PRINT ISSN 1119-8362
Electronic ISSN 1119-8362

Full-text Available Online at
https://www.ajol.info/index.php/jasem
https://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 26 (3) 453-457 March 2022

The Use of Coconut-Shell Based Activated Carbon as an Adsorbent in the Treatment of Hard Water

***ADEWUYI, AS; OLABANJI, TO**

Department of Civil and Environmental Engineering; Federal University of Technology, Akure, Nigeria
**Corresponding Author Email: adew.steve@gmail.com*

ABSTRACT: One of the undesirable characteristics of some groundwater sources is hardness, which has adverse effects on water pipes, boilers and soap consumption. Therefore, several treatment processes have been introduced to remove or reduce the hardness from water. One of the innovations in this regard is coconut-shell which is readily available and could be used to produce resource materials such as activated carbon that is of public health importance. The initial values of Calcium, Magnesium and Total Hardness in the raw water sample were 120.24mg/L, 98.29mg/L and 588.00mg/L, respectively which are above the World Health Organization (WHO) standard. The highest quantities of Calcium, Magnesium and Total Hardness were removed at a contact time of 60 minutes with removal efficiencies of 80%, 60.44% and 66.71%, respectively. Also, the optimum dosage occurred at 1.2g for Calcium hardness, 1.5g for Magnesium hardness and Total hardness. In conclusion, the adsorbent obtained from the coconut-shell has the potential of removing Calcium, Magnesium and Total Hardness in water.

DOI: https://dx.doi.org/10.4314/jasem.v26i3.12

Impact factor: http://sjifactor.com/passport.php?id=21082

Google Analytics: https://www.ajol.info/stats/bdf07303d34706088ffffbc8a92c9c1491b12470

Dates: Received: 10 January 2022; Revised: 22 February 2022; Accepted: 15 March 2022

Keywords: Coconut-shells; Activated carbon; Adsorbent; Calcium hardness; Magnesium hardness

Water is a compound made up of two molecules of Hydrogen and one molecule of Oxygen (Chaudhari et al., 2015). Among the various water constituents, Calcium and Magnesium salts are of great concern since they lead to water hardness (WHO, 2011). Water hardness is a measure of the number of divalent ions such as calcium and magnesium in water. It is not caused by a single substance but by various dissolved polyvalent metallic ions, predominantly calcium and magnesium cations, however other cations (e.g., aluminium, barium, iron, manganese, strontium and zinc) also contribute. (WHO, 2011). Hardness is commonly expressed as milligrams of calcium carbonate equivalent per liter. Water containing calcium carbonate at concentrations below 60mg/l is considered as soft; 60-120mg/l, moderately hard; 120-180mg/l, hard; and more than 180mg/l, very hard (McGowan, 2000). Although hardness is caused by cations, also it may be discussed in terms of carbonate (temporary) and non-carbonate (permanent) hardness. Paul et al. (2009), opined that water hardness causes many economic problems for water heaters, laundry washers, dishwashers, beverage machines, showerheads, faucets, fixtures, and other household units. Other issues include difficult lathering with soap, undesirable spots on clothes as well as toughening of skin and hair. Hard water is also said to cause serious health problems such as urolithiasis, cardiovascular disorder, kidney problems, anencephaly, and cancer. Additionally, WHO reports that excess intake of calcium is associated with kidney stones and that of magnesium leads to diarrhoea and laxative effect due to changes in bowel habit (Chaudhari et al., 2015). Seyrig and Shan (2007) stressed that the hardness of water varies considerably from place to place. In general, groundwater are harder than surface waters. There are several methods to remove the hardness present in water. Some of the methods to remove hardness from water are boiling of hard water, adding slaked lime (Clark's Process), adding washing soda (Calgon's Process), ion exchange process and using ion exchange resins. Each technique for the removal of water hardness has its unique advantages and disadvantages, such as boiling water which precipitates calcium carbonate. WHO (2009) reported that the ion exchange softening

