International Journal of Electrical and Power Engineering 2 (5): 300-305, 2008
ISSN: 1990-7958

The Performances of Okpara Coal, Enugu State, Nigeria, in Fluidized Bed Combustion

[1]I.I. Ozigis, [2]Z.O. Opafunso, [3]A.A. Asere and [4]I.A. Adetunde
[1]Department of Mining Engineering, Federal University of Technology, Akure, Nigeria
[2]Department of Mining Engineering, University of Mines and Technology, Tarkwa, Ghana
[3]Department of Mechanical Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria
[4]Department of Mathematics, University of Mines and Technology, Tarkwa, Ghana

Abstract: A fluidized bed, using locally available material for the combustion of Okpara coal for generating steam to drive turbine for electricity generation, has been designed, constructed and commissioned. Two areas of investigation were looked into in this research. These were combustion at different coal particle sizes from 4.5-50.0 mm and steam generation at constant coal particle size with bed temperature ranging between 700 and 900°C. Results shows that a temperature of 153°C maximum was obtained at atmospheric combustion and much higher temperature could be anticipated at higher pressure with this type of bituminous coal and combustor.

Key words: Coal, combustion, fluidized, steam, electricity, thermal, sieve

INTRODUCTION

Fluidized bed combustion is a method of burning fuel in a stream of fluid-like bed of inert materials. The fuel is fed into the bed continuously supported by upward flowing combustion air that causes the bed to behave like turbulent fluid at full fluidization (Kunii and Levenspiel, 1991). Fluidized bed combustor technology had revolutionized the process of generating electric power burning solid fuel that met pollution control standards (Rao and Parulekar, 2004). It has brought to the fore the environmental acceptance of the combustion of various fuel previously unacceptable to environmentalist. It is economical and efficient. In addition to other economic gains, its ability to handle different fuels and hazardous wastes with a destruction and removal efficiency exceeding 98% had made it acceptable to coal fired thermal power stations (Wildi, 2002). Table 1 shows a typical characteristic of coal fired thermal generating plant. Nigeria coal fuel needs to be subjected to fluidized bed combustion to gain engineering, operating and environmental friendly worldwide acceptance. The application of fluidized bed coal combustion in Nigerian will lead towards modernization and mechanization of Nigerian coalmines and coal fired thermal power stations. Electric Power supply is not efficient in Nigeria principally due to problematic power stations traceable to engineering fundamentals. These are:

Table 1: A typical characteristic of coal fired thermal generating plant

Parameter	Model Rating	Capacity
Electric power output	40×12 MW	480 MW
Coal consumption	40×1 kg s^{-1}	40 kg s^{-1}
Air intake	40×10 kg s^{-1}	400 kg s^{-1}
Boiler thermal power	40×30 MW	1200 MW
Steam output	40×8 kg s^{-1}	320 kg s^{-1}
Cooling water	40×360 kg s^{-1}	14,400kg s^{-1}
Heat carried away by the water	40×15 MW	600 MW

Source: (Wildi, 2002)

- The over and under flow of River Niger have tremendous negative effects on our hydro power stations at Kainji, Jebba as well as Shiroro and Kura falls in Plateau state, Nigeria.
- The oil and gas price fluctuations, political uncertainty, strike and because of its global significant also have negative effects on our oil and gas fired thermal stations located at Sapele (Ogorode), Afam and Ughelli in Delta State; Egbin and Ijora in Lagos State, Nigeria.
- Oil and gas fired thermal power stations were considered as back up at peak periods for electric power generating stations while coal fired and hydro power stations were considered as base and intermediate electric power stations, respectively. Nuclear power stations also complement electric power generation in most industrialized nations.

The average electric power output in Nigeria is about 4000 MW with additional gas fired thermal stations under repair, which are expected to peak at 10,000 MW. The Nigeria energy mix is as follows: Obtained from Hydropower, 43%; oil fired thermal stations about 15% while gas fired thermal stations contribute the balance of

Corresponding Author: I.A. Adetunde, Department of Mathematics, University of Mines and Technology, Tarkwa, Ghana

42%. Coal utilization is zero despite abundant and cheap coal availability in Nigeria (NCC, 2000). This contrast with South Africa, United States of America and China where coal fired power generation contribute about 90, 70 and 80%, respectively (Rao and Parulekar, 2004). For renewable energy sources, there are huddles for it to be utilized in national grid and it is presently limited to isolated settlements. Its share of electric power supply has not exceeded 5% of the national electric power consumption in countries such as Britain and U.S.A. where application are much in progress (Rao and Parulekar, 2004).

