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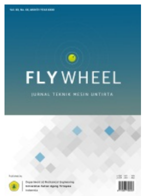

Efficiency Analysis of Incinerator Combustion Chamber Using Variations in the Number of Burners with the Computational Fluid Dynamics Method

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ABSTRACT

Waste is a global environmental problem that is increasing with population growth and consumption. Based on SIPSN 2023 data, waste generation in Indonesia reached 69.9 million tons, dominated by food waste (41.60%) and plastic (18.71%), with households as the main source (44.37%). Incinerators are an effective solution to reduce waste volume by 50–90% and have the potential to generate energy through heat conversion. This study designed an incinerator with a capacity of 45 kg with a double burner system fueled by Compressed Natural Gas (CNG) to optimize the combustion process and reduce emissions. The design was carried out using SolidWorks 2022, while flow and emission simulations were carried out using ANSYS 2023 R1. This study compares the combustion performance of single-burner and double-burner systems based on CO and CO_2 exhaust emissions. Simulation results show that the single-burner system produces a CO mass fraction of 0.6144 and CO_2 of 0.1452, while the double-burner system produces a CO fraction of 0.6845 and CO_2 of 0.0910. The combustion efficiency of the single-burner system was recorded at 19.1%, while the double-burner system only achieved 11.7%. These values indicate that the single-burner system has more complete and efficient combustion than the double-burner system, in terms of exhaust.

Keywords: *waste, burner, combustion efficiency, CO and CO_2 emissions*

1. INTRODUCTION

The biggest environmental problem facing societies around the world is waste. Waste is always generated by human activities from local, industrial, and commercial sectors. According to data from the National Waste Management Information System (SIPSN), waste generation in Indonesia in 2023 will be 69.9 million tons [1].

One method that is widely used is incinerators, which are high-temperature waste burners that can reduce waste volume by up to 90% and reduce the majority of waste accumulation and reduce environmental pollution caused by waste accumulation [2, 3]. Combustion efficiency in incinerators is strongly influenced by temperature distribution, air-fuel ratio, and burner system design [4]. The use of Compressed Natural Gas (CNG) fuel is considered cleaner and more efficient than conventional fuels [5].

To analyze combustion performance in detail, the Computational Fluid Dynamics (CFD) method is used. CFD enables numerical and efficient modeling of fluid flow, temperature distribution, and gas emissions [6]. Previous showed that CFD can accurately predict the temperature distribution and flow behavior in incinerators [7, 8].

Based on this, this study aims to compare the performance of single burner and double burner systems in a 45 kg capacity incinerator fueled by CNG. The main focus lies on CO and CO_2 gas emissions, as well as combustion efficiency, in order to obtain more efficient and environmentally friendly combustion.

2. METHODOLOGY

This research was conducted by numerical simulation to design an incinerator combustion chamber with a double burner system, and analyze its combustion efficiency based on temperature distribution and flue gas emissions. The research was conducted at the Mechanical Engineering Computer Laboratory, Tidar University, using CAD (Computer Aided Engineering) software for geometry modeling, and CFD (Computational Fluid Dynamics) for numerical simulation.

The approach used includes technical calculations, three-dimensional (3D) design, and analysis of results in the form of temperature and composition of combustion gases.

The initial stage began with a literature study to determine design parameters, such as combustion capacity, combustion chamber volume, and burner configuration. The incinerator capacity was set at 45 kg per batch, assuming the waste came from household waste. The volume of the combustion chamber was determined using the equations [9]:

$$V = \frac{m}{\rho} \ldots\ldots\ldots (1)$$

With V is the volume of the combustion chamber (m³), m is the mass of waste (kg), and ρ is the density of waste (kg/m³).

Next, the combustion chamber geometry is designed using CAD software, followed by mesh creation and simulation settings in Computational Fluid Dynamics. The simulation uses a 3D, steady-state, and pressure-based solver approach. The physical models used include the Realizable k-ε turbulence model, energy model, and species transport to analyze CO and CO_2.

Meanwhile, the combustion efficiency is evaluated from the simulation results of CO and CO2 gas mass fractions, and is calculated by equation [9]:

$$\eta = \left(\frac{[CO_2]}{[CO_2] + [CO]}\right) 100\% \ldots\ldots\ldots (2)$$

Where CO_2 and CO are the mass fraction of each simulated gas. The higher $\boldsymbol{\eta}$ the value, the more efficient the combustion is.

3. RESULTS AND DISCUSSION

Design of Combustion Chamber in this study, the combustion capacity was set at 45 kg of waste per batch. To determine the volume of the combustion chamber, a geometric approach was used.

