82-E-3

812167

THE COLORADO CORPORATION

OLD NICK - NICKEL PROSPECT

ARTIC GOLD AND SILVER MINES, LTD.

O. W. WALVOORD, INC.
JUNE 1970

WALVOORD

O.W. WALVOORD, INC.
Denver, Colorado

CONSULTATION
DESIGN
CONSTRUCTION

Please Reply To: 2105 East Virginia Ave.
Denver, Colorado 80209

June 4, 1970

The Colorado Corporation
200 Brooks Tower Building
1020 15th Street
Denver, Colorado

Attention: Mr. Fred Groth - Vice President

Dear Mr. Groth:

We are pleased to submit the following preliminary comments on the information made available to us on the leaching possibilities of the Old Nick Nickel Prospect of the Artic Gold and Silver Mines, Ltd.

A number of significant areas remain to be clarified geologically, mining and metallurgically before definitelimits can be established as a basis for "Order of Magnitude Estimates."

The memo from M. J. Fitzgerald to Dr. S. E. Jerome dated May 14, 1970 is apparently a summary of the current thinking on the economics of the project.

On page 4 of the memo, a capital cost of $42,000,000.00 is assumed for the conventional milling and leaching plant, which appears to be reasonable for a 10,000 ton per day operation with the present knowledge of the metallurgy. A net operating profit of $1.57 per ton of ore is indicated which would result in approximately a 13% return on the estimated capital investment before amortization. The estimated capital investment without an interest charge would be returned in approximately 7.6 years.

If the full potential of 100,000,000 tons is developed and processed at a net profit of $1.57 per ton, the return will be 3.73 times the capital investment over a period of 28.6 years at 10,000 tons per day processing capacity.

The heap leaching approach for treatment of these ores is, as yet, an experimental technique with no operating experience in nickel processing to rely upon for firm data. A number of questionable areas are as yet to be defined and it is doubtful that a reasonable capital cost estimate could be made at this time. It should be pointed out, however, in translating copper heap leaching practice to nickel practice that the capital and operating costs for copper used by Shoemaker & Darrah[1] are based on 7 to 12 lbs. of copper recovered per ton of ore. Many operating and capital costs are proportional to tons, gallons per minute flowrates, grams per liter of value or other criteria and do not necessarily apply equally to nickel and to copper processes.

Considering the magnitude of operations with the tonnages to crush, the solution volumes to send to solvent extraction and electrowinning and the long period of heap leaching time involved, the capital requirements should receive additional consideration.

The heap leaching will result in large working capital requirements as a portion of the operating cost will be tied up for the length of the leaching cycle which is indicated to be in the range of three to five years. The net profit indicated by Fitzgerald is presumed to be before amortization and allowances for working capital costs. ?

A number of metallurgical approaches are open to better define the capital and operating costs and further study or information is needed on the marketing of nickel to actually develope a meaningful analysis of the project.

These comments are presented for your consideration before any further studies on our part will be undertaken.

Very truly yours,

O. W. Walvoord, Inc.

[1]Shoemaker, R. S., and Darrah, E. M., "The Economics of Heap Leaching," Mining Engineering, December, 1968.

Encl.

OWW:jh

4- Groth
1- O. W. Walvoord, Inc.

TO: Dr. S. E. Jerome

FROM: M. J. Fitzgerald

RE: Leaching Possibilities on the Old Nick Nickel Prospect of Arctic Gold and Silver Mines Limited

DATE: May 14, 1970

On May 13, Egil Livgard and I met with D. W. Duncan and A. Bruynesteyn of B.C. Research to discuss the problems in leaching the nickel-bearing quartzite on the Old Nick prospect of Arctic Gold and Silver Mines Limited, near Osoyoos, B. C. B.C. Research has done a large amount of work on leaching with the support of major copper producers including Phelps Dodge, Anaconda, and Duval. I will first attempt to summarize some of the major points which B.C. Research has discovered concerning sulfide leaching and will then summarize Duncan's and Bruynesteyn's thoughts on application to the Old Nick property.

