Effect of Particle Size on Combustion of Coconut Shell in a Bubbling Fluidized Bed Combustor

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ABSTRACT

Combustion characteristics of coconut shell (CS) samples in an experimental model bubbling fluidized bed combustor (BFBC) was investigated with special focus on effect of particle size of the CS. CS waste obtained from farm were crushed and classified into three sizes; Size X (12-50mm), SizeY (2-12mm) and Size Z (<2mm). For overbed feeding of the feedstock, the impact of the particle size on emission and combustion performance were examined. in a 150mm diameter experimental model BFBC. Throughout the investigation inert bed temperature was fixed to a constant value of 750 °C by means of electronic based inert bed temperature regulating unit (ITRU). Results showed that CS particle size have pronounced impact on combustion characteristics and the pollutants emission from the BFBC. It was observed that the Pollutants' emission was within acceptable limits for Size Y at about 310ppm for CO, <200PPM for NOx and almost zero for SOx. The results indicate that CS could be used as combustion feedstock for environmentally energy generation in a BFBC.

1.0 INTRODUCTION

At the rate at which research is being conducted on bio-energy in general and use of biomass as fuel for combined heat and power production in particular, it is pertinent that Nigeria act appropriately and rapidly in other not to be left behind. Nigeria with estimated annual biomass turn-over of 144 million tonnes (144 x 10^9)/year is abundantly blessed with biomass resources. Out of this 43.4 x 10^9 Kg of is consumed annually as fuel-wood [1], leaving huge quantities for cheap, renewable and sustainable energy generation. Apart from firewood which is extensively employed for domestic processes other agricultural and silvicultural wastes like Coconut shell, Oil palm solid wastes, cassava sticks, maize stems, animal waste etc, are generally left wasted in the farm.

One of Nigeria notable agricultural crops is coconut trees. It is estimated that the country have over two million coconut trees occupying about 13615hectares of land [2]. With potential to put additional1.2 million hectares of land under cultivation in different part of the country [3], a huge quantity of coconut wastes including CS will potentially be available as feedstock for renewable energy generation using appropriate conversion technology.

NOMENCLATURE

BFBC		Bubbling Fluidized Bed Combustor
FBC		Fluidized Bed Combustion.
PKS		Palm Kernel Shell
CS		Coconut shell
ITRU		Inert bed temperature regulating unit
EA	%	Excess air
CE	%	Combustion efficiency
CO	PPM	Carbon monoxide
CO(6)	PPM	CO reference to 6% oxygen in flue gas
V_o	[m/s]	fluidizing air approach velocity
V^o	[Nm^3/kg]	Theoretical volume of air needed for combustion
f_d	[kg/hr]	Biomass feed rate
LHV	KJ/kg	low heating value
T_b	(K)	inert bed temperature
q_{ic}	%	heat loss due to incomplete combustion
q_{uc}	%	heat loss due to unburned carbon
V_{dg}	Nm^3/kg	Volume of flue gas at 6% oxgen

Greek Letters

Φ	(m)	BFBC internal diameter
ρ_{ref}		Excess air coefficient

Burning of biomass for heat energy generation predate other conversion technology, it is the oldest and most successful method of generating energy known to man. The discovery of fossil fuel however relegate its use to the background. The issue of climate change due to emission of pollutants principally from combustion of fossil fuel and concerns over energy security due to depleting fossil fuel reserve has however heightened interest in use of biomass as a renewable and sustainable feedstock for heat and electrical energy generation. Several conversion technologies are available for firing biomass, however Bubbling fluidized bed combustor has been described as the most versatile and environmentally friendly method of harnessing energy from biomass

The potential of agricultural waste as fuel for energy generation in BFBC has been investigated by many researchers. [4] reported an efficient and sustainable combustion of pre-dried Thai sugar cane bagasse when fired in a conical FBC. The combustion efficiency was found to be in the range of 96 to 99.7% for firing the pre-dried bagasse in wide ranges of the operating conditions. [5] Investigated co-firing of eucalyptus bark and rubberwood sawdust in a conical bubbling fluidized bed combustor with axial flow swirler. It was reported that by maintaining excess air between 50% and 55%, the co-combustion of high-moisture eucalyptus bark and rubberwood sawdust in the proposed combustor occurs in a stable regime with high combustion efficiency of more than 99.6%. [6] examined the characteristics of palm waste in an experimental model BFBC. 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. [7] 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 fibre.

There is scarcity of literature on combustion of coconut shell in a bubbling fluidized combustor, hence the importance of the current study.

Coconut shell like many other biomass varies widely in composition this attribute in conjunction with low bulk density and inconsistence character are key disadvantages of biomass as a combustion feedstock, which essentially necessitate their pre- processing before usage. As much as could be tolerated, using biomass waste 'as received' or with minimal pre-processing could be beneficial on the long run in term of lowering operational cost and reducing step to generate renewable energy especially in commercial scale fluidized bed combustor.

The objective of this investigation is to examine thermal and emission characteristics of CS in a BFBC with special focus on impact of particle size.

2.0 EXPERIMENTAL STUDIES.

Apparatus

The experimental model BFBC employed in this article has been properly described in another technical papers [8,9]. 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 as well as to enable determination of the fuel feed rate and the bubbling regime at room temperature. 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, the feeder discharge is located 400mm above the distributor plate. 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.

To prevent excessive heat loss fibre glass insulation, thickness 75mm secured by means of 0.5mm galvanized steel plate was used to cover the combustor body from the distributor plate to the last module.

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 is designed to perform this function in three different modes:

i)by switching on and off the biomass feeder and or the centrifugal blower as soon as the preset T_b is achieved.

ii)by switching off only the biomass feeder, ensuring the centrifugal blower is constantly on during the experiment

iii)by switching off only the centrifugal blower, ensuring the biomass feeder is constantly on.

