

Properties of Activated Carbon Prepared from Coconut Shells in Ghana*

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Abstract

Activated carbons have applications in various industrial processes in Ghana including purification of water and gold adsorption from gold solutions. Materials commonly used for preparation of activated carbons include coal and coconut shells. Ghana generates over 30,000 tonnes of coconut shells annually from coconut oil processing activities but apart from a small percentage of the shells, which is burned as fuel, the remaining is usually dumped as waste. To increase recycling and utilisation of the coconut shells, activated carbons were prepared from the shells by carbonisation of the shells at 900°C in an inert atmosphere of nitrogen, followed by steam activation of the resulting char also at 900°C activation temperature and various durations of activation. The adsorptive properties determined for the resulting Coconut Shell Activated Carbons (CSAC) fell within the values of the reference commercial activated carbon (Norit RO 3515) commonly used by most Ghanaian mining companies. For example, the specific surface area of the CSAC reached a maximum value of 795 m²/g after 3.5 hours of activation: well within the range of 780-812 m²/g obtained for Norit RO 3515. Also, the maximum total pore and micropore volumes developed in the CSAC were 0.42 cm³/g and 0.38 cm³/g respectively compared to 0.44 and 0.39 for the Norit RO 3515.

1 Introduction

According to several authors (Bouchelta et al., 2008; Kim et al., 2001; Su et al., 2003; Guo and Lua, 2000; Marsh, 1997) activated carbon may be defined as 'a porous carbon material, a char, which has been subjected to reactions with gases, sometimes with the addition of chemicals; before, during or after carbonisation in order to increase its adsorptive properties'. Carbon is activated, by removing hydrogen-rich fractions and other volatile constituents from the carbonaceous raw material to produce an open, porous residue.

Activated carbons have applications in many processes including removal of colour, for example, from sugar syrup during the commercial production of sugar and also to remove odours and tastes from potable water, edible oils, fats and alcoholic beverages (Mudoga et al., 2008; Satyawall and Balakrishnan, 2007; Tennant and Mazyck, 2003). Many common water treatment processes do not effectively remove 2-methylisoborneol (MIB) and geosmin to below their threshold odor concentrations (Ishida and Mayaji, 1992; Kim et al., 1997). Adsorption by activated carbon has been shown to be the best available technology for controlling these odorants (Gilligly et al., 1998; Tennant and Mazyck, 2003). In the gold industry, activated carbon is used mainly to recover dissolved gold complexes from solutions (Soleimani and Kaghazchi, 2008; Navarro et al., 2006; Yalcin and Arol, 2002).

Activated carbon can be produced from almost all

carbon containing materials. In practice, materials such as coal, bones, sawdust, palm kernel shells and coconut shells, wood, peat, lignite, nut shells and fruit stones have been used for activated carbon manufacture (Daud and Ali, 2004; Su et al., 2003; Laine and Yunes, 1992; Guo et al., 2007; Guo and Lua, 2000). A suitable precursor must be cheap, readily available and possess high carbon content together with a low percentage of inorganic impurities (Rodriguez-Reinoso, 1997).

Coconut shells are generated in substantial quantities in Ghana mostly during extraction of oil from coconut fruits. It is estimated that about 27,000 tonnes of coconut shells are generated annually by established industries in Ghana in addition to what is generated by informal coconut oil processing groups. Out of this, only about 5% is burned as fuel and the remaining dumped as waste (Lartey et al., 1999). The low recycling level of coconut shells in Ghana is probably due to inadequate evidence on the properties of the shells and products obtained from them. The paper presents the properties of activated carbons prepared by carbonisation of coconut shells in Ghana to produce bio-char followed by steam activation of the resulting char. The qualities of the derived activated carbons have been compared with a commercial activated carbon.

