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Heavy Metal Removal from Aqueous Solution by Opuntia: A Natural Polyelectrolyte

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ABSTRACT

The removal of toxic heavy metal ions from wastewaters is of great importance from an environmental viewpoint. Different agricultural residues were used for the removal heavy metals from aqueous solutions. In this study, the removal of Chromium and Nickel ions by Opuntia, a natural polyelectrolyte was investigated. The working concentration of metals used in this study was 10 mg/L. The different Opuntia polyelectrolyte concentrations used in this study was 5%, 10% and 20% (v/v). The equilibrium time needed for maximum metal removal was 18 h. The removal of both the ions was found to be Opuntia polyelectrolyte concentration and agitation speed dependent. 10%(v/v) Opuntia ficus indica polyelectrolyte and 150 rpm at 30^0 C are optimum conditions for removal of Cr and Ni ions from aqueous solution. Metal ion concentrations were determined by Spectrophotometer. The maximum removal of Cr and Ni by Opuntia polyelectrolyte after 18 h of equilibrium was 68% and 88.4% resp.

Key words: *Opuntia ficus indica*, polyelectrolyte, Chromium, Nickel, Spectrophotometer.

INTRODUCTION

Heavy metal ions have become an ecotoxicological hazard of prime interest and increasing significance, because of their accumulation in living organisms. Chromium and its compounds are toxic metals introduced into natural water from a variety of industrial wastes. The major sources are from leather tanning, textile dyeing, electroplating and metal finishing industries which cause severe environmental and public health problems. The hexavalent form of chromium is considered to be a group “A” human carcinogen because of its mutagenic and carcinogenic properties. It leads to liver damage, pulmonary congestion, edema and causes skin irritation, resulting in ulcer formation. Its concentration in industrial waste water ranges from 0.5 mg/L to 270,000 mg/L . The tolerance limit for the discharge of Cr(VI) into inland surface water is 0.1 mg/L and in potable water is 0.05 mg/L . A wide range of physical and chemical processes are available for the removal of Cr(VI) from waste water as electro-chemical precipitation, ultra-filtration, ion exchange, electro-dialysis, reverse osmosis, chemical precipitation and adsorption .

The major drawbacks with these processes are high cost, toxic sludge generation or incomplete metal removal (12).

Nickel is silvery-white. hard, malleable, and ductile metal. It is of the iron group and it takes on a high polish. It is a fairly good conductor of heat and electricity. In its familiar compounds nickel is bivalent, although it assumes other valences. It also forms a number of complex compounds. Most nickel compounds are blue or green. Nickel dissolves slowly in dilute acids but, like iron, becomes passive when treated with nitric acid. Finely divided nickel adsorbs hydrogen.

Although not recognized until the 1970s, nickel plays important roles in the biology of microorganisms and plants. In fact urease (an enzyme which assists in the hydrolysis of urea) contains nickel. The NiFe-hydrogenases contain nickel in addition to iron-sulfur clusters. Such [NiFe]-hydrogenases characteristically oxidise H_2. A nickel-tetrapyrrole coenzyme, F430, is present in the methyl coenzyme M reductase which powers methanogenic archaea. One of the carbon monoxide dehydrogenase enzymes consists of an Fe-Ni-S cluster (7). Other nickel-containing enzymes include a class of superoxide dismutase (20) and aglyoxalase(21). Exposure to nickel metal and soluble compounds should not exceed 0.05 mg/cm^3 in nickel equivalents per 40-hour work week. Nickel sulfide fume and dust is believed to be carcinogenic, and various other nickel compounds may be as well (9 , 3). Nickel carbonyl, $[Ni(CO)_4]$, is an extremely toxic gas.

