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COMBUSTION STUDIES OF FLUFF REFUSED-DERIVED FUEL (RDF) IN FLUIDIZED BED (FB) SYSTEM

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ABSTRACT
Among most conventional incineration systems, the fluidized bed combustor (FBC) had been described as one of the most advantageous by providing simple operation with ability to accommodate low quality fuel as biomass, sludge and MSW with high moisture; reduced auxiliary fuel use; reduced operating and maintenance costs. This could only be achieved if optimal operating parameters are determined. This paper presents the methods and part of the findings of an on-going research aimed at optimizing the operating parameters that gives lowest emissions in the combustion of a fluff refused-derived fuel (f-RDF) in pilot scale fluidized bed combustor. The method adopt includes – cold fluidization studies in rectangular model column to determine the fluidizing velocity of the inert bed material (silica sand), and the effects of increasing fluidizing numbers on the mixing behavior of bed and fuel. This is closely followed by combustion study in the pilot scale FBC. Experimental findings from the cold fluidization studies indicates that a sand with particle size range (300 – 600 μm) gave a fluidizing velocity of 0.1 m/s at bed height 1W of column. Similarly, fluidizing numbers of 4Umf and above gave better mixing of inert bed material with fuel. Although, the combustion study is at its preliminary stage, the results from the cold fluidization shows that the fluidization is better at bubbling fluidization regime against circulating fluidization regime which requires much higher fluidizing velocities and higher turbulence.

Keywords: Incineration Systems; Auxiliary Fuel; Fluidization; Fluidizing Number; Fluidization Regime

1. INTRODUCTION

Urbanization results in increased solid waste generation such that the current per capita solid waste generation of Malaysia as a result of urbanization is between 0.45 – 1.44 kg per day, (Consumer association of Penang report, 2001) and had increased recently to 1.7 kg/person/day in major towns (Kathiravale, 2003; Hassan et al., 2000). It is expected that the amount of MSW generation will reach 31,000 tons by the year 2020 (Latifa, 2009). It has become an essential environmental and public health concern in the urban areas in Malaysia (Latifa, 2009). Landfill as the predominant waste management option in Malaysia (Sharifah, 2008); Kathiravale, 2003), are usually open dumping area that produce serious environmental and social hazards (6). Hence solid waste incineration had been identified as the primary treatment method for volume reduction; risk-free and energy recovery (Yan, 2006; Kathiravale, 2003, and Xiadong et al., 2002). However, conventional thermal treatment process for MSW is usually by mass burning incineration processes (Sabbas et al., 2003). This is met by stiff legislative emission standard; high financial start-up and operational capital requirements (Rand et al., 2000; Sabbas et al., 2003; Oh, 2010). But because of the undesirable and hazardous effects of landfill such as odour due to decomposition, carbon dioxide and methane which leads to greenhouse gas emissions etc., the disposal of solid waste is gradually being shifted from landfill to incineration. The fluidized bed system is one of the most efficient (Wan et al., 2008 and Hernandez, 2007) that could proffer such advantages as- simple operation, the ability to contain low quality fuels with high moisture content, the reduced use of supplementary fuel as well as the reduction in operating and maintenance costs with lower emissions.

Refused derived fuel (RDF) is an option for extracting energy from combustible material in a waste; mostly a waste pre-processing technique for boiler usage.
Therefore, the objective of this study is to establish the optimal operating conditions for the combustion of (RDF) in pilot scale fluidized bed system with the aim of achieving the highest combustion efficiency with minimal gas emission.

2. METHODOLOGY/ANALYSIS/EXPERIMENTAL SET-UP

Figure 1.shows the schematic diagram of 0.5m internal diameter (I.D) Pilot-scale fluidized bed combustor. The experimental set-up consist of a pilot-scale bubbling fluidized bed, a cyclone and exit gas into a stack as shown in Figure 1. The fluidized bed has a cross sectional-area of 0.5 x 0.5 m^2 and height of 5m. The bed height was 0.5 times the combustor diameter 0.5Dc, which is equivalent to a static bed height of 250mm from the standpipe gas distribution plate. Inert silica sand with particle diameter, (dp=300 – 600μm and minimum fluidizing number, Umf = 0.10 m^{s-1} at room temperature) was fluidized. Fluidizing air which serves both fluidization and combustion was initiated

using five standpipe gas distribution tubes each having 48 holes of 3mm diameter spaced 1mm apart. The flow rate to the tubes was made possible by the use of a wind box so as to ensure equal distribution of air to the bed. Secondary air inlet port was positioned at 2000mm from the bed wall.

