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# Comparative Study of Airflow Efficiency in Rectangular and Cylindrical Small-Scale Incinerator Designs

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**ABSTRACT**

This study investigates the design, simulation, and analysis of compact incinerators with the goal of enhancing the efficiency of household waste management. Two unique incinerator designs—one rectangular and one cylindrical—were developed using SolidWorks software using input from the community obtained through a survey. The designs were evaluated based on the airflow and combustion efficiency, resulting in the development of four design variations for further investigation. These variations included two cylindrical and two rectangular models, each employing distinct airflow techniques (top and bottom). Computational Fluid Dynamics (CFD) simulations were performed using SolidWorks flow simulations to evaluate heat transfer rates, temperature distributions, and airflow patterns. The simulations demonstrated that the cylinder configuration with bottom airflow had greater heat retention and combustion efficiency than the other designs, owing to its symmetrical shape which minimised stagnant areas and enhanced air circulation. However, the rectangular design has deficiencies in achieving consistent airflow distribution, especially when using the top airflow setup, resulting in partial combustion in certain regions. This study focuses on the efficacy of airflow designs positioned below, especially in cylindrical shapes, in achieving enhanced combustion efficiency and minimising emissions in home incineration scenarios. It is advisable to conduct additional experiments to confirm and enhance the design of incinerators for practical applications and to supplement the results obtained from simulations.

## 1. Introduction

There has been a considerable increase in the generation of municipal solid waste (MSW) all over the world because of the growing urban population and increasing consumption patterns. This increase in MSW is a significant environmental challenge in developing nations like Malaysia, particularly because of the strong reliance on landfills for the transportation and disposal of waste. Based on Kamaruddin *et al.,* [1], landfills are becoming increasingly unsustainable as urbanisation continues to grow. This is mostly due to the limited availability of land and the related environmental

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dangers, which include leachate pollution and greenhouse gas emissions. Landfilling techniques that have been around for a long time can have terrible consequences for the environment, including contamination of soil and water, and pose risks to human health. It is therefore necessary to implement waste management systems that are more environmentally friendly to lessen reliance on landfills and reduce the impact of these negative impacts [2].

In areas where space is limited and waste-to-energy (WTE) solutions are sought, incineration has emerged as a potential option for landfilling due to its ability to convert trash into electricity. Furthermore, incineration can transform garbage into usable energy, an advantage that has been widely adopted in countries such as Japan and Sweden [3]. Incineration not only reduces the amount of waste by up to 90% but also can convert waste into energy. These nations use cutting-edge incineration methods to create power and heat while simultaneously reducing the number of toxic gasses released into the atmosphere. On the other hand, large-scale incinerators are frequently greeted with opposition in developing countries because of concerns about the cost, efficiency, and pollution caused by the burning process [4].

The creation of small-scale incinerators that can be adapted to the requirements of local communities has garnered interest as a potential solution to these difficulties. These units are designed to manage smaller volumes of garbage, making them more suitable for use in residential areas or small towns [5]. This has made them more environmentally friendly. According to Kayiem *et al.,* [6], as a result of the heterogeneous composition of municipal solid waste (MSW) in Malaysia, which is predominantly composed of organic materials with high moisture content, incineration may not be an effective method of trash disposal if the garbage is not pre-treated. The purpose of this study was to investigate the configuration and simulation of the airflow in small-scale incinerators, with a particular emphasis on how effective control of the airflow can improve combustion efficiency and reduce emissions. To optimise the design, computational fluid dynamics (CFD) simulations were used. These simulations analysed both cylinder and rectangular geometries to determine which shape offered superior airflow and combustion performance [7].

The global crisis in solid waste management has become worse because of population development and the industrialisation of the world. As a result, it has been predicted that the amount of waste generated on a global scale will increase by 70% by the year 2050 [8]. The generation of garbage in Malaysia has followed a similar pattern, with an estimated 38,000 tonnes of rubbish being created each day, of which organic material accounts for 55% [9]. An additional factor that makes the effective management of trash more difficult to achieve is the absence of public participation in waste separation processes. Although there are governmental initiatives to encourage recycling and other waste reduction techniques, incineration continues to be an underutilised option. According to Hannan *et al.,* [10], the potential of waste-to-energy (WTE) incineration has not yet been completely realised. This is possible due to public concerns about air pollution and the initial expenses associated with the construction of incinerator plants.

