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COMBUSTION OF 'AS RECEIVED' PALM KERNEL SHELL IN A BUBBLING FLUIDIZED BED COMBUSTOR

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ABSTRACT

Low cost and minimum emission of green house gases are two of the key advantages of using agricultural wastes as fuel in a bubbling fluidized bed combustor; however this advantage could be neutralized if significant cost and energy is spent on processing prior to usage of the waste, therefore if processing stage could be circumvented without compromising effectiveness and efficiency, a substantial operational cost saving could be achieved when using biomass as fuel in a commercial scale bubbling fluidized bed combustor (BFBC). This research focus on use of 'as received' Palm kernel shell (PKS) in an experimental model bubbling fluidized bed combustor (BFBC). PKS feedstock received from the farm were combusted in several experiments in a 150mm diameter experimental model BFBC. The effect of large particle size feedstock of the 'as-received'(4-22mm) on thermal profile and emission characteristics during the combustion process were examined. Operational challenges such as fuel feeding, start-up and de-fluidization is examined and compare to situation when pulverized biomass is used. An electronic based inert bed temperature regulating unit ensure that the bed temperature is maintained at the pre-set value of 750^oC in all the experiments. It was noted that combustion and emission characteristics with 'as received' PKS compare favourably with that of pulverized, however it was discovered that for specific feed rate(f_d) and fluidizing air velocity(V_o) the frequency at which the inert bed temperature regulating unit cut-off is higher for the 'as received'. The results indicate that PKS sample obtainable from Nigeria farms could be fired directly to generate energy in bubbling fluidized bed combustor.

INTRODUCTION

Nigeria in view of its immense agricultural land size of about 71.9million hectares possessed enormous biomass potential, about 37% of Nigeria energy demands comes from use of biomass[1]. It is particularly popular among the rural dwellers and small section of urban populace who generally employ method of open air burning of the biomass as a route to extracting thermal energy; this has been proved to be, not only inefficient but detrimental to health of the people. Apart from firewood which is extensively employed for this purpose other agricultural and silvicultural wastes like Coconut shell, Oil palm solid wastes, cassava sticks, maize stems etc, are generally left wasted in the farm. One of the key agricultural crops in Nigeria is palm tree. It is found predominantly in southern Nigeria especially in the wet rain forests and savannah belt. It also exists in the wet parts of North central Nigeria, in areas like Southern Kaduna, Kogi, Kwara, Benue, Niger, Plateau, Taraba and Nasarawa States as well as the Federal Capital Territory (FCT) [2]. Solid waste from palm tree comprises of empty fruit branches (EFB), palm press fibres (PPF) and palm kernel shell (PKS) this waste collectively account for 48% of the original palm fruit branches, PKS alone account for 8% [3]. In Nigeria virtually every part of this wonder tree is traditionally useful for one thing or the other, however PKS is not been maximally utilized, only an insignificant portion of it is used for cooking or domestic processing vast majority of it is left unused in the farm creating environmental nuisance, since it could not rot and is useless for agricultural cultivation. Considering about 2.5million hectares of palm trees cultivated yearly [2], a huge quantity of PKS and other palm waste components which could otherwise be used for energy generation is wasted, a huge loss considering the aggregate energy generation possible if such biomass could be fired with appropriate technology.

NOMENCLATURE

BFBC		Bubbling Fluidized Bed Combustor
FBC		Fluidized Bed Combustion.
PKS		Palm Kernel Shell
ITRU		Inert bed temperature regulating unit
EA	%	Degree of excess air
CE	%	Combustion efficiency
CO		Carbon monoxide
V_o	[m/s]	fluidizing air approach velocity
f_d	[kg/hr]	Biomass feed rate

