

黃酸溶液으로부터 DOWEX G-26에 의한 구리의回收[†]

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Ion Exchange of Copper from Sulphate Effluent using DOWEX G-26[†]

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요 약

본 연구는 전자산업으로부터 발생하는 CMP 폐수와 유사한 0.3~0.5 mg/ml 구리를 함유한 조제 황산 용액으로부터 DOWEX G-26 양이온 교환 수지를 사용한 구리 회수 공정 개발에 관한 것이다. 합구리 황산 용액으로부터 구리를 회수하기 위해 용액의 pH, 수지의 사용량, 용액의 산 농도, 용액과 수지의 접촉시간 등을 변수로 다양한 조건에서의 회수 실험을 실시하였다. 평형 pH 2.5, 용액/수지의 비 100 mL/g 조건에서 14분의 접촉으로 99.99%의 구리가 흡착되었다. 구리의 흡착은 Langmuir isotherm을 따랐으며, 반응차수는 2차였다. 흡착된 구리는 묽은 황산에 의해 수지로부터 효과적으로 용리되었으며, 이로부터 구리 농축용액을 만들 수 있었다.

주제어 : 구리, 폐수, 흡착, 이온교환, DOWEX G-26

Abstract

In view of the increasing importance of the waste recycling to meet the strict environmental regulations, the present investigation reports an adsorption process using cationic exchanger DOWEX G-26 for the recovery of copper from the synthetic sulphate solutions containing copper 0.3 to 0.5 mg/ml, similar to the CMP waste effluent of electronic industry. Various process parameters viz. contact time, solution pH, resin dose, and A/R ratio for elution were investigated to recover copper from the effluents. Complete adsorption of copper from the solution was achieved at equilibrium pH 2.5 and aqueous / resin (A/R) ratio of 100 ml/g in 14 minutes contact time. The adsorption of copper on DOWEX G-26 resin was found to follow the Langmuir isotherm and second order reaction. The copper was eluted from loaded resin with dilute sulphuric acid to produce copper-enriched solution.

Key words : Copper, Effluent, Adsorption, Ion exchange, DOWEX G-26

1. Introduction

In electronics industries, copper is widely used as interconnecting material for the manufacturing of precious parts due to its good electrical and thermal con-

ductivity properties. During the manufacturing of electronics parts many processing steps viz. electroplating, etching, rinsing, and chemical and mechanical polishing (CMP) etc are used. CMP is a process used by semiconductor manufacturing industry to produce very smooth surfaces on each layer of a microchip by "sanding the microchip with water slurry of silica or alumina. In making microchips for computers, pagers,

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phones and other electronic equipment, a large volume of purified water is used for the dilution and rinsing steps of CMP process¹. Therefore, a large amount of copper bearing sulphate waste effluent is generated. The large amount of wastewater contains dissolved copper with low concentrations. The discharge of these waste wash water not only pollutes the environment but also causes health problem. The copper content in the solution varies and generally contained less than 1000 ppm¹. Most preferably, the copper content of the stream is less than about 500 ppm¹.

Electronic process waste is one of the major contributors to heavy metal pollution in surface water. The world health organisation (WHO) recommended a maximum acceptable concentration 1.5 mg/l of Cu(II) in water². Due to stringent pollution control regulations, the treatment of these effluents is essential before discharge to the environment. Generally, the metallic ions from effluents are removed by precipitation with lime/ caustic soda, sulphide etc. It consumes large quantity of chemicals to effectively decrease metals to acceptable pollution norms and generates sludge, which needs costly disposal procedure as landfill^{3,4}. Other treatment procedures for the removal and recovery of metals from solutions are evaporation, solvent extraction, ion exchange, reverse osmosis, membrane separation^{5,6}. The recycling of metallic value by evaporation of rinse water is highly energy intensive. The use of solvent extraction or solvent-based membrane process is also not effective for the separation of metals from dilute solutions as the loss of organic extractant in aqueous solution due to solubility and entrainment makes the process unattractive⁶. Ion exchange is a proven technique for the purification and separation of metals from different aqueous solutions using solid resins. Many studies on the adsorption of metal ions on ion exchange resins such as IR-120, Dowex A-1, Duolite GT-73⁷, IRN77⁸, and NKA-9⁹ were reported. Winterton et al. reported the use of DOWEX G-26 resin for the adsorption of copper from semiconductor processing sulphate streams¹⁰. An experimental study of heavy metal extraction from sludge was conducted by the researchers¹¹, using both Amberlite IRC-718 and Amberlite IR-120 resin. Ion exchange technique also finds major application in the purification of aqueous, extraction of acid from pickle

solution, extraction and separation of metals¹². The process is effective particularly for the removal of metallic ions from the dilute solutions (<0.5 g/L)¹³, where the precipitation is not efficient.

