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Removal of heavy metal ions from ground and surface water samples using carbons derived from date pits

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ABSTRACT

Activated carbon samples derived from date pits (DP) were prepared through physical and chemical activation. The raw material was physically activated with pure steam or steam with flow of nitrogen gas, while the chemically activated sample were prepared by impregnation of 10% calcium acetate. The produced carbon samples show specific surface area (S_{BET}) from 290 to 702 m^2/g and pour volume (V_p) of 0.248–0.321 mL/g. The prepared carbon samples were studied as adsorbents for metal ions (Co(II), Fe(III), Pb(II) and Zn(II)) and show removal percentage more than 95% of metal ions from solution. The prepared carbon samples were applied for removal of some ions (Pb^{2+}, Zn^{2+}, Co^{2+} and Fe^{3+}) from different ground and surface water samples collected from Aseer area, and they show that a removal reached 100% for the studied metal ions.

Introduction

According to figures recently issued by the World Health Organization (WHO) an average of 50,000 people die each day from diseases associated with contaminated water; one person about every two seconds [1]. Drinking water used is either groundwater sources or surface water sources (such as rivers, lakes, and streams). Nearly one-fifth of all water used in the world at present is obtained from groundwater [2]. Groundwater is considered superior in quality relative to surface water with respect to bacteriological content, turbidity, and total organic concentrations. While with respect to mineral content (hardness, iron, manganese), groundwater may be inferior and require additional treatment. Groundwater supplies are frequently pumped into the distribution system with minimal treatment [3]. Currently, the quality of groundwater with respect to trace concentrations of organic chemicals, such as pesticides, herbicides, and solvents, is of great concern. The concentrations of these pollutants should be measured at the location of landfills, buried storage tanks, etc., for evaluation of groundwater source [3]. Usage of ground water supplies could be optimized to provide a more reliable water source that uses the best features of both supplies [3].

The main sources of water pollution are sewage, industrial, agricultural, radioactive wastes and chemical wastes [4,5]. The large-scale use of insecticides, pesticides and other agrochemicals is gradually contaminating the water-resources with toxic chemicals. Similarly, untreated municipal effluents are dumped into water bodies [6–9]. Water pollution is one of the most important environmental problems in the world. Fecal pollution of water and drinking water has frequently caused waterborne diseases; in general waterborne diseases have been well controlled, especially in developed countries [10]. Today, waterborne toxic chemicals pose a great threat to the safety of water supplies in developing countries. There are many sources of toxic chemicals in the environment, such as badly managed landfill [11], industrial pollution and pesticide runoff [12]. Also the discharge of industrial acid wastes or mine drainage may increase the heavy metals levels in surface and ground water [13].

The last few decades have witnessed tremendous interest in development of new sorbents and modifying the performance of existing ones. As a result, different types of sorbent were studied for sorption of heavy metal ions from aqueous solutions. Activated carbon has been widely used as sorbent for the removal of heavy metals from aqueous solutions. Activated carbon is characterized by important advantages of high porosity and high surface area [14,15].

The production of activated carbon from agricultural by-products serves the environment from two points of view. Firstly, it converts unwanted, surplus agricultural wastes, (millions of tons are produced annually) to valuable adsorbents. Secondly, activated carbons are increasingly used in water treatment for removing organic chemicals and metals of environmental concern. Date pits (DP) were chosen to be applied as precursor material for

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Table 1
The collected water samples (ground and surface) from Aseer area, Abha city, KSA.

Sample no.	Sample name	Site	Sampling date	Well depth
S1	Surface water	Rejal alma	29-10-2011	Surface
S2	Ground water	Alharja	29-10-2011	95 m
S3	Ground water	SaratObiada	5-11-2011	30 m
S4	Ground water	Tamnia	11-11-2011	20 m
S5	Ground water	Alfaraa	11-11-2011	90
S6	Ground water	Alwadeen	13-11-2011	59

production of activated carbon. DP is characterized by its granular structure, insolubility in water, chemical stability, high mechanical strength, and its local availability at almost no cost.

Activated carbons derived from different sources (plants, animal residues and others) were produced and used as adsorbent material [15,16]. Activated carbons were characterized by a large specific surface area, which is an important physical property. Due to its characteristics, activated carbons are effective adsorbent for many pollutant compounds (organic, inorganic, and biological) of environmental concern [17,18].

In this study, selected adsorbents derived from DP were chosen as raw materials for removal of some heavy metal ions (Pb^{2+}, Co^{2+}, Zn^{2+}, and Fe^{3+}) from different ground and surface water samples in Aseer area, Abha City, KSA.

