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PERFORMANCE EVALUATION OF ACTIVATED CARBON PRODUCED FROM CORNCOB, COW BONE, AND COCONUT SHELL AS A FILTER MEDIUM

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ABSTRACT

Inaccessibility of safe drinking water coupled with poor sanitation and hygiene and its attendance effect is estimated to cost Nigeria about 1.3 billion dollars. The rural communities adopted different methods to filter their water however these methods have proven ineffective in removing certain impurities. The use of fabric cannot remove the microorganisms and chemicals present in water. It is given that activated carbon filters are applied in the removal of these chemicals to test the performance of activated carbon made from corncob, cow bone, and coconut shell as a filter medium, activated carbons were used separately, and combined in a model filter. Raw water samples from Kubanni River and the borehole in 55 apartment Dogon Itche Samaru, Zaria were filtered by the model without pretreatment. The sieve analysis carried out on the activated corncob, cow bone, and coconut shell shows effective sizes of 0.27mm, 0.08mm, and 0.21mm; and uniformity coefficients of 2.11, 5.38, and 2.33 respectively. The analysis showed that the combined media has the highest turbidity removal, 92% for the river sample and 89% for the borehole sample. In terms of acidity and chloride removal, the activated corncob gave better filtrate quality: 19% and 13% removal respectively. In the case of alkalinity, the activated cow bone and coconut shell showed a gradual removal in alkalinity from the borehole sample. The combined media showed more tendency to remove hardness compared to the other activated carbons.

Keywords: Activated carbon, Effective size, Uniformity coefficient, Turbidity removal, Hardness, Filter medium

INTRODUCTION

Access to safe drinking water is essential to health, a basic human right, and a component of effective policy for health protection (WHO, 2017). Not all water is safe for consumption, therefore, it is necessary to analyze the quality of water and ensure it fulfills the drinking water quality standards before consuming it. Access to safe water is a serious issue at the national, regional, and local levels (WHO, 2017). Huang et al., (2018) reported that about 660 million people lacked access to clean and safe water supply with about 2.2 million deaths attributed to diarrhea caused by consumption of contaminated water and lack of good sanitation practices. Both surface and groundwater sources of water are being contaminated by fertilizers, pesticides, and other chemicals due to increased agricultural activities which have also posed health problems to humans (Ahmad & Danish, 2018). Several researchers have employed different techniques in the purification of contaminated water. Some of these techniques include filtration (Teow & Mohammad, 2019); flocculation (Bolisetty et al., 2019); reverse osmosis (Yang et al., 2019); magnetic separation (Lingamdinne et al., 2019); adsorption (Mansour et al., 2018) among others. Of all the methods mentioned, adsorption is the most commonly used because of its cost-effectiveness. Simple to operate, environmental-friendliness, and low health risk (Balasundram et al., 2017; Oladipo & Ifebajo, 2018). Adsorption can be used to remove contaminants from water (Iwuozor et al., 2023). Activated carbon has demonstrated higher performance and stability when compared with other adsorbents like clays, zeolite, and polymers (Regti et al., 2017).

In the rural areas of Nigeria, groundwater mostly from hand dug wells is being consumed without any form of treatment. Boiling is the simplest method of purifying water.

Filtration is another method of water purification. It is the separation process of removing solid particles, microorganisms, or droplets from a liquid or a gas by depositing them on a filter medium also called a septum, which is essentially permeable to only the fluid phase of the mixture being separated (Ripperger et al., 2013).

Rural communities make use of different methods to filter their water however these methods have proven ineffective in removing certain impurities. For instance, the use of fabric cannot be employed to remove the microorganisms and chemicals present in water. It is this that activated carbon filters are applied in the removal of chemicals and sometimes heavy metals.

Adsorption

Adsorption is the grouping together of molecules on the surface of a solid or liquid; such "groupings" are the result of attractive forces between molecules. Adsorption operations exploit the ability of certain solids to concentrate specific substances from fluid onto their surfaces. The adsorbed substance is called adsorbate and the solid substance is called adsorbent. There are three major adsorption types: physical, chemical, and carbon. Of more concern in this study is the carbon adsorption

Carbon Adsorption

Carbon adsorption is a technology that has been widely applied in water treatment industries. The process takes advantage of the highly adsorptive properties of specially prepared carbon known as activated carbon (Louis & Sudha, 2013).

Activation is the process of creating porosity in the material by exposing it to chemical agents such as steam, CO_2, or a combination of the two (Reza et al., 2020). This process produces pores of different sizes and shapes leading to the enlargement of the surface area and pore volume of the material (Jiang et al., 2020).

Activated carbon otherwise called activated charcoal can be made from coal, wood, or coconut shells. Carbon from coconut shells is the most expensive and most effective form. Carbon is "activated" by adding a positive charge, which enhances the adsorption of contaminants that have a negative charge (Scherer & Johnson, 2015). The presence of inorganic and organic pollutants in wastewater is on the increase and several of them are not removed by conventional wastewater treatment processes and pose problems such as odor, toxicity, and foaming (Louis & Sudha, 2013). A packed bed of activated carbon, acting as an adsorbent, is a very good purification means for small to medium-sized water treatment systems. Many organic substances including chlorinated solvents, PCBs, PAHs, pesticides, and others, may be removed from the solution using carbon adsorption. Carbon adsorption is achieved by passing water residues through one or more columns containing granular activated carbon operated in parallel or series (Jayawardane, 1996). Mohd Samdin et al., (2015) conducted an investigation on the use of coconut shells activated carbon as a cost-effective absorbent in drinking water filters. The coconut shell-activated carbon used in filtering 5m^3 of water reduced the Methyl Tertiary-butyl Ether (MTBE) concentration from 15.2 ppb to a non-detectable limit of 0.69 ppb. The non-detectable level has sufficiently reduced the odor and taste problems.

