



Examination of the Effect of a Water Mist System on Exhaust Gas Emissions and Particulate Residue Characteristics in a Small-Scale Incinerator

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Abstract. The implementation of incinerators for waste treatment faces challenges associated with high exhaust gas temperatures and combustion emissions, particularly carbon monoxide (CO) and particulate matter, which may contribute to environmental pollution. This study presents a preliminary baseline investigation of a small-scale incinerator as a basis for evaluating an integrated cyclone–water mist emission control system. The first-year research focused on the design and fabrication of the incinerator, installation of the cyclone and water mist system, and preliminary combustion testing. The baseline tests were conducted in three experimental runs using approximately 5 kg of mixed municipal solid waste per run, with a combustion duration of 60 min and a constant combustion-air supply. The water mist system was not activated during the baseline tests. The results showed that increasing the combustion chamber temperature from 200°C to 615°C was accompanied by a decrease in CO concentration from 1300 ppm to 811 ppm, indicating improved combustion conditions at higher temperatures. Temperature fluctuations during waste feeding and smoke leakage through several structural joints were also observed. These preliminary findings establish the baseline performance and identify technical aspects requiring refinement before comparative testing. Subsequent research will compare incinerator performance with and without water mist to quantify its effects on exhaust gas temperature, particulate emissions, and emission-control performance.

Keywords: Carbon Monoxide, Cyclone Separator, Incinerator, Particulate Emission, Water Mist

1 Introduction

Waste management has become an increasingly serious environmental issue across various regions of Indonesia, including Bali Province (Wardana, 2023). Population growth and the expansion of the tourism sector along rising economic activity have led to an annual increase in waste generation. Waste sources consist of household (56.79%), Commercial establishment (21.19%), Offices (8.87%), Public facilities (7.08%) and others (6.06%) (kemenlh, 2025). On 2025, waste generation in Bali reached 70,802-ton s per day, with only 35% being managed (through composting, creative products, and energy recovery), while the remaining 65% was concentrated at

TPA. Waste processing systems at these sites employ various techniques such as open dumping, controlled landfill, and sanitary landfill which pose risk of air, water, and soil pollution then serve as potential sources of disease (Yusmaman et al., 2023; Yuliyanti et al., 2024).

As a measure to address the situation, The Bali Provincial Governments has issued several strategic policies such as Governor Regulation No. 47/2019 (Pergub Bali No 97, 2018) and Governor Decree No 381/03P/HK/2021 regarding guidelines for source-based waste management in villages, urban villages and traditional villages (Pergub Bali No 47, 2019), (Pemerintah Provinsi Bali, 2021). The Government's policy has become an important step; however, the implementation is not optimal yet due to combination of several factors involving infrastructure, public awareness, rising waste volumes and technology. Therefore, there is a need for effective waste processing innovative technology specifically the use of small-scale incinerators equipped with water mist system for emission control.

Incinerator serves as a reasonably effective waste treatment alternative for facilities with the limited space; however, it generates toxic residue-such as bottom ash and fly ash containing heavy metals (Pb, Cd, Cr) and high level of gas emissions (CO, CO₂, NO_x, SO_x, furans and dioxins) which exceed of the thermal emission standard set by the ministry of Environment and Forestry Regulation No. 70 of 2026. This emission contributes to air pollution, posing risk to respiratory health and causing environmental degradation (Bhikuning et al., 2025). Water mist technology has emerged as an innovative solution by spraying a fine water mist (droplets <1000µm). it effectively suppresses particulate emissions through cooling mechanism and chemical reaction that inhibit pollutant formation (Riyanto et al., 2024). In the global waste industry, water mist has been proven to reduce particulate matter by 80-90% (Kim & Joon, 2020),(Lee et al., 2022). Conversely, research on the application of water mist system on incinerator remains limited.

Consequently, this research focuses on the effect of water mist system implementation on particulate (residue) characteristic and exhaust gas emissions reduction in the incinerator. In addition is expected to support environmental regulation and the development of ecofriendly technology for sustainable waste management.

2 Methodology

This study employed a preliminary experimental approach to establish the baseline operating performance of a small-scale incinerator integrated with a cyclone separator and a water mist system. The preliminary stage was conducted to characterize the initial combustion and exhaust gas conditions prior to evaluating the specific effect of the water mist system. The research methodology consisted of sequential stages, including problem identification, literature review, system design, prototype fabrication, preliminary experimental testing, data collection, data analysis, and interpretation of the research outcomes. The literature review focused on combustion characteristics, particulate emission control, cyclone separators, and water mist technology for exhaust gas treatment. Three baseline experimental trials were conducted under controlled operating conditions, with a waste loading of 5 kg per trial and an operating duration

of 60 minutes per trial. During the baseline experiments, the cyclone separator was operated, while the water mist system was kept OFF to establish the control condition. The key parameters monitored during each trial included combustion chamber temperature, exhaust gas temperature, carbon monoxide (CO) concentration, and relevant combustion and operational observations. The three baseline trials were used to evaluate the repeatability and operating stability of the incinerator system and to establish representative baseline values. These baseline results provide the control condition for subsequent comparative experiments with the water mist system activated. Therefore, the present preliminary study does not claim the effectiveness of water mist in reducing exhaust gas temperature or emissions. The effects of water mist will be determined in the subsequent experimental stage by comparing the baseline condition (water mist OFF) with the treatment condition (water mist ON) under comparable operating conditions. The findings form literature were used to design the integrated incinerator with emission control system as shown in Figure 1.