T_b	(K)	inert bed temperature

Greek Letters

Φ	(m)	BFBC internal diameter

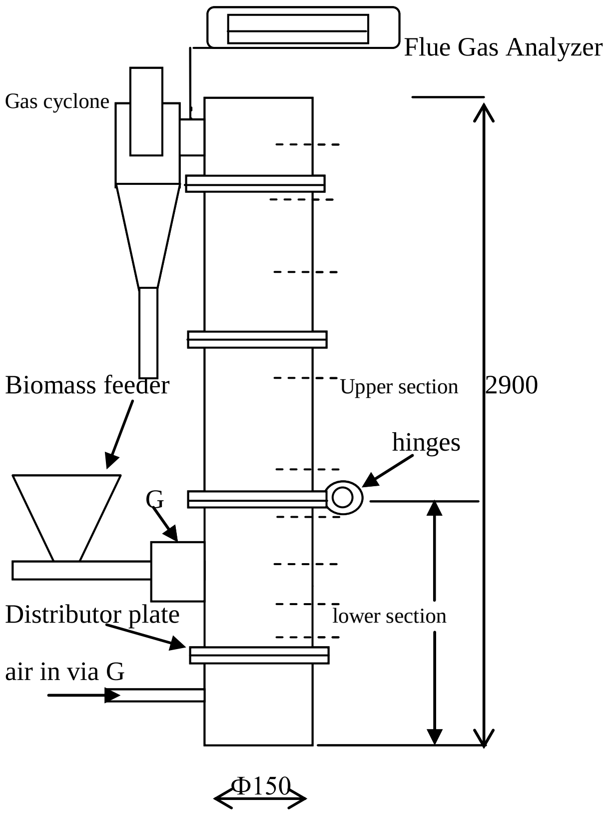
The potential of agricultural waste as fuel for energy generation has been investigated by many researchers. [4] investigated the effect of secondary air injection on combustion efficiency of sawdust in a BFBC with an enlarged disengagement section, maximum combustion efficiency of 99.2% efficiency was observed at 65% excess air. [3] examined the characteristics of palm waste when combusted in BFBC with modularly constructed combustion body of diameter 150mm. The study showed that oil palm waste could be burnt successfully in a BFBC, it was discovered that the relationship between excess air and combustion efficiency is such that CE increases with EA reach a maximum value for the particular feed rate then starts to fall this was explained with the fact that beyond the maximum point the EA promotes higher elutriation of unburnt fuels particle. A maximum CE of 92.47 was achieved at 50% excess air. [5] reported that the use of air staging is beneficial to reduction of CO emission when palm waste is combusted in a BFBC, a maximum combustion efficiency of 89% was achieved for palm fiber. Despite mirage of issue associated with use of agricultural waste as source of fuel for energy generation, it is still considered a credible alternative to use of fossil fuel; it has actually been rated higher than several other renewable energy sources firstly since the conversion technology already in existence for coal could be used for biomass without major alteration and secondly for the disproportionately low cost of as received agricultural wastes. However experiments had shown that pre-processing of agricultural waste such as PKS principally via reduction in size might be imperative to minimize operational problems such as the biomass feeding and enhance combustion characteristics; however such pre-processing will impose additional step hence additional technical complication and definitely cost which could potentially render use of the waste vis a viz use of coal uncompetitive.

The objectives of this investigation is to examined the use of unprocessed as-received PKS as fuel in BFBC and to identify major problems that could accompany its use as a source of renewable energy generation.

EXPERIMENTAL STUDIES.