**Corresponding Author Email: adew.steve@gmail.com*

process is the most common way of reducing hardness in drinking water, while Abeliotis et al. (2015) revealed that conventional water heater could soften hard water to some degrees, it creates mineral deposits on the heater. Agostinho et al. (2012) reported that lime-soda softening for treating hard water is generally applied as a conventional water treatment process for municipal use. However, for industrial use, this treatment is not applied, and Shrestha et al. (2009) made it known that the high cost of the synthetic resins and the limited availability of natural zeolites makes the method inappropriate for developing countries. Many scientists, engineers and environmentalists have investigated the possibility and efficiency of utilization of agricultural products as adsorbents for water treatment (Adeolu et al., 2016). Apart from being very cheap, they are produced in large usable quantities, making them abundantly available. Some of the low-cost agricultural waste products that has been studied include; rice husk, soya bean hulls, cowpea husk, yam peel, banana peel etc. (Mohan and Singh, 2004). Mohan and Singh (2004) defined Activated carbon (AC) as a black, amorphous solid containing significant portion of fixed carbon content and other materials such as ash, water vapour and volatile matters in smaller percentages. Activated carbon can be produced from biomass that contains a high number of lignin and cellulose, such as coconut-husk waste. Coconut husk waste contains about 32.5% cellulose and 37% lignin (Usman et al., 2020). Therefore, the objective of this paper is to assess the use of activated carbon produced from coconut-shell as adsorbent for treatment of hard water.

MATERIALS AND METHODS

Source, Description and Preparation of the Coconut Shells: Coconut shells were collected at the Coconut Plantation farm in Ilesa, Osun State, Nigeria. The shells were washed with distilled water and sun-dried for 168 hours and then oven-dried at 45°C to constant weight. The samples were grounded and stored in a polythene container for analysis and treatment of water.

Water Sample Collection: Well-water sample was collected from the Hospital road in llara-Mokin and brought to the laboratory for preparation and analysis using standard laboratory procedures and methods by APHA (1998).

Physiochemical Analysis of Water: The following tests were carried out on the water sample: pH test was carried out using a Jenway pH meter, 370 model. The temperature was measured using a glass thermometer. Applying the standard procedure, the Total Hardness was measured using the following reagents; Sodium hydroxide, Standard Calcium solution, Eriochrome black T powder, EDTA solution and Buffer solution.

Carbonization and Activation of the Coconut-Shells: 1.2 kg of raw Coconut-shells was prepared by burning under a temperature of 400°C for one hour in a closed system (porcelain crucible, which is a local clay pot), and then cooled to room temperature. The charcoal (gotten from burning the Coconut-shells) was subjected to citric acid activation (obtained from lemon juice). The charcoal was agitated in citric acid after the agitation; the charcoal slurry was left overnight at room temperature and then dried at 110°C for 24 hours. The sample was then heated to an optimum temperature of 400°C and maintained at a constant temperature for one hour before cooling. After cooling down, the activated charcoal was washed several times with distilled water to remove the excess activating agent. The following equations summarize the entire process;

$$\text{Raw Coconut} - \text{shell} \xrightarrow[\Delta]{400^0, 60\ min} \text{C(s)} + \text{CO (carbonization)}$$

$$\text{Raw Coconut} - \text{shell} \xrightarrow[\Delta]{AA, 400^0, 60\ min} \text{AC} + CO_2\text{(Activation)}$$

Where; AA represents Activating Agent; AC represents Activated Carbon

Adsorption Studies for the Hardness of the Water sample: A series of batch experiments was carried out according to Badmus et al. (2007) to determine the adsorption isotherms of selected magnesium and calcium ions on the adsorbents. The steps of the experiments are described below:

Step 1 (Effect of Contact time): A known amount of activated carbon (1.2g) was added into each flask and agitated intermittently for the desired periods. The mixture was shaken thoroughly at 1000rpm. With an electric shaker (centrifuge) for 5, 15, 30, 45 and 60 minutes to attain equilibrium. The suspension was filtered through Whatman No.1 filter paper to remove any suspended adsorbent. Initial and final hardness concentrations of treated water were determined. The study was performed at a temperature of 29°C.

Step 2 (Effect of Adsorbent doses): A known amount of activated carbon (0.6, 0.9, 1.2, 1.5 and 1.8g) was added into each flask and agitated intermittently for the desired period (30 minutes). The mixture was shaken thoroughly at 1000rpm with an electric shaker (centrifuge) throughout the time of operation. It was assumed that the applied shaking speed allowed all the surface area to come in contact with water hardness throughout the experiment. The suspension was filtered through Whatman No.1 filter paper to remove

any suspended adsorbent. Initial and final hardness concentrations of treated water were determined, and the study was performed at a temperature of 29°C.

RESULTS AND DISCUSSION

The physiochemical characteristics of the raw water sample as compared with the World Health Organization (WHO) standard is given in Table 1.

Table 1: Physiochemical characteristics of the raw water

Parameters	Value	WHO standard
pH	7.5	6.5-8.5
Temperature (ºC)	29.0	<40
Calcium hardness (mg/L)	120.24	75
Magnesium hardness (mg/L)	98.29	50
Total hardness (mg/L)	588.00	500

Effect of contact time on the removal of calcium hardness: The values were generated by varying the contact time (5-60 minutes) at a temperature of 29°C. The result, as shown in Table 2, revealed that at a certain point in time (45 minutes), maximum adsorption sets in, and the amount of free hardness remain constant even with further elongation of the time.

