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# Characterization of the Performance of the Enerflow Cyclone Burn Grate (ECBG) for the Treatment of Hazardous Waste at an Isolated Diesel Power Plant

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**Keywords**
Enerflow Cyclone Burn Grate; Mini Turbo Incinerator; Pongok Diesel Power Plant; Combustion Efficiency; Isolated Area

**ABSTRACT**

As the world's largest archipelagic nation, Indonesia faces significant challenges in managing hazardous and toxic waste (B3) generated by diesel power plants (PLTD) in isolated areas. The Portable Turbo Burn Incinerator RC80 manufactured by Scholer Industries Australia, which was modified by PT Enerflow Engineering Indonesia into the Enerflow Cyclone Burn Grate (ECBG), also known as the Mini Turbo Incinerator (MTI), incorporates several technical modifications, including a 14-meter chimney, wet scrubber integration, a two-stage combustion chamber, and industrial design rights protection to comply with Indonesian regulatory requirements. This study aims to comprehensively characterize the combustion efficiency and operational performance of ECBG at various feed rates using liquid and solid B3 waste through field testing at the Pongok Island PLTD. Field tests were conducted under three experimental scenarios with varying total waste masses (36.5 kg, 40.0 kg, and 44.0 kg) and combustion durations ranging from 1.0 to 2.0 hours. The evaluated performance parameters included combustion temperature, burn rate, waste destruction efficiency, and emission characteristics. The results demonstrate that ECBG achieved an average waste destruction efficiency of 95.2%, with a maximum volume reduction of 98% under optimal operating conditions. The combustion rate ranged from 18.25 to 44.00 kg/hour, depending on waste composition and operational parameters. The integrated wet scrubber system effectively controlled exhaust gas emissions and complied with BAPEDAL quality standards. This research provides the first comprehensive performance characterization of a locally modified thermal treatment technology with wet scrubber integration and intellectual property protection for B3 waste processing in isolated power plant environments.

## INTRODUCTION

Indonesia, with more than 17,000 islands, faces significant challenges in managing hazardous and toxic materials (B3) waste generated by diesel power plants (PLTD) located in isolated areas. PLTDs in remote regions produce B3 waste, including used oil (49 L/month), used filters (0.7–60 kg/month), and contaminated rags (2–3 kg/month), which can accumulate and pose toxic risks to the environment and human health if not managed in accordance with applicable regulations (Kementerian Energi dan Sumber Daya Mineral Republik Indonesia, 2023; Kementerian Lingkungan Hidup dan Kehutanan Republik Indonesia, 2022).

The Pongok Island Diesel Power Plant (PLTD), located in South Bangka Regency, Bangka Belitung Islands Province (coordinates: 2°52′26″ S and 107°01′54.6″ E), represents a specific example of the challenges associated with B3 waste management in remote areas. The island's geographical location creates difficulties in transporting waste to licensed processing facilities, which are primarily concentrated in Java, resulting in high logistics costs, potential marine spill risks, on-site waste accumulation, and illegal disposal practices. The absence of local waste management solutions highlights the need to identify alternative on-site waste processing technologies (Rachman et al., 2023; Santoso et al., 2022).

Conventional incinerators have limitations, including incomplete combustion emissions and dependence on supplementary fuel (Lee et al., 2024). As an alternative, cyclonic combustion technology offers improved combustion efficiency through enhanced air turbulence and mixing processes (Lee & Park, 2025). The Portable Turbo Burn Incinerator RC80 manufactured by Scholer Industries Australia applies a two-stage cyclone combustion method, a Programmable Logic Controller (PLC) system, an operating temperature of 1100°C, and certification from the Australian Environment Protection Authority (EPA) (Scholer Industries Pty Ltd, 2020). However, its suitability for Indonesia's specific conditions, including archipelagic geography, monsoon climate patterns, and emission dispersion regulations, has not been systematically evaluated.

Previous research Fahmi et al., (2024) identified and evaluated weaknesses in the initial Turbo Burn RC80 design and formulated technical modifications through an engineering design approach. The resulting modifications involved: (1) adding a 14-meter-high chimney equipped with sampling points for emission testing; (2) integrating a wet scrubber system to control particulate emissions and acid gases (HCl, $SO_2$, and HF); (3) adding a filter tank as a wastewater management system for scrubbing effluent with recirculation capability; (4) modifying the combustion chamber into a two-stage system with increased operating temperatures (800–900°C in the first combustion chamber and ≥1000°C in the second combustion chamber); and (5) adjusting the blower chamber design to accommodate high humidity conditions in archipelagic environments. Industrial Design Rights protection (application number A00202303663) has been granted for these design modifications (Kementerian Hukum dan Hak Asasi Manusia Republik Indonesia, 2023).