The B.C. Research personnel believe that bacteria are the major factor in metal sulfide leaching. In the past it was believed that ferric sulfate was the dominant agent in sulfide breakdown, but their tests indicate that bacteria alone, or bacteria combined with ferric sulfate, are much more effective in leaching than sterile ferric sulfate. The rate of leaching in most commercial operations, whether in vats or heaps, is governed by the rate of oxygen supplied to the bacteria and not by the effectiveness of the bacteria themselves. The leaching bacteria require four basic nutrients in order to reproduce rapidly, 1) oxygen, 2) carbon dioxide, 3) ammonia, and 4) phosphate. Oxygen and carbon dioxide are generally supplied by air, phosphate is generally supplied by the rocks being leached, and ammonia is added to the leaching solutions.

As mentioned above, oxygen supply is critical to an effective leaching process and B.C. Research believe that the low recovery achieved from some dumps in the southwest is due to the fact that the dumps are too large. Tests have shown that air penetration in these dumps reaches a maximum of 150 feet from an exposed surface and that portions of a dump separated more than 150 feet from the free surface are essentially "dead".

Wetting and drying cycles are also very important in dump leaching and, contrary to previous belief, B.C. Research feels that effective leaching is accomplished only when the dump is in the drying cycle. The wetting cycle thus serves only to wash out the solubilized metals and to provide the bacteria with nutrients. Consequently, it would appear that the wetting cycle in many commercial dump-leaching operations is too long in duration.

Common metal sulfides have been found to be leachable in the following order:- sphalerite, chalcocite, covellite, bornite, pentlandite, and chalcopyrite. It is interesting to note that although the first four sulfides have been found to be leachable in all instances, the latter two are leachable only in some cases. For instance, chalcopyrite from Bingham is readily leachable, but that from Duval's Sierrita mine is not. Cases have also been found in which pentlandite is not leachable but this is not true of the pentlandite from the old Nick property.

APPLICATION TO THE OLD NICK PROSPECT

Two methods of approach to the Old Nick prospect were discussed with Duncan and Bruynesteyn; 1) mining, milling and leaching of concentrates, and 2) mining and heap leaching.

Mining, Milling and Leaching of Concentrates

Duncan and Bruynesteyn visualize a continuous vat leach of concentrate from a conventional mining and milling operation. The feasibility of the process is largely dependent on the results of the shake-flask tests conducted in 1969. These results were as follows:-

Flotation concentrate from Britton Laboratories - 65% - 200 mesh	90% recovery in 300 hours
Flotation concentrate from Britton Laboratories - reground to -400 mesh	92% recovery in 220 hours

On the basis of the above tests, regrinding of the standard flotation concentrates is definitely indicated.

The shake-flask tests indicate that, in a continous vat leaching process, the retention time would be in the 50 to 100 hour range or somewhat faster than most chalcopyrite. The concentrates would be introduced into the vat at 10-20% pulp density and, as violent agitation would be necessary to obtain sufficient oxygenation, an agitator similar to those used in modern sewage disposal plants would be used. Duncan and Bruynesteyn believe that the resulting pregnant liquor would contain 20-30 grams per liter nickel, a concentration which is amenable to direct electrowinning. The amount of impurities in the pregnant liquor is critical because of the effect on current efficiency in electrowinning.

Further research would be necessary to determine the actual leaching rate, the best type of agitation, the final concentration of nickel in the pregnant solution, and the amount and type of impurities in the pregnant solution before tight cost estimates could be projected for the process.

General estimates, believed to be conservative, of costs in an operation of this type, are projected as follows:-

Concentrate leaching costs	19.8¢ per lb Ni recovered
Electrowinning	10¢ per lb Ni recovered

Comparable[1] costs for copper leaching operations are 8-20¢ per pound copper recovered for leaching and 7¢ per pound copper recovered for solvent extraction and electrowinning. It should be noted that the copper leaching costs include the cost of acid and scrap iron and also the cost of solvent extraction, neither of which appear to be called for in this case. The relatively high costs projected for leaching and electrowinning in the nickel operation are used to allow for the higher costs expected to be incurred because of the low grade of the material being leached.

