

Developing a Local Capability for the Manufacture of Activated Carbon from Agricultural Waste.

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ABSTRACT

Commercial activated carbons are produced from bituminous and lignite coal. The environmental impacts and potentially increasing cost of coal has encouraged the search for other alternatives in agricultural wastes. The objectives of this study were to develop process flow diagrams for the large scale production of activated carbon from three agricultural wastes namely: coconut shells, oil-palm shells, and sugarcane bagasse as well as carrying out an economic evaluation to estimate the cost to manufacture these activated carbons.

Process flow diagrams were developed for the steam activation of coconut shells, steam activation of sugarcane bagasse and phosphoric acid activation of oil-palm shells. Process parameters were calculated for a production facility of 10,000 kg of each of the raw materials per day. Final product yields were approximately 50% for steam activation of coconut shell, 19.4% for steam activation of sugarcane bagasse, and 30% for the phosphoric activation of oil-palm shell. Therefore 5000Kg of the steam activated coconut shell, 1940Kg of the steam activated sugarcane bagasse and 3000Kg of phosphoric activated oil-palm shell could be produced per day. Mass losses were however incurred in the milling process (about 20%), during pyrolysis (about 65% for steam activation of coconut shell, 70% for steam activation of oil palm shell and 75% for phosphoric activation of sugarcane bagasse), during washing/drying (about 13% in all) and during sieving(about 5% in all).

Based on an annual cost of manufacturing of about N 552,000,000, annual produced quantity of 582,000Kg, steam activation of coconut shell would cost N442.81 per Kg. Also based on an annual cost of manufacturing cost of N567,000,000 annual produced quantity of 582,000Kg, steam activated sugarcane bagasse

would cost N1192.996 per Kg. And based on an annual cost of manufacturing of about N449,000,000 annual produced quantity of 900,000Kg, phosphoric acid activated carbon would cost N600 per Kg. All produced quantities were based on 300 days of production annually.

(Keywords: activated carbon, coconut shell, oil-palm shell, sugarcane bagasse)

INTRODUCTION

Activated carbon is a microcrystalline form of carbon with very high porosity and surface area. It is a form of carbon that has been processed to make it extremely porous and thus to have a very large surface area available for adsorption or chemical reactions.

Activated carbons are solid, porous, black carbonaceous material. They are tasteless (Budavari, 1996). Activated carbons are obtained from a carefully controlled process of dehydration, carbonization, and oxidation of organic substances. Most carbonaceous materials including agricultural waste do have a certain degree of porosity and an internal surface area in the range of 10-15m²/g. This increases during activation after which the carbon will have acquired an internal surface area between 700 and 1200m²/g.

There are three groups of pores that can be distinguished in an activated carbon:

1. Micropores (0-20 Angstrom*)
2. Transitional pores (20-500 Angstrom*)
3. Macropores (> 500 Angstrom*)

*One angstrom = 0.0000001 mm, or one tenth the size of a sugar granule.

Activated carbons are generally grouped into three main forms. These are:

1. Granular Activated Carbon (GAC) which are Irregular shaped particles sizes ranging from 0.2 to 5mm.
2. Powder Activated Carbon (PAC) which are pulverized carbon with a size predominantly less than 0.18 mm (US mess 80) used mainly in liquid phase applications and for flue gas treatment.
3. Pellet Activated Carbon which are extruded and cylindrical shaped with diameters from 0.8 to 5mm. They are mainly used for gas phase applications because of their low pressure drop, high mechanical strength, and low dust content (Wan Nik et al., 2006).

The raw material for an activated carbon plays a major part in determining the ability of the final product to adsorb certain molecular species. Activated carbons produced from coconut shells exhibit a predominance of micropores, while coal based carbons have a wider range of transitional pores. The development of an extensive macropore structure is found when either peat or wood is used as the raw material.

Sugarcane bagasse is a byproduct of the sugarcane industry obtained after the extraction of juice for production of sugar. Studies reveal that 54 million dry tones of bagasse are produced annually throughout the world (Umesh et al., 2001). In Nigeria, a relatively large quantity is produced from the sugar industries. Its uses are as fuel for boilers and as raw material for the manufacturing of pulp, paper, and building boards (Qureshi, et al., 2008).

Bagasse had been modified physically and chemically to enhance its adsorptive properties towards organic molecules or metal ions, routinely found in water and wastewater. This is effectively accomplished by converting bagasse to an activated carbon. Bagasse is reported as a suitable resource for preparation of activated carbon. (Qureshi et al., 2008). Sugarcane bagasse-based activated carbons have been evaluated for their ability to act as adsorbents for sugar de-coloration (Lavarack,1997).

Coconut is grown all over Nigeria in large quantities. A typical Nigerian coconut trees produce approximately 120 melon-sized fruits per

year. Each fruit has approximately 1.6 kg of total mass, consisting of 35% husk, 28% copra, 12% shell, 5% milk, and 20% water in the husk. Coconuts are purchased in market places around Nigeria with the husk already removed. The shells are not consumed but are disposed of and are found littering the streets especially in the suburban areas constituting environmental nuisance.

