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Recovery of Cobalt From Spent Copper Leach Solutions—Improved Elution and Impurity Removal Techniques, With Revised Process Economics

By P. G. Bennett and T. H. Jeffers

BUREAU OF MINES

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	L	liter
ft^3	cubic foot	L/min	liter per minute
g	gram	lb	pound
g/L	gram per liter	min	minute
gal	gallon	Mgal	thousand gallons
gpm	gallon per minute	MMBtu	million British thermal units
gpm/ft^2	gallon per minute per square foot	pct	percent
h	hour	ppm	part per million
in	inch	st	short ton
kW•h	kilowatt hour	yr	year

RECOVERY OF COBALT FROM SPENT COPPER LEACH SOLUTIONS–IMPROVED ELUTION AND IMPURITY REMOVAL TECHNIQUES, WITH REVISED PROCESS ECONOMICS

By P. G. Bennett[1] and T. H. Jeffers[2]

ABSTRACT

The Bureau of Mines developed a process using ion exchange to recover cobalt from spent copper leach solutions. A preliminary economic evaluation of the process indicated that about one-third of the capital cost was attributed to the total resin inventory, and one-third of the operating cost was required for reagents to remove iron from the ion-exchange eluates.

An agitated Pachuca elution system was investigated in place of a fixed-bed elution system. The Pachuca system reduced the resin inventory by 27 pct when compared with the fixed-bed elution system. Processing fresh spent copper leach solution reduced the resin inventory by 20 pct and resin iron loading by 80 pct. Reagent requirements for removing iron from the eluates were decreased because less iron was extracted. The Pachuca system, along with processing fresh spent copper leach solution, reduced the total resin inventory by 47 pct.

A revised cost evaluation of the cobalt recovery process was obtained to determine the effects of these process modifications. The estimated total capital cost for a plant processing 10,000 gpm of spent copper leach solution containing 26 ppm Co was $23.1 million. With credits for nickel, zinc, and copper byproducts, the estimated net operating cost was $5.10/lb of cobalt.

[1]Chemical engineer.
[2]Supervisory chemical engineer.
Salt Lake City Research Center, Bureau of Mines, Salt Lake City, UT.

INTRODUCTION

The Bureau of Mines developed a process using ion exchange to extract cobalt from domestic spent copper leach solutions (1-3).[3] These solutions, which are produced by heap or dump leaching of low-grade copper ores with dilute sulfuric acid, contain copper, cobalt, nickel, iron, zinc, and aluminum. Copper is generally removed from the solutions using cementation on scrap iron. Although the spent leach solutions typically contain only 15 to 30 ppm Co, five domestic resources have been identified with combined potential cobalt recoveries in excess of 2 million lb annually, or approximately 20 pct of the annual U.S. cobalt consumption. The United States currently imports over 95 pct of its cobalt supply, much of it from Africa (4).

The cobalt recovery process consists of four major unit operations: (1) ion exchange (loading and elution) to extract and concentrate the cobalt, (2) solvent extraction to remove coextracted impurities from the ion-exchange eluates, (3) a second solvent-extraction operation to separate the cobalt and nickel and concentrate the cobalt, and (4) cobalt electrowinning to produce a final product.

A preliminary economic evaluation of the cobalt recovery process was prepared by the Bureau's Process Evaluation Group. The estimated capital cost for a plant processing 10,000 gpm of feed solution containing 26 ppm Co was $29.9 million. This plant would produce about 1 million lb of cobalt annually at an operating cost of $17.58/lb of cobalt produced. Estimated byproduct credits for nickel carbonate, zinc oxide, copper-nickel residues, and cobalt-magnesium carbonate offset much of the operating cost, yielding a net operating cost of $9.36/lb of cobalt.

Two major contributors to the process costs were identified. About one-third of the capital cost was attributed to the initial resin inventory, and one-third of the operating cost resulted from reagent requirements for removing iron from the ion-exchange column eluates. The resin inventory required for the cobalt recovery process included resin in the multiple-compartment ion-exchange (MCIX) extraction column and resin in the elution circuit. Fixed-bed elution was utilized in earlier test work (2), and the preliminary cost evaluation was based on this elution mode. Elution time was an important factor in the resin inventory and associated costs. Reduced elution times were necessary to minimize the elution circuit resin inventory. Thus, several alternative elution procedures were evaluated in the laboratory. Those investigated included (1) fluidized-bed elution, (2) continuous fixed-bed elution, (3) stirred reactor elution, and (4) Pachuca air-lift elution.

