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# Performance and Thermal Efficiency Analysis of A Household-Scale Waste Incinerator without External Fuel

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## ABSTRACT

*Household waste accumulation has become a significant environmental issue in urban areas. This study evaluates the thermal performance and mass-reduction efficiency of a household-scale waste incinerator prototype operating without external fossil fuel under natural-draft airflow. The combustion chamber was fabricated from a cylindrical steel drum equipped with primary air inlets. Mixed household waste (initial mass 5 kg; moisture content 28%) was tested. Temperature was measured using a K-type thermocouple positioned at the chamber centre. The maximum recorded temperature reached 100°C within 40 minutes. Mass reduction reached 25%, calculated based on initial and final mass measurements. The estimated thermal efficiency was 7.1%, determined using a simplified energy balance approach. The results indicate that the prototype operates under low-temperature thermal degradation conditions rather than complete incineration. Design improvements are required to achieve standard incineration temperatures.*

*Keyword: Waste Incinerator; Combustion Performance; Thermal Efficiency; Mass Reduction; Natural Draft*

## 1. INTRODUCTION

The rapid increase in household waste generation presents serious environmental and sanitation challenges, particularly in urban areas (Tang et al., 2025). Conventional disposal methods such as landfilling may contribute to environmental pollution and greenhouse gas emissions (Ren et al., 2025). Thermal treatment through incineration is widely applied to reduce waste volume and improve sanitation performance (Arena, 2012).

Combustion performance in municipal solid waste incinerators is strongly influenced by airflow distribution, combustion stability, and calorific value of waste (Wang et al., 2024). Inadequate combustion conditions may lead to incomplete oxidation and the formation of harmful emissions such as dioxins (Zhang et al., 2019). Small-scale incinerators require proper combustion modelling and operational evaluation to ensure stable performance (Žnidarčič et al., 2023).

Recent studies have emphasised the importance of decentralised waste-to-energy technologies for sustainable waste management (Rahman et al., 2024). However, many community-scale incinerators depend on external fuel supply and forced-draft systems, which increase operational complexity and cost (Gonzalez et al., 2023). Therefore, the development of a fuel-independent incinerator operating under natural draft airflow is relevant for low-cost household waste treatment applications.

This study aims to evaluate the combustion temperature profile, mass reduction percentage, and simplified thermal efficiency of a household-scale waste incinerator operating without external fossil fuel.

## 2. METHOD

### 2.1 Research Procedure

The research included design, fabrication, combustion testing, and performance evaluation stages based on experimental combustion analysis methods (Wang et al., 2024).

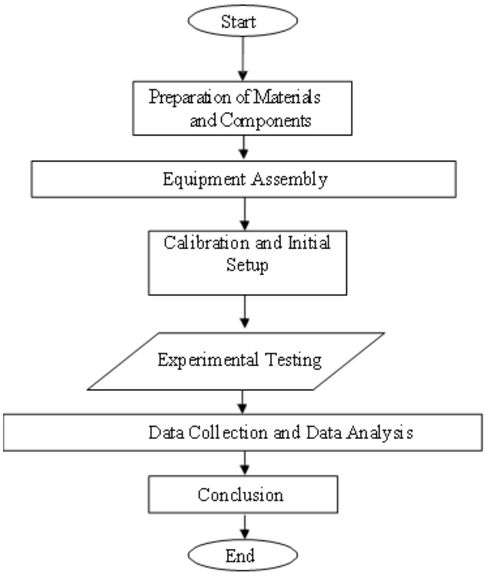

Figure 1. Research methodology flowchart

### 2.2 Incinerator Design

The incinerator used a steel drum combustion chamber with natural-draft airflow, designed to maintain combustion without external fuel (Žnidarčič et al., 2023).

