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Examination of Effluents Generated From Processing Domestic Laterites

By Laurel A. Powers and R. E. Siemens



UNITED STATES DEPARTMENT OF THE INTERIOR

Report of Investigations 8797

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James G. Watt, Secretary

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Library of Congress Cataloging in Publication Data:

Powers, Laurel A

Examination of effluents generated from processing domestic laterites.

(Report of investigations ; 8797)

Bibliography: p. 12-13.

Supt. of Docs. no.: I 28.23:8797.

1. Leaching--Waste disposal--Environmental aspects. 2. Laterite--Environmental aspects. 3. Nickel--Metallurgy. 4. Cobalt--Metallurgy. I. Siemens, R. E. (Richard E.). II. Title. III. Series: Report of investigations (United States. Bureau of Mines) ; 8797.

TN23.U43 [TD195.M5] 622s [669'.733] 83-600125

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cm	centimeter	mL	milliliter
cm/yr	centimeter per year	mL/hr-cm ²	milliliter per hour-square centimeter
°C	degree Celsius	mmho/cm	millimho per centimeter
g	gram	µg/g	microgram per gram
g/L	gram per liter	µm	micrometer
hr	hour	N	normality, gram equivalent per liter
kg/ha	kilogram per hectare	pct	percent
L	liter	t	metric ton
meq/g	milliequivalent per gram	t/d	metric ton per day
mg/L	milligram per liter	wt-pct	weight-percent

EXAMINATION OF EFFLUENTS GENERATED FROM PROCESSING DOMESTIC LATERITES

By Laurel A. Powers¹ and R. E. Siemens²

ABSTRACT

The Bureau of Mines process for recovering Ni and Co from low-grade domestic laterites uses a reduction roast followed by an ammonia, ammonium sulfate leach. This investigation examined the waste streams of the process for their potential environmental impact and focused on the laterite residue produced.

The U.S. Environmental Protection Agency's extraction procedure (EP) toxicity tests and column leaching showed that leachable metal concentrations would be low enough so that the residue would not be considered a hazardous waste under present definitions. Under nonacid leaching conditions, about the same amount of metal was extracted from laterites as from their residues, and the leachates were similar to water samples from an undisturbed laterite deposit.

Washing tests on the laterite residue showed that ammonia and ammonium sulfate concentrations were reduced according to equilibrium stage calculations, resulting in residues that would be acceptable for revegetation. With water washing only, the residue would not be considered a hazardous waste even though significant amounts of Ni and Co were absorbed from entrained leach solution onto the residue. Washing first with fresh leach solution and then with water prevented this absorption and thus improved the overall metal recovery.

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INTRODUCTION

Nickel- and cobalt-bearing laterite deposits occur in southwestern Oregon and northwestern California, and in many countries throughout the world. The lateritic soils of Oregon and California are the result of extensive weathering of ultramafic serpentine rocks. Serpentine-derived soils are usually depleted of Si and Mg, and enriched in Al, Fe, Cr, Ni, and Co, compared with the parent serpentine rock. The domestic laterites contain 30 to 40 pct Fe, 5 to 10 pct Mg, and 0.06 to 1.0 pct Ca, and from 0.5 to 1.2 pct Ni, 0.06 to 0.25 pct Co, and about 2 pct Cr as chromite. Vegetation on serpentine-derived soils is well known for its sparse and stunted growth (12).³ It has been suggested that this poor growth is due to levels of Mg, Ni, and Cr in the soil (in descending order of importance) that exceed tolerable levels and to low Ca:Mg ratios, high Fe levels, and low Ca content (24).

The concentrations of Ni, Co, Mg, and Cr and homogeneous distribution of the metals make the current commercial methods for Ni and Co recovery, including pyrometallurgical processes and acid leaching, ineffective for laterite processing (15). The Bureau of Mines has extensively modified existing reduction roast, ammonia leaching technology. The process devised by the Bureau incorporates a selective reduction roast at 500° to 650° C with carbon monoxide gas, followed by an oxidative leach with an ammonia, ammonium sulfate solution. Soluble Mg and Mn are removed from the pregnant leach solution by addition of monoammonium phosphate to precipitate (Mg,Mn)NH₄PO₄, a slow-release fertilizer. Nickel, cobalt, and minor amounts of copper are then recovered by solvent extraction and electrowinning. The process is outlined in figure 1 (8-10, 15).

An important aspect that should be considered during the development of any

process is its potential environmental impact. This investigation examined the effluent and wastes from the Bureau's process, with the intention of ensuring a healthful environment by recommending process modification or waste-handling procedures where necessary. Effluents from the process that could have an impact on the environment include--

1. Dust from laterite preparation,
2. Furnace offgases,
3. Steam and fugitive ammonia release,
4. Waste ash from carbon monoxide generation and fuel, and
5. Washed laterite residue.