The Pachuca reactor demonstrated the greatest potential for reducing the elution time and was thus chosen for further study. Although Pachuca reactors have been used for leaching gold (5-6) and uranium ores (7-8), an extensive literature search did not indicate that they have been used for eluting ion-exchange resins.

Reagent expenses for the removal of iron from MCIX column eluates represented a significant cost of the cobalt recovery operation. The resin used in this investigation, while coextracting iron, had a higher affinity for ferric than ferrous iron. Eluates collected from the elution circuit contained about 6 g of ferric iron per liter of wet-settled resin (WSR), and were processed in a solvent-extraction circuit using di(2-ethylhexyl) phosphoric acid (DEHPA). Sodium carbonate was used to strip iron from the DEHPA, and dextrose chelated the iron and prevented iron hydroxide precipitation. Although the DEHPA circuit effectively removed the iron from the eluates, each gram of ferric iron stripped required 15.9 g Na_2CO_3 and 0.7 g dextrose. Process modifications using fresh cementation plant effluent were therefore investigated to determine if lower ferric iron loadings in the MCIX column could be achieved; thus, reducing the sodium carbonate and dextrose reagent costs associated with iron removal from product eluates.

ELUTION STUDIES

FIXED-BED ELUTION

In earlier work (2), the fixed-bed elution procedure effectively resulted in a barren resin that was returned to the MCIX column. The elution procedure consisted of

1. One 20-min contact with pH 3.0 wash water to remove a portion of the iron, zinc, and aluminum impurities.
2. Two 20-min contacts with a recycled 30-g/L H_2SO_4 eluant to elute a portion of the cobalt and nickel and a portion of the iron, zinc, and aluminum impurities.
3. One 20-min contact with a fresh 30-g/L H_2SO_4 eluant to elute the remaining cobalt, the remainder of the iron, zinc, and aluminum impurities, and a portion of the nickel.
4. One 20-min contact with fresh water to remove residual H_2SO_4.
5. Three 20-min contacts with a recycled 3.5N NH_4OH eluant to elute copper and the remaining nickel.

[3] Underlined numbers in parentheses refer to items in the list of references at the end of this report.

6. One 15-min contact with fresh water to remove residual NH_4OH.

A total time of 180 min was required for complete resin elution. One hundred seventy-five minutes was needed for contacting the resin with the various eluants, and approximately 5 min was required for resin transfer to and from the fixed-bed column. The elution time was based on an eluant flow rate of 1 gpm/ft^2.

PACHUCA REACTOR DESCRIPTION

A Pachuca reactor was designed, constructed, and tested for eluting loaded resin from the 2-in-diam MCIX column. The Pachuca reactor is illustrated in figure 1. The body of the reactor vessel was fabricated from a 2-1/2-in-ID by 6-ft-high polymethylmethacrylate tube. The center draft tube consisted of a 3/8-in-ID by 43-in-high stainless steel tube. Pressurized air was used to move the loaded resin up through the center draft tube. Two perforated polyethylene disks were placed inside the Pachuca reactor to center the draft tube in the reactor vessel. Approximately 5 in above the top of the center draft tube, within the reactor, was a 3/8-in-ID by 27-in-high stainless steel tube with three 1/8-in-OD by 6-in-high welded stainless steel support rods used to connect the upper and lower portions of the draft tube. The openings between the rods allowed for resin-eluant overflow and circulation. The upper section of the draft tube extended 4-1/2 in above the top of the reactor. An adjustable collar was permanently attached to the top of this section to prevent movement of the draft tube during operation.

A threaded 5-in-OD by 5-in-high polyethylene cap was attached to the bottom of the Pachuca reactor. The cap was fabricated with a 45° sloping floor that led to three 3/8-in-diam openings allowing for the air intake, resin drainage, and eluate drainage. The eluate drain line was fitted with a screen inside the cap to prevent the discharge of resin from the reactor with the eluate solution.

