Production of activated carbon from poultry feathers for waste water treatment

Rue Chiramba, Gratitude Charis, Nonhlanhla Fungura, Gwiranai Danha and Tirivaviri Mamvura

ABSTRACT

Contamination of water bodies by heavy metal ions is a challenge many developing nations like Zimbabwe face, with negative environmental and socio-economic repercussions. Treating affected bodies usually requires a costly consignment of chemicals and activated carbon. This research investigates the possible use of an abundant waste resource – poultry feathers – to make activated carbon for heavy metal ion removal. Poultry consumption in this nation generates more than five million tonnes of feathers a year, with very few uses of this by-product. This research was carried out to evaluate the effectiveness of activated carbon synthesized from poultry feathers with sodium hydroxide as the activating agent. It was tested for removing heavy metal ions from waste water at Lake Chivero and the experimental work done showed that it had a removal efficiency as high as 97%, with a high affinity for lead ions as compared with chromium ions. Upon characterization, the activated carbon showed an iodine number of 520 mg and it worked best at a pH value of 8. The efficiency removal also increased with increasing adsorbent concentration as well as contact time up to a period where these factors ceased to be the limiting factors of the reaction.

Key words | activated carbon, adsorption, poultry feathers, waste water treatment

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INTRODUCTION

Water is an essence of life. Due to industrialization and urbanization, numerous impurities such as heavy metal ions, biological contaminants, salts etc. have been introduced in water, threatening the quality of the water available for consumption (Sag & Kutsal 2001). These impurities are not only toxic to humans, but also to aquatic life, when laden industrial effluents find their way into water bodies (Abdel-Raouf & Abdul-Raheim 2017). Purification of water is therefore a relevant challenge of the present day. Beyond being toxic, heavy metal ions are non-biodegradable and tend to accumulate in living tissues, multiplying their effects and causing several diseases and health disorders (Ademiluyi & Nze 2016). It is therefore necessary to eliminate heavy metals from water and waste water to protect public health.

Several methods to purify water have been employed, which include adsorption, precipitation, ion exchange, reverse osmosis, electrochemical treatments, membrane filtration, flotation and biosorption (Anisuzzaman *et al.* 2015; Abdel-Raouf & Abdul-Raheim 2017). Some of these techniques however, have disadvantages such as incomplete metal removal, high reagent and energy costs and generation of toxic sludge or other products (He & Chen 2014). Among all these techniques, this research focuses on the biosorption method since it is economically favourable, and mostly efficient at low heavy metal ion concentrations. Recent local and regional policies have emphasized the need for value addition and beneficiation (Sag & Kutsal 2001). In this research, waste chicken feathers were used as the raw materials in making activated carbon, an adsorbent to be used for removing heavy metal ions from effluents (Kawahara *et al.* 2015). In chemical activation the chicken feathers were mixed with a chemical reagent, sodium hydroxide, and then pyrolysis followed at a temperature of 450 °C, in the absence of air. Alkali activation is preferred in the production of

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micro-porous activated carbon as compared with acid activation as it has been seen to produce excellent and valuable properties (Sharath *et al.* 2017).

Activated carbon production

Activated carbon is made from any substance with high carbon content, where the adsorption property of the substance is enhanced to allow molecules of various contaminants to concentrate and adhere to the solid surface of the carbon. The general process flow in making activated carbon is shown in Figure 1.

MATERIALS AND METHODS

Raw material preparation

The poultry feathers used for preparation of activated carbon were obtained locally. The feathers were first washed using detergents to remove blood, dirt and droppings. They were then dried at 40 °C in an oven for 15 min. The dried feathers were cut to increase their surface area and were impregnated with 0.01 M NaOH for an hour in a water bath set at 50 °C. The treated fathers were then filtered through Whatman No. 41 filter paper and rinsed with distilled water to remove excess sodium hydroxide and dried in the oven. The procedure was adapted and modified from Mondal *et al.* (2019).