Fluidized bed combustion of coal compared in many respect with oil and gas fired thermal power stations. It burns coal-air mixture in the same way as an atomized liquid fuel (Gupta, 2005). Nigerian coal exploitable reserve is about 639 million metric tons with an additional inferred reserve summing up to 2.75 billion metric tons (MMSD, 2000). This quantity if utilized for electric power generation at 10,000 MW will last for over 100 years calculated from characteristic of coal fired thermal generating plant (Table 1). Coal burns effectively in crushed or pulverized form and suitable for steam production as required in conversion to electricity. Stocker has about 30% thermal efficiency but fluidization can raise it to about 40% thermal efficiency (Gupta, 2005). 90% of Nigerian economic coal deposits is mostly sub-bituminous coal with heating value of about 19.3-30 MJ Kg^{-1} (Table 2). It is relatively high in inherent moisture and its volatile matter, varying from 15-30% and some are high in sulphur content (MMSD, 2000). The drawbacks in the utilization of Nigerian coal were mainly very difficult to burn, combustion pollution, low output from mines due to poor technology, lack of modern coal combustion machinery and non-utilization by heavy industries in Nigeria. Furthermore, the availability of petroleum contributed negatively towards functional coal -fired power plants in Nigeria. The burning of coal serves as sources of high temperature in excess of 250°C up to 1600°C, which was needed in furnaces, kilns, industrial ovens, glass, mining, chemical and metallurgical industries (NCC, 2000). The performance of combustor is the measure of its evaporative capacity. The evaporative capacity depends on feed water temperature, working pressure, fuel and the final condition of steam (Khurmi and Gupta, 2003). The Evaporative capacity or power of a combustor is the amount of water evaporated or steam produced in kg h^{-1}, Kg kg^{-1} of fuel burnt or kg/h/m^2 of heating surface. Equivalent evaporation per kg of fuel, $M_e = M_s/M_f$, Where M_e = Mass of water actually evaporated, M_s = Steam Generated. M_f = fuel used.

Table 2: Chemical, physical and petrographical properties of okpara coal, Enugu state, Nigeria

Quantity parameter	Value (%)
Gross calorific (KJ kg^{-1})	27,711.30
Moisture (% ar)	7.50
Volatile matter (% ar)	38.26
Fixed carbon (% ar)	45.84
Ash (% ar)	8.40
Carbon (% ar)	65.40
Oxygen (% ar)	12.61
Hydrogen (% ar)	4.11
Total sulphur (% ar)	0.54
Nitrogen (% ar)	1.44
Sulphate sulphur (db)	0.01
Pyrite sulphur (% db)	0.05
Organic sulphur (% db)	0.69
Swelling No (Fsi)	1.00
Hard Groe index	37.80
Dilatometer test softening point c	356.00
Reconsolidation point c	477.00
Softening range	121.00
Contraction (%)	27.00
Dilatation (%)	0.00
Gray king coke type	B
Maximum fluidity (ddpm) dial division per minute)	3.00
Mean max reflectance (%)	0.45
Ventrinite (%)	51.40
Exinite (%)	8.40
Inertnite (%)	40.20
Gray king Assay coke/char (w%)	67.00
Gas (L 100 kg^{-1})	10.30
Tar and light oil (W%)	17.70
Liquor (w%)	6.40
Density Kg m^{-3}	1300.00
Rank (NCB)	802.00

Test obtained from NCC, Enugu, March 2003

The objectives of the study were: To evaluate the combustion process of Nigerian coal in fluidized bed combustion. To evaluate thermal performance of the combustor through measurement of combustion efficiency, heat transfer and ash depositions resulting in thermal losses and fouling in and outside the convective pass. To examine fouling qualitatively by assessing the operational performance and deposition on heat transfer surfaces, agglomeration or sintering of ash or bed material, changes in bed material, particle size and evidence of erosion or corrosion on heat removal surfaces.