Today's incinerators are far more efficient and environmentally friendly than their predecessors, thanks to recent technological advancements in the field of incineration, notably in the area of air pollution control measures. Chen *et al.,* [11] reported that contemporary small-scale incinerators equipped with cutting-edge filtration systems and plasma incineration technology can effectively limit the emission of dangerous pollutants such as dioxins and furans when used successfully. In addition, the installation of waste heat recovery systems makes it possible to convert the heat produced during the incineration process into either electrical or thermal energy, which contributes to an overall improvement in the incineration process's sustainability [12].

Especially when it comes to ensuring efficient burning with restricted airflow, the design of small-scale incinerators involves some issues that are unique to each incinerator design. Computational fluid dynamics (CFD) models are a significant tool for regulating airflow within the incinerator chamber. This helps ensure that waste materials are completely combusted at optimal temperatures. The results of previous research have demonstrated that efficient air distribution is essential for avoiding hazardous byproducts and reducing the amount of incomplete combustion. In this particular investigation, the simulation is centred on contrasting two distinct designs, namely a rectangular incinerator and a cylinder incinerator, both of which are intended for use on a household scale. Chen *et al.,* [13] stated that their findings shed light on how the air velocity, temperature distribution, and combustion efficiency are influenced in each design.

## 2. Methodology

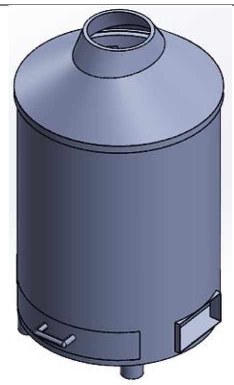
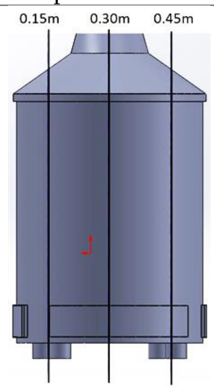
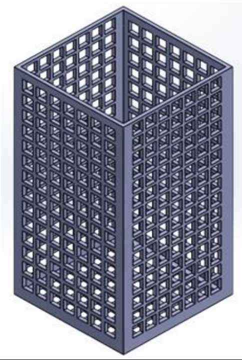
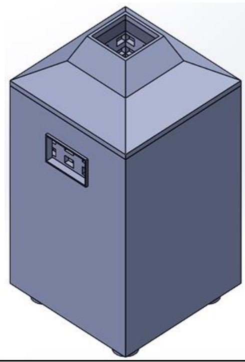
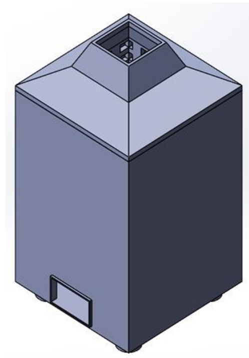
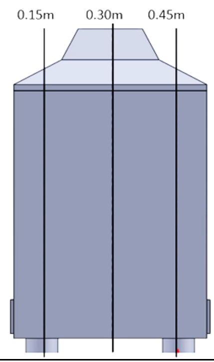
The design and analysis of small-scale incinerators were carried out using Computational Fluid Dynamics (CFD) simulations to optimise airflow, temperature distribution, and combustion efficiency. This methodology was chosen due to the ability of CFD to simulate real-world physical phenomena, such as fluid flow and heat transfer, which are critical for the efficient functioning of incinerators [14]. This project includes the development, computer modelling, and examination of compact incinerators to handle household waste. Using SolidWorks, a 3D modelling software known for its capability to create precise geometric representations for engineering purposes, two distinct incinerator designs were initially designed based on survey data collected from possible customers.

