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Emission studies from combustion of empty fruit bunch pellets in a fluidized bed combustor

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Abstract. Malaysia is producing a very large amount of biomass annually from milling activities of oil palm. This biomass is currently being used efficiently in many ways including as fuel for boilers together with fossil fuels. This paper reports the emission characteristics from biomass combustion in a swirling fluidized bed combustor (SFBC). Pelletized empty fruit bunch (PEFB), one of largest biomass produced from oil palm industries were used as fuel in the present study. Combustion experiments were conducted with several quantitiesof excess air: 20%, 40%, 60% and 80% for a constant fuel feedrate of 30kg/hr. The effect of excess air was investigated for three major emissions gaseous namely CO, CO_2 and NO_x. Fly ash produced from the combustion was also analysed to find the contents of unburnt carbon and other impurities. From the results, it was found that the emission of CO decreased from 64 ppm to 40 ppm while the amount of CO_2 increased slightly with the increasing of excess air from 20% to 80%. The NO_x emission also increased from 290 ppm to 350 ppm because of N_2 in the EA reacts with O_2 due to high combustion temperature. The combustion efficiencies of about 99% obtained in the present study, showing the prospects of using SFBC in commercial scale.

1.0 Introduction

The energy demand by mankind kept increasing on daily basis and it is very challenging to ensure the energy can be supplied continuously. This is because most of the energy resources are coming from fossil fuels, such as petroleum, coal and natural gas which cannot be replenished [1]. Transportation, electricity generation, heating and cooling are among most energy consuming areas. At the moment, these energy are produced widely from fossil-fuels. This is because fossil-fuels are reliable, highly efficient, lower production costs and very well established [2].

Biomass is environment friendly compared to the fossil fuel because it can reduce the global warming that caused by the release of greenhouse gas such as CO_2 from the combustion. Biomass has been considered as carbon neutral as the net carbon emission is zero as the CO_2 emission is absorbed by the trees and plants. Apart from that, the biomass usually emits very small amount of NO_x and SO_x in comparison to fossil fuels [3]. Biomass are largely available in many countries especially the develop nation. These biomass contain significant amount of energy and thus development of biomass technology has been takes place in many countries such as Malaysia [4].

From many research have been done before, combustion of biomass show very effective and producing electricity as one of renewable source to replace the fossil fuel [5]. Biomass is resources that have been considered as the key for the renewable resource for the future at small and large scale level. The usage of biomass for converting to energy already 14% for the world and on the average scale it have been use as primary energy up to 38% for developing country [6]. From Figure 1 shows biomass usage have been widespread in producing electricity because of the benefit from the biomass.

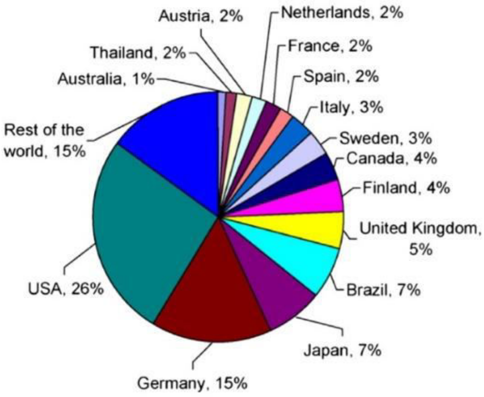

Figure 1. Global biomass usage for generate electricity [4].

Malaysia is a country well-blessed with one of it major agricultural is palm oil industry which is the major biomass disposal from this industry and it was the major sustainable energy resources for Malaysia [7]. The oil palm biomass show very high potential as the sustainable energy resources because 60 million tonnes of fresh fruit bunches (FFB), 7.3 million tones mesocarp fibre, 3.2 million tones of shell and 12 million tones empty fruit bunches (EFB) as biomass residue that came from Malaysian palm oil mills process [6].

Figure 2. Empty Fruit Bunch

Fluidized bed combustor is one of thermo-chemical conversion process of biomass in generating heat and energy. Many conventional fluidized bed combustor such as bubbling and circulating beds have been address as one of the efficient method for thermos-chemical conversion of biomass. Moreover the fluidized bed combustor already known to have very high combustion efficiency in range of 81-98% and low pollutant emissions [8][9]. In addition, these technology already known for a long period and it proven as a good thermo-chemical conversion especially for various type of biomass and very environmental friendly technology[10]. (Nowadays in present studies, the implication combustion of bio-fuel by fluidized bed already show good result and as the difficulties of solid fuel) to fluidized, the researcher overcome it by using a an inert material such as alumina, silica sand as the resident material to fluidized [11].

