

COMBUSTION TEMPERATURE ANALYSIS ON CO EMISSIONS IN A SIMPLE LIGHTWEIGHT BRICK-BASED INCINERATOR

(Case Study in Banjar Mukti, Singapadu Village, Sukawati District, Gianyar)

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Abstract. Residual waste management at the community level remains a significant environmental problem, particularly for mixed organic and inorganic waste. The use of a simple incinerator made from lightweight bricks is a practical solution due to its low construction costs and ease of operation. However, incomplete combustion can produce harmful gas emissions such as carbon monoxide (CO). This study aims to analyze the effect of combustion temperature on CO levels produced by a simple three-level incinerator using wood fuel. The incinerator design consists of an ash chamber on the lower level, a wood combustion chamber on the middle level, and a waste combustion chamber on the upper level with a volume capacity of 0.384 m³. The residual waste burned is 10 kg per cycle consisting of a mixture of organic and inorganic waste. Data collection was carried out 20 times by measuring the combustion temperature and CO levels using a gas analyzer. The results show an inverse relationship between combustion temperature and CO levels. Increasing the combustion temperature results in a more complete oxidation process, resulting in a significant decrease in CO levels. This study demonstrates that controlling combustion temperature is an important parameter in improving combustion efficiency and reducing harmful gas emissions in small-scale incinerators..

Keywords : incinerator, combustion temperature, carbon monoxide, lightweight brick, emission analysis.

1. INTRODUCTION

Waste management is an increasingly complex environmental issue as the population and human activity increase. Non-recyclable residual waste often presents a major challenge due to limited processing facilities, particularly in rural areas or settlements with limited infrastructure. Open burning remains a widely used method for waste reduction due to its practicality and affordability. However, this method has negative environmental impacts due to the harmful gas emissions it produces. [1], [2], [3].

One of the main pollutant gases produced from incomplete combustion is carbon monoxide (CO). CO gas is formed as a result of incomplete oxidation reactions due to limited combustion temperature, oxygen supply, and uneven heat distribution. High CO concentrations can pose a health risk to the public due to its toxic nature and ability to inhibit oxygen distribution in the human body. Therefore, controlling combustion parameters is a crucial aspect in designing an environmentally friendly waste incineration system. [4], [5], [6].

An incinerator is a waste processing technology that works through a thermal combustion process to significantly reduce waste volume. On a community scale, the use of simple incinerators made from lightweight bricks offers considerable potential due to their low construction costs, ease of construction using local materials, and superior heat retention compared to open combustion. Lightweight bricks have thermal insulation properties that help stabilize temperatures in the combustion chamber, potentially increasing combustion efficiency and

reducing harmful gas emissions. [7], [8].

Several previous studies have shown that increasing combustion temperature significantly impacts the quality of the combustion products. Higher temperatures tend to result in a more complete oxidation process, thereby reducing CO levels in combustion smoke. However, most research focuses on industrial-scale incinerators or complex combustion systems, while studies on simple, lightweight brick incinerators at a community scale are still relatively limited, particularly in real-world settings. [4], [9], [10]. [1], [11], [12].

In the Banjar Mukti area of Singapadu Village, Sukawati District, Gianyar, residual waste management is still carried out in a simple manner, requiring appropriate technological solutions that are easy to implement and still consider environmental aspects. Based on these conditions, this study was conducted to analyze the effect of combustion temperature on carbon monoxide (CO) levels produced by a simple incinerator made from lightweight bricks with a multi-stage combustion design.

This research is expected to provide a scientific contribution to the development of community-scale incinerator technology and serve as a technical reference for efforts to reduce hazardous gas emissions by controlling combustion temperatures. Furthermore, the research findings are expected to serve as a basis for developing more efficient, safe, and environmentally friendly waste incineration systems at the community level.

This research contributes scientifically to the field of small-scale waste incineration technology by analyzing the relationship between combustion temperature and carbon monoxide (CO) emission levels in a simple lightweight brick incinerator. Scientifically, this study enriches the current limited understanding of community-scale incinerator operational parameters, particularly in simple incinerator designs commonly used in rural areas.