Sound engineering practices using existing technology would be adequate to prevent or control any negative environmental impact emanating from most process wastes. Dust at the mine site and in laterite handling can be controlled by watering ore piles, using covered conveyor belts, and minimizing handling (6). Carbon monoxide can be eliminated from furnace offgas by an afterburner, and particulates controlled by cyclones and baghouse collectors. Steam cloud emission can be eliminated by using heat exchangers to recover heat and a cooling tower to recycle the water (17). Fugitive ammonia emissions from the plant can be kept at a minimum by covering all containers and recovering ammonia from all vent streams (23).

The amount of waste ash from carbon monoxide production, with petroleum coke as the preferred source of carbon monoxide, would probably be small. High-sulfur coal, if used, could present a problem, because of leachable salts and metal ions in the ash. It was felt that the evaluation of waste ash was out of the scope of this study, as the fuel used would be the choice of the commercial user.

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

nutrients, such as P, K, and Ca, would be necessary for revegetation. A field test of tall fescue grown on tailings supported these findings (5).

Another environmental investigation was performed by the University of Queensland on residue generated using a reduction roast, ammonia, ammonium carbonate leach at the Queensland Nickel Pty. Ltd. plant, Queensland, Australia (1). In this process, the leached residue is washed countercurrently in a seven-stage circuit with leach solution to achieve a 99-pct removal of soluble metals. The residue is in the form of a 50 pct solids slurry because gravity separation is used in the washing scheme. The ammonia and carbonate are then steam stripped from the residue. This removes about 99.5 pct of the ammonia. For final disposal the residue is pumped to tailings ponds, dewatered further, and eventually revegetated (13).

The revegetation study by the University of Queensland found that revegetation problems on the countercurrently washed residue were the result of extreme deficiency of P, deficiency of K, high salinity, and possible toxic levels of ammonia and Ni. To overcome these problems, the salinity and ammonia content were decreased by allowing the residue to be leached by one season's rain (111.1 cm). The residue was then fertilized and revegetated. Rhodes grass, a salt-tolerant species, gave good ground cover. Very high application rates of P (200 kg/

ha) were needed to overcome the residue's affinity for phosphate binding, which is probably due to iron oxide fixation (1).

Dames and Moore (3) have written an environmental impact report for California Nickel Corp. concerning the Gasquet Mountain project in Del Norte County, CA. Although the proposed processing method for this laterite deposit would not be the Bureau's process, the compilation of background environmental information is significant. A study of the hydrology of the area determined that there is about 280 cm/yr precipitation, with 215 cm/yr runoff. The greatest erosion would occur from landslides, slumping, and bank failures along streambeds and the Smith River. The depth and content of the ground water in the project area is unknown, but attempts at wells to supply water indicate that no large reserves are present.

Federal environmental regulations do not presently cover solid wastes from mining and mineral processing operations like the Bureau's process, but some general considerations may be used as guidelines for recommending the residue's final composition. The pH should be less than 9 to conform with most water quality regulations, and the ammonia and total salt concentration should be low enough to permit revegetation. As the residue would not be isolated from the ground water, it is important to prevent the leaching of excessive amounts of ammonium sulfate into the ground water system.

MATERIALS AND METHODS

Tests were performed on laterites from various deposits in Oregon and California and on the residue generated from continuous processing of these laterites in a 1/4-t/d, integrated-circuit, process research unit (PRU). A flowsheet of the roasting, leaching, solid-liquid separation, and washing sections of the PRU is presented in figure 2. In the washing section, the solid-liquid separation was

performed with a pilot-scale Bird⁴ solid-bowl centrifuge, where a 65 to 70 pct solids discharge was achieved. Repulping for washing was carried out at 20 to 25 pct solids. The residue is similar to the raw laterite except that partial

⁴Reference to specific equipment, trade names, or manufacturers does not imply endorsement by the Bureau of Mines.