In view of the above, an Ion exchange (IX) process has been developed for the recovery of copper from the waste effluent of electronic industry. The experiments were carried out by using artificial solution similar to the waste solution of electronic industry. Various parameters viz. contact time, pH of the solution, resin dose, A/R ratio for elution etc have been studied to understand the adsorption phenomena, loading capacity of the resin and kinetics of adsorption of copper from the aqueous feed. Based on the studies a process is developed for the recovery of copper. The process could be simulated for the operation in continuous mode to enrich the copper concentration in the solution.

2. Materials and methods

2.1. Materials

Synthetic sulphate solutions (copper 0.3-0.5 mg/ml) similar to CMP waste effluent of electronic industry were prepared by dissolving copper sulphate salt in distilled water in required proportion. The chemical reagents such as copper sulphate, sulphuric acid, hydrochloric acid, sodium hydroxide etc were laboratory reagent (L.R.) grade. The cationic resin, DOWEX G-26 (Styrene di-vinylbenzene) supplied by M/s Sigma & Aldrich Co., USA was employed without further purification. Hydrochloric acid was used for the activation of the resin. The pH of the solution was adjusted by adding 1M sulphuric acid or 0.1M sodium hydroxide.

2.2. Methods

Wrist action shaking machine was used to carry out the batch experiments for the adsorption of copper from the effluent at atmospheric condition. Vertical column was used for the adsorption of copper from the effluent by taking weighed amount of resin maintaining the flow rate. The resin was thoroughly washed with distilled water and then adsorption tests were conducted under different concentration of copper maintaining a constant flow rate at room temperature. After the

adsorption of copper, the resin bed was washed with the distilled water and the loaded metal ions were eluted by passing dilute sulphuric acid. The aqueous raffinate and eluted solution were analysed for copper content by Atomic Absorption Spectrophotometer (A Analyst 400, Perkin Elmer, USA).

3. Results and discussion

Adsorption studies for the recovery of copper from the sulphate solution containing copper 0.3-0.5 mg/ml (similar to the waste stream generated in electronic industry)¹⁾ were carried out to get copper enriched solution using cationic resin DOWEX G-26. The process has been developed by optimising the various parameters viz. contact time, pH of the solution, resin dose, acid concentration of the elution solution etc.

3.1. Kinetics of adsorption

Kinetics of the adsorption of copper from the synthetic solution containing 0.3-0.5 mg/ml copper by resin DOWEX G-26 was studied at different time interval. The aqueous to resin (A/R) ratio was maintained to 100. The percentage extraction versus time curve is shown in Fig. 1. Adsorption of copper from the solu-

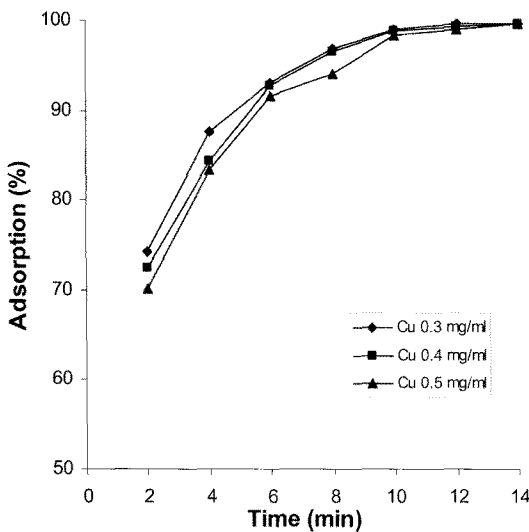


Fig. 1. Effect of contact time on the adsorption of copper using Dowex G-26 resin. (Aq. feed : Copper sulfate, volume = 20 ml, Resin : Dowex G-26, 0.2gram, A/R = 100)

tion was found to be increased with increase in contact time. At the experimental condition 2 minutes contact time and A/R ratio of 100, the percentage adsorption of copper was obtained 74.32, 72.5 and 70.19 for 0.3, 0.4, and 0.5 mg/ml copper in aqueous feed, respectively. The equilibrium percentage adsorption was found 99.7, 99.62 and 99.61 in contact time 14 minutes for 0.3, 0.4, and 0.5 mg/ml copper in aqueous feed, respectively. Based on the obtained data the order of reaction was determined. Kinetic expressions, namely pseudo-first and second order were used to fit the experimental data^{6,8,15)}.

