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On evaluation of high burnout performance in a rocket-engine-based incinerator for solid-particles burning

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HIGHLIGHTS

- Burning performance of solid wastes is evaluated experimentally in the RBI chamber.
- The measured burning rates are in a good agreement with the calculated ones.
- The burnout ratio based on CO_2 mole fraction is verified by comparative studies.
- High burning rate of the RBI shows feasibility in rapid burning of solid wastes.

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ABSTRACT

To dispose of solid biomass particles such as wood, municipal solid wastes (MSW), and animal carcass, burning of solid particles in the chamber of a rocket-engine-based incinerator (RBI) was suggested for the purposes of both high-performance burnout and mobility. For high burning performance, the chamber of an RBI has the shape of a rocket combustor and in-chamber swirl flow is formed by peripheral injectors. But, its high burnout performance was verified by only numerical analyses without experimental evidence. In this study, both burning tests and simulations are conducted for several operating conditions with a target performance, which is higher than that of conventional incinerators by a factor of 10. For the tests, bituminous coal is employed as a simulant fuel for solid particles from wastes. It is supplied into the chamber with air as in previous numerical simulations. The calculated burning rate of coal particles is validated by a measured one, which confirms the feasibility of higher burning rate with an RBI by one order of magnitude than with conventional incinerators or boilers. Burnout ratio, a quantitative parameter for burnout performance, is evaluated numerically and experimentally for a comparative study. For experimental evaluation of burning performance, burnout ratio based on CO_2 mole fraction is suggested and verified. Gaseous methane is supplied into the chamber to facilitate ignition of solid particles and its co-burning with coal affects burnout ratio significantly, which is increased by around 15% when methane of 20% is fed in mole fraction.

1. Introduction

Solid wastes are produced daily from various sources such as homes, offices, and industrial factories. There are several conventional methods for their disposal, e.g., land-fill, dumping to the sea, incineration, etc. Land-fill and dumping to the sea are primitive methods and they require broad space for storage of wastes, resulting in environmental problems in the long term after disposal. Accordingly, incineration or burnout could be a viable method to dispose of solid wastes [1–3]. Its main advantages are significant decrease in both mass and volume by >60% [1,2] as well as reduced biological reactivity of the wastes and heat recovery, which is an extra benefit from incineration of wastes.

Incineration technologies have gained long interest because human activities have continued to generate wastes and burn out them in places near the waste sources [4–6]. The method of incineration may cause the same environmental problems, e.g. pollutant emission and ash disposal [7], as land-fill and dumping to the sea do, but the problems can be solved technologically unlike the other methods. Furthermore, appropriate pre-processes of solid wastes before burning and post-processes of combustion products from the incinerator after burning can be considered [8,9]. And, it may be a sole alternative to the other methods.

Nevertheless, incineration still has disadvantage of relatively greater expense than the others because it requires large-scale

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burning facilities such as supply system of wastes, chamber or incinerator, drain system, flow and thermal control system, etc. To make incineration be viable even in the future, breakthrough in burning rate and scaling down needs to be done. Solid wastes are composed of components of hydrocarbon and thus, they can be regarded as solid fuels or coal with equivalent rank. Accordingly, performance of boilers or furnaces generating power through coal burning can be compared with that of an incinerator. At present, industrial boilers for coal burning in power-plants and conventional incinerator for burning solid wastes still have a typical range of 8–27 kg/h m^3 [10,11].

One of technologies to burn out or incinerate solid wastes is pulverized-coal-firing technology. Co-firing biomass fuels with coal is one of promising technologies in the aspects of power generation and environmental issues [10–14]. It has been studied for interest in using cost-effective waste-derived fuels with fluidized-bed boilers and numerical modelling of packed bed combustion is made [12–14] and also to examine adaptability of the existent coal-fired system for biomass burning [15–17].

Bhuiyan et al. [12] showed the possible impact of changing the fuel ratio and combustion atmosphere on the boiler performance considering co-firing concepts in a 550 MW tangentially fired furnace. With the increase of biomass sharing, peak flame temperature was reduced significantly. And, computational fluid dynamics modelling of the co-combustion of pulverized coal with highly volatile biomass having different blending ratios has been considered in 0.5 MWth combustion test facilities. The results were validated comparing against the experimental data to examine the effects of co-firing under different operating conditions and a reasonably good agreement was observed with the discrepancies in the ranges of 5–10% with the experimental data [13].

