Jurnal Teknologi, bil. 29, Dis. 1998 hlm. 35–41

EFFECT OF AIR STAGING ON PALM SHELL COMBUSTION IN FLUIDISED BED INCINERATOR

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Abstract. The combustion of wastes and very low-grade fuels aims at obtaining thermal energy by subjecting them to heat treatment in order to destroy nitrogen oxide constituents or to convert the materials into a less inconvenient or even potentially usable form. For these purposes, a small pilot plant-scale bubbling fluidised bed incinerator was designed, constructed and tested. This incinerator has a heat capacity of around 26 - 30 kW. It was facilitated with refractory-lined combustion chamber of 0.15 m square cross section and a total height of 1.5 m. The agricultural wastes that have been incinerated in this fluidised bed facility was palm shell wastes. The waste was combusted over a bed temperature ranging from 780 - 815°C. The use of air-staging technique of palm shell combustion test shows a reduction in the CO emission level. But, it results in a reduced combustion efficiency level due to high elutriation rate of carbon particles. The air-staging technique also effected the rise of NOx concentration level.

Keyword: Fluidised bed incinerator, air-staging technique, palm shell combustion, combustion efficiency, flue gas emission.

1.0 INTRODUCTION

Amongst the natural energy sources, wood is one of the oldest renewable resources which mankind has used from prehistoric times. The physical, chemical, transport and combustion properties of wood have been extensively investigated and the results are summarized in the monograph of Tillman (1978), Cremisinoff (1980) and Siau (1984). Wood combustion has been examined in commercial furnaces, fluidised bed systems and also in circulating fluidised bed combustors [Saxena, S.C., Jotshi, C.K., 1994]. Burning of wood and wood wastes not only provides economic heat energy and eliminates disposal costs but also has a favuorable environmental implication by reducing the global greenhouse effect. Incineration has been recognized all over the world as the best way of waste disposal for hazardous waste materials. The basic goal of incineration is to efficiently burn the waste and reduce them to ash (acceptable for landfilling) and harmless flue gas. In this process, the volume and weight reduction take place and the toxicity is removed [R Sethumadhavan, 1997; Mueller Association Inc., 1989; Saxena and C.K. Jotshi, 1994; Legros et. al., 1990]. Fluidised bed incinerator is one of several types of incineration system that has inherent advantages as compared to conventional combustion systems. These advantages include an effective burning of all types of fuel either low calorific fuel or high calorific fuel under stable conditions.

To get the effective burning of the fuel, there are some important factors that influence the combustion process in a fluidised bed incinerator. One of them is the supply of air to fluidise the bed sand through plate distributor. This supplied air is introduced from the main blower and has a significant factor to influence gas-solid contact during turbulence action of the sand bed. Related to them, the objective of the study was to determine the quality of combustion process and to assess the flue gas emission level that comes out from cyclone outlet.

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2.0 PILOT SCALE BUBBLING FLUIDISED BED FACILITY

The incinerator has the static bed height of 110 mm and expanded until 170 mm during fluidisation. The bed sand used was silica sand with a size of 400 - 600 (m. Air superficial velocity during combustion process was 1.1 - 1.8 m/s. A blower is used for fluidisation as well as for air mixing during Liquefied Petroleum Gas (LPG) combustion. The air distributor plate has nine nozzles, which is bubble cap type and has fractional open area of 1.14%. Entrained solids are separated from the gas leaving the riser in a cyclone with an inside diameter of 85 mm.

In this experiment, a simple secondary-air port was designed and constructed (see Figure 1). Its location is just above the bed sand surface. The reason was that the injected air is supposed to make an oxidation process directly in the combustion chamber, whereas the combustion temperature is high (above 750°C).