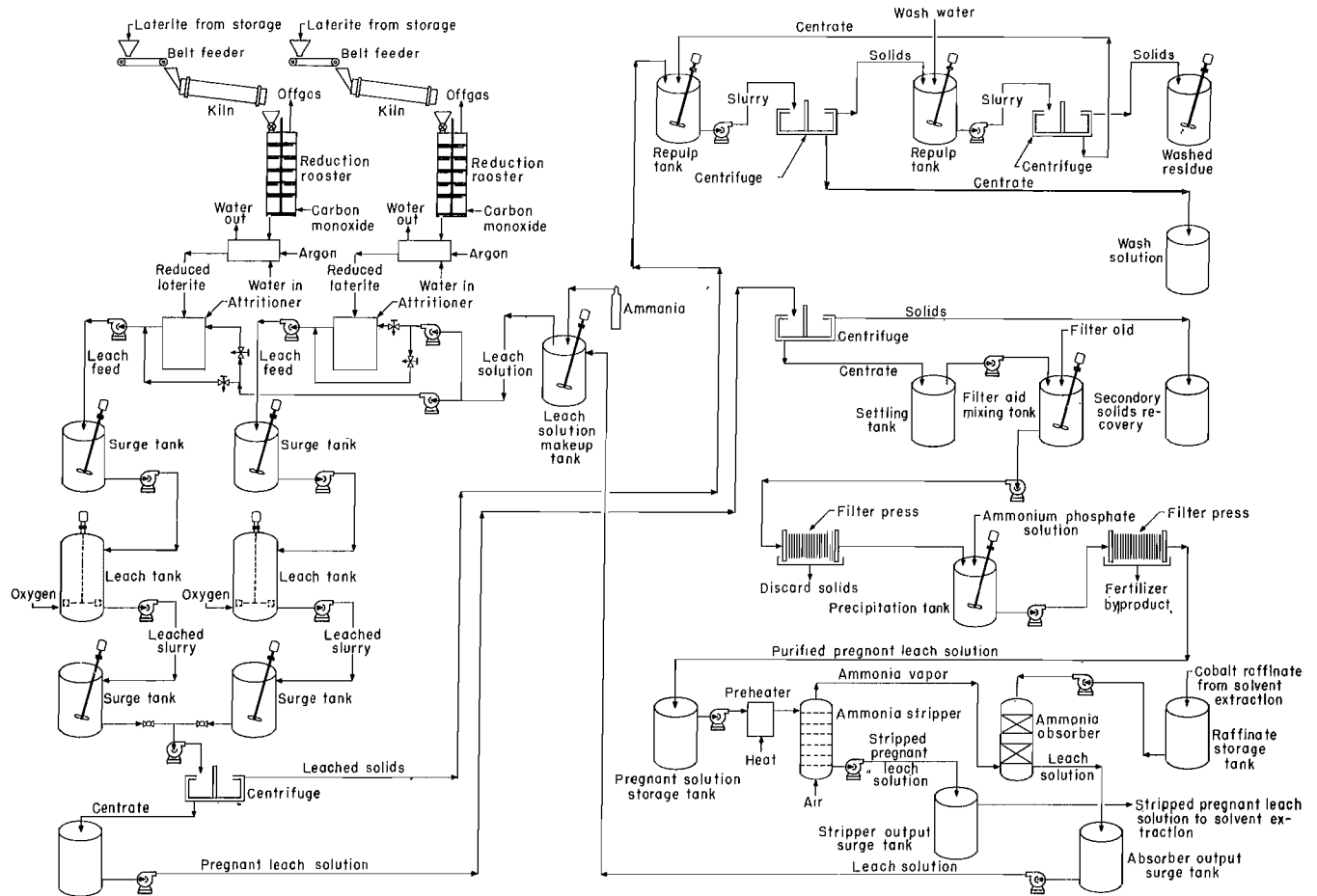


FIGURE 2. - Reduction, leaching, solid-liquid separation, washing, and solution purification units of the Bureau's integrated circuit, continuous processing system.

reduction of the Fe in the reduction roast changes the color from red to black, and the ammonia, ammonium sulfate leach changes the pH from near neutral to basic and adds soluble salts.

Cation exchange capacities of laterites and residues were measured at the Oregon State University Soil Testing Laboratory, using the ammonium acetate method (2). An HF-HCl-HNO₃ pressure dissolution technique (4) was used on the laterites and laterite residues. All solutions were analyzed for dissolved metals with flame atomic absorption. Particle size analysis was performed on particles smaller than 40 μm with a SediGraph particle size analyzer by Micromeritics.

The extraction procedure (EP) toxicity test, developed by the EPA as part of its hazardous waste identification program,

was used to compare laterites and laterite residues. In this test, a small amount of solid waste (100 g) is leached at pH 5 (adjusted with 0.5N acetate acid) in a large volume of water (1.6 L) for 24 hr. The slurry is then filtered with a membrane filter, brought up to a standard volume (2 L) with water, and analyzed for dissolved metals (21). Modified EP toxicity tests without acidification were also performed to simulate the nonacidic rain conditions in the southern Oregon and northern California laterite areas.

Laterite residues were leached in five columns with distilled water. The first column was 15 cm in diameter, 90 cm high and made of glass. A plastic disk with 0.16-cm holes was used as the column support plate. A filter paper was placed on the plate, the column assembled, and a layer of acid-washed glass beads and

diatomaceous earth placed on the bottom. The other four columns were similar but were 10 cm in diameter.

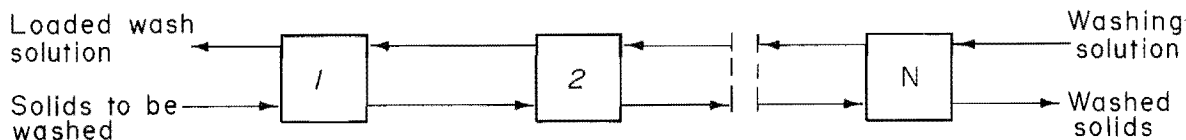
Washing tests on the laterite residue were performed to determine the extent of washing required to meet the plant growth criteria established by Oregon State University, and to examine the adsorption of Ni and Co onto the laterite residue during the washing process. The washing tests on the laterite residue simulated continuous countercurrent and crosscurrent washing, as outlined in figure 3.

