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Application of maize tassel for the removal of Pb, Se, Sr, U and V from borehole water contaminated with mine wastewater in the presence of alkaline metals

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ABSTRACT

In this study, the removal of Pb(II) from aqueous solutions by tassel powder was studied and optimised. Batch experiments were conducted on simulated solutions using tassel powder adsorbent and the effects of contact time, pH and concentration on the extent of Pb (II) removal was studied. Equilibrium and kinetic models for Pb(II) sorption were developed by considering the effect of contact time and concentration at optimum pH 4 and fixed temperature(25 °C). The Freundlich model was found to describe the sorption energetics of Pb(II) on tassel more fully than the Langmuir. A maximum Pb(II) loading capacity of 333.3 mg/g on tassel was obtained. The adsorption process could be well described by both the Langmuir and Freundlich isotherms with R^2 values of 0.957 and 0.972, respectively. The kinetic parameters were obtained by fitting data from the effect of contact time on adsorption capacity into the pseudo-first, pseudo-second-order and intra-particle diffusion equations. The kinetics of Pb(II) on tassel surface was well defined using linearity coefficients (R^2) by pseudo-second-order (0.999), followed by pseudo-first-order (0.795) and lastly intra-particle diffusion (0.6056), respectively. The developed method was then applied to environmental samples taken from borehole waters contaminated with mine wastewater. The removal of Pb (ND-100%), Se (100%), Sr (5.41–59.0%), U (100%) and V (46.1–100%) was attained using tassel. The uptake of the metals from environmental samples was dependent on pH, ionic strength and levels of other competing species.

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1. Introduction

Heavy metal contamination can have a deleterious effect on fresh water sources such as dams, lakes, rivers and underground aquifers. Aqueous industrial effluent from operations such as metal plating facilities, mining operations, and tanneries have been identified as major sources of surface and groundwater pollution [1–3]. Some metals associated with these activities are chromium (Cr), cadmium (Cd), lead (Pb), mercury (Hg), vanadium (V) and zinc (Zn). These metals have been classified as hazardous heavy metals.

Heavy metal toxicity can result in reduced mental and central nervous function, lower energy levels and damage to blood composition, lungs, kidneys and other vital organs [3]. Amelioration of heavy metal pollution in several countries has been effected by introducing strict regulations governing the release of industrial waste and the development of remediation technologies. Precipitation and adsorption are two of the common methods for the treatment of heavy metal containing water [4]. Coagulation, ion exchange, and ion exchange combined with precipitation are also widely used. Adsorption studies for Pb(II) and other heavy metal removal from aqueous solution on soft shell of *Antep pistachio* [5], sunflower seed peel [6], rice husk [7], olive cake [8], geopolymers [9], cocoa shells [10] and modified corncobs [11] have been reported. Adsorption of heavy metals by these materials might be attributed to their protein, carbohydrates and phenolic compounds, which have metal binding functional groups, such as carbonyl, hydroxyl, sulphate, phosphate, and amino groups [8,12–14].

Maize tassel is the male part of the maize plant. Its major purpose is the production of pollen grains which fertilise the female part of the maize flower which then develops into a cob. Pollination and fertilisation in a maize field covers a period of not more than 21 days if the plants germinate within 1 week. This means tassel has no production value after fertilisation. Farmers involved in seed

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production normally cut off the tassel after pollination period. The aim of this study was to optimise the removal of Pb(II) from simulated aqueous solutions by maize tassel powder and to apply the optimised method for the removal of lead and other heavy metals from environmental aqueous solutions. The possible role of alkaline metals in the uptake of heavy metals by tassel in polluted borehole water was also investigated.

2. Experimental

2.1. Materials

All chemicals used were analytical reagent grade. 1000 mg/L stock standards of Ag, Al, As, B, Be, Bi, Ca, Cd, Co, Cr, Cu, Fe, Ga, Ge, Hf, In, K, La, Li, Mg, Mn, Mo, Na, Nb, Ni, P, Pb, Rb, S, Sb, Sc, Se, Sn, Sr, Ta, Te, Th, Ti, Tl, U, V, W, Zn and Zr were purchased from Merck and Sigma–Aldrich. The reagents NaOH and HNO_3 were purchased from Sigma–Aldrich, RSA. Millipore deionised water (18.2 MΩ cm) was used for preparing working standards and diluting samples. The maize tassel was sampled from Tshwane University of Technology farm in Pretoria. The borehole location was in Mpumalanga Province, South Africa in the Steelpoort River valley. Water samples were taken directly below the water surface with a bailer. The sample taken was poured into the pre-marked sample bottles (500 and 250 mL preserved with HNO_3 to reduce volatility). The bottles were filled to the brim, squeezed slightly while the lid was screwed tightly in order to expel all the air from the bottles. The cap was sealed with insulation tape. In order to avoid cross-contamination, the bucket/jug was rinsed with distilled water after each sample. Thereafter, the sample bottles were properly labelled and placed in a cooler bag and taken to the laboratory for storage before analysis.