The main goal of these designs was to enhance the flow of air and improve the effectiveness of combustion to manage home garbage on a modest scale. The designs comprise a rectangular and cylindrical model, each designed to investigate distinct approaches to airflow and heat preservation. The rectangular shape of the design was derived from conventional incinerator models, but it was reduced in size to accommodate domestic waste. The design of the object provides a spacious surface area for garbage disposal, thereby making it easier to use and build. In order to enhance the flow of air and the combustion efficiency, an enclosure framework was introduced within the incinerator to augment the extent of the waste surface area that comes into contact with air during the burning process, as shown in Table 1 [15]. This design enhances the oxygenation of the waste, thereby providing a higher combustion efficiency. The cylinder design was selected due to its ability to improve heat retention and to provide even air circulation. The cylindrical shape of an object decreases the ratio of surface area to volume, resulting in reduced heat loss and enhanced energy efficiency during burning [16]. This design also had the interior components designed to optimise airflow and provide uniform exposure of the waste to the air, thereby enhancing the combustion efficiency.

Subsequently, the design underwent additional modifications, resulting in four separate iterations: two cylindrical and two rectangular, each featuring unique airflow arrangements. Two designs, one round and one rectangular, employed a top-airflow layout. In this configuration, air is delivered from above and directed towards the trash, causing the trash to ignite from the surface and facilitating downward burning. The remaining two systems incorporated a bottom airflow arrangement in which air was injected from beneath, guaranteeing the delivery of oxygen to the lower strata of the trash and facilitating upward combustion [17].

The airflow performances of these designs were assessed by conducting Engineering Fluid Dynamics (EFD) simulations using SolidWorks flow simulations. The proposed software facilitated the examination of fluid flow and heat transmission within a system, both internally and externally, while considering real-world conditions. The simulations were conducted using specific boundary conditions, which included an initial air velocity of 1 m/s to simulate average household settings and a temperature of 300°C. To simulate typical working conditions for home incinerators, the combustion chamber was maintained at a pressure of 2 bar [18].

**Table 1**
Incinerator model design

| Air flow | Cage | Top | Below | Cut plot |
|---|---|---|---|---|
| Cylindrical design |  |  |  |   |
| Rectangular design |  |  |  |   |

The analysis of the four designs revealed substantial disparities in thermal efficiency. The cylinder design featuring a bottom airflow exhibited superior heat retention and enhanced combustion efficiency compared to the alternative designs. The airflow pattern of this design facilitates uniform oxygen distribution to the waste material, thereby enhancing the combustion efficiency and minimising the presence of unburned material [18]. In contrast, the rectangular designs demonstrated significantly inferior heat distribution, particularly in the top airflow setup, resulting in an inadequate oxygen supply to select parts of the waste and incomplete combustion. Ultimately, this study integrated community-driven design feedback with advanced computer simulation to enhance the efficiency of small-scale incinerators intended for residential use. The computer simulations yielded useful insights into the thermal efficiency and airflow patterns of several designs. Among these, the cylindrical design exhibited higher heat retention and combustion efficiency. It is advisable to conduct additional experiments to confirm the simulation results and ensure that the designs function effectively in real-life situations.

## 3. Results

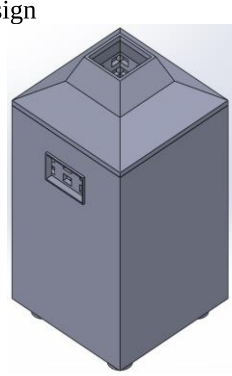
The velocity cut plots for the four incinerator designs: Rectangular Top Air Flow, Rectangular Below Air Flow, Cylindrical Top Air Flow, and Cylindrical Below Air Flow, were analysed at three different heights (0.15 m, 0.30 m, and 0.45 m), as shown in Tables 2 to 5. In each of these designs, the air velocity was held constant at 0.2 m/s across all heights. However, despite the constant velocity, the airflow dynamics differed significantly between the rectangular and cylindrical designs, and between the top and bottom airflow configurations. In the Rectangular Top Airflow design, air is introduced from above and directed downward towards the waste. The uniform air velocity of 0.2 m/s at all measured heights (0.15m, 0.30m, and 0.45m) indicates that the airflow is consistent near the surface of the waste. However, due to the rectangular geometry, airflow in the corners and lower layers of the waste may be restricted. This can result in uneven combustion because deeper layers may not receive adequate oxygen, leading to incomplete combustion in larger or denser waste loads [19].

