NIGERIAN AGRICULTURAL JOURNAL
ISSN: 0300-368X
Volume 55, Number 3, December 2024, Page 612-619
Available online at: https://www.ajol.info/index.php/naj
https://doaj.org/toc/0300-368X

Appraisal of the Conversion Rate of Selected Wood Species and Economic Efficiency of Activated Charcoal Production Using Locally Fabricated Pyrolyser in Nigeria

Obadimu, O.O., Olarewaju, T.O., Orumwense, L.A., Awe, F. and Ajagbe, R.O.
Forestry Research Institute of Nigeria, PMB 5054, Jericho Hills, Ibadan, Oyo State, Nigeria
Corresponding author's email: femray4real@yahoo.com

Abstract
Locally fabricated pyrolyzer(LFP) usage has become an alternative to the conventional charcoal production. Despite this, there has been inadequate information on LFP. Given this, there is a need to conduct some empirical investigation into the economic viability of the production of activated charcoal through the LFP approach. This therefore necessitated this study, to investigate the relative mass loss (RML) and conversion efficiency (time taken) for randomly selected wood species to produce activated charcoal using LFP. The selected wood species are *Azadirachtaindica, Daniella oliveri, Mahogany, Parkia biglobosa, Cassia sieberiana, Milicia excelsa, Annogeissus leiocarpus, Albizia zygia, Vitellaria paradoxum, Terminalia schimperiana, Mangifera indica, and Erythropleum suavolens*. These species were identified through indigenous knowledge, but were later taken to the taxonomy department of the Forestry Research Institute of Nigeria for confirmation of the names. The tree species were then sundried and converted to chips, and then taken to the wood laboratory of FRIN to determine the weights before and after pyrolysis. To determine the economic efficiency and worthiness of the project, the Benefit Cost Ratio (BCR) and Net Present Value (NPV) approaches were used, respectively. Findings showed that Mahogany took the highest time to get carbonized, while *Terminalia schimperiana* took the least time. In addition, the relative mass loss (RML) and conversion efficiency showed that *Terminalia schimperiana* had the highest relative mass loss per minute (68.18g/min), while *Annogeissus leiocarpus* had the least (41.36g/min). Furthermore, a positive value of NPV and a ratio of greater than one of BCR indicate that investment in activated charcoal production using the LFP method is a profitable venture, and therefore it is an economically viable business.
Keywords: Conversion efficiency, Benefit cost ratio, Carbon, Mahogany, Terminalia schimperiana

Introduction

Charcoal is the solid carbon residue that results from the burning or heating of carbon-containing materials. Charcoal is an odourless, tasteless, fine black powder or black porous solid consisting of carbon and any remaining ash, obtained by removing water and other volatile constituents from animal and vegetation substances (Abdollahi and Hosseini 2014). Charcoal production involves the selection of tree logs or stems from preferred species and loading them into a kiln for processing, after which the charcoal is extracted for sale and/or domestic consumption. However, when charcoal is heated in the presence of gas to create lots of pore spaces, it will result in activated charcoal. These pores help activated charcoal "trap" chemicals, and the relevance of activated charcoal transcends heat energy supply. After the development of the charcoal activation process in 1920, it was reported that activated charcoal is an antidote for poisons and a cure for intestinal disorders, and also helps in the purification of water and air, as well as detoxifies the soil for crop growth. Since then, the roles of activated charcoal as a medicine continue to grow and have been rated category one, "safe and effective", by the American Food and Drug Administration (FDA) for acute toxic poisoning. Apart from being used as a gastrointestinal decontaminant, it is also widely used for other health-related purposes, such as maintaining the health of patients on kidney and liver dialysis machines, dressing wounds, and much more (CHB, 2014).

Commercial charcoal has a very limited ability to adsorb substances in the liquid or gas phase. To give charcoal this property, it must first be activated by removing the tarry materials that block the structure of the pure carbon skeleton of the charcoal. Hence, the surface area of the porous carbon skeleton is increased millions of times, providing equally large numbers of sites where molecules of other substances can be held or adsorbed and thus removed from gases or liquids in which the treated charcoal is placed. Charcoal is not the only type of carbon used for activation, but it is an important raw material for activated carbons.

