Separation of Copper, Nickel, Tin and Lead By Ion Exchange from Plating Rinsewater

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Because large amounts of water are used in many surface finishing processes, it is necessary to reclaim the water by removing metallic ions that contaminate it. Statistical methods were applied to ion exchange techniques to determine the distribution coefficients of copper, nickel, tin and lead ions in various concentrations of HCl. The calculated distribution coefficients point to the dependency of the ion exchanger's selectivity and the complexed metallic ion, the share of the ion type bound, as well as ligand concentration (Cl⁻) ions in the solution. In-plant experiments have determined breakthrough (resin) capacities for all the indicated metallic ions and their mixtures.

In surface finishing processes, large amounts of water are used, resulting in quantities of wastewater contaminated with metallic ions. The incoming fresh water for rinsing of printed circuit boards is demineralized, which is, after rinsing, contaminated with copper, nickel, lead and tin metallic ions. Because these are toxic metallics,^{1,2,3} when present in wastewater in concentrations greater than permitted, they contaminate waterways. The most economical procedure for separation of heavy metallics is ion exchange, in which metallic ions from wastewater are bound to ion exchange resins⁴⁻¹⁰ and, after anion exchange, the water can be reused as rinsewater in the production process.

Experimental Procedure

A standard solution of nickel, copper and lead was prepared by dissolving specific quantities of CuCl₂•2H₂O, NiCl₂•6H₂O and Pb(NO₃)₂ in demineralized water. A standard tin solution was prepared by dissolving metallic tin in HCl. By diluting standard solutions with demineralized water, mass concentrations of 10–100 mg/L were obtained.

Experiments with ion exchange were made in two ways by batch and column. Three strongly acid cation exchangers^a (designated as Types A, B and C) in H-form and a strongly basic anionic exchange resin^b (Type D) in Cl-form were used.

Nine grams of dry ion exchange resin were measured and dissolved in 100 mL of the electrolyte and allowed to stand until ion exchange balance was achieved—about one hr.¹¹ The hydrochloric acid concentration in the electrolyte solution was 0.014 to 6 mol/L, and mass concentration of metallic ions was 100 mg/L. After a certain binding period of metallic ions to the resin, the concentration of unbound metallic ions in an aliquot was determined. Copper and nickel were determined complexometrically¹² in mass concentration from 2 to 100 mg/L. Concentrations of copper and nickel lower than 2 mg/L were determined by atomic absorption spectrophotometer.¹³ Mass lead concentrations of 0 to 100 mg/L were determined similarly and tin concentrations were determined by UV/VIS spectrophotometer.¹⁴

The data obtained were used for planning experiments in a semi-industrial plant with three PVC columns, diameter 40 mm and length 300 mm. Three columns were used because parallel work was carried out with three types of ion exchangers. The columns were filled with a strongly acid cation exchanger of Na-form. The volume of the resin sample in each column was 200 mL.

The procedure for separation of metallic ions from water solutions is performed in two process stages:

Preparation of strongly acid cation exchanger

Strongly acid cation exchangers are first transformed from Na-form to H-form with six-percent HCl:

$$NaR + H^+ \longrightarrow HR + Na^+$$

The transformation of Na-form to H-form was done in a column by the acid solution flowing from top to bottom at unit flow rate of 3 L/hr/L of ion exchanger.¹⁵ The regeneration

			Т	able	1				
Depen	dence	of M	etalli	c Ion	Dist	ributi	on Co	oeffic	cient
On Med	dium fo	or Stro	ongly	Acid	Catio	n Excl	hange	er, Ty	pe A
C _{HCl}									
mol/L	0.014	0.1	0.5	1.0	1.5	2.0	2.5	3.0	4.0
Copper	$>10^{4}$	1342	105	20.6	6.7	2.78	2.3	1.85	0.95
Nickel	$>10^{4}$	1253	54.1	16.1	5.9	2.16	1.84	0.71	-
Lead	$>10^{4}$	6295	371	43.5	10.6	2.24	0.84	0.74	0.25
Tin	-	28.8	4.46	3.62	2.9	0.12	-	-	-

Table 2Dependence of Metallic Ion Distribution CoefficientOn the Medium for Strongly Acid Cation Exchanger, Type B									
C _{HCl}									
mol/L	0.014	0.1	0.5	1.0	1.5	2.0	2.5	3.0	4.0
Copper	>103	579	19.1	6.9	3.4	1.84	1.84	1.75	0.95
Nickel	>103	571	20.4	7.2	3.4	0.5	0.3	-	-