In contrast, the Rectangular Below Air Flow design introduces air from beneath the waste, promoting upward airflow through the waste pile. With a constant velocity of 0.2 m/s at all three heights, this design ensures uniform oxygen distribution throughout the waste. This design is advantageous for promoting thorough combustion across all waste layers, reducing the risk of unburned material and improving thermal efficiency. The rectangular shape, while offering a larger surface area for waste, still faces challenges in terms of airflow efficiency at the corners. The cylindrical top airflow design, similar to the rectangular top airflow model, introduces air from above. However, due to the symmetrical geometry of the cylindrical design, the airflow was more evenly distributed, even with a constant velocity of 0.2 m/s across the heights. The circular shape minimises dead zones and improves gas flow, ensuring more uniform combustion. This design is particularly effective in maintaining combustion uniformity throughout the waste, although the downward airflow configuration may limit oxygen penetration to deeper layers [20].

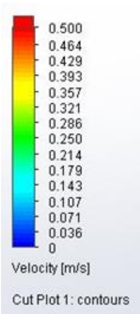
The cylindrical below the airflow design provides the most efficient airflow configuration, with air introduced from the bottom of the chamber and moving upward through the waste. A constant velocity of 0.2 m/s at all heights ensured that air reached every part of the waste, promoting complete combustion. The cylindrical geometry further enhances the airflow uniformity, minimising the likelihood of unburned material or localised areas of incomplete combustion. This design combines the benefits of the circular shape, which promotes even heat and airflow distribution, with the efficient oxygen delivery through the bottom airflow [20]. Across all four designs, the air velocity remained constant at 0.2 m/s, but the distribution of air and its interaction with waste varied depending on the geometry and airflow configuration. The cylindrical below the air flow design is the most efficient configuration, offering the most uniform air distribution, which is critical for optimising combustion and reducing emissions. The Rectangular Below Air Flow design also performs well in ensuring that oxygen reaches all layers of the waste, but it may face challenges at the corners of the chamber due to its geometry. On the other hand, the Top Air Flow designs (both rectangular and cylindrical) are less effective at penetrating deeper layers of waste, which could lead to incomplete combustion, especially in larger waste loads. In summary, the cylindrical below-air-flow incinerator is the most effective design for achieving complete combustion and efficient airflow, followed closely by the rectangular below-air-flow design. Although top airflow configurations are effective for surface-level combustion, they may require more optimisation to ensure complete combustion the entire waste mass.

**Table 2**
Velocity cut plot of the rectangular top air flow incinerator

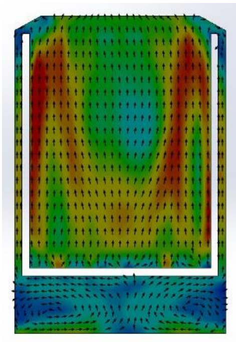
Rectangular top air flow incinerator design



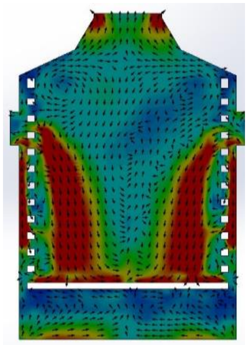
0.2 m/s




0.15 m



0.30 m



0.45 m

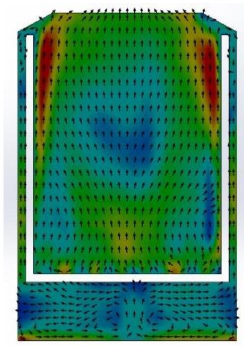
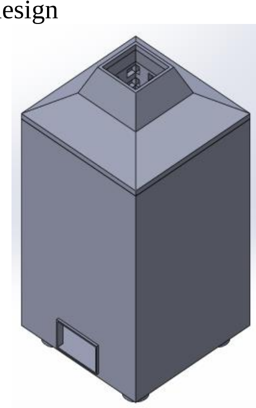
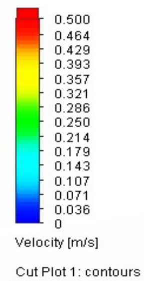


**Table 3**
Velocity cut plot of the rectangular below air flow incinerator

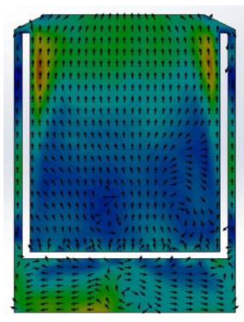
Rectangular below air flow incinerator design