These costs, as applied to a possible mining operation, are as follows:-

Mining Rate	10,000 TPD
Stripping Ratio	2:1
Mill Recovery	80%
Leaching Recovery	90%
Mill Concentrate Grade	2%
Ore Grade	0.22% Ni
Ultimate Nickel Recovery	3.17 lbs Ni/Ton
Gross Recoverable Value (3.17lbs @ $1.30)	$4.12

1. Shoemaker, R.S., and Darrah, E.M., The Economics of Heap Leaching, Mining Engineering, December, 1968.

	Cost Per Ton Ore Mined
Mining	$0.75
Milling	0.75
Regrinding and Leaching (@ 3¢ & 20¢ per lb Ni recovered)	0.73
Electrowinning (@ 10¢ per lb Ni recovered)	0.32
Total	$2.55

Operating profit per ton ore

Gross Recoverable Value	$4.12
Operating Cost	2.55
Net Operating Profit	$1.57

Capital Requirements

Mine Development and Equipment	$ 5,000,000.00
Mill	35,000,000.00
Leaching	2,000,000.00
	$42,000,000.00

Possible copper and cobalt values in the mineralization have not been included in the estimate because the chalcopyrite in nickel deposits is usually difficult to leach and because extraction methods for cobalt in solution are unknown.

Heap Leaching

The other alternative in treatment of the Old Nick mineralization would be heap leaching. The final extraction of nickel from the mineralized material cannot be projected until column testing of broken rock is undertaken but Duncan and Bruynesteyn believe that the shake-flask test results indicate that at least 45% of the nickel could be recovered by heap leaching in three to five years. Total extraction could be as high as 70-80% but all estimates given below are based on 45% extraction. Nickel recovery might be increased by one stage of crushing prior to piling on the dump and a cost has been allotted for crushing in the cost estimates. In addition, provision has been made for preparation of leach pads and careful heap building in the cost estimates.

An additional step would probably be required for heap leaching as the nickel concentration in the pregnant solution would probably be too low for efficient electrowinning. Solvent extraction is envisioned as several nickel-extracting solvents are known. Costs listed below have been extrapolated in part from existing copper leaching operations.

Cost estimates, again believed to be conservative, for a heap leaching operation, are as follows:-

	Cost Per Ton	Cost Per Lb Ni Recovered
Mining	$0.75	$0.377
Leach Pad Preparation and Dump Building	0.15	0.083
Crushing	0.05	0.028
Leaching (includes labor, power, supplies, etc.)	0.08	0.040
Solvent Extraction and Electrowinning (includes labor, power, reagents, supplies, etc.)	0.42	0.211
Total	$1.45	$0.739

Operating Profit

Gross Recoverable Value Per Ton	$2.59
Operating Cost Per Ton	1.45
Net Operating Profit	$1.14

OR

Nickel Value Per Lb	$1.30
Operating Cost Per Lb Ni Recovered	0.74
Net Operating Profit Per Lb Ni Recovered	$0.56

Capital Requirements

Mine Development and Equipment	$5,000,000
Leaching Equipment	1,000,000
Solvent Extraction & Electrowinning Plant	3,000,000
	$9,000,000

Comparison of Treatment Methods

Of the two treatment methods considered, the technique of mining, milling, and leaching appears to offer the advantage of higher operating profit per ton but has the distinct disadvantage of a considerably longer payout period due to the much larger capital investment required. Approximate periods for payout of capital plus interest for the two methods at an average grade of 0.22%Ni but without consideration of taxes, depletion, and allowances for working capital costs are as follows:-

Mining, Milling, Leaching of Concentrates	Heap Leaching
11.6 years	5.5 years

If 15 to 20 million tons of mineralization averaging 0.30%Ni is present on the property which could be mined in the beginning years, the approximate capital and interest payout period would be much more favorable:-

Mining, Milling, Leaching of Concentrates	Heap Leaching
6.0 years	2.6 years

Again, it should be noted that allowances have not been made for taxes, depletion, and working capital. Results of the current debate on the White Paper on Taxation and its effect on mining operations could alter the possible projected economics of the possible operation greatly.

Of the two methods, heap leaching appears to be the most favorable from a payout standpoint but has the disadvantage of requiring relatively unknown technology. The leaching research proposed by B.C. Research would be the key to application of either of the two methods.

DISCUSSION AND CONCLUSIONS

The cost estimates based on data supplied by B.C. Research appear to indicate considerable profit potential on the Old Nick prospect if the average nickel content of large tonnages is 0.2% or higher. If there is a substantial tonnage of mineralization on the property which averages 0.25%Ni or higher, the profit potential would be very healthy.