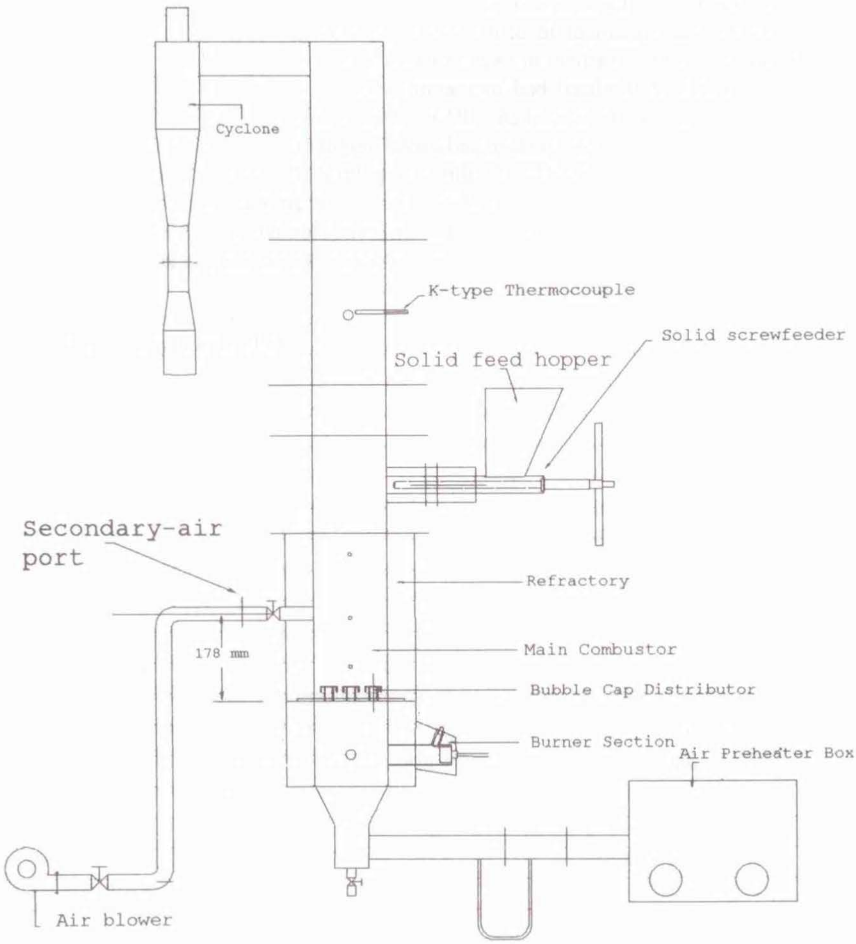

Figure 1 Position of the recent secondary-air port

3.0 OPERATING PROCEDURE

The incinerator operation was commenced by first fluidising the bed at a preselected air flow rate combustor and the air is preheated by 1 kW-heater coils until around 70 to 90°C. To raise the bed temperature until 500 - 550°C, it should be heated by LPG combustion. This bed temperature was reached in 20 minutes. Then the charcoal is fed slowly through the screwfeeder intermittently. Furthermore, the feeding process uses palm shell and gradually its feeding rate increased as well as the primary air flow rate. On the other hand, the charcoal feedrate slowly decreased until combustion temperature achieved 750°C. At this temperature, the Liquefied Petroleum Gas flow is shut off, therefore, it has already reached self sustaining combustion of the palm shell in the sand bed. To burn the solid wastes or palm shell until the bed temperature around 850 - 900°C, the solid flowrate as well as the primary air flow rate are gradually increased until reaching the exact air fuel ratio. The maximum of palm shell flow rate through fine screw feeder is about 90 g/min for particle size of 1.0 - 1.7 mm. For bigger sizes (1.7-2.8 mm) the flow rate is about 75 g/min. The maximum air flowrate for optimum combustion test is 55-85 Lpm (litre per minute).

Collecting the experimental data was done after the bed temperature achieved 750°C, whereas at this temperature the unburned particle could be reacted by incoming secondary-air (oxygen). The flowrate was varied from 30, 45, 60, 65, 70, 80 Lpm and fuel feed particle varied its flowrate at 65.7 and 90.5 g/min. To prevent more elutriation and entrainment of the particle, it use particle size : 1.7-2.8 mm. It was decided that the main air flow rate (Uf) of 1.01 m/s does not vary, because the selected air flow rate is low, so that if it were to be increased if could lead to more elutriation of the particle.