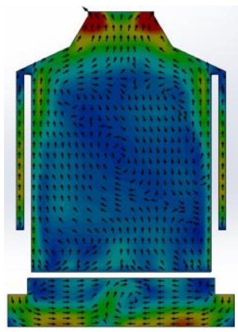
0.2 m/s




0.15m



0.30m



0.45m

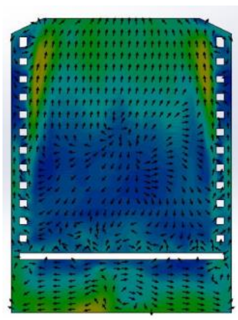


**Table 4**
Velocity cut plot of the cylindrical top air flow incinerator

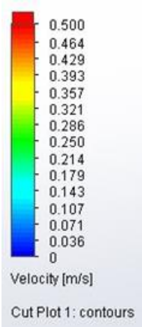
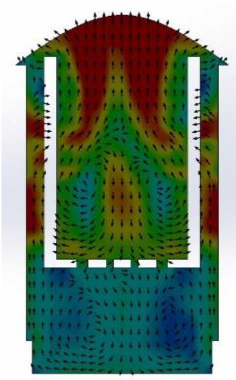
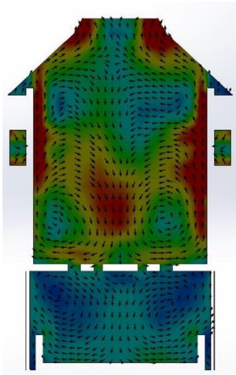
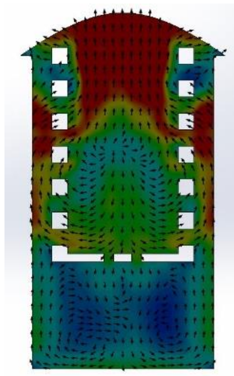
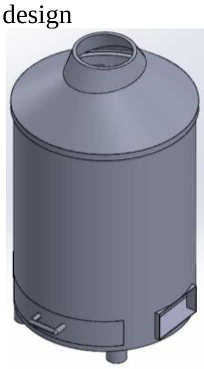
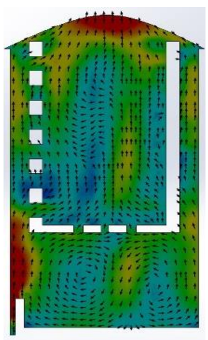
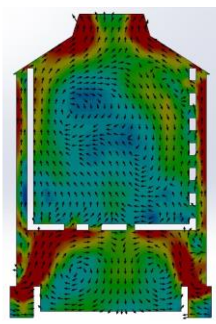
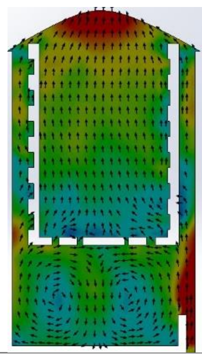
| Cylindrical top air flow incinerator design | | | |
|---|---|---|---|
| |  | | |
| 0.2 m/s | 0.15m | 0.30m | 0.45m |
|   |  |  |  |

**Table 5**
Velocity cut plot of cylindrical below air flow incinerator design

| Cylindrical below air flow incinerator design | | | |
|---|---|---|---|
| |  | | |
| 0.2 m/s | 0.15m | 0.30m | 0.45m |
|   |  |  |  |

## 4. Conclusions

This study investigated the performance of two small-scale incinerator designs—a rectangular models and a spherical model—by evaluating the airflow efficiency, heat transfer, and combustion uniformity through computational simulations. The spherical design with bottom airflow effectively distributes air and maintains heat retention throughout the combustion process. This design minimised the formation of dead zones, thereby promoting complete combustion and reducing emissions. In contrast, the rectangular design, while offering a larger surface area for waste placement, faced challenges in airflow distribution, particularly in the top airflow configuration, where incomplete combustion was observed. The findings suggest that circular design with below-airflow provides better overall combustion efficiency, making it a promising option for small-scale residential waste incineration. This work underscores the importance of airflow configuration in the design of efficient incinerators and its role in improving combustion performance and reducing environmental impact.

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