2.1.1. Preparation of adsorbent

The maize tassel was plucked off the woody parts of the maize plant, rinsed with deionised water and oven dried for 24 h at 100 °C. The material was then milled using a hammer mill. The resulting powder was then fractionated using analytical sieves. Particles of diameter range 50–150 μm were used for both simulated and borehole aqueous samples.

2.2. Instrumentation

Analysis of Pb(II) standards and simulated samples was done using a Varian 140 Atomic Absorption Spectrometer (Varian Techtron Pty Ltd., Springvale, Australia) linked to a HP Compaq CPU with an HP L1906 monitor (Tipei, Taiwan). An Inductively Coupled Plasma (ICP-OES), Spectro Ciros^{CCD} (Spectro Instruments, Kleve, Germany) with radial view configuration was used for the analysis of the environmental samples. A thermostatic water bath shaker with an adjustable speed and temperature [Labcon 3070U, Labdesign Engineering, Maraisburg, RSA] was used for sample agitation. A hand-held combination pH/EC meter (HI 98830) from Hanna Inc. was used for pH adjustments. A Surface Area and Porosity Analyzer (ASAP2020 V3. 00H, Micromeritics Instrument Corparation, Norcross, USA) was used to perform textural analysis. The nitrogen used for this purpose was instrument grade. Particle size analysis was performed with a Saturn Digisizer 5200 VI.II (Micromeritics Instrument Cooperation) and a Mastersizer 2000 Version 2.000 (Malvern Instruments Ltd., Malvern, UK). Fourier transform infrared (FTIR) spectrum of the adsorbent was recorded on a PerkinElmer GX2000 FTIR spectrometer (JEOL, Tokyo, Japan). Samples for FTIR were prepared by diluting the adsorbent to 5% in KBr and cast in disks for analysis.

2.3. Methods

Working standard solutions of Pb(II) and other metals which were profiled and analysed in borehole water samples were prepared by appropriate dilution of stock standard solutions. Borehole water samples were diluted to 50% before pH adjustment. The required pH was attained by drop wise addition of 0.1 M of HNO_3 or NaOH depending on the acidity or the alkalinity of the sample.

2.3.1. Batch experiments for simulated Pb(II) sample solutions

One gram (1.0 g) of tassel powder was added to each of the 250 Erlenmeyer flasks containing 50 mL of 10 mg/L Pb(II) solution and the pH of the resulting mixture was adjusted to pH 1 by the addition of few drops of 1.0 M HCl. The flasks were then transferred into a thermostatic water bath shaker which was then set at a speed of 100 rpm and a temperature of 25 °C. At predetermined times (1, 4, 10, 15, 20 and 24 h), the flask was removed from the shaker, centrifuged at 3000 rpm for 3 min and the supernatant filtered through 0.45 μm membrane. The concentration of Pb(II) in the filtrate was subsequently determined using flame atomic absorption spectrometry (FAAS). The percentage of Pb(II) removed was calculated from the difference between the concentrations of Pb(II) in aqueous solution before and after contact with the tassel powder.

To study the effects of concentration and pH on the efficiency of Pb(II) adsorption (i.e. the time required for equilibration as well as the % removal) the above procedure was repeated at pH 7 and 12 for reaction mixtures containing 15 and 20 mg/L Pb(II). Another set of batch experiments was conducted at pH 1, 7 and 12 after equilibration time of 5 h.

Optimal values for pH and contact time (i.e. the most cost-effective period required to reach equilibration) were then selected from the experimental data and used for the batch experiments for the borehole samples.

2.3.2. Equilibrium isotherm and kinetic studies of Pb(II) adsorption

Freundlich and Langmuir models were used for the sorption equilibrium studies between the tassel and Pb(II) ions. The pseudo-first-order, pseudo-second-order and the intra-particle diffusion models were used for kinetic modelling studies.

2.3.3. Batch experiments for borehole water samples

One gram of tassel powder was added into 50 mL of borehole water samples B1–B4 with the initial pH adjusted to the optimal value of 7.10 and the reaction mixture was equilibrated for the optimal contact time of 5 h at 25 °C in a thermostatic water bath with shaker set at 100 rpm. After equilibration the mixture was then centrifuged at 3000 rpm for 3 min and the supernatant filtered through a 0.45 μm membrane. ICP-OES was then used for the simultaneous analysis of the filtrate for unadsorbed Pb, Se, Sr, U and V and other inorganic species present. For the borehole water samples B5–B8 batch experiments covering the pH range *ca.* 2–8 were performed to investigate the possible influence of leachable alkaline metals from tassel powder.