The cellulosic structure of coconut shell determines its end product characteristics, which (at 30-40% yield on the carbonized basis) is a material of very high internal surface area consisting of pores and capillaries of fine molecular dimension. The pores are predominantly in the micropores range and these account for 95% of the available internal surface area. Activated carbon produced from coconut shell is granular with a highly effective adsorption properties. It only needs a short contact time and is an excellent alternative to palletize coal-based activated carbons. It is mostly used in gas phase and odour adsorption. Apart from being cost effective, experience has shown that it provides superior performance in an extensively array of gas phase treatment applications.

Oil palm shell is abundantly available as a solid waste from palm oil production operations especially in rural parts of Nigeria. Palm oil, which is used for cooking in Nigeria, is largely demanded and so its production rate is high. Oil-palm shell (also called endocarp) from palm oil processing mills is an agricultural solid waste. In Nigeria, about 90,000 tonnes of oil-palm shell are generated annually. Oil palm shells are also used as a boiler fuel or building material. Oil palm shells have been shown to make high quality activated carbons which are applicable in both liquid and gas phase adsorption.

METHODS

Process Flow Diagram for the Production of the Activated Carbon: The process flow diagrams used in this study are based on process descriptions culled from research by Chilton Ng, Wayne Marshall, Ramu M. Rao, Rishipal R. Bansode, Jack N. Lasso, and Ralph J. Portier in their work "Granular Activated Carbons from Agricultural By-products: Process Description and Estimated Cost of Production" which represents the culmination of research carried out by Pendyal et al. (1999) and Johns et al. (1998) for

the steam activation of sugarcane bagasse, Johns et al. (1999) for the steam and carbon dioxide activation of pecan shells, and Toles et al. (1998) for the phosphoric acid activation of pecan shells. Numerous variations to pyrolysis and activation temperatures were employed based on the fact that the agricultural material used in these processes differed and researches has shown that they produces good yield at different activation and pyrolysis temperatures. The process flow diagram was designed as to determine the basic process equipment necessary for constructing a manufacturing facility for the manufacture of GAC from the agricultural raw material chosen. The economic cost analysis were Microsoft Office Excel® based.

The development of the process flow diagrams was followed by the estimation of the equipment and capital costs which, as in the parent work, were from a combination of vender quotes and printed literature. Equipment costs represent actual purchase costs and not investment costs. This capital cost estimate was then used in a procedure to estimate fixed capital investment using ranges of process-plant component costs. The procedures from Peters and Timmerhaus (1991) were used for a high degree of automatic control and outdoor operation. Most equipment as designed by Chilton et al. was designed using procedures from Green (1984), McCabe et al. (1985), Peters and Timmerhaus (1991), Ertas and Jones (1993), or Biegler et al. (1997) referenced from Chilton Ng et al. (2003).

The design used carbon steel for the fabrication of the equipment and so all equipment costs, unless otherwise noted, are based on carbon steel.

RESULTS AND DISCUSSIONS

Process Description

Three activation processes will be considered for this work, these are:

1. Steam activation of coconut shell
2. Steam activation of sugarcane bagasse and
3. Phosphoric acid activation of oil palm shell

The diagrams for these three processes are shown in Figures 1, 2, and 3, respectively.

Steam activation of coconut shell (Figure 1)

The process description for the steam activation of coconut shell was a modification of the process for the steam activation of peacan shell culled from Chilton's et al. "Granular Activated Carbons from Agricultural By-products: Carbons from Agricultural By-products: Process Description and Estimated Cost of Production". The process was first outlined by Johns et al. (1999). The difference between the process described in this work and the former was the variation in the carbonization and the activation temperatures in the rotary kiln. The unit operation was also for the former operations are sample preparation, pyrolysis/activation, and screening/collecting. A yield value of between 50-52 percent for pyrolysis/activation of coconut shells is anticipated.

The description of the unit processes as described by Chilton et al. modified for the case of coconut shell is as follows.

Sample Preparation: Clean and dry coconut shells with moisture content of less than 13 percent are required for carbon production. Just like Chilton et al., long-term shell storage was not provided as it was anticipated that the 10,000 kg/day of shells would be delivered to the production facility and all shells would be processed the same day. The process begins by feeding clean and dry coconut shells into an 11.2 kW carbon steel hammer mill and milled to a 10- to 40-mesh (2.00 to 0.425 mm) particle size. Coarse particles (larger than 2.00 mm) were recycled back to the mill to produce more feedstock. Fine particles (smaller than 0.425 mm) generated by the hammer mill is to be directed for disposal or other use, such as to a boiler to provide the steam required for activation by burning the fines. The process stream is then to be directed into a rotary kiln.