Metal-ion removal from aqueous solutions is a major industrial activity covering processes ranging from water softening to hydrometallurgical recovery from ores to detoxification of waste-waters and contaminated natural waters. Attaching metal-ion-specific ligands or chelators to solid polymers is an important approach to solving such problems and has received considerable attention over the past 20 years (22). Note: the terms "chelate" and "multidentate" refer to a ligand that contains two or more binding sites for coordination with a metal ion. Solid chelating polymers are the basis of a number of successful selective industrial separations, including the removal of calcium to part-per-billion levels from brine and the removal of radioactive cesium from alkaline waste waters (8).

The application of water-soluble chelating polymers (WSCP) (often termed polyelectrolytes) in combination with ultrafiltration for the treatment of waste-waters contaminated with low levels of RCRA metal ions is a relatively new separation technology, which is being developed and implemented at Los Alamos National Laboratory **(**16-19**)**. It is possible to selectively retain certain metal ions on water-soluble polymers, concentrate the metal-loaded polymer by ultra filtration, and then recover the metals using either acid elution or electrode position processes. The basis for metal-ion separation involves the retention of metal ions bound to the chelating groups on the water-soluble polymer, while smaller unbound species and water pass freely through the ultra filtration membrane **(**5, 6**)**.

Different agriculture residues were used for heavy metal removal (11, 13). *Opuntia,* is another source of viscous natural polyelectrolyte bearing negative surface charges (4).

We have chosen the water-soluble polymer or polyelectrolyte approach to remove the chromium and nickel from the aqueous solution. The approach to and results of our methods-development studies are presented in this paper.

MATERIALS AND METHODS

The extraction of *Opuntia* natural polyelectrolytes:

The cactus waste was cut in small pieces, and approximately 132 g of cactus pieces with 750 ml of tap water were transferred to a 2 l flask and stirred for 30 min. The extraction of viscous natural polyelectrolyte (soluble sugars) was performed by decantation and keeping at 4ºC until use (15).

Treatment with natural polyelectrolytes:

In 250 ml Erlenmeyer flask with 50 ml metal aqueous solution were treated with 10% (v/v) natural polyelectrolyte and a control flask kept untreated, incubated at 30ºC and 150 rpm for 18 h.

Determination of heavy metal concentration in the filtrate:

Following metal treatment, culture filtrates were taken at certain intervals, centrifuged at 10,000 rpm for 5 min and the clear supernatant liquids was used to determine heavy metals ions concentrations by UV Double Beam Spectrophotometer.

RESULTS AND DISCUSSION

Effect of agitation speed on heavy metal settlement by *Opuntia* extract:

Table 1 and Fig. 1, indicates that, the optimum agitation is 150 rpm for settlement of heavy metals in biosorption media as percentage removal of Cr 51.70% and Ni 60.30% on using 15% (v/v) *Opuntia* natural polyelectrolyte under the same incubation conditions. Correspondingly, as demonstrated by **(**1), 150 rpm is the optimum agitation for settlement of heavy metals in biosorption media as (%) removal of Cu(II) 32.13., 12.54 Cd(II) ,Fe(III) 22.51(mg/l) on using 20% (v/v) *Opuntia* natural polyelectrolyte.

Table 1.Effect of agitation speed on removal capacity of *Opuntia* polyelectrolyte.

Agitation speed (rpm)	Cr	Standard deviation	Ni	Standard deviation
50	3.08	0.131	3.56	0.01
100	4.633333	0.02	5.27	0.04
150	5.17	0.017	6.03	0.02
200	5.146667	0.011	6.03	0.017

According to (15), this is may be due to mucilage hydrophilic character, several hydrogen bonds are formed between polyelectrolyte and water molecules. This association tends to occupy larger surface area causing its very high viscosity.

This results will be supported by La Mer and Healy (1963) and Nozaki, *et al.* (1993) who Suggested that natural polyelectrolyte have been used as auxiliary of flocculation and coagulation in wastewater treatment and water cleaning process (10, 14).