3. Results and discussion

3.1. Determination of physical properties of tassel

Table 1 shows the summary of the physical parameters of the two tassel fractions which were analysed for textural characteristics. The monolayer and S_{BET} surface area of tassel found in this investigation was quite low when compared to other known microporous adsorbents [15–18]. However the performance of

Table 1
Physical characteristics of maize tassel (obtained by applying the BET model to adsorption isotherms of nitrogen at −196 °C)

Particle size range (μm) (P/P_0 0.30)	Surface area (m^2/g) (P/P_0 0.98)	S_{BET} (m^2/g)	Pore volume (cm^3/g)	Pore size (4v/A BET) (nm)
150–300	2.22	2.52	0.00453	7.20
45–50	2.54	2.82	0.00604	8.60

tassel as an adsorbent was highly comparable to other established materials. BET textural properties of natural adsorbents such as carbonised avocado AGAP [18], and fly ash [12,19] has been determined. The avocado adsorbent had very large S_{BET} (143–1069 m^2/g) and pore volumes (0.073–1.053 cm^3/g) as compared fly ash S_{BET} (2.5–19.0 m^2/g). Possibly the high sorption capacity of tassel observed in this study despite its low pore volume could be attributed to both chemical and physical adsorption processes likely to occur on its surface. The pore width is used to classify adsorbent materials either as microporous (2 nm), mesoporous (2–50 nm) and macroporous (more than 50 nm) [20]. Hence tassel powder used in the present study should be mesoporous adsorbent material according to pore width classification.

3.2. FTIR analysis of tassel powder

Fig. 1 shows an FTIR of tassel which was obtained after diluting the sample in the ratio 1:20 in KBr. The FTIR spectrum of tassel was used to identify functional groups present on the surface maize tassel that could be responsible for uptake of heavy metal species. The spectrum of the adsorbent was measured within the range of 4000–600 cm^{-1} wave number. The absorption peak around 3466 cm^{-1} could possibly be due to the presences of OH or NH_2 groups [20]. The peaks observed at 2921 cm^{-1} can be assigned to stretching vibration of the C—H group. The absorption peaks at 1734, 1643 and 1036 cm^{-1} are associated with the presence of C=O, C=C and C—O respectively. The FTIR of used tassel is shown in Fig. 2. This spectrum has less number of peaks compared to the unused tassel. The prominent absorption peaks in the used tassel are observed at 3344.5, 2360.6, 2340.1, 1636.4, 668.1 and 620.1 cm^{-1}. A shift of peaks is evident since there is emergence of new peaks which could be associated to the uptake of Pb(II) and/or its speciation products [31].

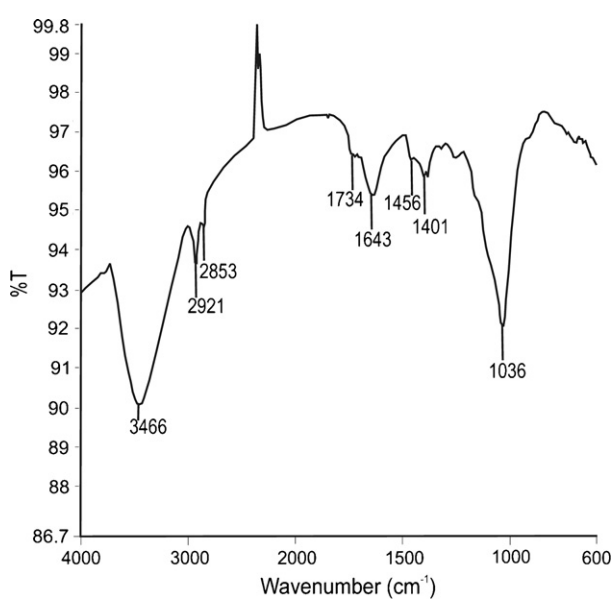

Fig. 1. FT-IR spectrum of unused tassel powder.

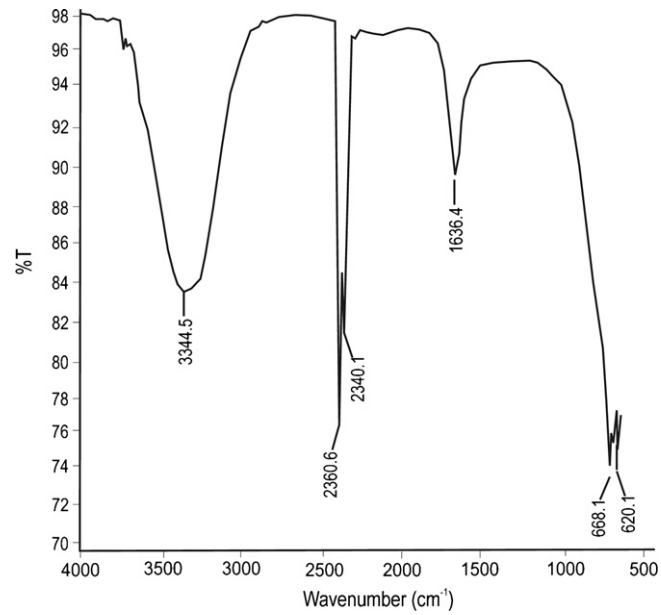

Fig. 2. FTIR of used tassel.

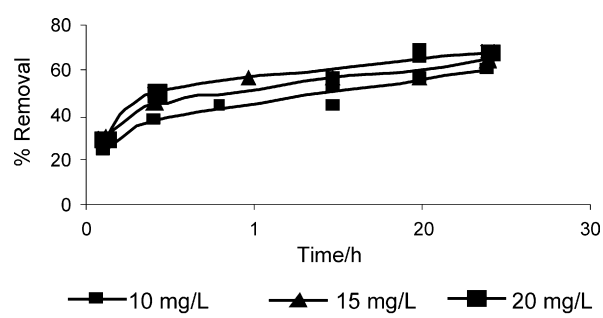

Fig. 3. Influence of contact time and concentration on adsorption at pH 1.