Experimental

All chemicals and reagents used in this work are of analytical grade purity and used without further purification. The samples were weighted using an analytical balance (Citizen, CY 204, Poland). Isotope hot plate stirrer (Fisher Scientific, USA), was used for stirring. The hydrogen ion concentration for the solutions were measured using a digital pH meter (Hanna instruments, pH 211) at the ambient laboratory temperature degree 25 ± 1 °C. The scale of the pH meter was calibrated before each experimental using Thermo-Orion standard buffer solutions, pH 7.00 and pH 4.01 at 25 °C. During batch experiments a good mixing for the solid and liquid phases was achieved using a mechanical thermostated water bath shaker (GFL, 1083, Germany). Complete separation of the two phases was attained by using a centrifuge (Hettich EBA 270, Germany) with maximum speed of 8000 rpm at ambient temperature. The concentration of the investigated metal ions solution was measured using an atomic absorption spectrometer (model: Z-8100 Hitachi/Flame Spectrophotometer).

The specific surface area was measured by the BET method (Coulter, model SA3100, USA) with N_2 chemisorptions.

Adsorbents

From 30 to 60 g of the roasted, crushed, date pits screened (1–3 mm) was admitted into a stainless steel reactor (400 mm × 40 mm) fitted with a perforated disk from the inside, and screw caps either inlet and outlet tubes (10 mm diameter) at both ends. A cylindrical electric furnace surrounded the slightly titled stainless steel reactor; the temperature was then raised to 350 °C (at 5 °C/min) and steam, generated from a side device was introduced. This was followed by a slower temperature rise (50 °C/10 min) up to either 700–800 °C, to hold for limited durations. First sample (AC1) was prepared under concurrent flow of N_2, passing though the boiling water in steam-generating device, at soak temperature of 700 °C. Second sample (AC2) was prepared by chemical treatment with 10% (w/v) calcium acetate at 700 °C after passing through N_2. Third sample (AC3) was prepared by pure steam at 800 °C. The outlet tube was connected to a cooled condenser and trap to collect condensates, and a side tube to vent non-condensable gases.

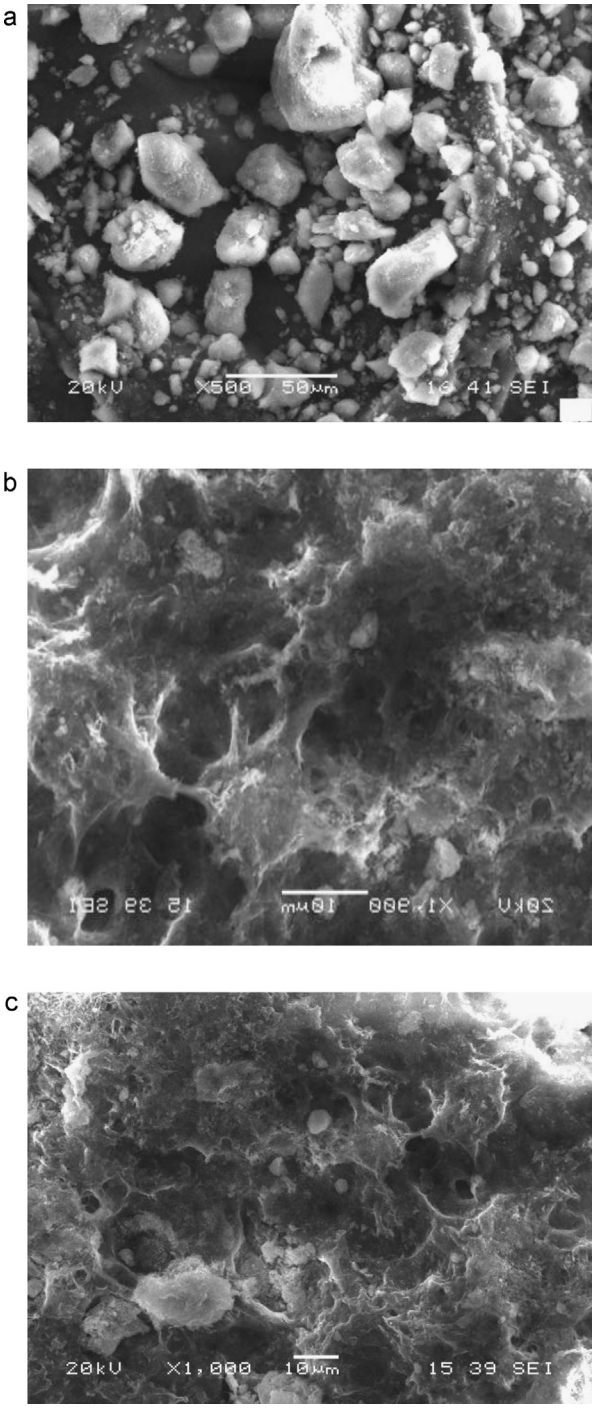

Fig. 1. (a) Scanning electron microscope for the activated carbon under concurrent flow of N_2. (b) Scanning electron microscope for the activated carbon by steam pyrolysis technique at 700 °C was performed in presence of catalytic gasifying acetate of calcium. (c) Scanning electron microscope for the activated carbon activated carbons by single-step steam pyrolysis conditions at 700 °C with accompanying flow of N_2-activation.