Bed preheating was carried out using diesel soaked palm kernel shell to achieve the desired operating temperature of about 800^oC – 850^oC. Type-k thermocouples attached to a continuous data acquisition system were placed at varying heights so as to measure the bed, freeboard and exit flue gas temperatures above the distributor plates. The fluff packaged RDF was fed manually through the loading chamber of the combustor at a predetermined timing. Gas sampling was carried out just before the exit to the cyclone to measure the flue gas emission which was achieved by the use of continuous German made on-line gas analyzer with model MRU SWG $300^{-1}$for CO, CO_2, NO_x, NO, SO_x and SO_2 concentrations.

2.1 *Analytical Tests*

The analytical tests include - proximate and ultimate analysis; the lower heating value (LHV in KJ/Kg) and the higher heating value (HHV in KJ/Kg) of the solid waste were determined.

i. Proximate Analysis (ASTM D3172)

Proximate analysis involves the determination of moisture content; volatile combustible matter; fixed carbon and ash in a fuel sample. Experimental procedures carried out involving the proximate analysis of the samples were done in accordance with the American Standards for Testing and Materials (ASTM). The first step in the analytical process requires that samples be grinded into powder having grain size of up to 250 µm.

ii. *Ultimate Analysis (ASTM D3176)*

Ultimate analysis provides the major elemental composition of a solid fuel, usually on a dry ash-free basis. This involves the use of Elemental Analyzer EA 1108 to determine the carbon, nitrogen, oxygen, sulfur, chlorine and hydrogen. The oxygen content was obtained by the difference of all the chemical elements that make up the solid waste composition as shown by Equation (1), while sulfur and chlorine were omitted from the composition for ease of calculation.

% Oxygen = 100 – (carbon content + hydrogen content + ash) (1)

2.2 *Hydrodynamic Studies on Rectangular Column Unit*

i. Determination of Minimum Fluidization Velocity of Sand Size (300 - 600µm)

Air was supplied through the lower base of the standpipe distributor into a column using dresser roots trinado 108 blower system at ambient temperature and minimum fluidizing velocity was observed by the first bubble appearance with increasing air supply. Volumetric flow rate of air supply was controlled using rotameter downstream of the blower. The minimum fluidization velocity was then calculated based on the ratio of the air flow rate to the cross-sectional area of the column.

ii. Determination of Effect of Fluidization Number on Mixing of Sand with Fuel

At fluidization numbers in the range (1Umf - 6Umf) which gives a bubbling regime (Miller, 2008), and at bed height of 300mm approximately equal to 1Width of the rectangular column; the mixing and fluidization pattern of bed with fuel at increasing fluidization velocity was determined and were graded accordingly. According to (Kaewklum and Kuprianov, 2008), both fluidization pattern and hydrodynamic characteristics of fluidization affects bed geometry significantly.

The optimal fluidizing number ranges from 3Umf and above which gives enhanced mixing of bed with fuel were therefore chosen for the combustion study in the cylindrical pilot-scale fluidized bed combustor.

3. RESULTS AND DISSCUSSION

The analytical tests include - proximate and ultimate analysis; the lower heating value (LHV in KJ/Kg) and the higher heating value (HHV in KJ/Kg) of the solid waste were.

Table 1 RDF analysis

Parameters	(Wt. %)
Proximate	
Moisture content	25
Volatile Matter	90
Fixed Carbon	1.15
Ash	10
Ultimate	
Carbon	60
Hydrogen	1.5
Oxygen	30
Nitrogen	4
Sulfur	0.1
Other Parameter	
Net Calorific Value (kcal/kg)	4200

The experimental results for the trial burning are shown in Table 2 and Figs. 2 – 3. Generally, from Table two, the bed temperatures from fluidizing numbers of 3; 4 and 5 under study indicates a promising temperatures for autogenous combustion of refused-derived fuel (RDF) in fluid bed system but the temperature profiles which gives the online operational temperature capture figures 2 and 3 shows otherwise at increasing fluidizing numbers. At 3Umf combustion commence at temperature of 800^oC and steadily increases autogenously for the burning period of 30 min. giving off carbon dioxide of about 1052 ppm. Similarly, at

4Umf even though combustion was initiated at elevated temperature of about 880°C the bed temperature steadily decreases with increasing time of combustion with higher carbon monoxide given off. This is true since higher carbon monoxide is indicative of incomplete combustion.