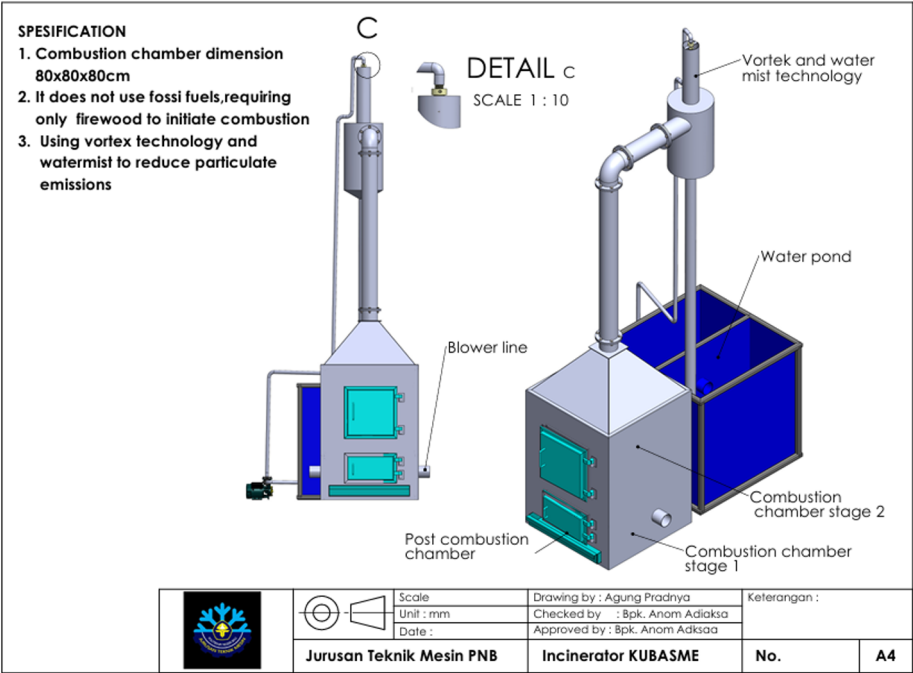


Figure 1. Design of Integrated Incinerator with Emissions System Control (Cyclone & Water Mist)

The experimental system consisted of a fixed-bed, two-stage incinerator, a cyclone separator, a water mist chamber equipped with a high-pressure nozzle, an exhaust duct, and a chimney. The first bed was used for municipal solid waste (MSW), while the second bed was used for wood and organic fuel to support combustion. The cyclone was positioned upstream of the water mist chamber to remove coarse particulate matter before the exhaust gas entered the misting section.

Three preliminary baseline trials were conducted using 5 kg of MSW per trial with a test duration of 60 min per trial. During these trials, the cyclone separator was operated, while the water mist system remained OFF to establish the baseline condition. Wood and organic material were used as auxiliary fuel. Moisture content, airflow rate, and feeding rate were not measured during this preliminary stage and will be quantified and controlled in the subsequent experimental trials. The monitored parameters included combustion chamber temperature, exhaust gas temperature, CO concentration, flame stability, visible smoke characteristics, and combustion residue. Temperature was measured using a thermal gun, with at least three measurements taken at the same location to obtain an average value, while CO concentration was measured using a portable gas analyzer. The baseline data were analyzed descriptively and used as the control condition for subsequent comparison with the water mist operating condition under more controlled parameters.

3 Result and Discussion

3.1 Result

The baseline performance of the incinerator was tested by monitoring the combustion chamber temperature and carbon monoxide (CO) concentration during the combustion process. The measured data are presented in Table 1.

Table.1. Baseline Combustion Temperature and CO Concentration

No.	Combustion Temperature (°C)	CO Level (ppm)
1	200	1300
2	250	1290
3	265	1275
4	282	1240
5	304	1235
6	327	1210
7	352	1201
8	365	1187
9	386	935
10	403	910
11	415	902
12	440	894
13	465	880
14	486	873
15	503	860
16	520	851
17	547	847
18	570	832
19	585	828
20	615	811

The relationship between combustion temperature and CO concentrated illustrated in Figure 2.

