International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:11, No:1, 2017

Incineration of Sludge in a Fluidized-Bed Combustor

Chien-Song Chyang, Yu-Chi Wang

***Abstract*—**For sludge disposal, incineration is considered to be better than direct burial because of regulations and space limitations in Taiwan. Additionally, burial after incineration can effectively prolong the lifespan of a landfill. Therefore, it is the most satisfactory method for treating sludge at present. Of the various incineration technologies, the fluidized bed incinerator is a suitable choice due to its fuel flexibility. In this work, sludge generated from industrial plants was treated in a pilot-scale vortexing fluidized bed. The moisture content of the sludge was 48.53%, and its LHV was 454.6 kcal/kg. Primary gas and secondary gas were fixed at 3 Nm^3/min and 1 Nm^3/min, respectively. Diesel burners with on-off controllers were used to control the temperature; the bed temperature was set to 750±20 °C, and the freeboard temperature was 850±20 °C. The experimental data show that the NO emission increased with bed temperature. The maximum NO emission is 139 ppm, which is in agreement with the regulation. The CO emission is low than 100 ppm through the operation period. The mean particle size of fly ash collected from baghouse decreased with operating time. The ration of bottom ash to fly ash is about 3. Compared with bottom ash, the potassium in the fly ash is much higher. It implied that the potassium content is not the key factor for aggregation of bottom ash.

***Keywords*—**Sludge incineration, fluidized bed combustion, fly ash, bottom ash.

I. INTRODUCTION

IT is often reported that environmental problems are caused by industrial production. A large amount of sludge is produced by the treatment of wastewater from factories, and the physical and chemical properties of the sludge vary greatly. The sludge still contains approximately 50% moisture content after dehydration.

Fluidized bed combustion technology was developed in the 1930s. It has been used for sludge incineration since the 1960s. It was proven to be the best technology for sludge disposal. The volume of high-moisture-content sludge can be reduced significantly, and residual sludge can be used as a raw material for cement or concrete.

In the previous study, [1] two types of coal particles were employed as the supplementary fuel. In order to understand the characteristics of a prototype vortexing fluidized bed combustion system for paper sludge incineration, the effect of various operating parameters, such as the primary airflow, excess air ratio, and secondary airflow rates, on temperature distribution, ash elutriation, combustion efficiency, and pollutant emissions were investigated.

The changes in pore structure characteristics of sewage sludge particles under effect of calcium magnesium acetate during combustion were investigated by Zhang et al. [2]. The effects of sewage sludge (SS) blended ratio, O_2/CO_2 ratio, and type of bituminous coal on the co-combustion characteristics of SS with bituminous coals were investigated by Zhang et al. [3].

TABLE I
PROPERTIES OF SLUDGE

Fuel	Sludge
Proximate analysis (wt. %, as-received)	
Moisture	48.53
Volatiles	18.96
Fixed carbon	0.55
Ash	31.96
Ultimate analysis (wt. %, dry and ash free)	
C	40.25
H	7.22
O	43.55
N	5.39
S	3.59
Mineral analysis (wt.%)	
Na	0.4217%
Mg	0.4131%
Al	4.849%
Si	7.421%
K	0.1893
Ca	5050.239 ppm
Cr	419.617 ppm
Fe	5.519%
Cu	5021.531 ppm
Pb	997.129 ppm
Heating value (kcal/kg)	
HHV (DB)	1595
LHV (WB)	454.6

TABLE II
WORKING CONDITIONS

Operating parameter	Values
Feed rate for sludge (kg/h)	60
Mean diameter of bed material (μm)	500
Primary flow rate (Nm^3/min)	3
Bed material	Silica sand

The results obtained by Duan et al. revealed [4] that the defluidization time is increased with superficial gas velocity and decreased with bed temperature. Eutectic composition with low melting point materials promotes defluidization at high temperatures.

In [5], the effects of fluidization velocity, bed temperature and fuel feeding rate on the agglomerate fraction in the fluidized bed combustion of rice straw were studied. Results showed that the stickiness of bed particles induced by coating layers is the direct reason for bed defluidization. The alkali metals such as K and Na mainly exist in the outer layer of rice straw particles. During combustion, the high temperature can cause the alkali species melting and coating the surfaces of ash particles.