Pyrolysis/Activation: Though a built-in-place kiln lowers expenses, a dual kiln system made from carbon steel with a chamber size of 4.6 m x 1.5 m and a 0.15 m refractory liner in each kiln is used in this design. This is to aid shipping from the fabricators to the manufacturing site. The process stream was split to feed each kiln. The shells were fed to the rotary kiln where pyrolysis can occur by maintaining the shells at 500° C for one hour under an inert atmosphere comprised of off-gases generated by pyrolysis.

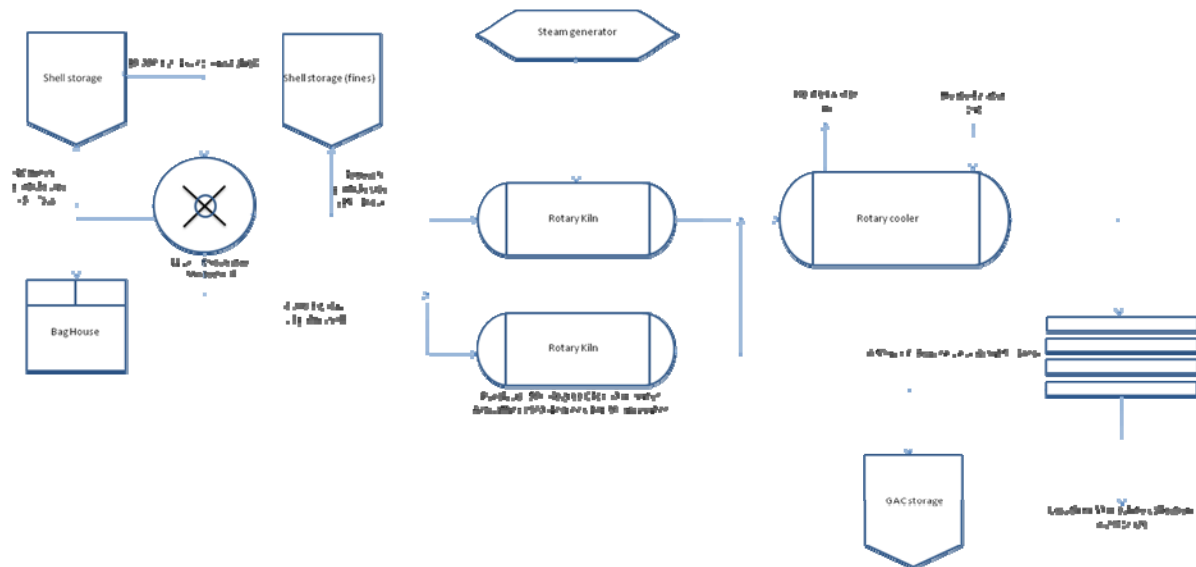


Figure 1: Steam Activation of Coconut Shells.

Considerable waste heat is available from this process, as well as off-gases generated during pyrolysis that are capable of further combustion. After pyrolysis, the char will be heated to 900° C for 30 minutes in the presence of steam to achieve activation (Pari, et al.). After activation, the carbons were conveyed to an indirect rotary cooler, one of the few types of coolers that can operate at high temperatures. Assuming a process stream (mass flow rate) of 1,440 kg/day, a rotary cooler with a surface area of 2.32 m² will be necessary to reduce temperature from 850° C to less than 100° C in less than 1 hour. The equations of McCabe et al. (1985) were followed in establishing the rotary cooler surface area required.

Screening/Collecting: After cooling to a temperature of 100° C or less, the carbon will be sieved to retain the 0.425- to 2.00-mm particles. A 0.53 m x 0.76 m sieve is adequate for this. A carbon loss of 5 percent is anticipated. The fines can be separated and bagged separately as powdered carbon. The 0.425- to 2.00-mm activated carbon can then be taken for bagging and storage. The bagging station was not included in the process flow sheet. Final yield for steam-activated coconut shell-based GAC is an estimated about 50.5 percent (Pari, et al.), or 5,000 kg/day of product generated based on a 10,000 kg/day feed.

Cost Analysis (Appendix Table 1a-f): Costs were developed assuming a 45 percent yield of coconut shell-based activated carbon (5,000 kg/day output), 320 days per year of production and two men per shift (three shifts) for 24 hours a day at N1000/day. Production of 1,120,000 kg/year of steam activated pecan shell carbon requires a fixed capital investment of about N727,080.590.00 and an annual manufacturing cost of about N551,709,114.00. The estimated product cost is about N442.81/kg.

Steam Activation of Sugarcane Bagasse (Figure 2): The process description described for the steam activation of sugarcane bagasse was culled from Chilton's et al. "Granular Activated Carbons from Agricultural By-products: Process Description and Estimated Cost of Production" which was an evolution of the a process Pendyal et al. (1999a), who used bagasse mixed with one of several binders, including sugarcane molasses and then pyrolyzed the samples and activated them with a mixture of carbon dioxide and nitrogen gas. The Pendyal et al. process was modified by Johns et al. (1998) who activated a bagasse/cane molasses mixture with steam after using the pyrolysis method of Pendyal et al. (1999). Chilton and his colleagues chose steam as the activant for the their process due to the lower cost of steam compared with carbon dioxide.