2 Materials and Methods

2.1 Preparation of Activated Carbons

The coconut shells used in this research work were obtained from some coconut oil processing groups in

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Takoradi in the Western Region of Ghana. The shells were crushed and sized to obtain the 3.35 – 10 mm size fraction, which was washed with water and dried at 110°C in an oven till constant weight before pyrolysis. The pyrolysis of the raw material was carried out at 900°C under inert atmosphere of nitrogen in a static bed batch pyrolysis reactor to obtain a char product. The char was sized to obtain the 1.4 – 2.8 mm size fraction, which was physically activated using steam as the activating agent with a molar flow rate of 0.0279 mol/h/g. The selected size fractions of the shells and the char were intended to ensure production of granular activated carbon of particle size range of 1.4 – 2.8 mm, suitable for gold recovery applications. The steam activation was also carried out at 900°C in the same static bed batch pyrolysis reactor, which had been modified to provide steam for the activation process. The activation was carried out for 60, 90, 120, 150, 180, 210 and 240 minutes to obtain activated carbons with different burn-off.

2.2 Characterisation of the Activated Carbons

The properties of the derived activated carbons including their relative hardness, densities, surface areas and pore volumes were determined. The hardness of the derived activated carbons was determined relative to the hardness of a chosen reference commercial activated carbon, the Norit RO 3515, which is used in most Ghanaian mining companies. The determination was carried out using a Hardgrove test machine, in which 10 g of the activated carbon was placed in the bowl of the machine and subjected to abrasion in the presence of eight steel balls for 1 minute. The relative hardness number was determined as the ratio of the weight of the test activated carbon, retained on a 0.707 mm screen to the weight of the reference activated carbon, retained on the same screen.

The helium densities of the coconut shell char, obtained after pyrolysis at 900°C and the activated carbons derived from it were determined using a Micromeritics Accupyc 1330 instrument. The samples were dried at 110°C for 24 hours prior to the helium density measurements. Sample weights were determined to an accuracy of 0.0001 g using a Sartorius 2001 MP2 analytical balance.

The surface areas of the activated carbons were determined by the Brunauer, Emmett, and Teller (BET) method (Gregg and Sing, 1982) by adsorption of nitrogen at 77K onto the activated carbons. Their micropore volumes were calculated by application of the Dubinin Radushkevich (DR) equation to the nitrogen adsorption isotherms of the activated carbons (Dubinin and Radushkevitch, 1947). The characteristics of the derived activated carbons were compared with those of the reference commercial activated carbon, Norit RO 3515.

3 Results and Discussion

3.1 Yield of the activated carbons

Fig. 1 shows the yield of the activated carbons, obtained as a result of activation of the coconut shell pyrolysis char at 900°C with respect to activation time. The results show that the yields of the activated carbons decreased with respect to activation time from 100% to 41.2% after 3 hours of activation.

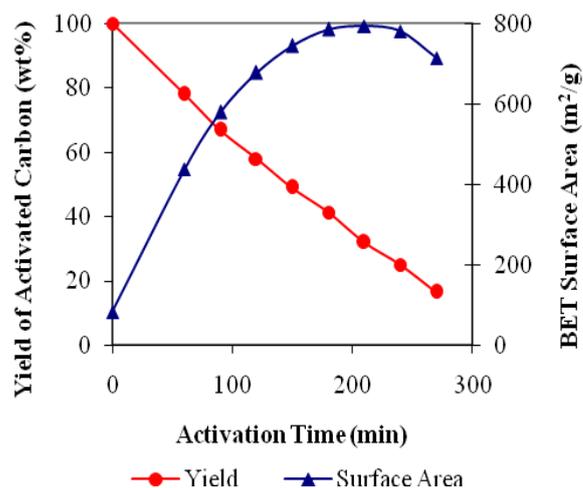


Fig. 1 The Yield of the Activated Carbons in Relation to Activation Times

The decrease in the yield of the activated carbons with activation time is attributed to increasing carbon-activation reagent reaction and consequently increase in the degree of carbon burn-off (Teng and Wang, 2000; Ariyadejwanich et al., 2003; Buah and Williams, 2010).

3.2 Density of the Coconut Shell Char and the Derived Activated Carbons

The apparent density of the char obtained from the pyrolysis of the coconut shells at 900°C prior to activation and that of the activated carbons produced from steam activation of the char at 900°C activation temperature and various activation times are presented in Fig. 2. An increase in activation time resulted in development of activated carbons with increased density. The density of the derived coconut shell activated carbons (CSAC) ranged between 1.91 and 2.04 g/cm³, which is comparable to the density of the tested commercial activated carbon (Norit RO 3515) of 1.94 g/cm³.