MATERIALS AND METHODS

The experimental tests were carried out at Abubakar Tafawa Balewa University's combustion test bay, Bauchi, Nigeria. The known quantity of silica sand, coal of various sizes and water were measured. During the tests, temperature and flow rate were taken at interval of 5 min. Six different parameters were measured during these experimental tests. Six different coal sizes were subjected to experimental run. The ambient temperature,

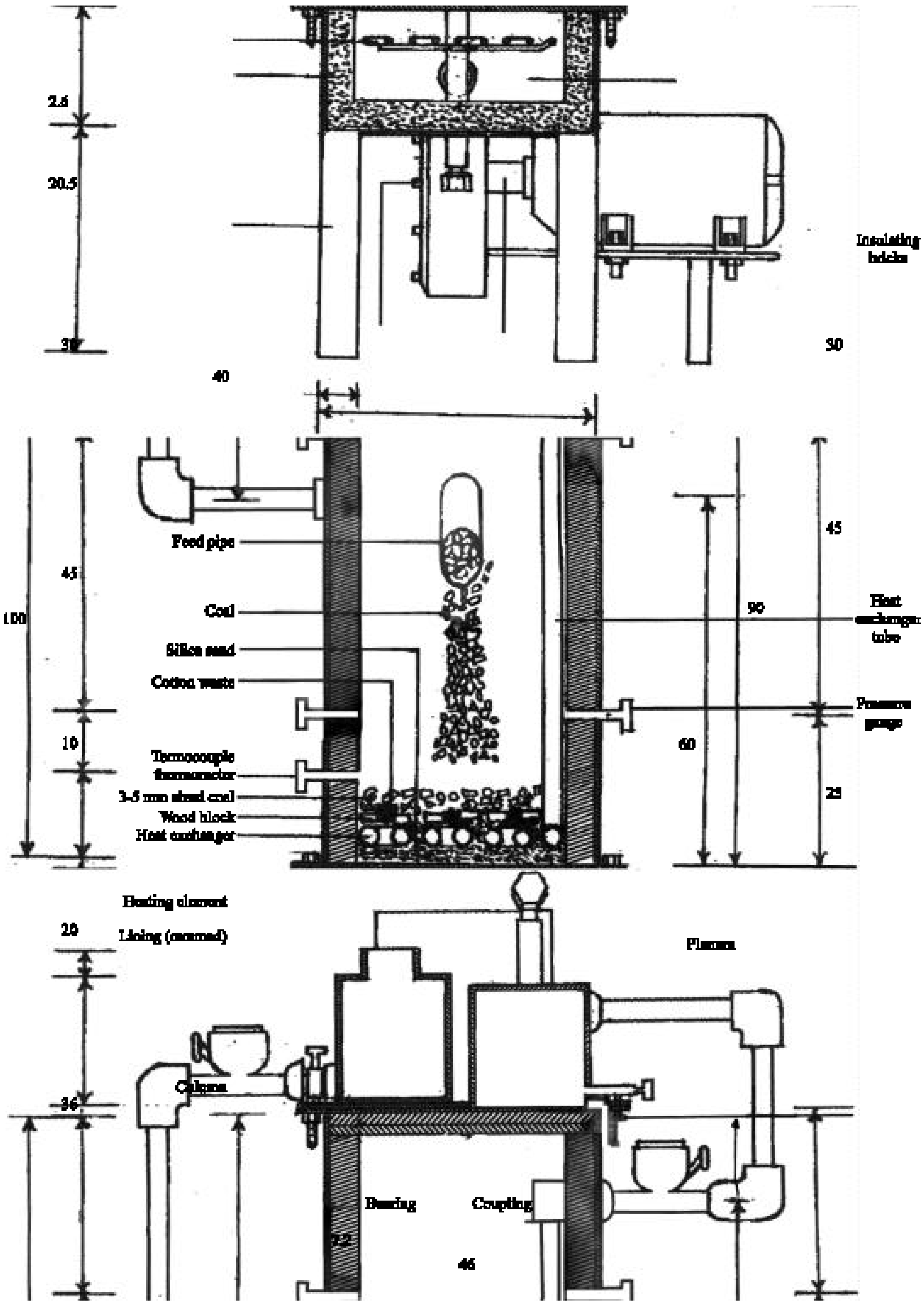

Fig. 1: Side view of the fluidizes bed combustor

steam temperature and combustor wall temperature were measured using the K-type thermocouples. The bed temperatures were obtained using a standard pyrometer. Heat absorbed and Heat loss were calculated using the collected data. The bed materials were made up of silica sand which ranges in sizes from 600-1000 μm, also placed on 300 μm sieve and fastened on 5.2% open area air distributor. This was to provide the means of upward flowing air for fluidization. The startup was by combustion of auxiliary fuel as a flame above the bed fluidized. The coal sizes used in the experimental runs were sieved. Coal combustion in a hot air stream was very rapid as soon as its ignition temperature was reached by the startup system. The physical and chemical changes took place between the hot fluid and solid fuel in airtight fluidized bed combustor. This liberated heat was absorbed by working fluid in heat transfer tube of the reactor. Fluidized bed combustor with its upward flowing air eliminated ash depositions. Dusts were trapped by the cyclone. The feed hopper was for intermittent feeding to avoid choke up and sticking of coal particles. The instrumentation, electrical system and the columns were designed to structurally support the combustor and give its unique compactness. Figure 1 shows the side view of the fluidized bed Combustor.

RESULTS AND DISCUSSION

Coal combustion tests: The startup was by combustion of auxiliary fuel as against gas burners or kerosene burners. The preheating of air improves the combustion efficiency of material in the reactor (Table 3). Table 4-7 shows rapid bed temperature distribution illustrating high firing qualities of the Okpara coal. Bed temperature ranges from 750-970°C within 15 min as shown in Table 4-7, while the combustor wall temperature ranges from 45-128°C. The wall temperature of the combustor did not exceed 128°C. The wall does not have insulating