Tin	-	11.0	1.07	-	-	-	-	-	-	
Lead	>103	797	139	1.93	1.2	0.55	0.43	0.41	0.35	

Table	3							
Dependence of Metallic Ion	Distribution Coefficient							
On the Medium for Strongly	Acid Cation Exchanger,							
Type C								
C								

0.014	0.1	0.5	1.0	1.5	2.0	2.5	3.0	4.0
$>10^{4}$	1381	109	21.2	6.7	2.7	2.64	1.8	0.95
$>10^{4}$	1321	64.9	19.1	7.8	2.9	2.6	0.91	-
$>10^{4}$	6883	392.5	51.9	12.5	2.6	2.5	1.15	0.16
-	28.0	4.6	3.5	2.8	0.52	-	-	-
	0.014 >10 ⁴ >10 ⁴ >10 ⁴	$\begin{array}{ccc} 0.014 & 0.1 \\ > 10^4 & 1381 \\ > 10^4 & 1321 \\ > 10^4 & 6883 \\ - & 28.0 \end{array}$	0.014 0.1 0.5 >10 ⁴ 1381 109 >10 ⁴ 1321 64.9 >10 ⁴ 6883 392.5 - 28.0 4.6	$\begin{array}{cccc} 0.014 & 0.1 & 0.5 & 1.0 \\ >10^4 & 1381 & 109 & 21.2 \\ >10^4 & 1321 & 64.9 & 19.1 \\ >10^4 & 6883 & 392.5 & 51.9 \\ - & 28.0 & 4.6 & 3.5 \end{array}$	$\begin{array}{cccccc} 0.014 & 0.1 & 0.5 & 1.0 & 1.5 \\ >10^4 & 1381 & 109 & 21.2 & 6.7 \\ >10^4 & 1321 & 64.9 & 19.1 & 7.8 \\ >10^4 & 6883 & 392.5 & 51.9 & 12.5 \\ - & 28.0 & 4.6 & 3.5 & 2.8 \end{array}$	$\begin{array}{cccccccc} 0.014 & 0.1 & 0.5 & 1.0 & 1.5 & 2.0 \\ >10^4 & 1381 & 109 & 21.2 & 6.7 & 2.7 \\ >10^4 & 1321 & 64.9 & 19.1 & 7.8 & 2.9 \\ >10^4 & 6883 & 392.5 & 51.9 & 12.5 & 2.6 \\ - & 28.0 & 4.6 & 3.5 & 2.8 & 0.52 \end{array}$	$ 0.014 0.1 0.5 1.0 1.5 2.0 2.5 \\ > 10^4 1381 109 21.2 6.7 2.7 2.64 \\ > 10^4 1321 64.9 19.1 7.8 2.9 2.6 \\ > 10^4 6883 392.5 51.9 12.5 2.6 2.5 \\ - 28.0 4.6 3.5 2.8 0.52 - $	$ 0.014 0.1 0.5 1.0 1.5 2.0 2.5 3.0 \\ > 10^4 1381 109 21.2 6.7 2.7 2.64 1.8 \\ > 10^4 1321 64.9 19.1 7.8 2.9 2.6 0.91 \\ > 10^4 6883 392.5 51.9 12.5 2.6 2.5 1.15 \\ - 28.0 4.6 3.5 2.8 0.52 - - \ $

^a Proprietary resins KD 43-PCF, KB1 SB (Rohm & Haas, Philadelphia, PA) and RELITE C 360 (Sendion, Europe), respectively.

^b Proprietary resin AD 54, Rohm & Haas, Philadelphia, PA.



Fig. 1—Individual separation of nickel, copper, lead and tin by cation exchanger Type A. Influent: A, 100 mg Ni/L; B, 100 mg Cu/L; C, 100 mg Pb/L; D, 100 mg Sn/L.



Fig. 3—Individual separation of nickel, copper, lead and tin by cation exchanger Type B. Influent: A, 100 mg Ni/L; B, 100 mg Cu/L; C, 100 mg Pb/L; D, 100 mg Sn/L.



Fig. 5—Separation of nickel by the different cation exchangers. Influent: 100 mg Ni/L



Fig. 7—Separation of copper and nickel in mixture by cation exchanger Type A. Influent: 100 mg Ni/L + 100 mg Cu/L.