Table 2
Concentration of metal ions in the collected water samples.

Sample no.	Co^{2+} (μg/L)	Fe^{3+} (μg/L)	Pb^{2+} (μg/L)	Zn^{2+} (μg/L)
S1	45	65	36	241
S2	55	75	34	89
S3	66	89	35	105
S4	60	66	47	75
S5	49	60	45	112
S6	54	65	55	96
Permissible level (WHO)	50	500	50	500

Table 3
General characteristics of selected adsorbents derived from DP.

Carbon types	Cond. of preparation	Density (g/cm^3)		Yield %	Ash %	pH	S_{BET}	V_P (mL/g)	$\bar{r}$ (Å)
		Apparent	Packed						
AC1	DP, Steam/N_2 1 h at 700 °C	0.3194	0.5379	16.5	10.4	10	188	0.095	10.1
AC2	Date pits, steam, calcium acetate 1 h at 700 °C	0.4518	0.6413	16.2	7.2	8.16	290	0.248	17.0
AC3	Date pits, pure steam-1 h at 800 °C	0.5465	0.7416	16.5	10.3	9.70	702	0.321	9.4

Adsorption capacity

Ground and surface water samples were collected from several sites in Aseer area, KSA. The ground water samples were collected from wells at depths between 20 and 95 m as shown in Table 1. The metal ion concentration in collecting samples are represented in Table 2. Water samples were collected by using plastic bottles (capacity 1.5 L), consequently acidified and kept at 5 °C. The samples were analyzed immediately after collection. The concentration of heavy metals was measured using atomic absorption spectroscopy.

Results and discussion

Surface morphology of the prepared samples

The samples of activated carbon prepared by different techniques were analyzed in a scanning electron microscope. The surface physical morphology of activated carbon samples were observed and the SEM photographs in Fig. 1a–c shows the variation in surface morphology and pores as a function of the activation technique. Also it is evident that the samples have wide variety of pores with fibrous structure.

Adsorption of metal ions onto the prepared carbon samples

Batch experiments were carried out to find out the optimum conditions for the removal of Zn(II), Co(II), Pb(II) and Fe(III) ions from aqueous solution by the different prepared activated carbon samples. Different parameters affecting the sorption processess were separately studied, such as particle size of sorbents, shaking time, sorbent weight, and metal ions concentration.

The effect of carbon particle size on the removal efficiency of Zn(II), Co(II), Pb(II) and Fe(III) from aqueous solution was studied within particle size range 30–200 mesh at pH 5.5 and 25 ± 1 °C. The removal of Zn(II), Co(II), Pb(II) and Fe(III) was found to increase from 60% to 99% as the sorbents particle size was decreased from 200 to 30 mesh. The higher sorption with smaller sorbent particle size may be attributed to the fact that smaller particles provide a larger surface area. Hence, carbon samples of particle size 30 mesh has been chosen for further experiments.

Some physico-chemical properties of carbon products

Table 3 displays several characteristics of obtained carbons: apparent and pack density (D_a, D_p), yield, ash, slurry pH, S_{BET} surface area, total pore volume V_P and average pore diameter ($\bar{r}$) were measured. The yield and Ash percentages for DP was found to be (16.2–16.5) and (7.2–10.4), respectively. An important general property of developed carbons is their apparent basic nature (pH = 8.16–10.1), which could be due to two factors: steam activation and high reaction temperature. In this case both surface area and total pore volume are raised to reach on S_{BET} of 290–702 m^2/g and V_p of 0.248–0.321 mL/g for DP-carbon. From the above-mentioned phsico-chemical characteristics and the sorption capacity of different carbon samples, it could be inferred that sample AC3 is the best sample as it has higher surface area and higher sorption capacity.

Adsorption isotherms

Adsorption isotherm was assayed by studying the adsorption of Zn(II), Co(II), Pb(II), Fe(III) with wide concentration range in aqueous solutions onto one carbon adsorbent. The amount adsorbed of metal ion onto carbon adsorbent (mg/g) was represented against the equilibrium concentration of metal ion in aqueous solution, Fig. 2.

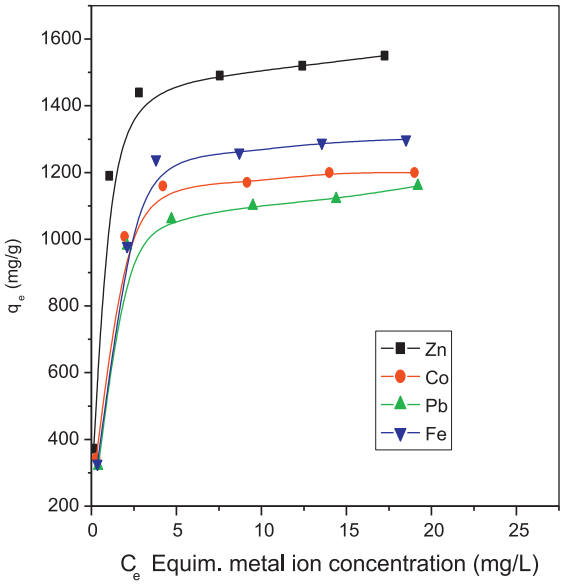

Fig. 2. Adsorption isotherm for adsorption of metal ions onto the prepared carbon sample AC3.

