Activated Carbon for Water Treatment in Nigeria: Problems and Prospects

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Abstract A field survey of activated carbon (AC) users and usage in Southwestern Nigeria was made using both purposive and random sampling methods to pick respondents. The survey was to identify sources of AC used, the cost and specifications and relevant information for users. Using predetermined activation conditions, a locally developed furnace was to produce good quality AC from PKS sourced in three different parts of the Rain forest belt of Southern Nigeria under the same conditions used in a standard furnace modified for the process. The results of the survey showed that almost all AC sold in Nigeria are imported from Europe and Asian countries and they have no specifications. There is no evidence of local production of this high-demand engineering material. There was no locational variation in the quality of the carbon adsorbents currently produced which has comparable quality to imported ones. The AC industry is viable, especially from agricultural farm waste including palm kernel shells, which have a 70% yield of AC. There is the need to regulate or standardize AC imported or produced locally. The prospect for local production in developing countries is high and this will be enhanced by the development of equipment and adoption of appropriate production technology.

Keywords Activated carbon • activation furnace • adsorption • carbon yield • waste management

1 Introduction

Activated carbon (AC) is a valuable engineering material for water treatment and material refining. AC has wide acceptance for use because of its relative cheapness and universal adsorptive capacity for majority of impurities over other favoured

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adsorbents such as silica gel and molecular sieves. Despite its wide use and ready source of raw materials for its production, AC is imported by most major industries, in particular, from Europe and Asian countries such as Thailand and Malaysia. The high demand, especially from the growing *packaged water industries* (PWIs) that produce treated water in plastic sachets or bottles, has led to the presentation of ordinary charred materials as AC to unsuspecting buyers. This is because there are no ready methods for the determination of the quality, except in few companies such as the beverage and liquor industries, which mostly receive supplies directly from foreign sources.

Literature is replete with studies showing that AC can easily be manufactured from carbonaceous wastes such as palm kernel shells (PKS), coconut shells, corn cobs and stalks (Ogedengbe et al. 1985; Adewumi 1999, 2006; Guo and Lua 2000a–c) bagasse wastes, and most other agricultural and livestock wastes including blood. What is critical to each raw material used as matrix is the carbonization and activation conditions for the production and the medium for such processing (Adewumi 2006).

Obisesan (2004) has shown that there are many palm oil plantations producing fresh fruit bunches (FFBs). These plantations produce as much as 15–18 t per hectare-year of mean (FFBs) of palm fruits, of which 30–50% are of the improved *Dura* type and 30–65% are of the wild (unimproved) *Dura* end up as PKS. The resulting PKS from these was estimated by Obisesan (2004) to be about 64% of the total biomass produced as fruit bunch.

Adewumi and Ogedengbe (2005) have established conditions for the development of AC from PKS at laboratory scale level using a modified electric muffle furnace that allowed the introduction of activating medium through a pipe into a specially fabricated metal crucible. In a recent study Adewumi (2006) developed a solid fuel fired furnace that took cognizance of erratic electricity energy source and also took advantage of readily available biomass. The furnace was lined with lateritic clay and fuelled with charred PKS with inlet that feeds the activation water medium into the material being processed as recommended by Adewumi (1999). The PKS used in the production of AC in the study were sourced from three different locations Ile-Ife (South Western), Uromi (Delta region) and Port Harcourt (South Eastern) along the Rain forest belt of Southern Nigeria. These varied locations helped to determine locational variation in the quality of the carbon adsorbent. The AC produced with the fuel-fired furnace and the laboratory scale AC types had comparable adsorptive quality with a prominently used AC available on the market (Adewumi and Ogedengbe 2005; Adewumi 2006). The adsorptive capacities of the AC samples were tested according to standard methods and each had a minimum iodine value of 1,000 and a surface area of not less than 1,100 m^2/g of AC which are comparable to specifications given in literature (Adewumi and Ogedengbe 2005; Adewumi 2006). There was also no locational variation and significant difference at 95% confidence level in the quality of the AC produced. What is of paramount importance are the processing conditions and the heating method which for PKS has been determined as specified above.

This paper reports the major problems in the production of AC in Nigeria and the prospects of establishing a viable AC production industry not only in Nigeria but the entire West African rain forest belt sub region.