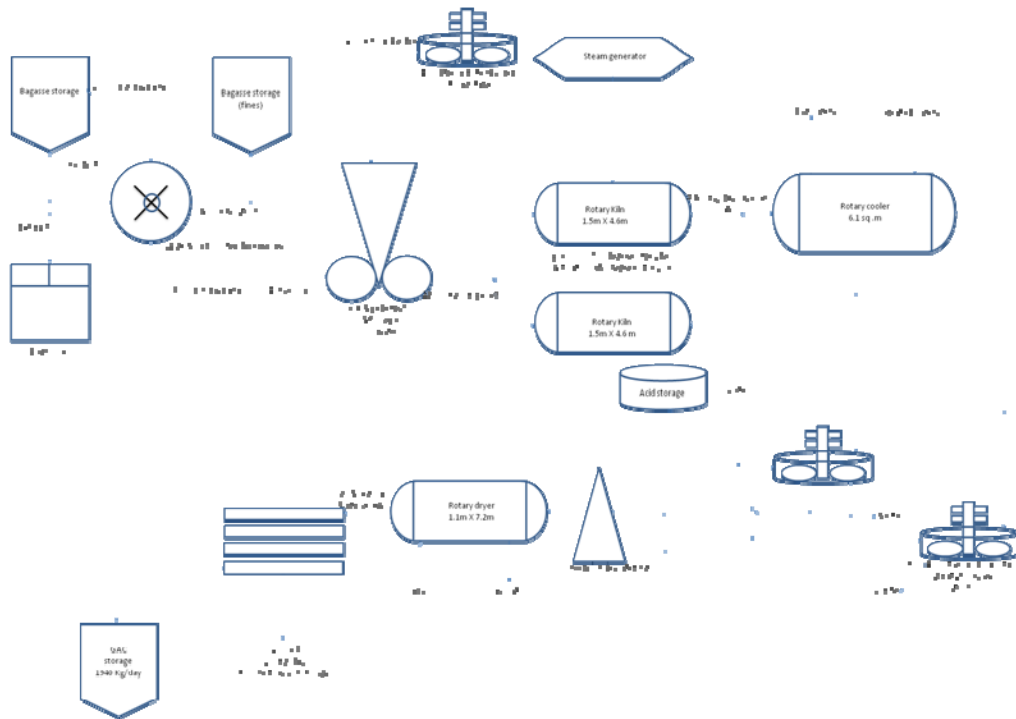


Figure 2: Steam Activation of Sugarcane Bagasse.

Surface areas are also similar for the two activation methods under most burn-off conditions (Johns et al., 1999).

The process used by the authors has many steps in common with the steam activation of pecan shells (also similar to steam activation of coconut shell described in this project), but the process is sufficiently different because of the need for a binder, which necessitates a pellet mill and a binder feed tank for the pelletization step, and acid wash tanks and acid storage for the acid wash step. The process steps as described by the authors are highlighted below

Sample Preparation: As with coconut shells, clean and dry bagasse, with a moisture content at or below 13 percent, is required for carbon production. Just as assumed by Chilton et al. It was assumed that specifications regarding cleaning and ensuring the proper moisture content of the bagasse would be adhered to by the raw sugar factory before delivery of the bagasse to the carbon manufacturing facility.

Milling: Also here, 10,000 kg/day of clean and dry bagasse is fed into an 11.2kW carbon steel hammer mill and milled to a particle size of 30 to

40 mesh (0.60 to 0.425 mm). Screens are an integral part of the hammer mills, and separate screening equipment should not be necessary. It is desired to have 80 percent by weight of the initial feed as 0.425- to 0.60-mm particles. The small particle size of the bagasse is necessary for effective interaction between bagasse and binder hence material larger than 0.60 mm is redirected back to the feed hopper and is passed again through the mill. Fines of less than 0.425 mm is to be directed for disposal or other use, such as to a boiler to provide the activation steam by burning the bagasse. The 0.425- to 0.60-mm particles, with an 80 percent or 8,000 kg/day recovery, are directed to a pelletizer.

Pelletization: As explained by Chilton et al. bagasse is mixed with sugarcane molasses binder in a 2:1 (bagasse:binder) ratio and compressed at 34,500 kPa at the die plate to form approximately 5 x 10 mm pellets. Because pellet mills run at a capacity of 46-182 kg/(kWhr) (Green, 1984), a 33 kW pellet mill will be required to pelletize the daily feed of bagasse and binder.

Sugarcane molasses has high viscosity at ambient temperature, and so a heated 4,000 L storage tank will be used to supply the pelletizer.

Depending on the physical distance between the pelletizer and storage tank, insulated or heated transfer lines may be necessary. Once the pellets are formed, they are delivered to a feed hopper and then the rotary kiln.