firebricks but only refractory firebricks were used. These low levels of wall temperature suggest that heat loss is minimal during the tests carried out. The average ambient temperature was 34°C. The experiments last about 35 min for each run depending on the quantity of coal feed. The highest heat loss was 20.13 KW m^{-2}, which occur when the bed temperature was also the highest at 970°C. From the Table 4-7 coal combustion reaches its peak of about 900°C within 15 min and fluctuates for the duration depending on coal feed and feed water. The slopes do not drop appreciably which indicate the combustor was well insulated. It compared favorably with coal oven, which gain flame stability and disappearance of smoke within 10-15 min. The amount of the deposition and corrosion were not analyzed due to inadequate facilities. The flue gas does not have fly ashes and particulates. The emission of sulphur dioxide and carbon dioxide, were not evaluated because there was no gas analyzer. Table 7 shows the effect of excessive coal feed which reduces the temperature illustrating the two extremes of coal combustion. That means excessive coal feed and insufficient air were not desirable.

Table 3: The sieve analysis of selected materials

Size	Weight	Remark
0.6-1.0 mm	4.536 kg	Silica-sand
1.12-4.5 mm	3.0 kg	Okpara coal
4.5-6.0 mm	3.5kg	„
6.0-14 .0 mm	4.0 kg	„
14. 0-20.0 mm	4.7 kg	„
20.0-37. 5 mm	13.2 kg	„
37.5-50.0 mm	9.45kg	„

Tests to determine heat absorbed by water: The average ambient temperature for feed water was 30°C. The steam temperature and the water flow rate were used to compute the heat absorbed. These are shown in Table 4-7. Table 5 shows that the highest temperature obtained was 153°C during the combustion of coal size range of 6-14 mm. The most effective coal size for the fluidized combustion was

Table 4: 4.5-6.0 mm Okpara coal experimental run

Time-min	Inner plenum temp (°C)	Bed temp (°C)	Wall comb temp (°C)	Heat loss KW m^{-2}	Tile temp (°C)	Steam temp (°C)	Heat gain KW
3.00-0	280	75	45	0.70	43c	-	-
3.03-3	270	310	-	-	-	-	-
3.07-7	264	540	99	10.26	70	-	-
3.10-10	211	950	-	-	98	-	-
3.15-15	195	900	112	18.33	111	103	4.08
3.20-20	186	750	114	14.80	160	107	4.30
3.25-25	184	800	116	15.91	180	111	4.53
3.30-30	180	900	118	18.20	210	123	5.20
3.35-35	180	850	120	16.99	350	123	5.20
3.40-40	179	900	120	18.15	400	107	4.30
3.45-45	178	850	121	16.96	440	103	4.08
3.50-50	175	800	124	15.73	450	103	4.08
			Av	16.85		Av	4.66