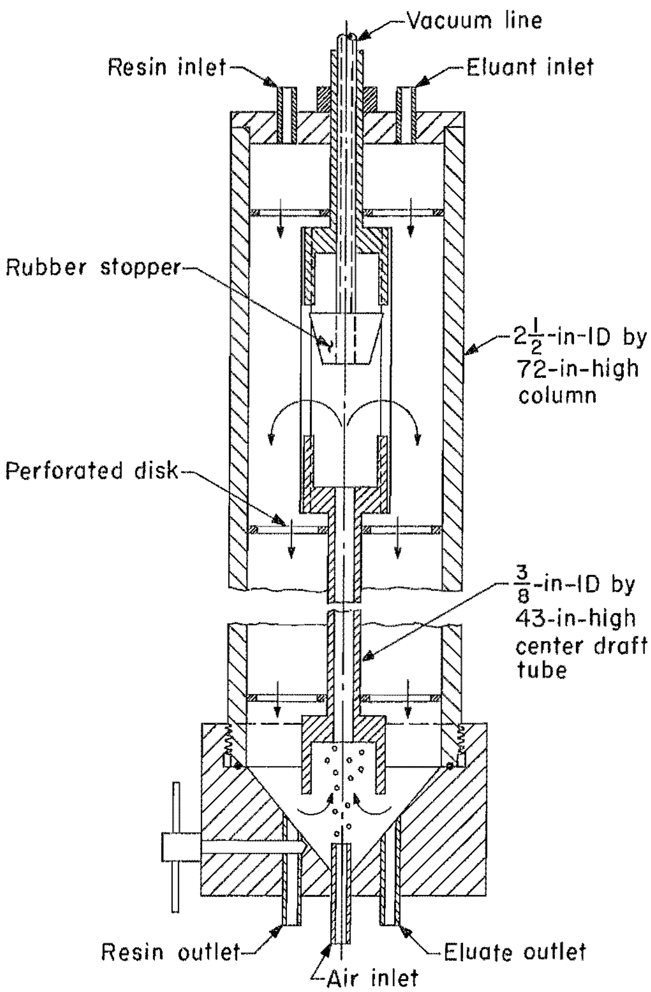

FIGURE 1.–Pachuca reactor.

PACHUCA REACTOR OPERATION

During operation of the Pachuca reactor, loaded resin, discharged from the MCIX column, was rinsed with fresh water to remove entrained feed solution. The resin-rinse water slurry was then transferred to the Pachuca reactor. The eluate drainline valve was opened, and the rinse water was removed from the vessel. The drainline was then closed, the appropriate amount of eluant was pumped into the reactor, and airflow for agitation was initiated. Operation of the Pachuca was a batch operation and required the brief application of vacuum through the draft tube to initiate resin circulation. An airflow rate of 0.08 L/min was required for minimum resin circulation, while an airflow of 0.9 L/min or greater was needed for complete resin agitation. All tests were performed at an airflow rate of 1.3 L/min.

Batch elution in the Pachuca reactor consisted of pumping fresh eluant to the reactor and contacting with the resin for a specified amount of time. Upon completion of an eluant contact, the intake air was discontinued, and vacuum was applied to the eluate line at the bottom of the reactor to assist in draining the metal-rich eluate from the reactor. Fresh eluant was then pumped into the reactor, and the elution procedure was repeated.

The complete Pachuca elution procedure, determined from preliminary tests, consisted of the following steps:

1. One contact with an H_2SO_4 eluant wash to remove a portion of the iron, zinc, and aluminum impurities. Cobalt losses were minimal.
2. Two contacts with an H_2SO_4 eluant to elute cobalt, the remaining iron, zinc, and aluminum, and part of the nickel.
3. One contact with fresh water to remove residual H_2SO_4.

4. Two contacts with an NH_4OH eluant to elute copper and the remaining nickel.
5. One contact with fresh water to remove residual NH_4OH.

Barren resin was drained from the reactor and returned to the MCIX column. Samples of the barren resin were taken after each completed elution and thoroughly stripped of any remaining metal values to monitor the progress of the elution and provide data for comparison with previous fixed-bed elution procedures.

PACHUCA ELUTION TEST CONDITIONS

Loaded resin discharged from the MCIX column was used for all elution testing in the Pachuca reactor (3). The loaded resin contained, in grams per liter of WSR, 0.78 Co, 1.40 Ni, 2.74 Cu, 6.33 Fe, 5.0 Zn, and 0.15 Al. The variables investigated were (1) resin-eluant contact time, (2) aqueous-to-resin (A-R) ratio, and (3) eluant concentration.

Preliminary results indicated that a minimum sulfuric acid concentration of 30 g/L was required to attain reasonable cobalt elution. Therefore, test work was performed to determine the effects of acid concentrations of 30 g/L H_2SO_4 or greater on cobalt elution.

