



Analysis of Dry Waste Combustion Temperature as a Potential Source of Thermal Energy for the Drying Process

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Abstract: Waste management poses a significant environmental challenge, yet dry waste holds potential as a renewable energy source through Waste-to-Energy (WTE) technology. This study aims to analyze the potential of utilizing heat from dry waste combustion for drying applications using a hybrid approach of experimental methods and Computational Fluid Dynamics (CFD) simulation. The experimental stage was conducted by burning dry waste in a furnace to obtain the average hot gas temperature, which was measured at 295.33°C. This value was then used as a boundary condition in the CFD simulation of an integrated heat exchanger system within the furnace. Air at a temperature of 30°C was flowed into the heat exchanger with four mass flow rate variations (0.087, 0.092, 0.126, and 0.165 kg/s). The simulation results show that the system is capable of heating the air to a temperature range of 46.05°C to 58.05°C, which is ideal for drying applications. An inverse relationship was found between the mass flow rate and the outlet temperature, where a lower flow rate results in hotter air. This research proves that the heat recovery system from dry waste combustion is technically feasible and has the potential to be a sustainable alternative energy solution for drying processes.

Keywords: Waste, Heat Recovery, Incineration, Heat Exchanger, CFD

1. INTRODUCTION

Dry waste management and energy recovery from waste are primary focuses in promoting a circular economy and reducing global carbon emissions [1,2]. The combustion of dry waste in incinerator furnaces not only reduces waste volume by up to 95% [3] but also generates heat that can potentially be utilized for other industrial purposes. Waste-to-energy (WTE) technology serves as a sustainable alternative to landfills, capable of producing significant electrical and thermal energy [4,5].

The combustion process yields varying temperatures, with an optimal range between 850°C and 1100°C to ensure complete combustion and minimal emissions [6]. Municipal Solid Waste (MSW) with low moisture content that has undergone a drying process can have a calorific value of up to 6500 kJ/kg, enabling a self-sustaining combustion process without the need for additional fuel [7]. The significant heat potential from this combustion can be widely utilized for various drying processes in other industrial sectors [8, 9].

Pipe-type heat exchangers are one of the primary technologies for utilizing heat from industrial waste [10]. High-temperature exhaust gas is channeled through the heat exchanger to raise the temperature of clean air, which serves as the drying medium. The application of this technology has been proven efficient in reducing primary fuel consumption by 12-40%, depending

on the system's design and operating conditions [11].

Computational Fluid Dynamics (CFD) plays a crucial role in the analysis and optimization of combustion and heat exchanger systems [12,13]. CFD simulation allows for the mapping of temperature distribution, flow patterns, and heat transfer efficiency with high accuracy, thus providing vital insights for system design optimization [12]. Several studies indicate that CFD simulations can predict system performance with an error rate of less than 5% compared to experimental data [12].

Various heat exchanger configurations, such as the shell and tube type, are frequently used due to their durability and ease of maintenance [14]. The heat recovery efficiency of this type can reach 14%, with a potential reduction in fuel consumption of up to 27 kg/hour in industrial heating applications [14].

Drying with hot air generated from waste heat recovery has proven effective in various industrial sectors. Inlet air temperature around 30°C can be heated to reach 75-101°C through an optimal heat exchanger, creating ideal conditions for drying agricultural and industrial materials [11]. A CFD study in Indonesia also showed that this approach results in significant energy efficiency and a more uniform temperature distribution in the drying chamber [15].

The economic aspect of heat recovery implementation shows significant value, with a short payback period and potential annual energy

cost savings between USD 1,786 and USD 18,460, depending on waste characteristics and local energy prices [16]. This makes heat recovery technology not only an environmentally friendly solution but also economically profitable for industrial scales [17].

In Indonesia, the potential for WTE with heat recovery is vast due to the increasing volume of MSW and continuously growing energy demands [4]. The high organic content and variable moisture levels in Indonesian MSW require a specific design approach for combustion and heat recovery systems [18]. The initial drying process of MSW is proven to increase calorific value and operational stability, as well as create good synergy with the heat recovery system [18].

Validation of experimental results with CFD simulations is a key factor in optimizing heat recovery systems [9,19]. Combined studies of this nature show that their integration can contribute to reducing energy consumption and CO₂ emissions by up to 12% [20]. This approach significantly enhances the reliability and accuracy of performance predictions for waste heat recovery systems.

Nevertheless, a research gap still exists, particularly in developing integrated systems that cover combustion, heat recovery, and drying which are responsive to variations in feedstock and dynamic operating conditions. Adaptive control strategies and predictive maintenance based on CFD are recommended to improve system efficiency and reliability. A comprehensive life cycle assessment and techno-economic analysis are also needed to support the widespread commercial implementation of this technology.

