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The Carbon Monoxides Reduction and Temperature Profile of Palm Shell and Palm Fiber Combustion in Fluidized Bed Combustor

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Abstract. The emission from FBC is very dependent on a number of operating conditions (temperature, staged air, fuel feed rate, excess air, etc.) and fuel properties. This paper describes the experimental results taken in a staged air fluidized bed combustion laboratory scale, using palm fiber and palm shell as fuels and silica sand as the inert bed material. In this experiment, a variation of excess air and secondary air were measured. Measurement of gas emissions of CO and CO2 concentrations, combustion efficiency and temperature, were taken along the combustor height as well as in flue gas. The experimental results show that the axial temperature profiles decrease successively along the FBC height. The CO emission obtained was lower for the staged-air condition than for the un-staged- air condition. The combustion efficiencies show satisfactory values.

INTRODUCTION

The concentration of greenhouse gasses in the atmosphere, CO_2 particularly, is changing the Earth's climate. Therefore, according to the Kyoto protocol, the international community agreed on binding emission targets and developed countries are committed to reduce their greenhouse gas emissions. A study done by the Asian Regional Research Programme in Energy, Environment and Climate Phase II (ARRPEC-II) implied that biomass energy appears to be the most important renewable energy resource in terms of technical and economic feasibility during the next few decades [1,2]. Also, there are some advantages using biomass as fuel in a boiler, such as mitigation of hazardous emissions likely CO_2, NO_x, CH_4, SO_x and CO; diversification of fuel supply and energy security [3]. Biomass as one of the renewable energy sources is defined as the biodegradable fraction of products, residues and waste from agriculture including vegetable and animal substances, forestry and related industries [4]. The increased use of biomass in energy systems is an important strategy to reduce the emissions [5-8]. Many journals discuss about rice husk as biomass fuel [9,10].

In this research, the reason for using palm oil wastes as a fuel because of many palm oil planting areas in Asian countries, such as Malaysia, Thailand, and Indonesia [11-13]. As one of the major agro-industries in Malaysia, palm oil industry get the raw material such as fresh fruit bunch, and solid materials is produced in the milling process. The diverse palm wastes are in form of empty fruit bunch (EFB), palm fibers (PF) and palm shell (PS).

There are some combustion technologies available for biomass combustion such as fixed bed combustion, fluidized bed combustion and pulverized bed combustion. However, it has been found that fluidized bed combustion is the best technology used to burn a fuel such as biomass with low quality, low calorific value and high ash content [3].

Fluidized bed combustion (FBC) nowadays has emerged as an environmentally attractive method for burning coal, biomass, and wastes [14-16]. Fluidized bed technology, as one of the technologies identified for future energy

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and electricity generation, uses successfully in numerous industrial processes such as the chemical and metallurgy industries and recently in power engineering.

FBC uses a continuous stream of air to create turbulence in a mixed bed of fuel, inert material, and coarse fuel ash particles. It occurs at temperatures typically between 800 and 950°C. Constant mixing of particles encourages rapid heat transfer and complete combustion. Fluidization, combustion, and emission formation are the fundamental issues of FBC.

The method used in this work was air staging with controlling of operating conditions, i.e., temperature and excess air (EA). Air staging was calculated by dividing the air supply into the in-bed fluidizing primary air and over bed secondary air (SA). The degree of air staging was expressed as the ratio of secondary to total air. Moreover, the effect of air staging on the FBC is a reduction of gaseous emission [17]. The objectives of this research are a measurement of gas emissions of CO and CO_2 concentrations, combustion efficiency and temperature using two kinds of palm waste that those were taken along the combustor height as well as in flue gas.

EXPERIMENTAL SETUP

Fig. 1 shows a set of a schematic diagram of the experimental combustor. The experimental combustor was fabricated from mild steel and is 0.5 m in height and 0.36 m squared in cross section. The insulated reactor was made from stainless steel cylindrical tube of 164 mm internal diameter and 2.0 m height and divided into five flanged sections. Silica sand of 300 μm mean particle diameter was used as the bed material. Air from a blower was introduced into the bed through a distributor with air outlets arrayed around a circular tube in six rows. There are a total of 36 air outlets with 6 outlets in each row of 5 mm in diameter. Reactor preheating was achieved by using auxiliary fuel. Flue gas exits the top of the freeboard and enters into a cyclone.

