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

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**Abstract:** In this study, 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 and 0.60 g/cm3, respectively, and cation-exchange capacities of 70 and 45 meq/100 g, respectively. The pH of both peat soils was 4.2 and the soils were amorphous for the most part; however, the fibrist peat was more porous than the saprist peat. Results of Fourier transform infrared spectroscopy and 13carbon 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 an Ni2+ and Co2+ 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 the sorption capacity of Ni2+ was two times greater than the sorption capacity of Co2+. Ni2+ may have been retained by a combination of ion exchange and complexation, while Co2+ may have been retained only by complexation.

**INTRODUCTION**

The treatment of wastewaters containing toxic metals continues to be a persistent environmental problem and none of the methods employed thus far has provided the much needed lasting solution. Elevated concentrations of Ni2+ and Co2+ as well as their complexes are toxic and possible human carcinogens (IARC 1990). Therefore, efficient removal of such compounds during metal refining is desirable, especially because of the lack of an effluent limit for Co2+ discharge.

Horticultural or fibrist peat soils have emerged as strong adsorbents for heavy metals [e.g., 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 and Kurniawan 2003; USGS(a) 2006; USGS(b) 2006; USGS(c) 2006]. It is easily harvested but the metal retention chemistry, which has limited large-scale application, has so far remained unclear. Peat is commonly found 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*. 2004; Gondar *et al*. 2005; Fong and Mohamed 2007), which requires breaking down of the original material and altering the functional groups, although studying peat with minimal break down of the original material is more realistic (Burba *et al*. 2001). Therefore, the main objectives of 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 using the saprist peat as an Ni2+ and Co2+ adsorbent in a vertical downflow column to better understand the metal retention mechanisms.

Column experiments are excellent options to study the removal of metallic impurities from wastewater (Naumova *et al*. 1995) and are explored in large-scale treatment techniques as well as in the evaluation of adsorbent potentials. The commonly used continuous downflow method is easy to operate and adsorbs contaminants in a single step while the solution flows through the column bed (Zhou *et al*. 2004). Over time, the equilibrium adsorption zone moves down the column and the concentration of the effluent contaminant increases. In geo-environmental engineering the adsorption breakthrough point is considered 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 there is steady flow (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), which was originally developed by Bohart and Adams (1920) and 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.

**MATERIALS AND 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 transported to the laboratory in flexi-bags. Portions of the peat soils were weighed and spread on a plastic tray to air dry at room temperature (23 °C), which removes about 70% of the moisture. 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 (Table 1) and the grain size of the air dried peats was determined by sieving triplicate samples over a series of mechanically stacked sieves (Table 2).

To determine the initial metallic contents, the air-dried homogenized peat soils were crushed in a mortar, acidified with HF and 8 N HNO3 and left on a hot plate for several days until completely digested (releasing all organic components). Then 6 N HCl and 8 N HNO3 were added to dissolve the samples (and release inorganic components). Finally, 8 N HNO3 was added and diluted with nanopure 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-II (Earth Sciences Department, MUN).

During peat characterization each of the 12 size fractions for the two peat types shown in Table 2 was analyzed separately by X-ray diffraction (XRD), scanning electron microscopy (SEM) and Fourier transform infrared (FT-IR) spectroscopy. Mineral content in the fractions was obtained by XRD and the samples were packed on a vertically placed stud of the Rigaku Rotaflex D/Max 1400. This equipment has a 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 using the JADE data software.

**TABLE 1.** Physico-Chemical Parameters of the Highly and Poorly Humified Peat Soils

|  Parameter |  Method used | ValuesSaprist peat Fibrist peat |
| --- | --- | --- |
|  Degree of decomposition von Posta 8H 3H pH (in de-ionized water) ASTM D2976-71 (2004) 4.2 4.2 Moisture content (%) ASTM D2974-71 (2008) 86 82 Fiber content (%) ASTM D1997-91 (2008) 68.8 75 Ash content (%) ASTM D2974-71 (2008) 9 16 Organic matter (%) ASTM D2974-71 (2008) 91 84 Fresh bulk density ASTM D4531-86 (2008) 0.65 0.60 (wet, g/cm3 ) Dry bulk density (g/cm3) ASTM D4531-86 (2008) 0.28 0.21 CEC at 7.0 pH(meq/100 g) Calcium acetate/chlorideb 70 45 |
| avon Post scale (Bozkhurt *et al*. 2001).bCalcium acetate/chloride method from Sheldrick (1984).CEC, cation-exchange chromatography. |

**TABLE 2.** Dry Granulometry Results for the Two Peat Types

|  |  |  |
| --- | --- | --- |
| Sieve No. | Sieve size (µm) | Average % retained by weight |
|  7H–8Ha 3Hb |
|  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 |

aSaprist peat

bFibrist peat

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

Functional groups in the two peat soils were identified using (i) a Bruker TENSOR 27 FT-IR spectroscope equipped with a MIRacle ATR accessory coated with crystallized ZnSe with an absorbance range of 4000–650 cm–1 and (ii) a solid-state 13C 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 13C (obtained from Department of Chemistry, MUN). With the 13C NMR, chemical shifts were referenced to tetramethylsilane using adamantane as an intermediate standard for 13C and samples were spun at 20 kHz. Cross-polarization spectra were collected with a Hartmann–Hahn match at 62.5 and 100 kHz with a decoupling time of 1 h. 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 Plexiglass columns (height: 14 cm; internal diameter: 6 cm). The solution tank was a constant head 1-l aspirator bottle repeatedly filled with 100 mg/l stock solutions of Ni2+ or Co2+ prepared from their hexahydrate salts, Ni(NO3)·6H2O and Co(NO3)·6H2O. A peristaltic pump with flow capacity of 250–1400 ml/h drew water from the column exit (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 (1.0 and 2.0 l/h) were tested.