Table 1 show the emission data of CO, C_xH_y, and NO from the combustion of empty fruit bunch (EFB) in a conical fluidized bed combustor which using the alumina sand as the bed material. This experiment been done by firing 40kg/hr for the pre-dried empty fruit bunch by the access air 19%, 42%, 59% and 76% of excess air (EA). The result show the emission of CO, C_xH_y, and NO decrease with increasing of EA this due to the combustion efficiency of the EFB also increase. When the combustion efficiency increase, it show the combustion gain enough oxygen to carried out the process [12]. This paper presents the effect of excess air on the combustion and emission of pelletized empty fruit bunch (PEFB) in swirling fluidized bed combustor.

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Table 1 : Emissions, Heat losses, and combustion efficiency of the Conical FBC [12]

	EA %	O2 at cyclone exit	Unburn carbon In PM%	Emission PPM %			Heat loss % due to		Combustion
				CO	CxHy	NO	unburn	incomplete	efficiency
Alumina sand	19	3.6	4.7	1452	1335	100	0.36	1.76	97.9
	42	6.3	6.14	631	542	139	0.56	1.03	98.4
	59	7.9	6.55	453	436	146	0.6	0.97	98.4
	76	9.1	7.36	351	253	150	0.68	0.81	98.5
Limestones	21	4	2.36	1619	1415	104	0.21	1.96	97.8
	40	6.1	1.63	785	535	141	0.14	1.08	98.8
	61	8	2.36	418	261	164	0.21	0.72	99.1
	79	9.3	2.91	168	156	173	0.26	0.47	99.3
Dolomite	20	3.8	3.2	1479	1351	98	0.28	1.76	98
	41	6.2	2.21	744	499	140	0.19	1.01	98.8
	58	7.8	1.93	450	276	157	0.17	0.71	99.1
	81	9.4	4.1	183	147	168	0.37	0.47	99.2

2.0 MATERIALS AND METHODS

In this section a brief description on the experimental procedures, equipment and instruments used were given together with fuel characterisation study through proximate and ultimate analysis. These analyses were conducted for obtaining the combustion stoichiometry. The pelletized empty fruit bunch (PEFB) was used as solid fuel and while the sand as inert material for the bed.

2.1 Fuel Preparation

The solid fuel that used in this experiment is empty fruit bunch from oil palm tree that have been pelletized. The pelletized EFB are analysed for its chemical and physical properties. To analysed the C, H, N and O content of EFB through

- Elemental analysed
- Moisture
- Calorific value (bomb calorimeter)

The result are as the following in Table 2:

Table2 : Results from proximate and ultimate analysis

Name	Mad%	Ad%	Vd%	St,d%	Cd%	Hd%	Nd%
Rice Husk	8.3	10.62	71.45	0.1	44.97	5.1	0.56
Oil Palm Shell	9.03	2.45	76.8	0.07	52.01	5.53	0.47
PEFB	9.38	10.35	70.82	0.1	46.24	5.15	0.56
Sugarcane Bagasse	7.42	2	83.3	0.16	47.51	5.64	0.49

Figure 3: Pelletized Empty Fruit

Figure 4: Sand 600µm-850µm

The chemical and physical properties provided the data needed for stoichiometric combustion analysis. Moreover, Sand having a size range between 600µm-850µm are sieved and used as resident particles in the present study. The sand being sieve using the sieving to get the required size range.

2.2 Experimental Setup

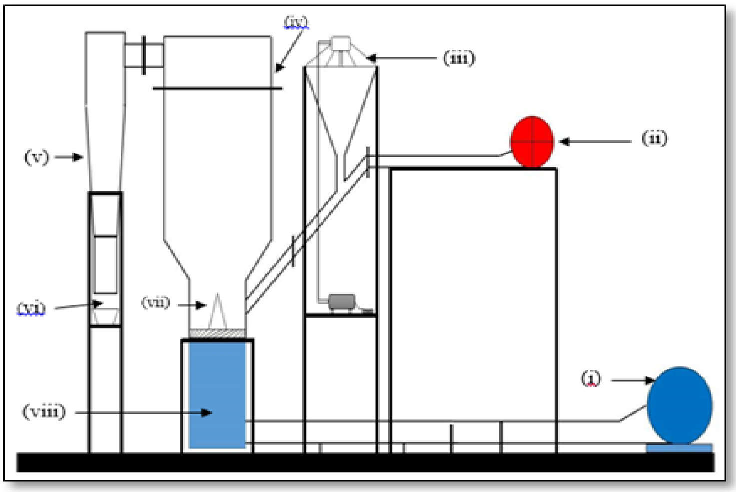

Figure 5: Schematic of SFBC

Major components of the SFBC that shown figure above:

i. Primary blower
ii. Secondary blower
iii. Fuel Feeder
iv. Combustor
v. Cyclone
vi. Fly ash collector
vii. Air distributor
viii. Plenum chamber