The pseudo-first order rate expression of Lagergren^{8,9,15)} is generally described by the following equation:

$$dq/dt = k_1 (q_e - q) \tag{1}$$

where q_e and q are the amounts of copper(II) ion, (mg/g) adsorbed on the resin at equilibrium and at time t , respectively and k_1 is the rate constant, (min^{-1}). Integrating and applying the boundary conditions, $t = 0$ and $q = 0$ to $t = t$ and $q = q_e$ at maximum equilibrium adsorption, equation takes the form:

$$\log(q_e - q) = \log(q_e) - (k_1/2.303)t \tag{2}$$

The rate constant k_1 was obtained from the slope of linear plots $\log(q_e - q)$ against t for aqueous feed

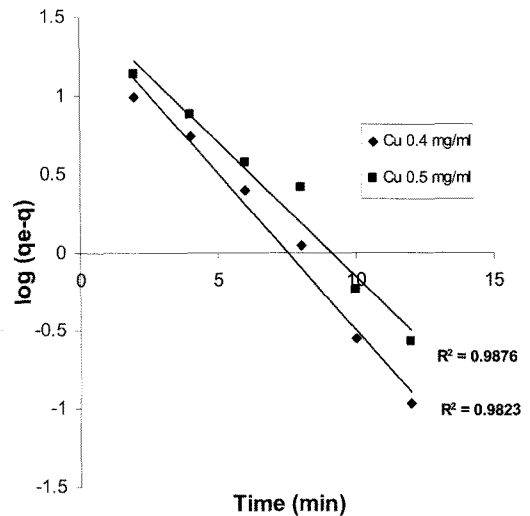


Fig. 2. First order reaction of copper using Dowex G-26 resin. (Aq. feed : Copper sulfate, volume = 20 ml, Resin : Dowex G-26, 0.2 gram, A/R = 100)

containing copper 0.4 and 0.5 mg/mL.

The pseudo-second-order rate reaction was also analysed by fitting the same data for copper adsorption and described by

$$dq/dt = k_2 (q_e - q)^2 \quad (3)$$

where, k_2 is the rate constant of pseudo-second order sorption (g/mg min). Integrating and applying boundary conditions $t=0$ and $q=0$ to $t=t$ and $q=q_e$, Eq. (3) can be presented in a linear form as:

$$t/q = (1/h) + (1/q_e)t \quad (4)$$

where $h = k_2 q_e^2$ is the initial sorption rate.

If second order kinetics is applicable, the plot of (t/q) against t of the above equation should give a linear relationship from which the constants k_2 could be determined for aqueous feed containing copper 0.4 and 0.5 mg/mL. For first order rate equation the plot between $\log(q_e - q)$ against t was made and presented as Fig. 2. Same data were checked for second order rate by plotting t/q against t and presented as Fig. 3. The rate constant k_1 and k_2 was also determined⁶⁾. The correlation coefficient for the second order kinetics was found 0.9977 and 0.9996 for the aq. feed solution 0.4 and 0.5 mg/ml of copper, which is comparatively greater than the value obtained for first order rate. Another thing is that the value of k_2 (Table 1) was found constant with a change in aqueous feed concentration 0.4 to 0.5 mg/ml copper. Thus, the copper adsorption by DOWEX G 26 follows the second order reaction rate similar to one reported by several

authors¹⁶⁻¹⁹⁾.

3.2. Effect of equilibrium pH on adsorption

The adsorption studies for the extraction of copper from the aqueous feed solutions containing 0.3–0.5 mg/ml copper were carried out with a fixed quantity of DOWEX G-26 resin. The results presented in Fig. 4 show that the adsorption of copper increases with the increase in equilibrium pH. At lower pH, the hydrogen ions compete with metal cations for the exchange site in the system. The metal cations are completely released under extreme acidic condition. The maximum

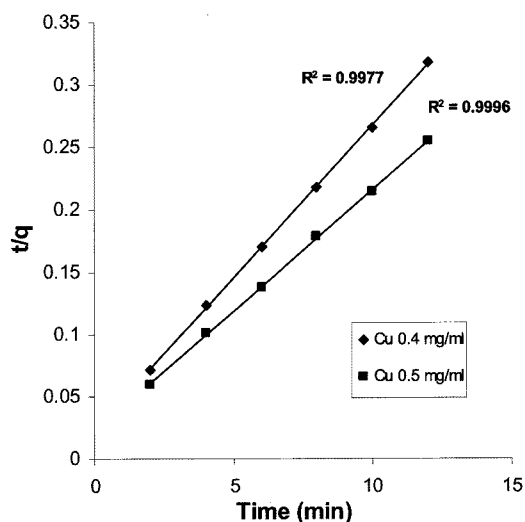


Fig. 3. Second order reaction of copper using Dowex G-26 resin. (Aq. feed : Copper sulfate, volume = 20 ml, Resin : Dowex G-26, 0.2gram, A/R = 100 Equilibrium pH = 2.48)

Table 1. Rate constants for first and second order reaction for copper adsorption on Dowex G-26 resin