Some manufacturers use various blends of carbon to achieve specific water quality and contaminant reduction (Scherer & Johnson, 2015). Adie et al., (2013) compared the performance of activated carbon produced from various sources, and they discovered that each of the activated carbon has a different rate of removal of some contaminants in water. Therefore, they concluded that activated carbon from different sources may perform better if combined for filtration.

Commercial activated carbon being costly has necessitated the development of activated carbon from cheaper materials (Louis & Sudha, 2013; Manimaran et al., 2019) developed a portable tap water filter using activated carbon produced from agricultural waste. The prototype was capable of reducing parameters such as turbidity, hardness, iron, and TDS to a significant level.

Activated Carbon is not suitable for removing suspended biological material. This can be done in an element that combines adsorption with biological activity (Sutherland, 2008) Since it does not remove sediment or particulate material very well, a sediment filter may be installed before the activated carbon filter. Doing this will extend the life of the activated carbon filter by eliminating large contaminants that otherwise would clog the activated carbon and reduce the contact area available for adsorption (Scherer & Johnson, 2015).

Flow resistance and adsorption rate in a water filter are partly affected by the particle size distribution of granular activated carbon (Mohd Samdin et al., 2015).

MATERIALS AND METHODS

Materials

i. Corncob
ii. Cow bone
iii. Coconut Shell
iv. Phosphoric Acid
v. Distilled Water
vi. Sand
vii. Gravel
viii. Cotton
ix. Fabric
x. Mortar and Pestle
xi. Steel Pot
xii. Clothing material
xiii. Plastic bottles

Method

Preparation of Activated Carbon

The preparation of activated carbon involves two basic processes- the carbonation and the activation processes. Carbonization is carried out through gasification at a higher temperature in inert conditions to produce biochar (Odetoye et al., 2013). The resulting biochar usually shows low absorption capacity hence the need for activation to improve the pore volume, the pore diameter, and the surface area of the biochar (Yang et al., 2019). In this study, Corncob, cow bone, and coconut shell were collected from the farm, abattoir, and market respectively. The materials were washed thoroughly to remove impurities and sun-dried for 3-5 days. The coconut shell and cow bone were crushed with a mortar and pestle to smaller sizes due to their hardness to improve carbonization. The method of pyrolysis employed was similar to (Manimaran et al., 2019) which is quite simple and can be adopted globally. Each material was fed into a steel pot, sealed, and fully ignited for 3-5 hours. Once the charcoal was completed, it was sorted by inspection to sort out the material that had been properly carbonized. The materials that were not properly carbonized were selected and saved for the next batch. After all the materials had been properly carbonized, they were crushed and sieved to remove large particles. Plastic Ziploc bags were bought, and labeled, and each material was stored inside before chemical activation.

The carbonized materials were impregnated with 15% phosphoric acid (H_3PO_4) for 24 hours for purification and enhancement of surface area and then washed several times with distilled water until a pH range of 6-8 was achieved. The materials were spread on a tray and allowed to be drained at room temperature. They were then oven-dried at the temperature of 110^{o}C for 3 hours and transported to the soil mechanics laboratory in the Department of Civil Engineering, Ahmadu Bello University, Zaria for particle-size determination.

Preparation of Gravel and Sand

The gravel and sand used in the setup are crushed rock acquired from the quarry. The gravel was sieved through B.S sieve sizes 12mm and 6mm. The gravel retained on the 12mm sieve was discarded and the rest was used as the drainage gravel. Sieve analysis was conducted on the sand using the B.S sieve sizes 1.18mm, 0.6mm, 0.3mm, 0.15mm, and 0.075mm. The material retained on the 1.18mm sieve was used as the separating gravel and the rest were used as the filtration sand.

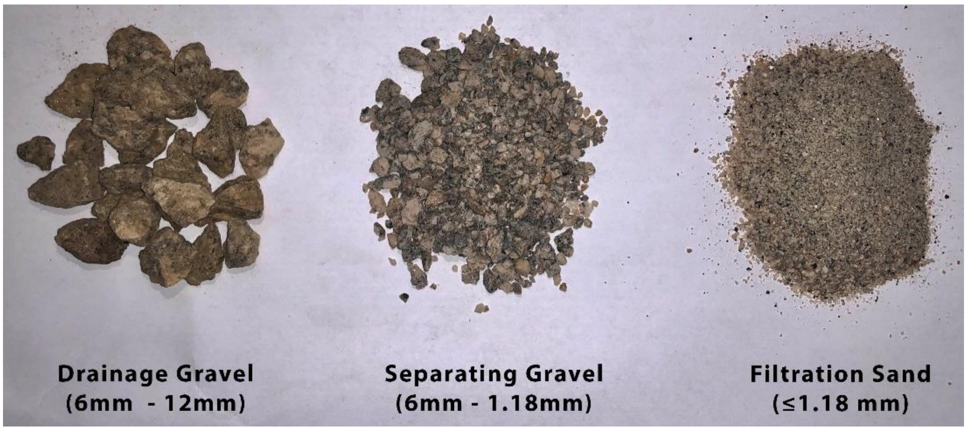

Plate 1: Filtration Sand and Gravel Sizes

Sample collection and Filter setup

Raw water samples were collected from Kubanni River (A.B.U Dam) and the borehole in 55 apartments, Dogon Itche; which are both located in Samaru–Zaria, Nigeria. The samples were put into a 10-liter Jerry Can and transported to the sanitary laboratory in the Department of Water Resources and Environmental Engineering, Ahmadu Bello University, Zaria, Nigeria.

