ADVANCED SWIRLING FLUIDIZED BED COMBUSTION (SFBC) PROCESS AND UNBURNED CARBON ANALYSIS FOR BIOMASS WASTE DISPOSAL

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Introduction

Increasing size and concentration of production is a long-established and continuing trend in the poultry producing industry. The size of poultry litter produced in this industry shows a sustained and increasing trend too. Daily fresh litter/manure output per is about 30 kg/100 birds. For example, the size of Delmarva broiler farms is average 50,000 heads, and the daily poultry litter production is 15,000kg. [1,2] The poultry litter/manure has historically been used as a source of plant nutrients and as a soil amendment. However, in areas of intense poultry production, over-fertilization of pasture lands with poultry manure occurs. The excessive nutrients have caused environmental problems, such as ground water run-off pollution by phosphorus. The thermal treatment of poultry litter/manure has been proven to be as an alternative method to treat the poultry litter. Juan et al. has presented that the poultry litter (basically constituting C, H, O, N, S) can be used an alternative fuel to the power generation. [3]

The objectives of this research are to: (1) apply the Fluidized Bed Combustion technology to burn the poultry litter; (2) find the carbon combustion efficiency based on the unburned carbon from the flying ash and residue; and (3) explore different operation condition effect on the carbon combustion efficiency.

Experimental Studies

The schematic diagram of the advanced swirling fluidized bed combustor (SFBC) is shown in Figure 1. The cylinder chamber is 0.2m diameter and 1.5m high allowing bed depths up to 0.3m with 1.2m in freeboard height. The chamber is covered inside with refractory ceramic. Bed material is sand with a particle size of 0.3 mm of mean diameter. At the bottom of the cylinder chamber stands the distributor plate and its caps connected to the air box. The primary air from the compressor was introduced through the air distributor and acted as both fluidization and combustion air. Three layers of nozzles at 0.65m, 0.85m and 1.1m above the four air distributors were distributed symmetrically at each layer and with injection direction tangentially. Each layer has control valve to adjust

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air amount to fit the experiment needs. The secondary air or swirling air was introduced into the chamber from these nozzles, which made the inside air and waste materials swirl. The swirling gas flow extends the materials residence time in the freeboard as well as reinforcing the combustion. The waste feeding window is located at 0.3m above the air distributor. Two layers of natural gas ignitors were installed at the height of 0.12m and 0.5m above the distributor. A cyclone is fitted to the combustor exit and two heat exchangers are allocated upper- and down-stream of the cyclone. The flue gas was cleaned in the filter bag before exiting to the gas pool.

The bed and freeboard temperatures and pressures were measured at eight (8) different heights above the distributor plate and at flue gas dust also shown in Figure 1. A K-type thermocouple was used for the temperature measurement and 20-channel pressure manometer for the pressure control. The temperature and pressure data are collected through a computerized data acquisition system. Gas samples were obtained at the exit of the combustor. The flue gas components were analyzed by the computerized emission analyzer. The ash from the bottom of the bed and cyclone separator was analyzed by the ash analyzer [4].