Two-contact acid elution tests were conducted in the Pachuca reactor with 30-, 40-, 45-, and 50-g/L H_2SO_4 at A-R ratios of 1:1, 2:1, and 3:1. Eluate samples representing 0.5 pct of the total eluant volume were withdrawn from the reactor at 5-, 10-, 15-, and 20-min intervals to monitor the progress of the elution. Two separate contacts were necessary because acid was neutralized during the elution, and the remaining acid concentration was insufficient to effectively elute the metal values from the resin. The first acid contact was a recycled solution collected as the eluate from a previous contact. The recycled eluant acid concentration was adjusted with sulfuric acid to the corresponding fresh acid eluant concentration by comparing the pH's of the two solutions. After the initial contact with recycled eluant, the resin was eluted with a fresh acid eluant contact. Table 1 presents the cobalt eluted when using the Pachuca reactor or the fixed-bed column at various operating conditions.

EFFECT OF CONTACT TIME

One of the objectives of this work was to determine the minimum contact time required to effectively elute the cobalt. Results from table 1 show that cobalt elution in the Pachuca reactor did not appreciably increase with an increase in contact time as the elution approached the target range of 95 to 100 pct. For example, with the 40-g/L H_2SO_4 eluant at an A-R ratio of 2:1, cobalt elution varied from 93 to 95 pct as the contact time varied from 5 to 20 min. The elution rate for other metals on the resin such as nickel, iron, and zinc showed similar trends. Thus, 5 min appeared to be sufficient contact time to effectively elute the loaded resin.

TABLE 1. - Effect of process variables on cobalt elution

A-R ratio	Contact time, min	Total Co eluted, pct, at H_2SO_4 concentration of–			
		30 g/L	40 g/L	45 g/L	50 g/L
	PACHUCA REACTOR, 2 CONTACTS				
1:1 . . .	5	35	62	81	78
	10	38	68	86	88
	15	36	65	87	90
	20	41	64	90	93
2:1 . . .	5	71	95	96	96
	10	75	93	97	98
	15	76	94	97	97
	20	77	94	98	98
3:1 . . .	5	88	94	98	96
	10	91	94	98	98
	15	91	93	97	98
	20	89	95	96	96
	FIXED-BED COLUMN, 3 CONTACTS				
3:1 . . .	15	66	81	ND	ND
	20	96	96	ND	ND

ND Not determined.

The most significant information from this research was obtained when comparing the contact time required for the fixed-bed elution with the Pachuca reactor elution. The fixed-bed elution results in table 1 show that three 15-min contacts using 30- and 40-g/L H_2SO_4 eluted only 66 and 81 pct of the cobalt, respectively, while three 20-min contacts using 30- or 40-g/L H_2SO_4 eluted 96 pct of the cobalt. Similar results were obtained with the Pachuca reactor at several operating conditions, and only two 5-min contacts were required. For example, 98 pct of the cobalt was eluted using two 5-min contacts with 45 g/L H_2SO_4 at an A-R ratio of 3:1. The reduced contact time achieved with the Pachuca reactor will reduce the total resin inventory because the resin will spend less time in the elution circuit and more time in the MCIX column extracting metal values.

EFFECT OF A-R RATIO

The data in table 1 also show the effect of A-R ratios on the cobalt elution. When the higher A-R ratios were used, cobalt elution increased. Overall, 94 pct or greater of the cobalt was eluted with an A-R ratio of 2:1 or 3:1 when using 40-, 45-, or 50-g/L H_2SO_4. However, the cobalt concentration in the product eluates decreased with increased A-R ratio. This was due to dilution associated with the greater volume of eluant. For example, after one elution using two 5-min contacts with a 40-g/L H_2SO_4 eluant, 62, 95, and 94 pct of the cobalt was eluted at A-R ratios of 1:1, 2:1, and 3:1, respectively, while product eluates, collected from the first acid contact, contained 0.42, 0.38, and 0.35 g/L Co, respectively. Eluates collected from the test series with the 2:1 A-R ratio contained 95 pct of the cobalt and were similar to the results obtained from the test series using the 3:1 A-R ratio. The A-R ratio of 2:1 was the preferred A-R ratio because the acid requirement was 33 pct less than the acid required with the 3:1 A-R ratio.

EFFECT OF ACID ELUANT CONCENTRATION

The results presented in table 1 also show the effect of the sulfuric acid eluant concentrations on cobalt elution. In general, as the acid concentration increased, the amount of cobalt eluted from the resin also increased. Cobalt elution was greater than 95 pct with two 5-min contacts at an A-R ratio of 2:1 and acid concentrations of 40-g/L H_2SO_4 or higher. The 40-g/L H_2SO_4 eluant required 11.1 and 20.0 pct less H_2SO_4 than the 45- and 50-g/L H_2SO_4 eluants, respectively.

