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A review of combustion in waste incinerator and its emissions

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Abstract

Nowadays, the waste problem has become a national issue that has to be handled seriously. Every member of society should be responsible for waste sorting into organic, non-organic, and poisonous waste. Organic waste, including biomass waste from wood and food waste, can be utilized as fertilizer and animal feed. Non-organic trash, such as plastic bottles, other plastics, and used clothing, can be converted into new products or recycled. The purpose of this study was to look at the incinerator machine utilized at the waste processing site and the exhaust gas produced. The method of this study is a literature review, which entails gathering and assessing publications regarding the ultimate waste processing system. The findings obtained were that waste-to-energy (WtE) incinerators are frequently a useful option. These incinerators are intended not only to decrease waste volume but also change it into usable energy, such as electricity or heat. The incinerators are often use modern pollution control systems to reduce emissions of pollutants such as NOx, SO_2, and particulate matter. High caloric value in waste can generate more heat during combustion. It is important to have high temperature in incinerator to ensure complete combustion, reducing volume of waste and eliminating the combustion.

Keywords

Waste incinerator, Emissions control, Waste-to-energy

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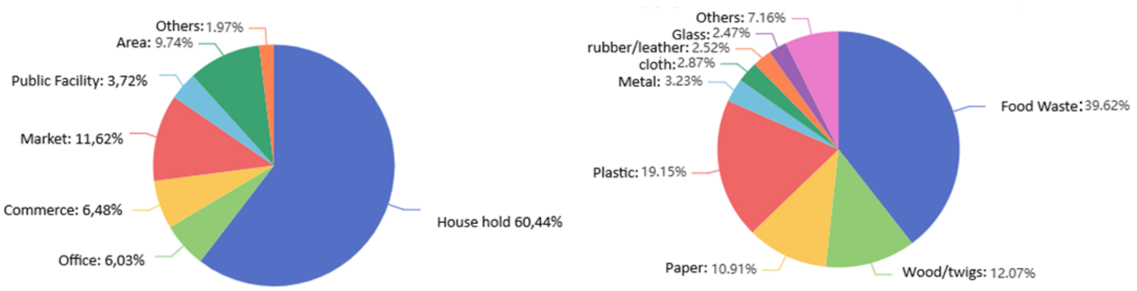
Introduction

Waste is always a concern to get the right solution to the environment. Currently, in public places there are separate waste disposal sites for organic, non-organic and poisonous materials waste. Organic waste is defined as garbage derived from organic elements, such as residual food waste and biomass waste (wood, twigs, and leaves) [1]. Organic waste can be used as fertilizer and animal feed [2]. While non-organic waste can be recycled into useful items [3].

Poisonous waste can be recycled into metal rod raw materials, and chemical raw materials. According to Indonesian waste data, 39.41% of total waste will remain unprocessed in 2023 [4]. Figure 1 shows the percentage of waste in Indonesia in the year of 2023. As can be seen in Figure 1 (a) waste from households is the highest wastes with 60,44% and Figure 1 (b) shows that food waste is the highest type of waste with 39,62%. Most of the waste are from organic, and other wastes are 7,16%. Waste management to handle some waste residue is by processing through a waste incinerator. A waste incinerator is a facility designed to burn waste materials, converting them into ash, flue gas, and heat.

Recently a study concerning waste incinerators has been conducted with several studies. Liu et al proposed α shape route flame incinerator to treat waste materials. The results show by analysing with Computational Fluid Dynamic (CFD) that an α shape route can increase the temperature of flue gas and can decrease the emissions level [5]. Denda et al. researched on a furnace with high-temperature mixed gas and recirculated exhaust gas coming in from the roof to accomplish steady low air-ratio combustion in stoker-type incinerator for municipal power generation. The results verified the achievability of stable low air ratio combustion with low NOx concentrations for waste of widely varying quality with lower caloric values ranging from 7.1 to 13.8 MJ/kg [6]. Another study, Jang et al. analyzed emissions of hazardous air pollutants from the burning of biodegradable sludge in a commercial fluidised bed plant are being investigated. Based on the fuel analysis, the incineration air flow rate was calculated to be 4567 Nm^3/h. Following combustion, the flow rate of incinerator gas increased to 8493.8 Nm^3/h. The semi-dry reactor's lime slurry injection operation factors for SOx and HCl were 64.20 and 4.81 kg/h, respectively. The wet scrubber's NaOH operation factors for SOx and HCl were 23.88 and 3.14 kg/h, respectively [7].