3.3. Analysis of simulated Pb(II) sample solutions

3.3.1. Influence of contact time

For a given substance to be effective as an adsorbent of metallic species, its adsorption rate must be fast and quantitative. Figs. 3 and 4 show the percent adsorption of Pb(II) ion by powdered

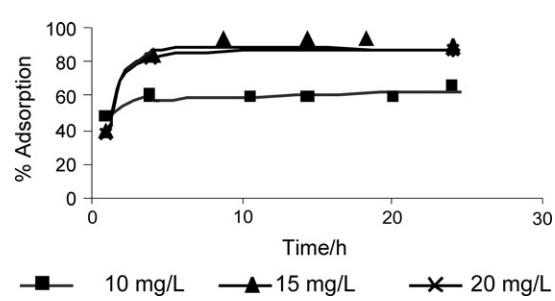

Fig. 4. Influence of contact time and concentration on adsorption at pH 7.

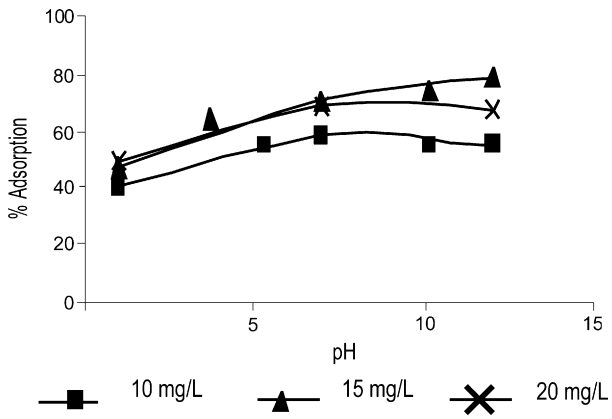

Fig. 5. Influence of initial pH on adsorption after equilibration.

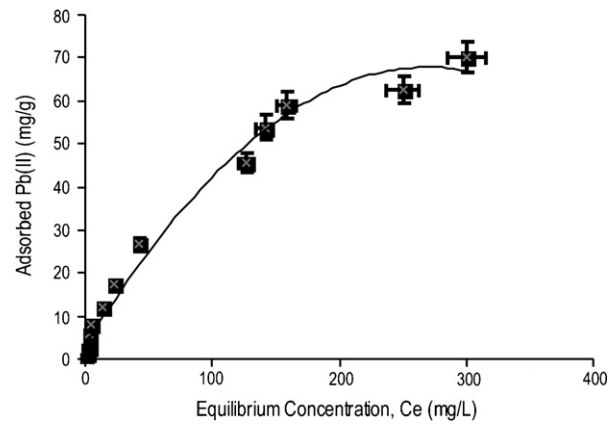

Fig. 6. Pb(II) ion adsorption capacity on maize tassel: (pH 4; 100 rpm agitation speed; contact time, 1 h; temperature 25 °C).

maize tassel as a function of contact time at pH 1 and 7, respectively. At pH 1 (Fig. 3) less than 20% adsorption was exhibited by 10 mg/L within 1 h; while at the other concentrations more than 20% adsorption was achieved. Increased adsorption was shown at all concentrations within 4 h; again 10 mg/L showed the lowest % adsorption compared to the other concentrations. This pattern is also evident at 24 h, where 15 and 20 mg/L concentrations showed more than 50% adsorption. The observed trend of increased adsorption with increasing contact time is repeated at pH 7 (Fig. 4). Similar patterns as observed in the present study have been reported for the removal of PO_4^{3-} with fly ash and ordinary Portland cement [12], Pb(II) and Cu(II) with rice husk [7], and Cd(II) with coconut shell [21,22].

3.3.2. Influence of pH and concentration

The influence of pH on the adsorption of Pb(II) ion over a range of concentration is illustrated in Fig. 5. Pb(II) adsorption increased from pH 1–7; thereafter it remained relatively constant up to pH 12, except for the 10 mg/L reaction mixtures which showed a slight decrease beyond pH 7. At pH 7, the three concentrations registered between 50 and 80% adsorption. As can be seen from Fig. 4 quantitative adsorption generally reached a peak *ca.* pH 7. This observed increase in adsorption capacity with increasing pH may be explained with respect to two concomitant phenomena. There is a decrease in the positive charge that tends to accumulate on the adsorbent surface at acidic pH (due to H^+), facilitating a closer approach of metal ions to the active sites; this decrease in surface positive charge also results in a lowering of coulombic repulsion of the sorbing metal ions. The trend of increased adsorption at elevated pH observed in the present study agrees with the reported work done on Pb(II) and Cu(II) removal using rice husk [7].