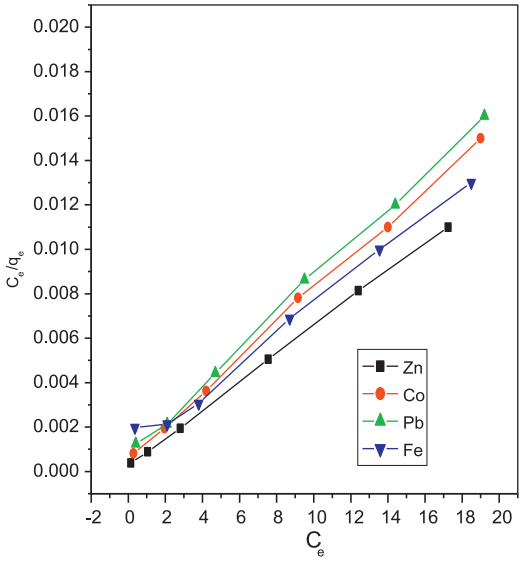

Fig. 3. Langmuir plot for adsorption of metal ions onto carbon sample AC3.

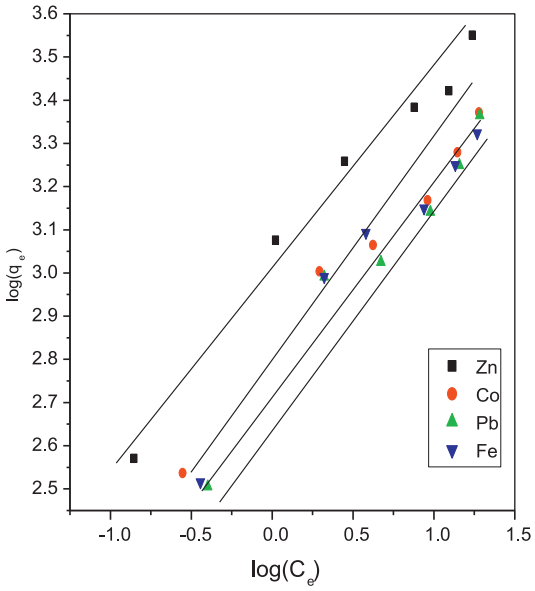

Fig. 4. Freundlich plot for adsorption of metal ions onto carbon sample AC3.

Langmuir isotherm model [19] is based on the assumption that maximum adsorption corresponds to a saturated monolayer of adsorbate molecules on the adsorbent surface that the energy of adsorption is constant and that there is no transmigration of adsorbate in the plane of the surface. Adsorption isotherm was obtained by shaking the adsorbent of fixed doses and the adsorbate solution containing varied concentrations of metal ion for 24 h.

The Langmuir isotherm model represents the equilibrium distribution of metal ions between the solid and liquid phases. The following equation can be used to describe adsorption isotherm according to Langmuir:

$$\frac{C_e}{q_e} = \frac{C_e}{q_o} + \frac{1}{bq_o} \quad (1)$$

where C_e is the equilibrium concentration of metal ion in solution (mg/L), q_e is the amount adsorbed at equilibrium on adsorbent (mg/g), q_o is the maximum metal ions uptake per unit mass of adsorbent (mg/g), which is related to adsorption capacity and b is Langmuir constant (L/mol) which is exponentially proportional to the heat of adsorption and related to the adsorption intensity. Thus, a plot of C_e/q_e vs. C_e should be linear if Langmuir adsorption were applicable; consequently the Langmuir constants could be calculated. The results in Fig. 2 show the equilibrium adsorption isotherm of metal ions in water samples, using carbon sample as an adsorbent. The isotherm rises sharply in the initial stages for low C_e and q_e values. This indicates that there are plenty of radial accessible sites. Eventually a plateau is reached, indicating that the adsorbent is saturated at this level. The decreases in the curvature of the isotherm are tending to a monolayer adsorption. Considerably increasing the C_e values with slight increase in q_e, is possibly due to less active sites being available at the end of the adsorption process and/or the difficulty of the edge molecules in penetrating the adsorbent, while metal ions partially covering the surface sites.

In order to optimize the design of sorption system for removal metal ions from water sample, it is important to establish the most appropriate correlation for the equilibrium curve. The linearized Langmuir plot is shown in Fig. 3, and the Langmuir parameters were calculated and recorded in Table 4.