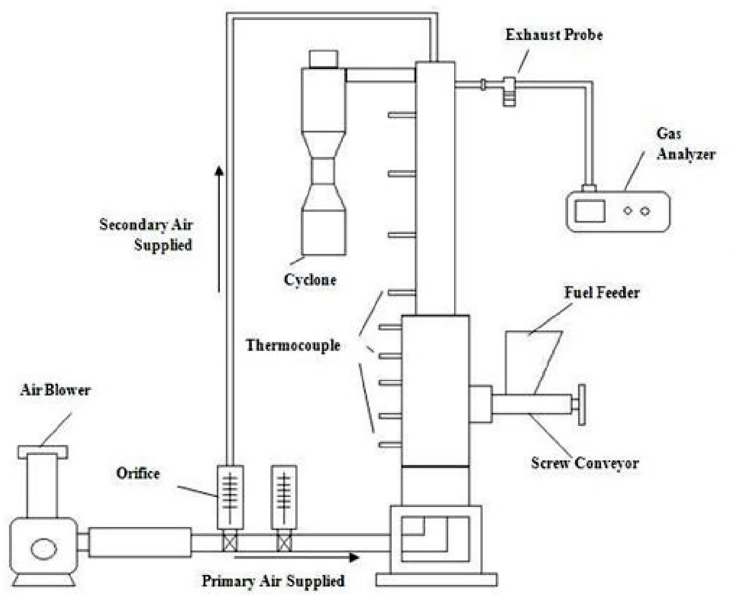


FIGURE 1. Schematic diagram of the experimental combustor

EXPERIMENTAL PROCEDURE

The task of heating the inert material was fulfilled by the preheating system. This was done by introducing the auxiliary flame directly into the combustion chamber. The fuel was fed when the bed temperature reached approximately 450^0C by a screw type feeder at the rate of 50 g/min fed fuel. The TOCSIN equipment was used to take emission readings. Emissions readings were taken when the bed temperature stabilized at approximately 950^0C and above. Air staging is achieved by dividing the total combustion air supply for stoichiometric operation into both the primary air (in bed fluidizing air) and secondary air. Secondary air was introduced at 400 mm above the distributor plate with a 0.55 mm internal diameter stainless steel tube. The air staging experiments were undertook with the secondary air to total air ratio varied from 0, 0.1, 0.2, 0.3 and 0.4.

RESULTS AND DISCUSSION

In these experiments, two kinds of palm wastes were used as fuel, palm shell (PS) and palm fiber (PF). Table 1 shows characteristics and compositions of palm shell and palm fiber. Those palm wastes contain a high percentage of moisture and volatile matter and a low percentage of fixed carbon (<20%). Fabrizio and Salantino found that the interaction of emitted volatile matters with fluidized bed had great influence on the combustion characteristics [18].

In addition, the combustion of volatile matters from high volatile solid fuels contributed high heat release, which emphasized the importance of mixing/segregation phenomena with respect to the fluidizing gas and bed inert solids.

TABLE 1. Characteristics and Compositions of Fuel [19]

Type of Fuel	Proximate Analysis (% by mass)				Ultimate Analysis (% by mass)					Calorific Value (MJ/kg)	
	Moisture content	Ash content	Volatile matter	Fixed carbon	Carbon C	Oxygen O	Hydrogen H	Nitrogen N	Sulfur S	Net	Gross
Palm Shell	12.15	1.96	79.22	18.82	47.978	45.781	5.487	0.714	0.04	18.84	21.44
Palm Fiber	13.98	3.63	84.78	11.59	50.091	41.147	6.247	2.385	0.13	17.64	19.60

Ash content in palm wastes was found to be very low (fewer than 5%), and this could prevent accumulation of ash in the bed. Hence, the collection of ash from the top of the bed was more suitable. Conversely, ash content above 5 % caused clinker problems, especially if the ash is in alkali oxides and salts, which produces eutectic mixtures with low melting points [20].

The composition of sulfur in palm waste was not significant. Hence, complete combustion of sulfur to form sulfur dioxide did not pose serious environmental problems.