Table 2: Effect of contact time on the removal of calcium hardness

Contact time (mins)	Final Conc. (mg/L)	Removal capacity	% removal efficiency
0	120.24	-	-
5	72.144	48.096	40.72
15	64.128	56.112	46.67
30	28.056	92.184	76.67
45	24.048	96.192	80.00
60	24.048	96.192	80.00

The result showed that percentage removal of hardness increased at a steady rate as contact time increased up to about 45 minutes, attaining a maximum value of 80%. The adsorption capacity increased at a constant rate as contact time increased up to about 45 minutes, attaining a maximum value of 96.192mg/L.

Effect of contact time on the removal of magnesium hardness: The result as shown in Table 3, showed that the removal rate was rapid within the first 15 minutes, sharply increased for 30 minutes and gradually increased between 45 and at 60 minutes it attained a maximum value of 60.44%.

Table 3: Effect of contact time on the removal of magnesium hardness

Contact time (mins)	Final Conc. (mg/L)	Removal capacity	% removal efficiency
0	98.29	-	-
5	60.800	37.490	38.15
15	48.826	49.464	50.32
30	43.776	54.514	55.46
45	41.344	56.946	57.94
60	38.888	59.402	60.44

The adsorption capacity increased at a steady rate as contact time increased up to 60 minutes, attaining a maximum value of 59.402mg/L. The initial faster rate was due to the availability of the uncovered surface area of the adsorbents, since the adsorption kinetics depends on the surface area of the adsorbents (Samuel and Osman, 1987).

Effect of contact time on the removal of total hardness: As shown in Table 4, the removal rate was rapid within the first 15 minutes, sharply increased for 30 minutes and gradually increased between 45 and 60 minutes attaining a maximum value of around 60.71%. The adsorption capacity increased steadily as contact time increased up to 60 minutes, attaining a maximum value of 375mg/L.

Table 4: Effect of contact time on the removal of total hardness

Contact time (mins)	Final Conc. (mg/L)	Removal capacity	% removal efficiency
0	588.00	-	-
5	451.50	136.50	23.21
15	441.00	147.00	25.00
30	315.00	273.00	42.86
45	273.00	315.00	53.57
60	231.50	357.00	60.71

Effect of adsorbent dosage on calcium hardness: The values were generated by varying the adsorbent doses (0.6 to 1.5g) at 29°C temperature. The result, as shown in Table 5, revealed that after a specific dose of adsorbent, the maximum adsorption set in (and the result indicates that the percentage removal of hardness increased at a steady rate as adsorbent dose increased up to about 1.2g attaining a maximum value of 80%) and a further increase in absorbent dose caused a decrease in the adsorption capacity, which may be due to the ratio of the volume of water to the adsorbent dose being almost equal and hence it took longer time for adsorbent to dissolve and more time to absorb hardness from the water. The adsorption capacity increased steadily as adsorbent dose increased up to about 1.2g (and attaining a maximum value of 96.192mg/L). In comparison, the same adsorption capacity was gotten with a weight of 1.5g, and adsorption capacity decreased for 1.8g.

Table 5: Effect of adsorbent dosage on calcium hardness

Adsorbent dose (g)	Final Conc. (mg/L)	Removal capacity	% removal efficiency
0.0	120.24	-	-
0.6	80.160	40.080	33.33
0.9	52.160	60.136	50.01
1.2	24.048	96.192	80.00
1.5	24.048	96.192	80.00
1.8	40.080	80.160	66.67

Effect of adsorbent dosage on magnesium hardness: The values were generated by varying the adsorbent doses (0.6 to 1.5g) at a temperature of 29°C. The result, as shown in Table 6, suggested that after a specific dose of adsorbent, the maximum adsorption sets in (and the result shows that percentage removal of hardness increased at a steady rate as adsorbent dose increased up to about 1.2g, attaining a maximum value of 57.94%) and a further increase in absorbent dose caused a decrease in the adsorption capacity, which may be due to the ratio of the volume of water to the adsorbent dose being almost equal. Hence, it took longer time for the adsorbent to dissolve and more time to absorb hardness from the water. The adsorption capacity increased steadily as adsorbent dose increased up to about 1.2g (and attaining a maximum value of 56.946mg/L). In comparison, an equal value of adsorption capacity was gotten for 1.2g and 1.5g and the adsorption capacity of the absorbent at 1.8g dropped below the value of 1.5g.