The results are expected to demonstrate that controlling combustion temperature is a key factor in suppressing the formation of CO gas, one of the harmful emissions resulting from incomplete combustion. Therefore, this research can serve as a scientific reference in the development of more efficient, safe, and environmentally friendly waste incineration systems.

The use of lightweight bricks in incinerator construction is crucial because they offer excellent thermal insulation properties, allowing them to maintain a more stable combustion temperature. This temperature stability directly impacts a more complete combustion process and has the potential to reduce harmful gas emissions.

Furthermore, lightweight bricks are relatively readily available, have affordable construction costs, and can be applied locally by communities without requiring complex technology. This makes lightweight brick incinerators a realistic, appropriate technology alternative for community-scale implementation.

Practically, this research is expected to provide direct benefits to the community, including:

- Providing simple technical guidance on operating incinerators to achieve more optimal combustion and minimize emissions.
- Supporting community-based independent waste management efforts that are safer for the environment.
- Reducing the negative impacts of open burning, which is commonly practiced by communities.
- Providing a scientific basis for village governments or environmental managers in designing more environmentally friendly small-scale waste management systems.

Thus, this research not only contributes to the development of scientific knowledge in the field of waste incineration technology but also has high applicability in supporting sustainable environmental management at the community level.

2. METHODS

2.1 Research Location

The research was conducted in Banjar Mukti, Singapadu Village, Sukawati District, Gianyar Regency, Bali. The research location was chosen because it is a residential area that still uses conventional waste burning methods (open burning), making it suitable for the implementation and testing of a community-scale incinerator. The environmental conditions of the research location allow for direct observation of combustion performance with variations in temperature and emissions..

2.2 Incinerator Design

The incinerator used is a simple lightweight brick incinerator with a three-level vertical combustion configuration. This design is designed to improve heat distribution and combustion efficiency by separating the functional zones as follows:

1. First level (bottom): ash collection chamber that serves as an accumulation area for combustion residue and an air inlet from below.
2. Second level (middle): combustion chamber for firewood, the primary heat source.
3. Third level (top): waste incineration chamber with an effective capacity of 0.384 m³.

The multi-level design concept aims to create a natural draft, allowing for a more stable and even combustion process. Lightweight bricks were chosen for their excellent thermal insulation, ability to retain heat within the combustion chamber, and availability locally. [8], [12].

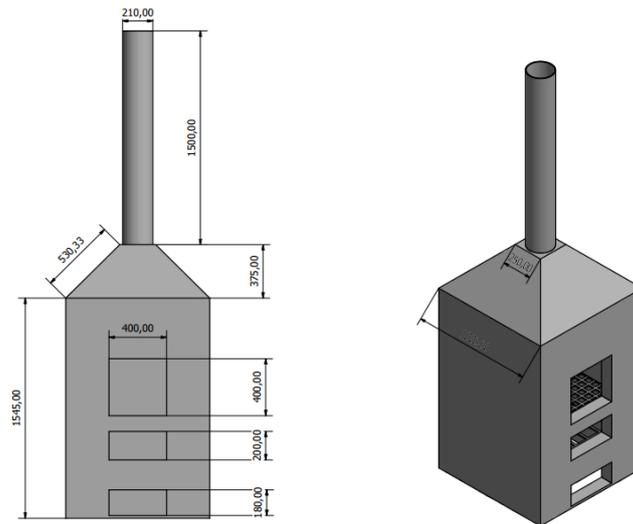


Figure 1. Simple incinerator design made from lightweight bricks



Figure 2. Existing image of a simple incinerator made from lightweight bricks and the combustion process as well as measuring temperature and CO levels.