Investigations had shown that only i and ii are practicable and likely to yield reliable results. For consistency mode i was employed in all the experimental runs in this work.

The frequency of switching off and on of the ITRU is an indications of the intensity of combustion taking place within the inert bed; the higher the intensity the higher the frequency.

Pressure Measurement

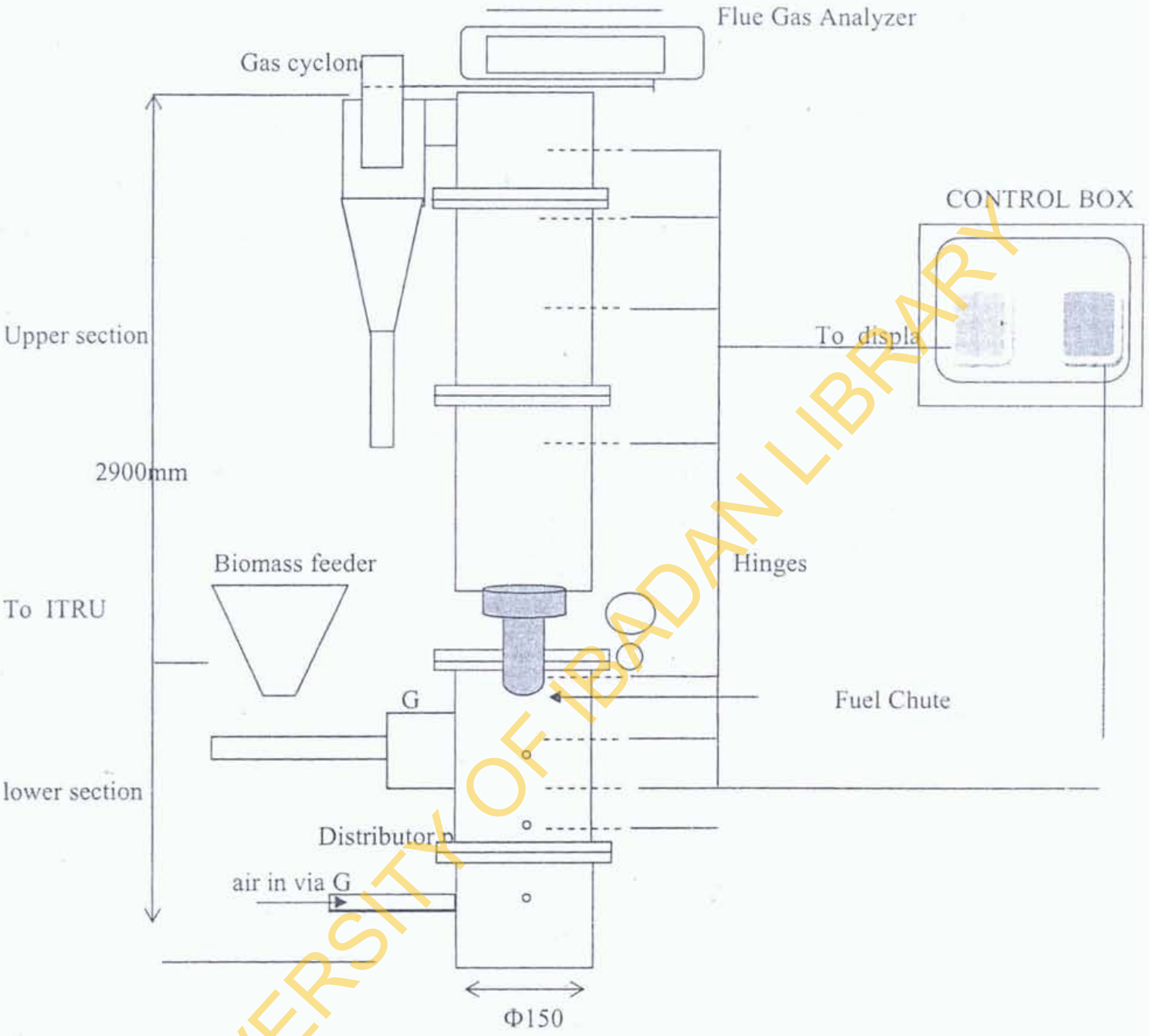
Pressure drop across the bed is a function of the fluidization air approach velocity, it therefore follows that the whole spectrum of the inert bed hydrodynamic behaviour could be monitored via adjustment of air velocity. In this experiment the pressure corresponding to different stages of inert bed (packed bed, incipient fluidization, bubbling stage, turbulent fluidization and transport condition were determined prior the experimental investigation. Four pressure taps were located along the combustor body, the first pressure tap located 60mm below the distributor plate was employed in determining the incipient, bubbling and turbulent regime.

With the upper section opened, the centrifugal blower was switched on. Air approach velocity (V_o) was gradually increased from zero using the gate valve. The appearance of the inert bed was monitored as the velocity and reading of the water manometer connected to the first tap increased. At 70mmH_2O vibration of the bed/small movement of bed particles was observed. With further increase the pressure actually dropped to 69H_20. Further increased small occasional bubbling was noticed obtained and this transits to full scale bubbling at reading beyond 70mmH_20. The chaotic movements get increasingly vigorous with higher pressure reading. These pressure readings was noted and on closing the upper section, this reading was used as the basic minimum setting to ensure the bed is in full scale bubbling regime at elevated temperature.

Biomass Feeding.

For this experiment, a major modification was made to the biomass supply to the inert bed primarily because of size of particles especially, Size X, which are too large for the biomass feeder.

A manual fuel feeding chute was welded to the combustor body. The port, inclined at an angle 85° to the horizontal was fabricated from 60mm diameter, 5mm thick stainless steel, welded to a location 450mm above the distributor



----- nine thermocouples (T1 – T9) arranged

axially along the combustor body.

G Fluidizing air pre-heater/Biomass

feeding pipe's cooling attachment.