The design modifications resulted in the development of the Enerflow Cyclone Burn Grate (ECBG), also known as the Mini Turbo Incinerator (MTI). The technology has received Environmentally Friendly Technology Registration from the Ministry of Environment and Forestry (number 047/TRL/Reg-2/KLHK) (Kementerian Lingkungan Hidup dan Kehutanan Republik Indonesia, 2020), Technical Approval (Persetujuan Teknis [Pertek]) for thermal processing of B3 waste at the Pongok Island Diesel Power Plant (Kementerian Lingkungan Hidup dan Kehutanan Republik Indonesia, 2021), and an Operational Feasibility Letter (Surat Laik Operasi [SLO]) (Kementerian Lingkungan Hidup dan Kehutanan Republik Indonesia, 2021).

Various studies have investigated the development of portable incinerators and emission control systems (Akpe et al., 2016; Honest et al., 2020; Relleta et al., 2024). Wet scrubbers have been demonstrated to be effective in reducing particulate emissions and acid gases, including HCl, $SO_2$, and HF. Other studies have examined the influence of combustion chamber design and operational parameters on combustion efficiency and emissions, with hazardous waste incinerator performance in Indonesia achieving combustion efficiencies of 99.9997–99.9999% under optimal conditions. However, several research gaps remain, including the lack of comprehensive evaluation integrating all design modifications, as previous studies primarily described the ECBG modification process theoretically without field verification; limited characterization of operational performance under various operating conditions in remote areas; insufficient empirical validation of regulatory compliance through scientific publications despite existing administrative approvals; and the absence of testing using actual B3 waste generated from isolated diesel power plants with specific waste characteristics.

The novelty of this research lies in six aspects: first, it provides the initial comprehensive performance characterization of ECBG as a locally modified thermal treatment technology integrated with a wet scrubber system for processing B3 waste in isolated areas; second, it provides empirical validation of design modifications previously examined only theoretically; third, it conducts direct field testing using actual waste generated from the Pongok Island PLTD; fourth, it presents comprehensive performance analysis covering both measured and derived operational parameters; fifth, it integrates technical, regulatory, and intellectual property protection aspects within a single evaluation framework, which remains rarely applied in Indonesian environmental technology research; and sixth, it contributes to the development of a localization framework for environmental technology during the post-modification and pre-commercial implementation stages while providing a reference for regulators and industry stakeholders in adopting compliant, legally protected, and sustainable portable B3 waste treatment technologies.

This study aims to address these research gaps by comprehensively characterizing ECBG performance through field testing at the Pongok Island Diesel Power Plant using actual liquid and solid B3 waste. The specific objectives are to evaluate operational characteristics at different feed rates, calculate destruction efficiency and fuel consumption, verify compliance with BAPEDAL emission quality standards, and provide operational recommendations for isolated areas. This research provides theoretical and practical contributions. Theoretically, it contributes to environmental engineering knowledge by presenting empirical validation of design modifications and operational performance data for portable incinerator technology in isolated regions. Practically, it provides insights for power plant operators in managing B3 waste in remote locations, offers empirical evidence for regulators in evaluating B3 waste management practices, and serves as a reference for technology developers in designing thermal treatment systems with wet scrubber integration and intellectual property protection.

## METHOD

### Research Design

This research employed a direct field trial approach at the Pongok Island Diesel Power Plant (PLTD), Bangka Belitung. Each test session lasted 60–120 minutes with varying waste compositions and feed rates. The research design followed an engineering design process approach consisting of needs identification, conceptual design, detailed design, theoretical calculation, and validation.

### Object of Study

Location: Pongok Island PLTD, South Bangka Regency, Bangka Belitung Islands Province.

Coordinates: 2°52'26" South Latitude and 107°01'54.6" East Longitude.
Implementation Period: September 2017-August 2021.

The location selection was based on the consideration that the Pongok Island PLTD is one of the PLTDs in a remote area (isolated area) that produces B3 waste and has Technical Approval for thermal processing of B3 waste using ECBG.

