LOGIC
Journal of Engineering Design and Technology
Vol. 26 No. 1 March 2026 ; p. 61 - 70

p-ISSN : 1412-114X
e-ISSN : 2580-5649
http://ojs2.pnb.ac.id/index.php/LOGIC

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 essential due to their excellent thermal insulation properties, which enable the system to maintain a more stable combustion temperature. This temperature stability plays a significant role in achieving a more complete combustion process and has the potential to reduce the formation of harmful gas emissions. In addition, lightweight bricks are relatively easy to obtain, cost-effective, and can be applied locally by communities without requiring complex technology. These characteristics make lightweight brick incinerators a practical and appropriate technological solution for community-scale implementation, particularly in areas with limited access to advanced waste management systems.

From a practical perspective, this research is expected to provide direct benefits to the community by offering simple technical guidance on operating incinerators to achieve more optimal combustion conditions and minimize emissions. It also supports community-based waste management initiatives that are safer for the environment and contributes to reducing the negative impacts of open burning practices that are still commonly carried out. Furthermore, the findings of this study can serve as a scientific basis for village governments or environmental managers in designing small-scale waste management systems that are more environmentally friendly.

Overall, this research not only contributes to the advancement of scientific knowledge in the field of waste incineration technology but also demonstrates strong 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 in this study is a simple structure constructed from lightweight bricks with a three-level vertical combustion configuration. This design aims to enhance heat distribution and improve combustion efficiency by functionally separating the combustion zones within the system. The bottom section serves as an ash collection chamber, which functions as both an accumulation area for combustion residues and an air inlet to support the combustion process. The middle section operates as the primary combustion chamber for firewood, which acts as the main heat source, while the top section is utilized as the waste incineration chamber with an effective capacity of 0.384 m³.

The implementation of a multi-level design enables the formation of a natural draft system, allowing airflow to circulate more effectively and resulting in a more stable and uniform combustion process. Lightweight bricks were selected as the primary construction material due to their good thermal insulation properties, which help retain heat within the combustion chamber, as well as their local availability and suitability for small-scale applications [8], [12].