The purpose of this study is to analyze the fly ash and bottom ash generated during sludge incineration. The entire

---

Chien-Song Chyang and Yu-Chi Wang are with the Department of Chemical Engineering, Chung Yuan Christian University, Taoyuan, Taiwan, R.O.C.32023 (e-mail: cschyang@cycu.edu.tw).

experiment was conducted in a pilot-scale vortexing fluidized bed combustor. To simulate the operating conditions of a conventional fluidized bed incinerator, secondary air was not applied. Diesel was used as the auxiliary fuel.

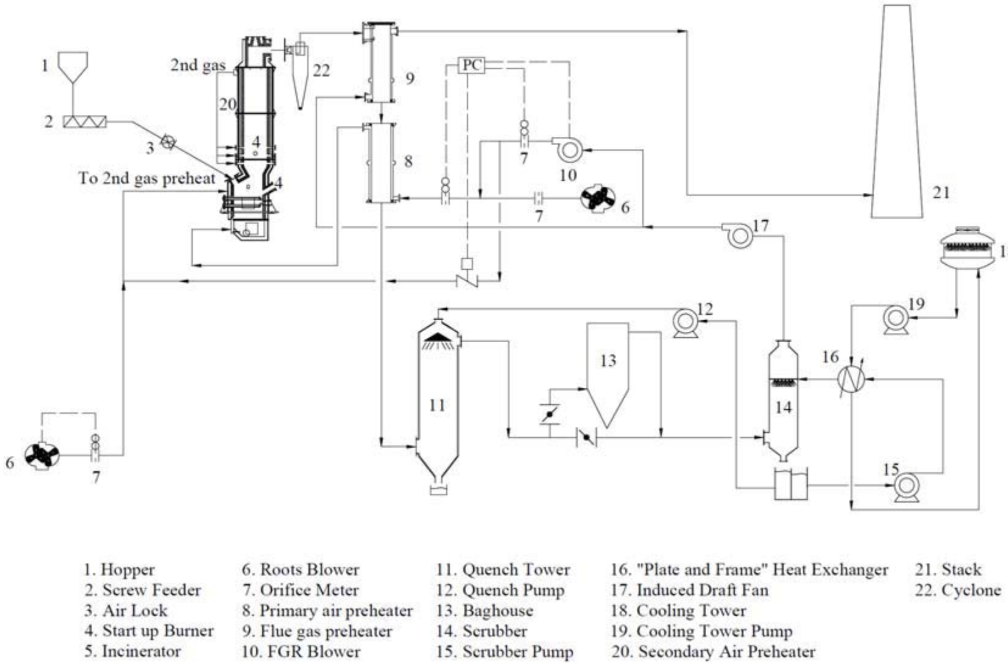

Fig. 1 Flow diagram of the vortexing fluidized bed combustion system

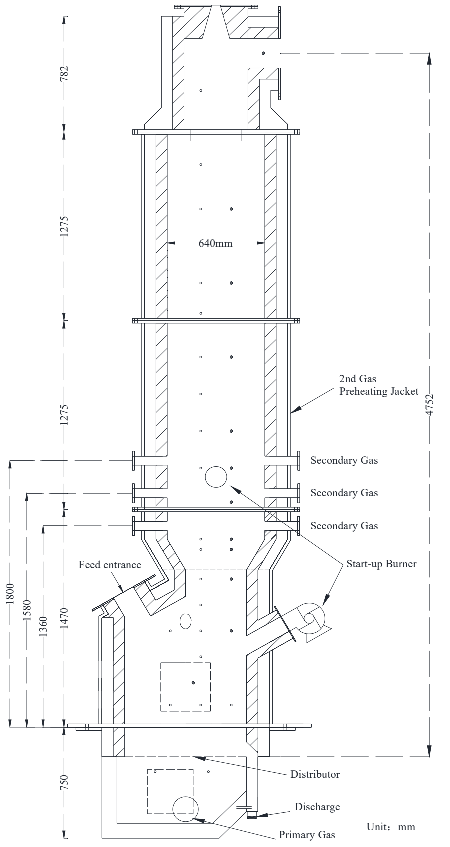

Fig. 2 Schematic diagram of the vortexing fluidized bed combustor

II. EXPERIMENTAL SECTION

A. Experimental Setup

Experiments were conducted in a vortexing fluidized bed combustion system, as shown in Fig. 1, and the configuration of the combustor is shown in Fig. 2. The combustor can be divided into four parts: the windbox, the distributor, the combustion chamber, and the freeboard. The combustion chamber has a cross-section of 0.8 m × 0.4 m and is built from 6 mm carbon steel lined with 150 mm refractory to reduce heat loss. The windbox has a cross-section of 0.8 m × 0.4 m and is made with 6 mm carbon steel lined with 100 mm refractory. The freeboard has a 0.64 m inner diameter and is positioned above the combustion chamber. Specifically, the combustion chamber was constructed from 6 mm carbon steel lined with 150 mm refractory material, and the open area ratio of the gas distributor was 0.516%. The detail is show in the previous study[6]. A Novatech oxygen analyzer 1632 (precision of 1%) measures the oxygen concentration of the flue gas at the outlet of the ID fan. The