**Tools and Materials Used**

**Main Equipment** : Enerflow Cyclone Burn Grate (ECBG) / Mini Turbo Incinerator (MTI) with the following specifications:

**Table 1. Tools and Fuels Used**

| Parameter | Specification |
|---|---|
| Tool Name | Enerflow Cyclone Burn Grate (ECBG) |
| Type | Cyclo Burn Grate with 1 blower and 1 turbo |
| KLHK Technology Registration | 047/TRL/Reg-2/KLHK |
| Industrial Design Rights | A00202303663 (August 26, 2023) |
| Combustion Capacity | 45 kg/hour (solid waste) / 35 liters/hour (liquid waste) |
| Combustion Chamber Volume 1 | 0.25 $m^3$ |
| Combustion Chamber Volume 2 | 0.028 $m^3$ |
| Combustion Chamber Temperature 1 | 800—900°C |
| Combustion Chamber Temperature 2 | ≥1000°C |
| Chimney Height | 14 m |
| Chimney Diameter | 0.2 m |
| Cyclone Angle | 25° |
| Material | SS 316L |
| Types of Wet Scrubbers | Double-stage Wet Scrubber |
| Blower System | 2 units + backup |
| auxiliary fuel | Firewood |

Source: Fahmi et al. (2024); KLHK (2021)

**Test Materials** :

- Liquid B3 waste: used lubricating oil (used oil from engines, hydraulics, gears, etc.) - code B105d (Kementerian Lingkungan Hidup dan Kehutanan Republik Indonesia, 2021)
- Solid B3 waste: used cloth contaminated with oil (code B110d) and used filters (code B109d)

**Measuring instrument** :

- Thermocouple/Thermogun to measure temperature
- Digital scales for weighing waste and ash
- Stopwatch to measure time
- Emission testing equipment according to SNI standards

**Research Variables**

**Table 2. Research Variables**

| Variables | Unit | Measuring instrument |
|---|---|---|
| Combustion temperature (average, highest, lowest) | °C | Thermocouple/Thermogun |
| Total burn time | minute | Stopwatch |
| Reduction of waste volume/mass | % | Scales |
| Burn *rate* | kg/hour | Scales + stopwatch |
| Mass of residue/ash produced | kg | Scales |

Source: Research Data, 2026

Derived Variables (Calculated):

**Table 3. Derived Variables (Count)**

| Variables | Formula | Unit |
|---|---|---|
| Waste Destruction Efficiency | (mass of waste burned / mass of initial feed) × 100% | % |
| Burning Rate | mass of processed waste / burning time | kg/hour |

Source: Research Data, 2026

**Research Variables**

ECBG operations follow the Standard Operating Procedure (SOP) with Document Number IK-5A21-02-00-02.00-01.0 dated August 3, 2021:

1. **Preparation** : Weighing B3 waste and firewood, checking the completeness of the equipment, ensuring the availability of water for the *wet scrubber system.*
2. **Waste Input** : Manually input B3 waste into the first combustion chamber at varying speeds.
3. **Ignition** : Lighting the fire in the first combustion chamber, closing the combustion chamber, turning on the turbo engine to inject air which creates a rotating effect ( *cyclone* ).
4. **Monitoring** : Operate *the wet scrubber* during combustion, record the temperature every 15 minutes, ensure the first combustion chamber temperature is ≥800°C
5. **Termination** : Burning continues until the fire is extinguished, weighing the remaining ash

**Testing Scenarios** : Three scenarios with different waste compositions:

**Table 4. Testing Scenarios**

| Parameter | Process 1 | Process 2 | Process 3 |
|---|---|---|---|
| Waste Composition | Majun Cloth: 2.5 kg Used Filter: 10 kg Liquid Waste: 30 L (24 kg) | Majun Cloth: 20 kg Used Filter: 20 kg | Majun Cloth: 20 kg Liquid Waste: 30 L (24 kg) |
| Initial Total Mass | 36.5 kg | 40.0 kg | 44.0 kg |

Source: Research Data, 2026

**Data analysis**

Data was analyzed by:

1. **Descriptive statistics**: Calculating the mean, standard deviation, minimum and maximum values
2. **Tabulation**: Presenting data in tabular form
3. **Visualization**: Creating a graph of the relationship between variables
4. **Conformity analysis**: Comparing measurement results with quality standards and regulatory requirements.