A combination of cylinder and truncated cone, with calculations based on waste density. The geometry of the combustion chamber is shown in Figure 1.

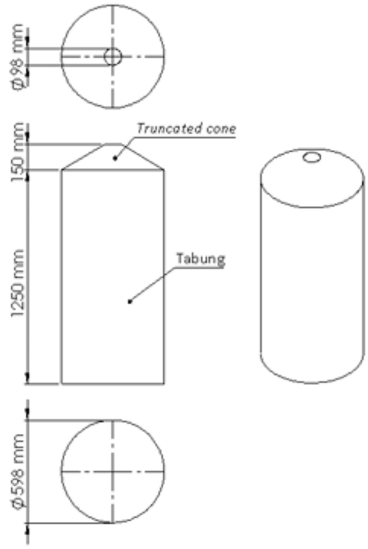

Figure 1. Geometry of combustion chamber

The total volume of the combustion chamber is calculated by the equations:

$$V_{total} = V_{cylinder} + V_{cone} \ldots\ldots\ldots (3)$$

Where:

$$V_{cylinder} = \pi r_1^2 h_1 \ldots\ldots\ldots (4)$$

$$V_{cone} = \frac{1}{3}\pi h_2 (r_1^2 + r_1 r_2 + r_2^2) \ldots\ldots\ldots (5)$$

With reference to the national waste density of 159 kg/m³ [10]. Then, the minimum volume of the combustion chamber is calculated as follows:

$$V = \frac{m}{\rho} = \frac{45}{159} = 0{,}2830 \text{ m}^3$$

The final design of the combustion chamber uses the following configuration:

- Cylinder radius / Cone bottom radius (r_1): 0,3 m
- Cylinder height (h_1): 1,25 m
- Top radius of the cone (r_2): 0,05 m
- Cone height (h_2): 0,15 m

  Based on these parameters, we obtain:
- Cylindrical volume:

$$V_{cylinder} = \pi(0{,}3)^2(1{,}25) = 0{,}3510 \text{ m}^3$$

- Volume of a truncated cone:

$$V_{cone} = \frac{1}{3}\pi(0{,}15)[(0{,}3)^2 + (0{,}3)(0{,}05) + (0{,}015)^2 = 0{,}0168 \text{ m}^3$$

- Total volume of combustion chamber:

$$V_{total} = 0{,}3510 + 0{,}0168 = 0{,}3677 \text{ m}^3$$

These dimensions are then used as a reference in 3D modeling using CAD software, to ensure compatibility between the volume of the combustion chamber and the waste capacity. A drawing of the 3D model of the combustion chamber is shown in Figure 2.

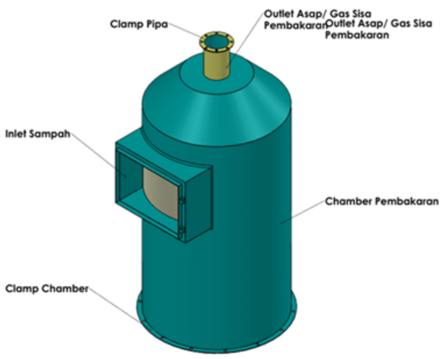

Figure 2. 3D model of combustion chamber

3.1 Air fuel ratio single burner

The methane fuel flow rate can be determined by knowing the air mass flow rate and the air-fuel ratio (AFR). The methane fuel flow rate can be determined by knowing the air mass flow rate and the air-fuel ratio (AFR). Then the methane fuel flow rate can be calculated as follows:

$$\dot{\mathrm{m}}_{\mathrm{CH_4}} = \frac{\dot{\mathrm{m}}_{\mathrm{air}}}{\mathrm{AFR}_{\mathrm{CH_4}}}$$

$$\mathrm{AFR}_{\mathrm{CH4}} = \frac{0{,}039\,\frac{\mathrm{kg\ air}}{\mathrm{s}}}{0{,}0022\,\frac{\mathrm{kg\ CH_4}}{\mathrm{s}}}$$

$$\mathrm{AFR}_{\mathrm{CH4}} = 17{,}72\,\frac{\mathrm{kg\ of\ air}}{\mathrm{kg\ of\ CH_4}}$$