Laboratory-scale tests were performed using 250-mL glass jars with a centrifuge for solid-liquid separation. The underflow was removed at about 50 pct solids and repulped to 20 pct solids. The first tests used a three-stage countercurrent wash (fig. 3A) or a three-stage

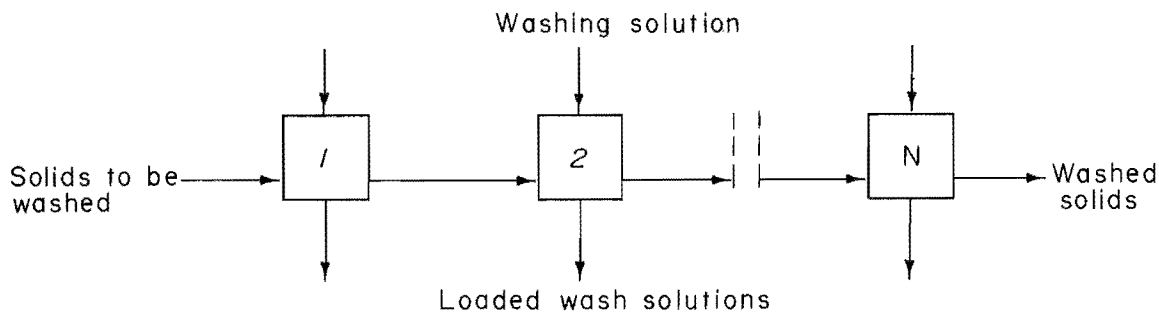
crosscurrent wash with water (3B). These tests were followed by a three-stage crosscurrent wash with ammonia, ammonium sulfate leach solution (3B) and a two-step wash test (3C) in which the residue was first washed with leach solution in a two-stage countercurrent setup, and then with water in a three-stage countercurrent wash. Washing with leach solution was done because other researchers have observed that Ni and Co are adsorbed onto the residue during washing with water only (11).

Washing tests were also performed in the PRU and consisted of a two-stage wash with water (fig. 3A) and a two-step test (3C), with two stages of washing with leach solution followed by a two-stage wash with water. These tests were carried out with 65 to 70 pct solids underflow and a 20 to 25 pct solids repulp.

A MULTISTAGE COUNTERCURRENT WASHING



B MULTISTAGE CROSSCURRENT WASHING



C TWO-STEP COUNTERCURRENT WASHING

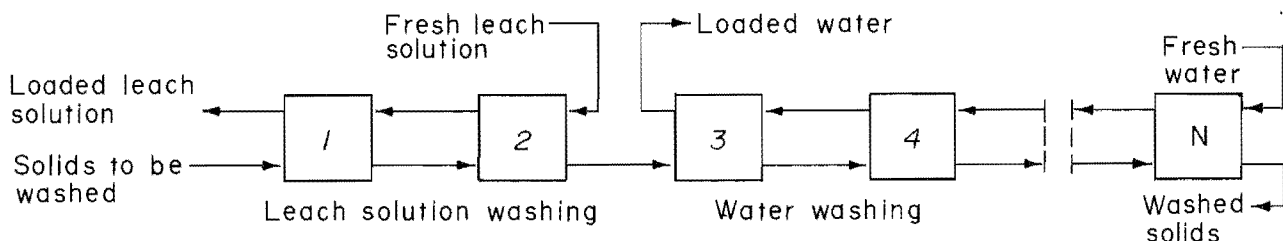


FIGURE 3. - Multistage washing of laterite residue.

RESULTS AND DISCUSSION

PHYSICAL AND CHEMICAL PROPERTIES
OF LATERITE AND RESIDUE

The chemical composition of laterites and typical residues used in this study are presented in table 1. Cation exchange capacities (CEC) were determined for four laterites and laterite residues, and are reported in table 2. Generally a CEC of less than 10 meq/100 g and a ratio of exchangeable Ca:Mg of less than 1 indicate poor soil conditions for plant growth. In most cases the CEC was less than 10, and it was as low as 3.8. There was a 15- to 35-pct reduction in the CEC values during processing in all but the

laterite with the lowest CEC (Rough and Ready Creek), which had a 15-pct increase in CEC. Processing also decreased the Ca:Mg ratio, which ranged from 0.75 to 0.03, by 25 to 85 pct. This was due to an average decrease in exchangeable calcium of 70 pct.