Table 6: Effect of adsorbent dosage on magnesium hardness

Adsorbent dose (g)	Final Conc. (mg/L)	Removal capacity	% removal efficiency
0.0	98.29	-	-
0.6	53.504	44.786	45.57
0.9	46.208	52.082	52.99
1.2	43.776	54.514	55.46
1.5	41.344	56.946	57.94
1.8	43.776	54.514	55.46

Effect of adsorbent dosage on total hardness: The values were generated by varying the adsorbent doses (0.6 to 1.5g) at a temperature of 29°C. The result, as shown in Table 7, showed that after a specific dose of the adsorbent, the maximum adsorption set in (and the result revealed that percentage removal of hardness increased at a steady rate as adsorbent dose increased up to about 1.2g, attaining a maximum value of 50%) and a further increase in absorbent dose caused a decrease in the adsorption capacity which may be due to the ratio of the volume of water to the adsorbent dose being almost equal, and hence it took longer time for adsorbent to dissolve and more time to absorb hardness from the water.

Table 7: Effect of adsorbent dosage on total hardness

Adsorbent dose (g)	Final Conc. (mg/L)	Removal capacity	% removal efficiency
0.0	120.24	-	-
0.6	441.00	147.00	25.00
0.9	336.00	252.00	42.86
1.2	315.00	273.00	46.43
1.5	294.00	294.00	50.00
1.8	323.00	265.50	44.64

The adsorption capacity increased steadily as adsorbent dose increased up to about 1.2g (and attaining a maximum value of 294.00mg/L). In comparison, the same value of adsorption capacity was gotten for 1.5g and adsorption capacity of the absorbent at 1.8g dropped below the value obtained from 1.5g.

Conclusion: It is evident from the study that the coconut shell has excellent potential for the uptake of hardness from raw water. It has also been observed that the adsorption capacity of the coconut-shells depends on conditions such as adsorption dose and contact time. Converting this waste into activated carbon can greatly help to reduce its menace in the environment and enhance effective waste management. It is, therefore recommended that the use of coconut shell for production of activated carbon for the removal of hardness in water should be greatly encouraged.

REFERENCES

Abeliotis, K.; Candan, C; Amberg, C; Ferri, A (2014). Impact of water hardness on consumers' perception of laundry washing result in five European countries. International Journal of Consumer Studies, Volume 39(1), pp. 60-66.

Adeolu, AT; Okareh, OT; Dada, AO (2016). Adsorption of chromium ion from industrial effluent using activated carbon derived from plantain (Musa paradisiaca) wastes. American Journal for Environmental Protection, 4(1), pp. 7-20.

Agostinho, CL; Nascimento, L; Cavalcanti, BF (2012). Water Hardness Removal for Industrial use: Application of the Electrolysis Process.. Open Acess Scientific Reports, 1(9).

American Public Health Association, APHA (1989). Standard Methods for the Examination of Water and Wastewater, Washington, DC: APHA.

Badmus, MA; Audu, TO; Anyata, BU (2007). Removal of Lead Ion from Industrial Wastewater by Activated Carbon Prepared from Periwinkle Sheels (Typanotonus fuscatus). Turkish Journal of Engineering and Environmental Sciences, Volume 31, pp. 251-263.

Chaudhari, PR; Aparnatu, KD; Upadhyah, JB; Judah, AL (2015). Chemical Unit Operations for Wastewater Treatment. India.

McGowan, W (2000). Water processing: residential, commercial, light-industrial, Lisle: Water Quality Association.

Mohan, D; Singh, KP (2004). Adsorption of cadmium and zinc using activated carbon derived from bagasse - an agricultural waste. Water Research, Volume 36, pp. 2304-2318.

Paul, DD; Gadkari, VV; Evers, DP; Goshe, ME; Thornton, DA (2009). Final report study on benefits of removal of hardness (calcium and magnesium ions) from a water supply, Lisle: Water Quality Association.

Samuel, DF; Osman, MA (1987). Adsorption process for water treatment, London: Butterworth.

Seyrig, G; Shan, W (2007). Chemical Precipitation: Water softening , United States: College of Engineering Michigan state university.

Usman, Y; Fatkhurrahman, M; Al Farouq, F; Putri, SA; Sipangkar, SP (2020). Utilization of coconut husk waste in the preparation of activated carbon by using chemical activators of KOH and NaOH.

World Health Organization, WHO (2009). Our Planet,Our Earth, Geneva: WHO Commission on Health and Environment.

World Health Organisation, WHO (2011). Guidelines for drinking water quality (4 ed., Vol. 38 (4)). Geneva: World Health Organisation.