Studying combustion in an incinerator is important to improve the efficiency in combustion and less emissions in the incinerator. The purposes of this study are to understand how to achieve complete combustion in waste incinerators, and how to eliminate the emissions in incinerators.



(a) Waste from Sources (b) Types of Waste

Figure 1. Percentage of Waste in Indonesia in 2023 [4]

Method

Combustion In Incinerator

The controlled process of combustion in a waste incinerator involves burning waste materials at high temperatures, usually between 900°C and 1100°C, while oxygen is present [8]. The waste is broken down into heat, flue gas, and ash via this process. Combustion in an incinerator consists of many steps as shown in Figure 2 [8]. First is waste feeding. In waste feeding, the incinerator receives waste, usually via a conveyor system or hopper. This purpose is to maintain a constant and controlled flow of waste into the combustion chamber. Then, combustion chamber. In combustion chamber the waste is dried and preheated. This condition is to maintain the moisture contents in waste is reduced. The waste is ignited and burns initially in the primary combustion zone. The temperature in the primary combustion is ranged between 600 °C to 800 °C. This temperature condition can produce heat and flue gases as it breaks down organic material into simpler chemicals. Then in the secondary combustion process. Secondary combustion happens in the temperature is between 900 °C to 1100 °C. In the secondary combustion chamber, the first zone's partially burned gases undergo further combustion. Oxygen is supplied to support the combustion process, ensuring that the waste is fully oxidized. Then heat recovery is when the heat created during combustion can be collected and used to generate steam or power. Next is pollution control. Pollution control is to achive less emissions from the combustion process like Sox, NOx and particulate matter. The last is ash handling. The residual ash is collected, disposed of, or processed for future use [8].

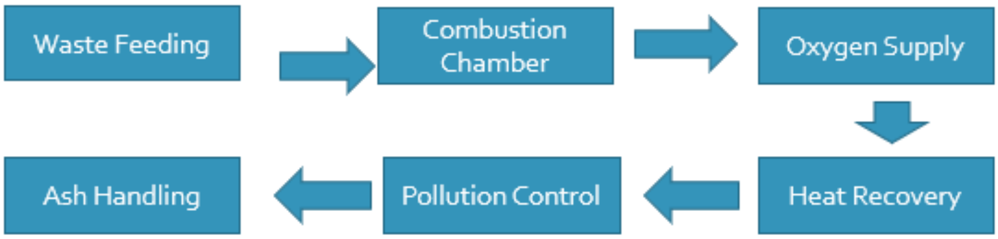


Figure 2. Combustion Proceses in Incinerator [8]

In order to achieve the optimal combustion in an incinerator. The combustion process should have a proper air supply in primary and secondary air to promote a complete combustion. Moreover, segregation and pretreatment of waste assist maintain optimal caloric value. Temperature monitoring and adjustment in various combustion zones increases efficiency and reduces emissions.

Results and Discussion

Complete and Incomplete Combustion

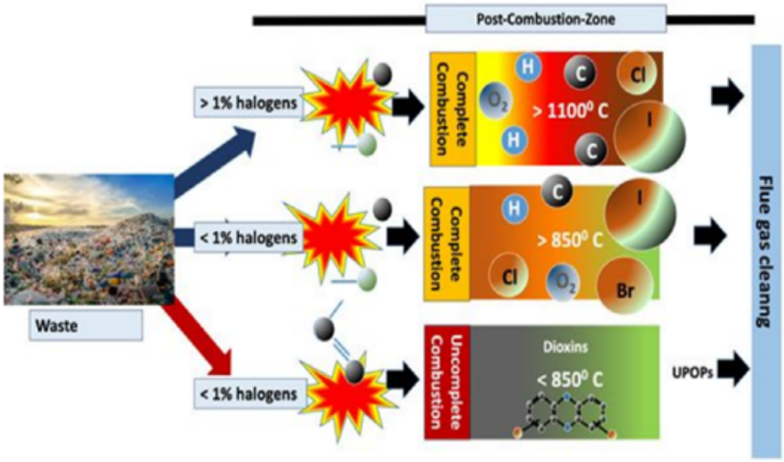


Figure 3. Complete and Incomplete Combustion in Waste Incinerator [9]

