Design and development of community incinerators using the CFD method

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Abstract. The research aims to develop municipal solid waste (MSW) incinerators for higher thermal efficiency and minimal pollution from combustion. The 3D CFD model is developed for incinerators that consist of a combustion chamber and a cyclone. A municipal waste incinerator with a 250 kg/h capacity is modeled. The incinerator model simulated the comparative behavior between the finned and smooth combustion chamber walls. The results indicated that finned-walled incinerators exhibited more turbulent flow and air distribution in the combustion chamber than conventional wall incinerators. This will result in more complete combustion and less pollution.

1 Introduction

Waste management has become a big problem all over the world. The quantity of municipal solid waste (MSW) is annually increasing due to the rapid development of society's economy and the continuous improvement of people's living standards. The World Bank has estimated that 2010 million tonnes of MSW were generated worldwide in 2016, which is expected to increase 1.7 times by 2050 [1]. Almost the same as in Thailand, the average annual production of MSW has increased by 2.5%. The waste management is landfill, MBT, RDF, and combustion, and most waste management is landfill [2,3]. The different living styles: poor, social, and privileged zones, provide various MSW generated. Compared to social and poor zones, the privileged zones can produce MSW twice as much and 1.3 times more, respectively [4]. Then, depending on the scenario, the landfill will increasingly be replaced by intense use of incineration due to a paucity of the landfill, economic concerns, climate issues, and low net operation costs [5]. Currently, MSW comprises a high concentration of flammable components such as plastics, paper, glass, cartons, and organic waste. Incineration is one of the best options for MSW disposal because of its characteristics, such as reasonably stable residue, high degree volume reduction, minimal space demand, and energy reclamation [6].

The incinerator technologies are fluidized bed, spouted bed, fixed bed (rotary kiln, grate-firing), and the combustion temperature is between 750-1100°C. For incinerator technology, grate firing (GF) is the most popular technology used because of without preparation fuel. The more recently developed FB combustion is not widely employed because it needs for fuel preparation. However, the investment cost of an FB system,

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excluding fuel pretreatment, is about 10% lower than a GF plant. A great advantage of FB is its ability to handle short and long-term variations in the fuel composition and a wider choice of fuels for co-combustion [7]. Waste to energy and small MSW incinerators in Thailand is moving in a more sustainable path, and the source of dioxins is residential combustion [8, 9]. The parameters to control the PCDD/Fs in the incinerator are combustion temperature, residence time, and turbulence [10]. Moreover, a secondary combustion chamber has effectively reduced the emissions of pollutants such as dioxins and furans [11].

MSW contains a high amount of food waste, varying from 15 wt.% to more than 50 wt.% and usually around 70 wt.%. Moisture content is known to have a significant impact on many aspects of MSW incineration and 30% of plastic [12]. As the moisture content increases, the ignition speed decreases, and the drying process can be prolonged almost over the whole conversion zone, taking up to two-thirds of the whole combustion process. High moisture content also reduces the average burning rate and is highly overlapped with the devolatilization process but intensifies the evaporation and char oxidation rate. Consequently, the structure of the in-bed conversion zone has exceeded the expectation of conventional fixed-bed theoretical combustion [13].

An experimental approach can provide verified data and analysis, but it necessitates costly setups. Additionally, measuring process variables in some parts of waste incinerators is challenging, and safety is seriously concerned. Numerical techniques are a promising complementary tool in this regard. Simulations can be carried out and replicated at a relatively low cost and typically in a short time, in contrast to many physical studies. For various scenarios, various simulation types have been created. Computational fluid dynamics (CFD) is increasingly being used to overcome combustion problems. Many effective tools are available to achieve the simulation model, such as MATLAB, ANSYS, CFX, and SolidWorks [14]. A model for the virtual prototyping of thermal equipment must be detailed enough to account for all the major physical phenomena that occur while also providing results in a reasonable processing time [15]. Solidworks 2012 software simulates the design parameters and analyzes fluid behaviors to fluid flow and heat transfer problems [16]. 2D of MSW grate incinerators is modeled and comprises the porous zone of the waste bed on a grate. The primary air flows and grate speeds can be effectively controlled the smooth incinerator operation with varying waste compositions. In addition, a higher moisture content causes an ignition delay and prolonged combustion time [17]. Furthermore, the particle size using MATLAB and ANSYS FLUENT has significantly influenced higher effective conductivity, great length, and residence time. Then, the primary air has to be sufficient in complete combustion [18-19].

