



International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Special Issue 1, March 2017

Characterization and Adsorption Mechanism OF Cu^{2+} , Zn^{2+} , Hg^{2+} , and Pb^{2+} Removal by PFR Resin Blended With Low Cost Carbons in Polluted Water

M. Meenakshisundaram*, K. Indra, P. Mithuirulan, N. Kannan

Center of Research and Post Department of Chemistry, Ayya Nadar Janaki Ammal College, Sivakasi,
Tamil Nadu, India

ABSTRACT: In the present study shows the removal of some heavy metal ions from aqueous solutions using Phenol formaldehyde resin (PFR) condensate with two different sulphonated activated charcoals like Gossypium barbadense carbon (GBSC) and Cocos nucifera carbon (GNSC). The prepared PFR and its condensates were characterized by FT-IR spectroscopy. The metal ions removals were studied by the column type experiment. Based on the cation exchange capacity of the metal ions on the PFR – condensates possess good CEC as like the pure PFR and then SCs.

KEYWORDS : Phenol formaldehyde resin (PFR), Gossypium barbadense carbon (GBSC), Cocos nucifera carbon (GNSC) and cation exchange capacity(CEC).

I. INTRODUCTION

The rapid industrialization and urbanization has resulted in the deterioration of water, air and land quality. Natural waters were contaminated with several heavy metals arising from mining wastes and industrial discharges. The heavy metals were of special concern because they were non- degradable and therefore persistent. These metals were toxic in both their chemically combined forms as well as in low concentration in the environment can prove to be harmful to human health.

The removal, separation and recovery of heavy metal ions from industrial wastewater have been a significant concern in all industrial branches owing to economic and environmental factors. Various separation – preconcentration techniques like solvent extraction ^[1], electro-deposition ^[2], coprecipitation ^[3], cloud point extraction ^[4], membrane filtration ^[5] and solid phase extraction (SPE) ^[6,7] were used for that purpose.

Until now, several kinds of sorbents, such as Amberlite XAD resins, activated carbon, ion exchange resins, chelating resins and various polymers have been used as solid phase material ^[8]. Ion exchange now is a well established technology, particularly in water purification and the concentration and removal of hazardous substances at very low concentrations in chemical process industries ^[9].

Ion exchange using polymeric resins has been used successfully to recover heavy metals from waste waters and process streams ^[10-14]. Many studies on the removal of metal ions by ion exchange resins have been conducted ^[10, 12, 15-25]. It has been reported that ion exchange is able to overcome some of the problems encountered in other techniques. The aim of the present work was to study and model the removal of heavy metal ions (Cu^{2+} , Zn^{2+} , Hg^{2+} , and Pb^{2+}) from aqueous solutions (obtained from agricultural waste) using PFR and its condensates (PFR-GBSC, and PFR-GNSC) and its pure carbons (GBSC, GNSC) in fixed bed columns.



International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Special Issue 1, March 2017

II. EXPERIMENTAL PROCEDURE

2.1. Apparatus

A SHIMADZU FT-IR spectro-photometer by using KBr pellets was used to characterize the PFR, PFR-condensates and pure sulphonated carbons were recorded. To sieve the samples, Jayant Sieves (India) was used.

2.2. Material and method

The raw/plant material used in the present study was Gossypium barbadense sulphonated carbon (GBSC) and Cocos nucifera sulphonated carbon (GNSC). These were the plant material freely available in Tamil nadu, India. Phenol and Formaldehyde used were of Fischer reagents. AR grade of conc. Sulphuric acid was used. The plant materials were locally collected, cleaned, dried and cut into small pieces of about 0.5 cm length. The other chemicals and reagents were of chemically pure grade (Anala R) procured from SD fine chemicals, India.

2.2.1. Preparation of sulphonated carbon

GBSC/GNSC plant material (500g) was carbonized and sulphonated by concentrated sulphuric acid (500ml) and kept at room temperature ($30 \pm 1^\circ \text{C}$) for 24 hours and heated at 90°C in a hot air – oven for 6 hours. It was then cooled, washed with distilled water several times and finally washed, rinsed with double distilled (DD) water in order to remove excess free acid (tested with BaCl_2 solution) and dried at 70°C for 12 hours. It was then labeled as GBSC/GNSC [26].

2.2.2. Preparation of Phenol- Formaldehyde Resin and condensates

Concentrated sulphuric acid (12.5 ml) was slowly added to phenol (10ml) in drop-wise with constant stirring by placing it in an ice-bath at $0-5^\circ \text{C}$. The mixture was heated at 70°C for 3 hours in a hot air-oven, then cooled immediately in ice and kept over night. It was then polymerized with formaldehyde solution (11.5ml) at 80°C and the product was cured in a hot air-oven for 8 hours. A brown coloured chunky solid mass was obtained. It was then ground, washed with distilled water and finally with DD water to remove free acid, dried, sieved (210-300 micron size) using Jayant Sieves (India) and preserved for characterization. It was labeled as PFR [27].

