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ACTIVATED CARBON FROM AGRICULTURAL WASTE: PROCESS DESCRIPTION AND ECONOMIC ANALYSIS

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Abstract : Adsorption refrigeration technology has been intensively investigated in many countries of the world because of its promising potential for competing with conventional vapour compression refrigeration, its relatively low operating cost and its environmental friendliness. The search for a good adsorbent for solar powered refrigeration technology has led to various attempts to manufacture activated carbon of high adsorptive property. In this study coconut shells plus 10% animal bones, agricultural wastes, were used as basic raw materials for the local production of activated carbons. The properties determined were the particle size diameter, iodine no, hardness no, bulk density, and tamped density of the activated carbon samples.

The results for the coconut shells only of mesh size 14 and maximum particle size of 2.36mm are: iodine no, 906.68mg/g, hardness no, 1, bulk density, 0.504g/ml, tamped density, 0.562g/ml and ash content, 0.012%; while that of the coconut shells with 10% bones of mesh size 14 and maximum particle size of 2.36mm are: iodine no, 870.51mg/g, hardness no, 1, bulk density, 0.585g/ml, tamped density, 0.604g/ml and ash content, 0.06%. In comparison with the imported activated carbons these can be classified as medium grade carbons.

This work has established the fact that activated carbons, the principal component for solar powered refrigeration technology can be locally sourced without compromising standards.

1. Introduction

Activated carbons are microcrystalline solids, which exhibit high porosity, adsorptive capacity and enormous surface area, which are produced from organic based materials. Its internal surface allows for the adsorption of organic materials as well as non-polar compounds and metal from gas and/or liquid media. For many decades activated carbons have been produced from a number of carbonaceous materials like coals, lignite, peat and wood. However agricultural wastes or by-products such as coconut shells, palm-kernel shells, wood chips, sawdust, corncobs, and un-commercial fruits still remain the cheapest and renewable sources of activated carbons [1].

The problem of waste management in Nigeria is an age long one. For many years, the problems of waste storage, collection, transportation, disposal, utilisation and environmental sanitation in our cities and urban areas throughout the country have occupied the attention of the Federal, State and Local Government Authorities. In Nigeria, about 21 million hectares of land is being cultivated every year for agricultural production with enormous amount of waste.

Keywords : Refrigeration, Solar, Adsorption, Activated Carbon, Mesh size

For Ibadan farmland, agricultural waste constituted about 18.8% of the 190,000 metric tonnes solid waste generated in 1998[2].

Activated carbons have several important uses, which include water purification such as in water treatment plant, gold mining, brewery and soft drink industries. Its also been used in solution purification in vegetable and animal fats and oil, alcoholic beverages, chemical and pharmaceutical industries and also in purification of gases, liquid phase recovery and separation processes as well as catalyst and catalyst supports. Globally, the demand for activated carbons is on the increase. Ghana for example imports substantial amount of activated carbon annually. Within the period 1992 to June 1997 Ghana imported a total of 4,681,866 kg of activated carbon value at 12 706 290.80 cedi. Obviously, Nigeria spends more than this amount on importation of activated carbon [3].

Many authors have reported on the capability of activated carbons for solar cooling purposes [4-10]. They all agreed that with the recent development in the area of adsorption technology efforts must be geared towards the production of activated carbons from agricultural wastes.

1.1 Justification

The development of local capability for the manufacture of activated carbon from agricultural waste will help in the processing and utilization of the enormous quantity of agricultural and wood residues generated annually in Nigeria. Between 1981 and 1993, the quantity of sawdust generated in the country has increased from about 1.72 to 3.87 million m^3 and there has been a steady increase since then due to expansion in the sawmilling industry [2]. These agricultural waste, which constitute environmental and health hazard presently, will be processed into an economic product with great important and as potential raw material for our industries.

Particularly on our campus, the development of this local capability for manufacture of activated carbons and re-activation of spent activated carbon will serve as basic raw material supply for purification of water in our water treatment plant and hence a drastic reduction in the huge sum of money spent by the University Council on the purchase of activated carbon.

On national level, the development of this local capability for manufacture of activated carbons will also help to limit the huge amount of our national reserves that goes into importation of activated carbon.

1.2 Goals

The main thrusts of the project are :

1. To apply the extensive knowledge and research findings of many years in the Faculties of Technology and Science in the development of a local capability for the manufacture of activated carbons from agricultural waste and the re-activation of spent activated carbon for the University of Ibadan water treatment plant.

2. To develop a local technology for a solar-adsorbent refrigeration system using activated carbon. This refrigeration system does not require electricity and is therefore most suitable for rural dwellers.

Coconut shells, palm kernel shells and sawdust will remain main targeted agricultural waste of this project because of their relative abundance in our community and the volume of research works that have been done on them.

