Peat Characterization and Uptake of Nickel (II) and Cobalt (II) in a Saprist Peat Column

By

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Abstract

Fibrist and saprist sphagnum peat soils taken from a bog in Torbay, Newfoundland, Canada were characterized. The saprist and fibrist peat soils had wet bulk densities of 0.65 g/cm^3 and 0.60g/cm^3 respectively, and cation exchange capacities of 70 meq/100g and 45 meq/100g respectively. Both peat soils were at pH 4.2 and were largely amorphous and the fibrist peat was more porous than the saprist peat. Fourier transform infrared spectroscopy and ^{13}carbon nuclear magnetic resonance suggested the presence of carboxylic acid, alcoholic hydroxyl, phenolic hydroxyl, amine and amide functional groups in both peats. The less reported amine and amide groups may have been observed because non-destructive characterization techniques were employed. The saprist peat was studied as a Ni^{2+} and Co^{2+} adsorbent in a vertical downflow fixed bed column and at the end of each column experiment, metal ions in the upper layer of the peat were desorbed with HCl. The metal sorption capacity of the saprist peat increased with decreasing flow rate and overall Ni^{2+} sorption was double the Co^{2+} sorption. Ni^{2+} may have been retained by a combination of ion exchange and complexation, while Co^{2+} may have been retained only by complexation.

Key words: XRD, SEM, FTIR, CEC, ^{13}C NMR, sorption

INTRODUCTION

Treatment of wastewaters containing toxic metals remains a persistent environmental issue and no method as yet employed has provided the needed lasting solution. Elevated concentrations of Ni^{2+} and Co^{2+} and their complexes are toxic and possible human carcinogens (IARC, 1990) and their efficient removal during metal refining is desirable especially since an effluent limit for Co^{2+} discharge is lacking.

Horticultural or fibrist peat soils have emerged as strong adsorbents for heavy metals such as Pb, Cu and Ni (Ho et al., 2000; Ho et al., 2002), Pb, Cu, Zn, Ni and Cd (Ringqvist et al., 2002), Cu and Ni (Gupta et al., 2009), Pb, Ni and Co (Bulgarlu et al., 2011) and peat is one of the least expensive adsorbents (Babel, 2003; USGS(a), 2006; USGS(b), 2006; USGS(c), 2006). It is easily harvested but the metal retention chemistry has remained unclear and this has limited large-scale application. Peat is most common in the northern hemisphere but large deposits have been reported in Brazil, Indonesia and South Africa (Twardowska et al., 1999)

Compared with the fibrist peat, the highly humified or saprist peat has hardly been studied as a metal adsorbent and previous studies have emphasized the extracted humic and fulvic acid fractions (Niemeyer et al., 1992; Baran, 2002; Li et al., 2002; Gondar et al., 2005; Fong and Mohamed, 2007), necessarily requiring destruction of the original material and alteration of the functional groups, although studying peat with minimal destruction is more realistic (Burba et al., 2001). Therefore, the main objectives in this study included focusing on non-destructive techniques to characterize fibrist and saprist peats obtained from the same bog in nearly their natural state, and employing the saprist peat as a Ni^{2+} and Co^{2+} adsorbent in a vertical down-flow column to better understand the metal retention mechanisms.

Column experiments are excellent for studying removal of metallic impurities from wastewater (Naumova et al., 1995) and are explored in large-scale treatment techniques and in the evaluation of adsorbent potentials. The commonly used continuous downflow method is easy to operate and adsorbs contaminants in a single step as the solution flows through the column bed (Zhou et al., 2004). Over time, the equilibrium adsorption zone moves down the column and the effluent contaminant concentration increases. In geo-environmental engineering the adsorption breakthrough point is taken to occur when 50% of the influent concentration is detected in the effluent (Yong et al., 1992) because at that point the adsorbent is usually completely saturated and steady flow is occurring (Schackelford, 1993).

Breakthrough curves describe the increasing exhaustion of the adsorbent bed (Cooney, 1999) and the rate of adsorbent exhaustion can be represented by the ratio of the outlet to inlet contaminant concentration, plotted on the y-axis, against time on the x-axis. The modified bed depth service time (BDST) model (Sharma and Forster, 1995; Sze et al., 2008) originally developed by Bohart-Adams (1920) which assumes that the rate of sorption is proportional to the sorption capacity remaining at any time, (known as the surface reaction theory,) was used in this study.

METHODS

The peat soils were obtained through the Traverse Nursery from a natural peat bog in Torbay, Newfoundland, Canada. They were harvested at depths of 0.4 m (fibrist) and 1.6 m (saprist) and transferred in flexi bags to the laboratory and portions of the peat soils were weighed and spread on a plastic tray to air dry at room temperature (23ºC) to about 70% moisture removal. Pebbles and woody materials were removed and the peats were homogenized by manual mixing. The physico-chemical properties that could influence metal adsorption of the peat soils were determined by standard methods (see Table 1) and grain size determination of the air dried peats was obtained by sieving triplicate samples over a series of mechanically stacked sieves (see Table 2).

To determine the initial metallic contents of the air-dried homogenized peat soils they were crushed in a mortar, acidified with HF and 8N HNO_3 and left on a hot plate for several days until completely digested (releasing all organic components). Then 6N HCl and 8N HNO_3 were added to dissolve the samples (and release inorganic components).