The Freundlich model was chosen to estimate the adsorption intensity of the metal ions on the carbon adsorbent surface. The Freundlich equation is presented as [20]:

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

where K_f (mg/g) and n are Freundlich constants incorporating all factors affecting the adsorption process such as adsorption capacity and intensity of adsorption. These constants are determined from the intercept and slope of linear plot of $\log q_e$ versus $\log C_e$, Fig. 4 and listed in Table 5. Although the correlation coefficients are greater than 95%, they do not correlate the data as well as the Langmuir isotherm, which has consistently higher correlation coefficients.

Sorption kinetics

The kinetics of sorption process were studied by carrying out a set of sorption experiments between the metal ions and carbon sample at constant temperature and monitoring the amount sorbed with time, Fig. 5. The sorption kinetics normally include two phases: a rapid removal stage followed by a much slower stage before the equilibrium is established. Assuming pseudo first order kinetics, the rate of the sorptive interactions can be evaluated by using the simple Lagergren equation [21]:

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

Table 4
Langmuir parameters for adsorption of metal ions onto AC3.

Metal ion	q_o (mg/g)	b (L/mol)	S.D.	R
Zn(II)	1594.00	2.45	8.32×10^{-5}	0.999
Co(II)	1317.52	1.40	1.98×10^{-4}	0.999
Pb(II)	1261.03	1.04	2.5×10^{-4}	0.999
Fe(III)	1555.20	0.459	4.5×10^{-4}	0.996

Table 5
Freundlich parameters for adsorption of metal ions onto AC3.

Metal ion	K_f (mg/g)	N	S.D.	R
Zn(II)	1004.38	2.26	0.06	0.988
Co(II)	633.86	2.33	0.048	0.989
Pb(II)	540.75	2.14	0.066	0.979
Fe(III)	588.84	2.24	0.062	0.981

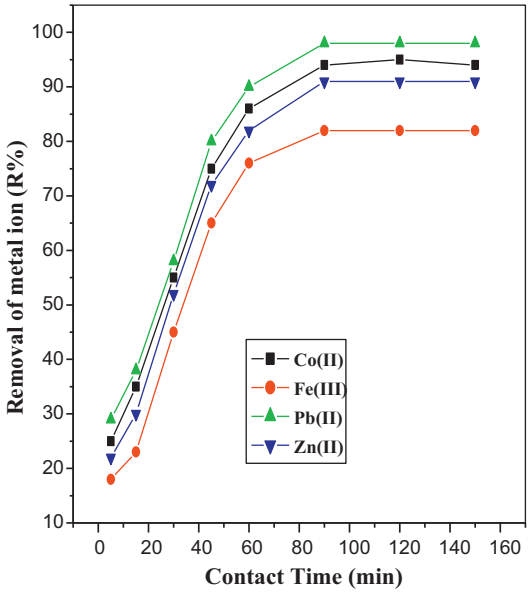

Fig. 5. Effect of contact time on the adsorption of metal ions onto carbon sample AC3.

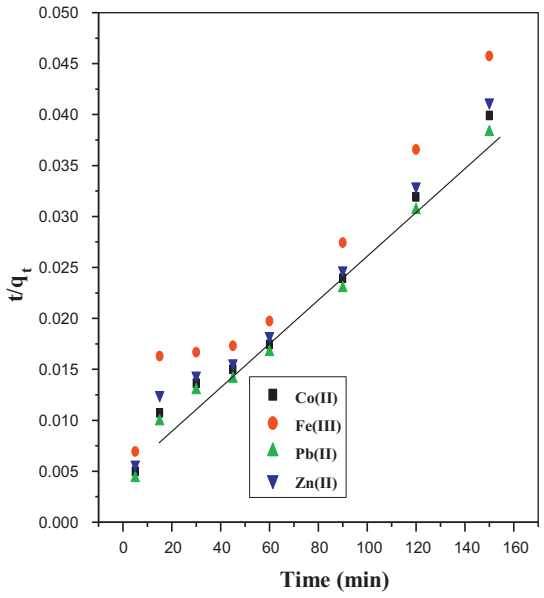

Fig. 7. Pesudo second order plot for adsorption metal ions onto carbon sample AC3.

where q_e and q_t are the values of amount sorbed per unit mass (mg g^{-1}) at equilibrium and at any time t, respectively and k_f is the pseudo first order sorption rate constant (min^{-1}). The k_f value could be obtained by plotting $\log(q_e - q_t)$ versus t at 25 ± 0.5 °C and pH 3.5. The obtained results are represented in Fig. 6. The plots show straight line with good linearity. The values of first order rate constant (k_f) and correlation coefficient (R^2) obtained from the plot are listed in Table 6. The experimental q_e values differed from the corresponding theoretical values. Thus, good linearity of Lagergren plots is not guarantee that the interactions of the metal ions with the carbon sorbents will follow first order kinetics.