## RESULTS AND DISCUSSION

### ECBG Operational Characteristics

The ECBG tested at the Pongok Island Diesel Power Plant (PLTD) has technical specifications in accordance with the design modification results presented in previous research Fahmi et al., (2024). and Technical Approval from the Ministry of Environment and Forestry. The ECBG uses the 3T principle ( Time, Temperature, Turbulence ) in its design:

- **Temperature** : The first combustion chamber operates at 800—900°C, the second combustion chamber ≥1000°C
- **Time** : Gas remains in the combustion chamber for at least 2 seconds
- **Turbulence** : Cyclonic flow from turbo air injection with a cyclone angle of 25°

**Field Test Results**

Based on testing conducted at the Pongok Island PLTD, the following results were obtained:

**Table 5. Field Trial Results**

| Parameter | Process 1 | Process 2 | Process 3 |
|---|---|---|---|
| Waste Composition | Majun Cloth: 2.5 kg Used Filter: 10 kg Liquid Waste: 30 L (24 kg) | Majun Cloth: 20 kg Used Filter: 20 kg | Majun Cloth: 20 kg Liquid Waste: 30 L (24 kg) |
| Initial Total Mass (Before) | **36.5 kg** | **40.0 kg** | **44.0 kg** |
| Burning Duration | **2.0 Hours** | **1.5 Hours** | **1.0 Hour** |
| Residual Mass (After) | 1.0 kg | 4.0 kg | 0.8 kg |
| Remaining Residue (%) | **3%** | **10%** | **2%** |
| Combustible Waste Volume (%) | **97%** | **90%** | **98%** |

Source: Field Test Data, 2026

**ECBG Performance Analysis**

**Burn Rate**

The burning rate is calculated using the formula:

$$\text{Burn Rate} = \frac{\text{Total Massa Limbah}}{\text{Durasi Pembakaran}}$$

**Table 6. Burning Rate of 3 Scenarios**

| Process | Total Waste Mass | Burning Duration | Burning Rate |
|---|---|---|---|
| Process 1 | 36.5 kg | 2.0 hours | **18.25 kg/hour** |
| Process 2 | 40.0 kg | 1.5 hours | **26.67 kg/hour** |
| Process 3 | 44.0 kg | 1.0 hour | **44.00 kg/hour** |

Source: Calculated from Field Test Data, 2026

**Analysis** :

- The highest combustion rate (44.00 kg/hour) was achieved in Process 3 with a composition of 30 L (24 kg) of liquid waste + 20 kg of majun cloth.
- The lowest combustion rate (18.25 kg/hour) occurred in Process 1 which contained 10 kg of used filters.
- The presence of used filters (Process 1 and 2) significantly reduces the combustion rate because:
    - Used filters contain metals and materials with high thermal conductivity that absorb heat.
    - Used filters have high density and low porosity so they are difficult to burn completely.

- The water content and remaining oil in the filter require additional energy for evaporation.

**Waste Destruction Efficiency**

The efficiency of waste destruction is calculated using the formula:

$$\text{Efficiency Destruction} = \frac{\text{Massa Limbah Awal}}{\text{Massa Residu}} \times 100\%$$

**Table 7. Waste Destruction Efficiency from 3 Scenarios**

| Process | Initial Mass | Residual Mass | Destruction Efficiency |
|---|---|---|---|
| Process 1 | 36.5 kg | 1.0 kg | **97.3%** |
| Process 2 | 40.0 kg | 4.0 kg | **90.0%** |
| Process 3 | 44.0 kg | 0.8 kg | **98.2%** |

Source: Calculated from Field Test Data, 2026

**Analysis** :

- The highest destruction efficiency (98.2%) was achieved in Process 3 with a composition of liquid waste + majun cloth.
- The lowest efficiency (90.0%) occurred in Process 2 which only contained solid waste (majun cloth + used filters)
- **Average crushing efficiency: 95.2%**

**Burn Time Variation Phenomenon**

The significant difference in burning duration (1.0—2.0 hours) is caused by several main factors:

Effect of Waste Composition

**Table 8. Effect of Waste Composition on Burn Time**

| Component | Impact on Burn Time | Mechanism |
|---|---|---|
| Liquid Waste (Used Oil) | ⬇ Speed up | High calorific value (≈42 MJ/kg), flammable, supplies additional energy |
| Rag | ⬇ Speed it up a bit | High porosity, large specific surface area, oxygen easily reaches the surface |
| Used Filters | ⬆ Slow down | Metal content, high density, requires more energy to reach reaction temperature |