2.3 Materials and tools

Materials and equipment used in the research include:

- Firewood as the primary fuel for combustion
- Mixed residual waste (organic and inorganic) of 10 kg per combustion cycle
- Gas analyzer to measure carbon monoxide (CO) concentration
- High-temperature thermometer to measure the combustion chamber temperature
- Stopwatch to control the data collection interval

The use of measuring equipment is carried out after a simple calibration process to ensure data consistency during the experiment.

a. Gas Analyzer Specifications

Carbon monoxide (CO) concentration measurements were performed using a portable gas analyzer based on an electrochemical sensor, namely a portable combustion gas analyzer. This device has a CO measurement range of 0–5000 ppm with an accuracy of $\pm 5\%$ of the reading and a measurement resolution of 1 ppm.

b. CO Measurement Points and Methods

Carbon monoxide emissions were measured at gas sampling points in the incinerator chimney to obtain representative concentrations of combustion gases. The measurement points were determined using the following parameters:

- Horizontal distance from the chimney tip: ± 30 cm
- Height of the measurement point above ground level: ± 1.5 m

3. The probe was positioned in the direction of the flue gas flow to avoid turbulence
4. Measurement duration per interval: 30–60 seconds until a stable value is read

Data were collected periodically throughout the combustion process at specific time intervals using a stopwatch as a recording reference.

c. Duration of Each Combustion Cycle

Each combustion cycle is carried out for a waste capacity of 10 kg with an average operating time of 45–60 minutes, depending on the waste characteristics and the stability of the combustion flame.

- The combustion cycle stages consist of:
- Initial ignition phase: ± 10 minutes
- Main combustion phase: ± 30 –40 minutes
- Final combustion and initial cooling phase: ± 10 minutes

Combustion chamber temperature and CO concentration data are recorded periodically during the main combustion phase because this is the stage where the oxidation process is most intensive.

d. Water Content of Burned Waste

The mixed waste (organic and inorganic) used in this study had an average moisture content of around 20–30% based on observations of the material's physical condition prior to combustion. Moisture content was determined simply through initial weighing and air-drying to avoid the influence of excessive humidity on the combustion process. Waste moisture content is an important parameter because high moisture content can lower the combustion temperature and increase the potential for CO gas formation due to incomplete combustion.

2.4 Research Variables

This study uses several variables as follows :

- a. Independent variables
 - Combustion temperature ($^{\circ}\text{C}$)
- b. Dependent variables
 - Carbon monoxide (CO) concentration (ppm)
- c. Control variables
 - Waste mass (10 kg)
 - Fuel type (firewood)
 - Combustion chamber volume (0.384 m^3)
 - Test environmental conditions

Variable control is carried out to ensure that changes in CO levels are mainly influenced by changes in combustion temperature.

2.5 Testing Procedures

The experimental procedure was carried out systematically as follows:

1. The incinerator is cleaned of any residue from previous combustion.
2. Firewood is loaded into the middle combustion chamber and lit until the flame is stable.
3. Residual waste is gradually fed into the upper combustion chamber to ensure even heat distribution.
4. Combustion is allowed to continue until it reaches operating temperature.
5. Temperature measurements are taken at the same observation point to ensure data consistency.
6. CO concentration is measured using a gas analyzer at the smoke outlet.
7. Data is recorded periodically throughout the combustion process.
8. Testing is carried out 20 times to obtain representative results.

2.6 Data Collection Method

Data were obtained through a direct experimental method, with simultaneous temperature and CO levels measured. Each data collection was conducted after combustion conditions had reached relative stability to ensure that the measurement results were not influenced by the initial combustion phase.

Repeated testing was conducted to increase data reliability and minimize experimental errors caused by variations in fuel and waste distribution.

2.7 Data analysis

The test data were analyzed quantitatively by comparing the relationship between combustion temperature and CO levels. The analysis used a descriptive approach and trend analysis to identify patterns of emission changes with increasing temperature. The results were then presented in tables and graphs to facilitate data interpretation.