S. No	Constants of kinetics expression		
	First order rate expression		
Co (mg/ml)	k_1 (min^{-1})	R^2	q_e (mg/g)
0.4	0.462	0.9823	32.59
0.5	0.395	0.9676	36.98
Second order rate expression			
Co (mg/ml)	k_2 (g/mg · min)	R^2	h (mg/g · min)
0.4	0.0253	0.9977	42.55
0.5	0.0173	0.9996	46.08

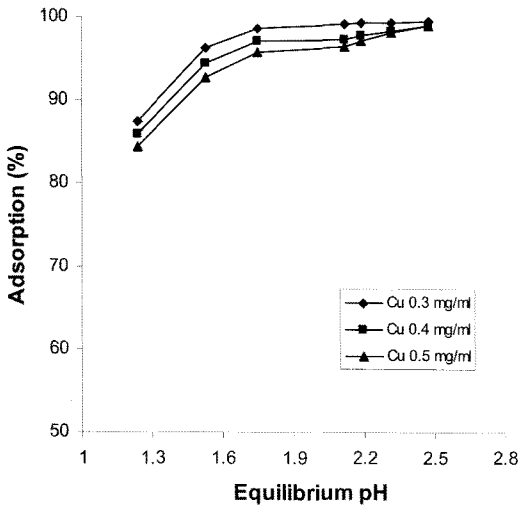


Fig. 4. Effect of pH on the adsorption of copper using Dowex G-26 resin. (Aq. feed : Copper sulfate, volume = 20 ml, Resin : Dowex G-26, 0.2gram, A/R = 100, Time 14 min)

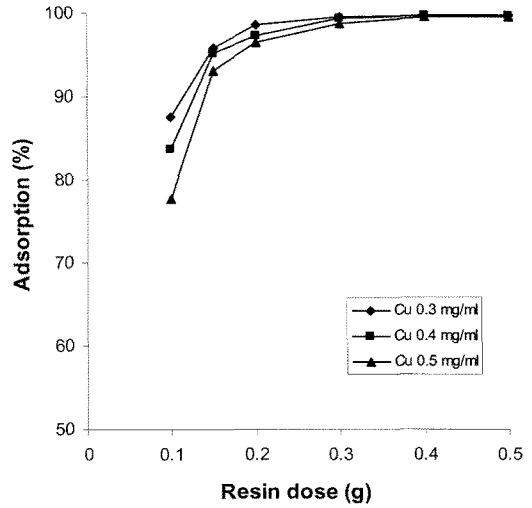


Fig. 5. Effect of resin dose on the adsorption of copper using Dowex G-26 resin. (Aq. feed : Copper sulfate, volume = 30 ml, Resin : Dowex G-26, Time 14 min)

adsorption of copper was obtained at equilibrium pH 2.5. The low adsorption at lower pH range is due to the high concentration and mobility of hydrogen ions, as hydrogen ions are preferentially adsorbed by resin in comparison to copper(II) ions⁶⁾.

3.3. Effect of resin dose

The effect of resin dose on adsorption of copper from the aqueous feed containing copper 0.3 to 0.5 mg/gram of resin at aq. feed pH = 5 was studied keeping 14 minutes retention time for mixing. The volume of solution was taken 30 ml and the resin dose was varied from 0.1 to 0.50 g (3.3 g to 16.66 g resin/L of aqueous solution). The results presented in Fig. 5 indicate adsorption of copper increases with the increase in resin dose as available sites or surface area increases with higher quantity of resin. An increase in the surface area of resin automatically enhances the rate of adsorption reaction.

3.4. Adsorption isotherm

Column studies were carried out to determine the loading capacity and adsorption isotherm for the adsorption of copper by the resin. Exactly, 0.5 grams of resin was taken in column and 50 ml of aqueous feed containing 0.3 and 0.4 mg/ml was contacted. The

repeated contact of the same resin was made with fresh aqueous feed to achieve equilibrium adsorption. In the first stage of contact, the adsorption of copper was found to be 39.49 mg/g resin from the aqueous feed of 0.4 mg/ml Cu at 2.5 pH and A/R of 100 ml/g. In subsequent stages of contacts, the extraction of copper from the aqueous feed decreased as the available site for the adsorption decreases in each contact. A cumulative adsorption in 7 stages was found to be 129.914 mg copper per gram of resin from the aqueous feed of 0.3 mg/ml copper at aqueous to resin ratio of 100. In other hand, cumulative adsorption in 6 stages was found to be 128.664 mg copper per gram of resin from the aqueous feed containing copper 0.4 mg/ml at A/R ratio of 100. Material balance was checked time to time, and the satisfactory material balance was obtained on comparing the results of copper adsorbed and eluted with sulphuric acid. The experimental equilibrium data for the adsorption of copper on DOWEX G-26 were analyzed using the Langmuir and Freundlich equations²⁰⁻²³⁾. Langmuir model assumes that the uptake of metal ions occurs on a homogeneous surface by monolayer adsorption without any interaction between adsorbed ions. The model can be represented in the linearised form as:

$$1/q = [(1/k_f \cdot q_m)(1/C_e)] + [1/q_m] \quad (5)$$

where, C_e = equilibrium concentration of metal in solution (mg/mL)

q = amount of metal adsorbed on the resin at equilibrium,

k_f = equilibrium constant related to the affinity of the binding sites for the metals or the Langmuir constant.