2 Materials and Methods

2.1 Field Survey

As a preliminary stage of the study on the characterization and specification of AC that can be produced from PKS for water treatment, field survey was made of Producers and Consumers of AC in southwestern Nigeria where most of the industry is concentrated. This involved the use of questionnaires and spot interviews of users and usage of AC. The key industries were first identified and then a decision as to the sampling method was taken based on the number of each type of industry. A list of registered PWIs prepared by the National Agency for Foods and Drugs Administration and Control (NAFDAC) was helpful in identifying industries within the study area.

The questionnaire used elicited information on the source and cost of AC purchased, the quantity required for operation per year and the impurities that the AC is expected to remove from the material being treated or processed. The ready availability of the material, whether or not they know other users and producers of AC, and if the AC bought or available came with specifications as to the quality and capacity, grain size, etc. were determined.

The sampling of the major multinational beverage or pharmaceutical industries was purposive because of the scarcity of plants, while the sampling of small scale enterprise establishments such as the PWIs was randomized using the *Epitab-Info 6* method (WHO 1991) to determine the minimum sample population. The list of registered industries in Osun State was keyed into the Excel package and the *RandF* programme was used to identify names with *RandF* values ≤0.33.

The analysis of the questionnaire was completed and the key impurities respondents expected to be removed were identified and used in the determination of the adsorptive capacity of AC that was produced in the laboratory from PKS apart from the standard tests for specification of carbon adsorbents.

3 Results and Discussion

3.1 Field Survey

The results of the field survey showed that AC is in high demand in Nigeria and the mean cost per kg varies between \$1.04 and \$1.67(₦ 125 and ₦ 200) (Adewumi 2006; Tables 1 and 2). There were 173 registered PWIs and beverage industries in Osun State

Table 1 Average quantity and cost of activated carbon (AC) used in removing specified impurities in sampled industries in Southwest Nigeria

S/No	Major industries using AC in Nigeria	Average quantity needed annually (purposive) (kg)	The mean (and range) of cost of AC (2002) ($:00/kg)	Average quantity needed annually (random) (kg)	The mean (and range) of cost of AC (2005) ($:00/kg)	*Code of impurities reportedly removed with AC
1	PWIs:		1 (0.83–1.67)	350	1.04 (0.83–1.67)	a–h
2	Beverages	2,000		350		a–h
3	Breweries	2,000	1 (0.5–1.67)		1.67 (0.83–2.33)	a, b, c, e, f
4	Pharmaceutical	750	1.67			a, c, d, f, g, h
5	Steel rolling mills	1,500	0.83			c, g, h
		(7.5 m^3)	1.25			

*Code of impurities in water/liquor usually removed with AC:

a – acidity

b – chlorine

c – colour

d – heavy metal ions

e – +microbes

f – (non-filterable) turbidity (NFT)

g – odour

h – taste

+Microbes are mainly removed with a combination of the ultraviolet light (UV) units and micro-filter units in all the packaged water industries (PWIs) visited.

at the time of the survey. Choosing values of z, d and p as being equal to 95%, 33% and 5% respectively the minimum sample was found to be 55. The summary of the responses to the inquiries in the questionnaire is presented in Table 1.

Both the purposive sampling of large scale industrial establishments in four industrial States (Edo, Lagos, Oyo and Osun States) and the randomized sampling of NAFDAC-approved PWIs in Osun State showed that AC is an essential engineering material needed for physical-chemical treatment of water and other liquids by adsorption. The analyses of the questionnaires showed that most of the TWIs have to replace spent AC within 3–5 months.

It is interesting to note that all the AC imported into Nigeria had no specification of iodine number, phenol value, methylene blue value, ash content, and appropriate medium for its use…Even NAFDAC has no specification yet for the types of AC to be used in the country. The only thing closest to a specification involves the requirements for the regulation of registration of PWIs. This is probably similar to requirements in developing countries. The methods used in quality testing in Table 2 showed that the major users have no scientific means of doing this due to lack of awareness or product education.