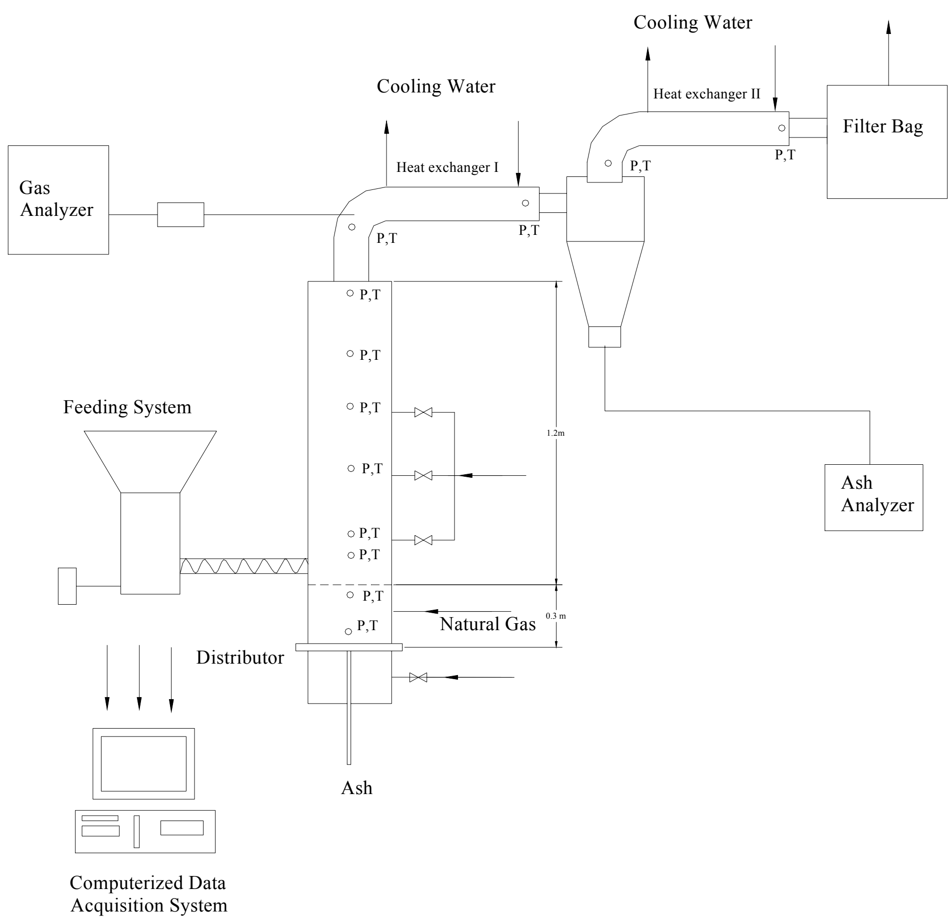

Figure 1 the schematic diagram of the SFBC laboratory scale waste disposal system

Fuel Characteristics

Table 1 Physical characteristics of tested biomass materials

Table 1 Proximate and ultimate analysis of the fuel

Type of Fuel	Poultry litter
Proximate analysis (wt. %)	
Moisture	15.02
Volatile	40.35
Fixed Carbon	13.71
Ash	30.92
Ultimate analysis (wt.%)	
Carbon, C	29.34
Hydrogen, H	4.16
Oxygen, O	25.80
Nitrogen, N	4.22
Sulfur, S	0. 1
Ash	36.38
Low heating value (kJ/kg)	6,030

Results and Discussion:

Assuming that the carbon in the fuel is completely converted to carbon monoxide and carbon dioxide, the carbon combustion efficiency can be roughly calculated as considering only the flue gas composition:

$$\eta_{CE} = \frac{\%CO_2 in.flue \cdot gas}{\%(CO + CO_2)in \cdot flue \cdot gas} \times 100 \qquad (1)$$

As carbon could be elutriated, a more accurate combustion efficiency can be taken as equation 2 [5]:

$$\eta_{CE} = \frac{B}{C} \text{x} 100 \qquad (2)$$

Where B and C are, respectively, mass fraction of burnt and total carbon in the fuel. Knowing flue gas composition, fractional excess air, and the ultimate analysis of fuel and unburned carbon in cyclone residue, B can be calculated. This equation has been verified to have a deviation of̣ 2% [5,6].

Figure 2 shows the effect of temperature on carbon combustion efficiency in two (2) different co-combustion cases of the poultry wastes with natural gas. An increase in the combustor temperature increased the carbon combustion efficiency due to the increase in the reaction rates. At the same temperature, the combustion efficiency of poultry litter is higher than the poultry manure combustion. This may be explained because the excess air for poultry litter is higher than for manure, and the higher particles and gas flow rate elutriated more unburned carbon.