q_m = the resin capacity (maximum possible amount of metallic ion adsorbed per unit mass of adsorbent)

Whereas, Freundlich model assumes that the uptake or adsorption of metal ions occurs on a heterogeneous surface by monolayer adsorption. The model is described by the following equation:

$$q = k_f \cdot (C_e)^{1/n} \quad (6)$$

$$\log(q) = (1/n) \log(C_e) + \log(k_f) \quad (7)$$

The common terms in above equation are described in Langmuir expression, and k_f and n are Freundlich constants that can be related to the adsorption capacity and adsorption intensity, respectively. The plots ' $(1/C_e)$ vs $(1/q)$ ' and ' $\log(C_e)$ vs $\log(q)$ ' were evaluated to validate the Langmuir and Freundlich isotherms, respectively for the aqueous feed containing copper 0.3 and 0.4 mg/ml. Where, C_e is the equilibrium concentration of metal in solution and q is the amount of metal adsorbed on the resin at equilibrium. The data are presented in Table 2. The data supports the Langmuir adsorption isotherm as R^2 values is close to unity and k value is also more constant. The langmuir isotherm is suitable for our data and presented as Fig. 6.

3.5. Determination of breakthrough curve

In a column process, the breakthrough takes place when the concentration of the counter ion in the effluent begins to increase predominantly until it

finally reaches the same concentration of aqueous feed. After this point no more ion exchange takes place. The breakthrough point is considered as the time of completion of the adsorption cycle in industrial applications. In simple cases, analytical equations relating concentration and time are obtainable. In these experiments, resin was packed in the column; bed volume of resin was 2.3 ml. Fig. 7 showed that copper broke through at around 80 BV for copper concentration 0.39 mg/ml and at around 60 BV for copper concentration 0.475 mg/ml. The ratio C_e/C_o increased rapidly after 80 BV because the active sites on the resin were decreased. Copper removal decreased with increasing copper concentration in waste water. Table 3 expressed the values of breakthrough capacity and adsorption capacity. At flow rate 0.88 and 1.15 ml/min keeping the bed volume 2.3 ml, the experiments were carried out by passing CuSO_4 (0.39 mg/ml Cu) solution

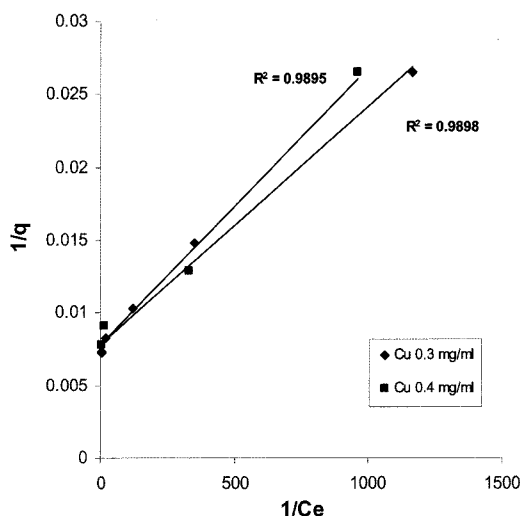


Fig. 6. Langmuir isotherm for copper using Dowex G-26 resin. (Aq. feed : Copper sulfate, volume = 50 ml, Resin : Dowex G-26, 0.5 gram, A/R = 100, Initial pH = 5.0)

Table 2. Constants and correlation coefficients for Langmuir and Freundlich Isotherm for adsorption of copper on Dowex G-26 resin

Solution Concentration (mg/ml)	Freundlich isotherm			Langmuir isotherm		
	n	k_f	R^2	q_m (mg/g)	k_1	R^2
0.3	4.286	238.616	0.9003	128.256	390	0.9898
0.4	5.537	166.494	0.8605	126.205	395	0.9895