A known amount of phenol was sulphonated with concentrated sulphuric acid by the above method to produce phenolsulphonic acid. Then GBSC/GNSC was mixed with various % (w/w) of sulphonated carbon in the blend as 10,20,30,40 and 50 respectively. It was shown in table 2.2.2.1 & 2.2.2.2.

Table 2.2.2.1. Amount of reagent used and yield of PFR, condensates (GB1-GB5) prepared by blending of PFR with various % (w/w) of GBSC

Sample	% of GBSC in IER	PhOH (ml)	HCHO (ml)	H_2SO_4 (ml)	GNSC (g)	Yield (g)	% of GBSC in IER
PFR	0	10	11.5	12.5	0	15.5	0
GB1	10	10	11.5	12.5	1.72	18.23	17.22
GB 2	20	10	11.5	12.5	3.87	20.86	19.35
GB 3	30	10	11.5	12.5	6.64	24.32	22.23
GB 4	40	10	11.5	12.5	10.33	27.04	25.82
GB 5	50	10	11.5	12.5	15.5	34.06	31.00
GBSC	100	10	11.5	12.5	-	-	100



International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Special Issue 1, March 2017

Table 2.2.2.2. Amount of reagent used and yield of PFR, condensates (GN1-GN5) prepared by blending of PFR with various % (w/w) of GNSC

Sample	% of GNSC in IER	PhOH (ml)	HCHO (ml)	H ₂ SO ₄ (ml)	GNSC (g)	Yield (g)	% of GNSC in IER
PFR	0	10	11.5	12.5	0	15.5	0
GN1	10	10	11.5	12.5	1.72	18.23	17.22
GN2	20	10	11.5	12.5	3.87	19.94	19.35
GN3	30	10	11.5	12.5	6.64	23.86	22.23
GN4	40	10	11.5	12.5	10.33	26.07	25.82
GN5	50	10	11.5	12.5	15.5	33.98	31.00
GNSC	100	10	11.5	12.5	-	-	100

III. RESULTS AND DISCUSSION

3.1. The characterization by FT-IR Spectroscopy

Table 3.1. FTIR Spectral data of PFR, PFR - condensate with 20% (w/w) of GBSC/GNSC and pure GBSC/GNSC

Group	Pure PFR	Condensate with 20% of (w/w) GBSC	Condensate with 20% (w/w) GNSC	Pure GBSC	Pure GNSC
S=O str.	1122.49	1122.49	1122.49	1122.49	1105.14
SO ₂ sym. Str	1193.85	1193.85	1193.85	1193.85	1193.85
C-S str.	599.82	599.82	599.82	599.82	599.82
Bonded -OH str.	3427.27	3415.70	3440.77	3415.70	3427
C-C str.	1635.52	1622.75	1628.75	1622.75	1628.75

FT-IR spectral studies were used to confirm the stretching frequencies of various functional groups and to identify the ion exchangeable group present in IER. The appearance of absorption bands at 1100-1137 Cm^{-1} (S=O str.) 1190-1200 Cm^{-1} (SO₂ sym. Str.) and 575-600 Cm^{-1} (C-S str.) in PFR (pure resin), condensate blended with 20% (w/w) GBSC(GB2)/GNSC(GN2) and pure GBSC/GNSC confirm the presence of sulphonic acid group (Fig. 3.1.1. and 3.1.2.). The relevant data were given in Table 3.1. The data also indicate the presence of phenolic groups.

The appearance of a broad absorption band at 3427-3459 Cm^{-1} (bonded -OH str.) indicates the presence of phenolic and sulphonic -OH (due to -SO₃H) groups in the samples. The appearance of an absorption band at 1621-1639 Cm^{-1} (C-C str.) confirms the presence of aromatic ring in PFR and its condensates obtained by 20%(w/w) blending of GBSC/GNSC with PFR and pure GBSC/GNSC.

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Special Issue 1, March 2017

Fig. 3.1.1. FTIR spectra of (A) PFR, (B) PFR blended with 20% (w/w) of GBSC (GB2) and (C) pure GBSC