Although the 40-g/L H_2SO_4 eluant used in the Pachuca system effectively eluted the resin, the acid requirements were approximately twice the acid requirements of the fixed-bed elution system using 30-g/L H_2SO_4. Thus, when compared with the fixed-bed elution system, the increased acid requirement in the Pachuca system will result in a higher annual acid operating cost. However, the Pachuca system will reduce the resin inventory, a major capital cost.

COMPLETE PACHUCA ACID ELUTION PROCEDURE

Preliminary test work indicated that downstream solvent-extraction processing of the product eluates was more efficient when these solutions contained a cobalt concentration higher than that achieved after one elution. Therefore, recycling the acid eluant for several elutions was investigated.

An elution scheme employing two 40-g/L H_2SO_4 eluant contacts at an A-R ratio of 2:1 for four elutions was determined to be an acceptable operating procedure for increasing the cobalt concentration of the eluate. The complete elution scheme for four elutions used 1 L of WSR per elution. The first elution produced 2 L of eluate per liter of WSR and contained, in grams per liter, 0.38 Co, 0.15 Ni, 0.005 Cu, 1.9 Fe, 1.8 Zn, and 0.02 Al. After the fourth elution, 4 L of product eluate, obtained from the second contact of the third elution along with the first contact from the fourth elution, was collected. The eluate contained, in grams per liter, 0.74 Co, 0.42 Ni, 0.009 Cu, 6.0 Fe, 4.2 Zn, and 0.035 Al. This product eluate contained a sufficient cobalt concentration for efficient downstream solvent-extraction processing. Although the cobalt concentration in the product eluate did not increase proportionally with each elution, the second acid contact per elution ensured that the remaining cobalt was eluted.

The Pachuca operating procedure utilizing four elutions sufficiently eluted the metal values from the loaded resin, with the exception of nickel. The nickel elution was incomplete, and after 10 to 15 loading and eluting cycles, the nickel buildup on the resin was sufficient to interfere with the cobalt extraction. A 250-g/L H_2SO_4 eluant was used as the second contact of the fourth elution to improve the nickel elution, thus 25 pct of the resin was subjected to a strong acid elution for each cycle. This contact eluted approximately 90 pct of the nickel and prevented the buildup of nickel on the resin. Approximately 50 pct of this eluate was used to adjust the recycled solutions to 40-g/L H_2SO_4 for the next series of four elutions. The remaining eluate, along with fresh 250-g/L H_2SO_4, was used as the next 250-g/L H_2SO_4 eluant contact. The 250-g/L H_2SO_4 eluate used to adjust the recycled acid eluant to 40-g/L H_2SO_4 resulted in excess eluant when maintaining an A-R ratio of 2:1. The excess 40-g/L H_2SO_4 eluant was removed from the system, blended with fresh 40-g/L H_2SO_4, and used for the first elution contact in the next series of four elutions.

EFFECT OF AMMONIUM HYDROXIDE ELUANT CONCENTRATION

Following the acid elution, the resin was contacted with ammonium hydroxide to eluate the copper and the remaining nickel. Earlier elution test results indicated a minimum concentration of 4<u>N</u> NH_4OH was sufficient to elute essentially all of the copper and a portion of the remaining nickel. Twenty percent of the NH_4OH eluant was removed after each cycle contact and replenished with an equivalent volume of 8<u>N</u> NH_4OH. This ensured that NH_4OH was available for further copper and nickel removal in subsequent elutions. The 20-pct bleed stream was processed for copper, nickel, and ammonia recovery.

Table 2 summarizes results obtained using two 5-min contacts with the 4<u>N</u> NH_4OH eluant at A-R ratios of 1:1, 2:1, and 3:1. Copper elution was essentially complete at the higher A-R ratios, while only a portion of the residual nickel was eluted. At an A-R ratio of 2:1, 95 pct Cu and 32 pct Ni was eluted, while at an A-R ratio of 3:1, 95 pct Cu and 40 pct Ni was eluted. Though 8 pct more nickel was eluted when using an A-R ratio of 3:1 than was eluted when using an A-R ratio of 2:1, the former required 33 pct more NH_4OH eluant. Therefore, the ammonium hydroxide elution was performed at an A-R ratio of 2:1, because less NH_4OH was required and the subsequent acid elution with the 250-g/L H_2SO_4 would prevent a buildup of nickel on the resin. In addition, economic evaluation indicated that a nickel carbonate byproduct obtained from the acid eluate was four times more valuable, \$3.10/lb versus \$0.79/lb, than the nickel residue collected from the NH_4OH eluate (<u>3</u>). Therefore, it would be more economical for the nickel to be collected in the acid eluates than in the NH_4OH solution.