3.2 Air fuel ratio double burner

The calculation of the methane air-fuel ratio with a double burner system can be calculated as follows:

$$\dot{\mathrm{m}}_{\mathrm{CH_4}} = \frac{\dot{\mathrm{m}}_{\mathrm{air}}}{\mathrm{AFR}_{\mathrm{CH_4}} \times 2}$$

$$\mathrm{AFR}_{\mathrm{CH4}} = \frac{0{,}039\,\frac{\mathrm{kg\ air}}{\mathrm{s}}}{0{,}0044\,\frac{\mathrm{kg\ CH_4}}{\mathrm{s}}}$$

$$\mathrm{AFR}_{\mathrm{CH4}} = 8{,}86\,\frac{\mathrm{kg\ of\ air}}{\mathrm{kg\ of\ CH_4}}$$

3.3 Combustion efficiency analysis

Combustion efficiency analysis was conducted to assess the performance of using single burner and double burner in optimizing the combustion process in the combustion chamber of a 45 kg incinerator. The evaluation was conducted through Computational Fluid Dynamics (CFD) simulations using CFD software, focusing on the distribution of carbon monoxide (CO) and carbon dioxide (CO_2) gas emissions. Combustion efficiency was calculated using the equation:

$$\eta = \left(\frac{[CO_2]}{[CO_2] + [CO]}\right) 100\%$$

Based on the simulation results, using a single burner produces a mass fraction of carbon monoxide of 0.6144 and carbon dioxide of 0.1452. Thus, the combustion efficiency is calculated as follows:

$$\eta = \left(\frac{0{,}1452}{0{,}1452 + 0{,}6144}\right) 100\% = 19{,}11\%$$

For the next efficiency calculation using a double burner variation incinerator. Based on the simulation results, using a single burner produces a mass fraction of carbon monoxide of 0.6845 and carbon dioxide of 0.0910 Thus, the combustion efficiency is calculated as follows:

$$\eta = \left(\frac{0{,}0910}{0{,}0910 + 0{,}6845}\right) 100\% = 11{,}7\%$$

The combustion efficiency in the single burner system is 19.11%, while in the double burner system it decreases to 11.7% or lower than the single burner incinerator combustion, due to the higher Air Fuel Ratio (AFR) in the single burner than double burner causing the results of CO and CO_2 to be better [11], results also affect the efficiency of incinerator. This shows that the single burner system is able to burn fuel more completely into the combustion chamber.

To clarify, Table 1 presents a summary of the simulation results of emissions and combustion efficiency using single and double burners.

Table 1. Simulation results of emissions and combustion efficiency

No	Parameters	Value
1	Single burner CO mass fraction	0.6144
2	Double burner CO mass fraction	0.6845
3	Mass fraction of CO2 single burner	0.1452
4	Mass fraction of CO2 double burner	0.0910
5	Single burner combustion efficiency	19.11%
6	Double burner combustion efficiency	11.70%

The distribution of CO and CO_2 emissions is also visualized in the CFD simulation, as shown in the Figure 3.