Recently, a compact incinerator with new concepts has been proposed for the purposes of high burning rate and mobility. It has been devised with the combined concepts of a rocket-engine combustion and swirl flow and it is called "an incinerator based on the rocket-engine technology" [18,19]. In this study, it is called a rocket-engine-based incinerator (RBI). The RBI has a key component of a rocket combustor with a nozzle [20] and adopts swirl flow for long residence time of solid particles in the chamber [21–24]. The new system for incineration has a compact size for mobility and has been devised for burning of solid particles with higher burning rate than that of conventional incinerators by a factor of 10 at least. But, only a conceptual design has been suggested based on numerical results and its feasibility of high burnout performance is to be pursued before its realization.

In this regard, a chamber of the main component of RBI is manufactured in compliance with the design concepts of RBI [18] in this study and combustion tests are conducted with it for experimental verification of its performance level. A quantitative parameter for burnout performance, burnout ratio, is evaluated numerically and experimentally for a comparative study. For experimental validation of burning performance, burnout ratio based on CO_2 mole fraction is suggested. Effects of gaseous fuel (CH_4) addition on burning are investigated in the aspect of solid wastes co-firing with gaseous fuels.

2. Numerical and experimental methods

2.1. Design and geometry of the chamber of RBI

Coal particles are selected to be a simulant fuel for solid particles from wastes so as to reduce ambiguity in fuel properties of solid wastes although coal is not the same material as solid wastes. And, the previous study [19] showed that the incinerator fit for coal burning would be still working effectively in burning the other solid particles of biomass. Burning rate depends on their properties and burning of the other particles can be correlated approximately with coal burning [19]. Accordingly, to make a reasonable target for burnout performance with coal fuel, a chamber is designed to aim at a target burnout performance of O (100 kg/h m^3) in the order of magnitude. It corresponds to 10 times higher one than that of industrial boilers for coal burning in power-plants as well as that of conventional incinerators [10,11], which have burning performance of O (10 kg/h m^3) aforementioned.

The geometry and major dimensional sizes of the manufactured chamber are shown in Fig. 1. The chamber consists of a cylindrical part and a contraction part of a nozzle. The length of the contraction part is 58 mm and the wall has thickness of 6.5 mm. The inner wall is cooled down by cold water flowing through a cooling channel around the chamber. At the top of the chamber, a quartz window is inserted for flame visualization.

There are mounted four sets of primary and secondary air injectors around the chamber, which are distributed equidistantly in a tangential direction. In each set of injectors, the primary injectors inject a mixture of coal and primary air and the secondary injectors, located 20 mm below the primary ones, do air only, which is secondary air. All the injectors have the diameter of 10 mm. Swirl flow is the key design concept adopted in the chamber of RBI to increase residence time of fuel in a chamber [18,19]. It is realized by tangentially deflected angle of the secondary injectors. To prevent coal particles from being blown up to the top of the chamber, the primary injectors are inclined downward. As one sample combination, the deflection and the incline angles of the injectors are chosen to be 30° and 15°, respectively.

To attain the target burnout performance which is 10 times higher than the conventional one, its value over 270 kg/h m^3 should be selected here. As an example, the present chamber is designed to aim at a target burnout performance of 400 kg/h m^3 as a conservative approach. With the chamber volume of 0.007 m^3 fixed, there are various possible combinations of coal supply rate and burning efficiency to meet the target performance. By considering reasonable coal supply rate for experiments, we select a coal supply or flow rate of 1.47×10^{-3} kg/s and a burning efficiency over 53% with a chamber volume of 0.007 m^3, that is, 1.47×10^{-3} kg/s ÷ 0.007 m^3 $\times 0.53 \approx 400$ kg/h m^3. It means that the burning efficiency higher than 53% must be realized in the pre-

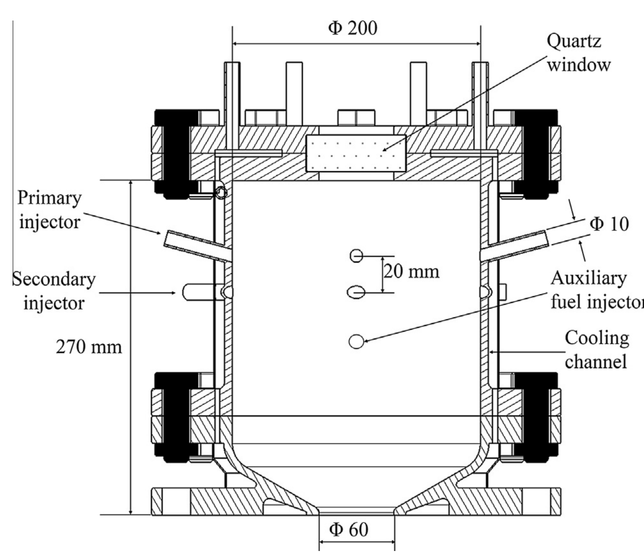

Fig. 1. Geometry and dimensional sizes of the chamber of an RBI (Rocket-Engine-Based-Incinerator).