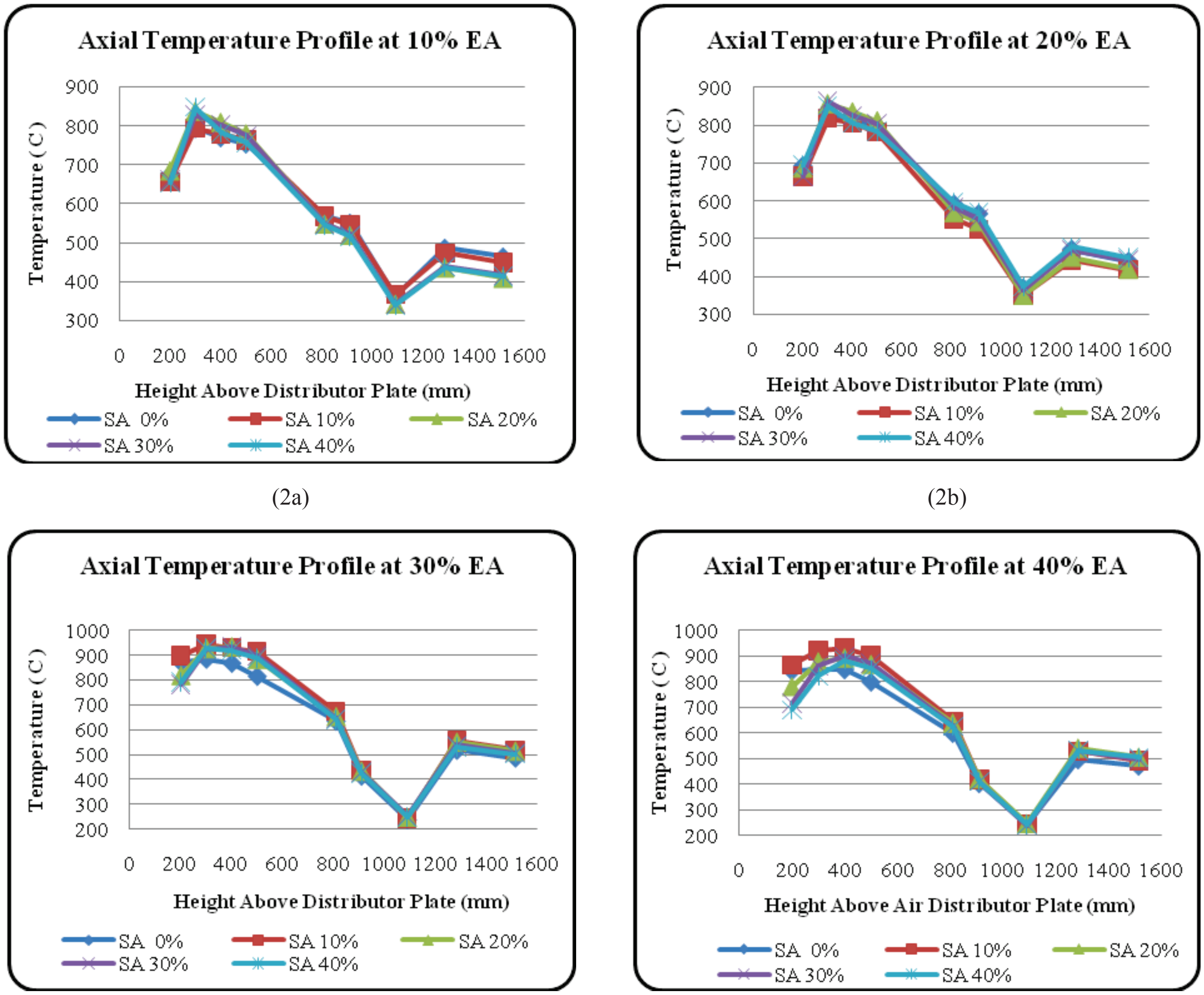
Temperature Distributions

Fig. 2a to 2d show the effect of excess air and secondary air-to-total air ratio on the axial temperature distributions of palm shell at some variation of excess air level from 10% to 40%, with increments of 10%. In addition, Fig. 3a to 3d show the effect of excess air and secondary air-to-total air ratio on the axial temperature distributions of palm fiber at some variation of excess air level from 10% to 40%, with increments of 10%.