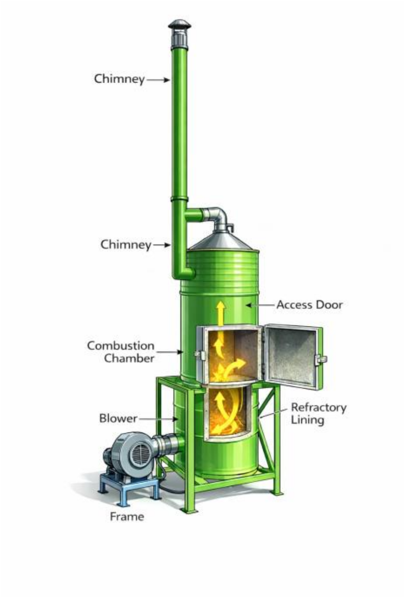

Figure 2. Design of a household-scale incinerator without external fuel

### 2.3 Incinerator Technical Specification

The geometric and structural specifications of the incinerator are summarised in Table 1

Table 1. Operational Incinerator Technical Specification

| Parameter | Value | Unit |
|---|---|---|
| Drum diameter | 0.58 | m |
| Drum height | 0.85 | m |
| Wall thickness | 2 | mm |
| Combustion chamber volume | 0.244 | $m^3$ |
| Primary air inlet | 6 holes (Ø 5 cm) | - |
| Chimney height | 1.2 | m |

The combustion chamber lacked a refractory lining or a secondary air injection system.

## 2.4 Waste Characteristics

The properties of the household waste used during combustion testing are presented in Table 2.

Table 2.Waste Properties

| Parameter | Value |
|---|---|
| Initial waste mass ($m_0$) | 5 kg |
| Final residue mass (m_r) | 3.75 kg |
| Moisture content | 28% |
| Estimated lower heating value (LHV) | 9.5 MJ/kg |

Moisture content was determined based on the weight difference before and after drying. The lower heating value (LHV) was estimated from typical municipal solid waste calorific values reported in literature.

## 2.5 Operational Conditions

Combustion testing was conducted under natural draft airflow without mechanical air injection. The waste was loaded into the combustion chamber and ignited using coconut shell and coconut husk. Temperature was measured using a K-type thermocouple positioned at the centre of the combustion chamber. Temperature readings were recorded every 5 minutes during combustion. The total combustion duration was approximately 2 hours. Initial and final waste masses were measured using a digital weighing scale to evaluate mass-reduction performance.

## 2.6 Mass Reduction Calculation

Mass reduction percentage was calculated based on the difference between initial and final waste mass using the following equation:

$$\text{MR} = \frac{m_o\, x\, m_r}{m_o}\, x\; 100\% \qquad (1)$$

Where:
$m_0$ = initial waste mass (kg)
m_r = final residue mass (kg)

Substituting the measured values:

$$\text{MR} = \frac{5-3.75}{5}\, x\; 100\% \qquad (2)$$

$$\text{MR} = 25\ \% \qquad (3)$$

This value represents mass-based reduction after combustion.

## 2.7 Thermal Efficiency Estimation

A simplified thermal efficiency estimation was conducted using a basic energy balance approach.

The theoretical energy content of the waste was calculated as:

$$Q_{theoretical} = m_o\, x\, LHV \qquad (4)$$

$$Q_{theoretical} = 5\, x\, 9.5 = 47.5\ MJ \qquad (5)$$

The energy required for moisture evaporation was estimated as:

$$Q_{water} = 0.28\, x\, 5 = 1.4\ kg \qquad (6)$$

$$Q_{evaporation} = m_{water}\, x\, 2.26 = 3.16\ MJ \qquad (7)$$

The sensible heat rise during combustion was estimated at approximately 0.21 MJ.

Thus, the total utilised energy is:

$$Q_{utilized} \approx 3.37\ MJ \qquad (8)$$

Thermal efficiency was calculated as:

$$\eta = \frac{Q_{utilized}}{Q_{theoretical}} \, x \, 100\% \qquad (9)$$

$$\eta = \frac{3.37}{47.5} \, x \, 100\% \qquad (10)$$

$$\eta = 7.1\ \% \qquad (11)$$

This simplified estimate provides an indication of thermal performance under natural-draft conditions.