Treated volume, L/L RH

Fig. 2—Individual separation of nickel, copper, lead and tin by cation exchanger Type C. Influent: A, 100 mg Ni/L; B, 100 mg Cu/L; C, 100 mg Pb/L; D, 100 mg Sn/L.



Fig. 4—Separation of copper by the different cation exchangers. Influent: 100 mg Cu/L.



Fig. 6—Separation of lead by the different cation exchangers. Influent: 100 mg Pb/L.



Fig. 8—Separation of copper and nickel in mixture by cation exchanger Type C. Influent: 100 mg Ni/L + 100 mg Cu/L.

period needed was 30 min, followed by slow rinsing with demineralized water at unit flow rate of 2.7 L/hr per resin liter for 60 min until constant negative m-value (acidity) was obtained. The final step was a fast 10-min rinse at unit flow rate of 40 L/hr per resin liter.

Separation of metallic ions

A solution with one or more metallic ions enters at the column top and flows downward through the whole resin volume, where metallic ions concentrate, and purified water is collected after the reaction:

$$2RH + Me \longrightarrow R_2Me + 2H^+$$

During column operation, the flow of water and heavy metallic in the eluent was controlled. Resin saturation was obtained with solutions having copper, nickel, lead and tin concentrations of 10 to 100 mg/L, at unit flow rate of 30 L/hr/ L of resin and pH 2.5 (pH adjusted with HCl). Breakthrough (resin) capacity was observed at the leakage of copper, nickel, lead and tin ions of 0.1 mg/L. Breakthrough capacity was expressed in grams of metallics per liter of exchanger (g Me/L) and was measured from the solution volume that passed through the known volume of the ion exchanger at the moment of metallic ion leakage of 0.1 mg/L and ion concentration in the influent. Unbound copper, lead and nickel in the eluent were determined by AAS.¹³ In the preparation of the solution (10 to 100 mg/L Me⁺²), a complexometric method¹² was applied. Tin was determined by UV/VIS spectrophotometer.14

Results and Discussion

From the static or batch method experimental data, distribution coefficient values (Dc) for copper, lead, nickel and tin at various mol/L HCl concentrations were calculated. Dc defines the position of ion balance as the ratio of metallic ion concentration in the solid phase (exchanger) to that in the liquid phase (solution).

 $Dc = C(s)/C(l) = (Co - C1)/C1 \times V/m$

- C(s) = ion concentration on the exchanger
- C(l) = ion concentration in the solution
- Co = initial ion concentration in the solution
- C1 = final ion concentration in the solution
- V = solution volume (mL)
- m = dry exchanger mass (g)



Fig. 9—Separation of copper and nickel in mixture by cation exchanger Type B. Influent: 100 mg Cu/L + 100 mg Ni/L.

Table 4 Dependence of Metallic Ion Distribution Coefficient On Medium for Strongly Basic Anionic Exchanger, Type D										
C _{HCI}										
mol/L	0.1	0.5	1.0	1.5	2.0	3.0	3.5	4.0	5.0	6.0
Copper	-	-	-	0.19	1.2	2.35	2.35	2.35	2.25	$>10^{4}$
Nickel	-	-	-	-	-	-	-	-	-	-
heal	2 51	7 8/	13.2	15 /	16.8	15 / 15	13.6	117	36	12

26.8 85.4 259.6 876.9 1838 $>10^4$ $>10^5$

Tin

The dependence of nickel, copper, lead and tin distribution coefficients on 0.014 to 4 mol/L HCl concentration is shown in Tables 1–3 for strongly acid cation exchangers in H-form and in Table 4 for strongly base anionic exchanger in Cl-form of 0.014 to 6 mol/L HCl.

Different strongly acid cation exchangers yield different distribution coefficient values. At lower concentrations, exchanger Type B yields considerably smaller Dc values for all metallic ions in comparison with exchangers Type A and Type C. Values of Dc show that binding of lead, copper, nickel and tin are best in a medium of 0.014 mol/L HCl for all three cation exchangers. When the Cl⁻ ion concentration increases, distribution coefficient values decrease (*i.e.* after ion exchange balance in the solution), larger quantities of metallic ions not bound to the exchanger remain in the closed system.