APPARATUS

The experimental model BFBC employed in this article has been properly described in another technical papers[6,7]; it consist of five 150mm diameter stainless steel modules partitioned into lower and upper section, modules 1 & 2 forms the lower section while the remainder fully assembled form the upper section. See fig 1. The objective of the partitioning is to enable observation of the fluidization process and the combustion process at start up or anytime necessary. The distributor plate which is sandwiched between module 1 & 2 is fabricated from 10mm thick stainless steel plate bearing 13 standpipies. Each pipe has forty 1.5mm holes drilled radially around it. Silica sand mean diameter of 500micron is employed as the inert bed material. Supply of the test fuel from the hopper to the inert bed is done with a conveyor-screw type biomass feeder equipped with an infinitely variable speed gear motor. At the junction between biomass feeding pipe and the combustor body a fluidizing air pre-heater / biomass feeding pipe's cooling attachment is provided; firstly, to prevent the biomass from burning before entering the fluidized bed and secondly, to utilize the heat energy that would otherwise be wasted and consequently cut down the fuel usage per useful energy generated, this unit is shown as G in fig 1. The BFBC is also equipped with an inert bed temperature regulating unit (ITRU), which enable the capability to fix the inert bed temperature to any specific value during the experimental runs. ITRU performs this function by switching on and off the biomass feeder and or the centrifugal blower as soon as the preset T_b is achieved. The frequency of switching is an indications of the intensity of combustion taking place within the inert bed; the higher the intensity the higher the frequency.



-----	nine thermocouples (T1 – T9) arranged axially along the combustor body.
G	Fluidizing air pre-heater/Biomass feeding pipe's cooling attachment.

Lower section is module 1& 2
Upper section is module 3, 4& 5

Figure 1: Schematic drawing of the developed BFBC.

THE FUEL

Three different sizes of PKS were employed in the investigation;

Size A: As-Received (6-22)mm
Size B: Grinded and classified by sieve (2mm-6mm)
Size C: (<2mm) was obtained from As-received via pulverization.

Proximate analysis of the PKS sample evaluated from laboratory analysis (Table 1) and the corresponding ultimate analysis obtained from correlation [8] is shown in Table 2.


(a)


(b)


(c)

Figure 2: A view of the sizes of PKS employed in the experimental studies, (a) Size A –'As received': 6-22mm
b) Size B: 2mm-6mm (c)Size C – Pulverized : <2mm

Table1: Proximate analysis (% by mass on dry basis,)

Items	PKS
Fixed carbon	11.79
Volatile matter	79.60
Moisture	6.93
Ash	1.68

Table2: Ultimate Analysis and HHV using correlation [8],[9] (% by mass on dry basis)

Elements	PKS
Carbon	43.73
Hydrogen	5.55
Oxygen	41.50
Nitrogen	NIL
Sulphur	NIL
Ash	1.68
NCV KJ/kg	16.53

The setting of biomass feeder for equivalent feed rate of the particles sizes were established prior to the investigation, no operational problem was found with feeding of PKS sizes.

EXPERIMENTATION.

With the control switched on, fluidization air via the centrifugal blower was tuned to achieve a mildly bubbling inert bed condition; at this point propane gas passed through 8mm diameter stainless steel pipe located 10mm above the distributor plate was switched on and ignited; allowing the inert bed temperature (T_b) to rise to 600^{o}c, this took about 29minutes. PKS was fed in via the screw feeder; for each sizes A, B and C three different runs at different degree of excess air (EA) were conducted. The composition of the flue gas (CO, CO_2, NO_x, SO_x), Excess air (EA) as well as Combustion efficiency (CE) were monitored using BACARACH PCA 3 flue gas analyser connected to a port located before cyclone separator inlet; temperatures were taken from nine zones located along the combustor height via Type K thermocouples fitted to the first 8 zones and in-built temperature sensors of the BACARACH PCA 3 records the temperature in the ninth zone. The thermocouple for zone 2, inert bed upper region was connected to the ITRU and this temperature 'T2 or T_b' in all the experimental runs was maintained at 750^{o}C this temperature is taken by the thermocouple located 20cm above the distributor plate. T1,T2,T3,T4,T5,T6,T7,T8, and T9 are located 10cm, 20cm,

35cm, 80cm, 120cm, 160cm, 200cm, 240cm and 260cm respectively above the distributor plate.
The results of the experimental runs for different particle sizes are shown on table 3.

