Applied Thermal Engineering 62 (2014) 706–713

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Development of a low-temperature two-stage fluidized bed incinerator for controlling heavy-metal emission in flue gases

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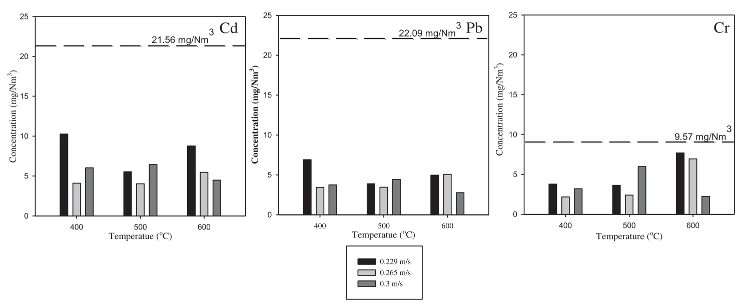
HIGHLIGHTS

- Low temperature two-stage system is developed to control heavy metal.
- The different first-stage temperatures affect the combustion efficiency.
- Surplus CO was destroyed efficiently by the secondary fluidized bed combustor.
- Metal emission in two-stage system is lower than in the traditional system.
- Temperature, bed adsorption, and filtration are the main control mechanisms.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 24 June 2013
Accepted 15 October 2013
Available online 25 October 2013

Keywords:
Low-temperature
Two-stage treatment
Fluidized bed
Heavy metals
Incineration

ABSTRACT

This study develops a low-temperature two-stage fluidized bed system for treating municipal solid waste. This new system can decrease the emission of heavy metals, has low construction costs, and can save energy owing to its lower operating temperature. To confirm the treatment efficiency of this system, the combustion efficiency and heavy-metal emission were determined. An artificial waste containing heavy metals (chromium, lead, and cadmium) was used in this study. The tested parameters included first-stage temperature and system gas velocity. Results obtained using a thermogravimetric analyzer with a differential scanning calorimeter indicated that the first-stage temperature should be controlled to at least 400 °C. Although, a large amount of carbon monoxide was emitted after the first stage, it was efficiently consumed in the second. Loss of the ignition values of ash residues were between 0.005% and 0.166%, and they exhibited a negative correlation with temperature and gas velocity. Furthermore, the emission concentration of heavy metals in the two-stage system was lower than that of the traditional one-stage fluidized bed system. The heavy-metal emissions can be decreased by between 16% and 82% using the low-temperature operating process, silica sand adsorption, and the filtration of the secondary stage.

1. Introduction

Municipal solid waste (MSW) has been a major problem in many developing countries even though some significant policies to prevent and recycle waste have been put in place. For example, China produces approximately 150 million tons of MSW, and the figure is increasing by approximately 8%–10% each year [1]. In other countries such as India and Thailand, over 68.8 and 15.16 million tons of waste is produced each year, respectively [2,3]. Such large quantities of waste promote the spread of diseases and affect public health, especially when such waste is not properly disposed of. Therefore, developing a suitable and effective waste treatment is a top priority.

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http://dx.doi.org/10.1016/j.applthermaleng.2013.10.027

Previous studies have reported a few of the advantages of the MSW incineration because it can reduce and detoxify a large volume of waste and secondary pollutants, while providing high thermal energy recovery [4–6]. Thus, MSW incineration has become the main management trend for this type of waste in developing countries. Among the many types of incinerators, the fluidized bed incinerator has certain advantages, such as high turbulence, great combustion efficiency (CE), efficient heat transfer, and good mixing [4,7,8]. Previous studies also indicated that the fluidized bed can be used not only in incinerators but also in air pollutant control devices. Some fly ash, heavy metals, and SO_2 can be filtered or adsorbed, depending on the different bed materials [9–12].

In fluidized bed incineration, some parameters are important. Previous studies indicated that high temperatures and different particle size distributions in the sand bed could affect the minimum fluidization velocity (U_{mf}). This study also indicated that higher operating gas velocities and higher bed heights affected retention time during organic combustion [13,14]. In fact, both organic and inorganic secondary pollutant emissions are significantly related to the operation of fluidized beds, especially combustion temperature. In the incineration process, emission of organic gases is related to the combustion temperature and oxygen content in the combustion air. In general, the removal efficiency of organic pollutants can be tracked by measuring carbon monoxide (CO). Hasselriss [15] indicated that the production of organic pollutants (such as: dioxin) was highly correlated with CO emissions. As such, when these emissions decreased, dioxin production was reduced. This study indicated that the amount of organic pollutants emitted would be decreased when the combustion temperature and oxygen content in the combustion air increased. However, for heavy-metal pollutants, the metals are transformed through homogeneous nucleation, heterogeneous deposition, and chemical adsorption [16]. Previous papers reported that heavy-metal emissions are highly influenced by temperature [17–19]. Wey et al. [19] showed that heavy-metal emission is positively correlated with combustion temperature.