1.4 Methodology

This project will be executed in five phases as follows :

Phase I Collection and transportation of Feedstock : In this phase, the coconut shells, palm kernel shells and sawdust will be sourced for, collected and transported to UI. The feedstock will be sorted and necessary laboratory evaluation of the feedstock will be carried out.

Phase II Design and fabrication of Machines : In this phase one unit each of pulverizing machine, drying machine, stream generating machine and furnace/reactor will be designed and fabricated using locally sourced materials. This fabrication will be done in the Faculty of Technology Metal and Wood Workshop, University of Ibadan.

Phase III Installation and testing of Machines : The designed machines will be installed and tested in the Faculty of Technology, University of Ibadan for a period of 5 months to study the system characteristics for possible optimization.

Phase IV Production and re-activation of activated carbons : In this phase activated carbons will be produced from coconut shells, palm kernel shells and sawdust of some selected African timbers. The products will be characterized and their appropriate applications for water purification will be determined. Re-activation of spent activated carbon from UI water treatment plant will also be carried out in this phase.

Phase V Design and fabrication of a solar-adsorbent refrigeration system : A solar-adsorbent refrigeration system using activated carbon will be developed in this phase for use in rural areas for refrigeration and for preservation of vaccine in rural areas where electricity is not available.

2. Process of manufacturing activated carbon

The process of activated carbon generation begins with the selection of a raw carbon source. These sources are selected based on design specifications, which include pore structure, particle size, total surface area and void space between particles, since different raw sources will produce activated carbon with different properties. After the selection of a source the feedstock is sorted to remove dirt and other inorganic component before crushing or pulverizing into suitable size. The crushed feedstock is then dehydrated or dried to remove moisture. The moisture content of the feedstock is an important parameter. If the moisture content is about 20% the water driven off during the early stage of pyrolysis or carbonization, reacts with off-gasses or impedes their removal. This allows the off-gasses to crack and restrict micropores opening in the product.

After dehydration, carbonisation or pyrolysis process, which involves slow heating of the feedstock in anaerobic conditions takes place. The use of chemicals such as zinc chloride or phosphoric acid as catalyst during dehydration and carbonisation has been found to enhance the processes. The main product of the carbonisation process is the carbonaceous char, with other by-products such condensable and non-condensable gases, and aqueous phase containing pyrogenic acid. The carbonised char may further be crushed to size, where necessary, before activation. The activation process involves the heating of the char to high temperature and addition of oxidizing agents such as steam or chemicals such as mixture of gases. The products of the activation process are the activated carbon and other gases such as H_2, CO and CO_2. The activated carbon is grounded or pulverized in to granules or powder. The processes required for the manufacture can be summarized in a flow sheet (Figure 1).

2.1 Raw materials availability

Studies carried out at the Federal Institute of Industrial Research Organization (FIIRO) and other independent researchers on raw material resource assessment for activated carbon production focused on the following wastes : coconut shells, saw dust, animal bones, cowries shells, and cereals.

Major producing areas of these wastes are : Badagry, Port Harcourt, Niger Delta areas, Forest region, Middle Belt areas and South West of Nigeria. The study revealed that the generation and availability of the raw materials coconut and palm kernel shells are linked to the production of the main products : coconut oil, palm oil, and palm kernel oil.

Production of these oils by the small scale or traditional producers is spread over various areas in the country whilst the established industries engage mainly in the production of palm oil.

However, to get access to palm kernel and coconut shells is relatively easier as many of the established industries crack the nuts to produce the kernels and shells. The kernels are further processed by the industries whilst the shells are dumped as wastes. It is interesting to know that both coconut and palm kernel shells produced by the traditional producers are sold as fuel for rural dwellers in the part of the country where electricity is not available.

For the pilot study carried out by the team in the Mechanical Engineering Department, University of Ibadan, Ibadan, it was discovered that major producing areas of these wastes (Palm kernel and Coconut shells) are at Badagry in the coastal region of Lagos state, and Western Nigeria. In these places palm trees are grown in large quantities. The spread of agricultural wastes within Nigeria is shown in fig-2.0