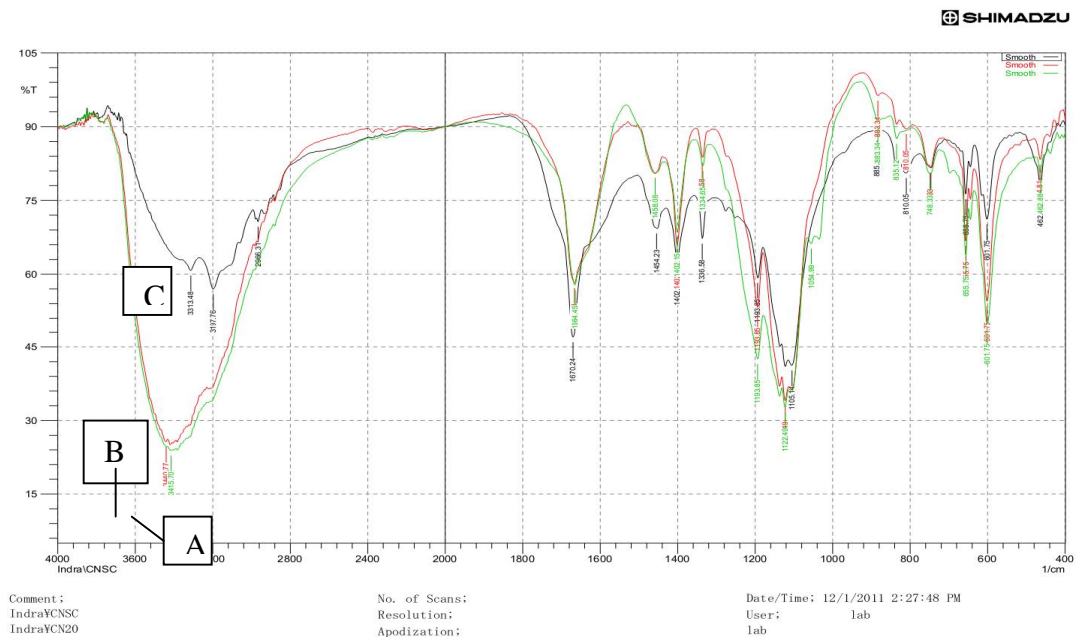
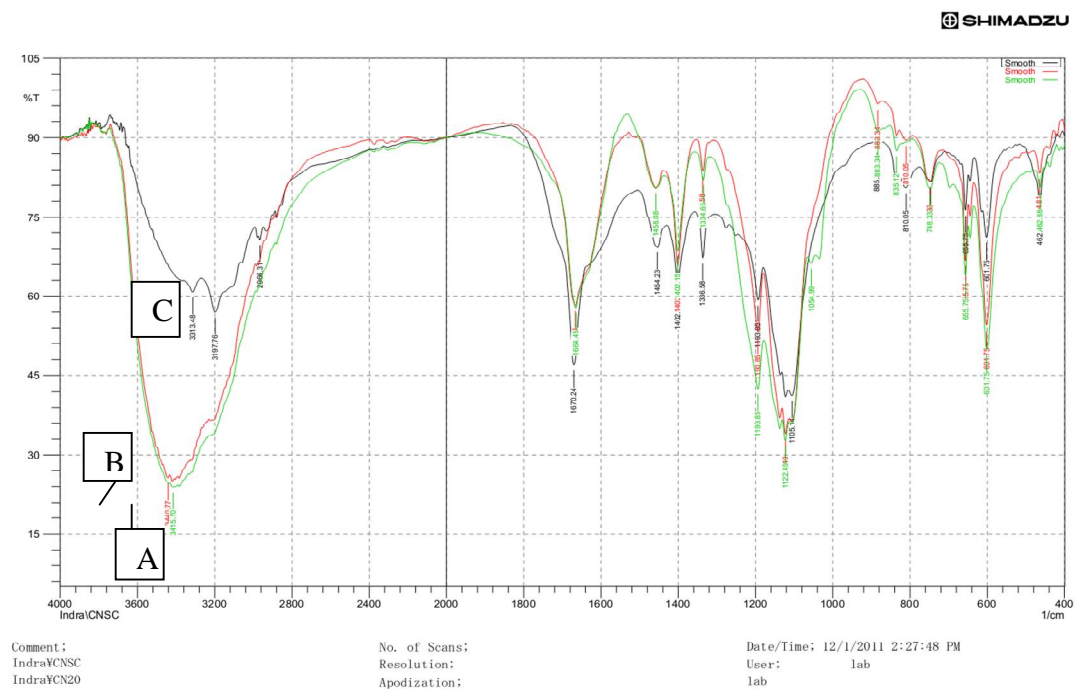


Fig. 3.1.2. FTIR spectra of (A) PFR, (B) PFR blended with 20% (w/w) of GN2 and (C) pure GN2





International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Special Issue 1, March 2017

3.2. Solubility of IER's

Solubility data indicates the chemical stability of IER's in various solvents. It reveals that PFR, condensates and GBSC/GNSC were practically insoluble in conc. H₂SO₄, HCl, HNO₃, CH₃COOH, CCl₃COOH, CH₃OH, C₂H₅OH, CH₃CHO, CHCl₃, CCl₄, CS₂, C₆H₆ and C₆H₅CH₃ except 20% (w/w) NaOH solution. Therefore, it may be concluded that PFR and the condensates were having high degree of cross-linking in the sample structure i.e., the basic polymeric unit has mostly high molecular weight fractions or at least the absence of very low weight fractions in it [28,29]. Hence, these condensates can be used as ion exchangers for treating non-aqueous effluents also [30]. At the same time the samples are partially soluble in 20% NaOH solution. This indicates the presence of phenolic groups in them. Hence, the industrial effluent having high alkalinity cannot be treated by these ion exchange materials. The insolubility of the IER's, even in the trichloroacetic acid express the rigidity i.e., high degree of cross-linking.