Finally 8N HNO_3 was added and diluted with nano-pure water according to the rock dissolution procedure in the Earth Science Department at Memorial University of Newfoundland (MUN) (modified EPA 3052 method). The samples were analyzed using inductively coupled plasma mass spectrometry (ICP-MS), specifically the ELAN DRC-2 (Earth Sciences Department, MUN).

During peat characterization each of the twelve size fractions for the two peat types shown in Table 2 was analysed separately employing X-ray diffraction (XRD), scanning electron microscopy (SEM) and Fourier transform infrared (FTIR) spectroscopy. Mineral content was obtained by XRD and samples were packed on a vertically placed stud of the Rigaku Rotaflex D/Max 1400 rotating anode powdered x-ray diffractometer with Cu-Kα radiation source operated at 40 kV and 100 mA from Rigaku/MSC - Japan equipped with an X-ray stream 2000 low temperature system (Earths Sciences Department, MUN). The diffractograms obtained were matched through the JADE data software.

Peat pore orientation and surface morphology micrographs were obtained by SEM using an Hitachi S-570. To prepare the soil samples each fraction from the dry granulometry was spread over a carbon taped stud and coated with 550X Sputter Coater for gold operated at 20 mA in a vacuum of 0.2 mbar for 2.5 minutes resulting in a 15 nm thick coating on the peat.

Functional groups in the two peat soils were identified using 1) a Bruker TENSOR 27 FTIR spectroscope equipped with a MIRacle ATR accessory coated with crystallized ZnSe with an absorbance range of 4000 – 650 cm^{-1} and 2) a solid state ^{13}C nuclear magnetic resonance (NMR) Bruker Avance II 600 spectrometer equipped with an SB Bruker 3.2 mm MAS triple-tuned probe operating at 600.33 MHz for 1 h and 150.97 MHz for ^{13}C (Chemistry Department, MUN). With the ^{13}C NMR, chemical shifts were referenced to tetramethylsilane (TMS) using adamantane as an intermediate standard for ^{13}C and samples were spun at 20 kHz. Cross- polarization spectra were collected with a Hartmann-Hahn match at 62.5 kHz and 100 kHz with 1h decoupling. The recycle delay was 2 s and the contact time was 2000 ms.

Vertical, downflow fixed bed column tests were conducted at room temperature in 14 cm high by 6 cm internal diameter Plexiglass columns. The solution tank was a constant head 1 L aspirator bottle repeatedly filled with 100 mg/L stock solutions of Ni^{2+} or Co^{2+} prepared from their hexahydrate salts, $Ni(NO_3)\cdot 6H_2O$ and $Co(NO_3)\cdot 6H_2O$. A peristaltic pump with flow capacity of 250 to 1400 mL/h drew water from the column exit (see Figure 1) and during the column tests the pump speed was gradually increased to maintain a constant flow, a requirement of the BDST equation. Two different constant flow rates of 1.0 and 2.0 L/h were tested.

The columns were charged with 110 g of air dried saprist peat of particle sizes ≤ 425 μm contained between 0.5 cm thick porous ceramic plates that prevented migration of the peat, provided support, and gave an effective peat depth of 12.5 cm. Two blank column experiments were carried out: 1) without peat to investigate the effects of the Plexiglass and ceramic plates on Ni^{2+} and Co^{2+} sorption, and 2) with peat and distilled water to determine if any initial Ni was eluted. Blank and single metal column tests were conducted in duplicate and the average of the results are reported.

Metal concentrations in the column effluents were determined using a Varian SpectrAA-55 flame atomic absorption spectrometer (Chemistry Department, MUN) and an air-acetylene flame. A slit width of 712 nm, lamp currents and wavelengths of 4 A and 232 nm for Ni and 7 A and 240.7 nm for Co, an air flow pressure of 60 psi, and an acetylene flow pressure of 11 psi, were employed. A blank solution was aspirated to stabilize and zero the instrument and standard solutions were prepared prior to analysis to calibrate the instrument. When samples were aspirated the mean absorbance value for each, within a 3% relative standard deviation (RSD), was obtained.

The modified bed depth service time (BDST) model is shown in equation (1).

$$\ln\left(\frac{C_t}{C_o}\right) = kC_o t - N_o k\frac{H}{v} \tag{1}$$

In this equation C_o is the initial concentration of solute (mg/L), C_t is solute effluent concentration at time t (mg/L), k is the adsorption rate constant (L solution/mg solute · h) and measures the rate of solute transfer from the fluid phase to the solid phase, N_o is the adsorption capacity (mg solute/L adsorbent), H is the bed depth (cm), v is the linear flow velocity of feed to the bed (cm/h), and t is the service time (h).

The bed volume (BV in L) or volume of metal solution consumed at breakthrough and the bed time (BT in h) or time until breakthrough, were also obtained from the column tests. In addition, the adsorbent exhaustion rate (AER) defined as the mass of adsorbent (g) per bed volume (L) for the two flow rates and for Ni^{2+} and Co^{2+} were determined.

After breakthroughs, samples were taken from the tops of the columns and analyzed using ICP-MS to determine the quantities of metals sorbed. Water at ~ 85 ^oC and 0.1 and 1.0 M HCl concentrations were added to the samples (40mL to 1.6 g), agitated for 2 h on a 5900 Eberbach reciprocal shaker, and filtered using quantitative filter paper with 45 µm openings (Anachemia Chemicals, Canada). The filtrates were analyzed using flame atomic absorption spectrometry (FAAS) to determine the amounts of metals desorbed.