In this main point, the small MSW incinerators for the village needed to be developed due to needing more landfill and environmental concerns. The volumetric area of primary air should be increased to complete the combustion. This study aims to enhance the combustion efficiency utilizing finned wall incinerators. The 3D model on CFD simulation using SolidWorks has been proposed. To evaluate the enhancement of volumetric area increasing, the conventional and finned wall incinerators are compared to provide the airflow behaviors in the combustion chamber, indicating more complete combustion and less pollution.

2 Research methodology

The design of the combustion chamber is very important to handle all waste streams effectively. A good combustion process depends on the distribution of the waste on the grate and the effectiveness of waste mixing to allow good contact between the fuel and the air at the drying pyrolysis zone. In this work, the assumption is that the walls of the combustion chamber with an evenly distributed air flow contribute to complete combustion. With an incinerator size of 250 Kg/hr, a combustion furnace was designed for a case study of a normal furnace and a fin-wall furnace. The airflow pattern will be a natural flow. The furnace volume is 2 m^3 and can store up to 1.2 m^3 of waste. The incinerator is designed to have three compartments at the front, with the top compartment (inlet 1) being used for filling waste. The second compartment (inlet 2) is for litter and ash. The bottom part (inlet 3) is for heaving the ash out and adjusting airflow. There are also six perforated holes (inlet 4) in the combustion chamber on both sides of the furnace; however, the three front ports can also be left open and allow air to flow in. Figure 1 shows the incinerator designed to have the combustion chamber attached to the cyclone with the exhaust chimney. Then determine the number of meshes and test for mesh independence. After that, the airflow simulation was performed using the CFD technique by setting parameters and boundary conditions. The inlets 1, 2, and 3 are specified to have the same pressure as the environment. The outlet velocity is 5 m/s. The characteristics of fluid flow in the incinerator model under the condition of a steady state based on turbulent flow are described by the conservation form of the fluid flow, which includes the continuity and momentum equations. Finally, analyze the simulation results and compare the airflow behavior inside the furnace.

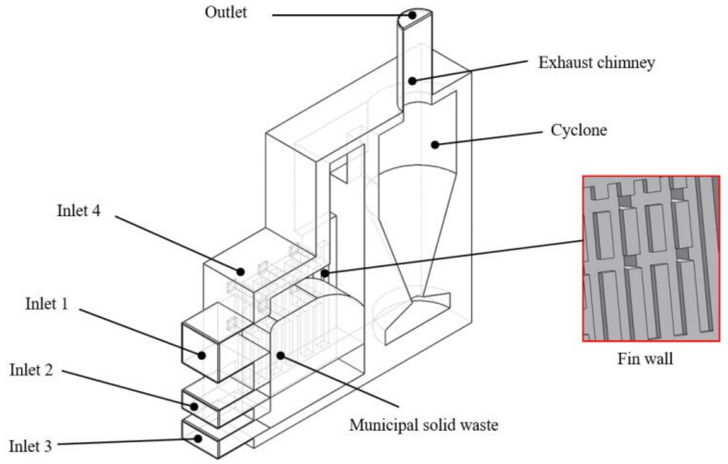

Fig. 1. The CFD model for the designed incinerator.

3 Results and discussion

The incinerator model was simulated using SOLIDWORKS FLOW SIMULATION. The mesh independence test found that the fine mesh of about 100,745 cells is the most suitable. The municipal incinerator with all front doors opened was simulated for a comparative flow in the case of flat (Left side) and finned furnace walls (Right side). Figure 2 shows the differences in airflow behavior in the combustion chamber. It can be seen that the airflow in the finned furnace distributes more than in the conventional furnace. Figure 3 shows that the air velocity inside the fin-walled incinerator (inlet 4) has a lateral airflow speed of about 1.7 m/s, while the airflow speed of a flat-walled incinerator is only 0.4 m/s. This is the result of the garbage inside the oven completely blocking the air vents around the side of the oven and at the bottom of the oven. Resulting in less airflow; most of the air that enters the furnace comes from the top front air vent, so the airflow does not spread.

The previous simulation was a case where the front door was completely opened. However, theoretically, the incinerator door should be closed after loading. To prevent hazards from combustion, such as an explosion from burning paint cans or other hazardous materials. If the front door is closed during combustion, the flow behavior will differ, as shown in figure 3. It can be seen that the velocity on the lower side of the kiln wall is smooth; the air velocity is very low compared to the finned wall case as shown in figure 4. This is especially the case when the incinerator is filled with a large amount of waste, and the front cover of the incinerator is completely closed.