3.3. Absolute density

The absolute density (Table 3.3.1 and 3.3.2) values in both hydrated (in water) and dehydrated (in toluene) states decrease steadily from PFR (100% pure resin) to 50% (w/w) GBSC/GNSC in condensate and then finally to GBSC/GNSC (100% pure SC). This indicates that PFR and the condensates (GB1-GB5 & GN1-GN5) were more closely packed [26,31-37]. It was found that the absolute density of 100% GBSC/GNSC possess only 69.4% and 59.1% /55% and 59.9% of density of PFR in hydrated (wet) and dehydrated (dry) states, respectively. This indicates that GBSC/GNSC also has closely packed structure [38] similar to condensate.

Table 3.3.1 Physico – chemical properties of PFR, condensates prepared by blending PFR with GBSC and pure GBSC

Sample	% of GBSC in IER	Density		% of Gravimetric swelling	% of Attritional breaking
		Wet	Dry		
PFR	0	2.083	2.197	79.79	7
GB1	10	1.562	1.922	77.71	11
GB 2	20	1.388	1.2816	69.97	22
GB 3	30	1.25	0.9612	66.30	27
GB 4	40	1.041	0.809	51.29	32
GB 5	50	0.833	0.668	35.86	38
GBSC	100	0.694	0.591	27.35	42

Table 3.3.2 Physico – chemical properties of PFR, condensates prepared by blending PFR with GNSC and pure GNSC

Sample	% of GNSC in IER	Density		% of Gravimetric swelling	% of Attritional breaking
		Wet	Dry		
PFR	0	2.083	2.197	79.79	7
GN1	10	1.777	1.970	77.99	38
GN 2	20	1.333	1.522	72.90	48
GN 3	30	0.941	1.149	62.17	58
GN 4	40	0.695	0.985	54.39	62
GN 5	50	0.640	0.811	36.65	82
GNSC	100	0.551	0.599	27.81	83



International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Special Issue 1, March 2017

The values of density of condensates in dry and wet states depend upon the structure of the basic resin unit, its degree of cross-linking and ionic form^[39]. Hence, high density values were obtained for these IERs. Tables 3.3.1& 3.3.2 indicate the high degree of cross-linking, and hence the condensate resins were suitable for making columns for treating polar and non-polar effluents. Moreover, the wet and dry density values are close to each other, which indicate that the IER samples may be macro porous in nature. From the data given in Table 3.3.1& 3.3.2, it was clear that there was no considerable decrease in absolute density in both hydrated and dehydrated states up to 20% (w/w) blending of GBSC/GNSC with PFR. In the condensates, indicating that they also have similar closely packed structure with high degree of cross-linking and hence they are suitable for making ion exchange columns for polar and non-polar liquids of high density^[39].

3.4. Gravimetric swelling

The percentage of gravimetric swelling Table 3.3.1& 3.3.2, decreases from PFR to sulphonated carbon. Condensates have intermediate values of gravimetric swelling (%). It indicates that the values of gravimetric swelling (%) for PFR and condensates were not as high as compared to conventional gel type IER's, indicating rigidity in the matrix and therefore the pores of condensates were of non-gel type and macro reticular^[38]. SC's has a swelling capacity compared to that of PFR. This extremely low value of percentage gravimetric swelling may be due to certain rigidity in the resin. The blending of PFR with 20% (w/w) of GBSC/GNSC has the gravimetric swelling value as 69.9%/ 72.90% of that of PFR, thus decreasing 9.82% /6.89% of swelling compared to that of PFR (100% for pure resin).

3.5. Attritional Breaking

The values of attritional breaking (in %) presented in Table 3.3.1& 3.3.2 also present the stability of the resin which increase from PFR to GBSC/GNSC. Therefore, the mechanical stability was good up to blending of PFR with 20% (w/w) GBSC/GNSC. This observation also shows the possibility of formation of resin in the capillaries of the sulphonated carbon particles^[28], during the blending of cationic matrices (PFR) with GBSC/GNSC.

3.6. Batch exchange experiments

In the batch exchange experiments an aliquot of dry resin (2.0 g)/resin condensate/ SC of the aqueous solution containing 1000 ppm of each metal ion were placed in a column for 4-5 hours at a fixed temperature (303K). After equilibrium, the resin was separated and the concentrations of metals in the aqueous phase were analyzed by an ETDA.

3.7. Cation Exchange Capacity

Cation /column exchange capacity (CEC) or Ion exchange capacity (IEC) values given in upon the valency of the ions, the concentration of metal ion in the influent solution and the anionic part of the metal salt. Inter ionic forces of attraction between anions and cations, which also plays a vital role in deciding the CEC values of metal ions for a given metal salt solution^[40, 41]. It was found that CEC values of IERs obtained by blending of PFR with 20% (w/w) of GBSC/GNSC for various metal ions viz., Cu²⁺, Zn²⁺, Hg²⁺, and Pb²⁺. The relative ion exchange capacity (IEC) of individual metal ions depends upon the atomic radius or atomic number.