In all cases, combustion temperature increases in the bed zone with height due to post-combustion temperature reaching a maximum value, and then, it significantly decreases in the freeboard zone due to heat transfer through the un-insulated combustor wall.

As shown in those figures, in the bed zone (under secondary air entrance), temperatures were reduced by increasing the secondary air ratio. This result is due to the shortage of oxygen to complete the reaction of the CO to CO_2, and rate of heat release decreases in this zone consequently. On the other side, temperatures in the freeboard diphase zone (above the secondary air entrance) diphase with an increase of secondary air ratio. Evidently, the secondary air was used to oxidize the volatile species that were produced from fuel rich conditions in the dense bed. Thus, more homogeneous reaction of carbon monoxide with the oxygen of secondary air which takes place in this region releases significant fraction of heat. The location of maximum temperature for all excess air levels is located between site 2 (400 mm) and site 3 (600 mm) of the thermocouple, where post-combustion took place.

Temperature distributions of palm shell are higher than temperature distribution of palm fiber. These are because the gross calorific value and the amount of fixed carbon of palm shell are higher than that for palm fiber. Therefore, hold up time of palm shell fuel in the bed was longer compared to palm fiber.



(2c) (2d)

FIGURE 2. Effect of excess air and secondary air-to-total air ratio on the axial temperature distributions of palm shell at EA = 10% (a), EA = 20% (b), EA = 30%, (c), EA = 40% (d)

CO Emission

The influence of secondary air ratio and excess air on CO concentration during air-staged combustion can be seen in Fig. 4. Both Figures exhibit a reduction in CO concentration with increasing secondary air ratio, which is mainly due to oxidation of CO to CO_2.

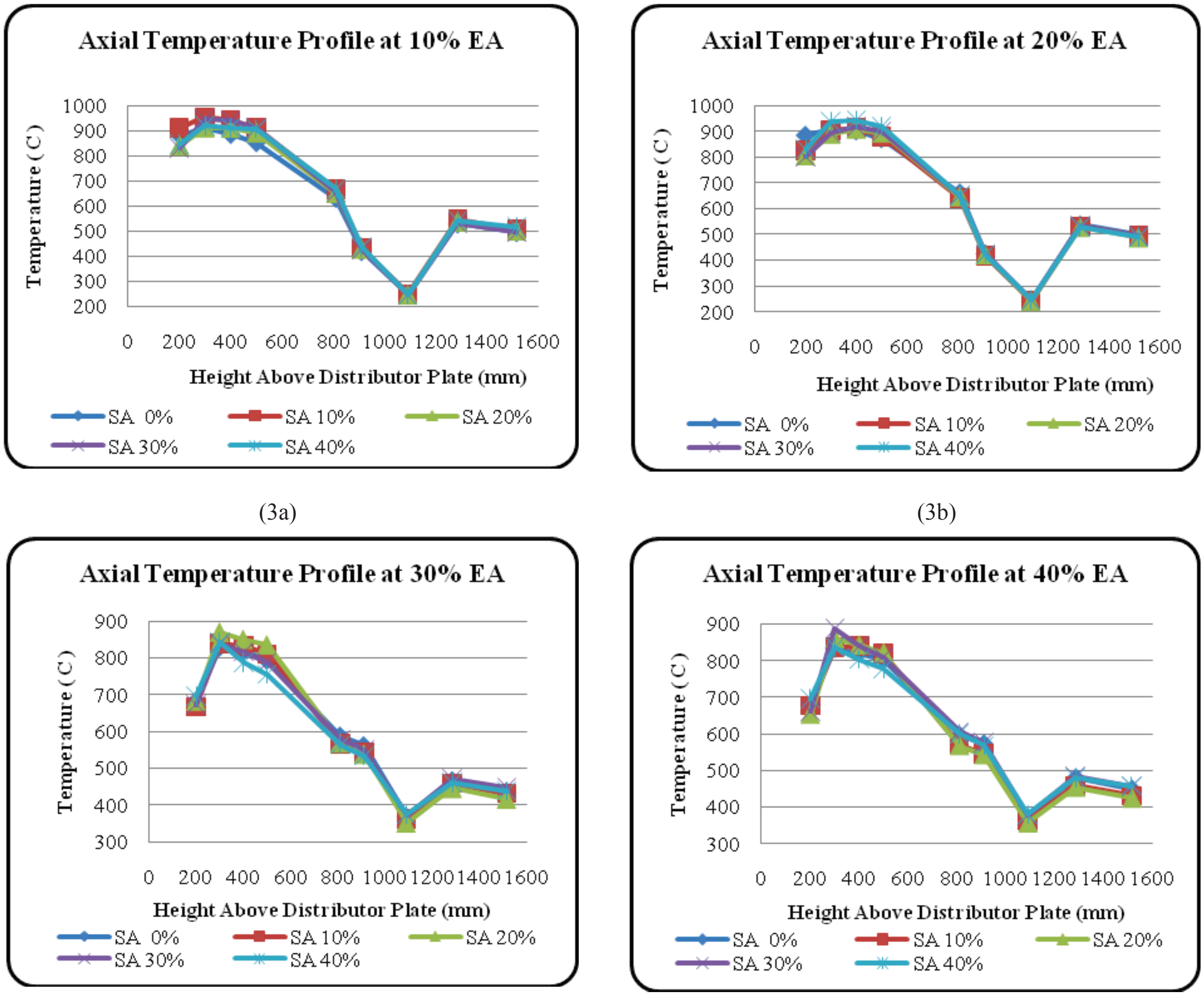
For palm shell, CO concentration tends to decrease except for EA 20%. However, for palm fiber, the CO concentration decreases considerably were observed with increasing excess air level. A higher stoichiometry with increasing excess air level provides additional oxygen to improve oxidation rate of CO to CO_2, hence the reduction in CO emission.