Table 2 Availability and specifications of AC in Southwest Nigeria

	Availability		Specifications	
Type of industry	Source of AC by industries	Usual weight of package (kg)	Specifications on package	[a]Coded method of quality verification
Packaged water industries:				
(i) Small scale	Open market	25	None	0^{++}, 2^{+}, 3^{+}, 5
(ii) Large scale	Open market	25	None	2, 3, 5
Beverages	Imported	20–25	None	4
Breweries	Imported	20	Grain size,	4, 6
Liquor	–	–	density	–
Pharmaceutical	Imported	[b]NS	–	2, 4
Vegetable oils	–	–	NS	–
Others:			–	
(i) Steel rolling mills	Imported/open market	20–25		4

[a]Coded methods of in-house verification of quality of AC in sampled industries:
[b]NS – not specified in the response to the questionnaire
0 – None
1 – Unspecified laboratory tests
2 – Visual assessment
3 – By hand abrasion
4 – Specified standard tests in in-house laboratory of the company
5 – Analysis by appointed consultant
6 – Claimed centralized analysis at the headquarters (of multinational companies) not known to respondent
Degree of responses: Numeral alone implies one or two respondents; ‘+’ as superscript implies *a few* respondents; and ‘++’ implies *most* respondents.

The study also showed that there are no major producers of AC in Nigeria, and even main users of AC only have information on where they buy the material and probably other users but do not know whether or not such AC comes with specification. Evaluation is made visually or taken at the seller’s words which experience and the findings presented in the present study have found to be far from the truth (Table 2).

The need for NAFDAC or other regulatory bodies to make it mandatory for producers or sellers of AC to provide specifications of the AC produced or imported into Nigeria cannot be overemphasized. Specifically, the listing of the iodine number, phenol value, grain size ranges, and medium for use must be put on the packaging for all AC whether imported or produced locally. Such simple procedures would enable quality verification by regulatory bodies and users.

For other farm wastes, such as corn cobs and stalks, the conditions for AC production have to be determined through laboratory analyses. Since these farm wastes are virtually free of charge, their conversion to carbon adsorbent adds value to the crops as it also provides a solution to solid waste management and pollution.

The charred PKS used by Adewumi (2006) was procured at about the cost of \$0.16–0.25 (₦ 20–30) per kg whereas the raw PKS would cost much less than this or even nothing to a farmer who wants to integrate AC production with oil processing. If the AC produced is then sold at the current market price of \$1.04–1.25 (₦ 125–150) per kg, it means the valorization of the erstwhile waste is both a viable venture and a source of employment. The use of PKS as fuel also reduces the cost of heat generation for the activation process. The cleaner environment and prevention of open burning of the wastes most importantly imply a cleaner production method.

In Adewumi (2006)'s study, the PKS and wood ash wastes from the heating of the PKS was used as raw material for extraction of the lye solution used for both the quenching of the charred shells and the activation of the pulverized shells. The need for chemical purchase for the activation is therefore solved within the same production process. Obisesan (2004) had shown that there is as much as PKS waste of 4.5–9.0 t/ha-year. Such quantity can support local AC production at a sustainable level.

The average AC yield producible from PKS in the optimization of AC production in the 2^3-factorial experiment is as shown in Table 3. For the BBC945 type of AC, which was the best in the study and had a 70% yield implies that at least 700 kg is producible from a metric ton of PKS. This aspect of the work is useful in estimating the quantity of AC that can be produced from a given mass of raw or charred PKS. It is also useful to engineers in the design of the furnace for activation of biomass.

With an estimated AC requirement of about 75 kg per filtration column and 150 t of AC per annum in Osun State alone or a conservative 4,320 t per annum in Nigeria. At a conservative selling price of \$1.04/kg this volume of wastes would generate an income of \$4.5 million from palm produce waste alone, not including other agricultural wastes. Even if a producer has to buy raw or charred PKS that presently costs less than \$0.16 per kg, 1.43 kg or say 1.5 kg of the raw or charred PKS will yield 1 kg of the BBC type AC which is at 70% yield. The operating and maintenance costs are not estimated in this present study but both are not expected to cost more than \$0.21 per kg. This will leave a net \$0.67 per kg as return on investment.