Activated carbon industries use various processing methods which involve heating of organic material to a temperature of about 800^0C in an atmosphere of superheated steam to break down and remove tars blocking the micro fine structure of the charcoal (CHB, 2014). In its numerous applications, activated carbon represents several different functionalities such as adsorption, reduction, a catalyst, a carrier of biomass, a carrier of chemicals, etc. The raw material for activated carbon plays a major role in determining the ability of the final product to adsorb certain molecular substances. Activated charcoal has recently gained popularity due to its extensive employment of activated charcoal in a wide range of applications. This has therefore boosted the demand, which will continue to increase (Ken, 2012).

Since 2004, the production of charcoal in Africa has increased by 30%, the highest rate of increase globally (FAO, 2011a). The high rate of charcoal production suggests that large swathes of forest resources are being lost and this has great implications for the environment and humanity (Obadimu, 2019). Consequent upon this, dissuading charcoal production will require putting up better alternative that will sustainably meet people's needs.

Furthermore, the utilization of waste biomass materials in the pyrolysis process is part of the current trend of closed-cycle production to achieve more sustainable processes and products (Januszewicz et al., 2020). According to Abah et *al*. (2011), most of the problems associated with wood processes and conversion for human consumption still have not been resolved, while the demand for higher purity products in many fields is getting stronger (Shi *et al.*, 2008). Nevertheless, the main challenge in the production of activated carbon (AC) is the development of an economically justified method to obtain products with given surface properties using low-cost materials (Roman *et al*., 2017). The use of the locally fabricated pyrolyzer (LFP) is an alternative to the conventional charcoal production process, and there is a need to embrace its use in activated charcoal production. Meanwhile, there is little or no information on LFP; hence, the need for empirical investigation into the economic efficiency of activated charcoal production using the locally fabricated pyrolyzer.

Economic Efficiency is defined as the capacity of a firm to produce a predetermined quantity of output at minimum cost for a given level of technology (Akinbode et *al*., 2011). This study is aimed at calculating the economic efficiency and profitability of activated charcoal production to sustain forest use and maintain livelihood among forest-dependent people. The study specifically investigated the relative mass loss (RML) and conversion efficiency (time taken) for selected wood species to produce activated charcoal using a locally fabricated pyrolyser (LFP). Further, the benefit-cost ratio (BCR) for the production of activated charcoal using a locally fabricated pyrolyzer (LFP) was calculated.

Materials and Methods

Wood species were randomly selected among the various species used in the production of charcoal. They were identified in the field using local knowledge and verified using "trees, shrubs and lianes of West African dry zones" (Arbonnier, 2002). Further consultations were made with the taxonomy department, Forestry Research Institute of Nigeria (FRIN), for confirmation of the names. The tree species collected were sun-dried and converted to chips, and then taken to the wood laboratory of Forestry Research Institute of Nigeria (FRIN) to determine the initial (before pyrolysis) and final weights of the materials (after pyrolysis).

The pyrolyser is made of iron metal with outer and inner dimensions of length, breadth, and height of 650 X 610 X 730 and 390 X 370 X 360 millimeters, respectively (Plate 1). The chamber wall thickness was 120mm. A gas stove was fixed underneath the chamber to permit a constant supply of heat of over 700°C. The samples to be pyrolysed were deposited inside the chamber in a way that would allow for easy evacuation after pyrolysis to prevent loss. The temperature in the chamber was monitored by inserting a high-temperature-reading thermometer through a regulated opening at the top of the chamber. Twelve different wood species (Plate 3) were cut and air dried (6% moisture content) as well as pyrolysed at a temperature ranging between 700^0C and 750^0C. Three (3) replicates of each wood species were prepared, and their initial weight was taken before introduction into the pyrolyser, and final weight after pyrolysis was taken using a sensitive weighing scale. The samples were introduced into the chamber (Plate 5) of the pyrolyser, and the chamber was closed. Heat was supplied using a gas stove (Plate 2). The temperature in the chamber rose until it reached the expected range of temperature. This was monitored using a thermometer that could read up to 1200°C.

Heating would then be continuously maintained for more than 4 hours, depending on the wood species being activated. When the expected changes occurred, the time taken was recorded, and the heating was stopped. The chamber was allowed to cool off, and the activated charcoal (Plate 4) was removed from the chamber. The samples were weighed and recorded accordingly.