3. RESULTS AND DISCUSSION

3.1 Experimental Test Results

Based on the characteristics of the lightweight brick incinerator, its waste capacity of 10 kg/cycle, and the recorded combustion temperature range of 220–608°C, firewood requirements can be estimated using a small-scale combustion energy approach. The initial temperature (220–350°C) requires the greatest energy supply to raise the combustion chamber temperature. Once the temperature exceeds approximately 400°C, the waste begins to burn more steadily, reducing the need for additional fuel.

The average firewood requirement is approximately 3–5 kg per combustion cycle. This value is considered efficient for community-scale incinerators because the lightweight brick walls help retain heat, resulting in lower fuel consumption compared to thin metal construction.

Test results show a decreasing trend in CO concentration as combustion temperature increases, indicating more complete combustion. However, evaluating compliance with emission standards requires converting the data to mg/Nm³ and standardized laboratory testing. The total cost of constructing a simple incinerator using lightweight bricks is 7.5 million rupiah.

Table 1. Shows The Results Of Measurements Of Combustion Temperature And CO Levels During Testing.

No	Combustion Temperature (°C)	CO levels (ppm)
1	220	1315
2	242	1298
3	264	1280
4	281	1265
5	302	1247
6	322	1230
7	341	1218
8	365	1201
9	385	1188
10	402	924
11	422	915
12	443	903
13	464	892
14	488	880
15	501	872
16	525	864
17	547	858
18	563	851
19	586	845
20	608	840

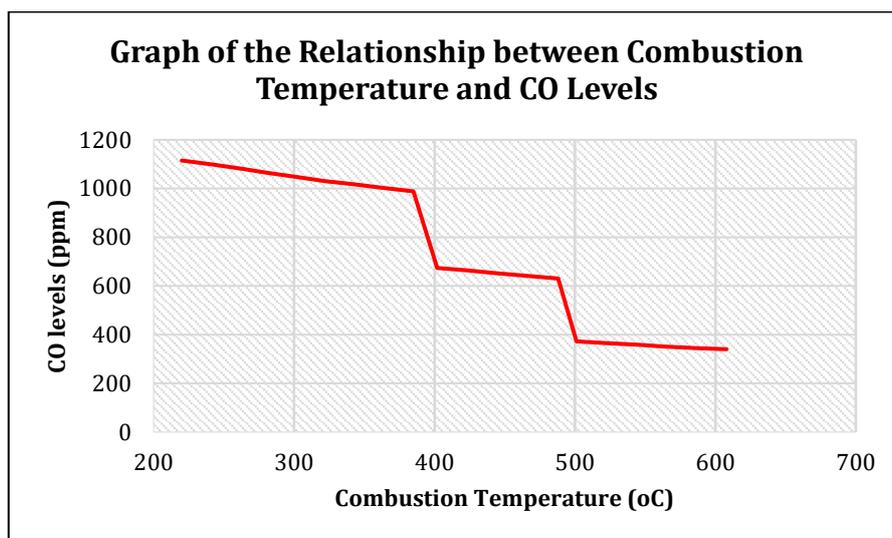


Figure 3. Graph of the Relationship between Combustion Temperature and CO Levels

3.2 Equality

The equation used in combustion analysis is as follows:

Heat energy from combustion:

$$Q = m \times c \times \Delta T \tag{1}$$

with:

- Q = heat energy (J)
- m = mass (kg)
- c = specific heat (J/kg·K)
- ΔT = temperature changes (K)

Estimated combustion efficiency:

$$\eta = \frac{T_{actual}}{T_{maks}} \times 100\% \tag{2}$$

dengan:

- η = combustion efficiency (%)
- T_{actual} = temperature measurement results (°C)
- T_{maks} = maximum theoretical temperature (°C)

The test was conducted 20 times, with the main parameters being combustion temperature and carbon monoxide (CO) levels. The measurement results show a variation in combustion temperature from 220°C to 600°C, with a tendency for CO concentration to decrease as the combustion temperature increases.