Concentrations of CO for palm shell are lower than palm fiber. This is caused by higher temperature distribution and oxygen composition in palm shell higher than in palm fiber. Hence the lifetime of palm shells is longer than palm fiber for completing combustion.

CO_2 Emission

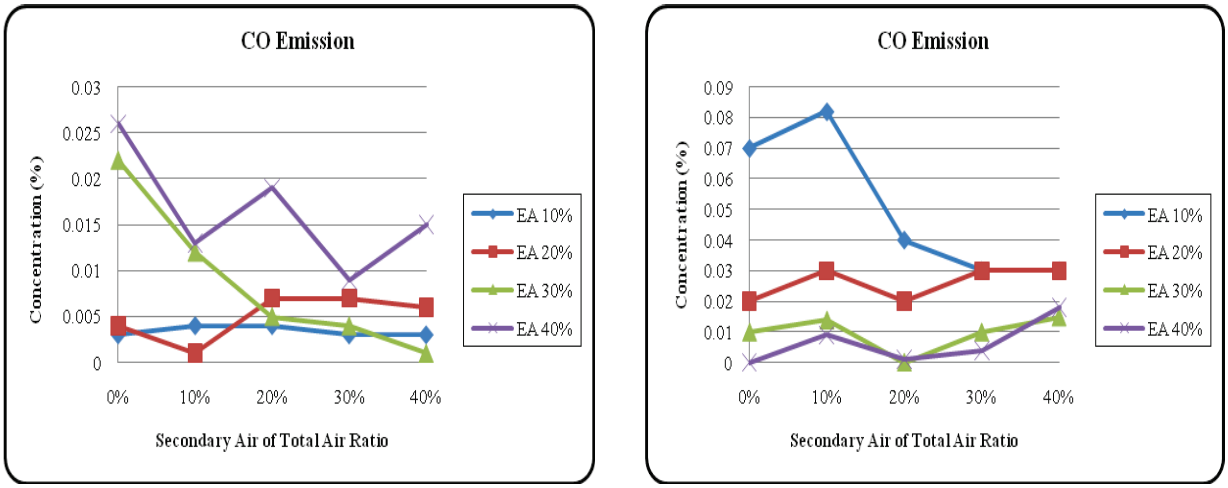
Reduction in CO concentration with increasing secondary air ratio, which is mainly due to oxidation of CO to CO_2. Therefore, CO_2 concentration tends to increase while CO concentration decreases as shown in Fig. 5. It can be seen that the concentration of CO_2 for palm shell is lower than palm fiber affected by CO concentration of palm shell are lower than palm fiber.