Pyrolysis/activation: In Chilton et al. design, a dual kiln system with a chamber size of 1.5 m x 4.6 m for each kiln is described. In this process design, just like in processing of coconut shell, a dual kiln system is used because of shipping considerations with larger kilns. In the process stream is split to feed each kiln. The bagasse/binder pellets are fed to the rotary kiln where pyrolysis occurs by holding the pellets at 700° C for one hour under an inert atmosphere comprised of off-gases generated by pyrolysis. Waste heat is used to maintain the pyrolysis temperature at 700° C and conserve natural gas used to generate this temperature initially. After pyrolysis, activation occurs by heating the char to 850° C for one hour in the presence of steam.

These pyrolysis/activation conditions are expected to achieve a 20 percent yield based on a target surface area of 700 to 800 m²/g. Earlier results of Pendyal et al. (1999a) and Ahmedna et al. (2000a) indicated yields of 25 percent to 30 percent using carbon dioxide activation of bagasse with a sugarcane molasses binder, but surface areas were only 200 to 400 m²/g. Johns et al. (1999) have noted that decreased yields during activation result in increased surface area. After activation, the carbon is conveyed to an indirect rotary cooler. With a process stream of 2,400 kg/day, a rotary cooler with a surface area of 3.5 m² will be required to achieve a reduction in temperature from 850° C to less than 100° C in less than one hour. The equations of McCabe et al. (1985) were followed in establishing the rotary cooler surface area required.

Acid and Water Wash: According to Chilton et al. the activated carbon is acid washed with 0.1 N HCl to remove any ash that has formed from pyrolysis of the binder and to a lesser extent from pyrolysis of the bagasse. The process stream is then water washed to remove the residual acid until the pH is 5-6. A dual wash tank system is used, with one tank filling while the other is acid or water washing. Two 4,000 L glass-lined wash tanks are included. The tanks would require 90 minutes to fill and 90 minutes to wash the carbon in alternating tanks. It is assumed that 10 kg of 0.1 M HCl are required for every kg of product. Neutralization of the acid wash and removal of

suspended carbon particles from the washing procedure would be handled by an effluent treatment system before the water is transported to the municipal sewer system. A 4,000 L tank is provided for acid storage. The tank will be filled six times per day, as needed, from a tanker truck parked outside the plant. The activated carbon is removed from the wash tanks and dried for two hours at 60° C in a rotary dryer.

Drying: Chilton et al. calculated the size of dryer needed for a throughput of approximately 2,500 kg/day of wet activated carbon using the equations of McCabe et al. (1985). With their previous assumptions, a 1.1-m x 7.2-m rotary dryer was to be required. Their avoidance of the possibility of rust make the use of a stainless steel dryer necessary. The step was followed by the sieving of GAC to be sieved to a 0.425-to 2.00-mm particle size.

Sieving/Collecting: After the drying process, the design was for the activated carbon to be sieved to retain the 0.425-to 2.00-mm particles. A 0.76-m x 0.53-m sifter was required. A carbon loss of 5 percent was anticipated. The fines were to be separated and bagged separately as powdered carbon. The finished product can then be taken for bagging and storage. A bagging station was not included in their flow diagram. Final yield for steam activated, bagasse-based carbon was estimated to be 19.4 percent based on an input of 10,000 kg/day of bagasse. They envisaged that if 4,000 kg/day of sugarcane molasses binder is also included as input, then the final yield will be 13.8 percent.

Cost (Appendix, Table 2a-f): For this project costs were developed assuming a 19.4 percent yield or 1,940kg/day output of bagasse-based granular activated carbon, 300 days a year of production and three men per shift (three shifts) for 24 hours a day at N1,000 a month. For this process, a fixed capital investment of about N809,906,578.00. An annual manufacturing cost was estimated at N566,838,397.00 for an annual output of about 582,000kg/year. The estimated cost to produce steam activated, bagasse-based carbon would be N1,017.00/kg. The proposed selling price is around N1,193.00/kg.

Phosphoric acid activation of oil-palm shells (Figure 3): For the production of GAC from oil-palm shells using phosphoric acid, a modification was done to the process designed