Five plastic bottles of approximately 20cm long, and 6.5cm diameter were acquired and 3cm from the bottom of the bottles were cut off. Three of the bottles were used in setting up the activated corncob, cow bone, and coconut shell filters respectively. The other two bottles were cut and joined together to increase the length to contain all three sources of the activated carbon.

The setup consists of the drainage gravel, followed by the separating gravel, then an activated carbon layer, and finally the filtering sand from top to bottom. A piece of cotton material was placed at the bottom to support the filtration sand and prevent particles from getting into the filtrate.

First Setup*:* Activated corncob char was used in the activated carbon layer. The setup was used to filter the two water samples, replacing the materials after each sample.

Second Setup*:* Activated coconut shell char was used in the activated carbon layer. The setup was used to filter the two water samples, replacing the materials after each sample.

Third Setup*:* Activated cow bone char was used in the activated carbon layer. The setup was used to filter the two water samples, replacing the materials after each sample.

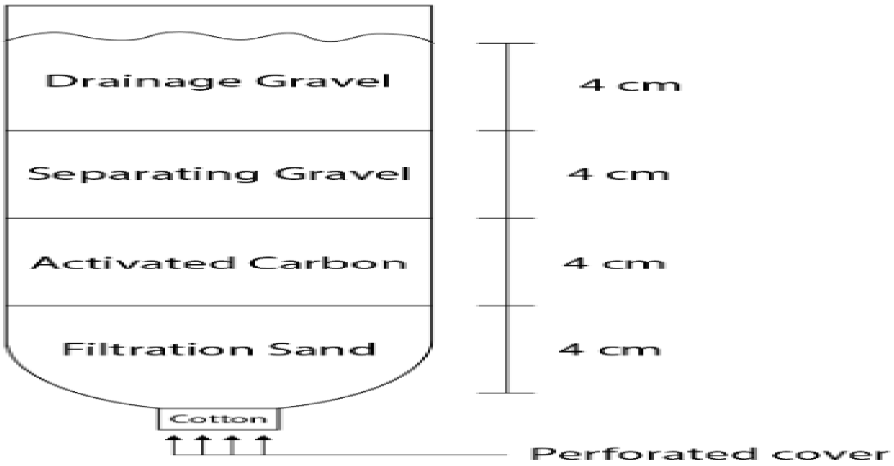

Figure 1: Illustration of the first three setups

Fourth Setup*:* Activated bone, corn cob, and coconut shell char were integrated into the sand bed filter in the order mentioned from the top with the filtration sand separating each of them. The setup was used to filter the two water samples, replacing the materials after each sample.

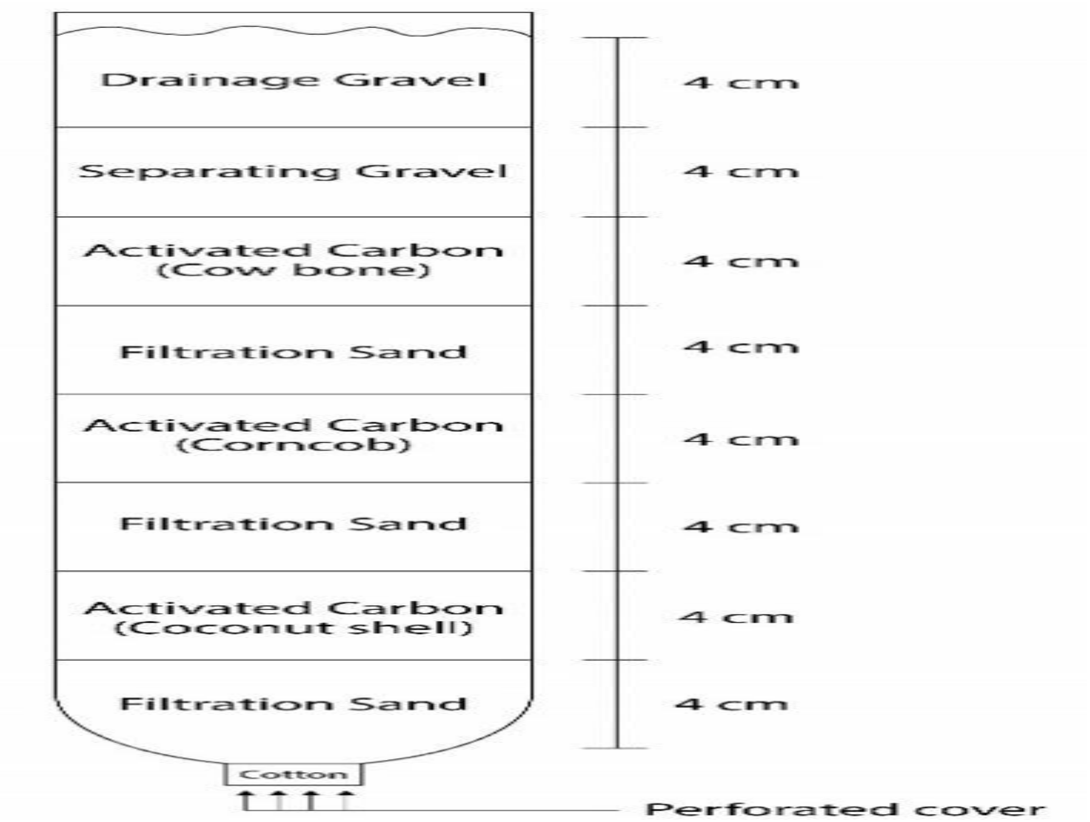

Figure 2: Illustration of the fourth setup

Water quality tests were carried out on the water samples and filtrate to determine the turbidity, pH, Total Dissolved Solids (TDS), Electrical Conductivity (EC), total acidity, total alkalinity, hardness, chloride, and lead concentration.