In an incinerator, waste items must burn completely with a plentiful supply of oxygen present. The objective of complete combustion is to reduce the amount of unburned wastes or pollutants while converting the waste's combustible components, such as carbon, hydrogen, and sulfur into their corresponding oxides, carbon dioxide (CO_2), water vapor (H_2O), and sulfur dioxide (SO_2) [9]. Whereas incomplete combustion happens when there is insufficient oxygen present for the fuel (waste) to undergo a full reaction. Instead of producing completely oxidized products like carbon dioxide (CO_2) and water vapor (H_2O), this produces a number of unwanted by-products, including carbon monoxide (CO), volatile organic compounds (VOCs), and particulate matters [9].

Figure 3 shows complete and incomplete combustion in incinerator. To achive a complete combustion in incinerator is when hazardous waste containing more than 1% halogenated organic compounds, represented as chlorine, is burned or co-incinerated, the temperature must be at least 1100°C. Moreover, to reach a complete combustion if the hazardous waste having a composition of less than 1% halogenated organic compounds; the temperature necessary to comply should be higher than 850°C. However, if the combustion occurs in less than temperature 850°C, so incomplete combustion will achieve resulting with appearance of emissions and also dioxins [9].

Caloric Value and Temperature

Perfect combustion in a waste incinerator is very important to ensure that the waste incineration process runs very well. The caloric value (or calorific value) of waste significantly affects the temperature in a waste incinerator [10]. A higher caloric value indicates that waste includes more combustible material, which produces more heat during combustion. This can result in greater temperatures in the incinerator, which improves combustion efficiency and energy recovery [11]. Waste with a low caloric content might not produce enough heat, which could result in incomplete combustion and lower temperatures [11]. This may lead to decreased energy recovery and increased pollution discharges.

Table 1. Optimize the Combustion Process by Caloric Value

No	Process	Methods	Benefit	References
1	Waste Segregation	Separate high-caloric value waste (like plastics and paper) from low-caloric value waste (like food scraps)	Ensures more consistent and efficient combustion, maintaining higher temperatures.	[12], [13]
2	Blending Waste with additive materials	Mix high and low-caloric value waste to achieve a balanced caloric input	Prevents temperature fluctuations, ensuring steady and efficient combustion.	[14]
3	Pre-treatment	Pre-dry or shred the waste to increase its caloric value.	Enhances combustion efficiency and reduces moisture content, resulting in higher temperatures.	[15], [16]
4	Air Supply Control	Optimize the amount of oxygen supplied to the combustion chamber	Ensures complete combustion, reduces the formation of pollutants, and maintains optimal temperatures.	[17]
5	Advanced Monitoring Systems	Install real-time monitoring systems to adjust combustion parameters.	Enables immediate adjustments to air supply, waste feed rate, and temperature, optimizing the combustion process.	[18], [19]
6	Energy Recovery Systems	Implement heat recovery systems like waste heat boilers.	Utilizes the heat generated from high-caloric value waste to produce steam or electricity, improving overall efficiency.	[20]