RESULTS AND DISCUSSION

Peat Characterization and Physico-chemical properties

The physico-chemical properties determination (Table 2) showed that both peat types were acidic, had high fibre contents and high moisture holding capacities. The saprist peat had a greater cation exchange capacity (CEC) and its smaller ash content might be attributed to its zone of formation within the bog (Spedding, 1988) and its greater degree of decomposition (Malterer et al., 1992). The more decomposed the peat, the greater the proportion of fulvic acid and hydroxyl groups compared to humic acid and carboxyl groups (Kalymkova et al., 2008).

The particle size distributions (Table 3) showed that the saprist peat was more dominated by fractions with smaller particle sizes. Fractions >850 µm were mostly fibre or unidentifiable decomposing materials while fractions > 2 mm were usually woody undecomposed materials present only in the fibrist peat. The elements detected (Table

3) suggest that both peat soils had a natural metal affinity and calcium and iron were the predominant metals.

The micrographs of the < 425 µm fraction (Figures 2a and 2b) showed inter-connected fibres and the saprist peat contained collapsed and overlapping pores, possibly due to compressive forces from decomposition and overlying peat. The pores in the fibrist peat (Figure 2a) were more distinct and could have originated directly from the plant forming materials. Peat has a cellular pore structure (Coupal and Lalancette, 1976) and greater decomposition can reduce the pore fraction as smaller particles become more packed together, increasing the bulk density (Bozkhurt et al., 2001). The compact and powdery saprist peat had the greater bulk density and this contributed to its greater moisture content (Table 2). Fibrist peat is favoured in gardening due to its greater porosity.

The X-ray diffractograms for both peats of all fractions were similar, with no unique or identifiable crystal peaks except for the ≤ 75 µm fibrist peat (Figure 3) that contained calcium and silicon oxide and therefore the saprist peat showed a greater amorphous nature. The hump-shaped curve between 18^o and 32^o is a unique characteristic of peat (Romão et al., 2007). Minerals in peat such as quartz and feldspar in a New York woody peat (Bloom and McBride, 1979) and calcite, kaolinite and quartz in an Alder-peat from Poland (Twardowska and Kyziol, 1996) have been observed.

The FTIR and ^{13}C NMR spectra for all size fractions ≤ 425 µm for both the saprist and fibrist peat samples were similar. The FTIR (Figure 4) and ^{13}C NMR (Figure 5) spectra are representative results as the spectra for all fractions of the two peats were similar. Similar spectra suggested that the two peats from the same bog contained similar chemical compounds but in varying proportions.

Table 4 (matched primarily with Lange's chemistry handbook) shows the probable functional groups suggested by the FTIR spectra and mentions other studies that observed the same functional groups. The FTIR analyses suggested that the fibrist and saprist peat samples contained mainly oxygenated functional groups, including N-groups, which generally have gone unreported. It is possible that the non-destructive characterization employed in this study preserved the N-groups whereas other previous studies that extracted the humic and fulvic acids inadvertently damaged the N-groups and this could be an area for future research.

The solid-state ^{13}C NMR spectra supported the FTIR results and showed the presence of *C in CH_3 long polymeric chain environment (18.05 -40.06 ppm), C in amine, alcohol, ethers and methoxyl (56.28 – 84.15 ppm), C in phenol and N-substituted aromatics (100.37 – 129.43 ppm) and C in carboxyls, amides and esters (150.78 – 173.38 ppm).*

The oxygenated carboxylic acid and alcoholic and phenolic hydroxyls species feature active electron sites in their primary structures. Complexation reactions, governed by electronic exchange and re-arrangement, and that could produce reaction products, might therefore dominate the peat - metal binding chemistry. Complex formations which are usually colloidal in nature may account for lower effective metal removal across an adsorption column as the adsorption layer is known to be restricted to a few centimetres on the surface of the peat bed (Pérez et al., 2005).

Vertical fixed bed column test with saprist peat

Breakthrough curves for pH 5.5 and 100 mg/L concentrations of Ni^{2+} and $Co^{2+}$with constant downflow rates of 1.0 and 2.0 L/h are shown in Figures 6a, 6b, 6c and 6d and the total effluent volumes (bed volumes) and bed times at breakthrough are given in Table 5. pH 5.5 was chosen for the Ni^{2+} and Co^{2+}solutions because at 100 mg/L the natural pHs were ~5.2 and only slight adjustment was required to attain pH 5.5. In addition, preliminary batch tests with the same peat showed that optimum removal of the two metals was obtained in the pH 5.0 – 6.5 range.

For Ni^{2+}, breakthroughs occurred at 153 h and 160 L at a flow rate of 1.0 L/h, and at 34 h and 63 L for a flow rate of 2 L/h. For Co^{2+}, breakthroughs occurred at 56 h and 51 L at a flow rate of 1.0 L/h, and at 10 h and 25 L for a flow rate of 2.0 L/h. The lower flow rate allowed more retention of Ni^{2+} and $Co^{2+}$and would be recommended for the design of adsorption columns. With a lower flow rate and longer solution contact time, quasi-equilibrium as exhibited by the more pronounced saw-tooth profile on the breakthrough curves, and increased metal uptake could be attained. Less Co^{2+} was retained compared to Ni^{2+} at both flow rates.

Other estimated BDST parameters are also reported in Table 5. The kinetic rate constant (k) increased with the flow rate for both metals. This suggested that increased flow rate enhanced the transfer rate of Ni^{2+} and Co^{2+} ions through the peat matrix, but reduced the relative amount of metals that were retained.