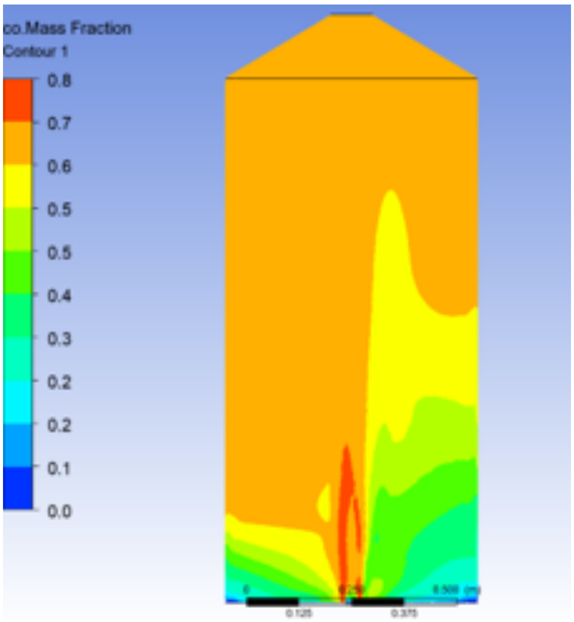

Figure 3. CO single burner

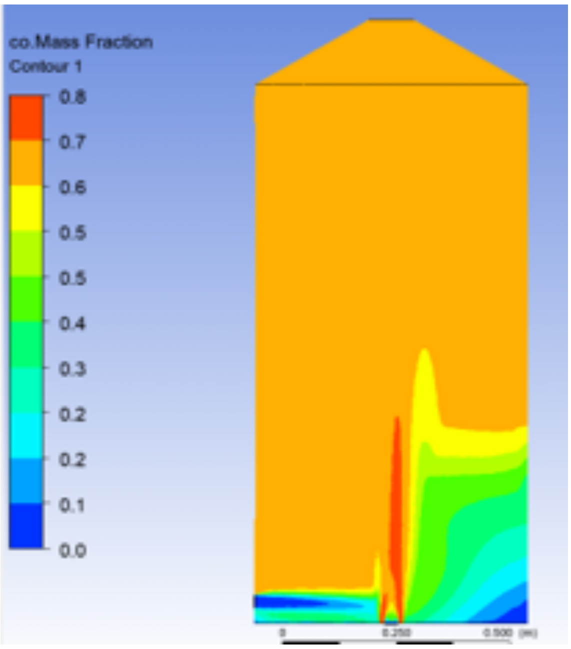

Figure 4. CO Double Burner

The simulation results show the difference in CO gas distribution between the single and double burner systems. In the single burner, the combustion spreads upward with a broad CO contour, while in the double burner, the combustion is more concentrated in the lower area. Although the CO contour of the double burner appears more concentrated at some points, the CO concentration of the single burner (0.6144) is lower than that of the double burner (0.6845). Because more fuel and limited air supply will result in higher CO [12].

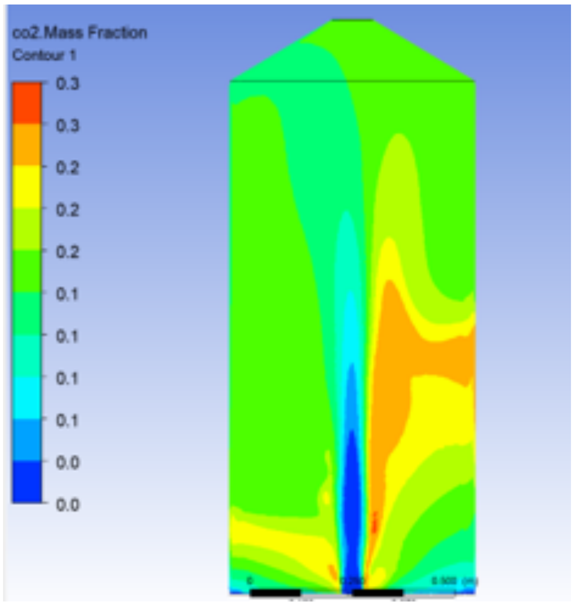

Figure 5. CO_2 Single burner

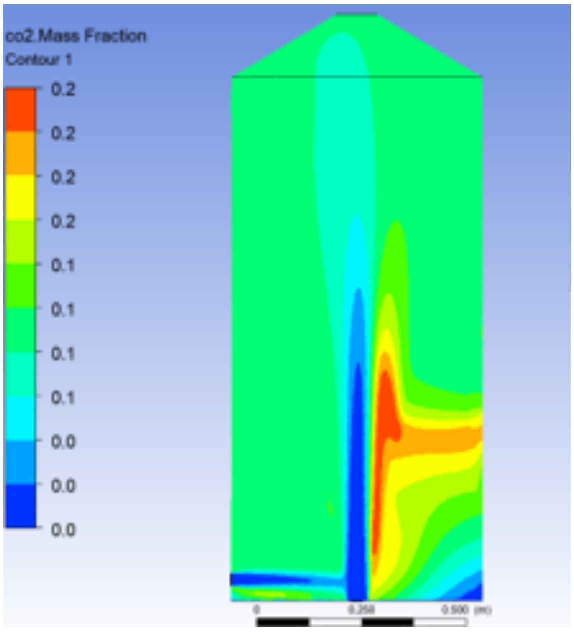

Figure 6. CO_2 Double burner

For the CO_2 contour, this is evidenced by the CO_2 number on the single burner which is 0.1452 for the double burner which is 0.0910. This difference proves that the single burner system provides more complete combustion results. The more perfect the combustion, the higher the CO_2 will be and the combustion will be perfect [13] lower concentration of CO and higher CO_2. This indicates good thermal efficiency and a significant reduction in harmful gas emissions for the single burner system.

4. CONCLUSION

Based on the results of numerical simulations using the Computational Fluid Dynamics (CFD) method, it can be concluded that the combustion system with a single burner shows better performance than the double burner system. The combustion efficiency of the single burner system reaches 19.1%, higher than the double burner which is only 11.7%.

This is supported by the flue gas emission data, where the CO concentration in the single burner system is lower (0.6144) and the CO_2 concentration is higher (0.1452) than the double burner system (CO: 0.6845; CO_2: 0.0910). This difference indicates that the combustion process in the single burner system is more complete, with a more efficient oxidation process. The double burner system has not been able to produce optimal combustion, presumably due to uneven air distribution in the combustion chamber.

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