Particle size analyses were not performed on the laterites used in each test because the laterite feeds were in a pelletized form. Sizing of several laterites before pelletizing showed that the laterites were about as follows:

60 pct..... plus 75 μ m

TABLE 1. - Chemical composition of laterites and laterite residues, percent

Sample	Ni	Co	Cu	Cr	Fe	Mg	Mn	Si	Al
Red Flats:									
Laterite.....	1.15	0.07	0.03	1.7	30	7.5	0.35	11.3	1.8
Residue.....	.20	.04	.02	1.7	30	7.5	.34	11.3	1.8
Gasquet Mountain:									
Laterite.....	.74	.09	.02	1.6	34	7.5	.42	11.5	2.4
Residue.....	.18	.04	.02	1.6	34	7.5	.42	11.5	2.4
Rough and Ready Creek:									
Laterite.....	.78	.10	.02	2.2	37	6.0	.25	8.7	3.2
Residue.....	.17	.04	.02	2.2	38	6.0	.25	8.7	3.2
Eight Dollar Mountain:									
Laterite.....	1.17	.07	.02	1.4	35	4.3	.25	11.7	3.4
Residue.....	.24	.03	.02	1.4	35	4.3	.25	11.7	3.4

TABLE 2. - Cation exchange capacity and Ca:Mg ratio of laterites and residues

Sample	CEC, ¹ meq/100 g	Exchangeable cations, meq/100 g ²							Ratio, Ca:Mg
		Ni	Fe	Mn	Mg	Na	Ca	K	
Red Flats:									
Laterite.....	11.4	0.24	<0.01	0.03	9.59	0.32	1.06	0.14	0.11
Residue.....	9.6	.02	.02	.01	9.12	.08	.23	.06	.03
Gasquet Mountain:									
Laterite.....	6.6	.03	<.01	.015	3.40	.52	2.54	.11	.75
Residue.....	5.7	.02	<.005	.04	4.97	.10	.55	.04	.11
Rough and Ready Creek:									
Laterite.....	3.8	.02	<.01	<.005	3.19	.15	.35	.08	.11
Residue.....	4.4	.01	.01	.009	4.10	.07	.14	.03	.03
Eight Dollar Mountain:									
Laterite.....	13.2	.14	<.01	.10	11.60	.13	1.04	.15	.09
Residue.....	8.4	.24	.02	.08	7.25	.21	.50	.07	.07

¹Cation exchange capacity.

²The Cu, Co, and Al contents of all samples were below the detection level. The values preceded by a "less than" sign (<) represent the lowest detection level.

10 pct..... 75 by 44 μm

30 pct..... minus 44 μm

Particle size analysis of the laterite residues indicated the following average size distribution:

18.5 pct.... plus 40 μm

9.8 pct.... 40 by 10 μm

14.0 pct.... 10 by 4 μm

18.3 pct.... 4 by 2 μm

22.3 pct.... 2 by 1 μm

17.1 pct.... minus 1 μm

The size distribution of the residue depends on the laterite handling and preparation, and the amount of attrition that the material experiences through processing.

ENVIRONMENTAL TESTING OF LATERITE AND RESIDUE

Column leaching of four laterite residues with distilled water gave effluent concentration diagrams similar to that for the Eight Dollar Mountain residue presented in figure 4. A decrease in Ni concentration was observed before the ammonium sulfate concentration began to decline. This indicated that the Ni was adsorbing onto the laterite residues rather than rinsing off. The flow of

water through these columns was very slow: 0.30 mL/hr-cm² initially and 0.02 mL/hr-cm² at steady state. This indicates that the residue would be resistant to waterflow in the backfilled pits.

Results of EP toxicity tests and modified EP toxicity tests are presented in table 3. In the EP toxicity test, if the concentration of any metal in the leachate is 100 times greater than the primary drinking water standard for that metal, the tested material is defined as a hazardous waste, unless it is specifically excluded. Presently, mining waste such as laterite residue would be excluded from the hazardous waste designation (21), but the test may be useful in comparing laterite with laterite residue.

Throughout the tests, the metals generally extracted in significant amounts were Ni, Co, Mn, and Mg; none of these metals are controlled in the primary drinking water standard. For all laterites and residues tested, the EP toxicity test, which maintains the leach water at pH 5, resulted in a higher metal concentration in the leachate than did the non-pH-controlled water extraction. For the laterites only, the EP extract contained about 10 times the nonacid leach values for Ni and Mn, and 2.5 times for Mg; Co was at or below the detection limit (0.02 mg/L) in both the EP extract and the water extract.