Water temp. = 30°C, Ambient temp. = 34°C, Weight of coal = 2.72 kg, Water = 40 kg; Q = 17. 743-KW m^{-2}; Time = 50; q = 4.93 KW, Pressure (max) = 2 bar, Date 8/9/03

Table 5: 6.0-14.0 mm Okpara coal experimental run

Time-min	Inner plenum temp (°C)	Bed temp (°C)	Wall comb temp (°C)	Heat loss KW m^{-2}	Tile temp (°C)	Steam temp (°C)	Heat gain KW
11.53-0	360	75	45	0.70	40	-	-
11.58-5	270	400	68	7.73	52	-	-
12.01-8	265	600	70	12.33	63	-	-
12.03-10	262	800	83	16.68	92	103	3.93
12.08-15	208	900	86	18.94	150	153	6.63
12.13-20	201	850	90	17.68	200	153	6.63
12.18-25	195	900	98	18.66	250	148	6.36
12.23-30	190	880	110	17.92	330	143	6.09
12.28-35	185	850	114	17.13	420	143	6.09
				Av = 16.39		Av	=5.96

Q = 16.884 KW m^{-2}, q = 6.4 15KW, Ambient temp = 34°C, Water temp. = 30°C, Date: 15/9/03, Weight of coal= 2.1 kg, Weight of water = 27 kg, Time = 35 min s; Pressure (max) =2 bar, Feed via feeder (gradual feeding), There are no flying particles

Table 6: 14.0-20.0 mm Okpara coal experimental run

Time-min	Inner plenum temp (°C)	Bed temp (°C)	Wall comb temp (°C)	Heat loss KW m^{-2}	Tile temp (°C)	Steam temp (°C)	Heat gain KW
1.48-0	380	80	48	0.744	-	-	-
1.53-5	275	393	69	7.54	-	-	-
1.58-10	230	800	90	16.52	56	-	-
2.03-15	202	900	108	18.43	68	103	3.50
2.08-20	198	850	110	17.22	76	113	3.97
2.13-25	195	900	113	18.31	110	121	4.36
2.18-30	192	850	115	17.10	128	125	4.55
2.23-35	186	700	118	13.54	130	103	3.50
				Av = 15.52		Av	=3.98

Ambient temp.=34 °C, Water temp.=30 °C, Date 15/9/03, Weight of coal = 1.93 kg, Weight of water = 24 kg, Time = 35 min, Q = 16. 798 KW m^{-2}, Pressure = 2bar, q=4.3228 KW, Feed via top feed, gradual feeding, there are no flying particles

Table 7: 20-37.5 mm Okpara coal experimental run

Time-min	Inner plenum temp (°C)	Bed temp (°C)	Wall comb temp (°C)	Heat loss KW m^{-2}	Insulator temp (°C)	Steam temp (°C)	Heat gain KW
1.58-5	275	420	90	7.68	56	-	-
2.03-10	218	800	101	16.26	73	-	-
2.08-15	208	900	109	18.41	80	101	3.26
2.13-20	201	850	112	17.17	90	116	3.95
2.18-25	196	900	116	18.24	102	121	4.18
2.23-30	190	750	122	14.61	118	123	4.27
2.28-35	187	700	128	13.31	133	103	3.35
				Av = 15.09		Av =	3.80

Ambient temp.=34°C Water temp.=30°C, Date: 22/9/03, Weight of coal= 2.2kg, Q = 16.583kw m^{-2}, Weight of water = 23 kg, q = 4.0031KW, Pressure = 2 bar, Time = 35 min

Table 8: Typical heat release rates (coal combustos, oil and gas tube boilers)

Parameters	Coal (Fabricated)	Coal	Oil	Gas
Heat release rate/unit volume KW m^{-3}	365	300-400	450-700	450-700
Heat release rate/water tube surface area, KW m^{-2}	139	200-220	200-220	200-220