temperature of the flue gas pumped from the ID fan ranges from 40 to 50 °C. The temperatures in the VFBC are measured with K-type thermocouples installed in the combustor. As shown in Fig. 2, the bed temperature is controlled by an adjustable heat-transfer tube immersed in the bed, and its value is the average of the values taken from the four lateral distribution thermocouples located 0.45 m above the air distributor. The freeboard temperature is the average of the values from the three axial distribution thermocouples located 2.55, 2.80, and 3.00 m above the air distributor. The temperature of the combustor outlet is measured with a thermocouple located 4.5 m above the air distributor. The components of the flue gas, such as CO, CO2, O2, SO2 and NOx, were analyzed by a HORIBA PG-250 portable gas analyzer. The values of the pollutant concentrations detected in this study were all corrected to 11% residual oxygen on a dry basis. The measurement accuracies of the gas analyzer for CO, CO2, O2, SO2 and NOx are 0.4%, 6%, 0.5%, and 1%, respectively.

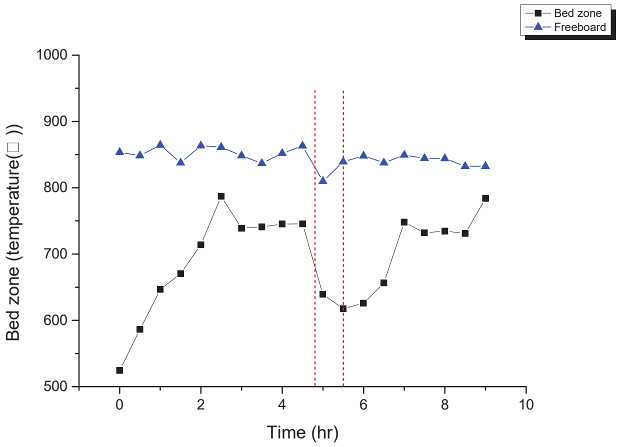

Fig. 3 Historical temperature vs. elapsed time with in the combustor

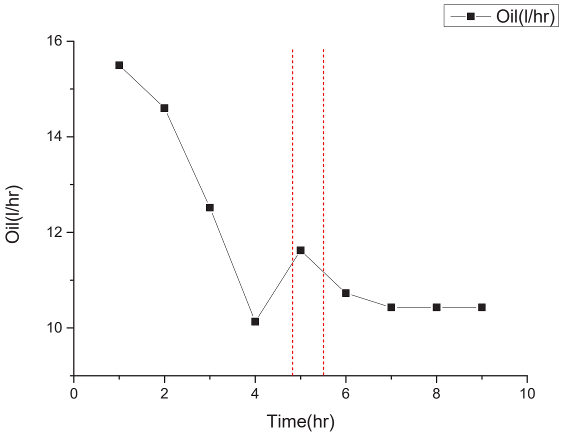

Fig. 4 Diesel consumption rate vs. elapsed time

B. Materials

Silica sand (99.5% SiO2) with a density of 2600 kg/m^3 and a mean diameter of 0.587 mm was used as the bed material. Sludge was fed into the combustor by a screw feeder at a rate of 60 kg/h. The properties of the sludge are listed in Table I. Proximate analysis revealed that the moisture and ash levels were high, whereas the fixed carbon content was only 0.55%. The mineral analysis showed that the ash was rich in silicon, iron, and aluminum. The higher heating value on dry basis was 1595 kcal/kg.