Table 2 Mass flow of fuels and experimental results for the trial burning for combustion at AF=1.0 at varying fluidizing numbers

Fluidizing numbers (U_{mf})	3	4	5	6	7
Fuel feed rate (g/min)	195	260	325	390	455
Temperature (°C)					
Bed	800	880	799	n/a	n/a
Freeboard	634	642	570	n/a	n/a
Stack	496	528	542	n/a	n/a
Gas in stack					
O_2 (%)	18.7	18.7	18.7	n/a	n/a
CO (ppm)	1052	1103	1083	n/a	n/a
CO_2 (ppm)	1.11	0.99	0.95	n/a	n/a
NO_x	217	253	291	n/a	n/a
CO (mg/m^3)	1321	1582	1234	n/a	n/a
SO_2 (ppm)	-195	-164	-192	n/a	n/a

n/a – not attempted

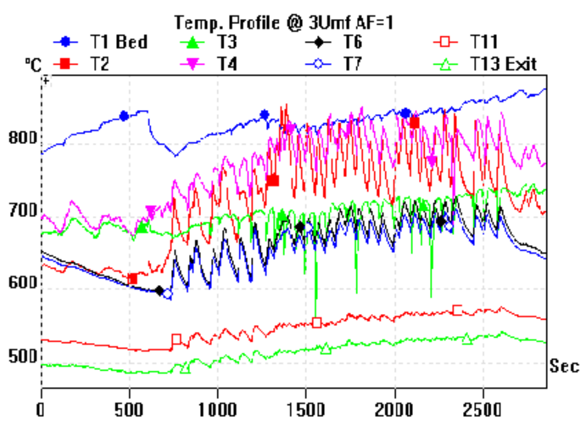

Figure 1 Temperature profile at 3 U_{mf} and primary air factor, PAF = 1

Freeboard temperatures obtained at the prevailing fluidizing numbers when compared to the bed temperature indicates that the combustion takes place in the bed, while these freeboard temperatures are sufficient to burn any released volatiles to the diffuse regions. As a trial run so many factors could be attributed to the discrepancies in obtained results which could include – variances in feed rate as well as temperature at which combustion was initiated, which also varies due to the bed pre-heating media and technique used in this case palm oil kernel shell. The experiment had to be stopped at 5U_{mf} due to the irregular burning trends at rising fluidizing velocities.

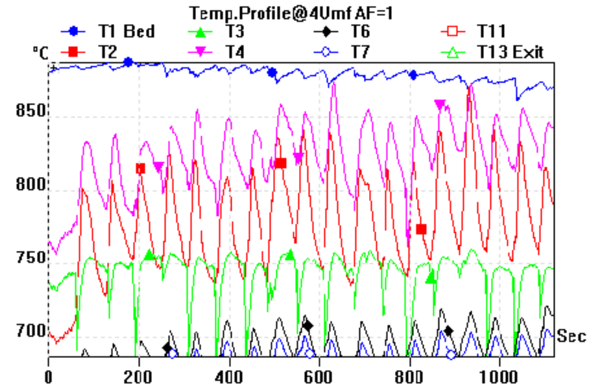

Figure 2 Temperature profile at 4 U_{mf} and primary air factor, PAF = 1

It could also be observed that there was a minimal CO_2 emission with an average NO_x given off. However, concentration of emission had not been compared with allowable threshold limits yet because further variation of air ratio at excess air levels is been considered at established optimal fluidizing number. Constant oxygen level was observed in all cases. Finally, the results of the trial runs, indicates there maybe the need for emission control system or the by the injection of appropriate catalysts. By then an ideal comparison of flue gas emission will be made with acceptable regulated values. This could only be achieved if there is a sustainable combustion.

4. CONCLUSION

A trial burn in the combustion studies of RDF in pilot-scale fluidized bed combustor was carried out with the aim of determining the optimal combustion conditions that gives higher efficiency with minimal gaseous emissions. The following conclusions can be inferred.

I. Combustion at 3Umf at stoichiometric air ratio gives enhanced fuel burning at bed with good temperature profiles.

II. Increased fluidization velocities lead to drop in combustor temperatures with unusual non-sustainable temperature profiles.

III. Combustion at stoichiometric air ratio which is the theoretical air required for combustion gives high gaseous emissions.

IV. Stoichiometric air ratio may not be the optimal desirable air ratio for combustion to give minimal flue gas emissions.

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