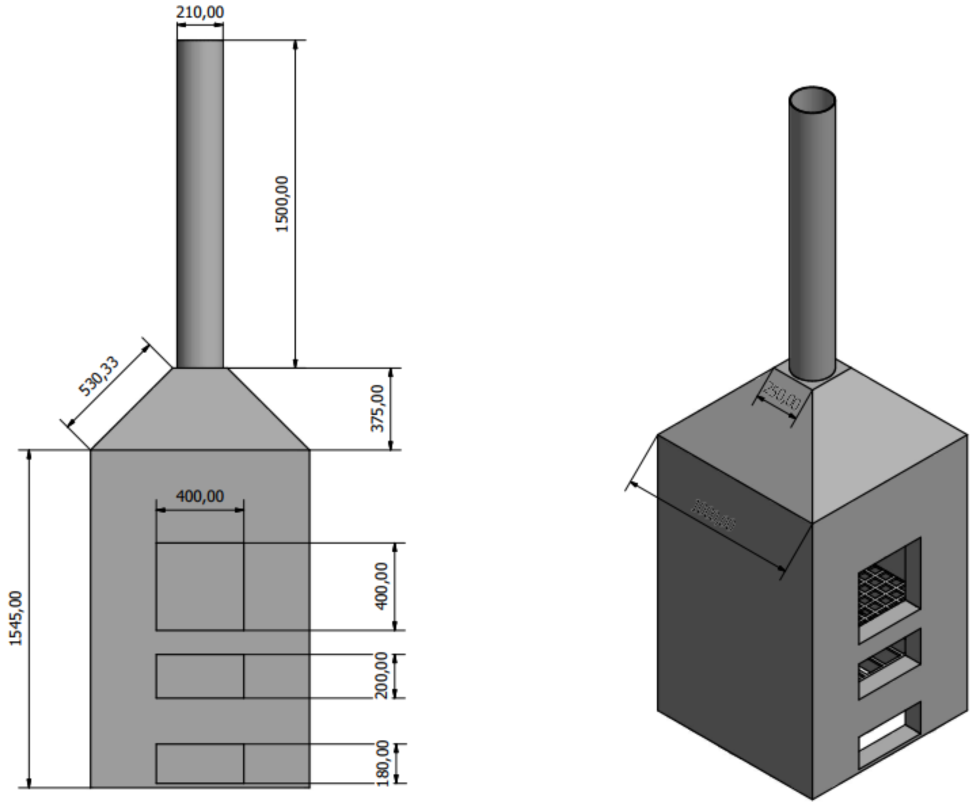

Figure 1. Simple incinerator design made from lightweight bricks

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

The materials and equipment used in this study include firewood as the primary fuel for combustion and mixed residual waste (organic and inorganic) with a mass of 10 kg for each combustion cycle. A gas analyzer was utilized to measure carbon monoxide (CO) concentration, while a high-temperature thermometer was used to monitor the combustion chamber temperature. A stopwatch was employed to control the data collection intervals. Prior to use, all measuring instruments underwent a simple calibration process to ensure data consistency during the experiment.

Carbon monoxide (CO) concentration measurements were conducted using a portable gas analyzer based on an electrochemical sensor. The device has a measurement range of 0–5000 ppm, with an accuracy of ±5% of the reading and a resolution of 1 ppm. Measurements were taken at the gas sampling point located in the incinerator chimney to obtain representative combustion gas concentrations. The sampling point was positioned approximately 30 cm horizontally from the chimney outlet and at a height of about 1.5 m above ground level. The probe was aligned with the flue gas flow direction to minimize turbulence, and each measurement was carried out for 30–60 seconds until a stable reading was obtained. Data were recorded periodically throughout the combustion process.

Each combustion cycle was performed using 10 kg of waste, with an average operating time ranging from 45 to 60 minutes depending on waste characteristics and flame stability. The combustion process consisted of three stages: an initial ignition phase of approximately 10 minutes, a main combustion phase lasting 30–40 minutes, and a final combustion and initial cooling phase of about 10 minutes. Temperature and CO concentration measurements were primarily recorded during the main combustion phase, as this stage represents the most intensive oxidation process.

The mixed waste used in this study had an average moisture content of approximately 20–30%, determined through initial weighing and simple air-drying based on the physical condition of the material prior to combustion. Moisture content is a critical parameter, as higher moisture levels can reduce combustion temperature and increase CO emissions due to incomplete combustion..

2.4 Research Variables

This study employed combustion temperature as the independent variable and carbon monoxide (CO) concentration as the dependent variable. Several parameters were controlled to ensure experimental consistency, including waste mass (10 kg), fuel type (firewood), combustion chamber volume (0.384 m^3), and environmental conditions during testing. These control variables were maintained constant to ensure that variations in CO emissions were primarily influenced by changes in combustion temperature.

2.5 Testing Procedures

The experimental procedure was conducted systematically, beginning with cleaning the incinerator to remove any residue from previous combustion cycles. Firewood was then placed in the middle combustion chamber and ignited until a stable flame was achieved. Subsequently, residual waste was gradually introduced into the upper combustion chamber to ensure even heat distribution. The combustion process was allowed to continue until the system reached its operating temperature.

Temperature measurements were taken at a consistent observation point to maintain data reliability, while CO concentration was measured at the chimney outlet using the gas analyzer. Data were recorded periodically throughout the combustion process. To obtain representative results, the experiment was repeated 20 times under similar conditions.

2.6 Data Collection Method

Data were collected through direct experimental observation, with temperature and CO concentration measured simultaneously. Each measurement was taken after the combustion process reached relatively stable conditions to avoid the influence of the initial ignition phase. Repeated testing was performed to improve data reliability and reduce experimental errors caused by variations in fuel distribution and waste composition..

2.7 Data analysis

The collected data were analyzed quantitatively to examine the relationship between combustion temperature and CO concentration. A descriptive and trend analysis approach was applied to identify patterns in emission changes as temperature increased. The results were then presented in the form of tables and graphs to facilitate interpretation and discussion.