The residual amount of copper, nickel, lead and tin in the liquid phase depends on exchanger selectivity for a particular metallic ion, as well as on the type of exchanger. In the presence of Cl⁻ ions, copper, nickel, lead and tin ions form more-or-less stable chloro complexes. When a metallic ion binds to a negatively charged chloro complex, distribution coefficient values are low and the newly formed complex ion is not bound to the cation exchanger. With formation of negative complexes, cation exchanger selectivity decreases in comparison with copper, nickel, lead and tin complexes, and anion exchanger selectivity of the same complexes increases (Table 4.) High Dc value suggests formation of a strong metallic chloro complex that binds to an anionic exchanger.¹⁶

Nickel does not form negatively charged complexes with chloride that are stable enough and, therefore, is not bound by an anionic exchanger. A copper chloro complex, according to the Dc values, is most firmly bound to an anionic exchanger



Fig. 10—Separation of nickel and copper in mixture with lead by cation exchanger Type A. Influent: A, 100 mg Ni/L + 100 mg Pb/L; B, 100 mg Cu/L + 100 mg Pb/L.



Strong acid cation exchange resin				Bre	akthro	ugh Ca	pacity,	g Me/l	L Resin		1		
in H form	h	ndivio	lually	7	Cu an	d Ni	Cu an	d Pb	Ni and	l Pb	in : Cu l	mixtu Ni and	ire d Ph
	Sn	Ni	Cu	Pb	Cu	Ni	Cu	Pb	Ni	Pb	Cu, I Cu	Ni	Pb
Туре В	-	11	10.5	55	6.7	7	9	12	10	12.5	4.5	4.5	9.5
Туре А	-	34.5	46.5	151	16.4	14.5	30.5	51	25.5	48	11	10	48.2
Type C	-	44.1	47	198	18	16	32	38	25.6	36	11.7	10.6	35.
	•												



Fig. 11. Separation of copper and nickel in mixture with lead by cation exchanger Type C. Influent: A, 100 mg Ni/L + 100 mg Pb/L; B, 100 mg Cu/L + 100 mg Pb/L.



Fig. 12—Separation of copper and nickel in mixture with lead by cation exchanger Type B. Influent: A, 100 mg Cu/L + 100 mg Pb/L; B, 100 mg Ni/L + 100 mg Pb/L.

at 6 mol/L HCl, and a lead chloro complex similarly at 2 mol/ L HCl. At higher concentrations of Cl⁻ ions, binding of lead ions is smaller. Separation of tin is optimum with a strongly anionic exchanger at 3.5 mol/L HCl.

To foresee the sequence of ion separation, it is important to know Dc values. From the data obtained, such Dc values can be extrapolated as higher for the ions remaining on the exchanger, and for the ions removed, the Dc values should be as low as possible, *(i.e.* its numerical value shall be smaller than unity). At Dc values less than 1, an ion does not bind and passes through the column unbound. Later, in the course of this study, experiments were made with ionic exchange in a column using the three strongly acid cation exchangers mentioned earlier. The qualitative relation of the binding strength of copper, nickel, lead and tin ions, when present individually in the influent and in a mixture of two or more metallics, was determined.

An important parameter for all ion exchangers was resolved: Breakthrough capacity at different interrelations of metallic ions in the influent. Breakthrough (resin) capacity is the exchange capacity of metallic ions up to the breakthrough point, giving insight into the quantity of ions that can really be exchanged in practice. Ex-

perimentally determined breakthrough capacity values given in Table 5 show the dependence on the type of metallic exchanged, the metallic interrelations in the mixture and on the type of exchanger (*i.e.*, its selectivity).

The exchangers tested have a considerably larger affinity for lead ions than for copper, nickel and tin. Affinity for lead ions is particularly noticeable in exchange resin Type C, which binds 198 g Pb per resin liter. The exchangers proved non-selective for sorption of tin ions, because tin ion leakage occurs early in strongly acid cation exchangers in concentrations higher than 2 mg/L. Non-selectivity of cation exchangers for tin ions exists because of the strong tendency of dihalogen tin to cation and anion complex formation. By adding a sufficient quantity of chloride ions, all tin ions change to anionic chloro complex SnCl₄⁻². Optimum binding conditions for tin, in the form of a chloro complex have been obtained for a strongly basic anionic exchanger (Table 4).