In order to find a more reliable description of the kinetics, second order kinetic equation was applied. The pseudo second order kinetics can be represented by the following linear equation [22]:

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

where k_s is the second order rate constant (g mg^{-1} min^{-1}). The kinetic plots of t/q_t versus t for sorption of the studied metal ions are shown in Fig. 7. The relationship is linear and the correlation coefficient (R^2) suggests a strong relationship between the model parameters and explains that the sorption process could follows pseudo second order kinetics. The equilibrium sorption capacity (q_e), the initial sorption rate (h) that represented as $h = k_s q_e^2$, the pseudo-second-order constant (k_s) along with correlation

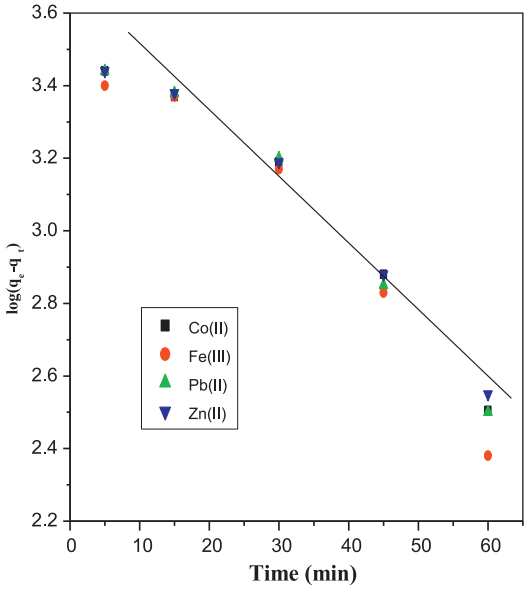

Fig. 6. Lagargren plot for adsorption of metal ions onto carbon sample AC3.

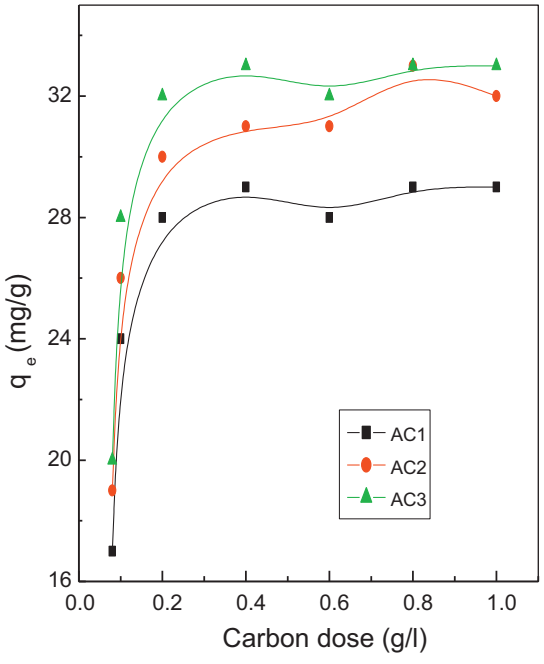

Fig. 8. Effect of carbon doses on removal of Co^{2+} ions from ground water S4 using the prepared carbon samples.

Table 6
kinetic parameters for sorption of metal ions onto carbon sample AC3.

Model	Parameter	Co(II)	Fe(III)	Pb(II)	Zn(II)
Pseudo first order (Lagergren)	k_f (min^{-1})	0.0392	0.0430	0.0400	0.0377
	R^2	0.979	0.968	0.979	0.983
	S.D.	0.091	0.122	0.0916	0.076
Pseudo second order	k_s ($g\,mg^{-1}\,min^{-1}$)	9.29E-6	7.09E-6	9.85E-6	7.90E-6
	h ($mg\,g^{-1}\,min^{-1}$)	188.67	125.31	210.08	158.98
	R^2	0.998	0.998	0.988	0.989
	S.D.	0.0015	0.00146	0.0027	0.00185

Table 7
The equilibrium concentration of Co^{2+} ion (C_e μg/L), amount adsorbed (q_e, mg/g) and removal percentage (R%) for adsorption of Co^{2+} onto prepared carbon samples.

Water sample	Carbon sample								
	AC1			AC2			AC3		
	C_e (μg/L)	q_e (mg/g)	R%	C_e (μg/L)	q_e (mg/g)	R%	C_e (μg/L)	q_e (mg/g)	R%
S1	2.7	21.15	94	1.8	21.6	97	0	22.5	100
S2	3.3	25.8	94	2.2	26.4	96	0	27.5	100
S3	3.96	28.2	94	1.98	32.01	97	0	33	100
S4	3.6	28.2	94	1.8	29.1	97	0	30	100
S5	2.94	23.02	94	1.47	23.76	97	0	24.5	100
S6	3.24	25.38	93	2.16	25.92	96	0.54	26.7	99

Table 8
The equilibrium concentration of Fe^{3+} ion (C_e μg/L), amount adsorbed (q_e, mg/g) and removal percentage (R%) for adsorption of Fe^{3+} onto prepared carbon samples.