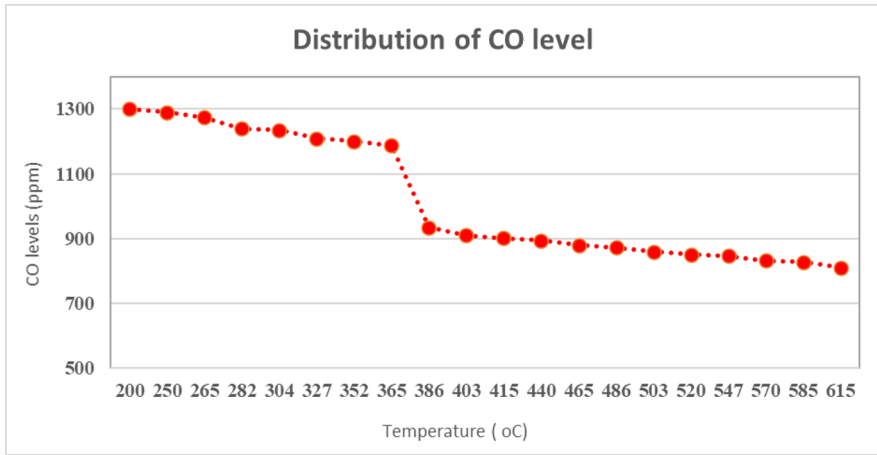


Figure 2. Relationship between combustion temperature and CO Concentration

As shown in Table 1 and Figure 2, the combustion chamber temperature increased progressively from 200°C to 615°C during the experiment, while the CO concentration decrease from 1300 to 811 ppm. The highest CO concentration was observed during the initial combustion phase at 200°C, whereas the lowest CO concentration was observed at the highest combustion temperature of 615°C. During the experiment, fluctuation in combustion temperature was observed during waste feeding process. Smoke leakage was also identified at several join structural of incinerator body. These observations were recorded during the process of experiment and will be considered in the next evaluation of the modified incinerator equipped with the water mist system.

3.2 Discussion

The experimental result demonstrated that increasing the combustion chamber temperature resulted in a continuous reduction of carbon monoxide (CO) concentration as presented in Table 1 and Figure 2. The combustion temperature increased from 200°C to 615°C while the CO concentration decrease from 1300 to 811 ppm. This trend indicated that combustion become more efficient as the operating temperature increased. Phenomena decrease of CO Concentration can be explained by the oxidation of carbon monoxide into carbon dioxide under sufficient oxygen availability and high temperature condition. The oxidation reaction is expressed as (1).



Where carbon monoxide reacts with oxygen to produced carbon dioxide. The reaction rate increase with temperature because the oxidation kinetics become faster, resulting in more complete combustion. Consequently, the amount of CO released in the exhaust gas decrease (Niessen, 2002). In addition to chemical kinetics, combustion efficiency

is strongly influenced by the availability of oxygen, mixing intensity and residence time of combustion gases. Complete combustion generally occurs when the combustion process satisfies the well-known 3T (Temperature, Time, & Turbulence) (Nnaemeka SP & Emeka, R, 2018). Higher combustion temperature promotes oxidation reactions, whereas sufficient residence time and adequate turbulence improve fuel air mixing (Mohit et al., 2026), reducing incomplete combustion products.

Although combustion efficiency was not directly measured in this study, the observed reduction in CO concentration indicates that combustion efficiency increases as the combustion chamber temperature (Safakish, 2012). However, fluctuations in combustion temperature during waste feeding indicated temporary disturbances in the combustion process. The introduction of fresh waste reduced the local combustion temperature because additional energy was required to evaporate moisture and initiate pyrolysis. Furthermore, smoke leakage detected at several joint of the incinerator suggest that part of the combustion gas escaped before passing through the designed exhaust line. Such leakage may alter air flow distribution and reduce combustion stability, thereby affecting gas emission.

Overall, the baseline experiment confirms that combustion temperature is one of the dominant parameters governing combustion quality in the developed incinerator. These findings provide the reference condition for evaluating the effectiveness of the integrated water mist system in the subsequent stage of this research.

4 Conclusion

This preliminary study established the baseline performance of a small-scale incinerator prior to evaluating the water mist emission-control system. The combustion chamber temperature increased from 200°C to 615°C, accompanied by a decrease in CO concentration from 1300 ppm to 811 ppm. The results indicate a reduction in incomplete combustion products at higher combustion temperatures. However, combustion efficiency was not directly measured, and the effect of the water mist system was not evaluated in this baseline stage. These findings provide a reference for subsequent comparative experiments under water mist OFF and ON conditions.

Acknowledgment

The authors gratefully acknowledge the support provided by Politeknik Negeri Bali, particularly the Research and Community Service Center (P3M) and the Department of Mechanical Engineering, for facilitating this research through laboratory facilities, technical support, and administrative assistance. The authors also thank all colleagues and students who participated in the fabrication of the prototype and the experimental work.

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