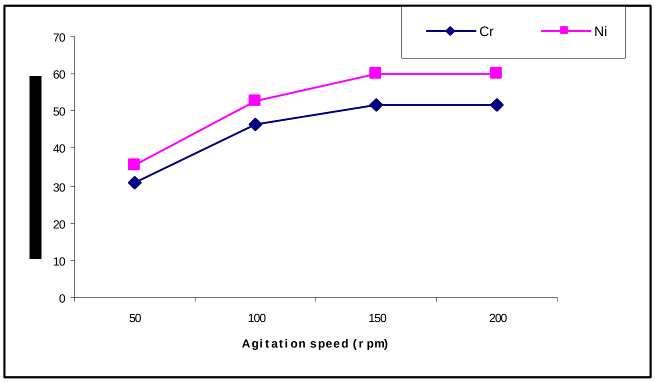

Figure 1. Effect of agitation speed on percentage removal of metals.

Effect of natural electrolyte concentrations on heavy metal settlement:

Treatment capacity of proposed process will depend on polyelectrolyte concentration. Table 2 and Fig. 2 display the maximum removal of Cr and Ni by Opuntia polyelectrolyte after 18 h of equilibrium was 68% and 88.4% resp. It also shows the variation in removal of chromium and nickel from the aqueous solution. It shows when the polyelectrolyte concentration increases from 10% to 20% (v/v), the removal of both the metals decreases. This result was supported by (Dorra et. al, 2009) (2).

(Olivera et al. 2001), revealed that the flocculation process induced by anionic polyelectrolyte such as the natural polyelectrolyte extracted from *Opuntia ficus indica*. The positive metals ion serves to form a bridge among the anionic polyelectrolyte and negatively charged functional groups on the colloidal particle surface. Cactus mucilage is a neutral mixture of approximately 55 high-molecular weight sugar residues composed basically of arabinose, galactose, rhamnose, xylose, and galacturonic acid. This natural product was characterized for its use as a flocculating agent (15).

Table 2. Effect of *Opuntia* polyelectrolyte concentrations on removal of heavy metals.

Polyelectrolyte conc. %(v/v)	Cr	Standard deviation	Ni	Standard deviation
5	3.82	0.015	4.213333	0.015
10	6.66	0.23	8.84	0.03
15	6.2	0.1	7.97	0.036
20	5.42	0.011	6.4	0.173

Table2 showed that 10%, v/v of mucilage provided the optimal effectiveness for metals removal in biosorption media. Figure 2 also, suggested that *Opuntia* mucilage proved the feasibility of applying mucilage as a method for heavy metals removal as a natural flocculating agent, as covalent bonds in vector compounds, or on cell cross-linking, that are innovative, environmentally benign, and cost effective.

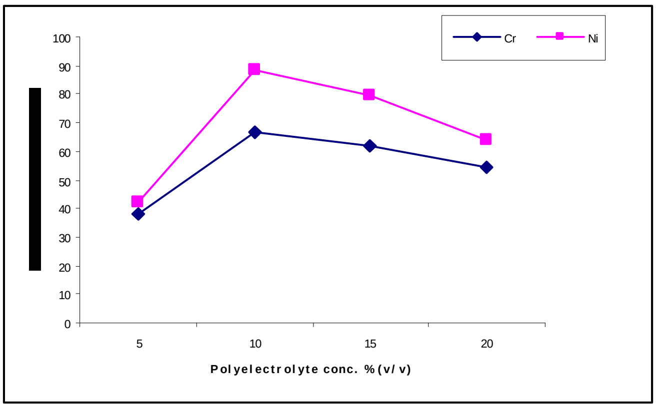

Figure 2. Effect of polyelectrolyte concentrations on percentage removal of metals.

CONCLUSION

Finally, the use of this type of green chemistry shows *Opuntia* mucilage as a resource for achieving potable water, as the use of natural eco-friendly agents in the treatment of drinking water is rapidly gaining interest due to their inherently renewable character and low toxicity. As a gum-like substance, cactus mucilage, which shows excellent flocculating abilities, is an economically viable alternative for low-income communities.

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