Water sample	Carbon sample								
	AC1			AC2			AC3		
	C_e (μg/L)	q_e (mg/g)	R%	C_e (μg/L)	q_e (mg/g)	R%	C_e (μg/L)	q_e (mg/g)	R%
S1	3.9	30.5	94	2.6	31.2	96	0.65	32.17	99
S2	4.1	35.4	94.5	4.5	35.25	96	0.75	37.15	99
S3	5.3	41.8	94	4.0	32.01	95.5	0.89	44	99
S4	4.29	30.8	93.5	2.64	31.68	96	0.66	32.6	99
S5	3.6	28.2	94	2.4	28.8	96	0.6	29.7	99
S6	4.81	30.0	92.6	2.6	31.2	96	0.65	32.17	99

Table 9
The equilibrium concentration of Pb^{2+} ion (C_e μg/L), amount adsorbed (q_e, mg/g) and removal percentage (R%) for adsorption of Pb^{2+} onto prepared carbon samples.

Water sample	Carbon samples								
	AC1			AC2			AC3		
	C_e (μg/L)	q_e (mg/g)	R%	C_e (μg/L)	q_e (mg/g)	R%	C_e (μg/L)	q_e (mg/g)	R%
S1	0	18	100	0	18	100	0	18	100
S2	0	17	100	0	17	100	0	17	100
S3	0	17.5	100	0	17.5	100	0	17.5	100
S4	0	23.5	100	0	23.5	100	0	23.5	100
S5	0	22.5	100	0	22.5	100	0	22.5	100
S6	0	27.5	100	0	27.5	100	0	27.5	100

coefficient were determined and listed in Table 6. From these data, it was observed that, the calculated correlation coefficient is extremely high and closer to unity for pseudo second order kinetic model than for pseudo first order kinetic model. The calculated equilibrium sorption capacity (q_e) is consistent with the experimental data. Therefore, the sorption reaction can be approximated more favorably by the pseudo second order kinetic model. These results suggest that a pseudo second order sorption is the

Table 10
The equilibrium concentration of Zn^{2+} ion (C_e μg/L), amount adsorbed (q_e, mg/g) and removal percentage (R%) for adsorption of Zn^{2+} onto prepared carbon samples.

Water sample	Carbon sample								
	AC1			AC2			AC3		
	C_e (μg/L)	q_e (mg/g)	R%	C_e (μg/L)	q_e (mg/g)	R%	C_e (μg/L)	q_e (mg/g)	R%
S1	12.5	114.4	95	14.46	113.27	94	0	120.5	100
S2	1.78	43.6	98	3.56	42.7	96	0	44.5	100
S3	2.10	51.4	98	1.05	51.9	99	0	52.5	100
S4	0.75	37.1	99	2.25	36.3	97	0	37.5	100
S5	2.24	54.8	98	2.24	54.8	98	0	56	100
S6	3.84	46.08	96	4.8	45.6	95	0	48	100

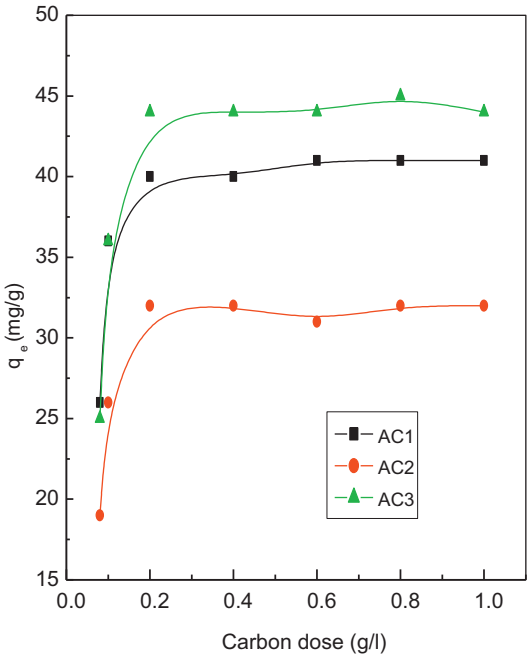

Fig. 9. Effect of carbon doses on removal of Fe^{3+} ion from ground water sample S4 using the prepared carbon samples.

predominant mechanism and the over all rate constant of the elements appears to be controlled by the chemisorption process [23].

Adsorption capacity of developed carbon adsorbent materials for metal ions in water samples

The initial metal ions concentration in the collected ground and surface water samples were measured. The percentage removal of metal ions from water samples was studied using 10 mg of activated carbon in contact with 50 mL of water sample and shaked for 1 h. In this concern, three different adsorbent samples were used to check their applicability for the removal of metal ions from underground and surface water.