The adsorption at pH 7 (Fig. 5) is higher than that observed at pH 7 in Fig. 4. The observed increase in adsorption at these concentration levels can be attributed to the availability of the active sites within the tassel adsorbent which were not fully occupied at short time interval. As the concentration of solution increased the active sites were becoming fully occupied such that the adsorbent was getting to its saturation point with increase in contact time. It can also be observed that the adsorption of Pb(II) ion by maize tassel was very rapid in the first 1 h followed by a gradual process. Equilibrium was attained between 4 and 24 h.

3.4. Equilibrium isotherm and kinetic studies of Pb(II) adsorption

Pb(II) ion adsorption isotherms of tassel powder are presented as a function of equilibrium concentration of metal ions in aqueous medium and time in Figs. 6 and 7, respectively.

The model proposed by Langmuir suggests that the adsorption occurs on homogeneous surface by monolayer sorption with no interactions between sorbed species. The model assumes uniform energies of adsorption onto the surface and no transmigration of sorbate in the plane of the surface [8,27]. The linear form of the Langmuir isotherm is defined by the following equation [8,30,34,35]:

$$\frac{C_e}{q_e} = \frac{1}{(q_{max} \cdot K_c)} + \frac{1}{1 + q_{max}} \cdot C_e \quad (1)$$

where C_e is the equilibrium concentration of adsorbate (mg/L), q_e the amount adsorbed at equilibrium (mg/g adsorbate, and), and q_{max}(mg/g) and K_c (L/mg) are the Langmuir constants related to the adsorption capacity and energy, respectively. A plot of C_e/q_e versus C_e gives a straight line with slope $1/q_{max}$ and intercept $1/(q_{max} \cdot K_c)$ as shown in Fig. 8. From the graph the values of q_{max} (333.3 mg/g), K_c (5.44×10^{-3} L/mg) and R^2 (0.957) were obtained. Kinetic studies by Garg et al. [34] showed that these parameters maybe used for the comparison of and correlation of the sorptive properties of the tassel.

The Freundlich isotherm model has been widely used for heterogeneous surface energies. The Freundlich equation has a general linear form [24,30,32]:

$$\log q_e = \log K_f + \left(\frac{1}{n}\right) \log C_e \quad (2)$$

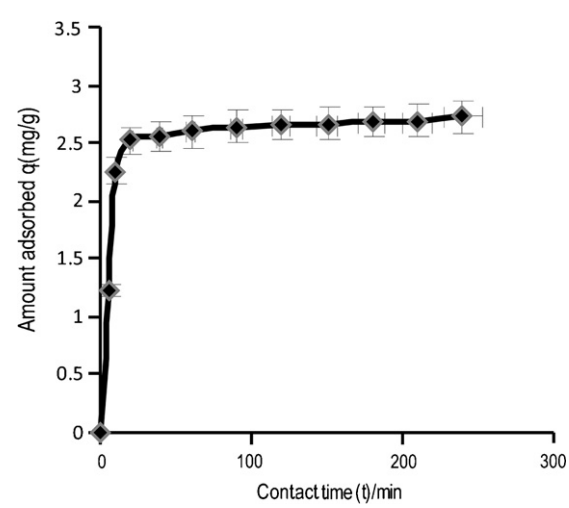

Fig. 7. Effect of contact time on the uptake of Pb(II) on maize tassel: [Pb(II)] = 30 mg/L; 1 g/100 mL adsorbent; 100 rpm agitation speed; pH 4.

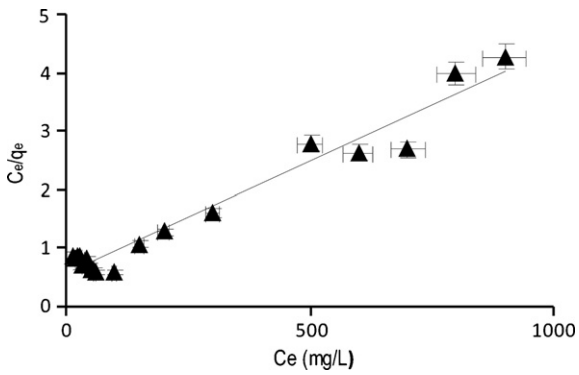

Fig. 8. Langmuir plot for the adsorption of Pb(II) by tassel: pH 4; 1 g/100 mL adsorbent; contact time, 1 h; and temperature 25 °C.

where q_e is the amount of adsorbate adsorbed per unit weight (mg/g adsorbent), C_e is the equilibrium concentration (mg/L) of adsorbate, and K_f and n are Freundlich constants. Both K_f and n are empirical constants being indicative of the extent of adsorption (sorption capacity) and the degree of non-linearity between solution and concentration, i.e. adsorption intensity, respectively [28]. From the plot of $\log q_e$ versus $\log C_e$ (Fig. 9), values of K_f (1.87 mg/g), n (1.49) and R^2 (0.972) were determined. From the linearity coefficients (R^2), it can be deduced that the Freundlich isothermal model described the adsorption of Pb(II) ions on tassel more successfully than the Langmuir.

Consequently, the sorption of Pb(II) ions on tassel follows the Freundlich isotherm model where the adsorption occurs on heterogeneous surface and the adsorption energy varies as a function of surface coverage, q_e, strictly due to variations in heat of adsorption [29].