RESULTS AND DISCUSSION

Sieve Analysis

Fig 3 shows the particle size distribution curve obtained from the result of the sieve analysis for the filtration sand. It shows that the sand has an effective size of 0.12mm and a uniformity coefficient of 4.08.

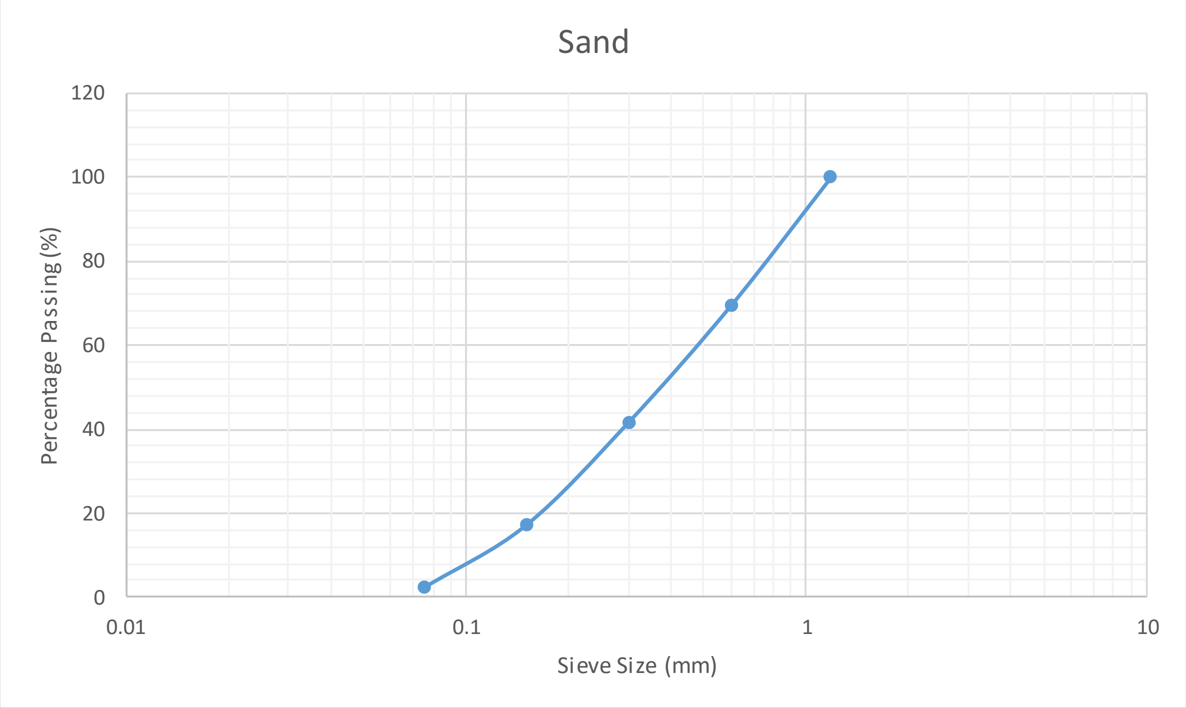

Figure 3: Particle size distribution curve for the sand

Figures 4, 5, and 6 show the particle size distribution curve obtained for the activated carbon. The curve shows that the activated corncob, activated cow bone, and activated coconut shell char have effective sizes of 0.27mm, 0.08mm, and 0.21mm; and uniformity coefficients of 2.11, 5.38, and 2.33 respectively.