TABLE 2. - Nickel and copper elution using two 5-min 4<u>N</u> NH_4OH contacts with a 20-pct bleed stream, percent

A-R ratio	Ni	Cu
1:1	21	87
2:1	32	95
3:1	40	95

SUMMARY OF PACHUCA REACTOR OPERATING PROCEDURE

The complete Pachuca reactor elution procedure consisted of the following steps. An A-R ratio of 2:1 was used for all contacts. One liter of fresh resin was used for each elution.

First Elution

1. One 5-min contact with 10-g/L H_2SO_4.
2. One 5-min contact with 40-g/L H_2SO_4 recycled eluant.
3. One 5-min contact with fresh 40-g/L H_2SO_4.
4. One 5-min contact with fresh water.
5. One 5-min contact with 4N NH_4OH recycled eluant with a 20-pct bleed stream.
6. One 5-min contact with fresh 4N NH_4OH.
7. One 2-min contact with fresh water.

Second Elution

1. One 5-min contact with 10-g/L H_2SO_4.
2. Two 5-min contacts with 40-g/L H_2SO_4 recycled eluant.
3. One 5-min contact with fresh water.
4. Two 5-min contacts with recycled 4N NH_4OH eluant with a 20-pct bleed stream.
5. One 2-min contact with fresh water.

Third Elution

Same the second elution.

Fourth Elution

1. One 5-min contact with 10-g/L H_2SO_4.
2. One 5-min contact with 40-g/L H_2SO_4 recycled eluant.
3. One 5-min contact with 250-g/L H_2SO_4.
4. One 5-min contact with fresh water.
5. One 5-min contact with recycled 4N NH_4OH eluant with a 20-pct bleed stream.
6. One 5-min contact with fresh 4N NH_4OH.
7. One 2-min contact with fresh water.

Total elution time with the Pachuca reactor was approximately 50 min per elution. Thirty-two minutes was required for contacting the resin with the various eluants, and approximately 18 min was required for eluant transfer, eluant drainage, and resin drainage at the end of an elution. The 18-min drain time was sufficient for this particular operation; however, in a scaled-up operation, the drain time could vary. The resulting barren resin contained, in grams per liter WSR, 0.03 Co, 0.4 Ni, 0.1 Cu, 0.01 Fe, 0.04 Zn, and 0.001 Al. Barren resin collected from the fixed-bed elution column, which required about 180 min, contained, in grams per liter WSR, 0.01 Co, 0.3 Ni, 0.3 Cu, 0.001 Fe, 0.01 Zn, and 0.001 Al.

RESIN INVENTORY

The MCIX column required a resin inventory of 10,400 ft^3 of WSR to process a 10,000-gpm stream containing 0.026 g/L Co. The resin inventory for the fixed-bed elution system was 6,100 ft^3 of WSR, and when operated in conjunction with the MCIX column, 16,500 ft^3 of WSR was required.

The resin inventory for the Pachuca reactor elution system was only 1,700 ft^3 of WSR, and a total resin inventory of 12,100 ft^3 of WSR was required when the Pachuca reactor was operated in series with the MCIX column.

The Pachuca reactor reduced the resin inventory in the elution system by 72 pct when compared with the fixed-bed elution column, and the total resin inventory was reduced by 27 pct.

IRON STUDIES

The feed solution used in the cobalt recovery investigation was copper cementation plant effluent. The solution was obtained in 5,000-gal batches and stored in open-air tanks until used. Although 90 to 95 pct of the iron in the as-received solution was in the ferrous state, the iron oxidized as it aged; solution processed in the MCIX column generally contained a high proportion of ferric iron. As the resin used for cobalt extraction had a greater affinity for ferric rather than ferrous iron (9), more iron was extracted as the solution aged.