The pH of the solution used in the EP toxicity tests had an even greater influence on the extraction of metals from the residues. The residues treated with the EP toxicity test (pH 5) resulted in much higher metal concentrations in the extract than did those treated with the modified test (nonacid). Extract from the pH 5 residue leach averaged 30 times higher for Fe and Mg, 100 times higher for Co, 600 times higher for Ni, and 1,000 times higher for Mn. When nonacid extraction of laterites and their residues were compared, the extractions were very similar, but the concentrations were very near or at the detection limit. Leachates obtained from both laterites and residues with nonacid leaching were

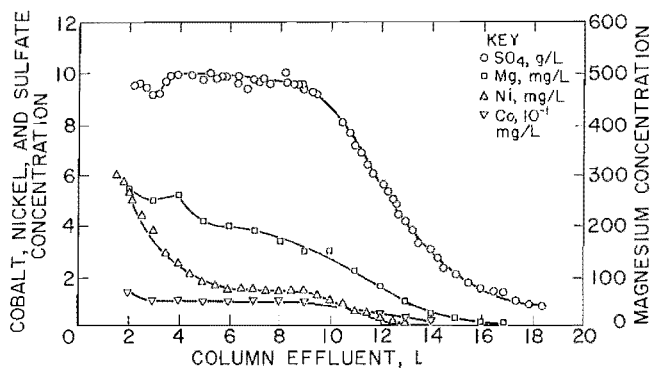


FIGURE 4. - Column effluent concentration for Eight Dollar Mountain laterite residue.

TABLE 3. - Composition of leachates from EP toxicity tests with and without pH control

Sample	0.5N ¹ acetic acid, mL	pH, final	Concentration, mg/L ²						
			Ni	Co	Cr	Zn	Mn	Mg	Fe
Untreated laterites:									
Red Flats.....	0	6.0	0.28	<0.02	<0.05	0.03	0.06	11.3	<0.02
	8.5	5.0	2.08	.02	<.05	<.02	.42	20.8	<.02
Gasquet Mountain.....	0	6.7	<.02	<.02	.05	<.02	.02	4.0	<.02
	9.9	5.0	.48	.02	<.05	<.02	.45	12.8	<.02
Rough and Ready Creek.....	0	6.0	<.02	<.02	<.05	<.02	<.02	4.40	<.05
	3.6	5.0	.12	<.02	.2	<.02	.06	7.60	<.05
Eight Dollar Mountain.....	0	5.8	.06	<.02	.2	<.02	.05	2.84	<.05
	4.4	5.0	.43	<.02	<.05	<.02	.29	8.40	<.05
Routine PRU test residues:									
Red Flats.....	0	9.4	.02	<.02	<.05	<.02	<.02	11.1	.02
	400	5.0	16.2	.74	.1	.05	14.0	65.5	2.25
Gasquet Mountain.....	0	9.2	<.02	<.02	<.05	<.02	<.02	5.20	<.05
	172.9	5.0	9.70	2.09	<.05	.04	30.2	197	.08
Rough and Ready Creek.....	0	9.2	<.01	.01	<.01	<.01	13.0	13.0	.03
	300.0	5.0	11.9	2.01	<.01	.06	18.3	456	.75
Eight Dollar Mountain.....	0	8.7	.03	.03	.2	<.02	<.02	4.50	.4
	135.4	5.0	18.5	2.88	.2	.06	16.1	126	2.2
Controlled washing test residues: ³									
Water only.....	0	9.1	.05	<.02	<.05	<.02	.02	.26	2.9
	109.0	5.0	26.2	2.73	<.05	.05	14.4	61.8	7.9
Two-step procedure.....	0	8.8	.03	.02	<.05	<.02	.05	.36	7.4
	75.5	5.0	5.6	1.04	<.05	.04	9.8	59	3.6
Standards:									
Primary drinking water (19).....	NAP	NAP	NA	NA	.05	NA	NA	NA	NA
Water quality criteria (22).....	NAP	NAP	.03	NA	.05	0.05-5.0	NA	NA	NA
Secondary drinking water (20)...	NAP	NAP	NA	NA	NA	5.0	.05	NA	.3

NA Not available. These metals are not controlled under these regulations. NAP Not applicable.

¹No acid was added for the modified EP toxicity test. For the EP toxicity test, acetic acid was used to adjust the pH of the slurry to 5; the differing amounts of acid added reflect the buffering capacity of the laterites and the presence of NH₄OH in the residue.

²The values preceded by a "less than" sign (<) represent the lowest detection level.

³Eight Dollar Mountain.

TABLE 4. - Composition and pH of Gasquet Mountain water samples

Location ¹	Composition, mg/L ²										
	Ni	Co	Fe	SO ₄	Mg	Na	Ca	Cu	Zn	Mn	pH
1.....	0.03	<0.02	<0.02	1.03	25.0	1.19	0.91	ND	ND	ND	7.0
2.....	.03	<.02	.05	1.54	11.5	1.40	.62	ND	ND	ND	6.5
3.....	.04	<.02	.04	.51	13.0	1.45	.81	ND	ND	ND	7.0
4.....	.23	<.02	1.3	5.1	16.8	1.89	1.8	<0.05	<0.05	0.02	7.3
5.....	.02	<.02	.03	1.03	14.7	1.23	.7	ND	ND	ND	7.3
Average freshwater (7).	.01	.0009	NA	11.2	4.1	6.3	15.0	.01	.01	.015	6.5
Average seawater (16)...	.0030	.0004	.028	2,711	1,300	10,800	410	.050	.011	.0058	8.1

NA Not available. ND Not determined.