On comparing the CEC values of condensates with that of the CEC values of PFR taking it as 100% (Fig. 3.7.1. & 3.7.2.) it is found that blending of GBSC/GNSC with PFR decreases its CEC value (Table 3.7.1 and 3.7.2). Blending of PFR with 20% (w/w) GBSC(GB1-GB5)/GNSC(GN1-GN5) has CEC values 0.055%-0.32%/0.055-0.32% for the exchange of H⁺ ions with the Cu²⁺, Zn²⁺, Hg²⁺, and Pb²⁺ ions compared to that of PFR. This indicates that these condensates can partially replace commercial IER's in making the low-cost ion exchangers for industrial applications. From the CEC data given in Table 3.7.1 and 3.7.2, the cation exchange capacity of the samples for given metal ions was found to decrease in the following order:

For GBSC Cu²⁺>Zn²⁺>Pb²⁺>Hg²⁺
For GNSC Cu²⁺>Zn²⁺>Pb²⁺>Hg²⁺

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

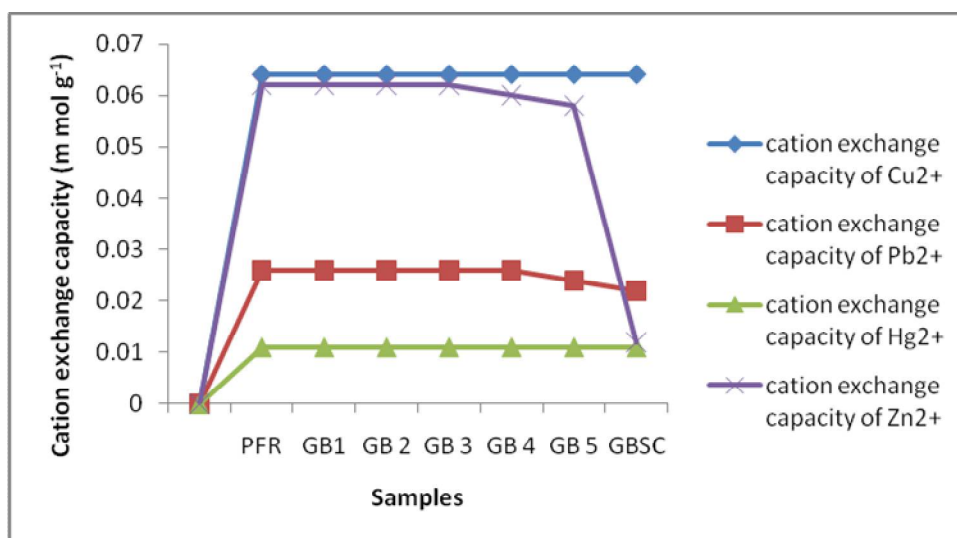
Vol. 6, Special Issue 1, March 2017

The selectivity order of metal ions i.e, orders of CEC value also depends upon the ionic potential and the hydrated atomic radius of the metal ions in solution. The order of exchange affinities of various metal ions is not unique to ion exchange system. Only under dilute conditions Hofmeister or lyotropic series is obeyed. But, under high concentration it is different. It is equally important to note that the relative behavior of these ions for other ionic phenomena do not obey the affinity order under the same condition^[42-44]. The observed order in the present study is different from that of the Hofmeister or lyotropic series. This may be due to the ionic strength of the metal ions, the internal structure of the polymeric matrix and also due to the selectivity of the metal ions.

Table 3.7.1 Cation exchange capacity of PFR, PFR – condensates and pure SC's

Sample	% of GBSC	Cation exchange capacity (m mol g ⁻¹)			
		Cu ²⁺	Pb ²⁺	Hg ²⁺	Zn ²⁺
PFR	0	0.064	0.026	0.011	0.062
GB1	10	0.064	0.026	0.011	0.062
GB 2	20	0.064	0.026	0.011	0.062
GB 3	30	0.064	0.026	0.011	0.062
GB 4	40	0.064	0.026	0.011	0.060
GB 5	50	0.064	0.024	0.011	0.058
GBSC	100	0.064	0.022	0.011	0.012

