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# Application of Smoke Washer Device in Waste Incineration Machine to Reduce Exhaust Gas Emissions at Jatibarang Landfill Semarang

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**Abstract**
Waste management at the Jatibarang Landfill, Semarang, faces challenges due to incinerator exhaust gas emissions, potentially decreasing air quality, and posing health risks to surrounding communities. This community service program implemented a smoke washer (wet scrubber) adapted to the conditions of a simple incinerator. The activities included designing and fabricating the device, integrating electrical and control systems, providing operational training for partners (CV Dewa Nata Persada and Jatibarang Landfill), and conducting field testing of exhaust gas quality. The tested parameters consisted of particulate matter (PM), carbon monoxide (CO), and sulfur dioxide ($SO_2$), which were compared with the quality standards of the Ministry of Environment and Forestry Regulation No. P.70 of 2016. The measurement results indicated that all parameters were below the threshold limits, with pollutant concentrations decreasing from the initial operation to the following hours, signifying more stable performance of the device under steady-state operating conditions. These findings demonstrate the importance of the community service program in enhancing partners' awareness and capacity in environmentally friendly waste management, underscoring the project's significant impact.

**Keywords:** smoke washer, incinerator emissions, pollution control, environmental health

## INTRODUCTION

Waste management in urban areas remains a significant challenge, including in Semarang. The Environmental Agency reports that the Jatibarang Landfill receives a large volume of waste daily, which is difficult to decompose naturally. Incinerators are one of the methods used to reduce this waste volume. Although this combustion method is effective in decreasing the quantity of waste, at the same time, incinerators generate exhaust gas emissions. Thick black smoke from the chimney reduces air quality and potentially causes health problems for workers and the surrounding community [1].

Emission control is therefore necessary to ensure that incinerators do not result in air pollution as a secondary impact of waste processing. One of the technologies that can be applied is the wet scrubber or smoke washer. This system directly contacts exhaust gases with a liquid medium [2,3]. The process lowers the gas temperature while simultaneously capturing dust and harmful compounds, making the emissions released into the atmosphere cleaner [4]. Although this technology has been widely applied in industrial-scale operations, its application in simple landfill incinerators is still limited [5]. This condition highlights the gap between the need for emission control and the facilities available in the field [6,7].

To address the gap in emission control technology, this comprehensive community service program focused on applying a smoke washer machine adapted to the conditions of the incinerator at the Jatibarang Landfill, Semarang. The program's activities covered every aspect, from equipment installation and operational training to partner assistance and emission testing. This thorough approach ensured that the combustion results consistently met quality standards. By adopting this comprehensive approach, the program reduced air pollution and significantly enhanced partners' capacity in more environmentally friendly waste management.

## METHOD

### Design and Fabrication of the Machine

The initial stage of the program was to design a smoke washer (wet scrubber) to be installed in the exhaust channel of the waste incinerator. The design was prepared considering the field's combustion capacity, chimney dimensions, and operational conditions. [8]. The main components designed included the scrubbing chamber with a gas–liquid contact area, water distribution system, connecting pipes, and an exhaust fan to maintain a stable smoke flow [9].

The fabrication was carried out at the Mechanical Engineering Laboratory, Faculty of Engineering, UNNES, through several stages, including material cutting, frame and chamber welding, pipe system assembly, and initial flow testing. The assembled unit was then adjusted on site to ensure direct integration with the incinerator [10]. With this construction, the combustion smoke was directed into the scrubbing chamber before being released into the atmosphere [11].

### Integration of Electrical and Control Systems

In addition to the mechanical construction, the machine was equipped with a simple electrical system to support its operation. A control panel was developed to regulate the power supply to the water circulation pump and exhaust fan. The panel was equipped with a main switch, safety fuses, and operational indicator lights to allow users to monitor the system status visually.

To enhance safety and user friendliness, a temperature sensor and fan current meter were added as early warning indicators in case of malfunction [12]. Although the control system remains basic, it is sufficient to ensure safer and more efficient machine operation [13]. With mechanical and electrical integration, the smoke washer functions not only as a passive device but also as a unit that can be monitored and adjusted according to field needs [14].

### Introduction of the Machine to Partners

The smoke washer was then introduced to the partners through socialisation activities. At this stage, the service team explained the machine's working principle, standard operating procedures (SOP), and routine maintenance procedures to ensure optimal performance [15,16]. Simulations were also conducted using the control panel, water circulation pump operation, and exhaust fan inspection to ensure that partners understood each integrated component [17].

To assess the feasibility and effectiveness of the device, performance evaluations were carried out through direct testing while the machine operated together with the incinerator. The service team provided intensive mentoring and monitored the activity per the planned schedule [17]. This monitoring served as a control mechanism, allowing any technical issues to be addressed immediately.