¹1. Hanging Valley Stream; seasonal stream, 25° C, clear.

2. Pit 67; dug June 1980; 3 to 8 m deep; near bog; not contaminated with rain; cloudy.

3. Pit 70; open several years, good circulation and full year round; clear water.

4. Pit 80; deep pit, dug summer 1980; not contaminated with rain; cloudy water, very slow filtering.

5. Bog; clear running water located on the lower part of the mountain.

²The values preceded by a "less than" sign (<) represent the lowest detection level.

similar in metal concentrations to water samples collected on the Gasquet Mountain laterite deposit (table 4). These water samples were neutral in pH and high in Mg (12 to 25 mg/L). In one sample, the Ni concentration was 0.23 mg/L, which is high for a freshwater source.

EP toxicity tests were also performed on residues generated in the PRU that were water washed or washed in a two-step procedure consisting of leach solution washing followed by water washing. The results are included in table 3. There were less extractable Ni and Co in the residue washed with the two-step procedure than in the residue washed with water alone.

In countercurrent washing of the laterite residue, it was found that the ammonium sulfate was washed from the residue according to theoretical calculations using equilibrium stage methods. This implies a 100 pct stage efficiency in countercurrent or crosscurrent washing. The removal of ammonium sulfate would depend on the number of stages and the amount of wash water used. With a 70 pct solids discharge and a 20 pct solids repulp, a discharge containing less than 4 g/L $(\text{NH}_4)_2\text{SO}_4$ would be obtained with two stages. With three stages, the discharged solids would contain less than 1 g/L $(\text{NH}_4)_2\text{SO}_4$; and with six stages, they would contain less than 1 mg/L $(\text{NH}_4)_2\text{SO}_4$.

Two-stage countercurrent water washing of laterite residue in the PRU, with the Bird centrifuge used for solid-liquid separation, gave final solids that had 3.9 to 5.4 g/L $(\text{NH}_4)_2\text{SO}_4$ in the contained solution. Thus, the electrical conductivity criterion established by Oregon State University, 4 g/L in 70 pct solids, was nearly met in the PRU test.

The countercurrent water washing of laterite residue in the laboratory showed that Ni and Co adsorbed onto the residue with washing. The concentrations of these metals in the wash solutions were lower than predicted by equilibrium stage calculations, and indicated an adsorption

of 5 and 11 pct, respectively, of the total Ni and Co extracted from the laterite. These results were supported by the crosscurrent water wash, which gave an overall adsorption of 10 pct of the Ni and 20 pct of the Co extracted. The laboratory prewashing of the residue with leach solution, followed by a wash with water, reduced the Ni adsorption to 3 pct. The same wash procedure resulted in 3 pct more Co in solution than was originally present after leaching, which would seem to indicate an additional extraction of Co.

Results from the set of washing tests performed during an extended PRU run with Eight Dollar Mountain laterite are presented in figure 5, which shows the theoretical and actual concentrations of Ni and Co in the wash solution at each

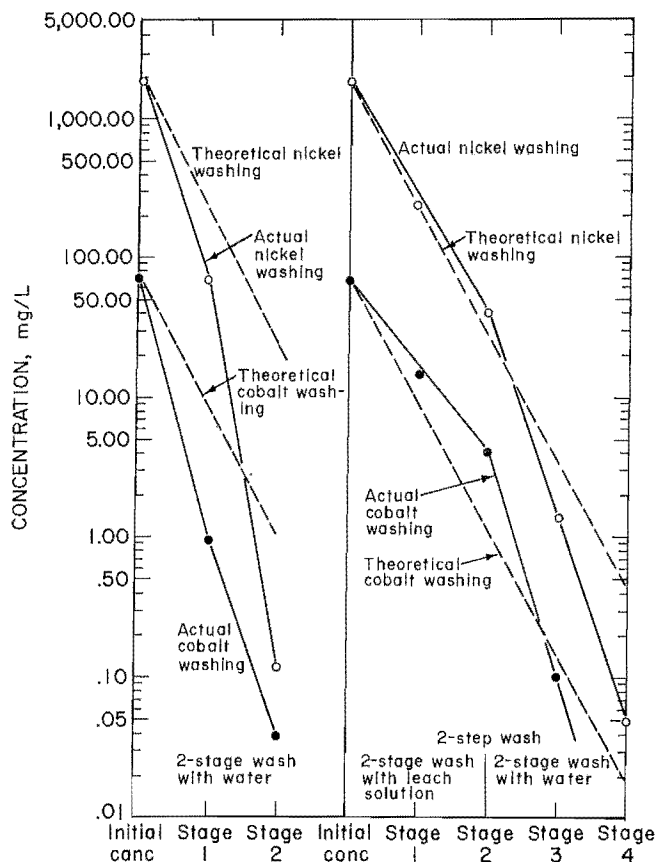


FIGURE 5. - Actual and theoretical solution concentrations for countercurrent washing of laterite residue in the PRU. Cobalt was below detection for stage four of the two-step wash.

