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Carbonization of coal from mai-ganga deposit for use in the production of activated carbons

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Abstract

Carbonization of coal from Mai-Ganga deposit for use in the production of activated carbons was achieved in this work. Coal as the precursor material was sourced from Mai-Ganga coal deposit located in Akko, Gombe State, Nigeria. The sample was crushed, ground and sieved to the required sizes of 1.0, 1.7- and 2.0-mm. Cleaning agent (Pentane oil) was used in different percentages of 10% 15% and 20%, each percentage was mixed with coal-water slurry to physically clean the coal samples. Carbonization was carried out in a fixed bed kiln at different carbonization temperatures of 600ºC, 650ºC and 700ºC and varying residence time (30, 45 and 60 minutes) on both cleaned and uncleaned samples. Samples produced were then characterized, properties such as percentage carbon yield, bulk density, pH value, percentage fixed carbon content and iodine number were obtained. Carbon yield ranges from 51.58 to 68.16%; bulk density ranges from 0.5 to 0.6 g/ml, pH values range from 6.23 to 10.27, fixed carbon ranges from 61.09 to 89.86% and the iodine number ranges from 18.48 to 458.18 mg/g. Analysis of variance (ANOVA) was used to analyst the results. The findings suggest that Mai-Ganga coal deposit can be used as precursor in the production of activated carbon since most of the properties evaluated are within accepted range, except for samples that had pH value above 8.5.

Keywords: Carbon form, porous carbon, pyrolysis, iodine number, charcoal

Introduction

In recent times, carbon has been one of the elements which have revolutionized materials science. Carbon provides materials with excellent properties for a large spectrum of industrial applications. From carbon we obtain the strongest fibres (carbon fibres), one of the best solid lubricants (graphite), one of the best electrically conducting materials (graphite electrodes), the best structural material for high temperature tribological application (carbon–carbon composites), one of the best porous liquid/gas absorbers (activated carbon), an essentially non-crystalline impermeable material (vitreous carbon), the hardest material (diamond), and now the most fascinating material, the fullerenes (a form of carbon having a molecule consisting of a large spheroidal cage of atoms, produced chiefly by the action of arc discharges between carbon electrodes). All these forms are made by meticulously choosing the raw materials and processing conditions [1].

Porous carbons can be grouped into two categories: i) Carbon foams; These are rigid porous materials consisting of interconnected network of ligaments, with desired architecture of pores for structural and thermal applications; the result is an inexpensive, lightweight, fire-resistant, impact-absorbing material that can be thermally insulating or conducting, and whose electrical resistivity can be varied over many orders of magnitude. Recently, these have been used as templates for making ceramics [2]. ii) Activated carbons; these are groups of porous carbons with highly developed internal surface area, active surface chemical groups and a highly porous adsorptive medium with complex structure mainly composed primarily of carbon atoms and are used in a wide variety of purification or chemical constituents' recovery applications, which are concerned principally with removal of organic contaminants as well as some inorganic contaminants [3, 1, 4]. The production of activated carbon entails in two stages, namely; carbonization of the precursor materials at temperatures above 400°C during which the evolution of volatiles results in porous materials with predominantly macroporous structures, which are essential for making activated carbons; and activation of the char (macroporous carbon) produced during carbonization which result in highly developed internal surface area and porosity of meso-micro pores [2].

Pyrolysis ('Carbonization,' a more common choice of word in the coal industries) has been used to produce biochar (a.k.a. charcoal) for thousands of years, charcoal from wood via pyrolysis was essential for extraction of iron from iron-ore in the pre-industrial era. In fact, the first application of pyrolysis of wood into charcoal dated back to around 4000 B.C.E. This practice continued until wood supplies nearly ran out and coal, produced inexpensively from underground mines, replaced charcoal for iron production [5]. The history of carbonization of coal goes back to two hundred and fifty years, but progress was slow until a hundred and fifty years ago, when Williams Murdoch first used coal gas for public lighting. From that time a great industry has developed and gas supply is one of the most important public utility undertakings in modern life [6].