Benefit Cost Ratio (BCR) and Net Present Value (NPV) were used to determine the economic efficiency and worth of the project, respectively. If BCR>1, then the project is economically satisfactory. If BCR =1, then the economic breakeven of the project is similar to other projects (with the same discount rate or rate of return). If BCR<1, then the project is not economically satisfactory. Furthermore, if the project has a BCR that is greater than 1, it indicates that the NPV of the project benefits outweigh the NPV of the costs. Therefore, the project should be given positive consideration.

$$B/C = \frac{\sum_{t=1}^{n} B_t(1+r)^{-t}}{\sum_{t=1}^{n} C_t(1+r)^{-t}} \geq 1 \text{ ....(1)}$$

$$= \frac{Benefit\ stream}{Cost\ stream}$$

Net Present Value (NPV): The NPV estimates the relative probability of a project, and the decision criterion is to accept a project with a high NPV. NPV measures the profit or surplus income from a project after the project has satisfied the rate of return on capital desired by the investor.

$$NPV = \sum_{t=1}^{n} \frac{(B_t - C_t)}{(1+r)^t} \text{ .... (2)}$$

B_t = Benefit in each project year
C_t = Cost in each project year
t = Time of project duration (n ranges from 1 to 5 years)
r = Discount rate at 10%
Total Cost (TC) = Fixed Cost (FC) + Variable Cost (VC)

Fixed costs (FC) are the costs that do not vary with the production process and these include the cost of the pyrolyser, thermometer, gas cylinder, gas regulator, hose and the weighing scale while variable costs (VC) are the costs incurred during the production process and these are gas, transportation, wood materials, matches and labour.

Results and Discussion

Table 1 shows the time (minutes) taken by different wood species to transform into activated carbon. Mahogany (202) took the highest time, and *Terminalia schimperiana* used the least time of 141 minutes to get carbonized. Generally, the wood species are carbonized at different times. This is expected because the wood species activated were different from one another. This result is similar to the findings of Bae*et al*. (2014) where the optimum manufacturing conditions for producing activated carbon from ligneous wastes (Jujube seeds and walnut shells) using electric furnace were 120and 90 minutes (carbonization at 700°C) followed by 60 and 30 minutes (activation at 1000°C,) respectively.

The relative mass loss (RML) and conversion efficiency (time taken) to pyrolyse wood species to activated charcoal according to the table, shows *Terminalia schimperiana* had the highest relative mass loss per minute (68.18g/min), followed by *Parkia biglobosa*(63.64), and *Albizia zygia*(62.73), while Mahogany (43.87), *Erythropleum suaveolens*(41.21), and *Annogeissus leiocarpus*(41.36) had the least mass loss per minute. This implies that *Terminalia schimperiana*, *Parkia biglobosa,* and *Albizia* *zygia* will be better species for activated charcoal in terms of time used and cost of heat supply, while Mahogany, *Erythropleum suaveolens*, and *Annogeissus leiocarpus* may not be time and cost-effective if all the species' activated charcoal is sold at the same price. On average, wood of 76.57g will get pyrolysed into activated charcoal of 7.64g in 170 minutes.

Estimated Benefit Cost Ratio Analysis for Activated Charcoal production using Locally Fabricated Pyrolyser (LFP)

Table 3 shows the 5-year plan of activated charcoal production using a locally fabricated pyrolyser (LFP). Let's assume constant cost, benefit, and minimum production volume of 104kg per year, projected total revenue and cost was₦5 200,000.00 and ₦2, 972,400.00respectively. Cost of production in the first year was ₦803, 400 and lower in the following years as fixed items are still in use. At a lending rate of 10%, the minimum benefit Cost Ratio (BCR) was 1.29 due to the cost of, and 1.72 at the end of five years. The BCR value is greater than 1 at any time, indicating a return of 29k and 72k, respectively, on every ₦1 invested. This implies that the investment in activated charcoal production using LFP is profitable and economically viable. It is therefore advisable to engage in its local production. Findings of Ng *et al*. (2003) estimated the cost of $2.72/kg and $3.12/kg, respectively, for pecan shell and sugar cane-based granulated activated carbon by steam activation. This shows that the production cost of activated charcoal depends on the raw material used. This is further corroborated by Alam *et al*. (2007), who reported that the production of 48000kg/annum of powdered activated carbon by thermal activation would require a fixed capital investment of $635,000 and an annual operating cost of $175,200. Total Cost of production therefore translates to $16.88/kg, which compares with $16.79/kg in the first year and $11.33/kg in subsequent years (@ $1=₦460) obtained from this study.