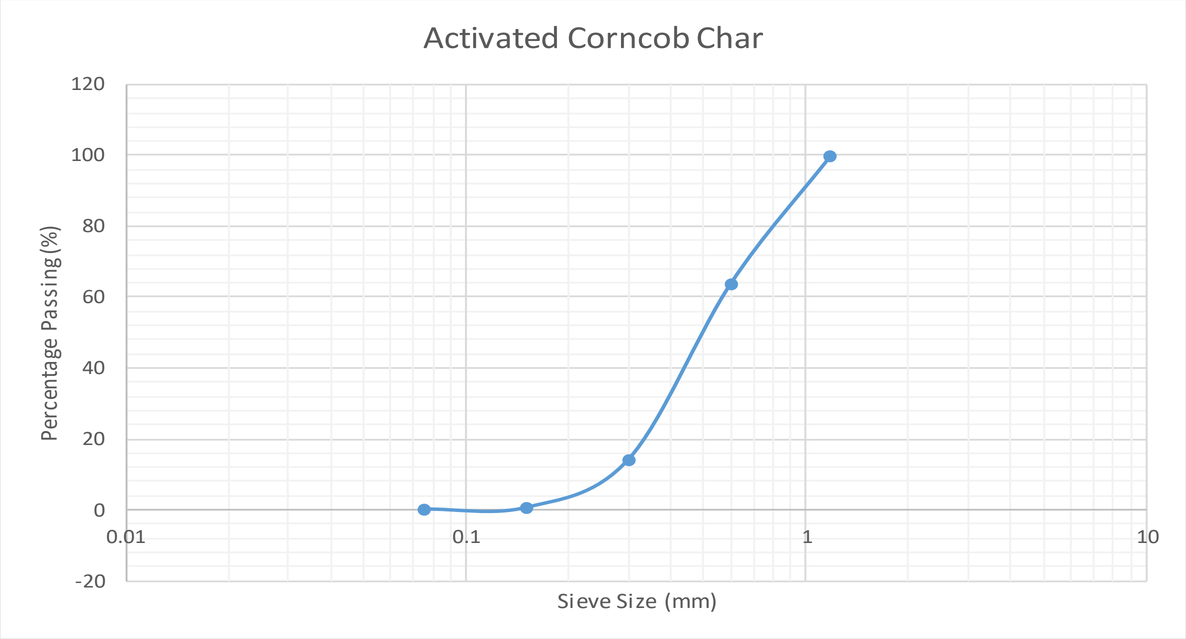

Figure 4: Particle size distribution curve for the activated corncob char

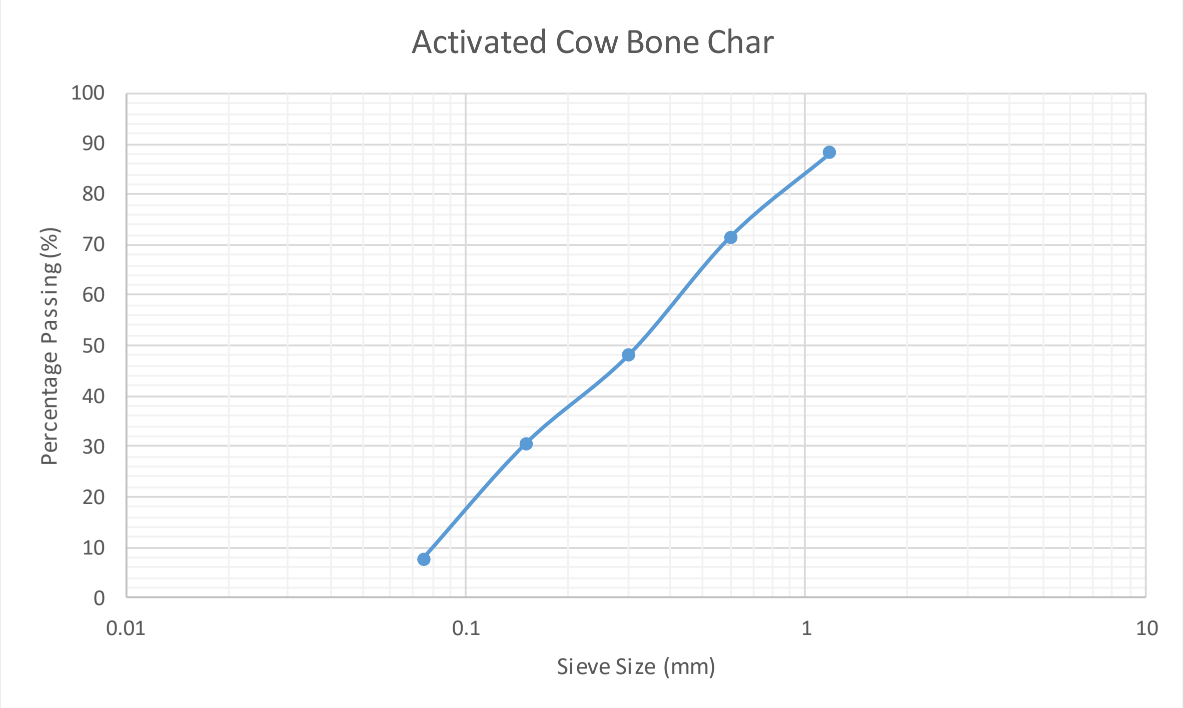

Figure 5: Particle size distribution curve for the activated cow bone char

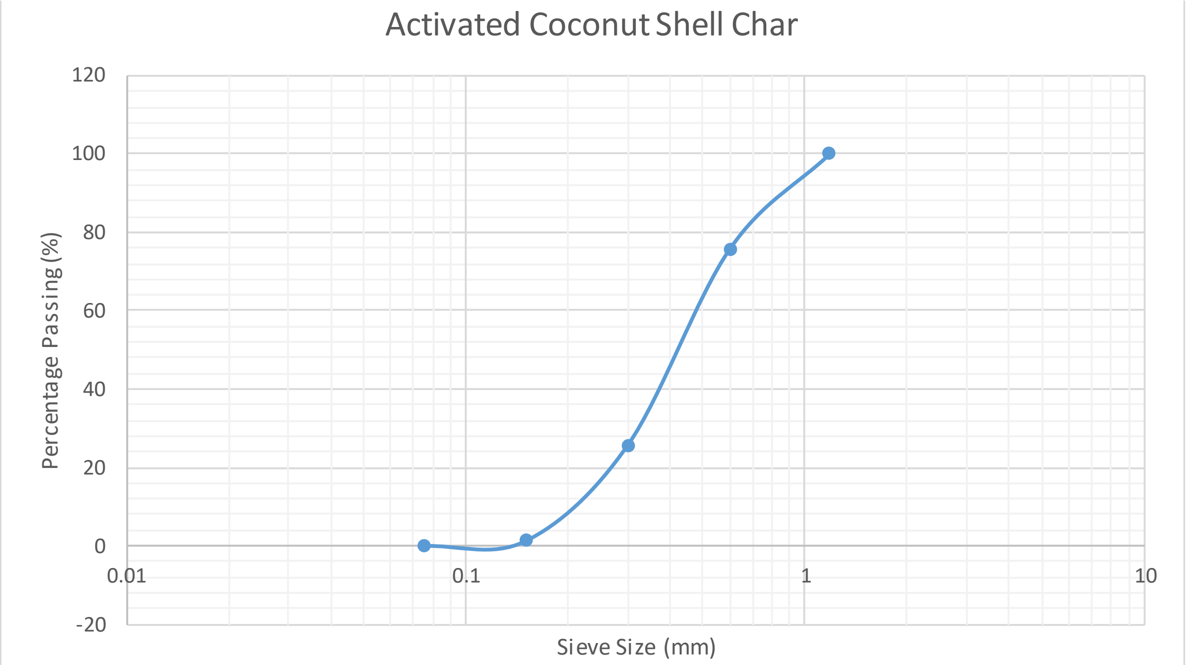

Figure 6: Particle size distribution curve for the activated coconut shell char

Table 1: Physical properties of the filtration sand and the activated carbons used

Filter materials	Effective Size (mm)	Uniformity Coefficient	Coefficient of Curvature
Sand	0.12	4.08	0.90
Activated Corncob Char	0.27	2.11	1.00
Activated Cow bone Char	0.08	5.38	0.65
Activated Coconut Shell Char	0.21	2.33	1.00

The uniformity coefficient (Cu) is defined as the ratio of D_{60} to D_{10}. A value of Cu greater than 4 to 6 classifies the soil as well graded. When Cu is less than 4, it is classified as poorly graded or uniformly graded soil. Uniformly graded soil has identical particles with a Cu value approximately equal to 1. A uniformity coefficient value of 2 or 3 classifies the soil as poorly graded. For the soil to be well graded, the value of the Coefficient of Curvature (Cc) must range between 1 and 3 (Arjun, 2020).

$$Cu = \frac{D_{60}}{D_{10}} \quad (1)$$

$$Cc = \frac{(D_{30})^2}{D_{60} \times D_{10}} \quad (2)$$

D_{10} is called the effective particle size. This means that 10% percent of the particles are finer and 90% of the particles are coarser than D_{10}. Similarly, D_{60} is the particle size at which 60% of the particles are finer, and D_{40} is the particle size at which 40% of the particles are finer.

Water Quality Tests

The raw water sample from Kubanni River showed a reduction in pH in all the filtrates. The raw water sample from the Dogon Itche borehole showed a reduction in pH for the activated cow bone and coconut shell char, and an increase in pH in the activated corncob char and combined media shown in Table 2. All the pH values are within the standards.

Table 2: pH Values

Sources	Raw Water	Activated Corncob Char	Activated Cow Bone Char	Activated Coconut Shell Char	Combined Media
Kubanni River (A.B.U Dam)	8.27	8.05	6.74	7.19	6.85
Borehole (Dogon Itche)	7.58	7.83	7.51	7.26	7.83
Standard Value	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5

Table .3 shows the variation of the turbidity of the raw samples with the filtrates compared with the recommended value.

Table 3: Turbidity Values (NTU)