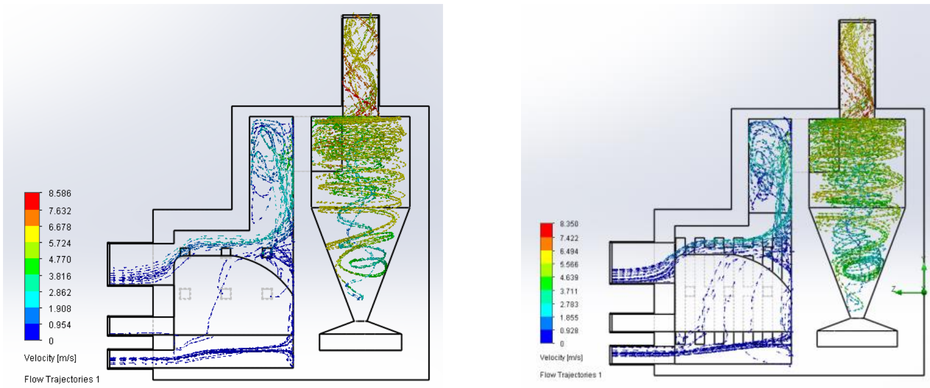

Fig. 2. Comparison of flow trajectories (air velocity) inside the combustion chamber between flat and finned combustion chamber walls.

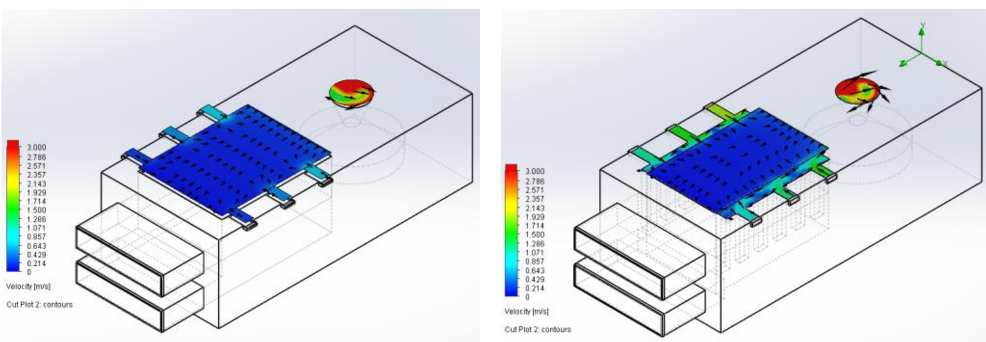

Fig. 3. Comparison of the velocity contours inside the combustion chamber between flat and finned walls (all front doors opened).

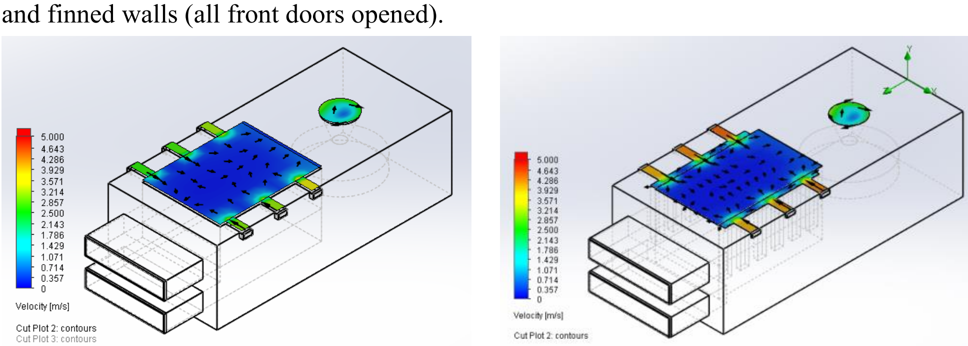

Fig. 4 Comparison of the velocity contours inside the combustion chamber between flat and finned walls (all front doors closed).

4 Conclusion

The 3D CFD model of the incinerator was done and analyzed. The airflow characteristics in the furnace of the community incinerator have been obtained. The side fins affect the air velocity from the bottom and allow for greater air velocity distribution than flat walls. The fins on the side of the furnace wall will greatly affect the airflow if the furnace front is completely closed and the furnace is almost filled with waste. The fins allow the air from the sides to flow more evenly into the furnace and achieve better fuel-air mixing than with flat walls. Thus, it results in a second airflow that completely re-burns the remaining gases from the first combustion.

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