Pyrolysis of poultry feathers

The weight of the poultry feathers was first noted before they were carbonized. The temperature of the furnace was set at 45 °C and the feathers put in the furnace. After an hour the activated carbon was removed from the furnace, cooled for two hours at room temperature, crushed and sieved using a 600 μm sieve to obtain the powdered activated carbon. The procedure was adapted from Ademiluyi & Nze (2016) and Sharath *et al.* (2017).

Characterization of activated carbon

Characterization was done using the iodine number test, defined as the amount of iodine adsorbed per gram of activated carbon at an equilibrium concentration (Sariol *et al.* 2016). The adsorption of aqueous iodine is considered a quick test for evaluating the surface area of activated carbons associated with pores larger than 1 nanometre and it was determined according to the procedure established by the American Society for Testing and Materials (ASTM 2011). A mass of 0.1 g of the activated carbon was placed in a dry 100 mL conical flask and 5 mL of 5% HCl added to it. The flask was swirled until the activated carbon was wetted and 10 mL of 0.1 M iodine solution was added. Then 10 mL of the filtrate was titrated against a standard 0.1 M sodium thiosulphate solution using starch as an indicator. The concentration of iodine adsorbed is equivalent to the surface area of the activated carbon (Sariol *et al.* 2016).

Evaluation of activated carbon adsorption efficiency

To assess the effectiveness of the activated carbon produced, two metal solutions were prepared by dissolving lead chloride and potassium chromate salts in concentrated hydrochloric acid (the procedure followed Mondal *et al.* (2019)). Standards of these solutions were also made that

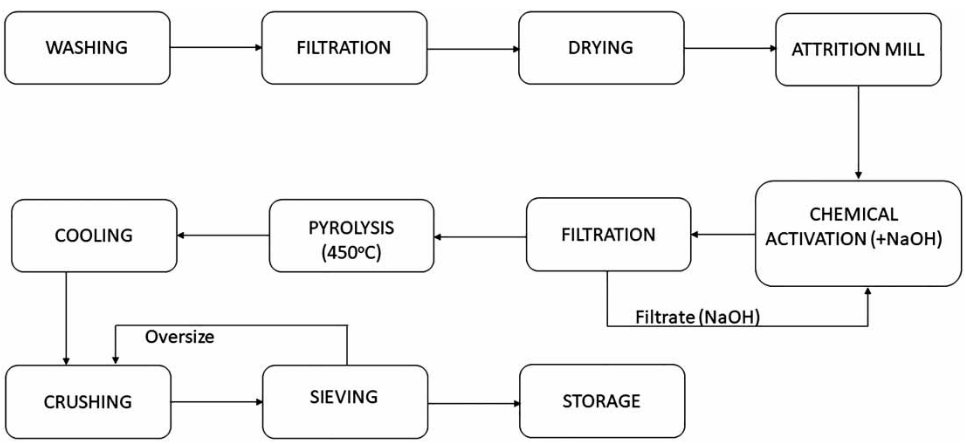

Figure 1 | Process flow for making activated carbon (Sharath *et al.* 2017).

were to be used in the atomic absorption spectrum (AAS) machine to facilitate the use of calibration curves. Adsorption was then conducted varying parameters like adsorbent dose, contact time, initial heavy metal ions concentration and pH.

A 50 mL measure of each sample (metal solution) was put in different test tubes and activated carbon was added to each test tube. The mixtures were then put on a rotary shaker for a specified time period. After shaking, the suspensions were filtered using the filter papers and the filtrates taken to the AAS for analysis of the concentrations of metal ions present after adsorption. The procedure was adapted from Banat & Al-Asheh (1999), Al-Asheh et al. (2003), Kar & Misra (2004), and Mondal et al. (2019).