This study aims to analyze the combustion temperature of dry waste in a furnace and its utilization as an energy source for drying processes via a pipe heat exchanger. The approach used is a combination of experiments and CFD simulation to understand the potential of using combustion heat as a heat source for drying air.

2. MATERIALS AND METHODS

This research was conducted using a hybrid approach, integrating experimental testing with numerical simulation to ensure an accurate analysis based on real conditions.

First, the experimental phase was carried out to determine the operational temperature of the heat source. Domestic dry waste with a consistently maintained composition was burned in a combustion furnace as shown in Figure 1. After the combustion process reached a stable flame condition, the temperature inside the combustion chamber was measured using a K-Type thermocouple. To ensure the validity and reliability of the data, this entire testing process was replicated three times. The results from the

three tests were then processed to obtain the average temperature of the combustion chamber, which became the fundamental reference data for the next stage.

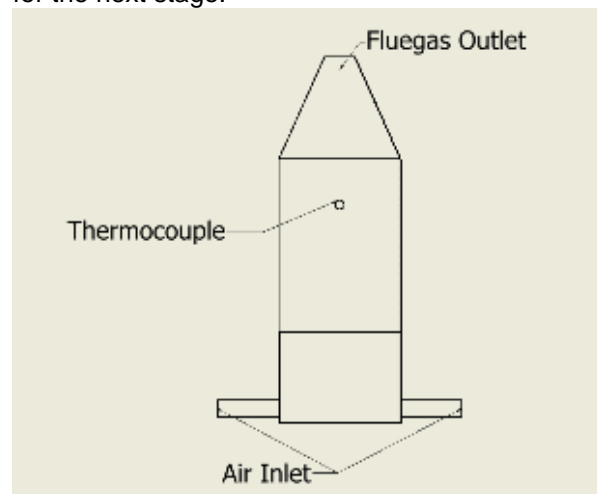


Figure 1. Waste combustion furnace

The average temperature obtained from the experiment was applied as a constant temperature boundary condition on the furnace walls. Ambient air at a temperature of 30°C was defined as the working fluid flowing into the heat exchanger pipes. To analyze the effect of flow rate on heat absorption effectiveness, the simulation was run with four different mass flow rate variations: 0.087, 0.092, 0.126, and 0.165 kg/s. The k-epsilon (k- ϵ) turbulence model was activated to model the realistic airflow inside the pipes. The primary parameter of focus for the analysis was the average air temperature at the outlet side of the heat exchanger system for each mass flow rate variation.

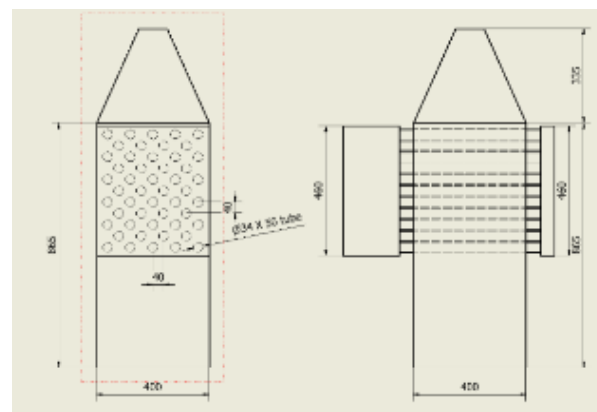


Figure 2. 3D Model of the furnace with HE

3. Results and Discussions

The initial phase of the research focused on determining the actual thermal conditions inside the furnace by conducting three dry waste combustion tests. From this series of tests, a consistent hot gas temperature was obtained, with a measured average value of 295.33°C. This

value reflects a realistic thermal energy source in a laboratory-scale furnace. This value was used as the primary boundary condition in the CFD simulation.

Based on this experimental data, the CFD simulation was run to evaluate the performance of the designed heat exchanger system. Ambient air at 30°C was flowed through the heat exchanger pipe arrangement with four different mass flow rate variations. The simulation results showed the system's ability to effectively recover heat, where the air was successfully heated to a temperature range between 46.05°C and 58.05°C.

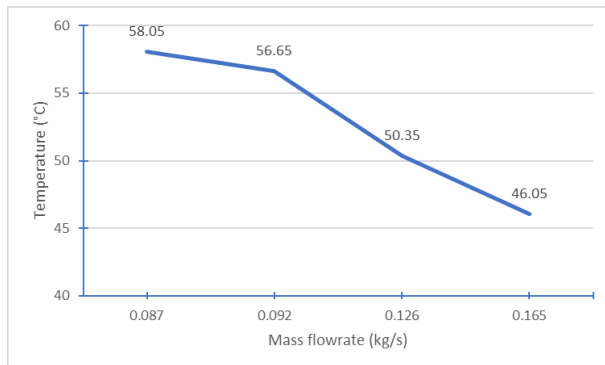


Figure 3. Relationship between mass flow rate and HE outlet temperature

Deeper analysis reveals a clear inverse relationship between the mass flow rate and the outlet air temperature. The highest temperature, 58.05°C, was achieved at the lowest mass flow rate, 0.087 kg/s. As the mass flow rate increased to 0.165 kg/s, the outlet temperature gradually decreased to 46.05°C. This phenomenon can be explained by the concept of residence time. At a lower flow rate, the air moves more slowly inside the pipes, giving it longer contact time with the hot surface to absorb maximum heat. Conversely, at a high flow rate, the short residence time limits the amount of heat energy that can be absorbed by each unit mass of air.