4.0 RESULTS AND DISCUSSIONS

4.1 Secondary air with bed temperature

The increase of secondary-air from 30 to 80 Lpm led to the increase of the bed temperature from 785 to 812°C on both two types of fuel rate (see Figure 2).

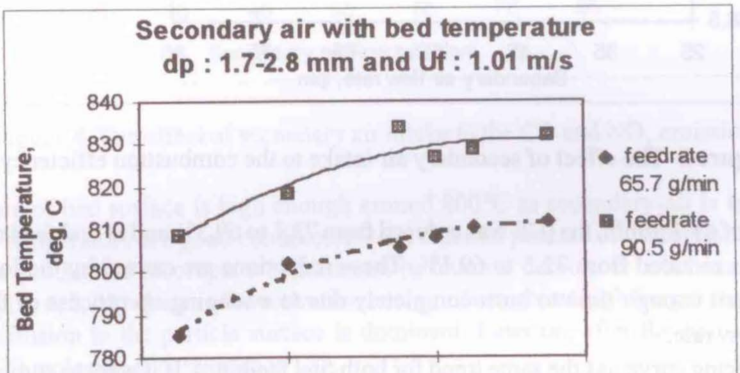

Figure 2 The effect of secondary air intake to the bed temperature

It indicated the injection of air at the right place that could lead to another combustion process of unburnt particle. The increase of bed temperature means there is a mass transfer process of oxygen with high kinetic rate at low secondary-air flowrate (between 30 to around 65 lpm), then, beyond this flow rate the kinetic rate decreased. It could be seen that the curve at high air flow rate tend to be horizontal.

The same Figure depicted the influence of different fuel feedrate over bed temperature. At fuel feed rate of 65.7 g/min, the injection of secondary-air from 30 to 80 lpm could increase the bed temperature from 785 until 812°C, then, at a higher feed rate of 90.5 g/min with the same flow rate of injected secondary-air, the bed temperature obtained were from 808.6 to 831.9°C. The effect of higher fuel feed rate would increase stoichiometric air-fuel ratio and therefore also activate the oxygen kinetic rate. Because of those reasons the bed temperature has increased.

4.2 Secondary air with combustion efficiency

Figure 3 shows the reduction of combustion efficiency (CE) while secondary-air flowrate increases.

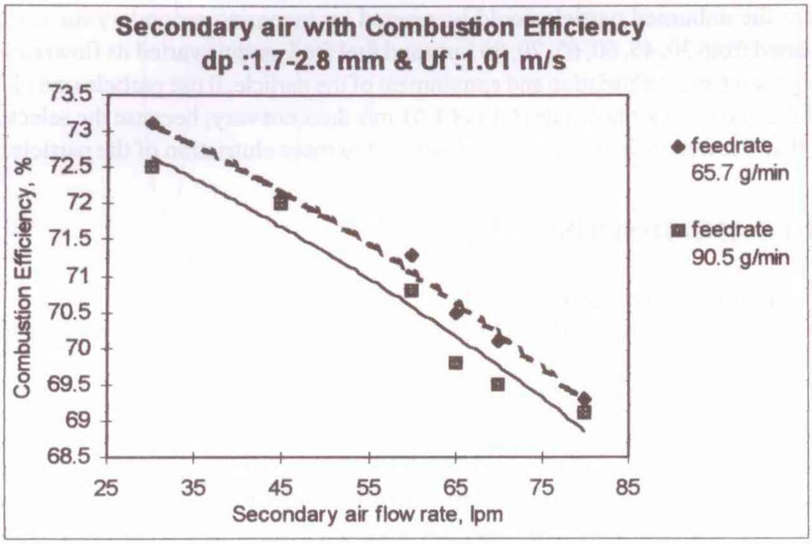

Figure 3 The effect of secondary air intake to the combustion efficiency

At fuel feed rate of 65.7 g/min, the (CE was reduced from 73.1 to 69.3% and at fuel feed rate of 90.5 g/min, the (CE was reduced from 72.5 to 69.1%. These reductions are caused by the loss of unburnt carbon that has not enough time to burn completely due to sweeping up process of the increasing secondary-air flow rate.