The kinetic parameters of Pb(II) ions sorption onto tassel powder were determined from the pseudo-first-order Lagergren equation, pseudo-second-order and the intra-particle diffusion models represented by the following linear equations, respectively [30,35]:

$$\log(q_e - q_t) = \log(q_e) - \left(\frac{k_1}{2.303}\right) \cdot t \quad (3)$$

$$\frac{t}{q_t} = \frac{1}{(k_2 \cdot q_e^2)} + \frac{1}{q_e^2} \cdot t \quad (4)$$

$$\log R = \log K_s + b \log t \quad (5)$$

where q_e and q_t are the amounts of Pb(II) ions on the adsorbent at equilibrium and at time t (respectively mg/g), k_1 is the first-order

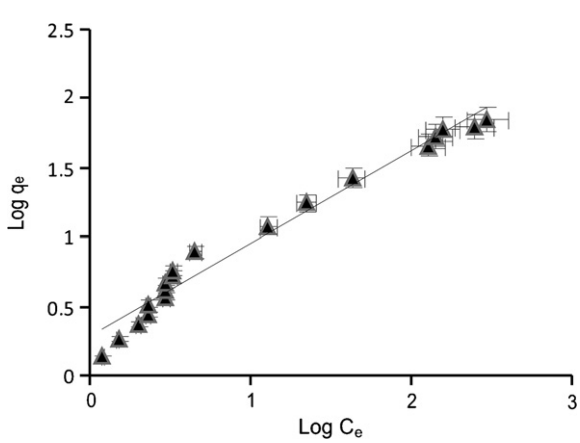

Fig. 9. Freundlich plot for adsorption of Pb(II) by tassel: pH 4; 1 g/100 mL. Adsorbent; contact time, 1 h; temperature, 25 °C and 100 rpm shaker speed.

Table 2
Elemental profiling of various borehole samples

Sample	pH	Element concentration (mg/L)												
		B	Ca	K	Mg	Na	P	S	Pb	Se	Sr	U	V
B1	7.14	0.82 ± 0.02	21.7 ± 1.22	3.30 ± 0.52	120 ± 1.84	450 ± 5.23	nd	88.0 ± 2.12	0.27 ± 0.08	0.16 ± 0.03	0.15 ± 0.04	0.32 ± 0.06	0.08 ± 0.02
B2	7.48	0.11 ± 0.04	160 ± 2.12	4.91 ± 0.63	237 ± 4.22	899 ± 4.12	0.26 ± 0.05	242 ± 3.02	1.11 ± 0.24	nd	3.40 ± 0.22	0.22 ± 0.01	nd
B3	7.33	nd	17.5 ± 0.2	11.7 ± 0.6	32.4 ± 0.85	52.0 ± 1.2	0.14 ± 0.14	20.1 ± 0.67	0.17 ± 0.05	0.14 ± 0.01	nd	0.38 ± 0.03	nd
B4	7.74	nd	24.4 ± 0.42	nd	22.9 ± 0.91	18.8 ± 1.5	nd	15.8 ± 0.88	0.05 ± 0.01	0.07 ± 0.02	nd	0.23 ± 0.01	2.14 ± 0.06

nd: not detected.

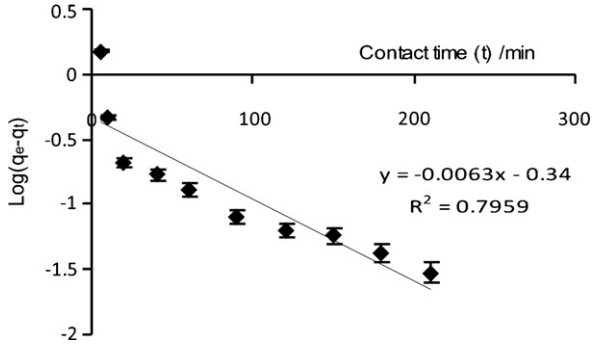

Fig. 10. Pseudo-first-order plot ($\log(q_e - q_t)$ vs. t) (C_o = 30 mg/L Pb(II) 1 g/100 mL adsorbent, agitation speed = 100 rpm, contact time = 1 h, Temp. = 25 °C, pH 4).

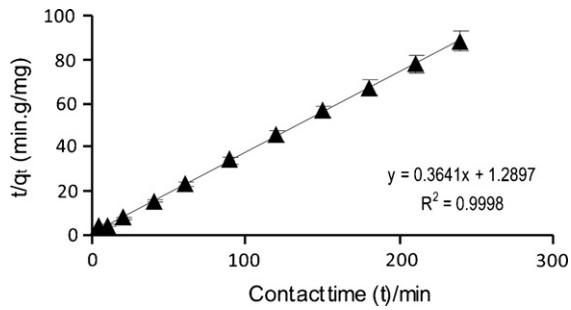

Fig. 11. Pseudo-second-order plot (t/q_t vs. t) (C_o = 30 mg/L Pb(II). 1 g/100 mL adsorbent, agitation speed = 100 rpm, contact time = 1 h, Temp. = 25 °C, pH 4).