C. Working Conditions

The working conditions are listed in Table II. The primary gas was fixed at 3 Nm^3/min and was supplied by a 15hp roots blower. Experiments were conducted after start-up was completed. The combustor was pre-heated by using diesel burners. The sludge was fed into the fluidized bed incinerator which bed temperature reach to 500°C. Temperature recording and flue gas sampling were carried out when the pre-set experimental conditions were reached and the system stabilized for 1 hour.

III. RESULTS AND DISCUSSION

A. Temperature Distribution

Fig. 3 shows the historical temperature profile within the VFBC. The bed temperature dropped significantly at the time interval of 4.8 h – 5.5 h. At in caused by the overbed burner clogged by the bed material, which attributed to the accumulation of bottom ash. Fig. 4 shows the rate of diesel consumption per hour. The high consumption rate at elapsed 1-3 hour can be attributed the bed wall temperature had not reached 750 ± 20°C. The diesel consumption dropped significantly after 4 h because of the clogging caused by accumulating bottom ash. The heating value of diesel is 8400 kcal/L. The consumption rate of diesel is about 10.5 L/hr at steady state with bed temper of 750°C. The feeding rate of sludge is 60kg/hr and the heat release rate in the combustor is about 11500 k cal/hr.

B. Exhaust Emissions

NOx and CO, the main pollutant emissions of FBC, have regulatory emission limits in most countries. This motivates us to identify the relationships between sludge and pollutant emissions from fluidized bed combustion. Fig. 5 shows the emissions of gaseous pollutants as a function of time. The NOx emission was below. 100 ppm, and the CO emission was negligible, except for the sudden increase. However, the SO_2 emission increased with time, which may be attributed to the gradual growing of the bed material, resulting in poor mixing in the bed zone.

TABLE III
MINERAL ANALYSIS OF BOTTOM ASH AND FLY ASH

	Bottom ash	Fly ash from baghouse	Fly ash from cyclone
Na	0.7615 %	0.961 %	0.7683 %
Mg	0.7079 %	1.151 %	0.6653 %
Al	9.521 %	5.237 %	8.87 %
Si	11.03 %	11.207 %	10.377 %
K	0.6371 %	7.143 %	1.0455 %
Ca	7.734 %	5.175 %	7.965 %
Fe	8.307 %	5.253 %	9.565 %
Cu	0.8028 %	0.1658 %	0.6943 %
Cr	584.272 ppm	879.452 ppm	548.5 ppm
Pb	85.821 ppm	453.196 ppm	75.9 ppm