At the greater flow rate the adsorption capacity of the peat bed, N_o decreased for both metals and more so for Ni^{2+}. This could be related to 1) the attainment of equilibrium or 2) the type of uptake mechanism. At the lower flow rate longer contact times between the peat matrix and metal ions were achieved before equilibrium was attained and this led to a slower adsorbent exhaustion rate. On the other hand, variation in the uptake mechanism and products formation could also have contributed. Less Co^{2+} was sorbed despite the promising nature of the initial Co^{2+} uptake. The products that were formed during the peat-Co^{2+} interaction could have inhibited the sorption reaction rate if complexation dominated metal uptake. The combination of ion exchange and complexation could have aided the larger retention observed with Ni^{2+} while uptake by ion exchange could have been insignificant with Co^{2+} leading to less retention as observed.

The extent of desorption using distilled water, 0.1 M HCl and 1.0 M HCl is summarized in Table 6. More Ni^{2+} than Co^{2+} was desorbed and more Ni^{2+} was desorbed at 1.0 M HCl than at 0.1 M HCl. Desorption would be more favored when the peat metal bonds are due to ion exchange, whereas complexation reactions would be more resistant to desorption. The small particle size of the peat allowed for easy cross linking of the metals and the peat matrix and chemical sorption via complexation of the cations with the active functional groups is suggested as the dominant uptake mechanism for Co^{2+}. However due to the poly-functional group nature of the peat, ion exchange at the less active sites by the Ni^{2+} could have occurred in addition to complexation thus, greater Ni^{2+} was adsorbed compared to Co^{2+} at the uptake conditions.

CONCLUSIONS

Ni^{2+} and Co^{2+} retentions on saprist peat were influenced by the flow rate and uptake mechanisms. Ion exchange and cations complexation are the two reactions suggested for the uptake of these metals. Ni^{2+} could have been removed by a combination of ion exchange and complexation, while Co^{2+} may have been retained only by complexation. Co^{2+} could have been expected to be adsorbed more due to its larger ionic radii and lower heat of hydration (smaller hydrated radii) compared to Ni^{2+}, but a single reaction (complexation) could have been the reason for the lower removal level compared to Ni^{2+}. Products formed by the peat-Co^{2+} interaction at pH 5.5 may have been more colloidal in nature, resulting in some blockage of neighbouring unoccupied active sites.

The ability to penetrate the active sites was increased at a flow rate of 2.0 L/h compared to that at a flow rate of 1.0 L/h as indicated by the column capacity for Co^{2+}. In addition, nitrogen containing groups such as amines and amides, detected by the instrumental analytical characterization of the saprist peat could be involved in varying degrees of complexation with Ni^{2+} and Co^{2+} resulting in the observed adsorption trends in the column. Overall, the saprist peat is a potential adsorbent for Ni^{2+} and Co^{2+}retention.

The non-destructive characterization of the peat may have resulted in preservation of the amine and amide groups which are not often reported in studies that focus on the humic and fulvic acids (or destructive characterization of organic materials).

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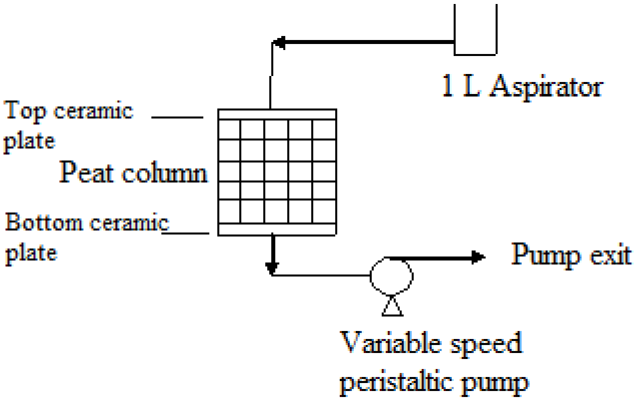


Figure 1. Schematic diagram of the column experiment set up.

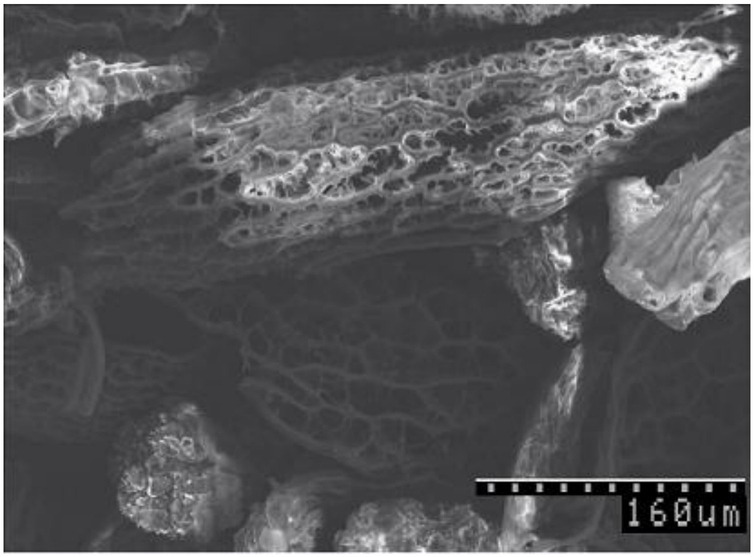


Figure 2a. Micrograph of fibrist NL peat (particle size ≤ 425μm) (Magnification X 1000)