stage, and in table 5, which lists the composition of the laterite residue after washing. Water washing of the residue in the PRU resulted in the adsorption of 5.8 pct of the Ni and 7 pct of the Co extracted, based on solution analysis. Prewashing with leach solution eliminated adsorption and resulted in an apparent increase in extraction of both metals (2.3 pct for Ni and 4.8 pct for Co). The increase in Ni and Co recovery in the leach solutions observed in the PRU and laboratory washing tests probably does not indicate an actual extraction of these metals, but may be due to

experimental inaccuracy, an incomplete leaching of the reduced laterite or, in the PRU, washing that was not at equilibrium. Analysis of the Ni and Co content of the laterite residue, while not as accurate as solution analysis, did show that prewashing with leach solution followed by water washing produced a lower metal content in the residue than did water washing alone. There was 0.32 pct Ni in the residue after water washing and 0.26 pct Ni after two-step washing, and the Co content was 0.04 pct after water washing and 0.03 pct after two-step washing.

SUMMARY AND CONCLUSIONS

An important aspect of any hydrometallurgical process is its potential effect on the environment. Some environmental impacts on our natural resources from mining and processing depend on site-specific factors and must be solved at individual plants and mines. Process-related problems can often be anticipated and avoided with proper study. Most wastes generated from processing domestic laterites with the Bureau of Mines reduction roast, ammonia, ammonium sulfate leach process could be adequately controlled or eliminated using presently available technology. This study concentrated on the residue, to ensure that environmental problems would not occur when it was returned to the mine site for disposal and revegetation. Tests were performed on both laterite and residue to compare what might be expected for the undisturbed soil and for the residue returned to the mine pit.

In a study at Oregon State University, it was found that in order to revegetate laterite residue from the Bureau's process, the electrical conductivity must be reduced to below 4 mmho/cm (14). This corresponds to 4 g/L $(NH_4)_2SO_4$ in the contained solution of 70 pct solids residue. Bureau washing tests showed that the ammonium sulfate was removed according to equilibrium stage calculations, and the two-stage wash with water in the PRU resulted in an ammonium sulfate concentration of 3.9 to 5.4 g/L. Thus, two- or three-stage water washing of the residue would provide adequate washing to meet plant growth criteria. The design of a specific washing circuit would depend on the location of the processing plant, and on local, State, and Federal regulations.

During preliminary laboratory-scale washing tests, Ni and Co, present in the

TABLE 5. - Composition of laterite residue after countercurrent washing in the PRU

Countercurrent washing	$(NH_4)_2SO_4$, wt-pct of total	Wt-pct of laterite residue	
		Ni	Co
Unwashed residue.....	10.5	0.38	0.04
One-step washing: two stages with water	.79	.32	.04
Two-step washing:			
After two stages with leach solution..	9.1	.26	.02
After two stages with water.....	.36	.26	.03

entrained leach solution, were observed to adsorb onto the laterite residue during water washing. In the PRU, this resulted in an overall adsorption of 6 pct of the Ni and 7 pct of the Co extracted. Prewashing the residue with leach solution not only solved this problem, it appeared to increase the extraction of Ni by 2.3 pct and Co by 4.8 pct. However, the observed increase in extraction in the PRU tests was probably due to analytical error, washing that was not at equilibrium, or inefficient leaching.

EP toxicity tests showed that the metal concentrations in the residue were sufficiently low that the residue would not be considered a hazardous waste, even without the present exclusion of mining wastes (21). It also appears that the leachability of Ni and Co may be slightly lower for the residue than for the undisturbed laterite under present nonacid rain conditions. Prewashing the residue with leach solution decreased the EP extraction of Ni and Co even further.

The very slow drainage obtained with column leaching of the residues indicates that ground water penetration would be slow. This, coupled with the high runoff rate observed on one laterite deposit (78 pct for the Gasquet Mountain area), indicates that movement of ammonia and ammonium sulfate through the ground water to rivers and streams may not be a problem. Further investigation would be needed to determine this impact at each particular site.

The residue itself does not greatly differ from the laterite soils before processing; the Ni and Co concentrations are lower, and it is finer sized. Some of the Fe has been reduced, changing the color from red to black. Reoxidation, with time, will return the laterite residue to the original color. The original serpentine-derived soils supported only sparse and stunted vegetation because of the presence of high concentrations of Mg, Ni, and Co. Based on chemical analysis and the cation exchange capacity, the laterite residue would face the same problem.

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