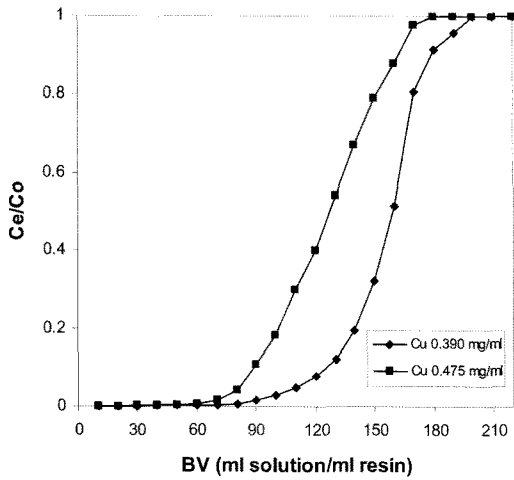


Fig. 7. Breakthrough curves of Dowex G-26 resin for copper adsorption. (Copper sulfate solution, Dowex G-26 resin, BV = 2.3 ml, Flow rate: 0.88 ml/min)

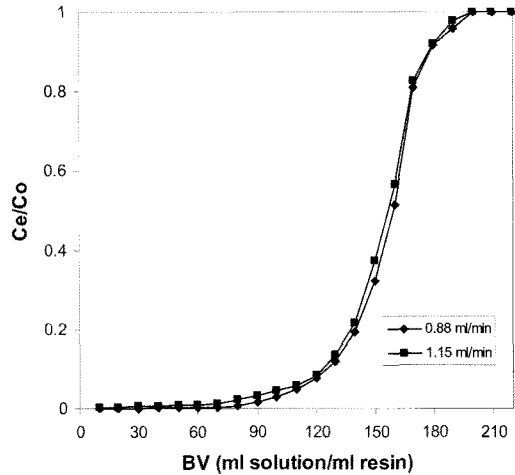


Fig. 8. Effect of flow rate on breakthrough capacity of Dowex G-26 resin. (Copper sulfate solution 0.39 mg/ml, Dowex G-26 resin, BV = 2.3 ml, Flow rate: 0.88 ml/min)

Table 3. Column performance of Dowex G-26 resin at different copper concentration

Copper concentration (mg/ml)	Breakthrough capacity (mg Cu/ml resin)	Capacity of resin (mg Cu/ml resin)
0.390	31.10	58.03
0.475	28.41	57.33

Table 4. Column performance of Dowex G-26 resin at different flow rate

Flow rate (ml/min)	Breakthrough capacity (mg Cu/ml resin)	Capacity of resin (mg Cu/ml resin)
0.88	31.10	58.03
1.15	27.08	56.92

through column to determine the effect of flow rate on copper adsorption by resin. Fig. 8 presented the result of column experiments with various flow rates. Copper broke through at around 80 BV for flow rate 0.88 ml/min and at around 60 BV for flow rate 1.15 ml/min. The results are presented in Table 4 showed that when flow rate increased breakthrough capacity decreased. If the flow rate is higher, copper solution does not have enough time to react with the ion exchange resin which consequently results in less volume of effluent.

3.6. FT-IR spectroscopic studies of resin on the copper extraction

The FT-IR spectrum of activated Dowex G 26 resin and copper loaded resin were recorded and plotted in

Fig. 9. The bands observed at 1414cm^{-1} , assigned the stretching of O-S-O group²⁴, at 831.02 and 771.48cm^{-1} presented aromatic out of plane C-H bend, at 670.02cm^{-1} showed the S-O bend^{24, 25}. When the spectra of copper loaded resin were compared with activated resin, the relative peak intensities of peak series at 1211 , 1152 and 1122.85cm^{-1} region were changed because of metal complex formation between copper ions and sulfonate groups of resin²⁶. The sulfonate ($-\text{SO}_3^-$) groups participating ion exchange are located in the $1122.85-1211\text{cm}^{-1}$ region for resin.

3.7. Elution and desorption studies

In order to elute copper from loaded resin the experiments were carried out using 10% sulphuric

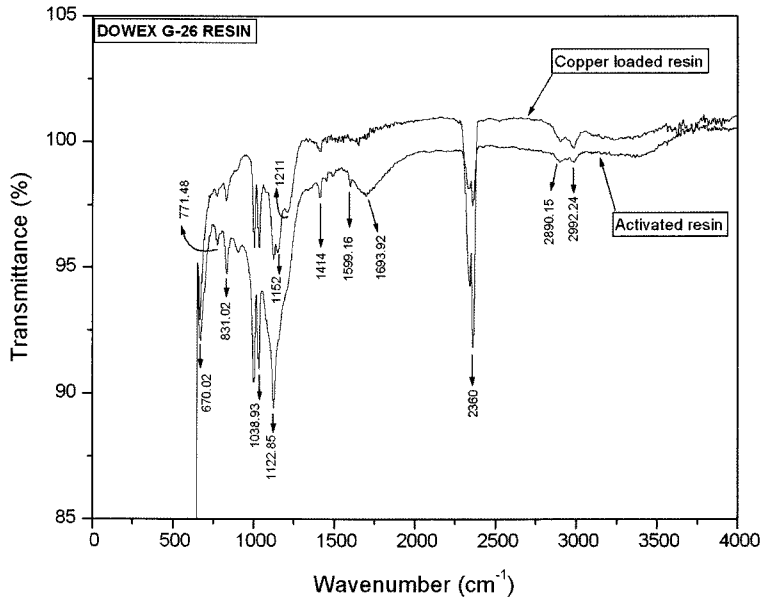


Fig. 9. FTIR spectra of activated and copper loaded Dowex G-26 resin.