Evaluations were conducted at every activity stage, including socialization, operational training, and field testing. The evaluation design covered the scheduling, performance indicators, and benchmarks for goal achievement. This approach ensured that the program's success could be measured clearly and provided a basis for continuous improvement [18].

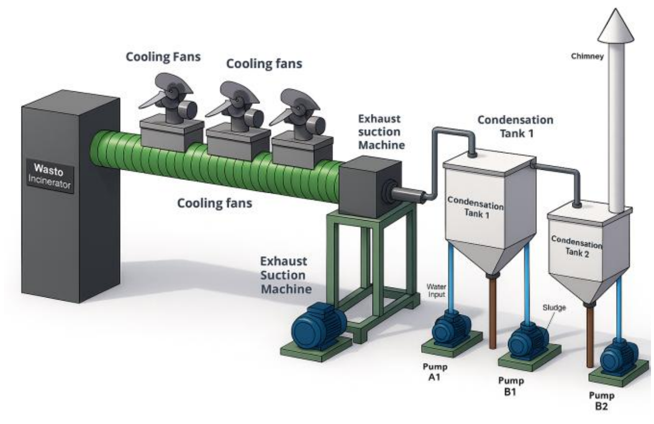


Figure 1. Smoke Washer Machine

**Smoke Quality Analysis**

Smoke quality testing is carried out to ensure that the exhaust emissions from the incinerator equipped with a wet scrubber are within safe limits per applicable regulations. The parameters tested focus on the main components that are often indicators of air pollution, namely particulate matter (PM), carbon monoxide (CO), and sulfur dioxide ($SO_2$). These three parameters were selected because they have the potential to significantly impact both human health and the surrounding environmental quality [19].

In line with the objectives of the activity, the smoke quality testing was conducted through four stages: (1) socialization with partners regarding the purpose and procedures of testing, (2) enhancing partner competency through simple technical training, (3) conducting field emission testing, and (4) evaluating measurement results by comparing actual data against the emission standards for incinerators.

**Particulate Matter (PM) Testing**

The particulate concentration analysis was carried out using the gravimetric method, as it is considered the most representative and straightforward for field testing. The process includes:

1. Sample Preparation

Incinerator exhaust gas is passed through a pre-weighed glass fibre filter. This filter captures dust, fly ash, and fine particles in combustion smoke.

2. Measurement

After sampling, the filter is dried under controlled conditions and reweighed. The difference in filter mass before and after use indicates the amount of particulates captured. This value is then calculated into a concentration ($mg/Nm^3$) by considering the volume of gas that passed through the filter [20].

3. Data Analysis

The particulate concentration data are directly compared with the threshold values stipulated in the Ministry of Environment and Forestry Regulation No. P.70 of 2016. If the measurement results are lower than the standard limit, the particulate emissions are considered to comply with environmental requirements.

**Carbon Monoxide (CO) Testing**

Carbon monoxide is an essential indicator of combustion quality. The testing was carried out through the following steps:

1. Sample Preparation

Samples were taken directly from the incinerator stack at the outlet point after the gas had passed through the wet scrubber.

2. Measurement

The CO concentration was measured using a portable gas analyser that reads gas levels in ppm in real time. The device also records supporting parameters such as oxygen ($O_2$) concentration and gas temperature, which can be used to assess combustion efficiency [21].

3. Data Analysis

The measurement results were compared with the emission standards for CO. If the values obtained were below the threshold limit, the exhaust gas quality was considered compliant and safe for release into the atmosphere.

**Sulfur Dioxide ($SO_2$) Testing**

$SO_2$ was selected as a test parameter because waste materials often contain sulfur compounds, which, when burned, can release harmful acidic gases. The testing procedure is as follows:

1. Sample Preparation

Exhaust gas is directed through the wet scrubber system, where absorption occurs via physical and chemical interactions with the scrubbing liquid.

2. Measurement

The $SO_2$ concentration is measured using a portable gas analyzer that detects gas levels in real time, expressed in either ppm or $mg/Nm^3$ [22].

3. Data Analysis

The measured $SO_2$ concentration is compared with the threshold emission standard. If the concentration is lower than the limit, it can be concluded that the incinerator emissions are safe from the potential hazards of acidic gases.

All measurement results are compiled in a table containing the actual values of each parameter compared with the standard limits. The evaluation is conducted using a descriptive approach, in which the effectiveness of the wet scrubber is assessed based on its ability to reduce pollutant levels to below regulatory thresholds [23]. If all parameters meet the requirements, the system is declared effective as an air pollution control measure for the incinerator.