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

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: (i) without peat to investigate the effects of the Plexiglass and ceramic plates on Ni2+ and Co2+ sorption and (ii) with peat and distilled water to determine whether 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 (Department of Chemistry, 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 used for our analysis. A blank solution was aspirated to stabilize and zero the instrument and standard solutions were prepared before the analysis to calibrate the instrument. When samples were aspirated the mean absorbance value for each, within a 3% relative standard deviation, was obtained. The modified BDST model is shown in equation (1).

  (1)

In this equation C0 is the initial concentration of solute (mg/l), Ct is the solute effluent concentration at time t (mg/l), k is the adsorption rate constant (L/mg·h) and measures the rate of solute transfer from the fluid phase to the solid phase, N0 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), which is defined as the mass of adsorbent (g) per BV (l), for the two flow rates and for Ni2+ and Co2+ were determined.

 After breakthroughs, samples were taken from the top of the columns and analyzed by ICP-MS to determine the quantities of metals sorbed. About 100 mL of water at approximately 85 °C is added to the samples. In addition, 0.1 and 1.0 M HCl concentrations were added to the samples (40 ml 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 to determine the amounts of metals desorbed.

**RESULTS AND DISCUSSION**

**Peat Characterization and Physico-chemical properties**

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

Particle-size distributions (Table 3) showed that the saprist peat was more dominated by fractions with smaller particle sizes. Fractions >850 µm were mostly fiber 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 2(a) and 2(b)] showed inter-connected fibers 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 2(a)] 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 of peat 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.

**TABLE 3.** Metals Detected by Inductively Coupled Plasma Mass Spectrometry Analysis of the Two Peat Types

|  |
| --- |
|  Concentration (mg/kg) |
| Metal |  7H–8Ha | 3Hb |
| Ca 2392 274354Fe 1012 971Ti 34 98Zn 15 88Sn 8 8 Mn 7 2752Cr 4 NDcNi 4 0.7Cu 2 0.377Se 1 NDc |

aSaprist peat

bFibrist peat

cNot detected



Figure 2. Micrographic images of (a) fibrist NL peat and (b) saprist NL peat (particle size for both peats ≤ 425 µm and magnification 1000×).

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° and 32° is a unique characteristic of peat (Romão *et al*. 2007). Some of the minerals reported in peat include quartz and feldspar [by Bloom and McBride (1979) in a New York woody peat] and calcite, kaolinite and quartz [by Twardowska and Kyziol (1996) in an Alder peat from Poland].



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

The FT-IR and 13C NMR spectra for all size fractions ≤ 425 µm for both the saprist and fibrist peat samples were similar. The FT-IR (Figure 4) and 13C 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 and Speight, 2005) shows the probable functional groups suggested by the FT-IR spectra and mentions other studies that observed the same functional groups. The FT-IR 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 13C NMR spectra supported the FT-IR results and showed the presence of C in CH3 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).



**Figure 4.** Fourier transform infrared spectrum of a saprist or fibrist NL peat (particle size ≤ 425 µm).



**Figure 5.** 13C nuclear magnetic resonance spectrum of a saprist or fibrist NL peat (particle size ≤ 425 µm).

**TABLE 4.** Probable Functional Groups from Fourier Transform Infrared Spectra

|  |  |  |
| --- | --- | --- |
| Wave number(cm–1) | Probable functional group assignedBand range (cm–1) | Comparable studies |
| 3518 Primary amines (aliphatic) 3550–3300 (m)a Secondary amines 3550–3400 (w)3352 Normal polymeric OH stretch1 Niemeyer *et al*. (1992)  |
| 3270 Ammonium ion 3300–3030 (s)b 2918 Carboxylic acids –CO2H, OH stretching 3000–2500 Orem *et al*. (1996)2850 Carboxylic acids –CO2H, OH stretching 3000–2500 Orem *et al*. (1996) Methylene (CH2) C–H asymmetric/symmetric stretch1  Niemeyer *et al*. (1992)2360 Tertiary amines R1R2R3NH+ 2700–2250 |
| 2341 Aliphatic CN1620 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 bend1 |
| 1375 =C(CH3)2 alkane residues attached to C ≈ 1380 (m) Orem *et al*. (1996) Nitro C–NO2 aromatic 1380–1320 (s)c |
| 1242 Aromatic ethers, aryl –O stretch (Φ–O–H)1 Artz *et al*. (2008) |
| 1150 Tertiary alcohol C–O stretch1 Niemeyer *et al*. (1992) |
| 1034 Hydroxyl O–H primary aliphatic alcoholsd Orem *et al*. (1996); Artz *et al*. (2008) –O–CH3 ethers (w-m) c 1030 Peroxides –O–O– 1150–10301 e (m-s) Alkyl Orem *et al*. (1996); Artz *et al*. (2008) |
| 915 Silicate ion1 |
| 845 Nitro C–NO2 aromatic 865–835c  |
| 825 Peroxides –O–O– 900–830 (w)e |
| 767 –CH2 rocking vibration |
| 720 Saturated CH2C 720 Artz *et al*. (2008) |
| 667 Hydroxyl O–H primary aliphatic alcohols 700–600d |