Source: Research Analysis, 2026

**Effect of Water and Volatile Content**

The process of burning B3 waste follows the following reaction mechanism [20]:

**Stage 1: Drying (Endothermic)**

H2O(l)+Energy→H2O(g) $H_2O(l) + \text{Energy} \rightarrow H_2O(g)$

Energy required: 2,260 kJ/kg water (latent heat of vaporization)

**Stage 2: Pyrolysis (Thermal Decomposition)**

CxHyOz→CH4+CO+H2+C(solid) $C_xH_yO_z \rightarrow CH_4 + CO + H_2 + C(\text{solid})$

**Stage 3: Gas Oxidation (Exothermic)**

CH4+2O2→CO2+2H2O+Energy CH 4+ 2O2 → CO2 + 2H2O O + Energy

2CO+O2→2CO2 + Energy2CO + O2 → 2CO2 + Energy

**Kinetic Theory of Combustion**

The combustion rate follows the Arrhenius equation [20]:

$$k = A \, . \, e^{-Ea/RT}$$

Where:

- k = reaction rate constant
- A = frequency factor
- Ea = activation energy (kJ/mol)
- R = gas constant (8.314 J/mol·K)
- T = absolute temperature (K)

For waste with high activation energy (such as used filters with metal content), the reaction rate becomes slower at the same temperature.

**Effect of Air-Fuel Ratio**

The ECBG uses a two-chamber combustion system with turbo air injection:

$$AFR = \frac{\dot{m}_{udara}}{\dot{m}_{bahan\ bakar}}$$

In Process 3 (44.0 kg/h), the AFR is close to the stoichiometric optimum (≈14.7 for hydrocarbons), resulting in rapid and complete combustion. In Process 1 (18.25 kg/h), the AFR may be excessive or insufficient, resulting in inefficient combustion and longer combustion times.

**Theoretical Analysis of Burning Duration**

**Calculation of Energy Requirements for Process 1 vs Process 3**

**Table 9. Comparison of Energy Requirements Calculations for 3 Scenarios**

| Parameter | Process 1 (36.5 kg) | Process 3 (44.0 kg) |
|---|---|---|
| Mass of liquid waste (oil) | 24 kg | 24 kg |
| Mass of majun cloth | 2.5 kg | 20 kg |
| Mass of used filters | 10 kg | 0 kg |
| **Total** | **36.5 kg** | **44.0 kg** |

Source: Calculated from Field Test Data, 2026

Total Calorific Value Calculation:
Calorific value (HHV) [24]:
Used oil: ≈42 MJ/kg
Majun cloth: ≈18 MJ/kg
Used filter: ≈8 MJ/kg (low due to metal content)

Process 1:
Energy Total = (24×42)+(2.5×18)+(10×8)
=1008+45+80=1,133 MJ

Process 3:
Energy Total =(24×42)+(20×18)+(0×8)
=1008+360+0=1,368 MJ

Energy Required for Evaporation of Water (Estimate):

If the used filter contains 20% water (2 kg in Process 1):
Evaporation Energy

2 kg×2,260 kJ/kg

=4,520 kJ=4.5 MJ

Analysis:
Although Process 3 has a total mass 20.5% greater than Process 1 (44 vs 36.5 kg) and a total energy 20.7% greater (1,368 vs 1,133 MJ), its combustion duration is actually 50% shorter (1.0 vs 2.0 hours). This indicates that the quality and composition of the waste are more important than the quantity, with the liquid waste acting as an "energy catalyst" that accelerates the combustion process.

**Laboratory Emission Test Results**

The results of emission tests carried out by accredited laboratories recommended by the Ministry of Environment and Forestry show that the exhaust gas emissions produced by ECBG with a wet scrubber system meet the quality standards [16]:

**Table 10. Emission Test Results**

| Parameter | Quality Standards | Test Results | Information |
|---|---|---|---|
| Dust particles | 50 mg/Nm³ | 47.63 mg/Nm³ | ✅ Fulfill |
| $SO_2$ | 250 mg/Nm³ | 4.61 mg/Nm³ | ✅ Fulfill |
| $NO_2$ | 300 mg/Nm³ | 41.6 mg/Nm³ | ✅ Fulfill |
| HCl | 70 mg/Nm³ | <1.5 mg/Nm³ | ✅ Fulfill |
| HF | 10 mg/Nm³ | <0.104 mg/Nm³ | ✅ Fulfill |
| CO | 100 mg/Nm³ | 176.8 mg/Nm³ | ❌ Not Fulfilled |
| Opacity | 10% | <10% | ✅ Fulfill |
| Combustion Efficiency | 99.99% | 99.85% | ❌ Not Fulfilled |