Fig. 3.7.1 Cation exchange capacity of PFR, PFR – condensates and pure SC's



International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

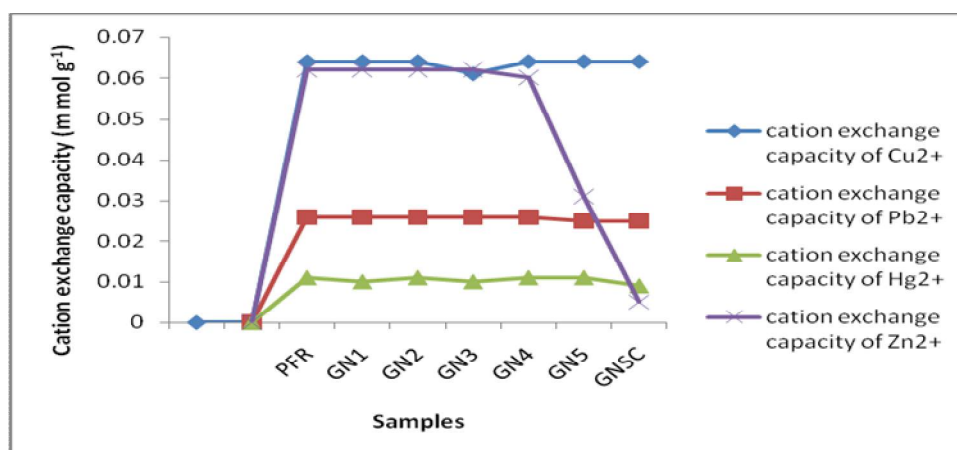
Website: www.ijareeie.com

Vol. 6, Special Issue 1, March 2017

Table 3.7.2. Cation exchange capacity of PFR, PFR – condensates and pure SC's

Sample	% of GNSC	Cation exchange capacity (m mol g ⁻¹)			
		Cu ²⁺	Pb ²⁺	Hg ²⁺	Zn ²⁺
PFR	0	0.064	0.026	0.011	0.062
GN1	10	0.064	0.026	0.01	0.062
GN2	20	0.064	0.026	0.011	0.062
GN3	30	0.061	0.026	0.01	0.062
GN4	40	0.064	0.026	0.011	0.060
GN5	50	0.064	0.025	0.011	0.031
GNSC	100	0.064	0.025	0.009	0.005

Fig. 3.7.2. Cation exchange capacity of PFR, PFR – condensates and pure SC's



3.8. Effect of stability of IERs on CEC

The chemical stability of PFR and condensates are tested by boiling the samples with 20 % (w/w) NaOH, benzene and water for an hour and then heated the samples for 12h^[33]. The resulting water boiled, benzene boiled and alkali boiled samples possess CEC value almost similar that of the parent/untreated resins. This indicates that these samples were chemically stable (Table 3.9.1); thermally stable up to 100°C. The CEC values of the thermally treated resins were found to be almost similar to the untreated IER/ parent resin (Table 3.9.1).

Table 3.8.1 Chemical and thermal effect on CEC of PFR and its condensates (GB2 and GN2) for exchange with 1000ppm Zn²⁺ ions at 303K

Reagents	Cation exchange capacity (m mol g ⁻¹)		
	PFR	GB2	GN2
Original capacity	0.062	0.058	0.061
Heated in oven for 12 h	0.062	0.055	0.060
20 ml of Benzene	0.060	0.055	0.060
20 ml of 20% NaOH	0.062	0.062	0.062
20 ml of Boiling H ₂ O	0.061	0.058	0.061



International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Special Issue 1, March 2017

3.9. Effect of particle size on CEC

CEC data given in Table 3.10.1, indicate that the resin with particle size of <210m was coarse as to cause low ion exchange capacity compared to the resin with 210-300m and >300m particle size of IER. Hence, for the effective IER, the particle size should be maintained and the recommended particle size is 210-300m.

Table 3.9.1 Effect of particle size on CEC

Sample	Particle size (micron size)	Cation exchange capacity (m mol g ⁻¹)	
		Pb ²⁺	Zn ²⁺
PFR	<210	0.026	0.062
	210-300	0.026	0.062
	>300	0.026	0.062
GB2	<210	0.022	0.061
	210-300	0.026	0.062
	>300	0.026	0.062
GN2	<210	0.025	0.062
	210-300	0.026	0.062
	>300	0.026	0.062

IV. CONCLUSION

It was concluded from the results of the present study that the PFR sample could be blended with 20% (w/w) of GBSC/GNSC, without affecting its physico-chemical, spectral and thermal properties including CEC. Also the effect of particle size on CEC. CEC values of various metal ions of 20% (w/w) GBSC/GNSC were very close to that of the PFR resin. Hence, the blending of PFR with 20% (w/w) of GBSC/GNSC will definitely lower the cost of IER. The cationic matrices blended in the 20% (w/w) of GBSC/GNSC could be used as low-cost IERs for water and wastewater treatment, especially for the removal of metal ions.