# 3. RESULTS AND DISCUSSION

## 3.1 Combustion Temperature Analysis

Temperature is a key parameter in evaluating combustion stability and thermal behaviour (Wang et al., 2024)

Table 3.Combustion Temperature Observation

| Time (minute) | Fuel-free incinerator temperature (°C) |
|---|---|
| 0 | 30 |
| 10 | 40 |
| 20 | 60 |
| 35 | 75 |
| 40 | 100 |

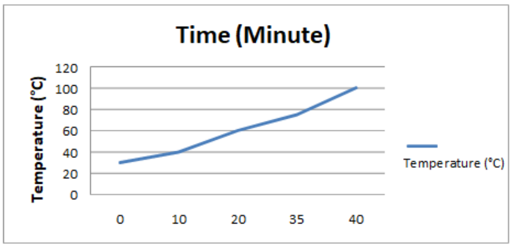

Figure 2. Graph of the relationship between temperature and initial combustion time

Temperature increased gradually, indicating stable combustion supported by biomass ignition and natural convection airflow (Arena, 2012). Thermal retention in the steel chamber contributed to heat accumulation, enabling stable combustion even without a forced-air supply. Natural draft airflow maintains combustion continuity by gradually supplying oxygen (Wang et al., 2024).

The maximum temperature of 100°C indicates that the system operates below conventional incineration temperature (600–850°C). Therefore, the observed process represents low-temperature thermal degradation rather than complete combustion.

## 3.2 Combustion Capacity Performance

Table 3.Combustion capacity

| Time (Hour) | Combustion capacity rate (kg/hour) |
|---|---|
| 1 | 0.6 |
| 1.5 | 1.5 |
| 2 | 2.1 |

The average combustion capacity reached approximately 1.6 kg/hour, indicating practical performance for decentralized waste management (Rahman et al., 2024).

Increasing combustion capacity indicates improved thermal equilibrium during continuous operation. Heat accumulation enhanced degradation efficiency, similar to that observed in natural draft incineration systems reported in previous research (Žnidarčič et al., 2023).

The average degradation rate was calculated using cumulative mass reduction:

$$\mathrm{m} = \frac{m_o - m_r}{\mathrm{t}} \qquad (12)$$

$$\mathrm{m} = 0.625\ \mathrm{kg/hour} \qquad (13)$$

The reported 1.6 kg/hour represents the peak degradation phase

### 3.3 Combustion Residue Analysis

Table 4.Combustion Residue Analysis

| Parameter | Value |
|---|---|
| Coconut shell residue | 33.3% |
| Biomass residue range | 30–45% |
| Waste reduction | 25% |

Residue formation reflects variations in oxygen distribution and combustion temperature. Design improvements, such as secondary airflow openings, may improve oxidation efficiency and reduce residual ash (Ren et al., 2025). Low residue reduction is strongly correlated with low combustion temperature.

### 3.4 Performance Comparison

Table 5. Performance Comparison

| Parameter | Prototype | Standard Incinerator |
|---|---|---|
| Max Temperature | 100°C | 600–850°C |
| Mass Reduction | 25% | 60–80% |
| Thermal Efficiency | 7.1% | 40–70% |

### 3.5 Environmental Consideration

Low-temperature combustion may produce incomplete combustion products when oxygen supply is insufficient (Zhang et al., 2019). Future improvements may include emission monitoring and airflow optimisation to enhance environmental performance (Li et al., 2026).

### 3.6 Research Limitations

This study was limited to temperature observations, combustion capacity, and residue analysis, without detailed emission measurements or gas composition analysis. Combustion testing was also conducted at the household scale, which may differ from that of industrial incinerators.

### 3.7 Future Research Direction

Future studies may focus on emission monitoring, airflow optimisation, thermal insulation enhancement, and the development of secondary combustion chambers to improve combustion efficiency and environmental performance.

## 4. CONCLUSION

The household-scale incinerator demonstrated low-temperature thermal degradation under natural draft airflow without external fossil fuel. The maximum temperature reached 100°C, resulting in 25% mass reduction and an estimated thermal efficiency of 7.1%. The prototype does not yet meet conventional incineration standards and requires improvements in airflow enhancement and thermal insulation.

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