Crowding effects also contributed to increased iron extraction as the solution aged. Laboratory results indicated that cobalt ions in the feed solution readily crowded ferrous iron off the resin. However, ferric iron was slowly crowded off the resin by cobalt ions. Because of the significant reagent cost associated with removing iron from the eluates produced in the Pachuca elution unit, tests were conducted using fresh, as-received cementation plant effluent containing a high proportion of ferrous iron. The as-received effluent contained about 2.0 g/L of total iron; 91 pct of the iron was in the ferrous state. Continuous tests in a 10-compartment MCIX column using flow rates of 5 to 6 gpm/ft^2 and an A-R flow ratio of 40:1 yielded resin with iron loadings of only 0.7 to 1.2 g/L of WSR. Cobalt extractions were enhanced during the tests because fewer resin sorption sites were occupied by iron, and essentially complete cobalt extractions were achieved in only eight compartments. The resin inventory for a 10-compartment MCIX column was 10,400 ft^3, and reducing the column size to eight compartments resulted in a 20-pct reduction in the resin inventory to 8,320 ft^3. Figure 2 illustrates these results. Thus, the optimum

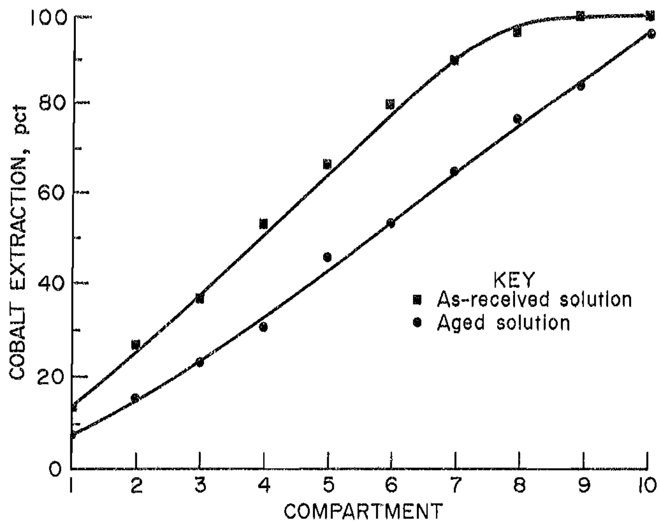

FIGURE 2.–Cobalt extraction using as-received and aged solution.

column size was reduced from 10 to 8 compartments, and a proportional reduction in the resin inventory was realized. The resin with a low iron content was eluted, and the resulting eluates contained about 1 g/L ferric Fe, considerably lower than the 6-g/L Fe eluates obtained in earlier work using aged solution. Reagent consumptions in the impurity-removal solvent-extraction circuit were therefore decreased. Total sodium carbonate consumption was lowered by 40 pct, and dextrose consumption was reduced by 70 pct.

TABLE 3. - Estimated capital costs

Fixed capital:	
Primary ion-exchange section	$7,478,200
Ammonia recovery section	277,500
Zinc solvent-extraction section	1,085,400
Cobalt solvent-extraction section	283,600
Cobalt electrowinning section	812,200
Byproduct recovery section	1,059,800
Steamplant	519,400
Subtotal	11,516,100
Plant facilities, 5 pct of above subtotal	575,800
Plant utilities, 6 pct of above subtotal	691,000
Basic plant cost	12,782,900
Resin and solvent inventory	5,413,600
Escalation costs during construction	416,400
Total plant cost	18,612,900
Land cost	0
Subtotal	18,612,900
Interest during construction period	994,700
Fixed capital cost	19,607,600
Working capital:	
Raw materials and supplies	460,900
Product and in-process inventory	1,025,200
Accounts receivable	1,025,200
Available cash	787,900
Working capital cost	3,299,200
Capitalized startup costs	196,100
Subtotal	3,495,300
Total capital cost	23,102,900

PROCESS ECONOMICS

Utilizing the data on reductions in resin inventory and reagent consumptions, a revised cost analysis of the cobalt recovery operation was obtained from the Bureau's Process Evaluation Group. As in the preliminary evaluation (3), the capital and operating costs were based on processing a 10,000-gpm stream containing 26 ppm Co.

CAPITAL COSTS

The capital cost estimate was of the general type called a study estimate by Weaver and Bauman (10). This type of cost estimate is usually within 30 pct of the cost to build the described plant; however, factors such as changes in material costs can have a significant impact on the accuracy. The estimated total capital cost for a commercial-scale cobalt recovery plant was $23.1 million, based on third quarter 1986 costs (Marshall and Swift index of 798.3). The plant was designed to operate three shifts per day, 7 days per week, and 330 days per year. MCIX columns containing eight compartments were utilized to process as-received copper cementation plant effluent at a flow rate of 5 gpm/ft^2 and an A-R flow ratio of 40:1. A summary of the capital cost is presented in table 3.