○ Pressure Tap

Lower section is module 1& 2

Upper section is module 3, 4& 5

Figure 1: Schematic drawing of the developed BFBC.

plate. The attached port served two purposes as a means of viewing the bed surface directly and a batch loading chute of the biomass fuel. See Fig 1 and Fig 12. For consistency all the particles size were fed in via this method. For each size 4.5kg/hr was employed via division of the test size into 30 units. Each unit size (m=150g) is fed in at specific interval as shown in Table 1 below. This unit size is chosen to ensure compliance with percentage of fuel in the inert bed which should be between 2-10%[10].

Table 1: Batch-feeding of the Biomass

SN	Time(mins)	Qty (g)	CS1	CS2	CS3
1	0	150	150	150	150
2	2	150	150	150	150
3	4	150	150	150	150
.	-	-	-	-	-
.	-	-	-	-	-
.	-	-	-	-	-
27	54	150	150	150	150
28	56	150	150	150	150
29	58	150	150	150	150
30	60	4.5kg	4.5kg	4.5kg	4.5kg

3.0 OPERATING PROCEDURE

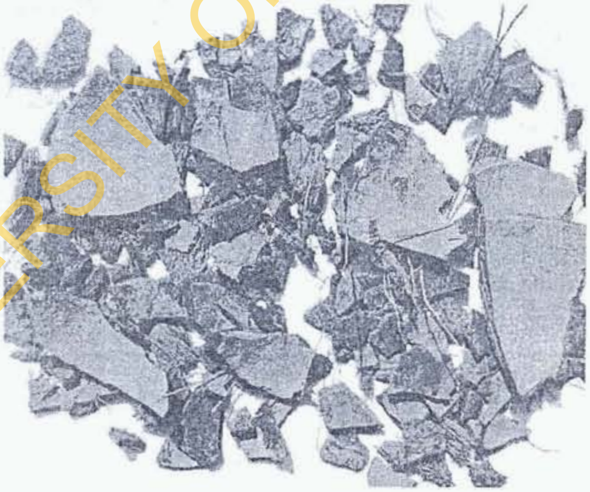
The Fuel

Coconut shell (CS) like other woody biomass is made up of cellulose, lignin, hemicelluloses (pentosan) and Ash [11]. Though a non-edible it has found numerous applications such as fuel for local minor processes. A number of potential uses has been proposed for it, such as raw material for activated carbon, in construction and decorative works, despite this however significant quantity CS is still left wasted in the farm hence the need to evaluate its potential as fuel for renewable energy generation.

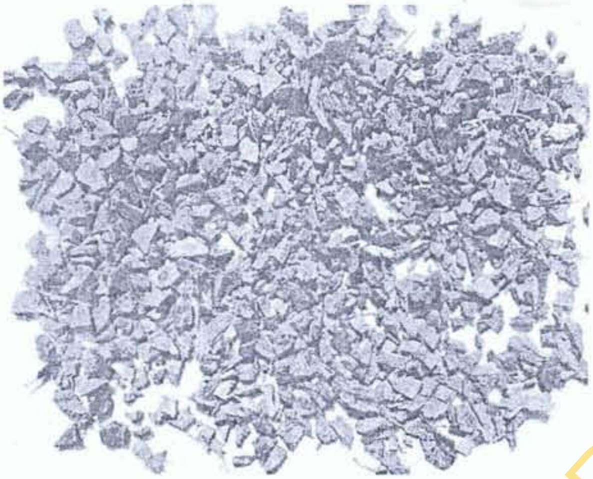
The methods of separating the CS from the edible endosperm generally leave a CS fragments resembling hollow plates with size ranging from 4 to 15cm depending on the original size of the coconut fruit. This fragments' size is too big for the biomass feeder of the experimental model BFBC and in fact bigger than what is recommended in literature for commercial scale BFBC (fuel particle size for BFBC<50mm). For the purpose of this investigation three sizes of CS were considered. See Figure 2.

Three different sizes of CS were employed in the investigation;

Size X: (12-50)mm
Size Y: (2mm-6mm)
Size Z: (<2mm)



(a)



(b)

(c)

Figure 2: A view of the sizes of CS employed in the experimental studies, (a) Size X: 12-50mm b) Size Y: 2mm-12mm (c)Size Z – Pulverized : <2mm

Typical Proximate and ultimate analysis of the CS sample is shown on Table 2.

Table2: Proximate analysis (% by mass dry basis,)

Items	CS[12]
Fixed carbon	6.69
Volatile matter	90.31
Ash	3.0

Table2: Ultimate Analysis and HHV, LHV [17] (% by mass dry basis)

Elements	CS[12]
Carbon	46.22
Hydrogen	5.2
Oxygen	41.63
Nitrogen	0.26
Sulphur	NIL
Ash	3.0
HHV KJ/kg	17408
LHV KJ/kg [17]	16232.6

4.0 EXPERIMENTATION.

With the control switched on, fluidization air via the centrifugal blower was tuned to achieve a vigorous bubbling inert bed condition (Manometer reading 74mmH2O); 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°c, this took about 29minutes. CS was fed in via feeding chute; for each sizes X, Y and Z three 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) were monitored using BACARACH PCA 3 flue gas analyser connected to a port located after 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 measurements accuracy of this equipment are: ±5% of reading or ± 10 ppm for CO in the range of 0-2000 ppm, ±10% for 2000-4000PPM.. ± 10% of Reading between 2001 to 4,000 ppm for NO and SO. 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 set to 750°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 the particle sizes are shown on table 3.