RESULTS AND DISCUSSION

For each of the fuel sizes, experimental runs were conducted at three EA (30%, 50% and 100%). From the results (Table 3) a plot (temperature profile) of the temperature against the zones arranged axially along the combustor height was plotted for comparison.

Emission value obtained were converted to emission value at 6% of oxygen in the flue gas, and plotted against the percentage of EA.

Table 3: Results of the experimental runs, note that T2 =T_b

	Size A (4-22mm)			Size C (< 2mm)			Size B (2-6mm)		
RUN	1	2	3	4	5	6	7	8	9
EA	30%	50%	101%	29%	50%	100%	30%	50%	102%
Temp	Deg. C	Deg. C	Deg. C	Deg. C	Deg. C	Deg. C	Deg. C	Deg. C	Deg. C
T1	654	655	662	480	405	302	576	652	550
T2	750	750	750	750	690	602	750	750	720
T3	724	705	730	805	743	705	805	679	805
T4	504	502	523	722	621	510	640	586	651
T5	478	461	436	620	546	489	643	579	592
T6	448	436	404	542	489	401	582	526	570
T7	412	386	363	455	405	332	551	510	516
T8	357	344	332	334	321	287	491	463	491
T9	237	173	241	220	214	207	284	439	402
CE	81	83.7	79.9	82.2	81.7	79.6	78.4	77.7	68.2
CO(6)	3250	760	91	2995	570	74	3057	856	104
CO2(6)	15.7	13.2	10	15.8	13.7	10.5	15.4	13.5	10
NO(6)	72	95	175	67	78	80	106	137	275
O2	4.8	7.4	10.3	4.7	6.8	10.1	5.2	7	10.7
SO(6)	301	93	54	279	271	145	22	10	5

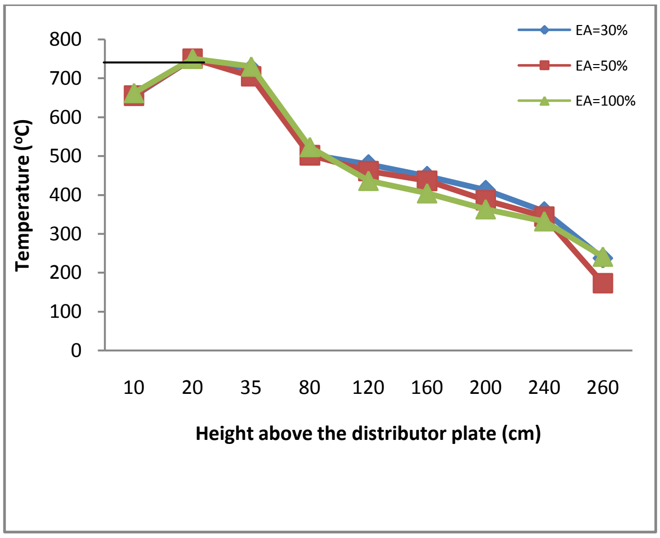


Figure 2: Temperature profile for combustion of 'as-received' PKS at different percentage of excess air

Temperature profile for SIZE A is shown in fig 2. It was observed that the frequency at which ITRU activate /deactivate the biomass feeder and the centrifugal blower is higher for this particle size. The rate was highest about 5 times per minute with EA=30%, and lowest (about 2 times per minute) with EA=101%, as stated earlier this is an indication of intensity of combustion in the inert bed furthermore it was noted that preset T_b of 750C was maintained at all EA examined when SIZE A was burnt.