biosorption rate constant (min^{-1}), k_2 is the second-order biosorption rate constant (g/mg min), R is the percent Pb(II) adsorbed, t is the contact time (min), b is the gradient of linear plots and K_s is the intra-particle diffusion constant. The kinetic constants for pseudo-first-order, q_e (0.457), k_1 (1.38×10^{-3}) and R^2 (0.795) were determined from the graph (Fig. 10). The pseudo-second-order kinetic constants, q_e (1.66), k_2 (0.282) and R^2 (0.999) were determined from Fig. 11. The kinetic constants for intra-particle diffusion, K_s (45.74), b (0.139) and R^2 (0.606) were obtained from (Fig. 12). From the linearity coefficients (R^2) of the three models, pseudo-second-order best describes the kinetic behaviour of Pb(II) ions on tassel surface since it had the highest R^2 value. This was followed by the pseudo-first-order and the intra-particle diffusion model had the least linearity correlation coefficients.

3.5. Analysis of borehole water samples

The elemental profiling of some of the borehole water samples at their natural pH is shown in Table 2. The metal ions present in these samples which are of environmental concern are Pb, Se, Sr, U and V and need amelioration. The other ionic species present in the samples have little or no heavy metal characteristics. The presence and levels of these alkali and alkaline earth metals in the samples probably influenced the ionic strength of samples.

Table 3
Uptake of Pb, Se, Sr, U and V from contaminated borehole water

		Element (% uptake)				
Sample	pH	Pb	Se	Sr	U	V
B1	7.10	3.74 ± 0.22	100 ± 1.85	5.41 ± 0.44	100 ± 1.95	100 ± 2.12
B2	7.10	37.1 ± 0.82	nd	59.2 ± 0.63	100 ± 2.06	nd
B3	7.10	13.0 ± 0.54	100 ± 2.06	nd	100 ± 1.87	nd
B4	7.10	100 ± 2.12	10.0 ± 0.23	nd	100 ± 2.01	67.0 ± .68

nd: not detected.

Table 4
Effect of ionic strength, on the uptake of heavy metals by tassel from borehole water samples

		Elemental concentration (mg/L)											
Sample	pH	B	Ca	K	Mg	Na	P	S	Pb	Se	Sr	U	V
B5	7.28	0.12 ± 0.01	25.0 ± 0.63	11.3 ± 0.06	28.6 ± 0.34	722 ± 4.36	nd	197 ± 1.02	nd	0.22 ± 0.03	nd	0.42 ± 0.01	12.5 ± 0.44
B5[a]	7.28	0.22 ± 0.08	48.5 ± 0.44	268 ± 0.08	63.4 ± 0.41	710 ± 4.55	10.1 ± 0.32	273 ± 1.22	0.05 ± 0.01	0.14 ± 0.02	0.01 ± 0.01	0.16 ± 0.01	6.6 ± 00.21
B5[b]	5.67	0.24 ± 0.02	50.2 ± 0.65	303 ± 2.12	63.4 ± 0.42	1080 ± 1.2	5.58 ± 0.02	329 ± 2.37	0.03 ± 0.01	0.14 ± 0.01	0.03 ± 0.01	0.00 ± 0.02	6.74 ± 0.32
B5[a]	2.15	0.29 ± 0.10	76.2 ± 0.42	281 ± 1.32	73.2 ± 0.35	707 ± 4.52	6.48 ± 0.52	324 ± 2.32	0.05 ± 0.02	0.16 ± 0.01	0.11 ± 0.01	0.00 ± 0.03	6.72 ± 0.28
B6	8.30	nd	8.48 ± 0.02	77.6 ± 0.61	30.9 ± 0.21	63.8 ± 4.12	nd	16.7 ± 0.26	0.14 ± 0.04	0.07 ± 0.02	nd	0.23 ± 0.02	nd
B6[a]	8.30	0.05 ± 0.01	28.8 ± 0.22	292 ± 2.16	54.7 ± 0.38	81.2 ± 0.88	7.12 ± 0.37	35.4 ± 0.52	0.14 ± 0.03	0.00 ± 0.05	nd	0.0 ± 0.05	nd
B6[b]	5.55	0.05 ± 0.01	38.6 ± 0.35	302 ± 5.02	63.4 ± 0.25	62.8 ± 0.68	11.1 ± 0.65	0.20 ± 0.01	0.14 ± 0.01	0.00 ± 0.01	nd	0.00 ± 0.01	nd
B6[b]	2.13	0.06 ± 0.01	56.6 ± 0.15	302 ± 3.15	72.4 ± 0.46	81.4 ± 0.67	15.1 ± 0.06	37.4 ± 0.53	0.14 ± 0.03	0.000.01	nd	0.00 ± 0.02	nd
B7	6.40	15.2 ± 0.32	75.2 ± 0.82	968 ± 2.02	192 ± 0.82	1900 ± 6.84	0.15 ± 0.09	460 ± 2.04	nd	0.41 ± 0.05	0.46 ± 0.02	0.35 ± 0.04	nd
B7[a]	6.40	12.1 ± 0.55	108 ± 0.55	1120 ± 6.85	202 ± 1.02	1960 ± 6.71	11.3 ± 0.56	6390 ± 8.2	nd	0.06 ± 0.01	0.46 ± 0.01	0.00 ± 0.02	nd
B7[b]	5.50	12.6 ± 0.48	107 ± 0.74	1220 ± 6.33	204 ± 1.33	1950 ± 6.18	11.1 ± 10.82	6370 ± 8.1	nd	0.07 ± 0.01	0.46 ± 0.03	0.00 ± 0.01	nd
B7[b]	2.15	12.5 ± 0.12	116 ± 0.61	1150 ± 6.45	209 ± 1.06	1960 ± 6.36	12.2 ± 0.32	6390 ± 8.9	nd	0.05 ± 0.02	0.46 ± 0.01	0.00 ± 0.05	nd
B8	2.77	nd	23.0 ± 0.37	nd	21.0 ± 1.24	17.2 ± 0.66	nd	14.3 ± 0.12	0.10 ± 0.01	nd	nd	0.37 ± 0.02	2.14 ± 0.08
B8[a]	2.77	0.07 ± 0.01	51.0 ± 0.32	156 ± 0.95	64.9 ± 2.12	39.0 ± 0.39	13.7 ± 0.63	42.5 ± 0.46	0.10 ± 0.01	nd	nd	0.0 ± 0.04	0.71 ± 0.05
B8[b]	5.88	0.05 ± 0.02	36.4 ± 0.22	134 ± 1.02	51.5 ± 2.67	52.3 ± 0.72	9.42 ± 0.45	35.3 ± 0.34	0.10 ± 0.01	nd	nd	0.00 ± 0.06	0.59 ± 0.04
B8[b]	7.00	0.04 ± 0.01	35.7 ± 0.12	141 ± 1.11	50.7 ± 2.49	20.8 ± 1.61	9.39 ± 0.91	34.4 ± 0.32	0.10 ± 0.02	nd	nd	0.00 ± 0.05	0.61 ± 0.04