The SFBC consists of few major components during the experimental setup as such the combustion chamber, plenum chamber, annular air distributor, start-up burner, cone body centre, screw feeder and a cyclone.

Combustion chamber is the biggest component in the SFBC in terms of its size and weight. The main feature of SFBC made of mild steel and was designed to fit properly with the screw feeder and cyclone attached. Moreover, a cone centre body was designed at a height of 79 mm. Cone function is to avoid the agglomeration of particles (e.g sand) at the centre of the combustion chamber since during the swirling process the centre of combustion chamber known as a dead zone. The annular distributor inside the combustion chamber was design with 48 blade at 15^o inclination to let the air coming through it. Primary air is supplied from the blower into the annular distributor to sustain the swirling characteristics of the SFBC, it was controlled using a 25HP inverter unit. To define the actual airflow rate and the valve opening, a pitot-static probe was used to measure the actual velocity of the air inside pipe. The cone plays a significant part in stabilize the swirling fluidization of the particles. The main reasons and advantage of the cone are to eliminate the occurrence of dead zone on the core of the bed as well as providing extra volume to accommodate the bed.

The inert sand bed material was pre-heated using four units of brazing torch at about of 600^oC prior to combustion. The brazing torch was switch off but upon attaining the desired bed temperature and secondary air (SA) delivery was controlled by using a frequency controller connected to the blower motor. The emission is an integral part of the SFBC especially in determines the combustion efficiency and determines the gas emitted to the atmosphere. The concentrations of O_2, CO and NO_x released to the atmosphere were measured using a suitable gas analyser. The K-Type thermocouple was placed at seven different levels along the height of the combustor in obtaining the temperature at each elevated height of the combustor, thus creating temperature profiles of the SFBC. In this experiment the primary is delivered at $0.088m^3/s$ and the fuel feed rate of the PEFB were set at 30kg/hr while the EA are being added by 20%, 40%, 60% and 80%. The EA was varied accordingly during the experiment. The stoichiometric equation was determine by doing proximate and ultimate analysis. The result from this analysis is shown in Table 2. Below was the stoichiometric equation that was obtain from the analysis pelletized empty fruit bunch (PEFB) of oil palm biomass

$$0.286C_{4.3}H_7O_{1.3} + 1.544(O_2 + 3.74N_2) = 1.23CO_2 + H_2O + 5.77N_2$$

The exothermic chemical reaction (a reaction in which heat is given off) of hydrogen and carbon atoms contained in fuels with oxygen is called combustion. The measurement of combustion efficiency can be determine by the effectiveness device consumes fuel. There are several parameter that have to be considered for measuring combustion efficiency such as temperatures, fuel and the oxygen that entering the combustion chamber. As per analysis given below, C_{fa}(%) get from Scanning Electron Microscope (SEM) from the fly ash from the combustion, CO (%) and CO_2 (%) were obtained from gas analyser that being used for emission analysis.

3. Result and Discussion

From the experiment works, data obtained are analysed in term of temperature distribution in the bed, emission concentration in the exhaust gaseous as well as combustion efficiency.

3.1 Bed Temperature Profile

The temperature profile inside the swirling fluidized bed combustor was acquired and plotted in the axial location inside the bed. This is because the bed exhibits homogeneity in its hydrodynamic characteristic. Therefore, from several earlier experiments the radial and tangential temperature distribution are very small. Hence, only axial temperature was plotted, and the average values are as in Figure 6.