Both envisioned methods of treatment appear to be potentially profitable and each has its advantages and drawbacks. Mining, conventional milling, and leaching of concentrates appears to be the more profitable of the two methods and, in addition, has the advantage of being fully profitable soon after the plant went onstream. The disadvantage of the method is the high initial capital cost (although only slightly higher than that of a conventional porphyry copper operation) and the considerably longer payout period. The alternative method of mining and heap leaching would appear to be somewhat less profitable on an operating cost basis but only about one-fifth the capital investment would be required with a resulting shorter payout period. The main disadvantage of mining and heap leaching from my viewpoint would be the three to five year time lag from the point at which the operation went onstream until full production was achieved.

Examination of the prospect and of all the data recovered from previous exploration indicates that the potential tonnage of mineralized material which might be mined by open pit methods on the prospect is in the 50-100 million ton range. There also appears to be good probability that the grade of the mineralization below the zone of near-surface leaching would be in the 0.20-0.25%Ni range. Discovery of a zone of mineralization in the 0.30%Ni grade range which could be mined in the early stages would greatly enhance the potential of the prospect. Results of the proposed leaching research are also very critical and initiation of the research program should be concurrent with additional drilling.

In conclusion, the prospect is believed to be worthy of a dual program to further investigate ore potential. The program would consist of, 1) 5 to 10 widely spaced drill holes to investigate the consistency and grade of the mineralization indicated by previous drilling and, 2) further investigation of the leaching characteristics of the mineralization. The estimated cost of the program would be as follows:-

Bulldozer trenching: 2000 linear feet - 50 hours @ $30/hr	$ 1,500
Drilling: 5000 feet @ $12/ft overall	60,000
Leaching Research: Including column, test heaps solvent extraction, and electrowinning testing	40,000
Total Estimate	$101,500

Heap leaching requires low capitalization but careful planning and pilot operation are needed to assure profitability.

The Economics of Heap Leaching

R. S. SHOEMAKER AND R. M. DARRAH

Expanded markets for copper in the past few years and a consequent search for new ore bodies have revitalized the widely known but seldom applied method of producing copper called heap leaching. Heap leaching is defined here as the process applied to oxide ores which have been mined solely for the purpose of leaching. In this case, all costs of mining the ore become a part (and a substantial one, as will be shown) of the cost of the copper produced, whereas in dump leaching the mining cost has already been accounted for as a stripping cost for the sulfide ore. Of course, with newly opened ore bodies, stripping costs may be divided through accounting procedures, between the copper produced by the mill and that obtained by leaching, but in general this type of operation must be economic on the basis of the sulfide ore alone.

Heap Leaching Requires Low Capitalization

Heap leaching, as a beneficiation method, is unique in that it is the only process used for the recovery of a metal in which the time involved from mining the ore to metal production is measured in months instead of hours or at the most, days. Then too, after the ore body has been depleted and mining has ceased, metal production will continue for some substantial period of time. Heap leaching is also unique because unlike any other method of beneficiation, metal recovery cannot be accurately forecast ahead of time and recovery will never approach that of a conventionally milled sulfide ore or even that of a vat leached oxide ore. Counter-balancing this drawback, however, is the relatively low capital expenditure necessary to put a heap leaching operation into production and the consequence that smaller ore bodies which would not support the higher capital cost involved in a vat leaching plant can be made into producers. Stated more simply, in heap leaching the operator accepts low recovery in exchange for low capital costs and low break even point. Whether the operator chooses vat leaching with its higher recovery and higher capital costs, is a matter of economics which depends in part on the nature of the ore to decide. For instance, an ore that will vat leach in 7 to 10 days using 7 pounds of sulfuric acid per pound of copper produced might use double or triple that amount of acid during the months that are required for heap leaching.

Although heap leaching reduces capital expenditures, it does require extensive test work and sound engineering to produce a successful operation. A company contemplating heap leaching must insist on a definite, well planned program of investigation. Adequate exploration is a necessity to assure that high acid consuming sections are not present in the ore body. Test work must be done on drill cores to determine if acid attack on the host rock will result in physical degradation which would blind a leach heap. Items such as acid consumption, seepage and evaporation losses, leaching rates and anticipated ultimate recovery must be established.