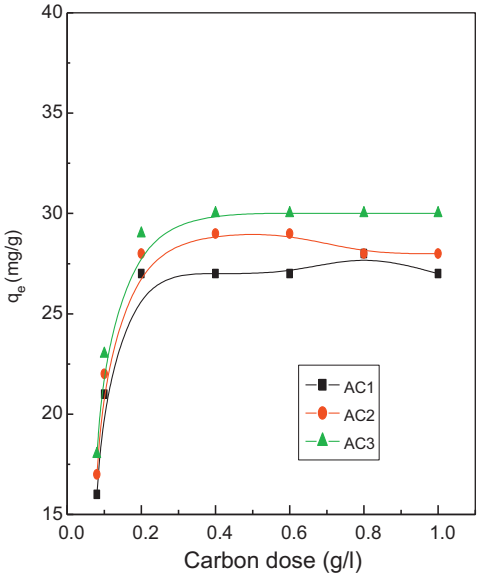

Fig. 10. Effect of carbon doses on removal of Pb^{2+} ions from ground water S6 using the prepared carbon samples.

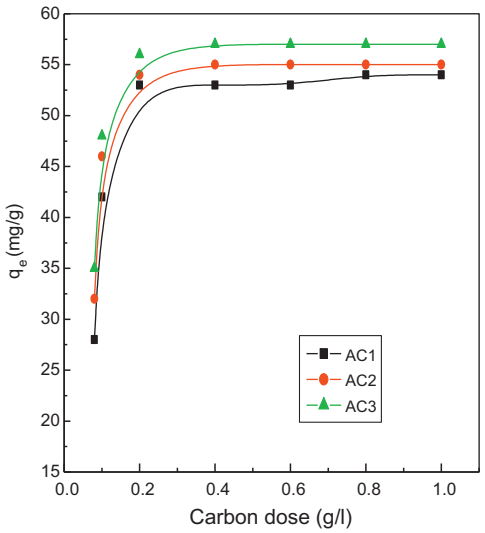

Fig. 11. Effect of carbon doses on removal of Zn^{2+} ions from ground water sample S5 using the prepared carbon samples.

The results in Fig. 8 and Table 7, show that the % removal of Co^{2+} ions from different ground and surface water samples using carbon samples are in the range 93–100% at 10 mg/50 mL. As shown in Table 7 we could say we need 20 kg of sorbent AC3 carbon to treat 10 m^3 of water containing 66 μg/L of Co^{2+} ions within 1 h of contact between the water and sorbent. The sorbent is capable of removal of up to 100% Co^{2+} ions from water samples in presence of another metals as Pb^{2+}, Zn^{2+} and Fe^{3+}.

Also the results in Table 8 and Fig. 9 show that the removal % of Fe^{3+} ions is in range 92–99% from different ground and surface water samples using the carbon samples. We could say that 10 m^3 of water containing 90 μg/L Fe^{3+}, needs 20.5 kg of AC3 within 1 h of contact between the water samples and sorbent. Thus, this sorbent is capable to remove all available Fe^{3+} ions from groundwater in presence of other metals as Zn^{2+}, Pb^{2+} and Co^{2+}.

The results in Table 9 and Fig. 10, show that the % removal of Pb^{2+} ions reached 100% from different ground and surface water samples using the prepared carbon samples. As shown in Table 9, let's say we want to treat 10 m^3 at 47 μg/L of Pb^{2+} ions, this requires 8.5 kg of AC3 carbon within 1 h of contact between the underground water and sorbent. Thus, this sorbent is capable to remove all available mentioned Pb^{2+} ions from water in presence of another metals as Co^{2+}, Fe^{3+} and Zn^{2+}, and can reach the permissible level.

As shown in Table 10 and Fig. 11, the % removal of Zn^{2+} ions from different water samples by using carbon samples reached 100% and the final concentration of metal after treatment was insignificant. It could be said that the treatment of 10 m^3 containing 241 μg/L of Zn^{2+} ions, requires 20 kg of AC3 sorbent within 1 h of contact between water and sorbent. Thus, the sorbent is capable to remove all available Zn^{2+} ions from water in presence of other metals as Co^{2+}, Pb^{2+} and Fe^{3+}, and can reach to the permissible level.

Effect of carbon dose

The adsorbed amount of the studied metal ion onto the prepared DP carbon samples was studied using different carbon doses (0.08–1 g/L). The results represented in Fig. 10 show that the optimum dose that could be used in further experiments is 0.2 g/L.

Conclusion

Carbon samples with good adsorption properties could be prepared from DP through chemical or physical activation as; (i) activated carbons by steam pyrolysis, (ii) activated carbons by single-step steam pyrolysis conditions at 700 °C with accompanying flow of N_2-activation, (iii) activated carbons by steam pyrolysis technique at 700 °C was performed in presence of catalytic gasifying acetate of calcium.

Carbon derived from DP could be considered as potential adsorbent material for metal ions with high sorption capacity. The prepared carbon samples could be potentially used for decreasing the content of the studied metal ion to below the permissible level. Adsorbents of varying physico-chemical properties were thus obtained with good to high adsorbing capacity.

In this concern, complete removal of contaminating metal ions was achieved in various ground and surface water under investigations. Also these adsorbents could be applied for removal of relatively higher metal ion concentrations from wastewater.

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