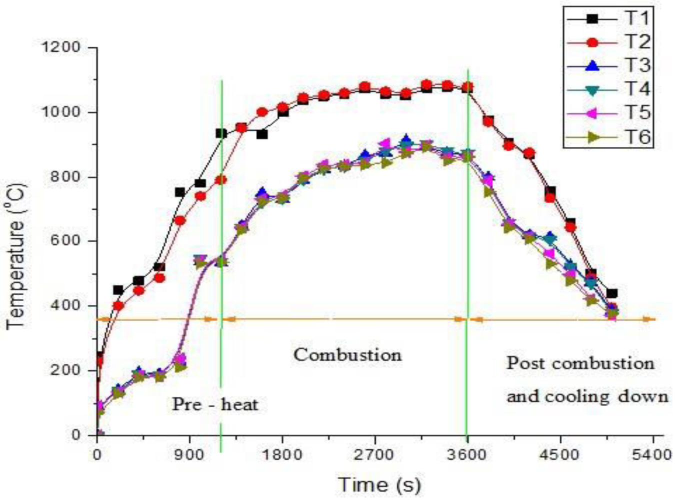

Figure 6: Temperature history

From the figure, the distribution of the temperature in the axial direction can be divided into three regions in accordance to bed operation. The first region is during pre-heating where the bed undergoes warming-up. During this region the PEFB is slowly being fed into the system until the temperature increases to about 500°C at the location near the bottom of the combustor. After that, the PEFB feeding is increased to 30kg/hr and the bed achieves its steady operating condition. The emission readings are taken at this region, called steady combustion. At the dense region, T_1 and T_2 recorded almost 1100°C. The other four temperatures recorded about 800-850°C before all temperatures slowly declines when the PEFB feeding is stopped.

3.2 Emission Analysis

The Figure 7, 8 and 9 will depict the O_2, CO_2, CO and NO_x emissions (i.e., the concentration measured at the cyclone exit), for firing PEFB at the fuel feed rates of 30 kg/h for the entire range of excess air.

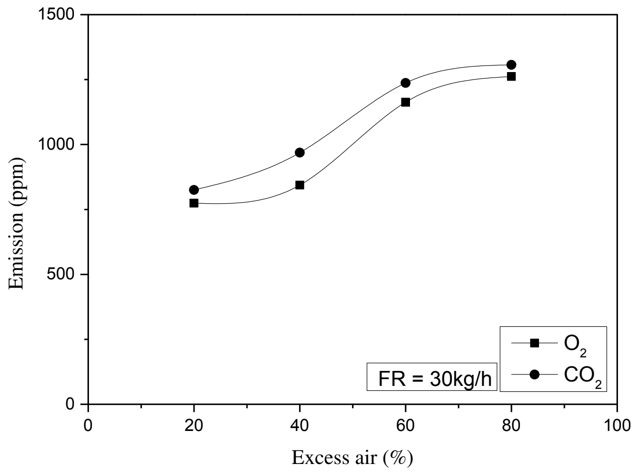

Figure 7. Effect of the fuel feed rate and excess air on the emission of CO_2 and O_2 from the conical FBC when firing PEFB.

Form Figure 7, the graph presents emission concentration of oxygen and carbon dioxide. When increased the EA, the O_2 also increased because the quantity of air is increased. It showed that the fuel will react with O_2 because O_2 aids the fuel achieve a complete combustion. Inherently, the amount of CO_2 depended on O_2 because it the former was the combustion product.

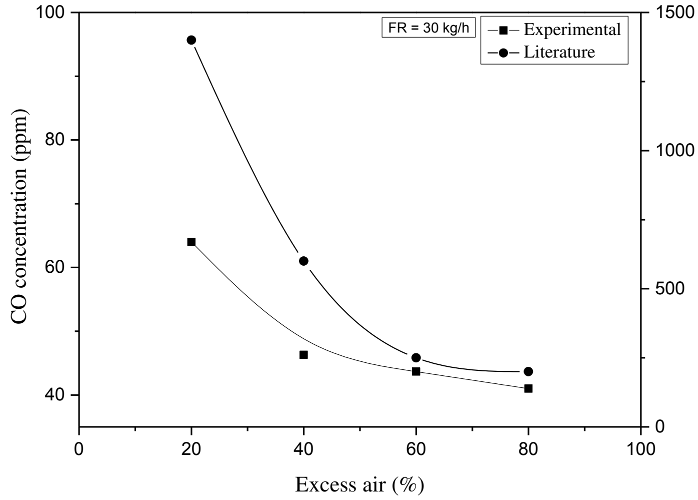

Figure 8. Effect of the fuel feed rate and excess air on the emission of CO from the conical FBC

Figure 8 shows the concentrated for CO emission from SFBC. Each colour represented experimental values and theoretical value from Ninduangdee and Kuprianov[10]. The CO emission can be controlled at a comparatively low level, below 70 ppm. On the contrary, at excess air lower than 40%, the CO emission exhibited quite strong effects of EA. Note that at EA = 20%, the CO emission was higher, about 60 until 70 ppm. However, the increase of EA can reduce the CO emission.