Table 1 shows that the highest CO values were recorded at low temperatures (220–280°C), while the lowest CO values were obtained at high temperatures (500–600°C). This pattern indicates that combustion performance is significantly influenced by thermal conditions within the combustion chamber.

In general, the experimental results show a negative (inverse) relationship between combustion temperature and CO levels, indicating increased oxidation efficiency at high temperatures.

3.2 Analysis of the Relationship between Combustion Temperature and CO Emissions

Carbon monoxide is a product of incomplete combustion that forms when the carbon oxidation reaction does not proceed completely. At low temperatures, the activation energy of the chemical reaction is not optimally achieved, so the combustion reaction only results in partial oxidation: [4], [6].



As the temperature increases, the kinetic energy of the particles increases, resulting in a higher frequency of collisions between molecules. This condition accelerates further oxidation reactions: [9], [10].



As a result, the measured CO concentration decreased significantly. This phenomenon is clearly visible in the test data, where increasing the temperature from 300°C to 500°C reduced the CO level by almost 60%. [4], [9], [7].

In addition, high temperatures increase the turbulence of the airflow within the combustion chamber, resulting in a more homogeneous mixture of fuel and oxygen. This increased homogeneity of the mixture contributes to more complete combustion.

3.3 Analysis of Combustion Stages in an Incinerator

During the experimental process, combustion in the incinerator can be divided into three main phases:

a. Drying Phase

In the initial stage of combustion (temperatures < 250°C), heat energy is used to evaporate the water content in the waste. During this phase, the oxidation process is still limited, resulting in relatively high CO₂ emissions.

b. Pyrolysis Phase

As the temperature increases (250–400°C), organic material begins to decompose into volatile gases. These gases are not completely burned, resulting in relatively high CO₂ emissions.

c. Intense Combustion Phase

At temperatures above 450°C, volatile gases burn more completely. The oxidation reaction takes over, resulting in a significant decrease in CO₂ levels. This phase represents the optimum operating conditions for the incinerator.

3.4 Effect of Multi-Stage Design on Combustion Stability

The three-tier incinerator configuration contributes significantly to the system's thermal stability. The ash chamber at the bottom allows for a natural draft, allowing a continuous flow of oxygen to the combustion chamber.

The wood combustion chamber at the middle level acts as the primary heat source, producing a stable and sustained temperature. The resulting heat then rises to the waste combustion chamber at the top through natural convection.

This distribution of combustion zones results in several technical advantages:

- Increased heat retention in the upper chamber
- Reduced thermal energy loss
- More even combustion
- Minimized temperature fluctuations

These conditions contributed directly to the reduction in CO emissions measured during testing.

3.5 Thermal Characteristics of Lightweight Bricks

Lightweight bricks have relatively low thermal conductivity, reducing heat loss to the surrounding environment. This thermal insulation property plays a crucial role in maintaining a high combustion chamber temperature even when the fuel supply is inconsistent. [13], [14], [15], [16], [17], [18].

Good heat retention allows thermal energy to be stored longer in the combustion chamber, allowing the oxidation reaction to continue. This is one of the main reasons why CO levels decrease in the high-temperature phase. [13], [19].

In addition, the use of lightweight bricks also increases operational safety because the outer surface temperature of the incinerator is relatively lower compared to conventional materials.

3.6 Combustion Efficiency Analysis

Based on the data trends obtained, increasing combustion temperatures can be used as an indicator of increased combustion efficiency. At high temperatures, most of the carbon content in the waste is oxidized to CO₂, resulting in a decrease in the CO fraction. [9], [7], [10].

Conceptually, combustion efficiency can be associated with a system's ability to produce maximum heat with minimal emissions. In this study, the temperature range of 500–600°C indicated the most efficient combustion conditions because:

- Stable temperature
- More homogeneous flame
- Low CO emissions
- More complete combustion of residues

3.7 Practical Implications for Waste Management

The research results show that operating a simple incinerator can still produce relatively clean combustion if the operating temperature is maintained within the optimal range. This is important for community-scale applications because:

- Reduce the impact of air pollution
- Increase the efficiency of waste volume reduction
- Improve the safety of the surrounding environment

Thus, temperature control can be used as the main parameter in operating a lightweight brick incinerator on a community scale.