However, air staging has some effects where CO_2 concentration of palm shell decrease to a maximum of 50% (on SA 10%), and CO_2 concentration of palm fiber decrease to a maximum of 38% (on SA 10%).



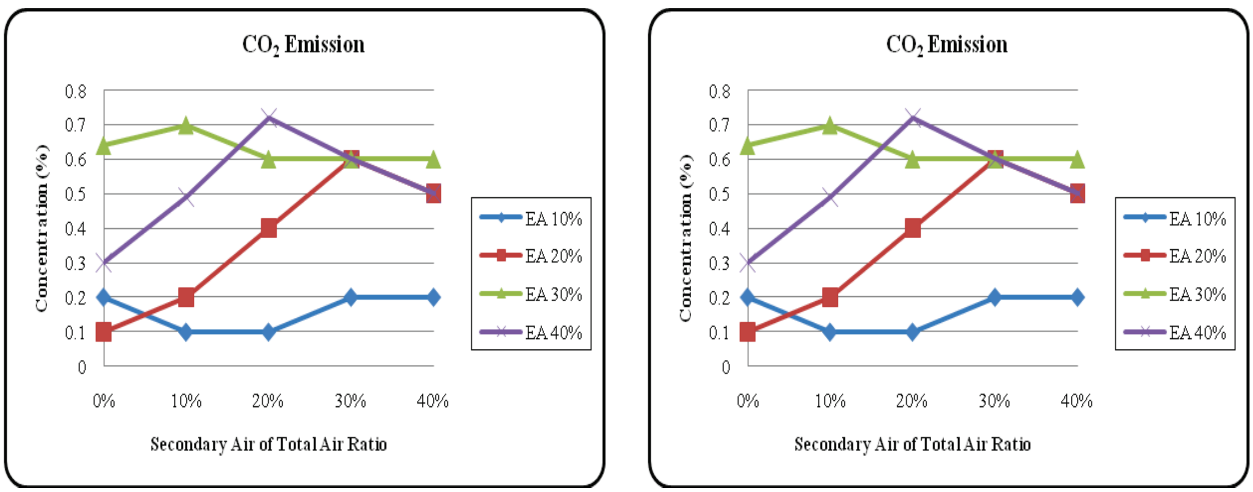
(3a) (3b) (3c) (3d)

FIGURE 3. Effect of excess air and secondary air to total air ratio on the axial temperature distributions of palm fiber at EA = 10% (a), EA = 20% (b), EA = 30%, (c), EA = 40% (d).



(4a) (4b)

FIGURE 4. Effect of secondary air on CO emission for palm shell (PS) (a), and for palm fiber (PF) (b)



(5a) (5b)

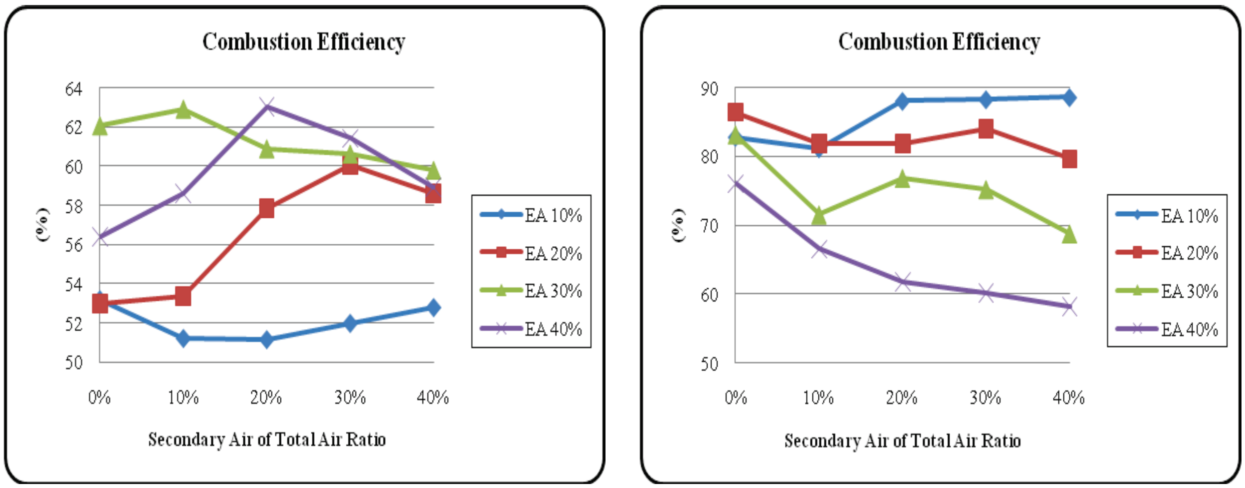
FIGURE 5. Effect of secondary air on CO_2 emission for palm shell (PS) (a), and for palm fiber (PF) (b)