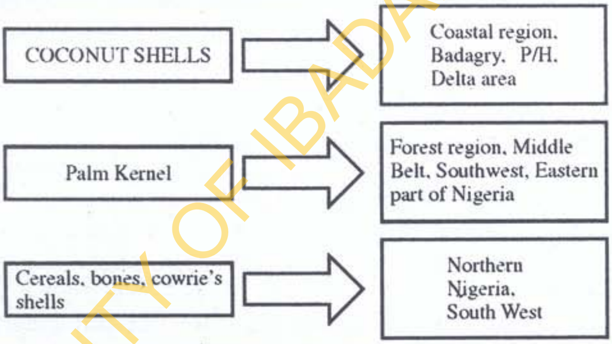

***Fig-2.0 :* Sources of materials for Activated carbon production in Nigeria**

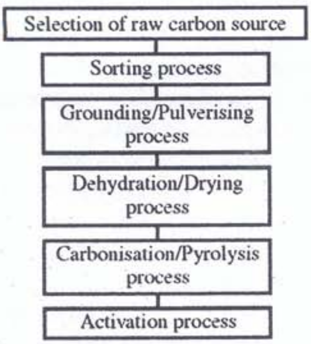

***Fig-1 :* Process flow sheet for the manufacture of activated carbon**

2.2 Project duration and work plan

The work plan for the project showing the time frame for each phase of the project is shown in Figure 2. The project is expected to be completed in about 24 months.

2.21 Project budget

The proposed budget for the project is presented in Table 1. The project is expected to cost a total of ₦2.0 million.

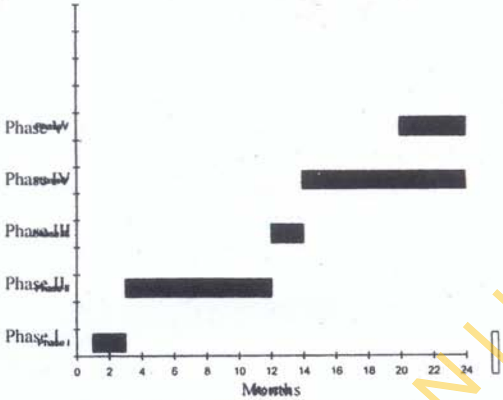

Fig-2 : **Project Activity Duration Chart**

Table-1 : **The Proposed Budget for the project**

A. **Phase I** Collection and transportation of Feedstock	100,000
Phase II Design and fabrication of Machines :	
Pulverising machine	300,000
Drying machine	200,000
Steam generating machine	300,000
Furnace/reactor	500,000
Phase III Installation and testing of Machines	200,000
Phase IV Production and re-activation of activated carbons :	
Purchase of chemicals	200,000
Phase V Design and fabrication of a solar-adsorbent refrigeration system	200,000
B. Honorarium for researchers :	
Project Team Leader	500,000
Project Team Members (@N300, 000 each)	2,100,000
C. Project report Preparation	200,000
D. Incidentals	200,000
Total budget	₦ 5,000,000

2.2 Raw material preparation

The first basic stage in the process of carbonization is the preparation of raw materials. The raw coconut shells were sorted out of dirt and then separated from the husk. Thereafter, the collected shells were crushed using pestle to suitable sizes. The crushed coconut shells were dried in an oven at a temperature of 70°C for about three hours. This was done to reduce the water content to a manageable limit. The moisture content of the raw material plays a very significant role in the activation process. If the moisture content is about 20%, the water driven off during the early stages of pyrolysis reacts with off gases or impedes their removal. This allows the off-gases to crack and restrict micropores openings. The carbonization was carried out without provision for the collection of the distillate material which contains some condensable and non-condensable gases.

2.21 Carbonisation process

This process (carbonization) was carried out at Federal institute of industrial research (FIIRO)

Oshodi-Lagos-Nigeria. The burning of the raw coconut shells was achieved with a gas fired kiln operated at temperature of between 650°C-800°C for about two hours. This temperature was maintained until complete carbonization was achieved. The carbonized shells were quenched using water as quenching medium. The yield obtained after this process was found to be about 20% meaning that 10kg shells produced about 2kg of activated carbons.

2.22 Activation process

This process involved treating the carbon specially with chemicals with the sole aim of opening an enormous number of pores in the 1.2 to 2.0 nanometer diameter range for gas-adsorbent carbons or up to 100 nanometer range for decolorizing carbons. After activation, the carbon is expected to have a large surface area to have good adsorption capacity.

Basically, there are two manufacturing processes for activation of carbons : Chemical activation and stem activation. Chemical activation is used for the production of activated carbons from almost all base materials including the coconut shells while the steam activation is generally used for coal-based materials. With this background information chemical activation was adopted in this work using phosphoric acid as activating agent. The carbon was soaked in the chemical and allowed to stay for about 24 hours before it was finally washed and dried in an oven. The produced activated carbons were then screened to remove fine sand dust using a 2.8 mm mesh sieve to meet the specification for a granular activated carbon (GAC).

3. Evaluation of physical, chemical and adsorption properties

To ascertain the suitability and adsorptivity of the produced carbons the following standard tests were carried out on the sample : Iodine number, Ash content, Bulk/apparent and tamped densities, Hardness, Abrasion no/particle size diameter and pore size distribution. Experimental results obtained were shown in Tables 2-5.

There are other properties apart from the above tested ones. These include : Carbon tetrachloride activity, internal surface area, Molasses number, Butane number, Total surface area and Feasibility testing.