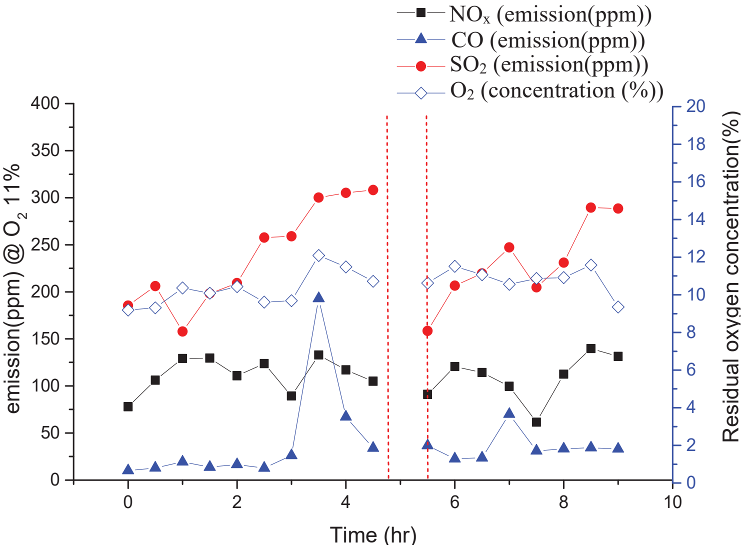

Fig. 5 The emissions of gaseous pollutants as a function of time

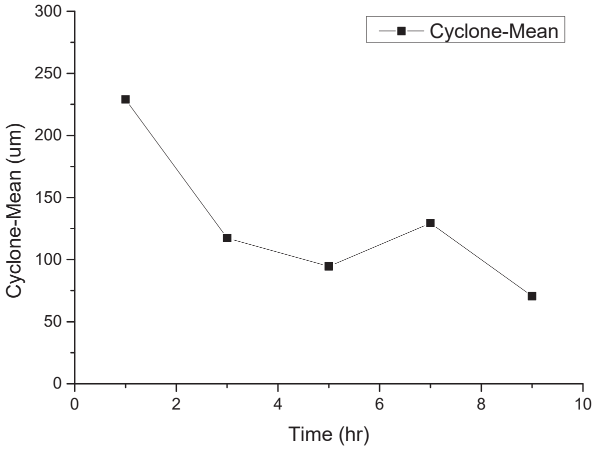

Fig. 6 The mean particle size of fly ash collected from the cyclone vs. elapsed time

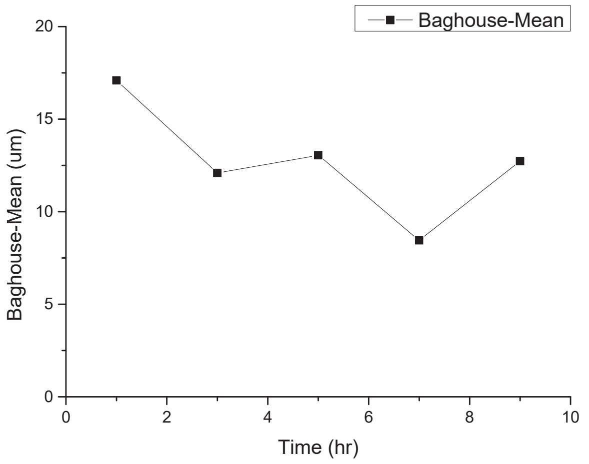

Fig. 7 The mean particle size of fly ash collected from the baghouse vs. elapsed time

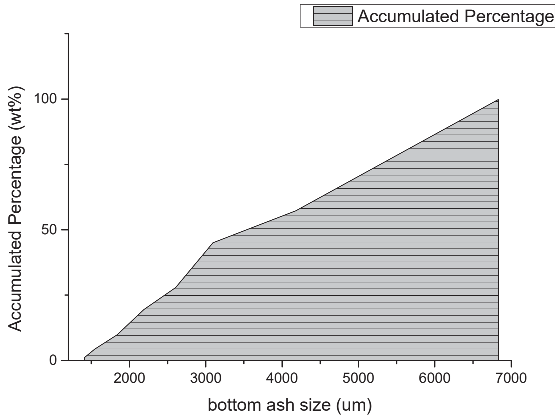

Fig. 8 Cumulative particle size distribution of bottom ash

C. *Particle Size of Fly Ash and Bottom Ash*

The ratio of the total amount of fly ash to bottom ash is approximately 1:3. Bottom ash is a general waste that should be used comprehensively. Figs. 6 and 7 show the variation in particle size of fly ash in the cyclone and in the baghouse, respectively. When the temperature was taken into account (Fig. 3), the particle size of fly ash was observed to decrease as the bed temperature increased. A higher bed temperature would accelerate the combustion process, thus improving the burnout of fly ash. Fig. 8 shows the cumulative particle size distribution for bottom ash. The median diameter was 3000 μm, which is much higher than the size of the bed material. To investigate the reason for the increase, we conducted a mineral analysis, which is discussed in section *E*.

D. *Photographs of Fly Ash*

Fig. 9 shows the fly ash collected during the operation of the combustor. Fly ash was collected every 2 hours. The picture reveals that the longer the operation time, the lighter the color of the fly ash, implying that the unburned carbon content decreases as the operation time increases.

