 396 seconds

For plastic waste, a similar trend is observed. The incinerator consistently reduces combustion time compared to conventional methods, with differences ranging from 18 to 252 seconds depending on the mass. This suggests improved thermal degradation of polymers due to the controlled high-temperature environment, which is critical given the environmental concerns associated with incomplete plastic burning. The food waste category further emphasizes the limitations of conventional combustion. Like wet leaves, food waste cannot be burned using ordinary methods, likely due to its high moisture content. The incinerator, however, successfully processes it, although with relatively longer combustion times (462–588 seconds), reflecting the additional energy required to evaporate moisture before combustion can occur. Finally, for mixed waste, the incinerator demonstrates superior performance. While ordinary combustion can process waste, it requires a significantly longer duration, peaking at 924 seconds for a 750 g sample. In contrast, the incinerator effectively reduces the combustion time across all tested weights by 120 to 396 seconds. This demonstrates its effectiveness in handling heterogeneous materials, which typically pose challenges in open burning due to varying ignition and combustion characteristics.

In summary, the incinerator outperforms conventional combustion in all evaluated aspects: it can process a broader range of waste types (including high-moisture materials), operates at a consistently higher temperature, and significantly reduces combustion time. These advantages suggest that incinerator-based systems are more efficient and reliable for waste management, particularly in handling complex and non-uniform waste streams.

4. CONCLUSION

The household-scale incinerator designed and fabricated in this study has been proven capable of burning both organic and inorganic waste more effectively than conventional open burning methods in terms of combustion temperature and duration. This is demonstrated by the device's ability to reach a maximum temperature of 432°C and maintain an operating temperature around 421°C, resulting in a more uniform and controlled combustion process. The combustion performance varies significantly depending on the waste type. Dry leaf litter (DLL) and plastic waste (PW) exhibit higher combustion rates of 8.33 g/h and 8.8 g/h, respectively, due to their lower moisture content. In contrast, food waste (FW) shows lower combustion efficiency and produces a high ash yield of up to 24.8%, while mixed waste (MW) demonstrates intermediate behavior with a combustion rate of 5.3 g/h and an ash yield of 12.4%. Overall, the findings highlight that the proposed incinerator system offers improved combustion efficiency compared to open burning, particularly in terms of achieving higher temperatures and maintaining sustained combustion utilizing waste oil and water as fuel. However, this study is subject to certain limitations, as it did not quantitatively measure the initial moisture content of the waste samples nor the resulting exhaust emissions, such as CO, CO_2, NOx, SOx, particulate matter, or dioxins. Consequently, while the incinerator improves physical thermal parameters, definitive conclusions regarding its quantitative environmental impact and emission reduction compared to open burning cannot yet be drawn. Future work should focus on addressing these limitations by integrating emission control systems, precisely quantifying moisture content pre-treatments, and evaluating flue gas compositions to achieve a fully verified, environmentally friendly, and sustainable waste management solution.

ACKNOWLEDGEMENTS

The authors would like to express their sincere appreciation to all parties who have supported the completion of this study. The support and contributions, both direct and indirect, are greatly acknowledged. The authors also extend their gratitude to the institution and all individuals involved for providing the necessary facilities and assistance. Finally, appreciation is given to the families for their continuous support and encouragement throughout this work.

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