REFERENCES

1. L.H.J. Lajunen, A. Kubin, *Determination of trace amounts of molybdenum in plant tissue by solvent extraction-atomic absorption and direct-current plasma emission spectrometry*. Talanta 33 (1998) 265-670.
2. Z.C. Ansky, P. Rychlousky, Z. Petrova, J.P. Matousek, *A technique coupling the analyte electrodeposition spectrometry for analysis of samples with high NaCl contents*. Spectrochim. Acta 62B (2007) 250-257.
3. S. Saracoglu, M. Soylak, L. Elci, *Enrichment and separation of traces of cadmium, chromium, lead and manganese ions in urine by using magnesium hydroxide coprecipitation method*. Trace Elem, Electrolytes 18 (2001) 129-133.
4. Y. Ebihara, T. Shimizu, K. Jinno, N. Uehara, *Speciation of chromium (III) and chromium (VI) in river water by graphite furnace atomic absorption spectrometry after cloud dithiocarbamate*. Bunseki Kagaku 56(2007) 737-743.
5. A.V. Karatepe, M. Soylak, L. Eici, *Separation /preconcentration of Cu(II), Fe(III), Pb(III), Co(II) and Cr(III) in aqueous samples on cellulose nitrate membrane filter and their determination by atomic absorption spectrometry*. Anal. Lett. 35(2002) 1561-1574.
6. C.E. Dogan, G. Akcin, *Solid Phase extraction and determination of lead in water samples using silica gel homogeneously modified by thiosalicylic acid*. Anal. Lett. 40(2007) 2524-2543.
7. M. Soylak, L.Elci, M. Dogan, *Flame atomic absorption spectrometric determination of cadmium, cobalt, copper, lead and nickel in chemical grade potassium salts after an enrichment and separation procedure*. J. Trace Microprobe Tech. 17(1999) 149-156.
8. A. Cigdem, S. Bekts, *Preconcentration and determination of lead, cadmium and nickel from water samples using a polyethylene glycol dye immobilized on nickel from water samples using a polyethylene glycol dye immobilized on poly(hydroxyethylmethacrylate) micro spheres*. Anal. Sci. 22 (2006) 1025-1029.
9. E. Pehlivan, T. Altun, *The study of various parameters affecting the ion exchange of Cu²⁺, Zn²⁺, Ni²⁺, Cd²⁺ and Pb²⁺ from aqueous solution on Dowex 50W synthetic resin*. J. Hazard, Mater. B134 (2006) 149-156.
10. J. Yang, A. Renken, *Heavy metal adsorption to a chelating resin in a binary solid fluidized bed*. Chem. Eng. Technol. 23 (2000) 1007-1012.
11. K.S. Rao, D. Sarangi, P.K. Dash, G.R. Chaudhury, *Treatment of wastewater containing copper, zinc, nickel and cobalt using Duolite ES-467*. J. Chem. Technol. Biotechnol. 77(2002) 1107-1113.
12. F. Gode, E. Pohlivan, *A comparative study of two chelating exchange resins for the removal of chromium (III) from aqueous solution*. J. Hazard. Mater. B100 (2003) 231-243.
13. S.H. Lin, C.D. Kiang, *Chromic acid recovery from waste acid solution by an ion exchange process equilibrium and column ion exchange modeling*. Chem. Eng. J. 92 (2003) 193-199.



ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Special Issue 1, March 2017

14. A. Dabrowski, Z. Hubicki, P. Podkosocielny, E. Robens, *Selective removal of heavy metal ions from waters and industrial wastewaters by ion-exchange method*. Chemosphere 56(2004) 91-106.
15. S. Rengaraj, S.H. Moon, *Kinetics of adsorption of Co (II) removal from water and wastewater by ion exchange resins*. Water Res. 36 (2002) 1783-1793.
16. M.E. Malla, M.B. Alvarez, D.A. Batistani, *Evaluation of sorption and desorption characteristic of cadmium, lead and zinc on Amberlite IRC-718 iminodiacetic chelating ion exchanger*. Talanta 57 (2002) 277-287.
17. R.K. Sharma, N. Bhojak, S. Mittal, B.S. Gorg, *Chelating resins and their applications in the analysis of trace metal ions*. Microchem. J. 61 (1999) 94-114.
18. J. Lehto, A. Paajanen, R. Harjula, H. Leinonen, *Hydrolysis, H⁺/Na⁺ exchange by chelex 100 chelating resin*. React. Polym. 23(1994) 135- 140.
19. L.C. Lin, R.S. Juang, *Ion – exchange equilibria of Cu(II) and Zn(II) from aqueous solutions with chelex 100 and Amberlite IRC 748 resins*. Chem. Eng.J. 112 (2005) 211-218.
20. M.G. Rao, A.K. Gupta, E.S. Williams, A.A. Aguwa, *Sorption of heavy metal ions on chelex 100 resin*. AIChE Symp. Ser. 78(219) (1982)103-111.
21. C.N. Haas, V. Tare, *Application of ion exchangers to recovery of metals from semiconductor wastes*. React, Polym. 2 (1984) 61-70.
22. V. Tare, S.B. Karra, C.N. Haas, *Kinetics of metal removal by chelating resin from a complex synthetic wastewater*. Water, Air, Soil Pollute, 22 (1984) 429-439.
23. E. Korngold, N. Belayeu, L. Aronov, S. Titelman, *Influence of complexing agents on removal of metals from water by a cation exchanger*. Desalination 133 (2001) 83-88.
24. T.H. Karppinen, A.Y. Pentti, *Evaluation of selective ion exchange for nickel and cadmium uptake from the rinse water of a plating shop*. Sep. Sci. Technol. 35 (2000) 1619-1633.
25. F. Mijangos, M. Diaz, *Metal-proton equilibrium relations in a chelating iminodiacetic resin*. Ind. Chem.Eng. Res. 31 (1992) 2524-2532.
26. L.C. Lin, R.S. Juang, *Ion exchange kinetics of Cu(II) and Zn (II) from aqueous solution with two chelating resin.*, Chem. Eng. J. (2007) 205.
27. S. Juang, *Ion exchange equilibria of Cu(II) and Zn (II) from aqueous solution with chelex 100 and amberlite IRC 748 resins*. Chem. Eng. J. (2005)211.
28. N. Kannan, R.K. Seenivasan, *Synthesis and studies of phenol formaldehyde cationic exchangers blende with Eugenia jambolana lam carbon*. Desalination (2007) 216,77.
29. G. Cimino, A. Passerini, G. Toscano, *Removal of toxic cations and Cr (III) from aqueous solution by cadmium from aqueous solution by perlite*. J. Hazard. Mater. (2002) 94,291.
30. P. Kaewsarn, O. Yu, *Cadmium (II) removal from aqueous solution by pre-treated biomass of marine alga Padina sp*. Environ.pollut. (2001) 112,209.
31. E. Pehlivan, T. Altun, *Ion exchange of Pb²⁺, Cu²⁺, Zn²⁺, Cd²⁺ and Ni²⁺ ions from aqueous solution by Lewait CNP 80*.J.Hazard. Mater. (2007) 140,299.
32. A. Bakara, P.J. Hall, M.J. Heslop, *Melamine-Formaldehyde-NTA chelating resin: synthesis, characterization and application for copper (II) ion removal from synthetic waste water*. J.Hazard. Mater. (2007) 140,86.
33. W. Jei, Z.Q. Yiu, Gui, Z. Deep, *Removal of copper from cobalt sulfate electrolyte by ion exchange*. Transactions of Nonferrous metals society of china (2010) 20,1534.
34. L. Lin, R.S. Juang, *Ion exchange equilibria of Cu (II) and Zn (II) from aqueous solution with chelex 100 and amberlite IRC 748 resins*. Chem. Eng. J. (2005) 12,211.
35. R. Raghavan, C.V. Bhatt, *Comparative study of certain ion exchange resins for application in copper bearing process solution*. Hydrometallurgy, (1988) 50,169.
36. R. Juang, S.H.C. Kao, M.H. Theng, *Effect of Formaldehyde on Cu (II) Removal from synthetic complexed solutions by ion exchange*. Chemosphere. (2005) 59,1355.
37. J. Chun, R.S. Juang, *Ion exchange kinetics of Cu (II) from aqueous solutions with two chelating resins*. Chem. Eng. J. (2007) 132,205.
38. U. Garg, M.P. Kaur, G.K. Jawa, D. Sud, V.K. Garg, *Removal of cadmium (II) from aqueous solutions by adsorption on agricultural waste biomass*. J. Hazard. Mater. (2008) 154,1149.
39. P. Woodberry, G. Stevens, K. Northcott, I. Snape, S. Stark, *Field trial of ion-exchange resin columns for removal of metal contaminants, Thala , Valley Tip, Casey Station*. Antarctica J. Cold Reg. Sci. Tech. (2007) 48,105.
40. T. Shek, A. Ma, V.K.C. Lee, G. McKay, *Kinetics of zinc ions removal from effluents using ion exchange resin kinetics of zinc ions removal from effluents using ion exchange resin*. Chem. Eng. J.(2009)146,63.
41. C. Lasanta, I. Caro, L.Perez, *Theoretical model for ion exchange of iron (III) in chelationg resins: Application to metal ion removal from wine*. Chem. Eng. Sci. (2005) 167,3477.
42. T. Mathialagan, T. Viraraghavan, *Adsorption of cadmium from aqueous solution by perlite*. J.Hazard. Mater. (2002) 94,291.
43. G. Vazquez, J. Gonzalez-Alvarez, S. Freire, M. Lopez-Lorenzo, G. Antorrena, *Removal of cadmium and mercury ions from aqueous sloution by sorption on treated Pinaster bark: kinetic and isotherms*. Bioresour. Tech. (2002) 82,247.
44. H.K. An, B.Y. Park, D.S. Kim, *Crab shell for the removal of heavy metals from aqueous solution*. Water. Res. (2001) 35,3551.
45. C.W. Cheung, J.F. Porter, G. McKay, *Sorption kinetic analysis fort the removal of cadmium ions from effluents using bone charcoal*. Water. Res.(2001) 35,605.