Research objective

The aim of this work was to study the viability of carbonizing coal obtained from Mai-Ganga seam coal deposit for the production of activated carbons.

This can be achieved through the following objectives;

1. Preparation of the coal sample through coal sizing and cleaning with 10%, 15% and 20% pentane as cleaning agent;
2. Thermal decomposition of the coal under varying carbonization temperature (600, 650 and 700 ºC) and residence time (30, 45, and 60 minutes); and
3. Evaluating the physico-chemical characteristics and adsorption properties of the char produced.

Previous Work

Coal exploration in Nigeria started as far back as 1916. Available data show that coal (mainly sub-bituminous seam coals except for the Lafia-Obi bituminous coking coal) occurrences in Nigeria have been indicated in more than 22 coalfields spread over 13 States of the Federation [7]. The proven coal reserves so far in Nigeria total about 639 million metric tonnes while the inferred reserves sum up to 2.75 billion metric tonnes.

In the Upper Benue, borehole occurrences of coal seams within the Gombe sandstone have also been reported since 1963. They occur in Kerri-Kerri Formation of Paleocene age and Formation of Maastrichtian-Campanian age. Laterally extensive beds (about 2 m thick) of lignite and subbituminous coals outcrop along the bank of River Kolmani in Gombe town and along a stream channel behind the village of Hamman Gari about 20km from Gombe on the Gombe – Yola road. Coal seams of about 1.7m were also discovered near Doho in Kwami LGA of Gombe State. Several coal outcrops of about 2 – 4.6m thick have been reported from Garin Maiganga, south of Gombe (Fatoye and Gideon, 2013). Presently ASHAKACEM (Lafarge) uses the Mai-Ganga coal deposits for firing its cement kilns.

Carbonization is the thermochemical decomposition of organic matters (coal and biomass) at low presence or complete absence of oxidizing agents, eliminating non-carbon species and producing a carbon mass with a rudimentary porous structure (Basu, 2010). The pyrolysis of any carbonaceous material in the absence of air involves decomposition of organic molecules, evolution of tarry and gaseous products, and finally solid porous carbon mass. The porous carbons so obtained are predominantly macroporous and, as such, are practically inactive [2]. According to [8], the basic coal components are carbon, hydrogen, and oxygen and carbonization is associated with regular and specific alterations of the amounts of these elements. The many variations among carbon compounds account for its peculiar properties, the most significant of which is the ability to form strong atomic bonds.

Iodine number is the most fundamental parameter used to characterize activated carbon performance. It is a measure of activity level (Higher degree indicates higher activation) often reported in mg/g (with typical range of 500 – 1200 mg/g). It is a measure of the micropore content of the activated carbon (values > 0 to 20 A^o or up to 2 nm) by adsorption of iodine from solution. It is equivalent to surface area of activated carbon between 900 m^2/g and 1100 m^2/g and it tells about carbon that preferentially adsorbs small molecules [9].

According to [10], iodine test method is based upon a three-point adsorption isotherm. A standard iodine solution is treated with three different weights of activated carbon under specified conditions. The carbon treated solutions are filtered to separate the carbon from the treated iodine solution (filtrate). Iodine remaining in the filtrate is measured by titration. The amount of iodine removed per gram of carbon is determined for each carbon dosage and the resulting data used to plot an adsorption isotherm. The amount of iodine adsorbed in milligrams per gram of carbon at a residual iodine concentration of 0.02 N is reported as the iodine number.

Research Methodology

The raw material selected as precursor material for this study is a Nigerian coal. This coal (Plate I) was sourced at Mai-Ganga seam coal deposit located in Akko local government area of Gombe State, Nigeria. The cleaning agent used was pentane oil which was procured from Nima foam limiled, Bajabure industrial area, Jimeta-Yola.