Sources	Raw Water	Activated Corncob Char	Activated Cow Bone Char	Activated Coconut Shell Char	Combined Media
Kubanni River (A.B.U Dam)	121.1	96.1	8.6	31.2	8.7
Borehole (Dogon Itche)	13.8	11.7	10.6	7.7	1.5
Standard Value	5	5	5	5	5

There was a reduction in the turbidity of all the samples with the combined media showing more tendency in reducing turbidity by reducing the turbidity by 93% in the Kubanni river sample, and 89% in the Dogon Itche borehole sample. The turbidity values in the raw water samples were both above the standard and were reduced significantly by the combined media causing the turbidity of the raw sample from the Dogon Itche borehole to meet the standard.

Tables 4 and 5 show the variation of the TDS and EC of the raw samples with the filtrates compared with the recommended value. There was an increase in the TDS and EC of all the filtrates. This might be due to the rock material used in the filter media. The TDS/EC values were above the recommended value. However, no recent health implications have been associated with high levels of TDS/EC (WHO, 2017).

Table 4: TDS (mg/l)

Sources	Raw Water	Activated Corncob Char	Activated Cow Bone Char	Activated Coconut Shell Char	Combined Media
Kubanni River (A.B.U Dam)	60.7	79.9	395	111	434
Borehole (Dogon Itche)	542	573	613	549	596
Standard Value	500	500	500	500	500

Table 5: EC (µS/cm)

Sources	Raw Water	Activated Corncob Char	Activated Cow Bone Char	Activated Coconut Shell Char	Combined Media
Kubanni River (A.B.U Dam)	120.8	160.4	787	223	886
Borehole (Dogon Itche)	1094	1155	1234	1096	1192
Standard Value	1000	1000	1000	1000	1000

Table 6: Alkalinity Values (mg/l as $CaCO_3$)

Sources	Raw Water	Activated Corncob Char	Activated Cow Bone Char	Activated Coconut Shell Char	Combined Media
Kubanni River (A.B.U Dam)	24	31	58	41	54
Borehole (Dogon Itche)	70	113	57	67	81

Table 6 shows the variation in the alkalinity of the raw samples with the filtrates. The raw water sample from the Kubanni River has low alkalinity. Alkalinity less than 30mg/l is considered low for surface waters (Lew, 2021). There was an increase in alkalinity in all the filtrates. The alkalinity of the filtrates of the Dogon Itche borehole increased for the activated corncob char and combined media but decreased by 18.6% and 4.3% for the activated cow bone and coconut shell char. It is not unusual for alkalinity to range from 0 to 750mg/l as $CaCO_3$ (Lew, 2021). Table 7 shows the variation in the acidity of the raw samples with the filtrates.