COMBUSTIONEFFICIENCYAND HEAT LOSSES

Using heat balance method combustion efficiency was estimated as [13]:

$$Q = 100-(q_{ic}+q_{uc}) \qquad (1)$$

According to [14],, q_{ic}, q_{uc} may be estimated as

$$q_{ic} = 126.4 \times 10^{-4} CO(6)\, V_{dg} \,/\, LHV \qquad (2)$$

$$q_{uc} = \frac{32866}{LHV} A \left(\frac{C_{fa}}{100-C_{fa}}\right) \qquad (3)$$

where, V_{dg} the theoretical (reference) volume of dry flue gas (Nm^3/kg, at 0°C and 1 atm is related to V^0 the theoretical volume of air (Nm^3/kg, at 0°C and 1 atm) requiredfor firing 1 kg biomass fuel under stoichiometric conditions as [13]:

$$V_{dg}(6\%) = 0.01866(C + 0.375S) + 0.79V^0 + 0.008N + (\rho_{ref} - 1)V^0 \qquad (4)$$

C_{fa} and A are the unburned carbon fraction in the flue gas and the fuel ash content respectively

For the current investigation the unburnt carbon contribution was neglected, and CE was estimated as:

$$CE = 100-q_{ic} \qquad (5)$$

5.0 RESULTS AND DISCUSSION

For each of the fuel sizes, experimental runs were conducted at three EA (20%, 60%, and 100%). For solid fuel combustion, literature had shown that optimum combustion characteristics should lie within this range of excess air [3],[4],[6]. Performance characteristics of each size was evaluated, based on axial temperature profile, the composition and value of emission in the flue gases. Emission values referenced to 6% oxygen the flue gas were plotted against the EA value.

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

	X(12-50mm)			Y (2-12mm)			Z (<2mm)		
RUN	1	2	3	4	5	6	7	8	9
EA	20%	60%	100%	20%	54%	105%	23%	64%	100%
Temp	Deg. C	Deg. C	Deg. C	Deg. C	Deg. C	Deg. C	Deg. C	Deg. C	Deg. C
10	720	722	775	691	709	710	698	675	620
20	750	750	750	750	750	750	750	750	740
35	723	735	726	805	718	721	717	735	691
80	624	639	602	586	584	673	665	671	561
120	639	678	575	498	531	608	614	605	510
160	554	588	524	488	481	536	552	516	465
200	515	535	490	428	448	490	509	462	442
240	448	475	447	398	413	443	455	422	402
260	308	279	211	262	265	278	269	267	253
CO(6)	>4000	3211	300	3810	311	350	>4000	3675	1201
CO2(6)	16.7	12.8	10.1	16.9	13.3	10	16.3	12.4	9.9
NO(6)	69	166	175	113	147	197	119	132	201
O2	3.8	7.8	10.6	3.7	7.3	10.7	4.2	8.3	10.5
SO(6)	689	323	11	279	2	0	344	263	56

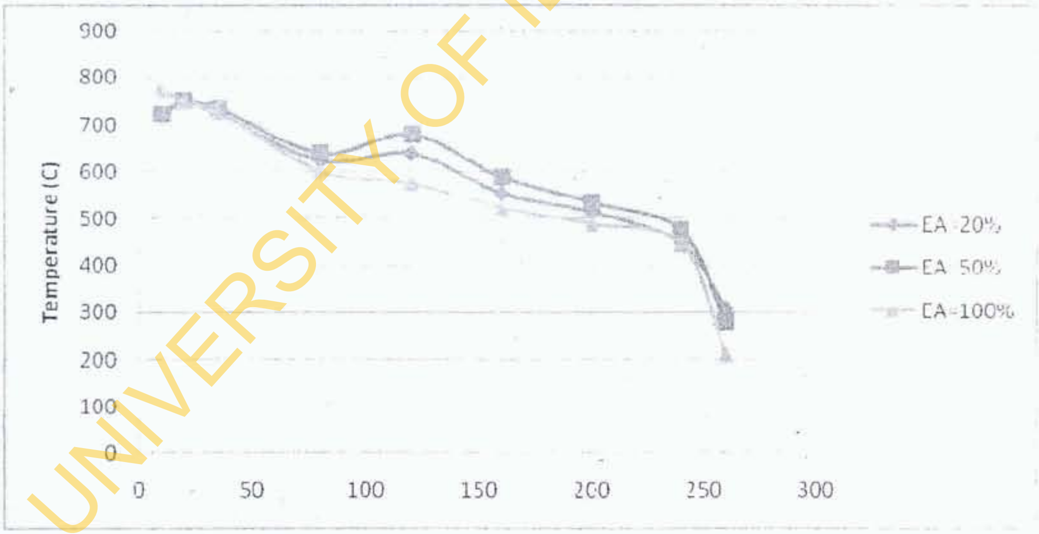


Figure 3: Temperature profile for combustion of particle size X at different percentage of excess air

Temperature profile for SIZE X is shown in fig 2. A sustained combustion was achieved when firing this size. The effect of excess air was rather mild, from Fig 3, the value of the temperature in all the zone appear quite close for all the EA. Higher T1 temperature noted for EA =100% could be attributed to increase heat transfer rate due to higher turbulence of the inert bed and burning char mixture at this EA. It was also observed that frequency of switching on and off of ITRU was noticeably higher for this size than for Z. but about the same for Y. This might be due to weight effect. The fact that X particle are comparatively heavier than both X and Z promote burning within the dense phase therefore higher combustion intensity. 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.