Factors Affecting Cost Estimates

Recovery of copper during heap leaching cannot be accurately forecast by presently available technology. As a part of the testwork and an aid in predicting recovery, we believe a test leaching column 16-20 ft high and 4-5 ft in diam offers the best possibilities for most accurate predictions. The ideal test work would be done on a test heap of the ultimate height to which the ore would be heaped, but this is obviously too expensive and time consuming. Lacking positive information as to recovery, the owner must necessarily make fairly broad assumptions and then temper them with conservative judgement. However, a fairly competent rock containing acid soluble oxide copper that leaches

R. S. SHOEMAKER and R. M. DARRAH, SME members, are respectively, Consulting Metallurgist and Senior Engineer with Bechtel Corp., San Francisco, Calif.

easily, and which is heaped on an impervious pad should give an ultimate recovery of the order of 60%. If the ore contains some sulfide copper and recovery is by cementation which will produce some ferric iron, some additional copper may be recovered over a long period of time but this copper should not be considered when calculating the economics of the project.

This article looks at the various elements of cost which are involved in heap leaching and which should receive careful study. As an aid in examining these costs, we will assume a hypothetical heap leaching operation and use the following criteria:

Grade	0.5% to 1.0% Acid Soluble Copper
Stripping Ratio	1 to 1
Ultimate Copper Recovery	60%
Acid Consumption	5 to 9 lbs. per lb Cu Produced

(1.5 lb. for copper leaching—1.0 lb. used in reaction with scrap iron, remainder used in reaction with gangue minerals)
Copper to be Recovered by Cementation

Capital charges for heap leaching and cementation operations are relatively low and, therefore, we must look very carefully at operating costs. A minor portion of these are relatively fixed in amount (labor, power, water, supplies and scrap iron) while the major costs can vary substantially (mining and sulfuric acid).

The largest of the fixed costs is that for the scrap iron that is presently priced at $50-52 per ton delivered which represents about 2.5¢ per pound. It does not appear that this price will vary substantially in the near future. Since roughly 1.5 lbs of iron will be used per pound of copper produced, the cost of the iron will be about 3.8¢. The remainder of the fixed costs per day will be approximately as follows:

Supervision and Salaried	$140.00
Labor—10 Shifts per Day @ $40.00	400.00
Power—4000 kwh @ $0.015	60.00
Water	100.00
Miscellaneous Supplies	50.00
Total	$750.00

Based on 60,000 lb. of copper per day, this would amount to $0.013 per lb. of copper produced. Freight to the smelter and smelter charges will amount to $0.07 per lb. of copper.

Mining Ore for Heap Leaching

Mining of oxide ore for heap leaching can represent a very substantial cost, particularly if a good portion of the ore is hard enough to need blasting, however, the physical nature of these ores generally permits mining by ripping and scraping thus taking advantage of these low cost methods of earth moving. In order to keep capital investment to a minimum, it may be advantageous to contract the mining operation but in this case, extra care must be taken so that over-burden or high acid consuming ore is not put on the leach heaps. A mining contract should also be written to permit renegotiation after a period of time since drilling and seismic testing will not permit an exact forecast of ripping and scraping costs. Thus, mining costs may be lowered as the contractor gains experience.

Fig. 1 shows ore mining costs plotted against pounds of copper recovered per ton of ore and indicates that under favorable conditions of high re-

Fig. 1—Mining costs vs. pounds of copper recovered per ton of ore.