The results of density values obtained by Guo and Lua (2000), and Laine and Yunes (1992) for CSAC are in agreement with those obtained in the current research. Laine and Yunes (1992), for example, obtained average densities of 1.83 to 2.13 g/cm³ for CSAC produced under various conditions.

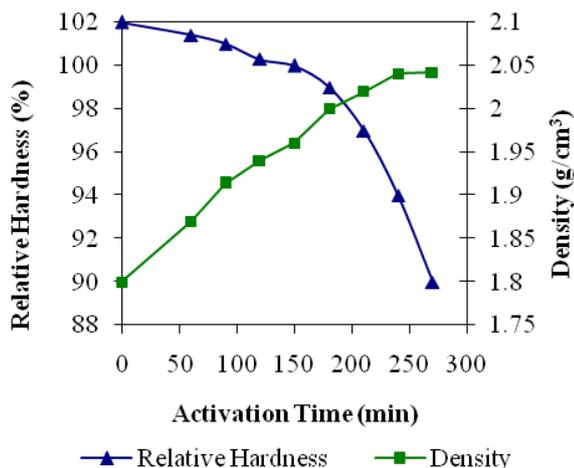


Fig. 2 Relative hardness and density of the coconut shell activated carbons, produced at 900°C activation temperature and various activation times

The results of density values obtained by Guo and Lua (2000), and Laine and Yunes (1992) for CSAC are in agreement with those obtained in the current research. Laine and Yunes (1992), for example, obtained average densities of 1.83 to 2.13 g/cm³ for CSAC produced under various conditions.

The increase in the apparent density of the derived activated carbons with increasing activation time is an indication of removal of lighter volatile materials from the activated carbons, opening of closed porosity, increasing ash content and densification of the carbon matrix during the activation process. Gale et al. (1995) indicated that the release of volatiles and increase in the true density of coal whatever the form and ash content is an indication of increasing ordering of layered carbon planes due to increase in aromaticity during devolatilisation. They indicated that this is not merely a function of increasing inorganic matter, but a densification of the organic char matrix.

3.3 Relative Hardness of the Activated Carbons

The hardness of activated carbons is a measure of their resistance to attrition. The higher the relative hardness value the more resistant the activated carbon is to attrition. The hardness of the activated carbons, produced in less than 3.5 hours of activation of the 900°C coconut shell pyrolysis char compared very well with that of the reference commercial activated carbon. However, a general decrease in hardness, as shown in Fig. 2, was observed with increasing activation time for the derived activated carbons. The decreasing hardness with increasing activation time could be attributed to increasing porosity of the activated carbons with increasing activation time.

Luo and Stevens (1999) investigated porosity-dependence of elastic moduli and hardness of 3Y-TZP ceramics. They concluded that the three elastic moduli (Young, shear and bulk) of material decreased with increasing porosity and went further to indicate that the effect of porosity on the hardness of the material is similar to its effect on the elastic moduli.

3.4 Nitrogen Adsorption Characteristics of the Activated Carbons

Fig. 3 shows nitrogen adsorption isotherms of some of the activated carbons obtained from the coconut shell char after activation for 60, 120, and 180 minutes at 900°C activation temperature.

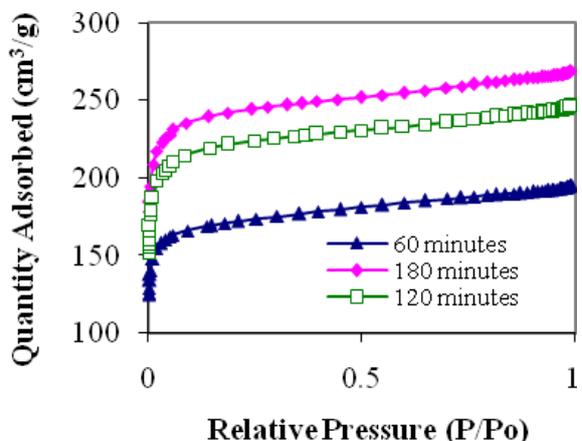


Fig. 3 Adsorption Isotherms of N₂ at 77 K on the Coconut Shell Activated Carbons, Produced at 900°C Activation Temperature and various Activation Times

The isotherms of the CSAC produced at smaller activation times, indicate the activated carbons demonstrated a microporous structure but developed a mesoporous structure at higher activation times.