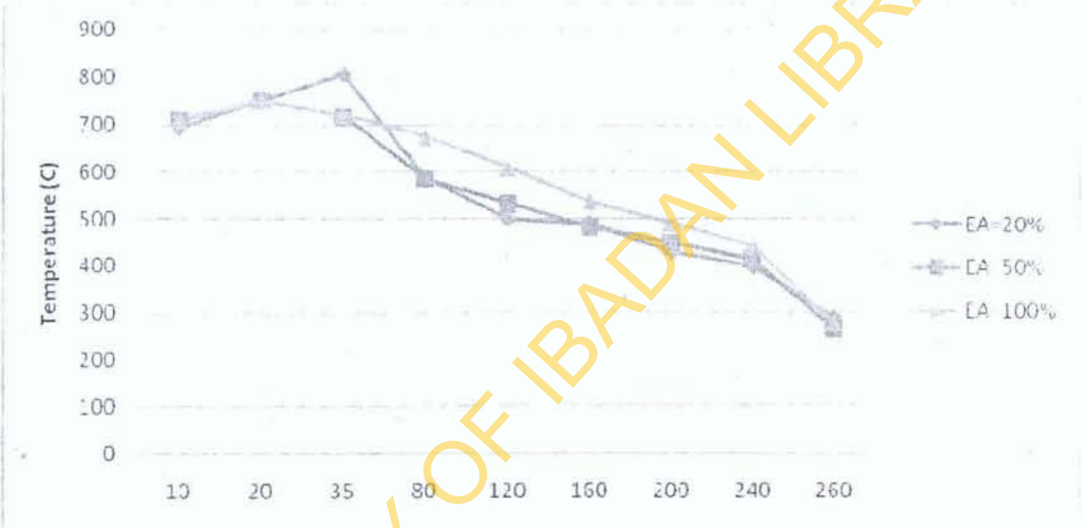


Figure 4: Temperature profile for combustion of Size Y at different percentage of excess air

Temperature profile for Y indicate that this particle size could be fired for sustainable energy generation in BFBC. At all EA stable combustion occur in the inert bed.

The frequency of switching on and off of the ITRU is as high as X, however the period of deactivation is shorter. These were not accurately measured in this experiment

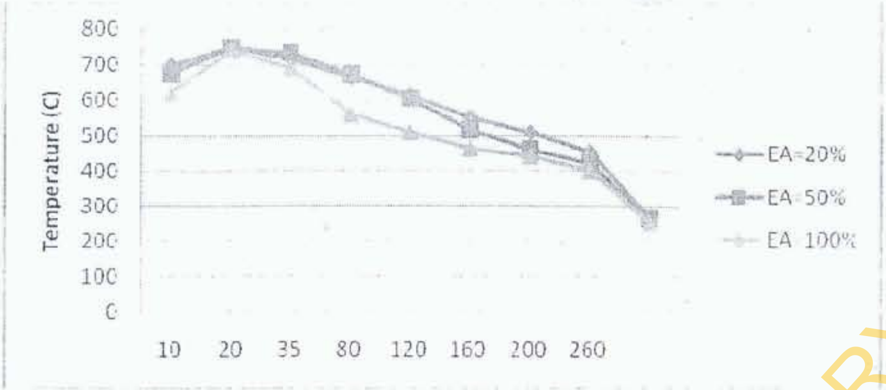


Figure 5 : Temperature profile for the combustion of Size Z (Fine particles) at different percentage of EA.

For particle Z, sustained combustion was obtained at lower EA (20% and 60%). Noticeable drop in temperature was observed within the inert bed region, for instance TI for this size was comparatively lower than for Y and Z. Also at EA = 100%, it was observed that the ITRU did not switched off and the temperature progressively drop to 740C. This is a confirmation of pronounced effect of the particle size. This also indicate that heat generation from combustion of fuel in the inert bed was not enough to achieve preset T_b. An explanation for this is that Z (<2mm) is too light and since over-bed feeding of the fuel was employed, as EA approaches 100% (increase fluidization velocity) 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 reduced thereby lower char oxidation in this region resulting in a lower bed (T1 and T_b). and consequently lower freeboard temperature due to reduced pyrolysis. Also according to [10], beacause biomass are reactive and of low bulk density it tends to float on the inert bed surface, small particle size (like size Z) will therefore implies greater concentrations of the CS in upper region of the inert bed with consequent effect of lower dense phase temperature, as observed above.

Figures 4 and 5 provide a clearer picture of the difference in the combustion characteristics of the fuel sizes. It should be noted that X is bigger and heavy therefore it falls inside the bubbling bed where it gradually burn. At all percentage of EA, most of X fixed carbon and fraction of its volatile burn within the bubbling bed thereby ensuring T_b is maintained at the preset value of 750°C without any problem. Contrarily bulk density of Z is low and most of it is blown to the freeboard zone where it burnt hence comparatively higher freeboard temperature (T3-T8) and lower dense phase temperature (T1 and Tb) (fig

4). At higher excess air EA=100% under the influence of higher fluidization air minimal quantities of the Z get to the inert bed thereby lower Tb and T3-T8, Figure 8.

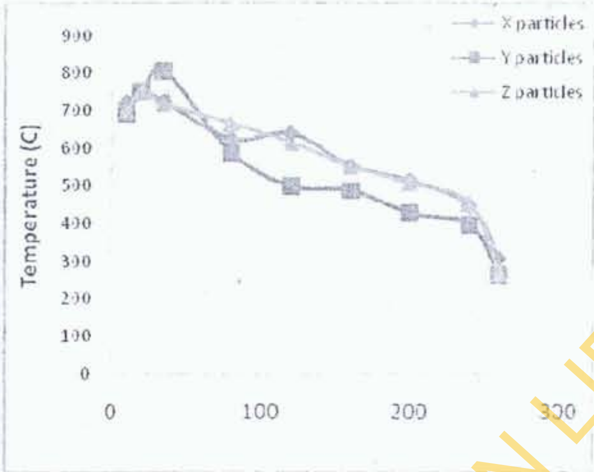


Figure 6: A comparison of the temperature profile for all the particle size at EA=20%