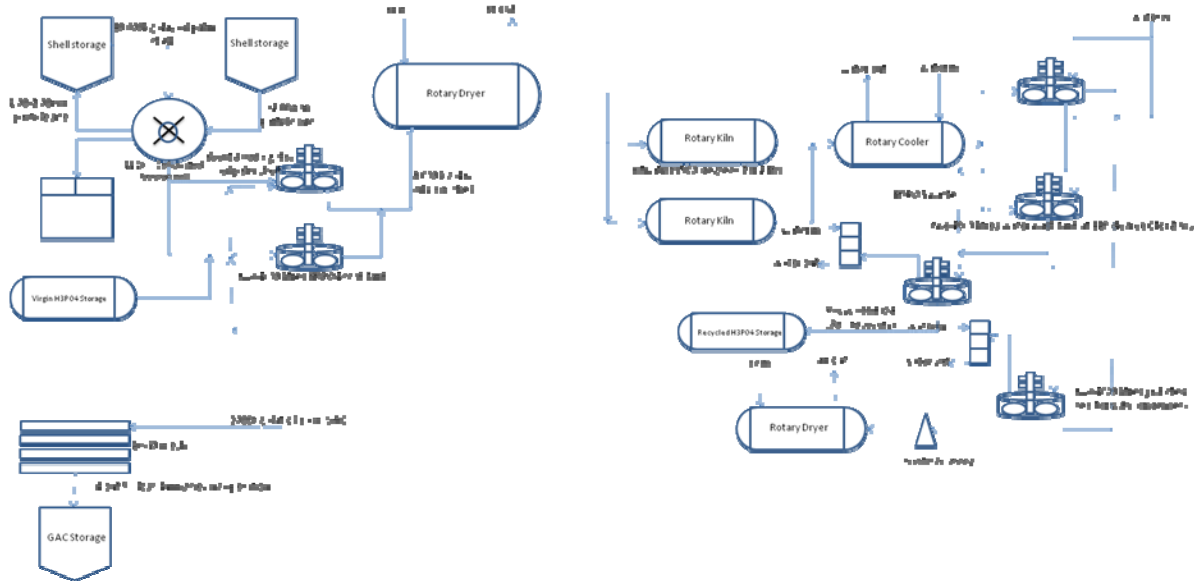


Figure 3: Phosphoric Acid Activation of Oil-Palm Shells.

for the phosphoric activation of pecan shell also by Chilton et al. The process was the same process flow as the one designed by Chilton and his colleague only that the activation temperatures changes including the holding times. This is at 500°C with an holding time of 2 hrs (Wan Nik et al., 2006). For this process four unit operations were considered and as described by Chilton and his colleague, these include:

Sample preparation: The acid-soaked shells were dried before being fed to the kiln. Just as for Chilton et al. assuming a process load of 16,000 kg and using the parameters defined by McCabe et al. (1985), a 0.97-m x 6.1-m rotary dryer will be required. Possibility of rust and reaction with phosphoric acid is to be avoided by using a stainless steel dryer.

Pyrolysis/activation: This happens after the acid-coated shells from the dryer were conveyed to a feed hopper of a rotary kiln. A dual kiln design was used, the same design as used for the steam activation process. In the kiln, the feedstock was carbonized at 500° C for 2 hours under the off gases produced. The activated carbon is then to be conveyed directly from the rotary kiln to a rotary cooler. Based on the same calculations and assumptions for rotary cooler size as in the production of steam-activated pecan shells in Chilton et al. work, and assuming a process stream of 3,600 kg/day at this point as

also in Chilton et al., a rotary cooler with a surface area of 5.2 m² will be necessary.

Water wash/acid recovery: As designed by Chilton et al. the cooled carbon must be water washed to remove any residual phosphoric acid. This was done by washing the carbon with 80-90° C water for 2 hours at a ratio of 40 L water per kg carbon. This will be done in one of two 4,000 L glass-lined reactors. The dilute phosphoric acid must be concentrated before being mixed with virgin phosphoric acid for use in the acid soak tanks. This will be done in two 4,000 L glass-lined reactors with condensers.

Drying/screening and collecting: The activated carbon was collected on a dewatering screen and taken to a rotary dryer before it is ready for packaging or storage. Also as in Chilton et al. assuming a process load of 3,500 kg of wet carbon and using the parameters defined by McCabe et al. (1985), a 0.97-m x 1.95-m rotary dryer will be required. A stainless steel dryer must be used to avoid rusting. Screening and collecting processes were carried out as described previously for steam activation. Roughly estimating, a loss of 5 percent will be experienced by screening the carbons. Therefore, the roughly estimated final yields for phosphoric acid activated carbons are around 30% percent.

Cost (Appendix 1, Tables 3a-f): Costs were developed assuming a 30 percent yield or 3,000

kg/day output of acid-activated carbon, 300 days a year of production and three men per shift (three shifts) for 24 hours a day at N1,000.00 a month. For the phosphoric acid activation process, a fixed capital investment of N977,056,053.00 is required. An annual manufacturing cost was estimated at about N448,354,059.00 for an annual output of 960,000 kg. Therefore, the estimated cost for acid-activated carbon would be N600.00/kg. Equipment for energy recovery was not included in this design.

SUMMARY AND CONCLUSION

In this work, three different process flow diagrams were developed. For the steam activation of coconut shell, phosphoric activation of oil palm shell and steam activation of sugarcane bagasse. The process flow diagrams for these processes was a reapplication of Chilton et al. process flow diagrams in their work "Granular Activated Carbons from Agricultural By-products: Process Description and Estimated Cost of Production" where they developed process flow diagrams for

the steam and phosphoric activation of pecan shell and the steam activation of sugarcane bagasse.