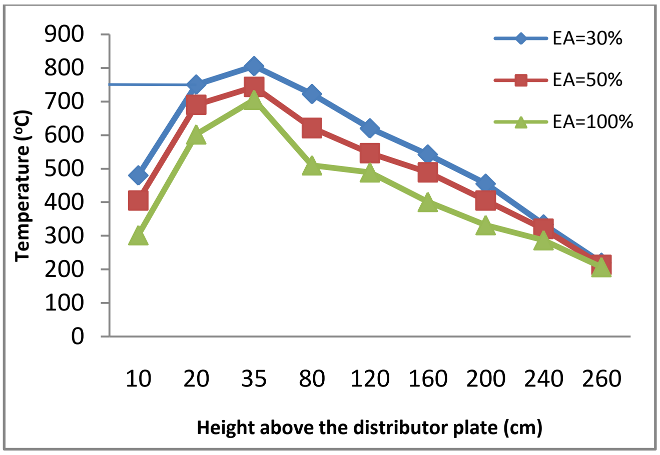


Figure 3 : Temperature profile for the combustion of Size C (pulverized) at different percentage of EA.

For SIZE C (Figure 3) revealed higher freeboard temperature but lower inert bed temperature (T1 and T_b). It was observed that the value of T1 and T2 decreased as EA increases. With EA> 30% the ITRU did not switched off; which indicate that heat generation from combustion of fuel in the inert bed was not enough to achieve preset T_b. At EA= 50% temperature in all the zones started dropping and the investigation was stopped to re-start the BFBC via infusion of propane gas. A possible explanation for this is that the SIZE C (<2mm) is too light and since over-bed feeding of the fuel was employed, when EA> 30% the particles being light a significant percentage of it are easily blown to the freeboard region, this give rise to two actions simultaneously. Firstly, the fuel supply to the inert bed gradually stopped thereby terminating the char oxidation in this region resulting in a lower bed (T1 and T_b). Secondly, the particles at the freeboard region de-volatilized and burn therefore the higher freeboard temperature. At high percentage of EA, the combustion process practically stopped in the inert bed. At this point the fluidizing air merely fluidized and cool the bed hence the rapid drop in temperature observed at EA=101%.

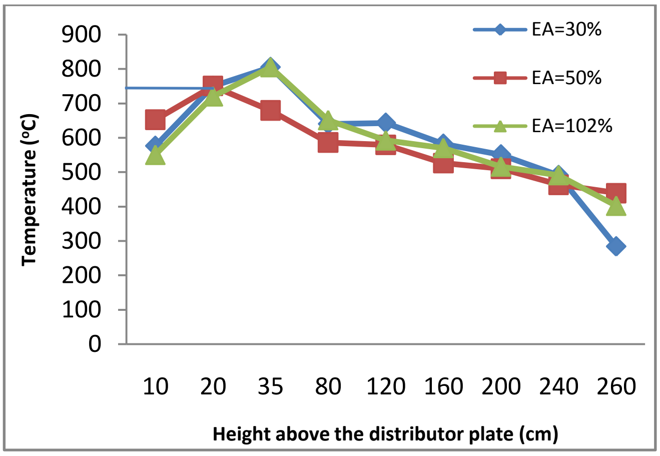


Figure 4: Temperature profile for combustion of SIZE B at different percentage of excess air

The temperature profile for SIZE B (fig 4) indicates a characteristics that lies between the Size A and Size C. The combustion of B was noted stable until higher EA was employed; at this point combustion characteristics observed was similar to that of pulverized, for instance for EA= 100%, ITRU did not switched off at all and temperature dropped to 720^{o}C where it remained constant. This signifies reduced rate of combustion within the inert bed.

Figures 4 and 5 provide a clearer picture of the difference in the combustion characteristics of the fuel sizes. It should be noted that SIZE A is bigger and heavy therefore it falls inside the bubbling bed where it gradually burn. At all percentage of EA, most of SIZE A's fixed carbon and fraction of its volatile burn within the bubbling bed thereby ensuring T_b is maintained at the preset value of 750^{o}C without any problem. SIZE C on the other hand is the is so light and most of it is blown to the freeboard zone where it burnt hence higher freeboard temperature (fig 4). At higher EA however insufficient quantities of the SIZE C get to the inert bed thereby stopping the combustion process resulting in rapid drop of temperature as revealed in Figure 6.