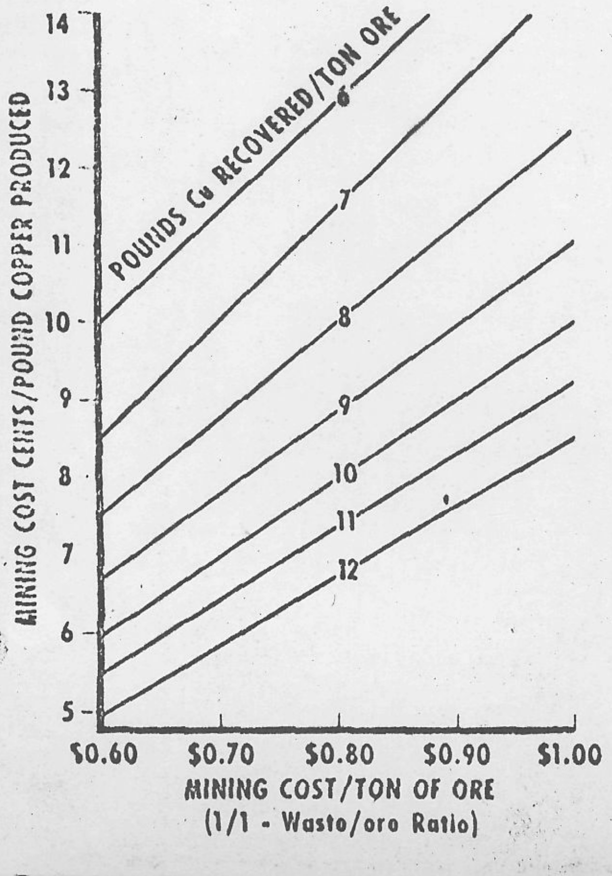
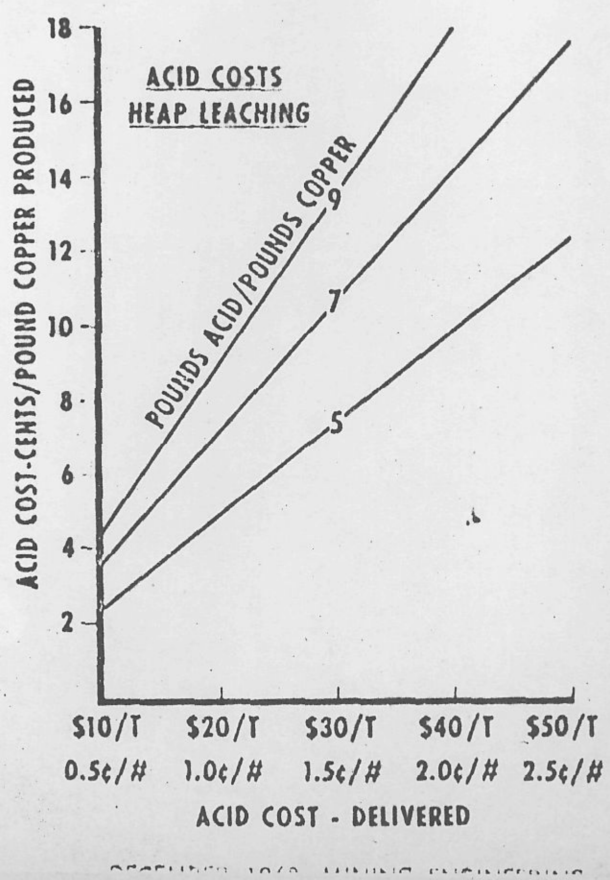


Fig. 2—Acid costs per pound of copper produced vs. price of acid.



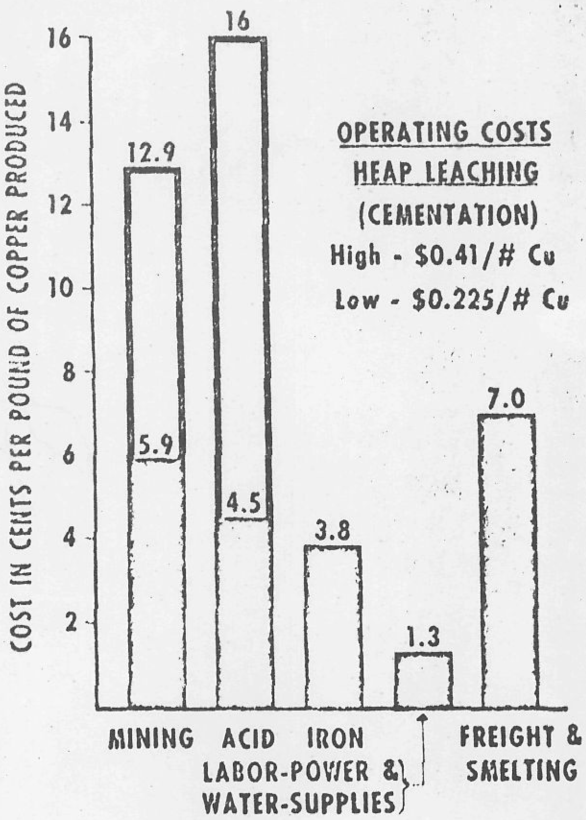


Fig. 3—Operating costs in heap leaching.

covery and low mining costs, a mining cost as low as $0.059 per pound of copper produced would be realized. The opposite conditions, however, would indicate mining costs of $0.129 or more per pound of copper produced. These figures are for $0.70 and $0.90 per ton of ore mining costs and 12 and 7 lb. copper recoveries. An operation encountering the higher cost and lower recovery would be more than a borderline one.