## RESULTS AND DISCUSSION

### Exhaust Gas Emission Test Results

Exhaust gas emission testing of the incinerator equipped with a wet scrubber was conducted under two operating conditions: Sample A (after 1 hour of incinerator operation) and Sample B (after 4 hours of incinerator operation). The parameters tested included particulate matter concentration, carbon monoxide (CO), and sulfur dioxide ($SO_2$).

Table 1. Results of Exhaust Gas Emission Testing of the Incinerator with Wet Scrubber

| No | Parameter | Sample A (1 hour) | Sample B (4 hours) | Unit |
|---|---|---|---|---|
| 1 | Particulate Matter | 65 | 58 | $mg/Nm^3$ |
| 2 | Carbon Monoxide (CO) | 85 | 70 | ppm |
| 3 | Sulfur Dioxide ($SO_2$) | 72 | 60 | $mg/Nm^3$ |

The measurement results are compared with the national emission standards as a reference. The incinerator emission standards are regulated under the Minister of Environment and Forestry of the Republic of Indonesia No. P.70/MenLHK/Setjen/Kum.1/8/2016 concerning Emission Standards for Hazardous Waste Management Activities[24].

Table 2. Emission Standards for Incinerators (Regulation of the Minister of Environment and Forestry No. P.70 of 2016)

| No | Parameter | Maximum Permissible Limit | Satuan |
|---|---|---|---|
| 1 | Particulate Matter | ≤ 150 | $mg/Nm^3$ |
| 2 | Carbon Monoxide (CO) | ≤ 100 | ppm |
| 3 | Sulfur Dioxide ($SO_2$) | ≤ 100 | $mg/Nm^3$ |

The results presented in Table 1 indicate that the concentration of particulate matter in Sample A was 65 $mg/Nm^3$, which decreased to 58 $mg/Nm^3$ in Sample B. These values remain well below the 150 $mg/Nm^3$ emission limit, as listed in Table 2. The declining trend in particulate concentration during operation suggests that the gas scrubber system performs more effectively once the incinerator reaches stable combustion conditions. This observation is consistent with the findings of [25], who reported that longer operating durations enhance scrubber efficiency, with extended gas-liquid contact time reducing particulate matter by up to 70%.

For carbon monoxide (CO), the concentration measured in Sample A was 85 ppm, which declined to 70 ppm in Sample B. Both values are still below the regulatory limit of 100 ppm. This reduction can be attributed to stabilizing combustion chamber temperature after several hours of operation, which promotes more complete oxidation of CO to $CO_2$. Barroso et al. (2020) Likewise, it is noted that maintaining stable combustion temperatures plays a key role in lowering CO emissions by as much as 30%. Furthermore, modern wet scrubbers may facilitate additional CO oxidation through reactions with hydroxyl radicals (OH) generated in the scrubbing liquid, as highlighted by Wang & Liu (2019) In their study on Fenton-like wet scrubbing systems.

Similarly, $SO_2$ concentrations decreased from 72 $mg/Nm^3$ in Sample A to 60 $mg/Nm^3$ in Sample B, remaining below the 100 $mg/Nm^3$ threshold. This decline demonstrates the capacity of wet scrubbers to capture acidic gases effectively. The result is in line with Zhao et al. (2021), who explained that $SO_2$ absorption in spray scrubbers occurs via both physical and chemical processes, following the two-film theory and providing reliable predictions of removal efficiency. (Chin et al.,(2022) Further emphasised that $SO_2$ absorption efficiency is influenced by pH, ion concentration, and the oxidation potential of the scrubbing solution, with sodium chlorite ($NaClO_2$) identified as particularly effective in binding acidic gases.

The test results confirm that all three parameters (particulate matter, CO, and $SO_2$) comply with national emission standards. The consistent reduction in pollutant levels from Sample A to Sample B also indicates that system performance becomes more stable after extended operation of the incinerator. This finding agrees with Chin et al. (2022) and Huang et al. (2024), who observed that the effectiveness of wet scrubbers tends to improve once steady-state operating conditions are reached. Therefore, applying a damp scrubbing system in incinerators has been proven to effectively reduce exhaust gas emissions in compliance with regulatory requirements, while significantly mitigating air pollution in landfill areas.

## CONCLUSION

The community service program, which focused on applying a wet scrubber system in the incinerator at Jatibarang Landfill, Semarang, demonstrated effective outcomes. Emission test results showed that the concentrations of particulate matter, carbon monoxide (CO), and sulfur dioxide ($SO_2$) after the installation of the wet scrubber remained below the emission standards stipulated in the Ministry of Environment and Forestry Regulation No. P.70 of 2016. The reduction in pollutant levels from Sample A (1 hour of operation) to Sample B (4 hours of operation) further indicated that the system performs more efficiently once the incinerator reaches stable operating conditions. Thus, the implementation of this technology not only mitigates air pollution around the landfill area but also enhances partners' awareness of the importance of environmentally friendly waste management practices.

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