Table 1 shows how to optimize the caloric value of combustion in waste incinerator. These strategies can effect in efficient combustion, reducing emissions, and maximizing energy recovery. These techniques can be implemented in waste incinerator by separated high caloric value waste and low caloric value waste [12]. Waste segregation with the separation between high caloric waste and low caloric waste. This implimentation can increase the efficiency of combustion [13,14]. Blending waste can also increase the caloric value by blending with additive materials . Additive materials can be woods, engine oil, rice husk, coconut husk with the proportion of 20%, 30%, 40% and 50%. The caloric values can rise to 1500-2400 Kcal/kg with 30% additive [14]. To accelerate hydrolysis, mitigation methods such as substrate thermal pretreatment can be applied to increase the caloric value. The best pre-treatment environment was around 72 °C for 22 minutes, which enhanced hydrolysis and produced a positive energy balance [15]. Air control supply can optimize the amount of oxygen in the combustion chamber. This can be used by method of liniear quadratic regulator (LQR). LQR method can analyze the combustion control in the incinerator plant to perfom complete combustion [16]. Advanced monitoring system is using intellegent control system.

These modules were integrated into the existing distributed control system, allowing for exact detection and change of crucial operating parameters. The intelligent control module may considerably increase system stability and parameter control accuracy, lowering operating workload and pollution emissions [17]. Moreover, using waste materials like paper and plastic that have a relatively high lower heating value and superheating boiler steam with methane gas in the combined system were the two main factors that affected the energy recovery efficiency [18].

Emissions and Control

Waste incinerators can provide some emissions. Especially when incomplete combustion appears in the incinerator. Some emissions, such as CO_2, NOx, SO_2, particulate matter, dioxin and furan can emerge in the incinerator if in the combustion temperature is not reached at high temperature of around 1100 °C. This condition must be controlled in the waste incinerator to achieve complete combustion and resulting in less or no emissions appears. Table 2 shows the emissions control in the waste incinerator that can be applied and improve the efficiency in combustion process.

Table 2. Emissions Control in Waste Incinerator [9,11,19–22]

Emissions	Source	Impact	Control
CO_2	Produced during the combustion of organic material.	Major contributor to climate change.	Modern incinerators employ energy recovery systems to make the process more efficient.
NOx	Formed during high-temperature combustion.	Contributes to smog and acid rain, and can cause respiratory problems.	Selective Catalytic Reduction (SCR) and Selective Non-Catalytic Reduction (SNCR) systems are used to reduce NOx emissions.
SO_2	Released from the combustion of sulfur-containing materials.	Contributes to acid rain and respiratory issues.	Flue Gas Desulfurization (FGD) systems, such as wet scrubbers, are employed to capture SO_2.
Particulate Matter (PM)	Produced during the combustion process.	Can cause respiratory and cardiovascular issues.	Electrostatic precipitators and baghouses are used to capture and reduce particulate emissions..
Dioxins and Furans	Formed unintentionally during combustion.	Highly toxic and can cause cancer and other serious health problems.	-High-efficiency combustion and advanced pollution control technologies, such as activated carbon injection, are used to minimize these emissions. -High temperature controlled - Flue gas treatment system

Table 2 shows emissions from waste incinerators can arise during the combustion process. These conditions can be impacted by environmental problems from climate change (CO_2), contributing to acid rain (NOx and SO_2), causing respiratory and cardiovascular problems (PM), and reaching toxic levels, causing cancer and other health problems (Dioxins and furans) [20,21]. These emissions should be eliminated by controlling the waste incinerator by using modern incinerators, using selection catalytic reduction (SCR) and non-SCR, applying Flue Gas Desulfurization (FGD) systems, utilizing electrostatic precipitators, and having high-efficiency combustion and high temperature control [23].

Conclusion

Separation of waste is very important to facilitate the process from different types of waste. Combustion in a waste incinerator is burned in the presence of oxygen at high temperatures, typically between 900°C and 1100°C. To achieve complete combustion in waste incinerators that burn or co-burn hazardous waste with a halogenated organic matter content of more than 1%, expressed as chlorine, the temperature required to meet these requirements must be at least 1100 °C. A higher caloric value of waste can generate more heat during combustion. This can lead to higher temperatures in the incinerator, improving the efficiency of the combustion process and energy recovery. Moreover, having a complete combustion in waste incinerator can improve the efficiency of the incinerator, resulting in fewer emissions. Furthermore, emissions from waste incinerator should be controlled and manage in order to prevent the environmental pollution.

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