E. Mineral Analysis of Bottom Ash and Fly Ash

Table III and Fig. 10 describe the mineral analysis of bottom ash and fly ash. The results show that both the bottom ash and fly ash are rich in aluminum, silicon, calcium, and iron. As mentioned above, the particle size of bottom ash was much greater than that of the initial bed material. A previous study showed that combustion at high temperatures can cause alkali species to melt and coat the surfaces of ash particles, which causes the ash particles to become sticky and adhere to the surfaces of bed particles [7]. However, we found that the potassium and sodium content were lower in bottom ash. Thus, the growth of bottom ash may not be caused by this agglomeration mechanism. From Fig. 10, we can find the concentration of Al in the bottom ash is much higher than that in the flash ash. We can infer that clay content in the raw sludge cause hith bottom ash in the sludge incineration.

Fig. 9 Fly ash collected during the operation of the combustor

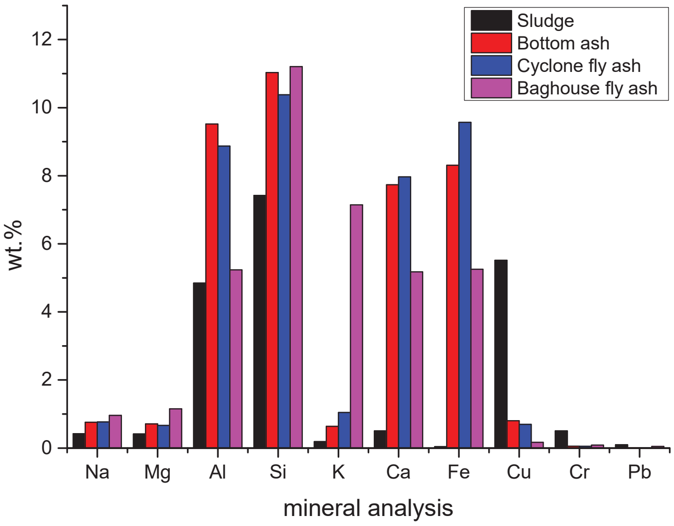

Fig. 10 Concentration of ash mineral of collected from different equipment

IV. CONCLUSIONS

The particle size of fly ash decreases as the bed temperature increased. The longer the operation time, the lighter the color of fly ash. This implies that the unburned carbon content decreases as the operation time increases. The growth bottom ash may not be caused by the agglomeration mechanism because the concentrations of alkali species were lower in bottom ash. The concentration of potassium in the fly ash is much higher than that in bottom ash. We can infer that potassium is not the key point why quantity of bottom ash is higher than fly ash. Further work is needed to understand the cause.

REFERENCES

[1] Teng, Hsisheng, Chien-Song Chyang, Sheng-Hui Shang, and Jui-An Ho. Characterization of Waste Tire Incineration in a Prototype Vortexing Fluidized Bed Combustor. J. Air & Waste Mang. Assoc. 47, 49-57. (1997).

[2] Zhang Lihui, Duan Feng, Huang Yaji, Chyang Chien-Song. Effect of calcium magnesium acetate on the forming property and fractal dimension of sludge pore structure during combustion. Bioresource Tech. 197, 235-243 (2015).

[3] Zhang, Yousong, Lihui Zhang, Feng Duan, Xiaoxiang Jian, Xiaoru Sun, Chien-Song Chyang, Co-combustion characteristics of sewage sludge with different rank bituminous coals under the O2/CO2 atmosphere. J Therm. Anal. Calorim. 121, 729-736(2015).

[4] Duan, Feng, Chien-Song Chyang, and Siang-Fong Yin. Bed agglomeration characteristics of rice straw combustion in a vortexing fluidized-bed combustor. Bioresource Tech. 183, 195-202(2015).

[5] Huanpeng Liu, Yujie Feng, Shaohua Wu, Dunyu Liu. The role of ash particles in the bed agglomeration during the fluidized bed combustion of rice straw. Bioresource, Technology, 100, 6505–6513(2009).

[6] Duan, Feng, Jian Liu, Chien-Song Chyang, Chun-Hsan Hu and Jim Tso. Combustion Behavior and Pollutant Emission Characteristics of Refuse Derived Fuel (RDF) and Sawdust in a Vortexing Fluidized Bed Combustor. Energy, 57, 421-426 (2013).

[7] Huanpeng Liu, Yujie Feng, Shaohua Wu, Dunyu Liu. The role of ash particles in the bed agglomeration during the fluidized bed combustion of rice straw. Bioresource, Technology, 100, 6505-6513(2009).