RESULTS AND DISCUSSION

Activated carbon yield

The weight of prepared chicken feathers before and after pyrolysis was measured to determine the yield. The poultry feathers weighed 203.2 g before pyrolysis, while the activated carbon formed weighed 89.34 g. The activated carbon yield was then calculated based on the equation below (Anisuzzaman et al. 2015):

$$Yield\ (\%) = \frac{\text{weight of activated carbon}}{\text{weight of feathers}} \times 100 \tag{1}$$

$$Yield\ (\%) = \frac{89.34}{203.2}$$

$$Yield\ (\%) = 44\%$$

The results show that for any mass of poultry feathers used, the yield is 44%. This is due to the high carbonization temperature used, which results in a large amount of volatiles being easily released as well as moisture loss to a lesser extent. The yield determined in the study was in the range determined by Anisuzzaman et al. (2015) of 39% to 73%.

Determination of iodine number

Iodine solution was used before and after pyrolysis to assist in determining the iodine number. The results for the four runs done are shown in Table 1.

Table 1 | Experiments to determine the iodine number for adsorption using activated chicken feathers

Experiment number	1	2	3	4
Initial burette reading (mL)	0.00	23.00	0.00	18.50
Final reading (mL)	23.00	47.00	18.50	37.50
Titrated volume	23.00	19.00	18.50	19.00

$$Average\ titre = \frac{19 + 18.50 + 19}{3}$$

$$= 18.83\,\text{mL}$$

Calculation of iodine number (ASTM 2006):

$$I_n = \frac{X}{MA} \tag{2}$$

where X = mg of iodine adsorbed by activated carbon

M = mass of activated carbon in g

A = correction factor depending on the residual normality N_r of the filtrate (ASTM 2006):

$$N_r = N^2 \frac{V}{50} \tag{3}$$

$$N_r = 0.0145$$

Finding the corresponding value of A with N_r on the correction factor for iodine adsorption, $A = 1.04$.

Therefore, iodine factor $I_n = 520$ mg/g.

From calculation, it is observed that the iodine value of the activated carbon from poultry feathers is 520 mg, which is recommended (>500 mg) and comparable to good values quoted in the literature (Okey-Onyesolu et al. 2016). The iodine number is influenced by the impregnation ratio due to the reaction of the sodium hydroxide and the carbon surface. It should be noted however that while this number generally shows the adsorption capability, the activated carbon material might not be efficient when used to adsorb specific elements or compounds (Ademiluyi & Nze 2016). This is why the actual adsorption tests, performed on the actual medium to adsorb the unwanted compounds, is necessary.

Kawahara et al. (2015) produced activated carbon using feathers co-carbonized with water-soluble phenolic resin and performed iodine tests for feathers and feathers co-carbonized with the resin. They obtained iodine absorption capacities of 320 and 550 mg/g respectively. Our study determined an iodine absorption factor of 520 mg/g, which was close to theirs which was co-carbonized. This showed the competitiveness of our activated carbon.

Evaluation of activated carbon adsorption efficiency

Results for the effect of initial metal concentration on adsorption

The effect of metal ion concentration on adsorption efficiency is shown in Figure 2.

This sorption characteristic indicates that the surface saturation is dependent on the initial concentrations. At low metal ion concentrations, adsorption sites took up the available concentration. However, as the concentration increases above 30 mg, the adsorption sites become saturated and the remaining surface sites are difficult to occupy because of repulsion between the solute molecules of the solid and bulk phases.

Mondal *et al.* (2019) investigated alkali-treated chicken feathers on removal of chromium ions and observed that the removal efficiency increased with an increase in initial metal concentration up to a maximum before it started decreasing. The same trend was observed with our results up to 30 mg/L but our efficiencies were higher than in their study.

Results for the effect of adsorbent dose on adsorption

The effect of adsorbent dose on removal efficiency is shown in Figure 3.

The above results show that the removal efficiency of the metals is directly proportional to the adsorbent dose.