Acid a Major Cost Item

The largest cost variable in heap leaching is the amount and particularly the price of sulfuric acid. The amount of acid used is, of course, dictated by the mineralogy of the ore but it would appear that at the present time the price of acid depends greatly on local supply. It is reported that prices of sulfuric acid (delivered) in the Southwestern states range from $12.00 to $44.00 per ton. It would seem, however, that with pressure being brought to bear on the smelters by air pollution authorities, that some pressure will in turn be put on acid prices in that area in the next few years.

Fig. 2 presents acid cost per pound of copper produced as a function of delivered acid cost and acid consumed per pound of copper. Here again, favorable conditions will result in favorable costs. With acid at $0.0075 per lb and 6 lbs. of acid used per pound of copper, the cost per pound of copper would be $0.045. With acid at $0.02 per lb. and 8 lbs. consumed, the cost would be $0.16 per lb. of copper produced. It is reported that one operation uses 10 pounds or more of acid per pound of copper but most heap leaching operations use considerably less.

It should be noted that theoretical acid consumption with pure copper minerals is 1½ lbs. of acid per pound of copper. The remainder of the acid used on an ore is consumed by carbonates, clays, etc.

One of the intangibles involved in heap leaching is the amount of acid and copper lost by seepage and, unless the ground under the heap is completely impermeable, a considerable amount of acid will be consumed by reaction with that soil or rock underlying the heap. Cases are known and they are not unusual, where a ton of surface soil will consume 50 lbs. of sulfuric acid. If the soil under the heap were to be wetted to a depth of 6 ft and it weighed 100 lbs. per cu. ft, as much as 135 lbs. of acid could be lost per square yard of heap area. At the same time, if the pregnant solution coming through each square yard of the heap contained 3 gpl of copper and the soil soaked up 15% of its weight of solution, then 2.4 lbs. of copper would be lost. Even at the minimum case of acid at $0.0075 per lb. and with a net of $0.12 per lb. lost on copper that would not be produced, this loss from seepage and reaction would be $1.30 per sq. yd. of heap area and it could be as much as $3.00 per sq. yd. with acid at $0.02 per lb. Since recent costs of clearing, leveling and coating with asphalt have been $1.80 to $2.00 per sq. yd., it would seem that sealing the area under the leach heap would be imperative unless comprehensive testwork dictated otherwise.

The operating costs cited above have been summarized in Fig. 3. The figures for mining and acid costs have been given as minimums and maximums and it is easy to see that the operating costs for a heap leaching operation can vary from a low of $0.225 to a high of $0.41 per lb. of copper produced. Unfortunately, a few of the latter operations have been started on the basis of insufficient test work. They are not in operation at the present time.

Benefits of Solvent Extraction and Electrowinning

A discussion of heap leaching economics would not be complete if it ended at the production of cement copper which still is subject to smelting charges before it may be sold. To complete the picture, the production of cathode copper through solvent extraction (liquid ion exchange) and electrowinning should be thoroughly investigated. Investing in a smelter for a small tonnage of copper concentrates obtained from conventional milling of a small sulfide ore body would, of course, be out of the question. When, however, the copper is in the form of a pregnant solution and where concentration of this solution and electrowinning of its values will yield a highly saleable product, it should behoove the owner to investigate such a process which would permit a direct sale of the product to the smelter. The benefits of solvent extraction and electrowinning over cementation are immediately apparent in three ways: the smelting and freight charge of 7¢ per lb. of copper is nullified, the charge of 3.8¢ per lb. of scrap iron will no longer apply, and from 1.1 to 3.0¢ per lb. will be saved

(Continued on page 90)

ing of the charge which is not present in wet grinding mills. Where small (2½- to 2-in.) diameter rods are needed for fine grinding, rod lengths of 12 to 14 ft seems to be the limit. This limits the mill diameter to about 10 ft inside the shell.