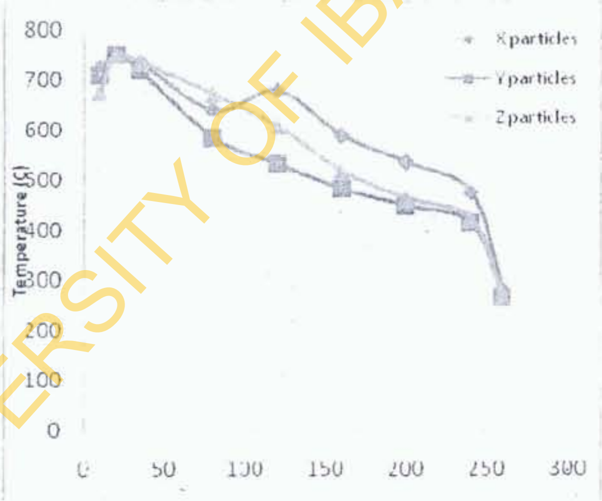


Figure 7: A comparison of the temperature profile for all the particle size at EA=60%

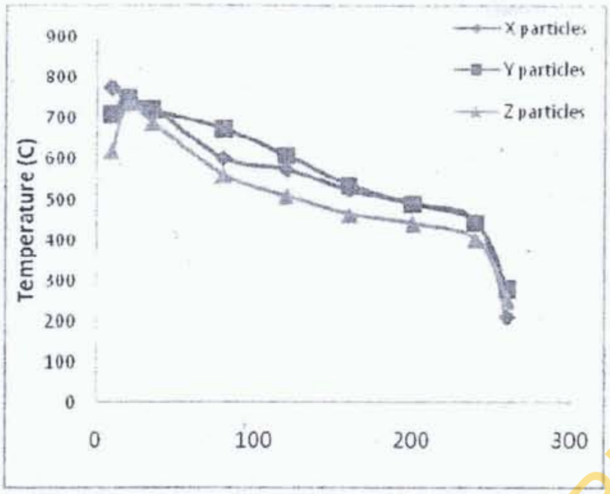


Figure 8: A comparison of the temperature profile for all the particle size at EA=100%

POLLUTANTS EMISSION.

Value of CO obtained for each particle size is graphically shown in Figure 9. Being so hazardous, low emission of CO is not only a prerequisite to high combustion efficiency but critical to safety and well being of personnel using the combustion equipment. The results obtained show good agreement with what is available in the literature [5],[6],[7],[9] (not shown). However CO reading seems very high compare with equivalent condition when PKS was used as feedstock. CO emission was rather high at EA=20%; several values obtained exceeded the maximum measurable by the Bacharach flue gas analyzer (≤4000PPM) and a theoretical method was used to determine such CO values.

According to [15], a good approximation for excess air (EA) can be calculated from equation 6. This calculation as noted by [15] is often used to automatically calculate % Excess Air in electronic combustion analyzers, like TSI's CA-CALC Combustion Analyzer.

Therefore with EA, O_2 known (from flue gas analyser results) one can estimate CO concentration. This method was employed in calculating CO value in 2 cases where Bacharach gas analyzer could not give value for the reason that CO exceeded maximum measurable values of 4000ppm. See fig 7

$$EA = \frac{O_2 - 0.5CO}{20.9 - (O_2 - 0.5CO)} \qquad (6)$$

and therefore, we may write:

$$CO = \frac{O_2 - EA(O_2 - 20.9)}{0.5(EA + 1)} \qquad (7)$$

Equation 7 was used to calculate approximate value for CO that could not be displayed by Bacharach for being above 4000ppm.