3.8 Comparison of Research Results with Previous Studies

To evaluate the position of the results of this study, a comparison was made with several previous studies that discussed small-scale incinerators, the relationship between combustion temperature and CO emissions, and the use of lightweight brick materials as thermal insulation.

a. Comparison with Small-Scale Incinerator Studies

Several previous studies have shown that the performance of small-scale incinerators is significantly influenced by operating temperature, waste moisture content, and combustion chamber design.

A study by Nyoti et al. on small-scale incinerators showed that high operating temperatures can improve combustion quality and reduce exhaust emissions, while low temperatures produce denser smoke and higher emissions. [20]

The results of this study show a similar pattern, where increasing the temperature from 220°C to 608°C resulted in a decrease in CO concentration from 1315 ppm to 840 ppm. This indicates that the lightweight brick incinerator can achieve combustion performance comparable to that of other small-scale incinerators studied. The results of this study are similar to previous studies in showing that high temperatures increase combustion efficiency and reduce emissions.

b. Comparison of the Relationship between Combustion Temperature and CO Emissions

Other studies on incinerator emission performance have shown that increasing operating temperature significantly reduces combustion gas emissions. Emission evaluation studies on small-scale incinerators report that high temperatures result in more complete combustion and lower CO emissions compared to low-temperature conditions. [21]

Your study showed a significant change when the temperature exceeds approximately 400°C, where CO levels drop sharply (1188 → 924 ppm). This phenomenon indicates the existence of a critical temperature for optimal combustion, the condition where carbon oxidation occurs most completely. The results of this study are more informative because they show a clear temperature transition point, not just a general trend of decreasing CO.

c. Comparison with the Study of Lightweight Bricks as Thermal Insulation

Material studies show that lightweight bricks have low thermal conductivity, making them effective as heat insulation materials. Research on lightweight mortar and materials indicates a thermal conductivity of $<0.2 \text{ W/(m}\cdot\text{K)}$, which contributes to better heat retention. Other studies on lightweight bricks also report that lightweight materials can improve thermal insulation and reduce heat energy loss during the heating process. [22] [23]

In this study, the use of lightweight bricks allowed the combustion chamber temperature to increase steadily to $>600^\circ\text{C}$ with relatively low firewood consumption ($\pm 3\text{--}5 \text{ kg/cycle}$). This demonstrates good thermal insulation performance, preventing energy from being easily lost to the environment. The results of this study are consistent with the literature that lightweight bricks increase thermal efficiency. Practically, the incinerator maintained a stable temperature without additional insulation.

Overall, the results of this study confirm previous findings that increasing combustion temperature contributes to reduced CO emissions. However, this study adds value through the implementation of a lightweight brick incinerator that demonstrates high temperature stability in a simple, community-scale system. Thus, this study not only confirms existing scientific trends but also provides a more relevant, applicable approach for low-cost waste treatment technologies.

4. CONCLUSION

Based on the research results, it can be concluded that combustion temperature has a significant influence on the carbon monoxide (CO) levels produced by a simple incinerator made from lightweight bricks. Increasing the combustion temperature reduces CO concentrations due to a more complete oxidation process. The most effective combustion conditions occur in the temperature range of 500–600°C, where CO emissions are lowest and combustion is more stable.

The multi-level incinerator design improves combustion stability through better heat distribution and air supply, while the lightweight brick material plays a role in heat retention, thus increasing combustion efficiency. The results of this study indicate that temperature control is a key factor in reducing harmful gas emissions in small-scale incinerators.

Overall, a simple incinerator made from lightweight bricks has the potential to be a practical and environmentally friendly waste management solution at the community level. Further research is recommended to evaluate other emission parameters and optimize the air supply system to improve combustion performance.

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