The maximum outlet temperature of 58.05°C (at 0.087 kg/s) is physically plausible even though the heat source is only 295.33°C. The temperature increase ($\Delta T = 58.05 - 30 = 28.05^\circ\text{C}$) is only ~9.5% of the available temperature difference ($295.33 - 30 = 265.33^\circ\text{C}$). This low heat recovery is reasonable due to several factors: a small heat transfer area (lab-scale heat exchanger), short residence time even at low flow, convection resistance on both the exhaust gas and air sides, and the fact that the heat exchanger used a parallel flow configuration (not counterflow).

CFD validation was performed by comparing the heat transfer rate from the simulation against the energy balance calculation at the lowest flow rate, 0.087 kg/s.

$$\dot{Q} = \dot{m} \cdot c_p \cdot \Delta T$$

$$\dot{Q} = 0,087 \text{ kg/s} \cdot 1005 \text{ J/kg.K.} (58.05-30)$$

$$\dot{Q} = 2452 \text{ Watt}$$

This analytical calculation value was then compared with the heat transfer rate data from the CFD simulation in Table 2.

Table 2. Heat transfer rate results from CFD simulation.

| No | Air mass flowrate (kg/s) | ΔT (°C) | Heat rate (W) |
|----|--------------------------|-----------------|---------------|
| 1 | 0.087 | 28.05 | 2460 |
| 2 | 0.092 | 26.65 | 2470 |
| 3 | 0.126 | 20.35 | 2580 |
| 4 | 0.165 | 16.05 | 5660 |

From the table, it is clear that the analytical and CFD simulation calculations of the heat flow rate show no significant difference, which can be a reference that the simulation run can represent real conditions.

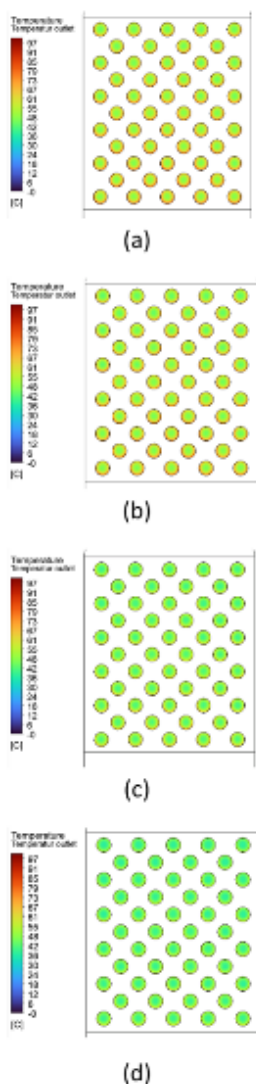


Figure 4. HE outlet air temperature contours (a). 0.087 kg/s, (b). 0.092 kg/s, (c). 0.126 kg/s, (d). 0.165 kg/s

From the heat transfer rate calculation, the greater the mass flow rate, the greater the heat transferred due to the increase in the convective heat transfer coefficient. However, the increase in mass flow rate results in a decrease in the air temperature rise within the heat exchanger. The temperature distribution contours of the air exiting the heat exchanger can be seen in Figure 4.

This indicates an important operational trade-off: a low flow rate is preferred to achieve high temperatures, whereas a high flow rate is more suitable for producing a larger volume of warm air at a lower temperature. Overall, these results confirm that the proposed system is capable of converting heat from waste combustion into a functional and controlled hot air stream for drying applications.

4. CONCLUSIONS

Based on the research combining experimental testing and numerical simulation, it can be concluded that this heat recovery system from dry waste combustion is technically feasible Available online at <https://conference.lppm.unila.ac.id/index.php/icsiger> DOI: <https://doi.org/10.23960/icsiger>

for drying applications. Experimental data show that waste combustion is capable of producing hot gas with an average temperature of 295.33°C, which is a significant thermal energy source.

CFD simulation confirms that this heat can be effectively transferred through the designed heat exchanger, successfully increasing the air temperature from 30°C to a range of 46.05°C to 58.05°C, corresponding to the variations in air mass flow rate. Furthermore, this study reveals that the outlet air temperature can be controlled by adjusting the mass flow rate, where a lower flow rate results in a higher temperature. These findings demonstrate the great potential of this system as a practical waste-to-energy solution for generating hot air for small to medium-scale drying processes.

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