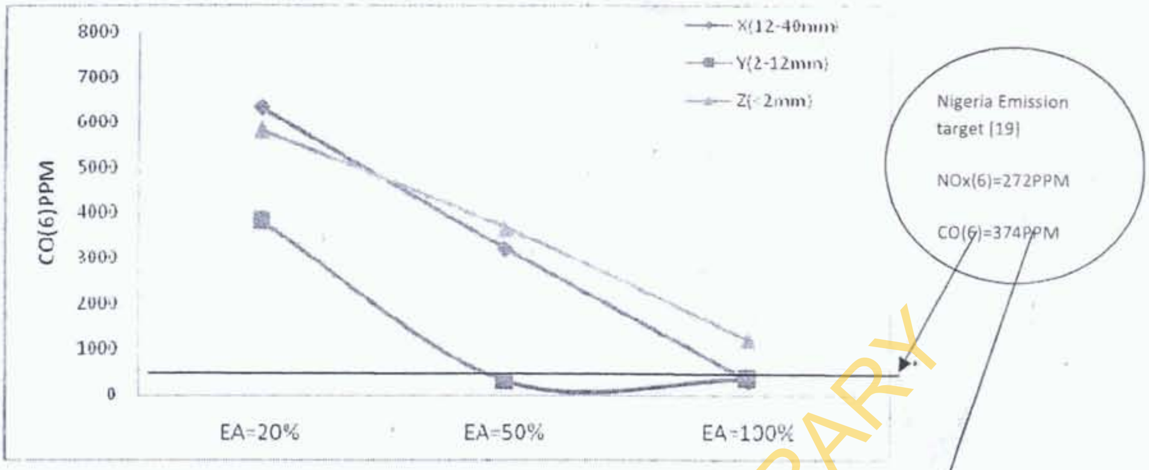


Figure 9:A plot of CO concentration at different degree of EA

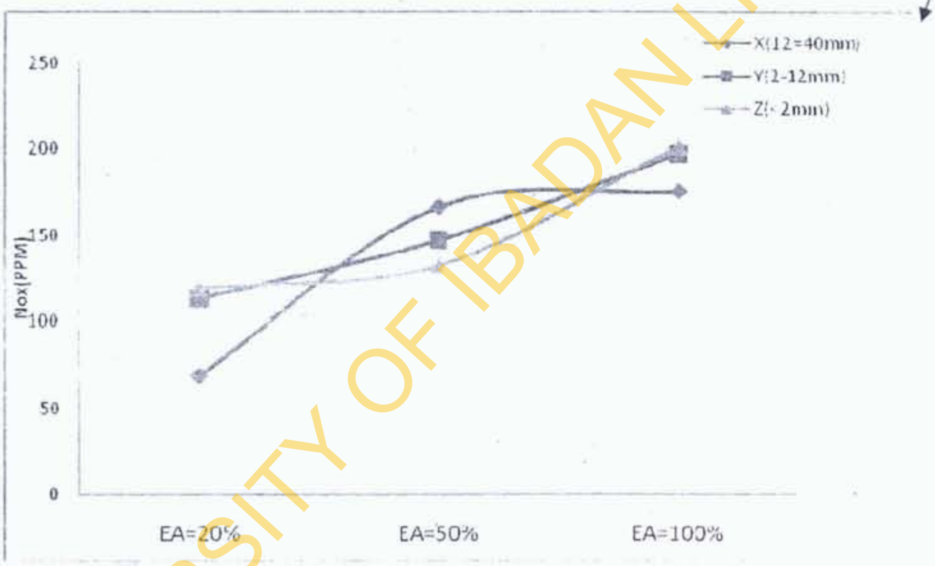


Figure 10: A plot of NO_x against the percentage excess air for each of the fuel particle size

From Figure 10, it could be seen that EA has pronounced effect on NOx formation. The value were observed to increase progressively for all the sizes as EA increases.

It should be noted also that the complete control of inert bed temperature, with the aid of ITRU, such that the temperature within combustor is ensured below 900C implies insignificant thermal and prompt NOx formation which indicate that NOx obtained were principally through oxidation of fuel Nitrogen compounds via these routes [10]

1. homogenous oxidation / gaseous compound reduction involving NCO,HCN and NH3(NOx precursors).[16] released as volatiles which may be represented by following equations [10]

$HCN(Volatiles)+O \leftrightarrow NCO+H$

$NCO+O \leftrightarrow NO+CO$

$NCO+NO \leftrightarrow N2O+H$ and

$NH3+5/4O2 \leftrightarrow NO+3/2H2O$

2. heterogeneous oxidation of nitrogen in char particles or nitrogen reduction on char surfaces,

SOx Emission

The result indicates strong influence of EA on SOx reduction during combustion of CS. The manner of formation and decomposition of this pollutant also suggest a possible influence of particle size and reaction of SOx with the ash in the inert bed, From Fig 11, it could be seen that decomposition of SOx is more pronounced with size X and Y, where SOx dropped from 689ppm and 279ppm at EA=20% to 11ppm and 0ppm respectively at EA=100%.

Since combustion intensity is high for these two sizes for all the excess air, it might be appropriate to suggest that the ash from the CS fuel is somehow responsible for phenomenon drop in SOx concentration. This may be buttressed with the observation that Size Z still have reasonably higher SOx value and lower inert bed combustion intensity at EA =100%. Possibility of ash reacting with SOx has been mentioned in literature [18]

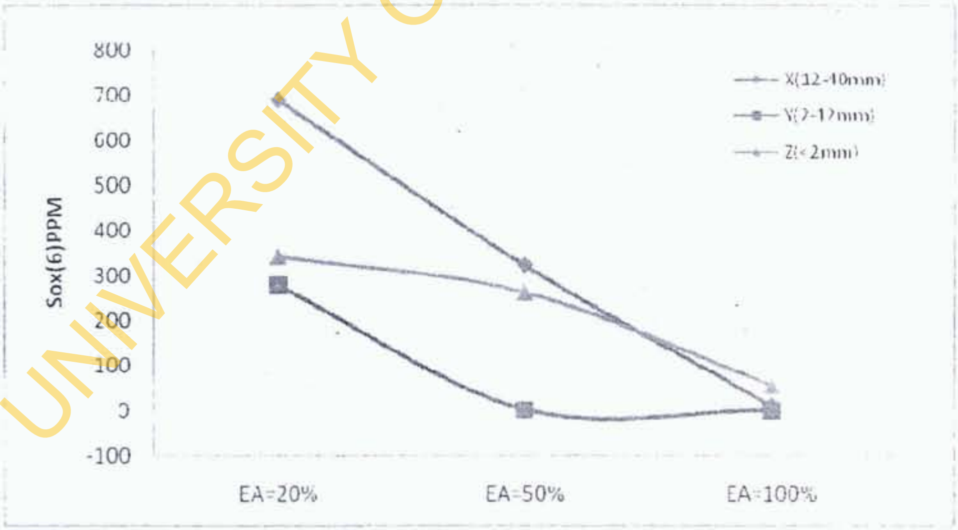


Figure 11: A plot of SO_2 against the percentage excess air for each of the fuel particle size

Combustion Efficiency

Using equation 6, CE was calculated as.

	Size X	Size Y
CE (EA=20%)=	97.2%	98.2%
CE (EA=60%)=	98.5%	99.8%
CE (EA=100%)=	99.8%	99.8%

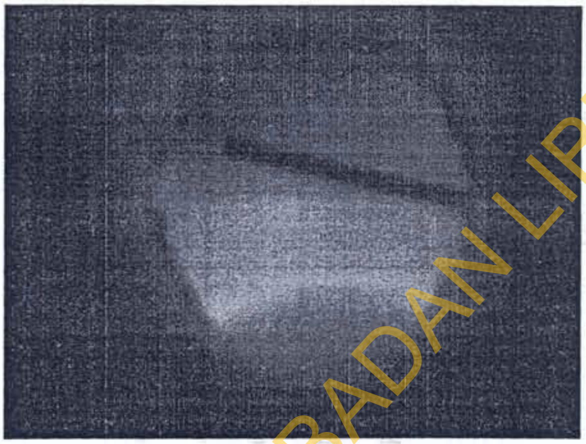


Figure 12: a view (through fuel chute) of the inert bed during the experimental run. Temperature = 750°C

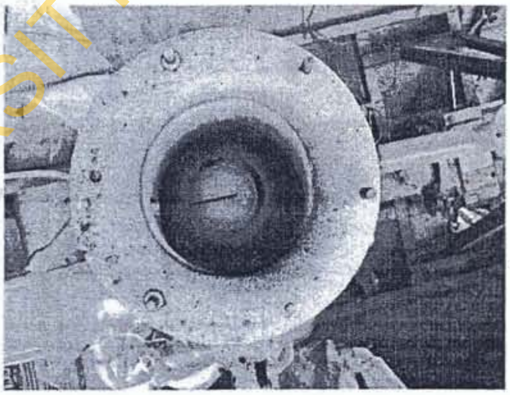


Figure 13: a view (through the partition) of the inert bed during experimental run. Temperature=801°C

6.0 CONCLUSION

The effect of particle size on combustion of Coconut shell in an experimental model bubbling fluidized bed combustor has been investigated.