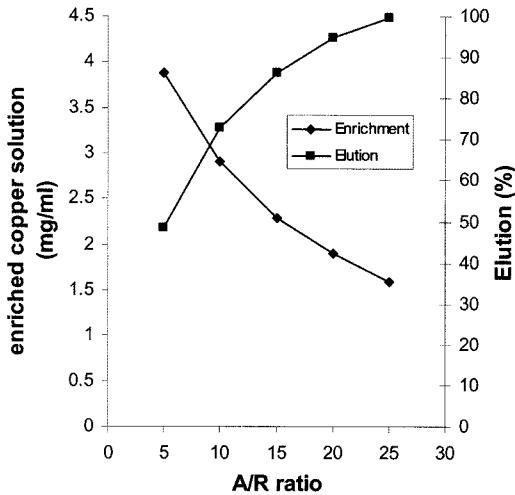


Fig. 10. Elution of copper from loaded resin to enrichment. (loaded Dowex G-26 resin:0.04 gram Cu/gram of resin, Solution for elution: sulfuric acid 10%, Contact time = 20 min)

acid. The A/R ratio was varied to get enriched copper sulphate solution. The results presented in Fig. 10 indicate that the copper can be eluted completely by using 10% sulphuric acid. To enrich the copper content in solution, effect of A/R ratio were studied. Result presented in Fig.10 shows that the copper could be

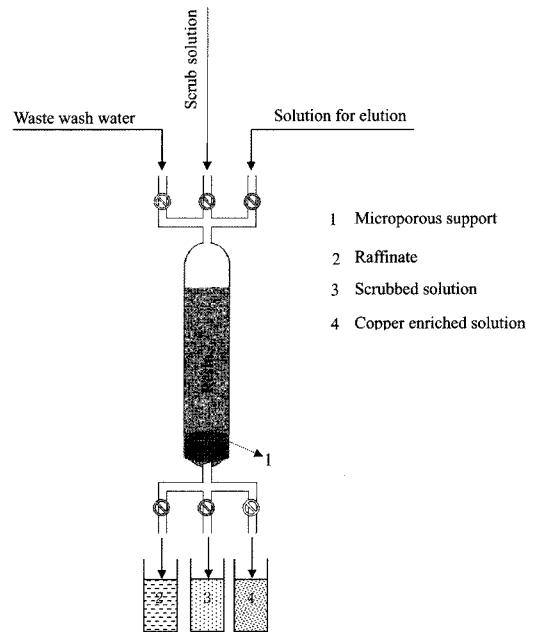


Fig. 11. Schematic diagram of the experimental set up.

eluted completely even at A/R ratio 25 and enriched to 1.57 g/L of copper in solution. A systematic diagram for the complete process to recover copper from waste solution is presented as Fig. 11.

4. Conclusions

Bench scale studies carried out in shake out flask showed the increase in adsorption of copper with increase in time and reaches equilibrium in 14 minutes. The equilibrium pH 2.5 was found to adsorbed 99.70% copper from the solution. Adsorption of copper studied in different contacts showed the loading capacity of resin 129.914 and 128.664 mg copper /g of resin from the aqueous feed containing 0.3 and 0.4 mg/ml of copper. The data for adsorption of copper was found to be fitted well for Lagmuir isotherm in comparison to Freundlich isotherm. The kinetic studies showed that copper adsorption was found to follow the second order rate equation better. The copper could be eluted from loaded resin by 10% H₂SO₄ to get pure and enriched copper solution.