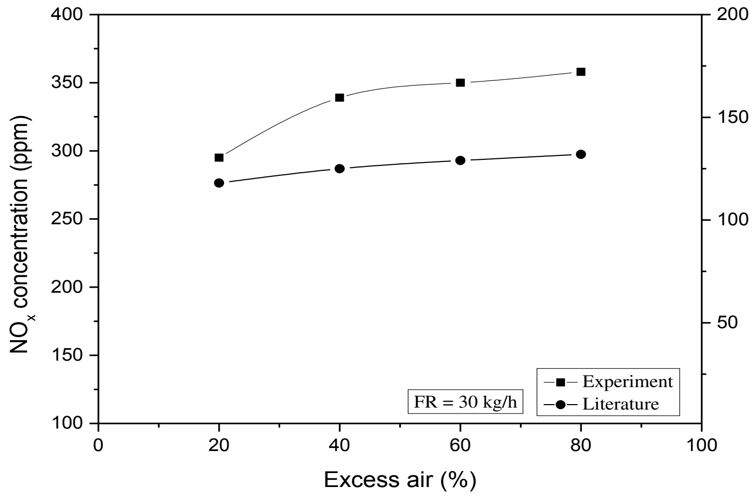

Figure 9. Effect of the fuel feed rate and excess air on the emission of NO_x from the conical FBC when firing PEFB

Figure 9 showed the NO_x emission during combustion process. Each colours represent for experimental value and theoretical value from Ninduangdee and Kuprianov [16]. Note that EA = 20%, the NO_x is above 290 ppm. To achieve complete combustion the amount EA must be increased because more O_2 will make combustor achieve complete combustion. Beside of that, the nitrogen in the air also will react to the amount of oxygen. Furthermore, NO_x was created when the temperature is high, around 1000 °C.

In SFBC, when combustor achieves complete combustion the NO_x will increase, but it was not pass the national limits. However, this achievement was accompanied by the conventional effects of EA leading to the increase in the NO_x with higher EA.

3.3 Combustion Efficiency
Combustion efficiency have been described as the ability of the thermos-chemical conversion and energy release by the process. This show the value of fuel have been utilized during the combustion process by the heat loss toward the incomplete combustion and the unburn carbon. The combustion efficiency equation 1 are one suggested equation by Kuprianov et al, [13]. Data analysis is given in the Table4 which carbon fly ash (C_{fa}) get from the scanning electron microscope (SEM) , and CO and CO_2 obtained from the gas analyser. The value A was obtained from the proximate analysis while LHV get from the bomb calorimeter machine.

Table3. Combustion efficiency

Excess Air (%)	C_{fa} (%)	CO (%)	CO_2 (%)	A (%)	LHV (MJ/kg)	η_{comb}
23.3	6.00	0.0055	12.25	6.87	18.795	99.998
38	8.50	0.0045	10.25	6.87	18.795	99.998
59.2	12.78	0.0029	11.96	6.87	18.795	99.998
83.6	39.85	0.0041	7.42	6.87	18.795	99.991

$$\eta_{comb} = 100 - (q_{ic} + q_{uc}) \quad (1)$$

Heat loss due to unburned carbon (q_{uc}):-

$$q_{uc} = \frac{32{,}866}{LHV}\left(\frac{C_{fa}}{100 - C_{fa}}\right) A \quad (2)$$

Heat loss due to incomplete combustion (q_{ic}):-

$$q_{ic} = \frac{CO}{CO + CO^2} \quad (3)$$

4.0 CONCLUSION
It can be concluded that the SFBC is an efficient and viable technique for combustion of oil palm biomass. In the present study, it was found the SFBC may achieve combustion efficiencies approaching 100% which indicates the superiority of the system for thermo-chemical conversion. From the results, it was found that the emission of CO decreased from 64 ppm to 40 ppm while the amount of CO_2 increased slightly with the increasing of excess air (EA) from 20% to 80%. The NO_x emission also increased from 290 ppm to 350 ppm as a result of N_2 in the EA reacts with O_2 due to high combustion temperature. The combustion efficiencies about ~ 99% obtained in the present study, showing the prospects of using SFBC in commercial scale.

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