The results indicate that efficient and environmentally friendly combustion of Coconut shell could be strongly influenced by the size of the particles employed.

It was found that Size Z(fine particle) could not be used in the BFBC for extended period at EA>60% since beyond this point the result indicate reduced combustion intensity(manifested as ITRU not switching off) and subsequent drop of T_b below the preset value. This indicates that with continual firing, temperature will drop to a level where combustion may no longer be sustainable.

Size X (12-50mm) and Size Y(2-12 mm) however gave stable combustion and acceptable axial temperature distribution. Combustion efficiency was noted to be above 98% for both sizes at EA≥60%.

At EA= 60%, which seems to be the optimum excess air for combustion of this fuel, pollutants emission value (CO, NOx and SOx) and combustion efficiency for size Y appear to be better than for size X and Z . In view of this, it may be suggested that acceptable combustion and emission characteristics may be obtained if coconut Shell is classified in the range of 2-12mm prior usage as fuel in a Bubbling Fluidized bed Combustor.

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REFERENCES

[1] ICEED Federal ministry of power and steel, federal republic of `Nigeria. Renewable electricity action program (REAP), 2006, `pp. 23-37

[2] Eziashi, E. and Omamor, Lethal yellowing disease of the coconut palms (cocosnucifera l.): An overview of the crises. Nigerian Institute for Oil Palm Research (NIFOR), Plant Pathology Division, P.M.B. 1030 Benin City, Edo State, Nigeria. 2010.

[3] Nigerian Institute for Oil Palm Research, Conserved coconut germplasm from Nigeria. nifor@infoweb.com.ng

[4] Kuprianov, V.I., Permchart, W. and Janvijitsakul, K. 2005. Fluidized bed combustion of pre-dried Thai bagasse. Fuel Process. Technol. 86:849-860.

[5] Songpol Chakritthakul, Vladimir I. Kuprianov., Co- firing of eucalyptus bark and rubberwood sawdust in a swirling fluidized-bed combustor using an axial flow swirler.Bioresource Technology 102 (2011) 8268–8278

[6] Suthum P. Fluidised Bed Combustion of Oil Palm Solid Waste. Waste Incineration Research Center (WIRC). Department of MechanicalEngineering, King Mongkuts Institute of Technology North Bangkok. 2004

[7] Rosyida ,P., Kang, K. H., Mohammad, N. M. J., Emissions Characteristics of palm Wastes in .Fluidized Bed Combustion. Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia. (2006)

[8] Raji, T.O, Oyewola, O.M, Salau, T.A.O., Development of experimental model bubbling fluidized bed combustor for combustion of biomass, Proceedings of the 8th International Conference on Heat Transfer. Fluid Mechanics, and Thermodynamics, Mauritius, Paper COM 2.5, July 2011.

[9] Raji, T.O, Oyewola, O.M, Salau, T.A.O., New Features for Performance enhancement of experimental model bubbling fluidized bed combustor. International Journal of Scientific & Engineering Research Volume 3, issue 1, January-2012 1 ISSN 2229-5518

[10] S.A.Oka, 2003. Fluidized bed combustion. Mercel Dekker, New York..

[11] Howard R.L., Abotsi E, Jansen van Rensburg E.L.and Howard S. Lignocellulose biotechnology: issues of bioconversion and enzyme production. AfricanJournal of Biotechnology Vol. 2 (12), pp. 602-619, December 2003

[12] Wan, W.A., AbKarim Ghani, Reza, A. M., Mohd Salleh, M.A., and Alias,A.B. 2009. Air Gasification of Agricultural Waste in a Fluidized Bed Gasifier: Hydrogen Production Performance. *Energies* 2009, 2, 258-268; doi:10.3390/en2020 0258

[13] Basu, P., Cen, K.F., Jestin, L., 2000. Boilers and Burners. Springer, New York.

[14] Vladimir I. Kuprianov a, Rachadaporn Kaewklum, Songpol Chakritthakul. Effects of operating conditions and fuel properties on emission performance and combustion efficiencyof a swirling fluidized-bed combustor fired with a biomass fuel. Energy 36 (2011) 2038 - 2048.

[15] TSI Incorporated, An Overview of Measurements, Methods and Calculations Used in Combustion Analysis 2004

[16] Li Lian Tan, Chun-Zhu Li, Formation of NOx and SOx precursors during the pyrolysis of coal and biomass. Part I. Effects of reactor configuration on the determined yields of HCN and NH3 during pyrolysis Fuel 2000; 79:1883–9.

[17] Prbir Basu, Combustion Calculations unit 5. Downloaded From poisson.me.dal.ca/.../04_Fuels%20&%20Combustion %20calculation.16/06/12

[18] Chungen Yin, Lasse A. Rosendahl, Søren K. Kær, Grate-firing of biomass for heat and power production Progress in Energy and Combustion Science 34 (2008) 725– 754

[19] Nigeria LNG Limited, Our environment EIA issues and measures. Downloaded from www.nlg.com on June 14, 2012