1 John Coates in *Encyclopaedia* of Analytical Chemistry.

aprimary amine bands at 3550–3300 and 1650–1560.

bammonium ion bands at 3300–3030 and 1430–1390.

cnitro C-NO2 aromatic bands at 1380–1320 and 865–835.

dprimary aliphatic alcohols bands at 1085–1030 and 700–600.

eperoxide bands at 1150–1030 and 900–830.

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 centimeter 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 Ni2+ and Co2+with constant downflow rates of 1.0 and 2.0 l/h are shown in Figures 6(a–d) and the total effluent volumes (BVs) and BTs at breakthrough are given in Table 5. A pH of 5.5 was chosen for the Ni2+ and Co2+ solutions because at 100 mg/l the natural pHs were approximately 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 range of 5.0–6.5.

Figure 6a

Figure 6b

**Figure 6.** (a and b) Breakthrough curves for 100 mg/l Ni2+ adsorptions at pH 5.5, with concentration and flow rates of 1.0 and 2.0 l/h, respectively.(c and d) Breakthrough curves for 100 mg/l Co2+ adsorptions at pH 5.5, with concentration and flow rates of 1.0 and 2.0 l/h, respectively.

Figure 6c

Figure 6d

For Ni2+, 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 Co2+, 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 Ni2+ and Co2+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 Co2+ was retained compared with Ni2+ 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 Ni2+ and Co2+ ions through the peat matrix, but reduced the relative amount of metals that were retained.

**TABLE 5.** Summary of the Estimated Bed Depth Service Time Parameters

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  Flow rate (l/h) | BVa(l) | BTb (t50) (h) | kc × 10-6(l/mg.h) | N0d × 104(mg/l) | AERe(g/l) | r2 |
|  1.0 160 153 18 3.56 0.69 0.79Ni2+ 2.0 63 34 132 0.09 1.75 0.88 |
|  1.0 51 56 106 0.25 2.16 0.93Co2+ 2.0 25 10 472 0.11 4.4 0.79 |

aBed volume (BV) at breakthrough. bBed time (BT) at breakthrough. cAdsorption rate constant. dAdsorption capacity. eAdsorbent exhaustion rate (AER).

At greater flow rates, the adsorption capacity of the peat bed (N0) decreased for both metals and more so for Ni2+. This could be related to (i) the attainment of equilibrium or (ii) the type of uptake mechanism. At lower flow rates, longer contact times between the peat matrix and the metal ions were achieved before equilibrium was attained and this led to a slower AER. On the other hand, variation in the uptake mechanism and products formation could also have contributed to the difference in flow rates. Less Co2+ was sorbed despite the promising nature of the initial Co2+ uptake. The products that were formed during the peat–Co2+ 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 Ni2+ while uptake by ion exchange could have been insignificant with Co2+ 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 Ni2+ than Co2+ was desorbed and more Ni2+ was desorbed at 1.0 M HCl than at 0.1 M HCl. Desorption would be more favoured 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 Co2+. However, due to the poly-functional group nature of the peat, ion exchange at the less active sites by the Ni2+ could have occurred in addition to complexation, and therefore, greater Ni2+ was adsorbed compared with Co2+ in the applied uptake conditions.

**TABLE 6.** Ni2+ and Co2+ 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

|  |  |
| --- | --- |
|  Ni2+ (mg/kg) |  Co2+ (mg/kg) |
| Initial adsorption 25.7 24.2After desorption with distilled water 25.7 24.2After desorption with 0.1 M HCl 24.4 24.1After desorption with 1.0 M HCl 4.8 24.1 |

**CONCLUSIONS**

Retention of Ni2+ and Co2+ 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. Ni2+ could have been removed by a combination of ion exchange and complexation, while Co2+ may have been retained only by complexation. Co2+ could have been expected to be adsorbed more due to its larger ionic radii and lower heat of hydration (smaller hydrated radii) compared with Ni2+, but a single reaction (complexation) could have been the reason for the lower removal level compared with Ni2+. Products formed by the peat–Co2+ 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 with a flow rate of 1.0 l/h as indicated by the column capacity for Co2+. 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 Ni2+ and Co2+ resulting in the observed adsorption trends in the column. Overall, the saprist peat is a potential adsorbent for the retention of Ni2+ and Co2+ ions.

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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