Combustion Efficiencies

The combustion efficiencies are shown in Fig. 6 as a function of secondary air ratio and excess air level respectively. The gain in combustion efficiency was mainly attributed to the unburned carbons or volatiles which can be completely consumed during the secondary addition. With staged operation the fluidization velocity decreases since an amount of air was introduced in the freeboard. Consequently, char comminuting (attrition and fragmentation) lessens as the bed becomes less turbulent. Moreover, a lower percentage of particulates with terminal velocities which is less than the fluidization velocity will be entrained out of the bed. With further increase in secondary air ratio, combustion efficiency reaches a maximum and then declines, as shown in those Figures. Besides that, bed temperature is also a factor affecting the combustion efficiency. Higher secondary air ratio means lower bed temperature. Decreasing the temperature will lead to a reduction in combustion efficiency.

From the results of our experiments, for palm shell, increasing the degree of air staging has the effect of increasing the combustion efficiency, as shown in Fig. 6. The maximum combustion efficiency for palm shell is 63% and for palm fiber is 88%. With the staged operation, the rate of char burning decreases due to the lower concentration of oxygen in the bottom zone, and then, char concentration in the bed builds up. Consequently, the rate of char comminuting increases hence producing a higher rate of elutriated particulates. Hence, reduction in the combustion efficiency was observed. Moreover, the combustion efficiency decreases with lowering bed temperature as reactivity of char burning turns out to be lower.

The excess air level has a large influence on combustion efficiency when the fly ash is not recycled. Incomplete burning of the fuels will produce carbon monoxides and cause the efficiency of combustion to decrease. Supplying excess air to the combustor can solve this problem, as shown in Fig. 6 for palm shell. In addition, the higher fluidizing velocity causes the turbulence of the bed to increase and result in better mixing between fuels and the media in the bed. Therefore, it can improve combustion efficiency.



(6a) (6b)

FIGURE 6. Effect of secondary air on combustion efficiency for palm shell (PS) (a) and for palm fiber (PF) (b)

Conversely, with palm fiber in Fig. 6, the negative impact of excess air level on combustion efficiency is evident in these plots. Adding excess air causes the efficiency of combustion to decrease. It could probably occur due to fly ash content. Whereas fly ash content of palm fiber is higher than palm shell. The increase of excess air level also results in higher fluidizing velocity, thus enhances the elutriation of unburned fuels and reduces combustion efficiency. Excess air also decreases the overall flame temperature, and this consequence contributes to a loss in thermal efficiency.

CONCLUSIONS

Based on the experimental results, some conclusion can be drawn as follows:

- The axial temperature profiles decrease successively along the FBC height.
- Temperature distributions of palm shell are higher than temperature distribution of palm fiber.
- The palm shell gives the lower number of CO and CO_2 concentration than palm fiber.
- CO_2 concentration of palm shell decreases to a maximum of 50% and of palm fiber decrease to a maximum of 38%.
- Palm wastes combustion gives a significant contribution to the agreement of reduction of their greenhouse gas emissions (CO_2 emission).
- The combustion efficiency of palm shell is lower (63%) than palm fiber (88%).