4 Conclusion

Activated carbon is in high demand in Nigeria by almost all industries. The results presented in this paper showed that although AC is not presently produced in Nigeria due to lack of facilities, the production equipment could be produced locally to meet local demands for AC. The AC materials imported to Nigeria presently have no specification and regulatory bodies on health and food are yet to provide information on the minimum standards for AC quality. The AC industry may be a viable industry that will turn current wastes into useful engineering material and provide producers with high return on investment if well managed. There is the need for regulatory bodies in Nigeria to enforce the listing of the specifications for AC on the packaging to facilitate quality control of such product.

Table 3 The effect of temperature, treatment medium and contact time on the yield of AC produced from PKS

AC code[a]	Mass after carbonization (%)	Average mass after carbonization (%)	Mass after activation (%)	Average mass after activation (%)	Average yield of process (%)
ACC520	90.24				
	79.9				
		85.1	–	–	85.1
BCC520	80.41				
	83.86				
		82.0	–	–	82.0
OCC520	81.71				
	89.03				
		85.5	–	–	85.5
BAC715	90.16		70.00		
	82.62		69.84		
		86.4		70.0	70.0
BAC745	91.84		67.14		
	84.38		66.41		
		88.4		66.8	66.8
BAC915	88.84		65.85		
	90.49		68.73		
		89.7		67.3	67.0
BAC945	89.87		58.14		
	89.01		66.23		
		89.4		62.2	62.0
BBC715	87.17		68.26		
	91.27		72.75		
		89.2		70.5	70.5
BBC745	92.03		72.40		
	85.14		70.00		
		88.58		71.2	71.2
BBC915	89.34		69.00		
	88.48		70.76		
		88.91		70.0	70.0
BBC945	90.63		73.72		
	86.55		65.82		
		88.59		69.78	70.0

[a]The codes ACC520, BCC520, OCC520 are PKS carbonized only and quenched in acidified water, alkaline water or ordinary water respectively; BAC715, BBC715 are BCC520 shells activated in acidified steam or alkaline steam respectively at 700 °C for 15 min; 745 ones are at a duration of 45 min; BAC915, BBC915 are the BCC520 shells activated in acid steam or alkaline steam respectively at 900 °C for 15 min; the 945 ones are at a duration of 45 min.

References

Adewumi, I.K. (1999), Development of a Commercial Grade Activated Charcoal Using Palm Kernel Shells, Unpublished M.Sc. thesis, Obafemi Awolowo University (OAU), Ile-Ife.

Adewumi, I.K. (2006), Characterization and Specification of Activated Charcoal Produced from Palm Kernel Shells for Water Treatment, Ph.D. thesis, Obafemi Awolowo University, Ile-Ife.

Adewumi, I.K. and Ogedengbe, M.O. (2005), Optimizing conditions for activated charcoal production from palm kernel shells, *Pakistan Journal of Applied Sciences*, 8(6):1082–1087.

Grayson, M. (ed) (1985), Kirk-Othmer Concise Encyclopaedia of Chemical Technology, Wiley, New York, pp. 97–105.

Guo, J. and Lua, A.C. (2000a), Preparation and characterization of adsorbents from oil palm fruit solid wastes, *Journal of Oil Palm Research*, 12:64–70.

Guo, J. and Lua, A.C. (2000b), Effect of surface chemistry on gas-phase adsorption by activated carbon prepared from oil-palm stone with pre-impregnation, *Separation and Purification Technology*, 18:47–55.

Guo, J. and Lua, A.C. (2000c), Effect of heating temperature on the properties of chars and activated carbons prepared from oil palm stones, *Journal of Thermal Analysis and Calorimetry*, 60:417–425.

Obisesan, I.O. (2004), Yield, the Ultimate in Crop Improvement, Inaugural Lecture Series No. 168, Obafemi Awolowo University, Ile-Ife.

Ogedengbe, O., Oriaje, A.T. and Tella, A. (1985), Carbonization and activation of palm kernel shells for household water filters, *Water International*, 10:132–138.

World Health Organization (WHO) (1991), An Epidemiologic Approach to Reproductive Health, Wingo, P.A., Higgins, J.E., Rubin, G.L. and Zahnizer, S.C. (eds), WHO, Geneva.