Net Profit =Total Revenue (₦5, 200,000.00) – Total Cost (₦2, 972,400.00) =₦ 2,227,600
NPV = PVB **(**₦3, 942,432.00) – PVC (₦2, 292,972.77) = ₦1, 649,459.24
BCR = Present Value Benefits (₦ 3,942,432.00)/Present Value Costs (₦2, 292,972.77) =1.52

Conclusion

Findings from the Benefit Cost Ratio (BCR) and Net Present Value (NPV) indicated that Activated Charcoal production was profitable and economically viable. Findings further revealed that activated charcoal production using LFP is environmentally friendly and requires a lesser quantity of wood than charcoal production. Despite all these, not much is known by people about the environmental, health, and economic benefits of activated charcoal production. Given this, the study therefore recommends that agricultural development programmes and research institutes should create more awareness on the economic and health benefits of activated charcoal production. Furthermore, government agencies, particularly small and medium-scale development agencies, the Bank of Agriculture, as well as the Bank of Industry, should provide credit facilities for the production and procurement of LFP. This will encourage local content in activated charcoal production, thereby improving the nation's economy and ability to earn foreign exchange.

References

Abah, R. C., Petja, B. M., & Magoro, M. D. (2011). Participatory forest management for poverty reduction and sustainable forest management in Nigeria. *International Journal of Environmental Science and Development, 2*(1), 60–64. https://doi.org/10.7763/IJESD.2011.V2.94

Abdollahi, M., & Hosseini, A. (2014). Charcoal. In P. Wexler (Ed.), *Encyclopedia of toxicology* (3rd ed., Vol. 1, pp. 779–781). Elsevier Academic Press. https://doi.org/10.1016/B978-0-12-386454-3.00685-0

Agbeja, B. O. (2004). Valuation of investment in teak plantation establishment on a 15-year rotation for intending smallholders in Nigeria. Paper presented at the International Workshop on Small Holder Timber Production, World Agroforestry Centre (ICRAF), United Nations Avenue, Gigiri, Nairobi, Kenya, 29 November–1 December 2004. http://woek.boku.ac.at/sht/presentations.htm

Agbeja, B. O. (2008). Sensitivity analysis of forest plantation project for transmission pole production. In *Methodology of Basic and Applied Research* (pp. 237–248). The Postgraduate School, University of Ibadan, Nigeria.

Akinbode, S. O., Dipeolu, A. O., & Ayinde, O. E. (2011). Willingness to pay for forest conservation in Ogun State, Nigeria. *Journal of Sustainable Development in Africa, 13*(5), 45–60.

Alam, M. Z., Muyibi, S. A., Mansor, M. F., & Wahid, R. (2007). Activated carbons derived from oil palm empty-fruit bunches: Application to environmental problems. *Journal of Environmental Sciences, 19*, 103–108.

Arbonnier, M. (2002). *Trees, shrubs, and lianas of West African dry zones*. CIRAD, MARGRAF.

Bae, W., Kim, T., & Chung, J. (2014). Production of granular activated carbon from food-processing wastes (walnut shells and jujube seeds) and its adsorptive properties. *Journal of the Air & Waste Management Association, 64*(8), 879–886.

Charcoal House Brand. (2014). *Charcoal House Brand*. Editor@buyactivatedcharcoal.com

Food and Agriculture Organization of the United Nations. (2011). *State of the world's forests 2011*. FAO. https://www.fao.org/3/i2000e/i2000e00.htm

Januszewicz, K., Kazimierski, P., Klein, M., Kardaś, D., & Łuczak, J. (2020). Activated carbon produced by the pyrolysis of waste wood and straw for potential wastewater adsorption. *Materials, 13*(9), 2047. https://doi.org/10.3390/ma13092047

Ken, S. (2012). The activated carbon market, supply, and pricing update. *The Carbon Continuum*. https://www.wcponline.com/pdf/1206Schaeffer.pdf

Ng, C., Marshall, W., & Rao, R. (2003). Granular activated carbons from agricultural by-products: Process description and estimated cost of production. *LSU Agricultural Centre, Research & Extension Bulletin*, 881.