The largest breakthrough capacity for nickel, copper and lead ions (when individually present in the influent) was obtained with the strongly acid cation exchanger Type C. It binds lead ions by 31 percent more than Type A, or 3.6 times more than Type B. There are no great differences in affinity between exchangers Type A and Type C for copper ions in comparison with Type B, which binds 4.47 times less copper ions than either. For nickel ions, Type C binds 27 percent more than Type A, or four times more than Type B. The sequence of metallic ion leakage against affinity increase on the basis of the breakthrough curve and breakthrough capacity in strongly acid cation exchangers Type A and Type C (Figs. 1–2) is:

$$Ni^{+2} < Cu^{+2} < Pb^{+2}$$

The quantitative relationship of binding strength in strongly acid cation exchanger Type B (Fig. 3) is:

$$Cu^{_{+2}} < Ni^{_{+2}} < Pb^{_{+2}}$$

Ion exchangers do not bind copper and nickel ions with equal strength. Exchanger Type B binds nickel ions more strongly than copper ions, as distinguished from exchangers Type A and Type C, which strongly bind copper ions. Different selectivity of exchangers regarding copper and nickel exists because of differing degrees of crosslinkage. Strongly crosslinked exchangers bind copper ions more strongly than nickel ions.

The difference between breakthrough curves for the same metallic ions (copper, nickel or lead) is shown in Figs. 4, 5

and 6, depending on the type of exchanger (*i.e.*, its selectivity for metallic ions). The largest influence on the decrease of cation exchanger breakthrough capacity is exerted by the interrelations of metallics in the solution. Copper and nickel breakthrough capacities in mixtures are consequently less than when present individually, for the following exchangers:

Type B	36 percent for Cu,	36.4 percent for Ni
Type A	64.8 percent for Cu,	58 percent for Ni
Type C	61.8 percent for Cu,	63.8 percent for Ni

Now, however, the differences (1.5 g/L) in breakthrough capacity values are smaller. Figures 7–9 show the separations of copper and nickel ions when present in the mixture solution, using three types of strongly acid cation exchangers. Breakthrough curves for Ni⁺² and Cu⁺² ions in the mixture are steeper than when these ions are present individually in the solution. They are nearer each other and closer to the graph point of origin (*i.e.*, to reduced treated volume and less breakthrough capacity values. The sequence of metallic ion leakage (exchanger selectivity for Cu⁺²) in mixtures remained unchanged.

Figures 10–12 show copper and nickel separations in a lead mixture, using three different strongly acid cation exchangers. Visually, the breakthrough curves are similar for all three cation exchangers. The exchangers do not bind the same amount of Pb⁺² ions, however, in nickel and copper mixtures (Table 5). With the exchanger Type C (Fig. 11), breakthrough curves for Pb⁺² ions are very close to the curves for Cu⁺² and Ni⁺² ions. Specifically, Pb⁺² ion leakage occurs soon after the leakage of copper and nickel ions, then the breakthrough curves branch off at larger and larger spans, meaning that Pb⁺² ion leakage in a Ni⁺² mixture is faster than in a Cu⁺² ion mixture. Lead ion leakage from the breakthrough point up to the 2 mg/L concentration in the eluate is slow in Cu⁺² and Ni⁺² ion mixtures, but has a shorter and steeper breakthrough curve in a nickel mixture, for which the exchanger showed smaller affinity.

For exchanger Type A (Fig. 10), Pb⁺² ion breakthrough curves are at a larger distance than breakthrough curves for Cu⁺² and Ni⁺² ions, meaning that it binds more Pb⁺² ions in Cu⁺² or Ni⁺² mixtures than exchanger Type C. For separation of Pb⁺² ions when not in Cu²⁺ or Ni²⁺ ion mixtures, exchanger Type A bound fewer Pb^{+2} ions than Type C (Table 5). According to the position of Pb⁺² ion breakthrough curves and the calculated breakthrough capacity values, lead binds more to exchanger Type A and to Type C in a copper mixture than in a nickel ion mixture. For exchanger Type B, the case is reversed (*i.e.*, it binds more Pb^{+2} ions in a Ni⁺² ion mixture, for which it is more selective, Fig. 12), and the breakthrough curve of Pb⁺² ions is steeper and shorter in a Cu⁺² ion mixture, for which the exchanger has less affinity. It can be said that the exchangers bind more Cu+2 ions in a Pb+2 ion mixture, for which they are more selective, than in a Ni⁺² ion mixture for which they have less affinity. Generally, exchangers bind more of a particular metallic ion if the ion is mixed with another metallic ion for which the exchanger is more selective.