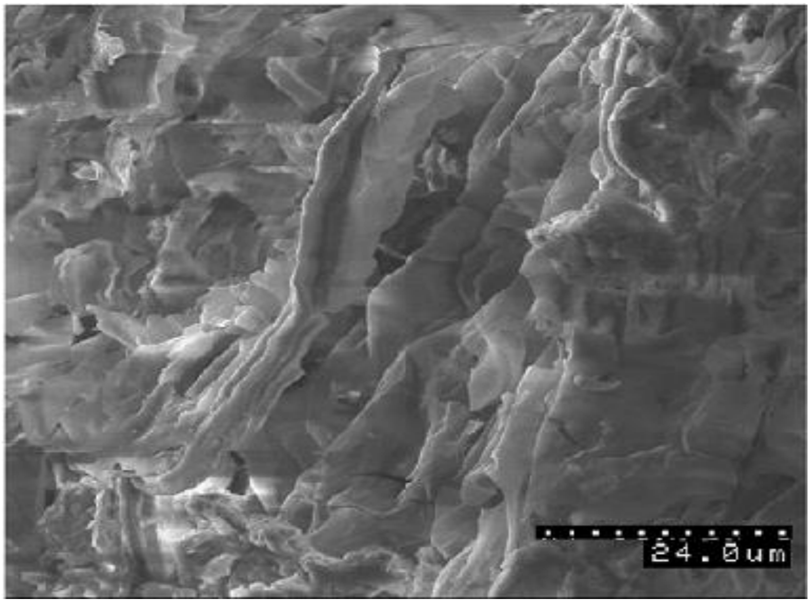


Figure 2b. Micrograph of saprist NL peat (particle size ≤ 425μm) (Magnification X 1000)

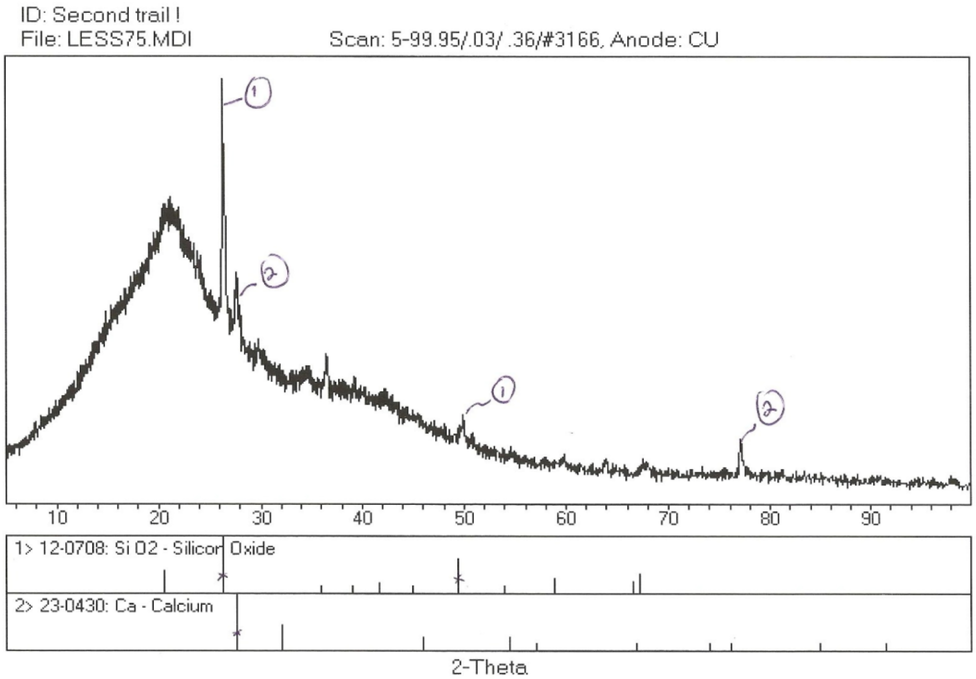


Figure 3. Diffractogram of fibrist NL peat fraction ≤ 75 µm (1 corresponds to silicon oxide and 2 corresponds to calcium)