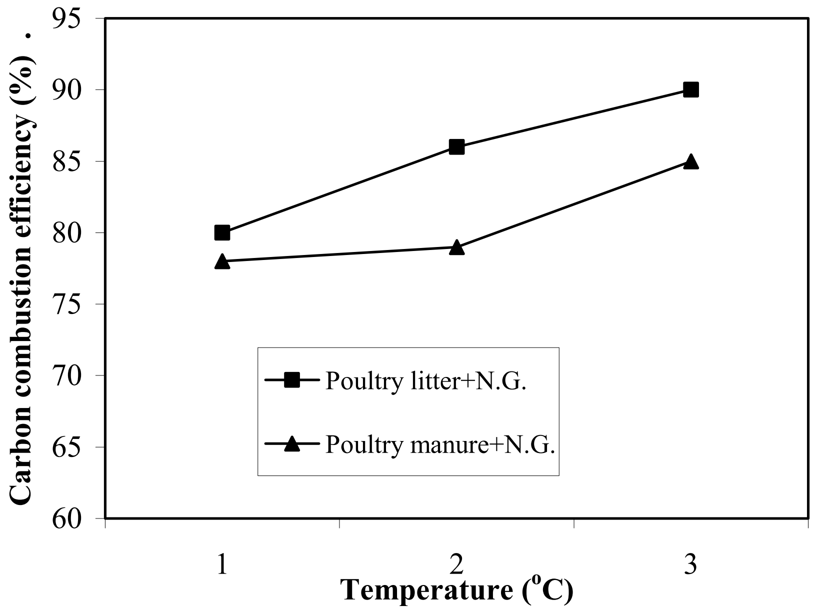

Figure 2 Effect of temperature on the carbon combustion efficiency

At a fixed amount secondary air, the carbon combustion efficiencies are observed, as shown in Figure 3, to increase as the excess air increases to a certain point and begin to decrease as the extra air goes beyond that point. This observation indicates that the optimization excess air used in this SFBC combustor can be obtained as shown in Table 2. As the excess air goes from the stoichiometry, the excess air increased the particles movement and oxygen concentration. Thus the combustion is improved. While the excess air reach the optimal value, the high extra air will unfortunately bring more fine unburned carbon elutriated to the cyclone.

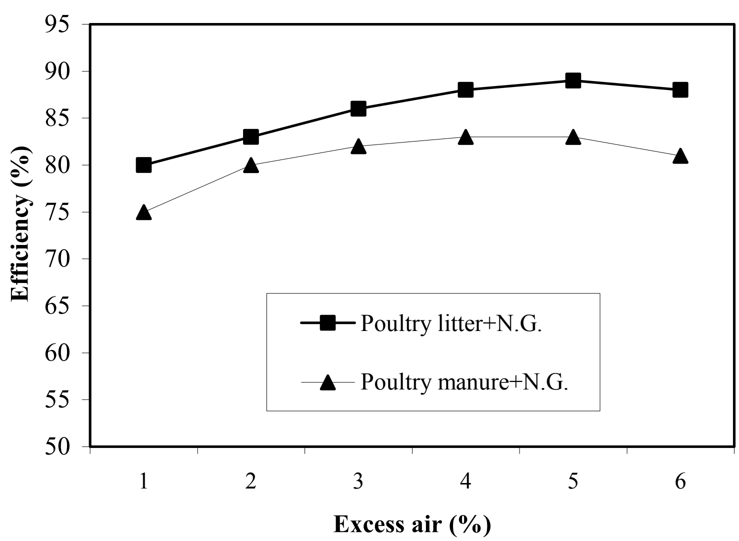

Figure 3 Carbon combustion efficiency as function of excess air ratio
(Secondary air 20%, with 0.85m injection height)

Table 2 Optimal operations for the co-combustions

Operation condition	Poultry litter co-combustion	Poultry manure co-combustion
Excess air ratio, %	30	30
Secondary air ratio, %	20	30
Secondary air injection height, m	0.85	0.65
Carbon combustion efficiency, %	89	83

As shown in Figure 3, when the excess air ratio was fixed, the carbon combustion efficiency was observed to increase as the secondary air ratio increased to a certain amount, and then the efficiency decrease. This can be expected, since the secondary air was introduced to bed symmetrically from the tangential direction that makes the freeboard particles and gas flow swirling. The swirling flow elongates the residence time of the flow gas and particles and thus restrains the unburned carbon elutriation until the secondary air reach a certain amount. As found in this experiment, the optimal amount of secondary air ratio is also shown in Table 2.