These process diagrams, besides simplifying material and energy balance calculations, also offer a systematic approach in determining purchased equipment costs and total fixed capital investment. The economic costing of the equipments and other incurred costs were based on the approximated percentage as given by Peters and Timmerhaus, 1991. As stated by Chilton et al., the design of most process equipment follows accepted standard formulae and methodology used in engineering practice.

From these process flow diagrams, an estimated fixed capital investment was developed and an estimated manufacturing cost for each different feedstock and activation condition. The unit cost of production and the unit selling price was also evaluated for each of the activated carbons. The uses of Microsoft excel spreadsheet for the economic cost analysis afforded the opportunity of varying details in order to reduce cost and eliminate losses.

APPENDIX A: Economic Cost Analysis for the Steam Activation of Coconut Shells.

Table 1a: Estimated Capital Investment.

Storage tanks	1534500.00		
Hammer mill	1534500.00		
Two-rotary kiln	68200000.00		
Rotary cooler	11082500.00		
Sieve	356500.00		
Steam Generator	50000000.00		
Purchased equipment delivered	132708000		
Installation of equipment	53083200.00		
Insulation	11943720.00		
Instrumentation	17252040.00		
Piping	41139480.00		
Electrical installation	19906200.00		
Buildings including services	62372760.00		
Yard improvement	26541600.00		
Services facilities	72989400.00		
Land	10616640.00		
Facilities	315845040.00		
DIRECT PLANT COST		315845040.00	
Engineering and supervision	13270800.00		
Construction expense and contractor's fee	56852107.20		
Contingency	25267603.20		
INDIRECT PLANT COST		95390510.40	
FIXED CAPITAL INVESTMENT			727080590.40
WORKING CAPITAL			109062088.60
TOTAL CAPITAL INVESTMENT			836142679.00

Table 1b: Raw Material Cost.

Cost of coconut shell/Kg, including processing	120
Annual cost of coconut shell	360000000

Table 1c: Operating Labor Calculation.

Equipment	Workers/day/shift Required
Rotary kiln	1
Rotary cooler	1
Steam generator	0
Shell storage tank	1
Sieve and GAC storage	1
Operating labor required/day	4
Operation labor required for 300 days annual production	120

Table 1d: Estimated Manufacturing Cost.

Raw materials	360000000.00	
Operating Labor	1200000.00	
Direct supervisory & Clerical labor	180000.00	
Maintenance and Repair	13270800.00	
Operating supplies	1990620.00	
Power and utilities	21600000.00	
Royalties	23894485.20	
DIRECT PRODUCTION COST		422135905.20
Depreciation	72708059.04	
Rent	14541611.81	
Taxes	29083223.62	
Insurance	7270805.90	
FIXED CHARGES		119317648.60
PLANT OVERHEAD COST		10255560.00
MANUFACTURING COST		551709113.8
Administrative cost	1465080.00	
Distribution and selling cost	42213590.52	
Research and development cost	8442718.10	
GENERAL EXPENSE		52121388.62
TOTAL PRODUCT COST		603830502.40

Table 1e: Unit Cost of Production.

TOTAL PRODUCT COST	603830502.4
ANNUAL PRODUCED QUANTITY/kg	1500000
UNIT COST OF PRODUCTION	402.55

Table 1f: Total Sale of Product.

PROPOSED % PROFIT/KG	10
UNIT COST OF PRODUCTION	402.55
PROFIT/KG	40.255
SELLING PRICE	442.81

APPENDIX B: Economic Cost Analysis for the Steam Activation of Sugarcane Bagasse.

Table 2a: Estimated Capital Investment.

Dryer	23482500		
Pellet mill	12680550		
Binder feed tank	1565500		
2 acid/water wash tanks	27280000		
Hammer mill	1534500		
Two-rotary kiln	68200000		
Rotary cooler	15655000		
Sieve/collector	511500		
Steam Generator	50000000		
Purchased equipment delivered	200909550		
Installation of equipment	80363820.00		
Insulation	18081859.50		
Instrumentation	26118241.50		
Piping	160727640.00		
Electrical installation	80363820.00		
Buildings including services	94427488.50		
Yard improvement	40181910.00		
Service facilities	110500252.50		
Land	16072764.00		
Facilities	628837796.00		
DIRECT PLANT COST		626837796.00	
Engineering and supervision	20090955.00		
Construction expense and contractor's fee	112830803.30		
Contingency	50147023.68		
INDIRECT PLANT COST		183068782.00	
FIXED CAPITAL INVESTMENT			809906578.00
WORKING CAPITAL			121485986.70
TOTAL CAPITAL INVESTMENT			931392564.7

Table 2b: Raw Material Cost.

Cost of sugarcane bagasse/annum, including processing	270000000
Cost of binders, acid and other raw materials/annum	75000000
Annual cost of coconut shell	345000000

Table 2c: Operating Labor Calculation.