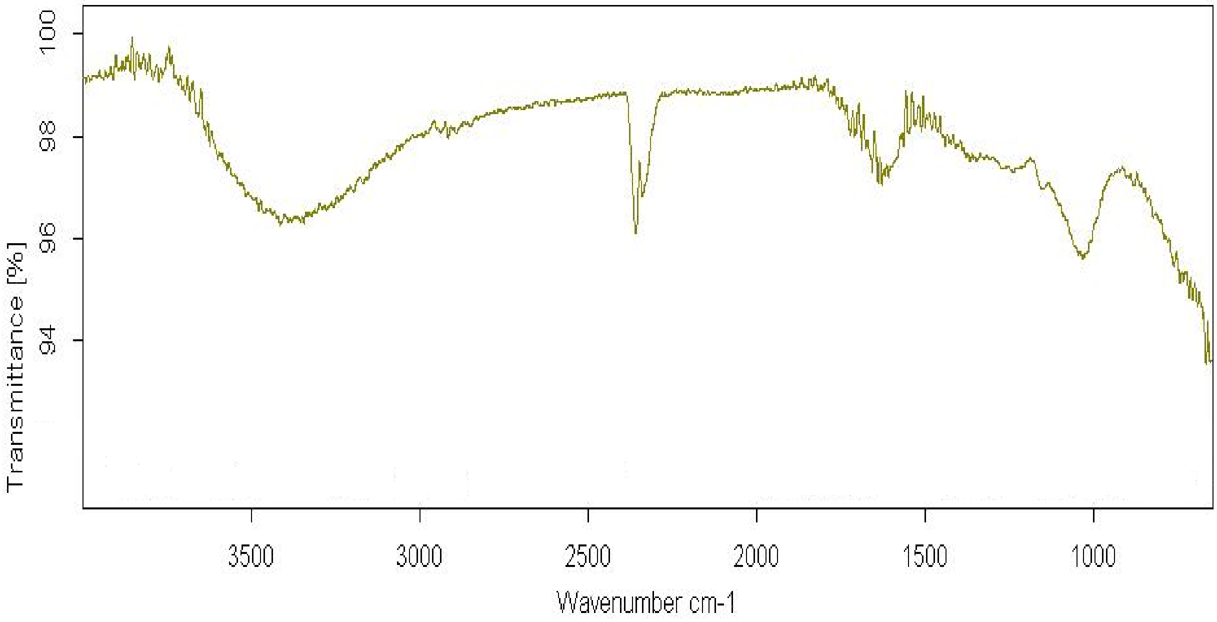


Figure 4. FTIR spectrum of a saprist or fibrist NL peat (particle size ≤ 425 μm)

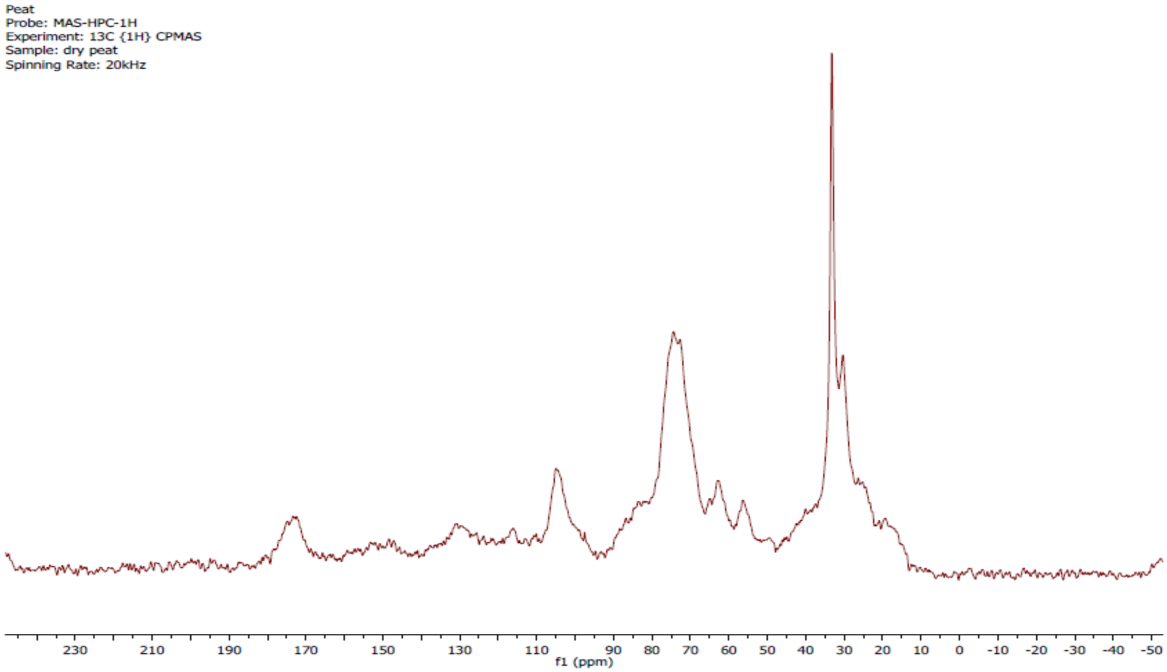


Figure 5. ^{13}C NMR Spectrum of a saprist or fibrist NL peat (particle size ≤ 425 μm)