Table 7: Acidity (mg/l as $CaCO_3$)

Sources	Raw Water	Activated Corncob Char	Activated Cow Bone Char	Activated Coconut Shell Char	Combined Media
Kubanni River (A.B.U Dam)	160	140	750	325	1120
Borehole (Dogon Itche)	210	170	445	230	215

Table 8: Hardness (mg/l as $CaCO_3$)

Sources	Raw Water	Activated Corncob Char	Activated Cow Bone Char	Activated Coconut Shell Char	Combined Media
Kubanni River (A.B.U Dam)	40.40	50.50	80.81	60.60	40.40
Borehole (Dogon Itche)	212.12	111.11	101.01	121.21	111.11
Standard Value	150	150	150	150	150

Table 8 shows the variation in the hardness of the raw samples with the filtrates compared with the recommended value. The filtrates of the raw water sample from Kubanni River showed a small increase in hardness for the activated corncob and coconut shell char and a relatively higher increase for the activated cow bone char: this may be due to the presence of traces of calcium ion in it. The hardness in the combined media remained the same. The hardness of the raw water sample from the Dogon Itche borehole was above the recommended value. The high level of hardness in the sample may be associated with the high mineral content in groundwater. The hardness was significantly reduced by all the filters to meet the standard.

Table 9: Chlorides (mg/l)

Sources	Raw Water	Activated Corncob Char	Activated Cow Bone Char	Activated Coconut Shell Char	Combined Media
Kubanni River (A.B.U Dam)	7.00	7.00	135.46	7.50	146.46
Borehole (Dogon Itche)	63.48	54.98	66.48	66.98	61.48
Standard Value	250	250	250	250	250

Table 9 shows the variation of the chloride of the raw samples with the filtrates compared with the recommended value. The filtrates of the raw water sample from Kubanni River showed a high increase in the chloride levels of the filtrates that passed through the activated cow bone char and combined media. The filtrates of the raw water sample from the Dogon Itche borehole showed a 13% and 3% reduction in chloride for the activated corncob char and combined media. The activated corncob char tended to reduce chloride ion concentrations more than the others. All the values of the raw water samples and the filtrates are in line with the standards.

Table 10: Lead Values (mg/l)

Sources	Raw Water	Activated Corncob Char	Activated Cow Bone Char	Activated Coconut Shell Char	Combined Media
Kubanni River (A.B.U Dam)	0.0067*	0.0086*	0.0082*	0.0081*	0.0076*
Borehole (Dogon Itche)	0.0090*	0.0079*	0.0076*	0.0087*	0.0115*
Standard Value	0.01	0.01	0.01	0.01	0.01

(* below detection point)

Table 10 shows the variation of the lead of the raw samples with the filtrates compared with the recommended value. The lead in the concentration of the samples and the filtrates was below the detection limit.

Analysis of the water filter

Apart from TDS/EC values which increased in all the filtrates, all other values of the filtrates in the combined media were in line with the Nigerian standards for drinking water. Due to the high removal of turbidity, ability to reduce hardness, moderate alkalinity values, and the likelihood of removing chloride in the raw water sample from the borehole in Dogon Itche, the combined media was selected, and installed in the prototype water filter. The sand was washed several times before it was installed in the filter. The activated cow bone char was also washed with distilled water to reduce the silt content. The raw water sample from the Dogon Itche borehole was run through the filter thrice while measuring the TDS after every run. It was observed that after the third run, the TDS in the filtrate decreased. It can be observed from the results that the prototype water filter improved in terms of acidity and TDS removal compared to the laboratory model. $0.01m^3$ (10 liters) of water was run through the water filter, and the flow rate was calculated to be $0.0000042m^3/s$ (0.0042L/s).

CONCLUSION

From the study, it was observed that the activated corncob char showed the least removal in turbidity, and an increase in the alkalinity of the filtrates, but showed the highest tendency in removing acidity and chloride. The activated cow bone char showed a high tendency to remove turbidity and a gradual removal in the alkalinity of the raw water sample from the Dogon Itche borehole. It showed the likelihood of increasing hardness and chloride levels. The activated coconut shell char also showed a tendency to remove turbidity. Similar to the cow bone, it showed a gradual removal in the alkalinity in the raw water sample from the Dogon Itche borehole. The combined media showed the highest tendency in removing turbidity and hardness in all the samples, a gradual increase in the alkalinity of the filtrates, and a decrease in the level of chloride in the raw water sample from the Dogon Itche borehole. In addition, all the parameters of the combined media met the Nigerian standard for drinking water except for the TDS that increased in the filtrates from all of the activated carbon filters. Hence, the combined media was selected and installed in the prototype water filter. The prototype water filter performed better when the sand and activated bone char were washed again before installation, and after running the experiment three times, there was a gradual removal in the alkalinity and chloride, and a significant removal in the turbidity, acidity, and hardness of the raw water sample. The method of activation used may have also influenced the results from the different samples. Therefore, further investigation on the use of activated carbon in filtration should be carried out comparing the modified method employed, and the conventional method of activation.

REFERENCES

Adie, D. B., Lukman, S., Sani, B., & Yahaya, I. A. (2013). *Comparative Analysis of Filtration Using Corn Cob, Bone Char, and Wood Chippings*. *June 2014*.

Ahmad, T., & Danish, M. (2018). Prospects of banana waste utilization in wastewater treatment: A review. *Journal of Environmental Management*, *206*, 330–348.