nd: not detected.
[a] Samples where tassel has been applied at natural pH.
[b] Samples where tassel has been applied after pH adjustment.

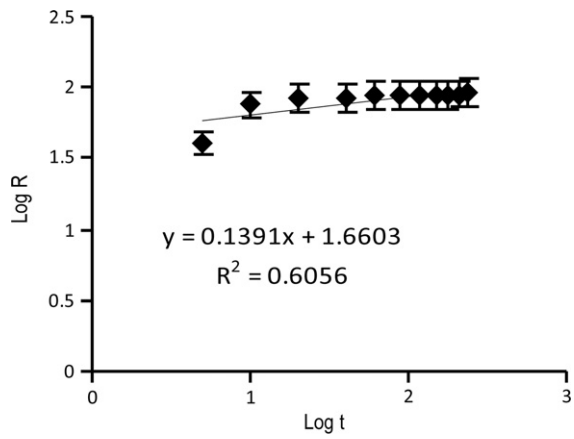

Fig. 12. Intra-particle diffusion plot (log R vs. log t) (C_o = 30 mg/L Pb(II) 1 g/100 mL adsorbent, agitation speed = 100 rpm, contact time = 1 h, Temp. = 25 °C, pH 4).

Table 3 shows the uptake of Pb, Se, Sr, U and V at pH 7.10 which was optimised for Pb(II) uptake by tassel. The uptake of Pb(II) in the environmental samples ranged from 3.74 to 100% in samples B1–B4. The uptake variation could be ascribed partly to the concentration of other non-adsorbate and adsorbate species present in each sample. The non-adsorbate species would, probably affect the ionic strength whereas other adsorbate species will compete with Pb(II) for binding sites. Se and U had 100% uptake in the four samples. The adsorption of Sr and V appeared to be influenced by the presence of the other species. Adsorption of Se and U by tassel is another avenue of recovery of these metals for possible commercial use [23,25,26,33].

Table 4 contains the results of elemental profiling of samples B5–B8 and those of the effect of pH on the adsorption of heavy metals present in the samples (B5–B8b). Of interest from Table 4 is the leaching of alkaline elements from the tassel powder as the pH is lowered, hence the increase in the metals like Ca, K, Mg and Na. Samples B6 and B8 show how critical the ionic strength is in the adsorption Pb(II). No uptake of Pb(II) was observed in the two samples for pH values above and below the optimum value of pH 7.10. Similar behaviour has been reported by other workers [24,26]. The uptake of Se and U at pH above 7.10 is something up to 100%.

4. Conclusions

The ability of tassel, a solid phase adsorbent to extract varied concentrations of lead, selenium, strontium, uranium and vanadium in simulated and environmental samples was demonstrated. The Freundlich isothermal model was found as the best fit model to describe the adsorption behaviour of Pb(II) ions on tassel surface. Kinetic modelling studies demonstrated that the pseudo-second-order model gave the best fit for Pb(II) uptake with $R^2 \approx 1$. The uptake of Pb, Se and Uranium was optimal in the pH range 7.00–7.20. The concentration of other ions present in the samples especially S, had negative impact on the uptake of lead. Furthermore, it was demonstrated that tassel can be used to concentrate uranium present in most mine wastes in South Africa.

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