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REFERENCES

1. ARRPEEC II Team. Energy, Environment and Climate Change Issues: Thailand. (*Asian Institute of Technology*, ISBN 974-241-715-6 2002).
2. R. Sims. Climate Change Solutions from Biomass, Bioenergy and Biomaterials. Agricultural Engineering International: (*The CIGR Journal of Scientific Research and Development*, September 2003), Vol. V.
3. R. Saidura, E.A. Abdelaziza, A. Demirbasb, M.S. Hossaina, S. Mekhilefc. A review on biomass as a fuel for boilers. (*Renewable and Sustainable Energy Reviews*, 15, 2011), pp. 2262-2289.
4. European Commission - Directorate General Environment. Refuse Derived Fuel, Current Practice and Perspectives (B4-3040/2000/306517/MAR/E3). (*Final Report WRc Ref: CO5087-4*, July 2003).
5. Wahlund, B. Rational Bioenergy Utilisation in Energy Systems and Impacts on CO_2 Emissions, Doctoral Thesis, *Department of Chemical Engineering and Technology, Royal Institute of Technology*: Stockholm, (2003).
6. Nussbaumer, T. Combustion and Co-combustion of Biomass: Fundamentals, Technologies, and Primary Measures for Emission Reduction. (*Energy & Fuels,* 17, 2003), pp.1510-1521.
7. Webster, T.; S. Drennan. Low NOx Combustion of Biomass Fluels. Coen Company, Inc. http://www.coen.com/Ihmtl/white_lownoxbiom.hmtl.
8. C. Casaca; M. Costa. NOx Control through Reburning using Biomass in a Laboratory Furnace: Effect of Particle Size. (*Proceedings of the Combustion Institute*, 32, 2009), pp. 2641-2648.
9. Vladimir I. Kuprianov, Rachadaporn Kaewklum, Kasama Sirisomboon, Porametr Arromdee, Songpol Chakritthakul. Combustion and emission characteristics of a swirling fluidized-bed, combustor burning moisturized rice husk. (*Applied Energy*, 87, 2010), pp. 2899-2906.
10. T. Madhiyanon, P. Sathitruangsak, S. Soponronnarit. Combustion characteristics of rice-husk in a short-combustion-chamber fluidized-bed combustor (SFBC). (*Applied Thermal Engineering*, 30, 2010), pp. 347-353.
11. Prasertsan, S; Prasertsan, P. Biomass Residues from Palm Oil Mills in Thailand: An Overview on Quantity and Potential Usage. (*Biomass and Bioenergy* 11(5), 1996), pp. 387-395.
12. Teoh Cheng Hai. The Palm Oil Industri in Malaysia. From Seed to Frying Pan. Prepare for WWF Switzerland. (*WWF Malaysia*, November 2002).
13. Barlow, C.; Zen, Z.; Gondowarsito, R. The Indonesian Oil Palm Industry. (*International Oil Palm Study Group* 2003).
14. Mckendry Peter. Energy Production from Biomass (part 3) Gasification Technologies. (*Journal of Bioresource Technology*, 83, 2002), pp.55-63.
15. Armesto, L.; Boerrigter, H.; Bahillo, A.; Otero, J. N2O Emissions from Fluidised Bed Combustion. The Effect of Fuel Characteristics and Operating Conditions, (*Fuel,* 82, 2003), pp. 1845–1850.
16. Fabrizio Scala and Riccardo Chirone. Fluidized bed combustion of alternative solid fuels. (*Experimental Thermal and Fluid Science* 28(7), 2004), pp. 691-699.
17. Rosyida Permatasari; Kang Kin Hui; Mohd. Ja'afar, M. N. Combustion Characteristics of Palm Wastes in Fluidized Bed Combustion. (*International Conference on Environment and Electrical Enginering*: Karpacz, Poland, 2009), Paper 82.
18. Fabrizio Scala; Piero Salatino. Modeling Fluidized Bed Combustion of High Volatile Solid Fuel. (*Chemical Engineering Science*, 57, 2002), pp. 1175-1196.
19. Mohd. Rozainee Taib; Sin Yang Lim; Simon Yat Seong Looi. Palm Wastes Combustion in Bubbling Fluidized Bed. (*Regional Symposium on Chemical Engineering (RSCE)*: Petaling Jaya Selangor, Malaysia, October 28-30, 2002).
20. Kaewklum, R.; Kuprianov, V.I.; Janvijitsakul, K.; Permchart. Influence of Fuel Moisture and Excess Air on Formation and Reduction of CO and NOx in a Fluidized-bed Combustor Fired with Thai Rice Husk. (*Asian Journal of Energy & Environment*, 8(1-2), 2007), pp. 97-115.