The (CE reducing curve has the same trend for both fuel feedrates. If it were to compare with each other, the fuel feedrate of 65.7 g/min has a higher (CE in average than a fuel feedrate 90.5 g/min. Logically by raising the fuel feed rate, the (CE should also increase, but in this experiment the result was different. There are some possibilities, firstly, the mass of fuel at 95.5 g/min has not enough time to burn or the burning process of fuel was slower than the lower feed rate (65.7 g/min). Secondly, the lower stochiometric air-fuel ratio thus produced more incomplete combustion (see Figure 4). Thirdly, the design of combustion chamber capacity is not available for this feed rate (95.5 g/min). It means the feedrate per area of the chamber is not appropriate, that the heat released product is not optimum. However, if the dimension of the chamber is modified to a bigger dimension, then the heat released product will be higher as compared to the recent one.

4.3 Secondary air with gas emission

4.3.1 Analysis of CO *emission*

The CO emission characteristic depends on the availability of the supplied air in the combustion chamber. The process of generating CO emission is much influenced by gas residence time, temperature of the oxidant and stoichiometric ratio (moles O2/mole fuel). The injected air through secondary-air port may control the level of CO emission. Figure 4 shows the effect of secondary-air level to reduce the CO emission. At a fuel flow rate of 65.7 g/min, CO emission was reduced from 540 to 305 ppm while secondary-air flow rate increased from 30 to 80 Lpm and for fuel flow rate 90.5 g/min at the same increase of secondary-air flow rate, the CO emission decreased from 623 to 387 ppm.

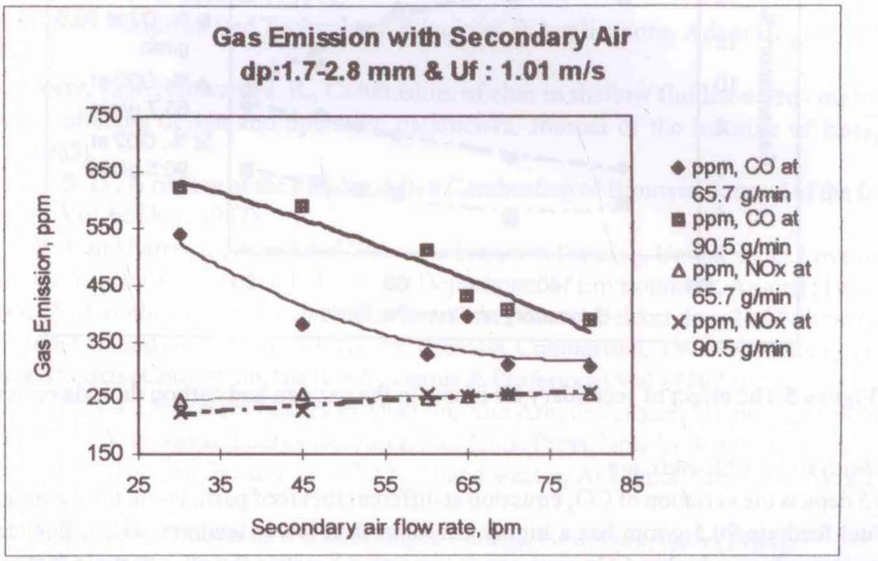

Figure 4 The effect of secondary air intake to the CO and NO_x emission

The temperature of bed surface is high enough around 800°C as secondary-air is injected into the chamber. This temperature is a good condition for the reaction process of the incoming oxygen with particles as the product of incomplete combustion or unburnt carbon. It is the implementation of Arhenius law [10, 6, 2, 3], whereas the activation energy of oxygen at high temperature is desired, so that oxygen diffusion to the particle surface is dominant. Later on, after the oxidation process of particles, the CO molecule is converted to CO_2.

The fuel feedrate of 90.5 g/min has a higher CO emission than feedrate of 65.7 g/min (Figure 4). The reason is that a higher feedrate has a tendency for slower burning process. Thus, it leads to a lower char oxidation process and as a consequence, the combustion process is predominate by the formation of CO molecules rather than CO_2.