The Dubinin Radushkevich plots from the nitrogen adsorption isotherms of the activated carbons were used to determine the micropore volumes of the activated carbons. The total pore volumes were determined from the N₂ adsorption isotherms and the results are shown in Table 1.

The table shows that the total and micropore volumes of the CSAC, produced after various activation times at 900°C, increased with the initial increase in the activation time up to 3.5 h. The maximum total pore volume and micropore volume of the derived activated carbons attained under the current experimental conditions were 0.42 cm³/g and 0.38 cm³/g respectively and compared very well with the total pore volume and micropore volume of 0.44 cm³/g and 0.39 cm³/g respectively of the reference com-

mercial activated carbon tested under similar conditions. After 3.5 h there was a decrease in both the total and micropore volumes of the derived activated carbons with increasing activation time. Devolatilisation during the early stages of activation develops rudimentary pores in the activated carbons and the C-H₂O reaction also enhances existing pores and creates new ones, thereby increasing the porosity of the activated carbons (Ariyadejwanich et al., 2003). The observed decline in the total and micropore volumes of the CSAC after 3.5 hours of activation could be attributed to excessive burn-off and even loss of some walls between pores.

Table 1 Surface Area and Pore Volumes of the Coconut Shell Activated Carbons, Produced at 900°C Activation Temperature and Various Activation Times

Activation Time (minutes)	BET Surface Area (m ² /g)	Total Pore Volume (cm ³ /g)	Micropore Volume (cm ³ /g)	Mesopore Volume (cm ³ /g)
0	82.77			
60	439.00	0.261	0.230	0.031
90	579.98	0.301	0.267	0.033
120	678.00	0.334	0.300	0.033
150	745.00	0.366	0.331	0.034
180	786.54	0.416	0.381	0.034
210	795.00	0.417	0.381	0.036
240	782.00	0.378	0.360	0.037
270	715.16	0.381	0.340	0.040

3.5 Surface Area of the Activated Carbons

The BET surface area of the activated carbons produced by steam activation at 900°C activation temperature and various durations of activation of the coconut shell pyrolysis char is shown in Fig. 1. The surface area of the activated carbons increased with increasing activation time, reaching a maximum value of 795.0 m²/g after 3.5 hours of activation and thereafter, an increase in the activation time resulted in a decline in the BET surface area. The increasing activation time resulted in a prolonged C-H₂O reaction, which consequently increased the degree of carbon burn-off and developed rudimentary pores and increased the surface area of the activated carbon. However, the decline in surface area of the activated carbons after 3.5 hours of activation could be attributed to excessive carbon burn-off, resulting in widening of their pores and even loss of some walls between pores. The surface area of the activated carbon produced after 3.5 hours of activation falls within the range of values (780 m²/g - 812 m²/g) obtained for the commercial activated carbon tested under similar experimental conditions.

4 Conclusions

Activated carbons were prepared by carbonisation of coconut shells produced in Ghana followed by steam activation of the resulting char at 900°C and various activation times. The qualities of the derived activated carbons strongly depended on the preparation conditions. The activated carbons demonstrated a microporous structure when the activation times were short but developed a mesoporous structure at longer activation times due to pore widening. The density, hardness and adsorption properties of the derived activated carbons were similar to those of the tested commercial activated carbon, Norit RO 3515. The process of producing coconut shell activated carbons in Ghana can be commercialised after an economic evaluation is undertaken for a large scale production process. If found profitable, this has the potential to generate employment for the youth, reduce foreign exchange spent on the importation of activated carbons, produce an invaluable accessory product for several industries and minimise waste generation by the coconut processing industry.

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