7. Closed circuiting of dry grinding rod mills is successful in controlling the top size in the product; however, it can generate circulating loads approaching 200% which can affect material transport through mill restricting mill capacity. Frequently the circulating load is in a narrow size range which can contribute to the flow problems.
8. In addition to the normal wet-to-dry grinding conversion factor, there is an additional inefficiency factor in dry grinding rod mills. With the most suitable conditions for good grinding, the degree of this inefficiency is a variable between 10 and 100%. This inefficiency factor still has to be defined and a means to measure it established. At present the degree of this factor is a judgment factor based upon the grain structure, moisture content and flowability of the material to be ground.
9. The Bond work index formula[1] can be used to determine the power required for dry rod milling. The power determined should be multiplied by all the required inefficiency factors and by the 1.3 wet to dry grinding factor. It is also necessary to apply the inefficiency factor discussed above.
10. All dry grinding rod mills should have air drawn through the mill. A rule of thumb is 3 to 4 cfm of air per mill horsepower. This performs two functions. It prevents dust from escaping around the spout feeders and the peripheral discharge housing. If the feed contains some moisture, a continuous draw of air through the mill prevents coating in the mill and the peripheral discharge housing. Coating in the mill contributes to swelling of the rod charge. When the amount of moisture in the air discharging from the mill is high enough to cause condensation in the ducts from the mill to the dust collector, this duct work should be insulated and heated if necessary to prevent condensation. Condensation can cause a buildup eventually plugging the duct.
11. Rod wear data is being developed and indications are that it is less than for wet rod milling. Little exact data is available because the rod breakage and bending problems have added to the rod consumption to a great degree and clouds the entire picture. ∇E

References

[1] Bond, F. C., "Crushing and Grinding Calculations," *British Chemical Engineering*, June and August 1961.

Heap Leaching *(Continued from page 70)*

from the 1.5 lb of sulfuric acid which will be generated per pound of copper produced in the electrowinning circuit. The total savings here amount to 11.9-13.8¢ per lb. of copper produced.

Counterbalancing the above figures will, of course, be the cost of constructing and operating the solvent extraction plant. Here, because of varying local conditions and costs as well as degrees of sophistication sometimes specified by operators, capital costs cannot be given accurately. But for a small yearly production of copper, we believe the capital cost of a solvent extraction and electrowinning plant will be of the order of $170,000 to $190,000 (1968 prices) per daily ton of cathode copper produced.

Operating costs for a solvent extraction and electrowinning plant of 60,000 lbs. per day capacity will be approximately as follows:

Supervision and Salaried	$ 140.00
Labor—12 Shifts per Day @ $40.00	480.00
Power—85,000 kwh @ $0.015	1,275.00
Organic	1,000.00
Lead Anodes	170.00
Starting Sheets	575.00
Miscellaneous Supplies and Maintenance Items	560.00
Total	$4,200.00

Based on 60,000 lbs. of copper per day, this would amount to $0.07 per lb. of copper produced. Added to this figure would be the 1¢ that it would cost to operate the leaching system. The total operating cost for produced cathode copper would then be approximately as follows:

	Low	High
Mining	$0.069	$0.129
Acid	0.034	0.130
Leaching	0.010	0.010
Solvent Extraction & Electrowinning	0.070	0.070
Total	$0.178	$0.339
SX Electrowinning - Cementation Differential	0.062	0.071

The difference in savings attributed to solvent extraction and electrowinning is accounted for by the different values assigned to the sulfuric acid generated in the electrowinning process. From the increased operating margin shown above for coupling solvent extraction and electrowinning to a heap leaching operation, it seems clear that this course of action should at least be investigated by the operator who is contemplating the recovery of copper from an oxide ore body. Capital costs are, of course, more than for a cementation operation but the possibility of increased profit plus the advantage of being independent of a smelting operation makes it most attractive.

Conclusion

The prospects for heap leaching in the future seem to be bright. Research programs are now being carried out that will increase our knowledge of the chemistry of heap leaching (and increase recoveries also) and permit far more adequate assessments of the feasibility of heap leaching. With time recoveries should be forecast with accuracies approaching those for conventionally milled sulfide ores.