Plate 1: Mai-Ganga Coal Sample

In this experimental design, the factors considered were coal size, percentage coal cleaning agent, carbonization temperature and carbonization time. The experimental design parameters are as shown in Table 1. Therefore, the whole experiment comprises of three (3) coal sizes, three (3) cleaning agent percentages plus raw sample, three (3) carbonization temperatures and three (3) carbonization time settings.

Thus;

3 coal sizes x 4 percentage cleaning agent = 12 prepared coal samples

And 3 carbonization temperatures x 3 time carbonization = 9 experimental sets

And 9 experimental sets x 12 prepared coal samples = 108 experimental samples.

Therefore, a total of one hundred and eight (108) samples were used but only one hundred and five (105) samples were characterized because three (3) were damaged during the carbonization.

Table 1: Experimental design parameters

Factors	**Conditional Levels**			
Coal Size (mm)	1.0	1.7	2.0	
Coal Cleaning Agent (% wt.)	0.0	10	15	20
Carbonization Temperature (°C)	600	650	700	
Carbonization Time (min)	30	45	60	

Coal sizing was achieved through crushing of the coal sample manually in batches using mallet and other available crusher (mortar) to reduce the sample size prior to grinding of the coal to a designated size. These were achieved using a portable grinding machine. After the grinding, sizing of the sample was carried out manually according to [11] in a sieve stack that was arranged to accommodate the required sieve sizes i.e. from No. 8, 10, 12, 16 and 18 (2.36, 2.0, 1.7, 1.18

and 1.0mm) US mesh sieves (American Society for Testing and Materials, 2004). The coal samples that cannot pass through No.8 sieve were re-grinded and re-sieved to pass through the designated sieves. The required coal sizes were stored in a plastic bucket (paint buckets) prior to cleaning processes.

The physical cleaning of coal was carried out using a laboratory scale floatation unit (Plate II), where fuel oil or pentane was mixed vigorously with coal/water slurry to render the coal particles hydrophobic [12, 13]. Three kilogram (3kg) of coal was weighed and poured into the floatation unit containing 10L of water. The content was stirred using a motorized agitator for 3min., thereafter, pentane oil was added to the coal-water slurry and then it was vigorously stirred (which makes the mineral matters hydrophilic) for 5mins. The percentages of the pentane oil added to the coal/water slurry were varied for three (3) different percentages (that is; 10, 15 and 20% w/w). Thereafter, the coal sample was then rinsed twice with plenty of water and then air-dried on a smooth clean floor area of the laboratory for 20 to 24 hours.

Plate 2: Floatation unit set-up; (a) coal slurry with percentage cleaning agent before and (b) after stirring.

Results and Discussion

1. Coal Properties

1.1 Raw coal properties

The coal properties investigated were moisture content, volatile matter content, ash content, fixed carbon content, energy content and sulphur content as shown in Table 2 The Mai-Ganga coal sample can be ranked as subbituminous B and non-agglomerating coal, because the gross calorific values when calculated to a moist, mineral-matter-free basis falls within the range of subbituminous B (that is 22.1 to 24.4 MJ/Kg) and the non-agglomerating character of the sample was observed by examination of the residue or an agglomerate button showing swelling or cell structure in the crucibles during the volatile matter determination according to [14].

The proximate analysis result (Table 2) of the raw coal sample determines the distribution of its contents. The *as-received* results indicated that 48.2% weight of the sample leaves the sample when heated during the analysis, out of which 35.96% was volatile matter and 12.24% moisture content. The ash content of the sample was 7.27% and the fixed carbon content of the sample was 44.53%. These values give an overview about the properties and composition of the coal and also the values fall within the composition and property ranges for the subbituminous coal rank [15]