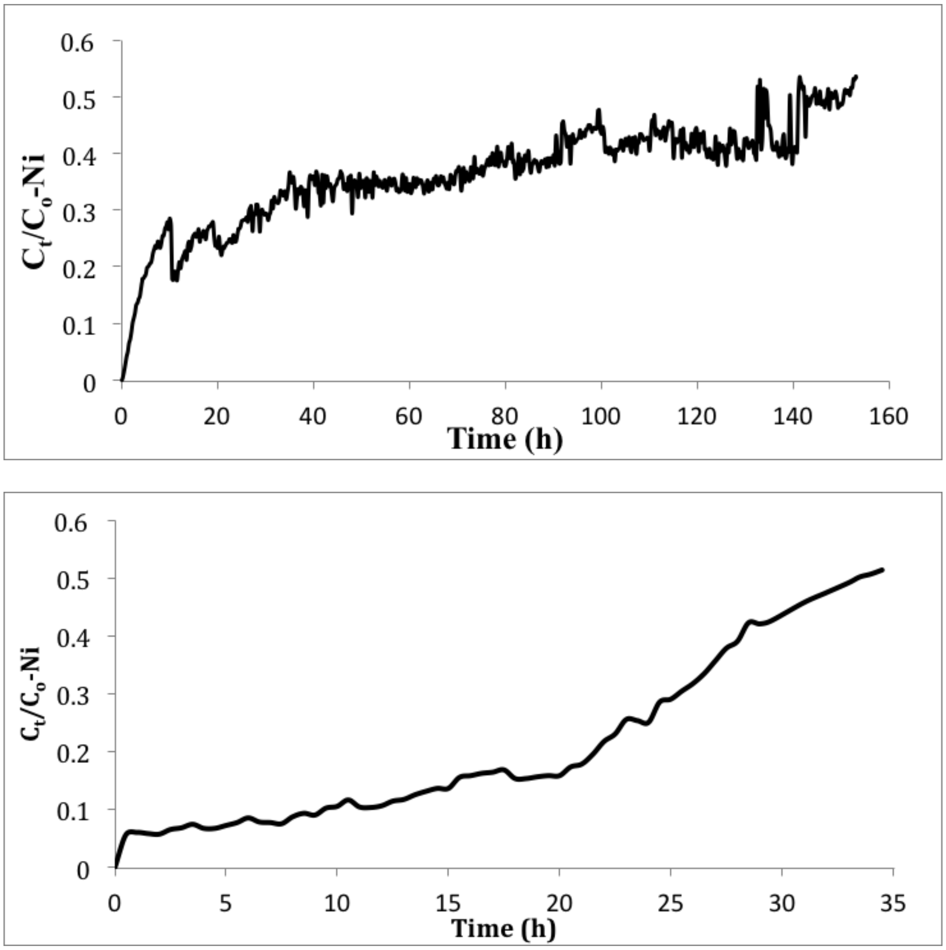
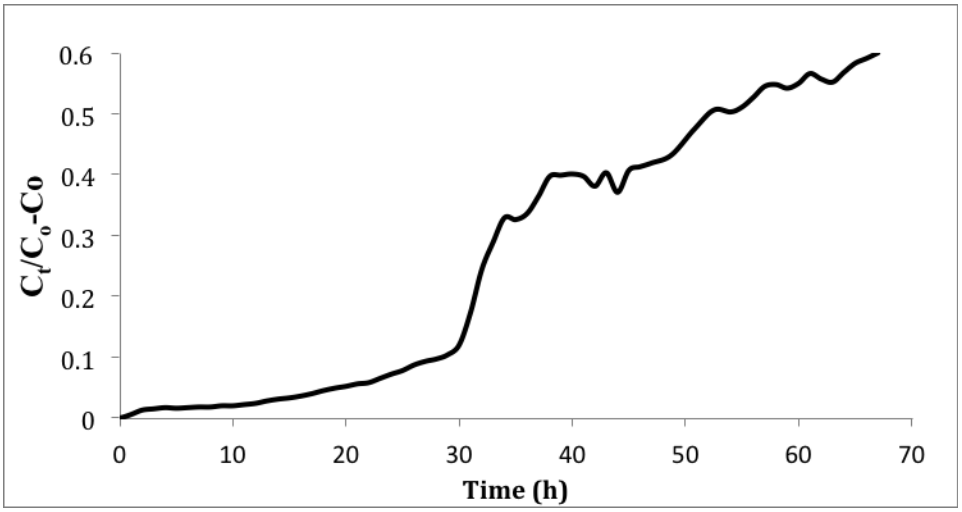


Figure 6a Figure 6b

Figure 6a and 6b: Breakthrough curves for 100 mg/L Ni^{2+} adsorptions at pH 5.5, conc., and

flow rates of 1.0 and 2.0 L/h



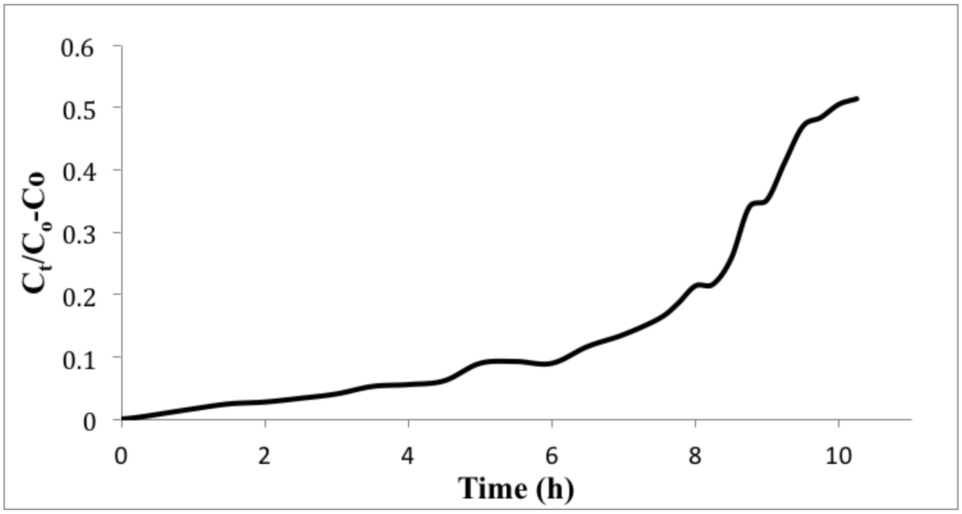


Figure 6c Figure 6d

Figure 6c and 6d: Breakthrough curves for 100 mg/L Co^{2+} adsorptions at pH 5.5, conc., and

flow rates of 1.0 and 2.0 L/h

Table 1. Physico-chemical parameters of the highly and poorly humified peat soils