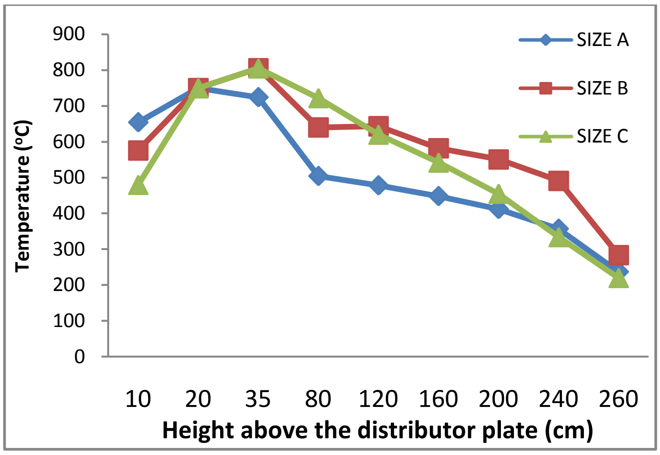


Figure 5: A comparison of the temperature profile for all the particle size at EA=30%

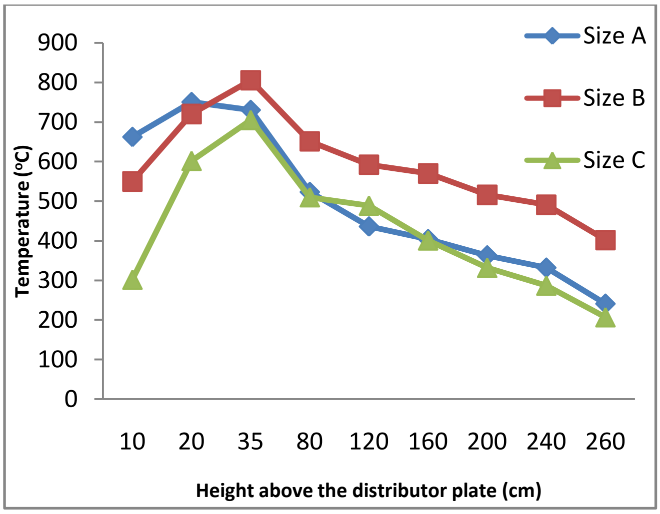


Figure 6: A comparison of the temperature profile for all the particle size at EA=100%

EMISSION CHARACTERIZATION.

Figure 7 show CO emission reading from the experimental runs. It should be noted that the present results follows similar pattern and compare favourably well with the work of [3,5] (not shown). In all cases CO emission was rather high at low value of EA, Highest CO reading of 3057PPM was obtained at EA=30% for SIZE B, a rapid lowering of CO was observed for all the sizes with increase in excess air. The value decreased at EA=50% to 760, 856 and 570ppm for A,B, and C respectively