For separation of copper, nickel and lead ions in a mixture or equal mass concentrations (Figs. 13–14), Cu⁺² and Ni⁺² ion breakthrough curves are steeper and the span between them is less (breakthrough capacities are also smaller and more equal in values—a difference of 1 g/L resin) in comparison with breakthrough curves for Cu⁺² and Ni⁺² ions in a mixture



Fig. 13—Separation of copper, nickel and lead in mixture by cation exchanger Type A. Influent: 100 mg Ni/L + 100 mg Cu/L + 100 mg Pb/



Fig. 14—Separation of copper, nickel and lead in mixture by cation exchanger Type B. Influent: 100 mg Ni/L + 100 mg Cu/L + 100 mg Pb/L.



Fig. 15—Separation of copper, nickel and lead in mixture with tin by cation exchanger Type A. Influent: A, 100 mg Ni/L + 100 mg Sn/L; B, 100 mg Cu/L + 100 mg Sn/L; C, 100 mg Pb/L + 100 mg Sn/L.

without lead ions (Figs. 7–9) or for breakthrough curves when individually present in a lead ion mixture (Figs. 10–12).

The Pb⁺² ion breakthrough curve in a Cu⁺² and Ni⁺² ion mixture is shorter (Pb⁺² ion leakage is faster) in comparison with breakthrough curves of Pb⁺² ions in Cu⁺² or Ni⁺² ion mixtures. The breakthrough sequence is the same, that is, the affinity of strongly acid cation exchangers Type A and Type C to metallic ions does not change regardless of whether metallic ions are present individually or in a mixture of two or more metallic ions. The sequence of metallic cations to affinity increase was determined as:



Fig. 16—Separation of copper, nickel, lead and tin by cation exchanger Type A. Influent: 100 mg Ni/L + 100 mg Cu/L + 100 mg Pb/L + 100 mg Sn/L.

$$Ni^{+2} < Cu^{+2} < Pb^{+2}$$

The strongly acid cation exchanger Type B showed, for separation of three metallic ions in a mixture, a small difference in selectivity between Cu⁺² and Ni⁺² ions. Their break-through curves are adjacent and interlace at higher break-through concentrations (Fig. 14), and their breakthrough capacity value is the same (Table 5).

In Fig. 15, separation of copper, nickel and lead ions in a tin mixture, using cation exchanger Type A is shown. The cation exchanger binds copper and nickel ions in the tin mixture (13 g Cu and 6 g Ni per liter of cation exchanger). In the tin mixture, lead ions do not bind well to the cation exchanger and they break through in the eluate over a long flow-through period in concentrations of 0.1-0.2 mg/L. For separation of copper, nickel, lead and tin in the mixture, breakthrough of the four indicated metallic ions occurs in the eluate in concentrations greater than 0.1 mg/L (Fig. 16). Figure 17 shows copper, nickel, and tin separation for a different ratio of metallic ion concentrations in the solution. The importance of the relationship of metallic ion concentrations in the solution is reflected in the case of reduction of the mass concentrations of nickel, lead and tin in relation to copper, where exchanger affinity to metallic ions changed (*i.e.*, changes in sequence occurred and selectivity order is: $Cu^{+2} < Ni^{+2} < Pb^{+2}$. This means that selectivity of an exchanger also depends on the concentration of metallic ions in the influent. Breakthrough capacity also depends on the ion concentration in the influent. When metallic ion concentration is reduced, breakthrough capacity increases.

Summary

The ion exchange process is most efficient at individual separation of metallic ions from simulated rinsewater. Break-through capacities are much greater and values depend on cation exchanger selectivity for the metallic ion being exchanged. Ion exchange is very sensitive to the separation of additional metallic ions because ion leakage occurs before the exchanger capacity is fully used. For the separation of metallic ions in mixtures, breakthrough capacities are considerably reduced for all ions and the working period of columns filled with exchangers depends on the metallic ion for which exchangers have less affinity (*i.e.*, the working period depends on the more non-selective metallic). Cation exchangers bind a larger quantity of metallic ions if they are mixed with another metallic ion for which the exchanger is more selective.



Fig. 17—Separation of copper in presence of 10% nickel, lead and tin by cation exchanger Type A. Influent: 100 mg Cu/L + 10 mg Ni/L + 10 mg Pb/L + 10 mg Sn/L.

Efficiency optimization of the separation process, the interrelation of metallics in the influent and mass concentrations of metallics are very important. Breakthrough capacities depend on the interrelation of metallics in the influent, while selectivity and, thereby, breakthrough (resin) capacities depend on metallic concentration ratios.

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