4. Results and discussion

Costs were developed for the capital outlay for establishing manufacturing industries for coconut/palm kernel based activated carbon. The process flow sheet for the manufacture of

Table-2.0 : **Iodine No**

Samples	Wt. of sample (W)	Vol. of 0.1N Iodine solution	Vol. of 5% HCl solution	Vol. of filtrate used	Titre value of 0.1M Na Thiosulphate	Filtrate Normality	Factor
Activated Palm Kernel shell	1.0 g	10 ml	100 ml	50 ml	11.0 ml	0.022	0.98
Non-activated P.K. shell	1.0 g	10 ml	100 ml	50 ml	8.0 ml	0.016	1.04
Activated P.K. + 10% animal bone	1.0 g	10 ml	100 ml	50 ml	13.0 ml	0.026	0.96
Non-activated P.K. +10% animal bone	1.0 g	10 ml	100 ml	50 ml	10.0 ml	0.020	1.00

Table-3.0 **: Tamped Apparent Density**

Samples	Lb/ft²	Wt. of cylinder 100 ml	Wt. of sample + cylinder	Vol. of sample (ml)	Wt. of sample (g)	Tamped or apparent density (g/ml)
Activated Palm Kernel shell	41.64	132.44	183.77	92	61.33	0.667
Non-activated P.K. shell	40.89	132.44	191.40	90	58.96	0.655
Activated P.K. + 10% animal bone	44.18	132.44	193.90	87	61.46	0.706
Non-activated P.K. + 10% animal bone	43.14	132.44	193.63	88.5	61.19	0.691

Table-4.0 **: Bulk Density**

Samples	Wt. of cylinder 250 ml	Wt. of sample + cylinder(g)	Wt. of sample desired(ml)	Wt. of sample (g)	Bulk density (g/ml)	Lb/ft²
Activated Palm Kernel shell	231	332.25	150 ml	101.25	0.675	42.14
Non-activated P.K. shell	2.31	329.16	150 ml	98.16	0.654	40.83
Activated P.K. + 10% animal bone	2.31	328.27	150 ml	97.27	0.648	40.45
Non-activated P.K. + 10% animal bone	2.31	324.02	150 ml	93.02	0.620	38.71

Table-5.0 **: Sample B: Activated carbon (P.K.) + 10% Animal bone**

S/N	Sieve No	Wt. of sieve(g)	Wt. of sieve + sample(g)	Wt. of sample retained	% of sample retained
1	500 mesh	485	574	89	59.33
2	355 mesh	420	443	23	15.33
3	250 mesh	450	470	20	13.33
4	180 mesh	435	440	5	3.33
5	125 mesh	380	389	9	6.00
6	90 mesh	420	423	3	2.00
7	53 mesh	386	386.7	0.7	0.46
8	Base	401	401.3	0.3	0.20

activated carbon is shown in Fig.-1. The estimated budget for the plant is shown in Table-1. Experimental results are shown in Tables 2-5. Fig.2 shows the project duration activity chart for twenty four months. It was observed that the non-activated coconut shells exhibited high iodine no while the non-activated coconut shells with 10% bones exhibited higher iodine no.

For coconut shells only with mesh size 14 and maximum particle size of 2.36 mm, the following properties were identified : iodine no (906.68), hardness no (1), bulk density (0.504 g/ml), tamped density (0.562g/ml), and ash content (0.012%). The coconut shells with 10% bones had these properties: iodine no (870.51mg/g), hardness no(l), bulk density (0.585g/ml), tamped density (0.604g/ml), and ash content (0.062%). When compared with the available data in the literature, these products with these properties can be regarded as medium grade activated carbons.

5.0 Conclusions

From this preliminary work it can be concluded that activated carbons, whether coconut or palm kernel shells based can be produced locally with simple technology without compromising the standard. The proposed budget for the capital outlay for establishing a plant for the local production of coconut/palm kernel based activated carbon has been estimated to be around five million naira (₦5 000 000.00 or $41666.68). Chilton Ng et al [10] developed costs assuming a 30% yield or 3000 kg/day output of acid-activated carbon, 320 days/year of production, and three men per shift for 24 h/day at $18 per hour. The total estimated cost for phosphoric acid activation of pecan shells was $6324000 and annual operating cost of $2784000.

Toles et al.,[7] as reported by Ng et al.,[10] developed estimated costs of production for both steam-activated and phosphoric acid-activated almond shell carbons. They determined a production cost of $1.54 per kg for steam activation of almond shells. The capital outlay for establishing a production plant for activated carbons is within the reach of an average industry in this country (Nigeria) with little encouragement from the government. The local production will conserve the foreign exchange and generate employment opportunities for the teeming population of unemployed youth in the country.

Acknowledgement

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