4.3.2 Analysis of NO_x *emission*

NO_x formation in this experiment is largely a function of the percentage of nitrogen in the fuel and concentration of oxygen in the pyrolysis process[16]. For the experiment without air staging or secondary-air, the NO_x maximum concentration level is 100 ppm. Compared to the recent experiment, the air staging influenced the higher concentration i.e. around 250 ppm. It could be mentioned that the air staging led to a higher NO_x. The possibility is that the oxygen concentration of secondary-air is much influenced by the formation of NO_x. Thus, the increase of oxygen, as shown in Figure 5 contributed to the rise of NO_x formation. Therefore, as Figure 4 depicts, the rise of NO_x concentration is influenced by increasing secondary-air flowrate.

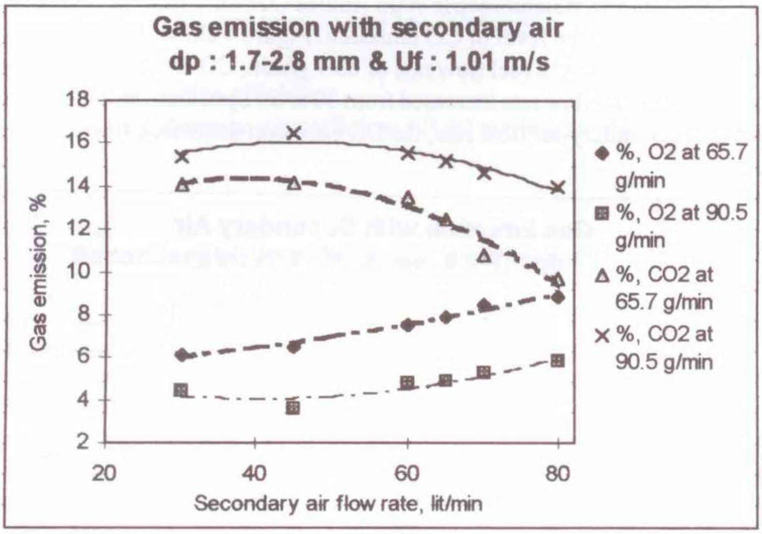

Figure 5 The effect of secondary air intake to the oxygen and carbon dioxide emission.

4.3.3 Analysis of CO_2 emission

Figure 5 depicts the variation of CO_2 emission at different fuel feed particles of 65.7 g/min and 90.5 g/min. Fuel feedrate 90.5 g/min has a higher emission than lower feedrate. The influence of higher feedrate in producing higher CO_2 emission is important because the char particle that reacted with oxygen is also high. Thus, for a lower feedrate the production of char particle is less Therefore, the CO_2 emission is also less. At a constant fuel feedrate e.g. 90.5 g/min, when the secondary-air flowrate increases from 30 to 45 lpm, the CO_2 concentration rose from 15.4% to 16.5%. Then beyond those flowrates, the CO_2 concentration is reduced from 16.5% to 14%. Similar trend is also being observed for a fuel rate of 65.7 g/min. The reason is, during a low fuel feedrate the oxygen diffusion toward the particle surface was in a proportional rate. However, increasing secondary-air is not to be followed by increasing of feedrate or the feedrate was constant. Thus the available oxygen is more than the char. Therefore as a result, CO_2 concentration is reduced.

5.0 CONCLUSIONS

Evaluations of the measurements of bed temperature, the flue gas emission and calculation of combustion efficiency have been conducted during the combustion of palm shell in the bubbling fluidized bed incinerator. The conclusions derived from the results of these experiments using air staging technique are as follows:

5.1 Bed temperature measurements showed the increasing of bed temperature from 785°C to 812°C (2.88% increased) at fuel feedrate of 65.7 g/min and from 808.6°C to 831.9°C (3.44% increased) at fuel feedrate of 90.5 g/min.

5.2 There were some reduction of combustion efficiency while increasing of secondary air around 4.7% until 5.2%.

5.3 CO and CO_2 emission level reduced significantly. For CO level reduced from 37.88 to 43.52% and CO_2 has a transient value, but it has a tend of the decreasing of emission level.

5.4 Different result from point 4.3, NO_x emission has increased if it were compared to without air staging.

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