(Source: Ozigis, 2005 and Highley and Kaye, 1983)

in the range of 6-14 mm due to air power of 1.008 $m^3 s^{-1}$ from the centrifugal fan. This provided the greatest heat transfer to the fluid (water) inside the heat exchanger. An excess coal will decrease heat evolution. The effect of heat loss from the combustor wall was fairly uniform in relation to all the particle sizes. Steam began to emit out of the heat transfer tube after 15 min and fluctuate till the end of experimental run. The result shows that 15 min was required before Steam production from heat exchanger. Table 5 shows that heat absorbed by water was 6.6 kw within 15 min and remains a near normal trend. Steam discharges from the heat transfer tube from minimum setting to its peak and remains there unless the system was shut down or the variables were altered. The fouling in and outside the convective pass could not be evaluated but the stainless steel heat exchanger provided high rate of heat transfer to the fluid within 15 min as against 30 min in some designs.

Comparative analysis of heat transfer rate by other fluidized bed combustors: The heat release rate from the fluidized bed combustor per unit volume was about 365 KW m^{-3}. Also, Heat release rate from the fluidized bed combustor per projected water tube surface area was about 139 KW m^{-2}. Although the present combustor makes use of locally fabricated rig unlike water tube boilers (Table 8) that made use of pump to circulate the boiling water through the tubes and better efficient fan than the Local fabrication. The attained temperature of 153°C was significant at atmospheric pressure (1.013 bars).

CONCLUSION

This research presents the performances of Okpara coal in fluidized bed combustion. The qualities of Okpara coal such as the physical, chemical, petrographical, corrosive, ignition, slagging and performance characteristics made it suitable for the optimum production of saturated steam. Its sulphur content of 0.54% was considered to be low in coal combustion processes. The following were the conclusions drawn from the series of experiments.

- The particle size of coal suited for fluidized bed combustor range from 6-14 mm with airflow rate of 1.008 m3 s^{-1} provided by centrifugal fan driven by 2 kW 3ph at 1500 rpm electric motor.
- The steam temperature was 153°C at atmospheric pressure within 15 min of start-up. There was greater consistency to increase in steam temperature at coal size of 6-14 mm than during the combustion of coal sized between 20-50 mm. This was due to the high volatile matter and appropriate coal size to centrifugal fan power.
- Insulating and refractory firebricks (fireclay, zircon and clay) locally obtainable can conveniently be used for the lining of combustors and furnaces.
- The locally constructed combustor requires sufficient combustion air and heating surfaces to extract heat by working fluid as the coal burned. This implies there was excessive heat loss that could be utilized to heat the steam.

REFERENCES

Gupta, O.P., 2005. Elements of fuels, furnaces and refractory, Khanna Publishers 2-B Nath Market, Nai Sarak, New Delhi 110006. 5th Edn., pp: 174-176, 506-509.

Highley, J. and W.G. Kaye, 1983. Fluidized Bed Industrial Boilers and Furnaces. In: Howard J.R. (Ed.), Fluidized beds combustions and applications, Applied Science Publishers Ltd. Ripple road, Barking, Essex, England, pp: 77-82, 86-110, 112-132, 115-167.

Khurmi, R.S. and J.K. Gupta, 2005. A textbook of Thermal Engineering printed in India by Rajandra Ravindra Printers (Pvt) Ltd., 7361, ram nagar New Delhi, pp: 230-360.

Kunii, O. and O. Levenspiel, 1991. Fluidization Engineering, Butter Worth-Heinemann, London. 2nd Edn., pp: 487.

MMSD-Ministry of Mines and Steel Development, Abuja 2000. Coal as Resources for Economic Recovery in Nigeria, pp: 1-6.

NCC-Nigerian Coal Corporation, Enugu, 2000. The use of Coal as a Suitable Alternative to Fuel Wood, pp: 1-5.

Ozigis, I.I., 2005. The Performances of Okpara Coal (Enugu State) in Fluidized Bed Combustion, Unpublished M. Eng Thesis, Abubakar Tafawa Belewa University, Bauchi, Nigeria.

Rao, S. and B.B. Parulekar, 2004. Energy Technology, Non Conventional, Renewable and Conventional, Published by Remesh Chander Khanna for Khanna Publishers, 2-B Nath market, Nai Sarak, Delhi-110006. 3rd Edn., 3rd Reprint, pp: 424-426, 960-962.

Wildi, T., 2002. Electrical Machines, Drives and Power Systems, Prentice hall. Int. 2nd Edn., pp: 565-569, 578-585.