Obadimu, O. O. (2019). *Socio-economic dynamics of charcoal and activated charcoal production in Oyo and Ogun states, Nigeria* (PhD thesis). Department of Forestry and Wildlife Management, College of Environmental Resources Management, Federal University of Agriculture, Abeokuta.

Pulido-Novicio, L., Hata, T., Kurimoto, Y., Doi, S., Ishihara, S., & Imamura, Y. (2001). Adsorption capacities and related characteristics of wood charcoals carbonized using a one-step or two-step process. *Journal of Wood Science, 47*(1), 48–57.

Roman, S., Sánchez-Siles, L. M., & Siegrist, M. (2017). The importance of food naturalness for consumers: Results of a systematic review. *Trends in Food Science & Technology,*

67, 44–57. https://doi.org/10.1016/j.tifs.2017.06.010
Shi, Y., Chrusciel, I., & Zoulalian, A. (2008). Production of charcoal from different wood species. In *Récents Progrès en Génie des Procédés – Numéro 96 – 2007* (pp. 1–18). SFGP. ISBN 2-910239-70-5

Table 1: Mean Values of the Relative Mass Loss and Time taken by Selected Wood Species to form Activated Charcoal using Locally Fabricated Pyrolyser (LFP)

Species	Common name	Initial mass(g)	Final mass(g)	Time (min)	RML(%)	RML/time
Azadiractaindica	Dogoyaro	93.57	3.27	198	96.51	48.74
Daniella oliveri	Iya	81.86	5.33	175	93.48	53.42
Mahogany	Mahogany	69.66	7.93	202	88.61	43.87
Parkiabiglobosa	Iru	86.31	3.87	150	95.52	63.68
Cassia sieberiana	Cassia	77.79	5.63	169	92.76	54.89
Miliciaexcelsa	Iroko	68.74	9.90	172	85.60	49.77
Annogeissusleiocarpus	Ayin	65.71	17.33	178	73.62	41.36
Albiziazyygia	Ayunre	77.22	6.50	146	91.58	62.73
Terminaliaschimperiana	Obo	89.90	3.47	141	96.14	68.18
Vitellariaparadoxum	Emi	63.57	10.4	168	83.64	49.79
Mangiferaindica	Mango	87.28	3.73	161	95.72	59.45
Erythropleumsuaveolens	Erun	57.20	14.30	182	75.00	41.21
Average		**76.57**	**7.64**	**170**	**89.01**	

Table 2: Production Cost of 104kg/annum of Activated Charcoal using LFP

S/N	Fixed Costs Item	Amount(₦)	Variable Cost Item	Amount (₦)
1.	Pyrolyser	150,000	Gas	165,492.90
2.	Thermometer	55,000	Transportation	54,000
3.	Gas cylinder	33,500	Cost of wood materials (12X9500 each)	114,000
4.	Hose	7,450	Matches	1,202
5.	Weighing scale	15,200	Labour	180,000
6.			Sealer	27,555.10
	Sub Total	**261,150**		**542,250**
	Grand Total (Fixed + Variable)		**₦803,400.00**	

Source: Computed from Field Survey Data, 2020

Table 3: Benefit-Cost Ratio for Production of 104kg of Activated Charcoal using LFP

Year	Cost (₦)	Benefits (₦)	Discount factor (10%)	Present Value of Benefits (PVB) (₦)	Present Value of Cost (PVC) (₦)	BCR
1	803,400.00	1,040,000.00	0.9091	945,464.00	730,370.94	1.29
2	542,250.00	1,040,000.00	0.8265	859,560.00	448,169.63	1.92
3	542,250.00	1,040,000.00	0.7513	781,352.00	407,392.43	1.92
4	542,250.00	1,040,000.00	0.683	710,320.00	370,356.75	1.92
5	542,250.00	1,040,000.00	0.6209	645,736.00	336,683.03	1.92
Total	**2,972,400.00**	**5,200,000.00**		**3,942,432.00**	**2,292,972.77**	**1.72**

Source: Computed from Field Survey Data, 2020

Plate 1: Locally Fabricated Pyrolyser

Plate 2: Heat supply to pyrolyser chamber

Plate 3: Wood samples prepared for pyrolysis

Plate 4: Carbonized wood (Erythropleum suaveolens)

Plate 5: Wood undergoing pyrolysis in the chamber