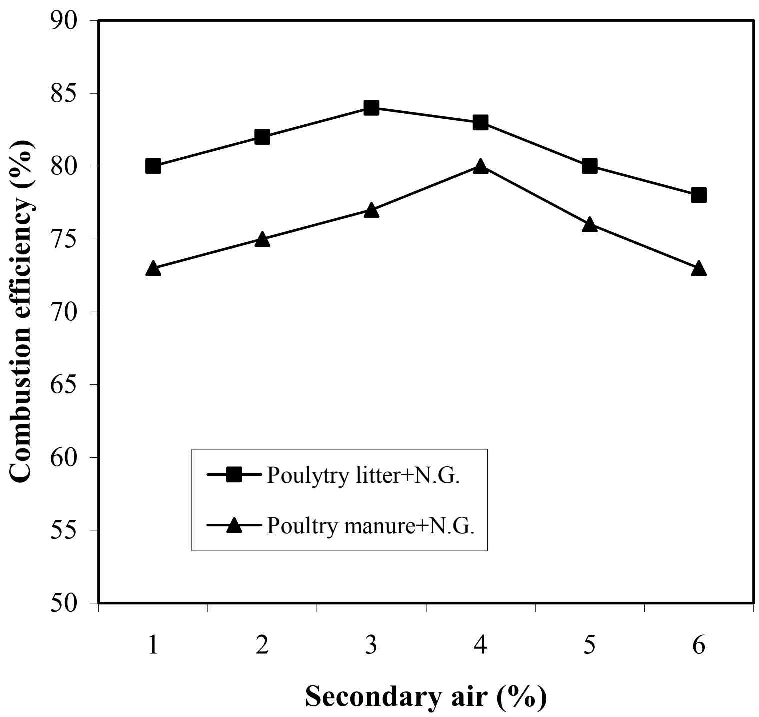

Figure 3 Carbon combustion efficiency as function of secondary air
(Excess air is 25%, secondary air height is 0.65m)

The different secondary air injection height also one of the dominant factors influencing the combustion efficiency as shown in Figure 4. When the excess air is less than 25%, a higher location of secondary air results in the lower combustion efficiency. When the excess air is greater than 25%, this trend becomes reverse for the injection height of 0.85m and 0.65m. At these two locations, the lower secondary air injection location enlarged more residence time at low excess air. When the excess air reach over 25%, the excess air could dominate the particles elutriation. For the highest secondary air injection location, the combustion efficiency is always the lowest and for all excess air amounts. It is believed that the elutriation rate is the highest and the residence time is the lowest.

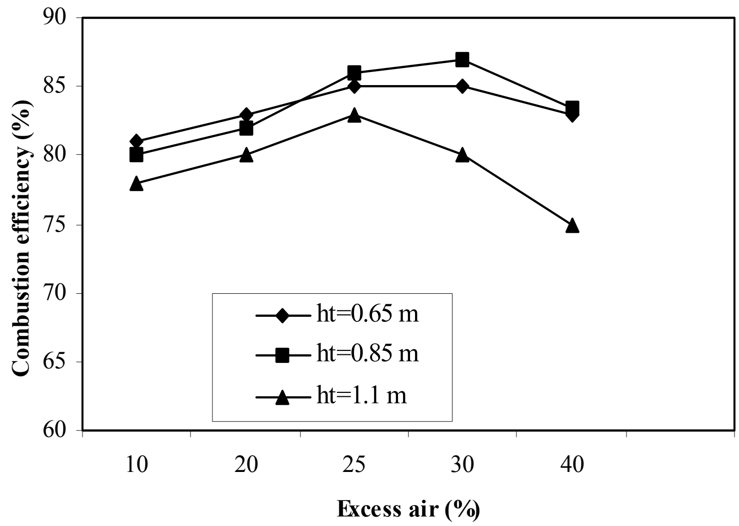

Figure 5 Carbon combustion efficiency as function of secondary air injection layer (Poultry litter +N.G., Secondary air 25%)

Conclusions

The following conclusion can be drawn:

1. The axial temperature in the bed and freeboard region and radial temperature are one of the most important indicators for the combustion performance. The temperature changes are affected mainly by the waste components, secondary air ratio, and fuel concentration.
2. The carbon combustion efficiency is changed with extra air ratio and secondary air ratio as well as the secondary air injection height. The highest carbon combustion efficiency was found at around 30% of excess air, 20% of secondary air (30% for poultry manure) and 0.85m (0.65m for poultry manure) above the distributor plate for the secondary air injection.
3. At the optimal operation conditions, the carbon combustion efficiencies for the three wastes could reach as high as 89% and 83% for co-combustion of poultry litter and poultry manure, respectively.

Reference:

1. Dennis W. M, Composting dead birds, Fact sheet 537, Cooperative extension service, University of Maryland, College Park, MD
2. Poultry manure management and utilization problems and opportunities, Bulletin 804, Poultry manure production
3. Zuan Z. D., Maria V. R., Pilar J., Evaluation of poultry litter as a feasible fuel, Thermochimica Acta 394 (2002) 261-266
4. Yunus A. Cengel, et al., 1995, Introduction to thermodynamics and heat transfer, McGraw Hill Companies, Inc.
5. Saxena, S. C. and Jotshi, C.K., 1994, Fluidized bed incineration of waste material. Progress in Energy and Combustion Science 20, 281-324.
6. Suksankraisorn, K., et al., 2003, Co-combustion of municipal solid waste and Thai lignite in a fluidized bed. Energy Conversion & Management (article in press)