Equipment	Workers/day/shift Required
Rotary kiln	1
Rotary cooler	1
Steam generator	0
Pellet mill	2
Shell storage tank	1
Sieve and GAC storage	1
Operating labor required/day	6
Operation labour required for 300 days annual production	1800

Table 2d: Estimated Manufacturing Cost.

Raw materials	345000000.00	
Operating Labor	1800000.00	
Direct supervisory & Clerical labor	270000.00	
Maintenance and Repair	20090955.00	
Operating supplies	3013643.25	
Power and utilities	20700000.00	
Royalties	23452475.90	
DIRECT PRODUCTION COST		414327074.10
Depreciation	80990657.80	
Rent	16198131.56	
Taxes	32396263.12	
Insurance	8099065.78	
FIXED CHARGES		136998655.20
PLANT OVERHEAD COST		15512668.50
MANUFACTURING COST		566838397.80
Administrative cost	2216095.50	
Distribution and selling cost	41432707.41	
Research and development cost	20716353.71	
GENERAL EXPENSE		64365156.63
TOTAL PRODUCT COST		631203554.50

Table 2e: Unit Cost of Production.

TOTAL PRODUCT COST	631203554.50
ANNUAL PRODUCED QUANTITY/kg	582000
UNIT COST OF PRODUCTION	1016.758303

Table 2f: Total Sale of Product.

PROPOSED % PROFIT/KG	10
UNIT COST OF PRODUCTION	1084.54
PROFIT/KG	108.454
SELLING PRICE	1192.996

APPENDIX C: Economic Cost Analysis for the Steam Activation of Oil-Palm Shells.**Table 3a: Estimated Capital Investment.**

Hammer mill	1534500.00		
2 Glass-lined, acid soak tanks	27280000.00		
2 Rotary dryers	51150000.00		
2 Rotary kilns	68200000.00		
Rotary cooler	15655000.00		
2 Glass-lined acid wash tanks	27280000.00		
2 Glass-lined acid recovery tanks	27280000.00		
Rotary dryer	23482500.00		
Sieves and collectors	511500.00		
Purchased equipment delivered	242373500.00		
Installation of equipment	96949400.00		
Insulation	21813615.00		
Instrumentation	31508555.00		
Piping	193898800.00		
Electrical installation	96949400.00		
Buildings including services	113915545.00		

Table 3a (Continued): Estimated Capital Investment.

Yard improvement	48474700.00		
Service facilities	133305425.00		
Land	19389880.00		
Facilities	756205320.00		
DIRECT PLANT COST		756205320.00	
Engineering and supervision	24237350.00		
Construction expense and contractor's fee	136116957.60		
Contingency	60496425.60		
INDIRECT PLANT COST		183068782.00	
FIXED CAPITAL INVESTMENT			977056053.20
WORKING CAPITAL			146558408.00
TOTAL CAPITAL INVESTMENT			1123614461

Table 3b: Raw Material Cost.

Cost of 3000000KG of oil-pam shell/annum, including processing	2088000000
Cost of phosphoric acid /annum	325500
Annual cost of oil-palm shell	208325500.00

Table 3c: Operating Labor Calculation.

Equipment	Workers/day/shift Required
Rotary kiln	1
Rotary cooler	0
Steam generator	0
Soak, acid wash and acid recovery tanks	2
Shell storage tank	1
Sieve and GAC storage	1
Operating labour required/day	5
Operation labour required for 300 days annual production	1500

Table 3d: Estimated Manufacturing Cost.

Raw materials	208325500.00	
Operating Labor	1500000.00	
Direct supervisory & Clerical labor	225000.00	
Maintenance and Repair	24237350.00.00	
Operating supplies	3635602.50.25	
Power and utilities	12499530.00.00	
Royalties	15025378.95	
DIRECT PRODUCTION COST		265448361.50
Depreciation	97705605.32	
Rent	19541121.06	
Taxes	39082242.13	
Insurance	9770560.53	
FIXED CHARGES		164732053.00
PLANT OVERHEAD COST		18173645.00
MANUFACTURING COST		448354059.40
Administrative cost	2596235.00	
Distribution and selling cost	26544836.15	
Research and development cost	13272418.07	
GENERAL EXPENSE		42413489.22
TOTAL PRODUCT COST		490767548.60

Table 3e: Unit Cost of Production.

TOTAL PRODUCT COST	490767548.6
ANNUAL PRODUCED QUANTITY/kg	900000
UNIT COST OF PRODUCTION	545.30

Table 3f: Total Sale of Product.

PROPOSED % PROFIT/KG	10
UNIT COST OF PRODUCTION	545.30
PROFIT/KG	54.53
SELLING PRICE	600.00

Note: The percentages used for the cost analyses are as given by Peters et al.,(1991)

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SUGGESTED CITATION

Odesola, I.F. and N.O. Daramola. 2009. "Developing a Local Capability for the Manufacture of Active Carbon from Agricultural Waste". *Pacific Journal of Science and Technology*. 10(2):275-288.

 [Pacific Journal of Science and Technology](http://www.akamaiuniversity.us/PJST.htm)