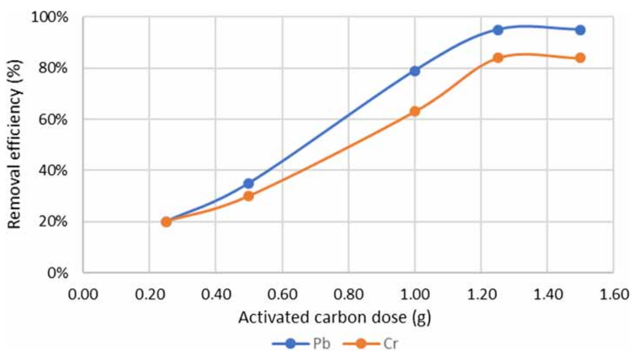

Figure 3 | Effect of adsorbent dose on removal efficiency.

An increase in the adsorbent dose from 0.25 g to 1.0 g generally increases the amount of metal ions adsorbed because of the greater availability of the exchangeable sites or surface area at higher concentrations of adsorbent. An insignificant increase was observed when the activated carbon doses were increased from 1.0 g to 1.5 g. This suggests that after a certain dose of adsorbent, maximum adsorption is attained since all the ions present in the solution would be bound to the adsorbent.

Mondal *et al.* (2019) investigated alkali-treated chicken feathers on removal of chromium ions and observed that the removal efficiency increased with an increase in adsorbent dosage up to 0.07 g to give a maximum efficiency of 45% before it started decreasing. The same trend was observed with our results giving a maximum efficiency of 95% for lead and 85% for chromium at 1.25 g activated carbon dosage.

Results for the effect of contact time on adsorption

The effect of contact time on the removal efficiency is shown in Figure 4.

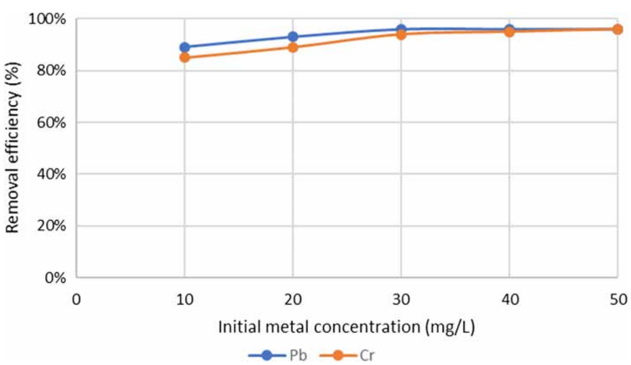

Figure 2 | Effect of metal ion concentration on adsorption efficiency.

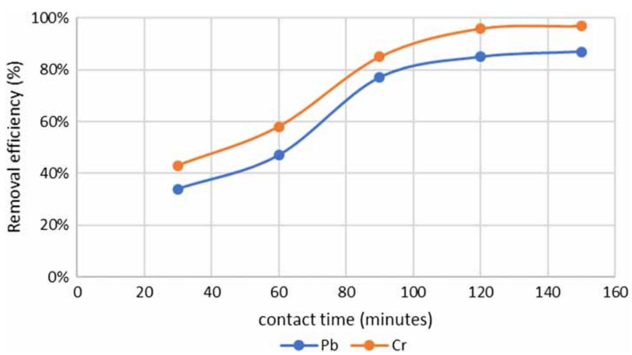

Figure 4 | Effect of contact time on removal efficiency.

The results show that as the contact time increases, the percentage adsorption generally increases. However, the unavailability of reaction sites, which decreases with time, causes the removal efficiency to remain constant.

Mondal *et al.* (2019) from their investigations observed that the removal efficiency increased with an increase in contact time up to 30 min to give a maximum chromium ion removal efficiency of 55%. From our study, the trend was similar with an increase to a maximum efficiency of 85% for lead ions and 96% for chromium ions at a contact time of 120 min.

Results for the effect of pH on adsorption

The effect of pH on removal efficiency is shown in Figure 5.