Parameter	Method Used	Values	
		Saprist peat	Fibrist peat
Degree of decomposition	von Post	8H	3H
pH (in de-ionized water)	ASTM D2976-71	4.2	4.2
Moisture content (%)	ASTM D2974-07A	86	82
Fiber content (%)	ASTM D1997-91	68.8	75
Ash content (%)	ASTM D2974-07A	9	16
Organic matter (%)	ASTM D2974-07A	91	84
Fresh bulk density (wet, g/ cm^3)	ASTM D4531-86	0.65	0.60
Dry bulk density (g/ cm^3)	ASTM D4531-86	0.28	0.21
CEC at 7.0 pH(meq/100g)	Calcium acetate/chloride[a]	70	45

[a] Calcium acetate/chloride method from Sheldrick, (1984)

Table 2: Dry granulometry results for the two peat types

		Average % retained by weight	
Sieve No.	Sieve size (µm)	7H - 8H[a]	3H[b]
4	4750	13	15
8	2000	-	19
20	850	52	-
40	425	15	45
50	300	5	-
60	250	-	9
100	150	6	4
200	75	3	6

[a] saprist peat
[b] fibrist peat

Table 3: Metals detected by ICP-MS analysis of the two peat types

	Concentration (mg/kg)	
Metal	7H - 8H[a]	3H[b]
Ca	2392	2743
^{54}Fe	1012	971
Ti	34	98
Zn	15	88
Sn	8	8
Mn	7	27
^{52}Cr	4	ND[c]
Ni	4	0.7
Cu	2	0.3
^{77}Se	1	ND[c]

[a] saprist peat
[b] fibrist peat
[c] not detected

Table 4: Probable functional groups from FTIR spectra

Wavenumber (cm^{-1})	Probable Functional Group Assigned Band range, cm^{-1}	Comparable Studies
3518	*Primary amines (aliphatic) 3550 -3300 (m)*[a]	
	Secondary amines 3550-3400 (w)	
3352	*Normal polymeric OH stretch*[1]	Niemeyer et al., 1992
3270	*Ammonium ion 3300-3030 (s)*[b]	
2918	*Carboxylic acids –CO_2H, OH stretching 3000 -2500*	Orem et al., 1996
2850	*Carboxylic acids –CO_2H, OH stretching 3000 -2500*	Orem et al., 1996
	Methylene (CH_2) C-H asymmetric/symmetric stretch[1]	Niemeyer et al., 1992
2360	*Tertiary amines $R_1R_2R_3NH^+$ 2700 - 2250*	
2341	*Aliphatic CN*	
1620	*Primary amines (aliphatic) 1650-1560 (m)*[a]	
	C=C conjugated with aromatic ring 1640 -1610 (m)	Orem et al., 1996
	α, β unsaturated carbonyl compounds 1640 -1590 (m)	
1412	*Ammonium ion 1430-1390 (s)*[b]	
	Vinyl C-H in-plane bend[1]	
1375	*=$C(CH_3)_2$ Alkane residues attached to C ≈ 1380 (m)*	Orem et al., 1996
	Nitro C-NO_2 aromatic 1380-1320 (s)[c]	
1242	*Aromatic ethers, aryl –O stretch (Φ-O-H)*[1]	Artz et al., 2008
1150	*Tertiary alcohol C-O stretch*[1]	Niemeyer et al.,1992
1034	*Hydroxyl O-H primary aliphatic alcohols*[d]	Orem et al., 1996, Artz et al., 2008
	-O-CH_3 ethers (w-m) c 1030	
	Peroxides –O-O- 1150 -1030[1] [e] *(m-s) Alkyl*	Orem et al., 1996, Artz et al., 2008
915	*Silicate ion*[1]	
845	*Nitro C-NO_2 aromatic 865 - 835*[c]	
825	*Peroxides -O-O- 900 - 830 (w)*[e]	
767	*-CH_2- Rocking vibration*	
720	*Saturated CH_2C 720*	Artz et al., 2008
667	*Hydroxyl O-H primary aliphatic alcohols 700-600*[d]	

[1] John Coates in Encyclopedia of Analytical Chemistry

[a] primary amine bands at 3550-3300 and 1650-1560

[b] ammonium ion bands at 3300-3030 and 1430-1390

[c] nitro C-NO_2 aromatic bands at 1380-1320 and 865-835

[d] primary aliphatic alcohols bands at 1085-1030 and 700-600

[e] peroxide bands at 1150-1030 and 900-830

Table 5: Summary of the estimated BDST parameters

	Flow rate (L/h)	BV[a] (L)	BT[b] (t_{50}) (h)	k[c] x 10^{-6} (L/mg.h)	N_o[d] x 10^4 (mg/L)	AER[e] (g/L)	r^2
Ni^{2+}	1.0	160	153	18	3.56	0.69	0.79
	2.0	63	34	132	0.09	1.75	0.88
Co^{2+}	1.0	51	56	106	0.25	2.16	0.93
	2.0	25	10	472	0.11	4.4	0.79

[a] bed volume at breakthrough

[b] bed time at breakthrough

[c] adsorption rate constant

[d] adsorption capacity

[e] adsorbent exhaustion rate

Table 6: Ni^{2+} and Co^{2+} retained by the top layer of the peat column at breakthrough and after desorption with distilled water, 0.1 M HCl and 1.0 M HCl.

	Ni^{2+} (mg/kg)	Co^{2+} (mg/kg)
Initial adsorption	25.7	24.2
After desorption with distilled water	25.7	24.2
After desorption with 0.1 M HCl	24.4	24.1
After desorption with 1.0 M HCl	4.8	24.1