Source: Laboratory Emission Test Results, 2026

**Important Note** : Test results show that the CO parameter (176.8 mg/Nm³) and combustion efficiency (99.85%) do not fully meet the required quality standards. This is due to:

1. Operational conditions during testing were suboptimal, with the sampling location very close to the combustion chamber. This was due to the lack of facilities to accommodate the isokinetic laboratory equipment for sampling, as the hole must be aligned with the exhaust gas sampling stick.

2. Need for air-fuel ratio adjustment
3. Characteristics of the waste tested with high water content

**Comparison of Modified Design vs Original Design**

**Table 11. Comparison of Modified Design vs. Original Design**

| Parameter | Original Design (Australia) [6] | Modification Design (Indonesia) [7] | Changes / Reasons |
|---|---|---|---|
| Chimney | There isn't any | 14 m with Wet Scrubber | Regulatory compliance and emission dispersion |
| Combustion Chamber Volume 1 | 0.2 $m^3$ | 0.25 $m^3$ | Increase ±25% for high water content |
| Cyclone Angle | 30° | 25° | Turbulence optimization |
| Material | SS 304 | SS 316L | Increased corrosion resistance by ±40% |
| Wet Scrubber | There isn't any | Double stage | Emission control according to quality standards |
| Blower System | 2 units | 2 + backup | Redundancy for continuous operation |
| Number of Combustion Chambers | 1 room | 2 rooms | Increased combustion efficiency |

Source: Scholer Industries (2020); Fahmi et al. (2024)

**Figure 1. Enerflow Cyclone Burn Grate**
Source: Fahmi et al. (2024); KLHK (2021)

**Figure 2. Turbo Burn RC08 Incenerator**
Source: Scholer Industries (2020)


**Figure 3. Enerflow Cyclone Burn Grate PLTD Pongok**
Source: Field Test Documentation, 2026

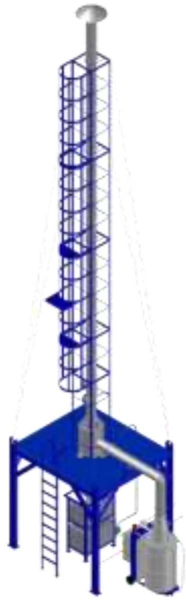

**Figure 4. 3D Enerflow Cyclone Burn Grate Modifikasi**
Source: Fahmi et al. (2024)

## CONCLUSION

Based on the results of ECBG performance characterization at the Pongok Island PLTD, this study concludes that ECBG demonstrates strong operational capability, achieving an average waste destruction efficiency of 95.2% and a maximum volume reduction of 98% under optimal conditions (30 L of liquid waste and 20 kg of contaminated rags over 1.0 hour). The combustion rate exhibited operational flexibility, ranging from 18.25 to 44.00 kg/h depending on waste composition. The highest combustion rates were achieved when processing used oil due to its high calorific value of approximately 42 MJ/kg. Meanwhile, combustion duration was significantly influenced by the presence of used filters with high metal content and density, as well as water input from the wet scrubber system. However, liquid waste functioned as an energy source that accelerated the combustion process. The integrated wet scrubber system effectively controlled exhaust gas emissions, including particulate matter, $SO_2$, $NO_2$, HCl, and HF, in accordance with applicable quality standards. However, CO emissions of 176.8 mg/Nm$^3$ and combustion efficiency of 99.85% still require further optimization to achieve the 99.99% performance standard.

From a regulatory perspective, ECBG has fulfilled Indonesian requirements through Environmentally Friendly Technology Registration (047/TRL/Reg-2/KLHK), Technical Approval for hazardous waste management, an Operational Eligibility Letter, and Industrial Design Rights protection (A00202303663) (Putra et al., 2024). This study provides the first comprehensive performance characterization of ECBG as a locally modified thermal treatment technology integrated with a wet scrubber system and intellectual property protection for processing hazardous waste generated by power plants in isolated areas. The findings address the research gap regarding empirical validation of design modifications and operational performance under actual field conditions.

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