OPERATING COSTS

Operating costs were also based on an average of 330 days of operation per year, and include direct, indirect, and fixed costs as detailed in table 4. The estimated annual operating cost for the plant was $13.2 million, which is equivalent to a cost of $13.76/lb of cobalt recovered. However, byproduct credits for a copper-nickel residue, zinc carbonate, nickel carbonate, and cobalt-magnesium carbonate amounted to $8.67/lb of cobalt, yielding a net operating cost of $5.10/lb of cobalt. At the current published price of cobalt, $7.00/lb, the rate of return on investment would be about 4 pct. A selling price of about $10.20/lb of cobalt would yield a 13-pct rate of return on the investment.

TABLE 4. - Estimated annual operating costs

	Annual cost	Costs per pound electrolytic cobalt
Direct costs:		
Raw materials:		
Sulfuric acid at $40/st	$1,453,500	$1.518
Ammonia at $0.14/lb	91,100	.095
Sodium carbonate, 58 pct at $83/st	3,122,500	3.261
Dextrose at $0.26/lb	457,700	.478
Ion-exchange resin at $600/ft^3	944,500	.986
DEHPA solvent at $3.60/gal	21,500	.022
Cyanex 272 solvent at $15/gal	89,600	.094
Chemicals for steamplant H_2O treatment	5,900	.006
Total	6,186,300	6.460
Utilities:		
Electric power at $0.047/kW•h	535,500	.559
Process water at $0.25/Mgal	59,500	.062
Raw water at $0.05/Mgal	1,000	.001
Natural gas at $6.00/MMBtu	1,615,600	1.687
Total	2,211,600	2.309
Direct labor:		
Labor at $9/h	636,500	.665
Supervision, 15 pct of labor	95,500	.100
Total	732,000	.765
Plant maintenance:		
Labor	297,000	.310
Supervision, 20 pct of maintenance labor	59,400	.062
Materials	297,000	.310
Total	653,400	.682
Payroll overhead, 35 pct of above payroll	380,900	.398
Operating supplies, 20 pct of plant maintenance	130,700	.136
Total direct cost	10,294,900	10.750
Indirect cost, 40 pct of direct labor and maintenance	554,200	.579
Fixed cost:		
Taxes, 1 pct of total plant cost	186,100	.194
Insurance, 1 pct of total plant cost	186,100	.194
Depreciation, 10-yr life	1,960,800	2.047
Total operating cost	13,182,100	13.764
Credit:		
Copper-nickel residue at $0.79/lb	3,127,100	3.265
Zinc carbonate at $0.24/lb	2,313,800	2.416
Nickel carbonate at $3.10/lb	2,808,700	2.933
Cobalt-Manganese carbonate at $2.70/lb	52,400	.055
Total	8,302,000	8.669
Net operating cost	4,880,100	5.095

SUMMARY AND CONCLUSIONS

A Pachuca air-lift reactor reduced the overall resin inventory of a cobalt recovery process by 27 pct and the elution resin inventory by 72 pct when compared with a fixed-bed elution column. Total elution time was reduced from about 180 min using the fixed-bed column to approximately 50 min utilizing the Pachuca reactor. Six 5-min contacts employing one 10-g/L H_2SO_4 scrub, two 40-g/L H_2SO_4 eluant contacts with a 250-g/L H_2SO_4 eluant as the second contact of the fourth elution, one water wash, two 4$\underline{N}$ NH_4OH eluant contacts with a 20-pct bleed stream, and one 2-min water wash effectively eluted the loaded resin. Approximately 18 min was required for eluant transfer, eluant drainage, and resin drainage at the end of a completed elution.

Processing fresh cementation plant effluent resulted in product eluates containing approximately 1 g/L Fe; whereas, those obtained from aged feed solution contained 6 g/L Fe. Lower iron concentrations in the eluates reduced reagent consumption for impurity removal. Total sodium carbonate consumption was reduced by 40 pct and dextrose consumption by 70 pct. Resin inventory was reduced by 20 pct using the eight-compartment MCIX column.

Utilizing the eight-compartment MCIX loading column along with the Pachuca reactor for resin elution resulted in a decrease in the total resin inventory by 47 pct; thus, a reduction in the capital cost. The processing of fresh feed solution lowered iron concentrations in the eluates, thus reducing the reagent cost for iron removal. Implementing the Pachuca elution system and processing fresh feed solution resulted in a net operating cost of $5.10/lb of cobalt. This value included byproduct credits.

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