From the results of these previous studies, it would appear that simultaneously reducing both organic and heavy metals could not be done. While organic pollutants were effectively controlled at higher temperatures, these temperatures would however increase heavy-metal emissions. In fact, organic pollutants were formed under different temperatures and excess air ratios [20]. Therefore, if the waste is gasified at low temperature in the first-stage of combustion, then the flue gas containing the organics can be treated by the secondary, high-temperature furnace to limit the organic pollutant emissions. On the basis of this concept, the proposed process could not only reduce heavy-metal emissions but also decrease energy usage. On the other hand, an added benefit of the lower operating temperature, the use of refractory materials can be minimized and building costs can thus be reduced. However, this concept has not been applied in the thermal waste treatment process.

In this study, a pilot-scale low-temperature two-stage fluidized bed incinerator for the treatment of MSW is developed. This new system can decrease the emission of heavy metals, lower construction cost, and save energy by lowering operating temperatures. To confirm the treatment efficiency of this system, combustion efficiency and heavy-metal emissions were determined. Wood chips and polyethylene (PE) were used as the artificial waste materials to which heavy metals, namely chromium (Cr), lead (Pb), and cadmium (Cd), were added. The studied operating parameters included the first-stage operating temperature and gas velocity. According to this study, a new treatment reactor was developed to treat the MSW and control the combustion emissions during incineration.

2. Materials and methods

2.1. Experimental instrument

Fig. 1 shows the reactor used in this study. The reactor was made of two combustion chambers. The height of first combustor was 670 mm, and the other was 1400 mm. All chambers were made of 3 mm-thick stainless steel (AISI 316SS) with an inner diameter of 60 mm. To compare with one-stage and two-stage systems, the secondary combustor should be adjusted in different situations. When the reactor was taken as a one-stage system, only the first combustor contained the bed material. The secondary combustor was vacant without any distributors. While the reactor was taken as a two-stage incinerator, both the two combustors contained the bed material. In the two-stage system, two gas distributors individually installed in the bottom of the first and second chambers. Both of them were made of stainless steel. All combustion chambers were heated by an electrical heating system. To prevent heat loss, all chambers were covered by 1-inch ceramic fibers on the surface. The temperature was controlled by a proportional integral derivative logical controller with the thermocouples. All the values of the temperature were recorded by computer. The pressure was determined by two detectors on the sand bed and freeboard of each combustion chamber. The detector was connected to different pressure transmitters, and the range of measurement was from 0 to 1000 mm H_2O. The temperature and pressure signals were recorded by a data acquisition system (ADVANTECH PC-Lab Card PCL-711S and VisiDAQ Professional Version 3.1). The input air was determined by a flow meter provided with a blower at normal temperature and pressure (NTP) condition. The feeder was designed with two valves to maintain pressure stability. During the experiments, all flue gases were ventilated by an induced fan. To

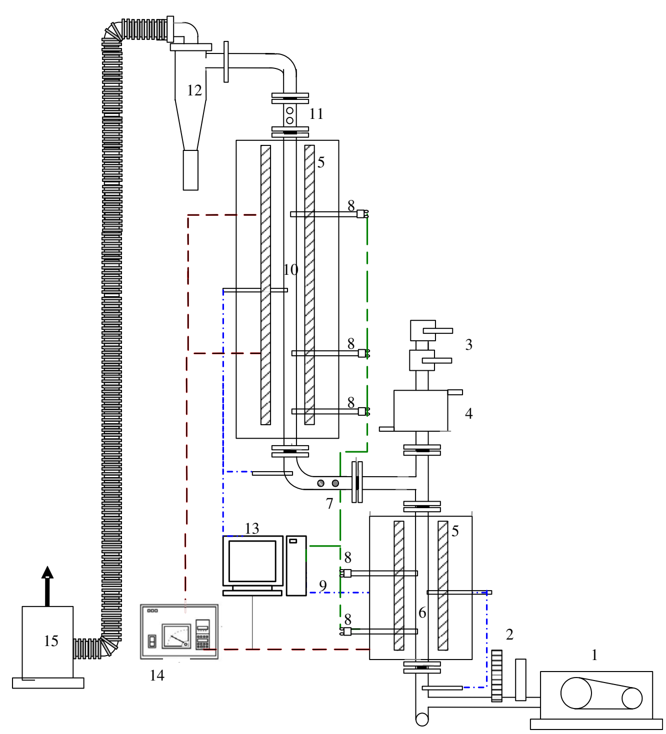

Fig. 1. Low-temperature two-stage fluidized bed incinerator: (1) blower, (2) flow meter, (3) feeder, (4) cooling jacket, (5) electric resistance, (6) first-stage combustion sand bed, (7) first-stage sampling place, (8) thermocouple, (9) pressure transducer, (10) secondary combustion sand bed, (11) secondary sampling place, (12) cyclone, (13) computer, (14) PID controller, and (15) induced fan.