Table 2: properties of Raw Coal

	Moisture (%)	**Ash (%)**	**Volatile Matter (%)**	**Fixed Carbon (%)**	**Calorific Value (MJ/kg)**	**Sulphur (%)**
As-Received	12.24	7.27	35.96	44.53	21.71	
Dry Basis		8.28	40.98	50.74	25.09	0.55
Dry, Mineral-Matter-Free			44.18	55.82	23.57*	

1.2 Raw coal properties

Table 3 shows the properties of the prepared coal samples after being cleaned with 10, 15 and 20 percent cleaning agent respectively. With the values calculated on dry basis (that is moisture free basis). The analysis of the cleaned coal samples indicates that there is a general decrease in the ash content of the cleaned coal samples, when compared with ash value of the raw coal. Figure 2 shows that as the coal size increases, the percentage fixed carbon values of the samples decrease across the increase in percentage cleaning agent used. Increase in percentage cleaning agent gives rise to increase in fixed carbon value of the samples. The increase in fixed carbon value reached a maximum value at 15% cleaning agent for 1.0 and 1.7 mm coal size and at 20% cleaning agent for 2.0 mm coal size samples. This suggested that 15% cleaning agent was sufficient enough for 1.0 and 1.7 mm samples and that increasing the coal size (above 2.0 mm) requires an increase in cleaning agent quantity which in-turn increases the cost of coal cleaning. It was observed that coal cleaning favours smaller coal particles, this is because the fixed carbon value of 1.0 mm coal size was higher than that of 1.7 and 2.0 mm coal samples. The increase in fixed carbon value as coal size decreases indicated the increase in cleaning efficiency. This can be attributed to the fact that mineral matter is dispersed in coal matrix as fine particles and as a result, the finer the coal particle fractions, the more mineral matter is removed during cleaning of the coal [16] and the higher the efficiency of the cleaning process.

Table 3: Properties of Clean Coal Samples

Sample	Ash Content (%)	Volatile Matter (%)	Fixed Carbon (%)	Calorific Value (MJ/kg)
A_{10}	7.06	41.04	51.9	26.23
A_{15}	7.32	39.16	53.52	23.58
A_{20}	7.21	39.74	53.05	26.17
B_{10}	7.74	40.48	51.78	26.13
B_{15}	6.79	40.02	53.19	25.41
B_{20}	6.87	40.63	52.5	21.06
C_{10}	6.85	41.77	51.38	25.47
C_{15}	6.98	40.77	52.25	25.33
C_{20}	7.37	39.70	52.93	26.28

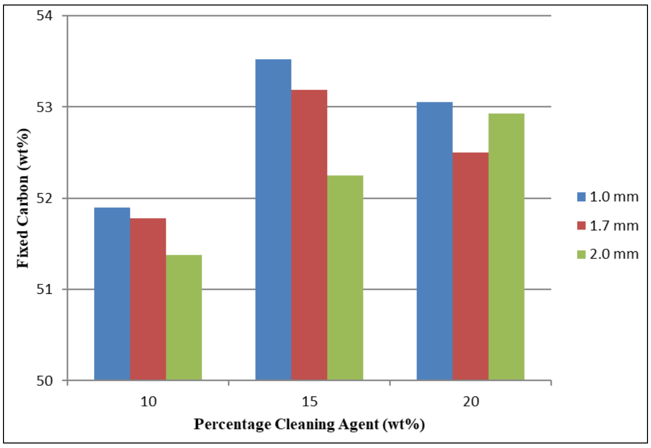

Fig 2: Effect of percentage cleaning agent on fixed carbon of samples.

Conclusion

Three coal sizes were studied in the production of coal-char by varying the percentage cleaning agent, carbonization temperature and time. They were evaluated for percentage carbon yield, bulk density, pH value, percentage fixed carbon content and adsorption capacity by iodine number determination.

All the three coal sizes show promising percentage yields of solid char with mean yields of 57.27, 57.88 and 57.53%, for 1.0, 1.7 and 2.0mm samples respectively.

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