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

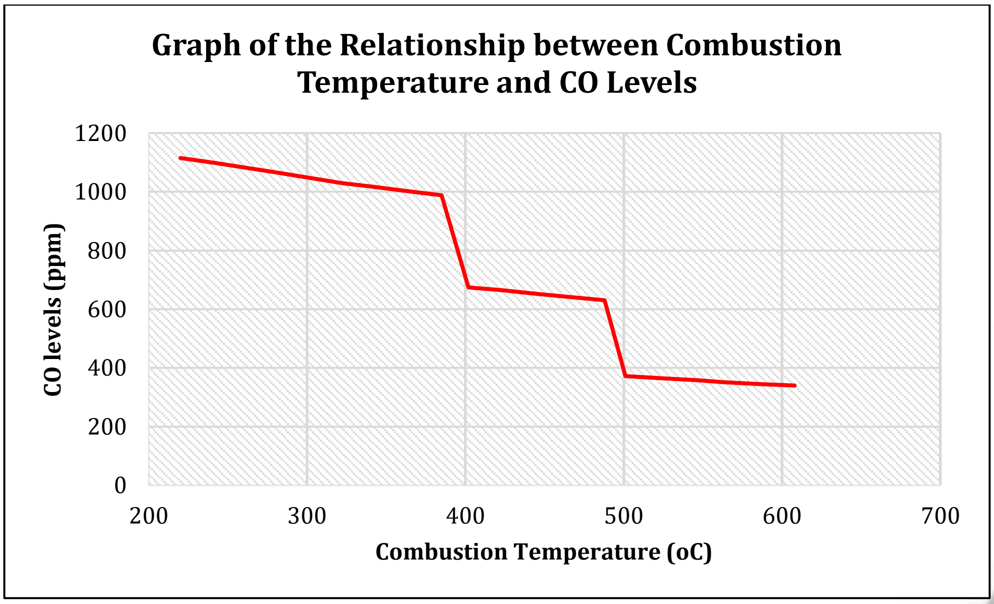

Figure 3. Graph of the Relationship between Combustion Temperature and CO Levels

3.2 Equality

The equation used in combustion analysis is as follows:

Heat energy from combustion:

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

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

Estimated combustion efficiency:

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

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 represented in Equation (3). 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 shown in Equation (4). 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.

$$C + \frac{1}{2}O_2 \rightarrow CO \tag{3}$$

$$CO + \frac{1}{2}O_2 \rightarrow CO_2 \tag{4}$$

3.3 Analysis of Combustion Stages in an Incinerator

During the experimental process, combustion in the incinerator can be classified into three main phases based on temperature characteristics and reaction behavior. In the initial stage, known as the drying phase (temperatures below 250°C), the supplied heat energy is primarily used to evaporate the moisture content present in the waste. At this stage, the oxidation process is still limited, which may lead to unstable combustion conditions and incomplete reactions.

As the temperature increases to the range of 250–400°C, the process enters the pyrolysis phase, during which organic materials begin to thermally decompose into volatile gases. These gases are not fully oxidized due to insufficient temperature and mixing conditions, which can result in the formation of incomplete combustion products.

At temperatures above 450°C, the system reaches the intense combustion phase, where volatile gases undergo more complete oxidation. In this phase, combustion reactions become more stable and efficient, leading to a significant reduction in incomplete combustion products. Therefore, this stage represents the optimum operating condition of the incinerator, where thermal efficiency and emission performance are improved.

3.4 Effect of Multi-Stage Design on Combustion Stability

The three-level configuration of the incinerator plays a significant role in enhancing the thermal stability of the combustion process. The bottom ash chamber functions as both a residue collection area and an air inlet, enabling a natural draft that ensures a continuous supply of oxygen to the combustion zones. The middle chamber, which is used for firewood combustion, serves as the primary heat source and provides a stable and sustained temperature during operation. The generated heat is then transferred upward to the waste combustion chamber through natural convection, promoting more effective thermal utilization.

This structured distribution of combustion zones improves overall system performance by enhancing heat retention in the upper chamber, reducing thermal energy losses, and ensuring a more uniform combustion process. As a result, temperature fluctuations within the incinerator can be minimized, leading to more stable operating conditions. These improvements contribute directly to the reduction of CO emissions observed during the experimental 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 CO_2, 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.

1.8 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 W/(m·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°C with relatively low firewood consumption (±3–5 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.

5. ACKNOWLEDGEMENT

The authors would like to express their gratitude to the community of Banjar Mukti, Singapadu Village, for their support during the research. They also express their gratitude to the Bali State Polytechnic for their academic support and research facilities.

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