The results above show that the removal of heavy metal ions is highly dependent on solution pH. For both metals, the adsorption efficiency increased with increasing initial pH. This is due to the protonation that occurs at the active sites of the adsorbent, which restricts the spontaneous uptake of heavy metal ions present in solution (Okey-Onyesolu *et al.* 2016). It determines the degree of ionization and speciation of metal ions and it also affects the surface charge of the adsorbent. The results show that percentage of metal ions removed has a characteristic change as the solution pH changes (Zavvar Mousavi & Seyedi 2010). Metal ions removed increase as the pH increases from 2 to 6 reaching a maximum value at 8. The removal efficiency then decreases as the pH is increased to 10. This is because, at lower pH, the surface sites are closely linked to the H^+ ions, making these unavailable for other cations, but as the pH is increased, the carboxyl groups are deprotonated with the result of negatively charged ligands which attract the cations and binding increases (Sariol *et al.* 2016).

Mondal *et al.* (2019) from their investigations observed that the removal efficiency decreased with an increase in pH to give a minimum chromium ion removal efficiency of ~38% at pH 7. From our study, the trend was opposite as there was an increase to a maximum efficiency of 95% for lead ions and 82% for chromium ions at pH 8 before it started to decrease.

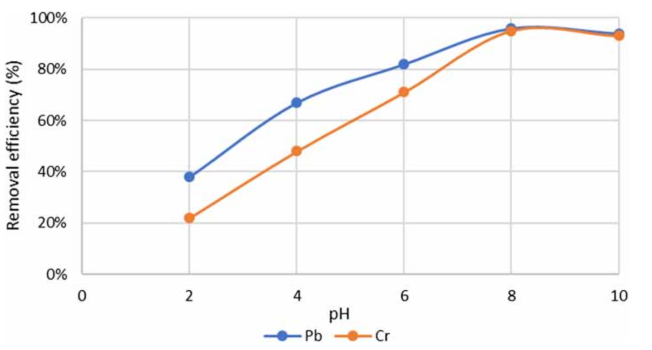

Figure 5 | Effect of pH on removal efficiency.

It can be observed that activated carbon made from poultry feathers works best with an initial metal concentration of 30 mg/L activated carbon dose of 1.25 g, for 120 min at a pH of 8. The produced activated carbon mostly favoured the removal of lead ions as compared with chromium ions. Lead was shown to be preferentially adsorbed at lower pH and also when the metal ion concentration was high.

Activated carbon (AC) adsorption is the most common technique for removing various pollutants due to its extended and specific surface area, high pore volume and well-developed porous structure (Sariol *et al.* 2016). Results for the current study have shown that the activated carbon from poultry feathers has the potential to treat waste water containing lead and chromium ions. However, there were no experiments done on actual waste water treatment. The advantage of producing activated carbon from poultry feathers is that even if there is contamination of poultry blood in the feathers, it will not affect the quality of the activated carbon because both the feathers and the blood can be similarly converted into carbon. Furthermore, it can be assumed that the activated carbon from poultry feathers will be an assembly of short hollow fibres as feathers have excellent strength-to-weight ratios as well as large surface areas (Kawahara *et al.* 2015). Due to our limited but effective tests, we can attest that the activated carbon produced assists in reducing waste at landfill sites, can remove heavy metals from waste water and can be produced at relatively affordable prices.

CONCLUSIONS

The observations that were made in this research are that the activated carbon produced from poultry feathers acted as a highly effective adsorbent with removal efficiency which increased with an increase in adsorbent concentration. This was compared against the study by Kawahara *et al.* (2015) who obtained iodine absorption capacities of 320 and 550 mg/g as against 520 mg/g from this study demonstrating the competitiveness of our activated carbon. Also, the results from the study compared favourably with those from Kar & Misra (2004) for change in initial pH for lead ions. The removal efficiency stretched from 85% to as high as 97%. The activated carbon was also seen to have a higher affinity for lead than chromium in the experimental work carried out and to work best at a pH value of 8. The iodine number of 520 mg shown is within the acceptable range documented in the literature (Okey-Onyesolu *et al.* 2016). The efficiency of removal also increases with increasing adsorbent concentration as well as with contact time up to a period where these factors cease to be the limiting factors of the reaction.

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