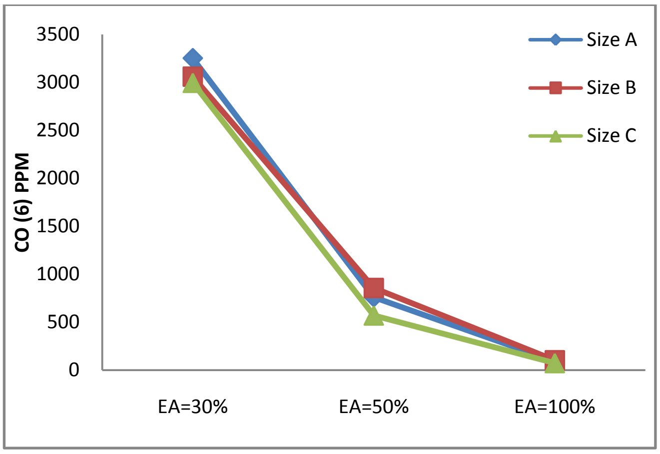


Figure 7:A plot of CO concentration at different degree of EA

NO_2 was not detected in the flue gas, NOx therefore represent value of NO in all the cases. NO_x emission for all the particle size was lowest at EA=30%. The value of NO_x from the graph suggest a significant influence of EA on the NOx formation; this is a typical fuel-NO formation route [10]. Similarly SO_2 was noted in significant quantities in the flue gas; the trends for all the particle sizes show that it reduced as EA increased (see Figure 9). The significant quantity of SO_X and presence of NO at a temperature far below threshold of thermal NO_x formation clearly confirmed presence of fuel Nitrogen and sulphur. While this was not unexpected, the present investigation clearly revealed a failure of the correlation [8] to comprehensively identify the elemental composition of biomass from proximate analysis and thereby confirmed its limitation.

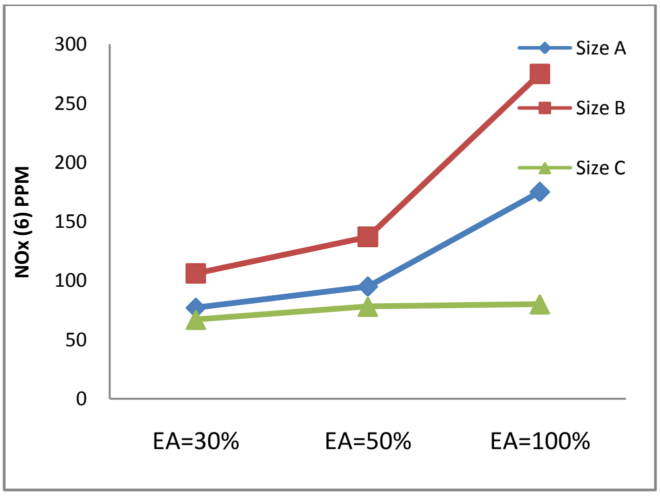


Figure 8: A plot of NO_x against the percentage excess air for each of the fuel particle size

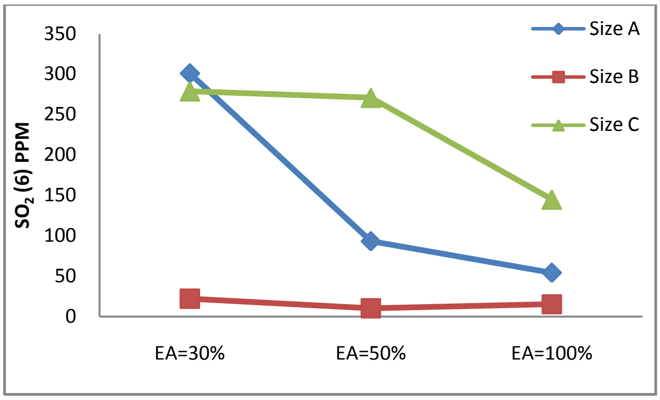


Figure 9: A plot of SO_2 against the percentage excess air for each of the fuel particle size

CONCLUSION

Combustion of three different sizes of Palm kernel shell has been carried out in an experimental model bubbling fluidized bed combustor

The results indicate that efficient and environmentally friendly combustion of Palm kernel shell could be achieved in a bubbling fluidized bed combustor, and that fuel particle size could have a pronounced effect on the inert bed temperature of the BFBC and combustion characteristics of this biomass.

It was found that Pulverized PKS could not be used in the BFBC for extended period at EA>50% since beyond this point the bed temperature drop continuously. On the other hand 'As received' PKS which is comparatively heavier, when fired over a wide range of EA gave a sustainable and efficient combustion.

The present results further suggest that, as shown in emission characteristics and thermal profile, Palm Kernel Shell obtainable from Nigeria farm may be used directly without any form of pre-processing to generate renewable energy in a Bubbling Fluidized Bed Combustor.

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