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References

- Campbell, D. E., Nguyen, T., and James, D. K., 2001: Process for treating waste water containing copper, March 20, US Patent 6203705.
- Gundogan, R., Acemioglu, B., and Alma, M. H., 2004 : Copper(II) Adsorption from Aqueous Solution by Herbaceous Peat, *J. Colloid Inter. Sci.*, **269**, pp. 303-309.
- Jha, M. K. *et al.*, 2007: Processing of rayon waste effluent for the recovery of zinc and separation of calcium using thiophosphinic extractant, *Journal of Hazardous Materials*, **145**, pp. 221-226.
- Jha, M. K., *et al.*, 2004: Studies on leaching and recycling of zinc from rayon waste sludge, *Ind. Eng. Chem. Res.*, **43**, pp.1284-1295.
- Jha, M. K., Kumar, V., and Singh, R. J., 2002: Solvent extraction of zinc from the chloride solutions, *Solvent Extraction and Ion Exchange*, **20**, pp. 389- 405.
- Jha, M. K. *et al.*, 2008: Treatment of rayon waste effluent for the removal of Zn and Ca using Indion BSR resin, *Desalination*, **228**, pp. 97-107.
- Demirbas, A., *et al.*, 2005. Adsorption of Cu(II), Zn(II), Ni(II), Pb(II) and Cd(II) from aqueous solution on Amberlite IR-120 synthetic resin. *J. Colloid Interf. Sci.* **282**, pp. 20-25.
- Rengaraj, S., *et al.*, 2002: Studies on adsorptive removal of Co(II), Cr(III) and Ni(II) by IRN77 cation-exchange resin, *J. hazardous materials*, **92-2**, pp.185-198.
- Omer, Y., Yalcin A., and Fuat, G., 2003: Removal of copper, nickel, cobalt and manganese from aqueous solution by kaolinite. *Water Research*, **37**(4), pp. 948-952.
- Winterton, J. D., Darmawan, F., and Doyle, F. M., 2005: Investigation of ion exchange resin for use in treatment of semiconductor waste streams, *Proceedings of EPD Congress 2005, TMS-2005, USA*.
- Lee, I. H., Kuan, Y-c., and Chern, J.-M., 2006: Factorial experimental design for recovering heavy metals from sludge with ion-exchange resin. *Journal of Hazardous. Materials*, **138**, pp. 549-559.
- Jackson, E., 1986: Separation, purification and enrichment processes for treatment of pregnant leach and waste solutions. In: *Extraction and Reclamation*, Ellis Horwood Ltd, England: 1986.
- Kentish, S. E. and Stevens G. W., 2001: Innovations in separation technology for the recycling and re-use of liquid waste streams. *Chem. Eng. J.*, **84**, pp.149-159.
- Lagergren, S., 1898: About the theory of so called adsorption of soluble substances, *Kungliga Svenska Vetenskap-sakademiens Handlingar*, **24-4**, pp.1-39.
- Rengaraj, S., *et al.*, 2007: Adsorption characteristics of Cu(II) onto ion exchange resins 252H and 1500H: kinetics, isotherms and error analysis. *J. Haz. Mat.*, **143**, pp. 469-477.
- Baral, S. S., *et al.*, 2007: Chromium removal by calcined bauxite, *Biochem. Eng. J.*, **34**, pp. 69-75.
- Sahoo, N., *et al.*, 2006: Chromium extraction from a chrome plating waste solution by ion exchange, *Proc. Int. Conf. on Non-ferrous Metals*, R. Bhima Rao, R.N. Prasad, C.R. Mishra and M.K.B. Nair, Eds., Bhubaneswar, India, 2006, pp. 6/1-6/10.
- Padmavathy, V., Vasudevan, P., and Dhingra, S. C., 2003: Biosorption of nickel (II) ions on Baker's yeast, *Process Biochem.*, **38**, pp.1389-1395.
- Chojnacka, K., 2005: Biosorption of Cr (III) ions by eggshells. *J. Haz. Mat.* **121**, pp. 167-173.
- Bayat, B., 2002: Comparative study of adsorption properties of Turkish fly ashes, I, The case of nickel(II), copper(II) and zinc(II), *J. hazardous Materials*, **B95**, pp. 251-273.
- Langmuir, I., 1918: The adsorption of gases on plane surfaces of glass, mica and platinum, *J. Am. Chem. Soc.*, **40-9**, pp. 1361-1403.
- Haggerty G. M. and Bowman, R. S., 1994: Sorption of chromate and other inorganic anions by organo-zeolite, *Environ. Sci. Technol.*, **28**, pp. 452-458.
- Benefield, L. D., Judkin, J. F., and Weand, B. L., 1982: *Process chemistry for water and wastewater treatment*, Prentice-Hall, Englewood Cliffs, NJ.
- Smith, B., 1999: *Infrared spectral interpretation: a systematic approach*; CRC Press, USA.
- Cortina, J. L., *et al.*, 1994: Extraction studies of Zn (II), Cu (II) and Cd (II) with impregnated and Levextrel resins con-

taining di (2-ethylhexyl) phosphoric acid (Lewatit 1026), Hydrometallurgy, **36**, pp. 131-142.

26. Mahmut Özacar, Ayhan Şengil, Harun Türkmenler., 2008; Equilibrium and kinetic data, and adsorption mechanism for adsorption of lead onto valonia tannin resin, Chemical

Engineering Journal, doi:10.1016/j.cej.2007.12.005, In Press.



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