Arjun, N. (2020). *Uniformity Coefficient(Cu) and Coefficient of Curvature(Cc) of Soil*. Geotechnical Engineering.

Balasundram, V., Ibrahim, N., Kasmani, R. M., Hamid, M. K. A., Isha, R., Hasbullah, H., & Ali, R. R. (2017). Thermogravimetric catalytic pyrolysis and kinetic studies of coconut copra and rice husk for possible maximum production of pyrolysis oil. *Journal of Cleaner Production*, *167*, 218–228.

Bolisetty, S., Peydayesh, M., & Mezzenga, R. (2019). Sustainable technologies for water purification from heavy metals: review and analysis. *Chemical Society Reviews*, *48*(2), 463–487.

Huang, T., Zhou, R., Cui, J., Zhang, J., Tang, X., Chen, S., Feng, J., & Liu, H. (2018). Fast and cost-effective preparation of antimicrobial zinc oxide embedded in activated carbon composite for water purification applications. *Materials Chemistry and Physics*, *206*, 124–129.

Iwuozor, K. O., Emenike, E. C., Stephen, A. A., Kevin, O. S., Adeleke, J., & Adeniyi, A. G. (2023). Thermochemical recycling of waste disposable facemasks in a non-electrically powered system. *Low-Carbon Materials and Green Construction*, *1*(1), 12.

Jayawardane, N. S. (1996). Handbook of water and wastewater treatment technology. *Agriculture, Ecosystems & Environment*, *60*(2–3), 213–214. https://doi.org/10.1016/s0167-8809(97)87011-9

Jiang, C., Yakaboylu, G. A., Yumak, T., Zondlo, J. W., Sabolsky, E. M., & Wang, J. (2020). Activated carbons prepared by indirect and direct CO2 activation of lignocellulosic biomass for supercapacitor electrodes. *Renewable Energy*, *155*, 38–52. https://doi.org/10.1016/j.renene.2020.03.111

Lew, D. (2021). *Acidity And Alkalinity - Water Quality*.

Lingamdinne, L. P., Koduru, J. R., & Karri, R. R. (2019). A comprehensive review of applications of magnetic graphene oxide-based nanocomposites for sustainable water purification. *Journal of Environmental Management*, *231*, 622–634.

Louis, N. S. M., & Sudha, S. (2013). Activated carbon from corn starch for treating dye wastewater. *International Journal of Engineering Science Invention*, *2*(9), 45–53.

Manimaran, S., Vithusan, U., Swathy, P., Noor, A. M. I., & Viswanath, T. (2019). *Portable Tap Water Filter Using Activated Carbon from Natural Waste Materials*. *6*(7), 422–429.

Mansour, F., Al-Hindi, M., Yahfoufi, R., Ayoub, G. M., & Ahmad, M. N. (2018). The use of activated carbon for the removal of pharmaceuticals from aqueous solutions: a review. *Reviews in Environmental Science and Bio/Technology*, *17*, 109–145.

Mohd Samdin, S., Peng, L. H., & Marzuki, M. (2015). Investigation of coconut shells activated carbon as the cost-effective absorbent in drinking water filter. *Jurnal Teknologi*, *77*(22), 13–17. https://doi.org/10.11113/jt.v77.6656

Odetoye, T. E., Onifade, K. R., AbuBakar, M. S., & Titiloye, J. O. (2013). Thermochemical characterization of Parinari polyandra Benth fruit shell. *Industrial Crops and Products*, *44*, 62–66.

Oladipo, A. A., & Ifebajo, A. O. (2018). Highly efficient magnetic chicken bone biochar for removal of tetracycline and fluorescent dye from wastewater: two-stage adsorber analysis. *Journal of Environmental Management*, *209*, 9–16.

Regti, A., Laamari, M. R., Stiriba, S.-E., & El Haddad, M. (2017). Potential use of activated carbon derived from Persea species under alkaline conditions for removing cationic dye from wastewater. *Journal of the Association of Arab Universities for Basic and Applied Sciences*, *24*, 10–18.

Reza, S., Yun, C. S., Afroze, S., Radenahmad, N., Bakar, M. S. A., Saidur, R., Taweekun, J., & Abul, K. (2020). Preparation of activated carbon from biomass and its ' applications in water and gas purification, a review. *Arab Journal of Basic and Applied Sciences*, *27*(1), 208–238. https://doi.org/10.1080/25765299.2020.1766799

Ripperger, S., Gösele, W., Alt, C., & Loewe, T. (2013). Filtration, 1. Fundamentals. In *Ullmann's Encyclopedia of Industrial Chemistry* (pp. 1–38). https://doi.org/10.1002/14356007.b02_10.pub3

Scherer, T., & Johnson, R. (2015). Filtration : Sediment, Activated Carbon, and Mixed Media. In *Extension Agricultural Engineer North Dakota State University* (Vol. 1, Issue 11, pp. 200–203).

Sutherland, K. (2008). Filters and Filtration Handbook, Fifth Edition. In *Elsevier* (Fifth). Elsevier.

Teow, Y. H., & Mohammad, A. W. (2019). New generation nanomaterials for water desalination: A review. *Desalination*, *451*, 2–17.

WHO. (2008). *WHO Guidelines for Drinking-Water Quality*. https://doi.org/10.1248/jhs1956.35.307

WHO. (2017). *Guidelines for Drinking_water Quality*.

Yang, Z., Zhou, Y., Feng, Z., Rui, X., Zhang, T., & Zhang, Z. (2019). A review on reverse osmosis and nanofiltration membranes for water purification. *Polymers*, *11*(8), 1252.