GL03957

FIELD TEST REPORT

Lakeshore Mine
Casa Grande, Arizona

November 15-18, 1982

Peter G. Chamberlain

INTRODUCTION

The Bureau of Mines and Noranda Lakeshore Mines, Incorporated, have agreed to cooperate on a research program designed to develop concepts for and evaluate the potential of in situ leaching for recovering copper from orebodies within the Lakeshore mine. The mine, located on the Papago Indian Reservation south of Casa Grande, Arizona, is presently mined by block caving and vat leaching.

The leachability of the ore and low copper price have stimulated investigation of in situ leaching techniques for copper recovery. Most of the chemistry has been worked out during vat leaching development. Prime unknowns that must be resolved before implementing any in situ leaching operations include: (1) the ability of the formations to conduct fluids (permeability) with or without blasting; (2) the change in permeability as copper minerals are leached; (3) leaching rate for the rock in place; and (4) the recovery of pregnant solutions in unsaturated formations. Basically one needs to know the solution grade and number of wells operating at a reasonable pressure that will provide an adequate flow to the tank house.

Leaching rate has been evaluated by a series of column leaching tests conducted at the Bureau of Mines Twin Cities Research Center, and at the Lakeshore Mine. The critical portion of the testing program remaining is an evaluation of the flow characteristics of the leaching solution. The sequence of steps envisioned is to determine: (1) the native permeability of the rock; (2) the change in permeability as a function of leaching time; (3) recovery of leaching fluids with various spacing of wells; and finally (4) leaching of various configuration injection/recovery wells at essentially full scale over a "unit cell".

The subject field trip was the first effort to determine the flow characteristics of the formation at Lakeshore. Its objective was to determine the basic permeability of the rock and the ability of water to migrate from injection wells to nearby recovery wells under reasonable operating pressures.

TEST PROGRAM

The permeability test method selected was simply to inject water into a well at a constant pressure--the popular "constant head" test. Packers were used to isolate zones of interest and permit higher test pressures than could be obtained in open holes. Although the formation was above the water table, the only difference in the test procedure from that used in saturated formations was in the calculation of the head or pressure in the test zone. The method was taken from the Bureau of Reclamation (1) procedures. Another version of the same technique was published in the Final Report for Contract J0265045 (2).

Apparatus

NQ core holes were drilled for the permeability tests. Triple-tube core barrels provided better core than usually achieved with standard barrels. Hole directional surveying equipment was a Humphries Company single-shot orienting device.

Key element for permeability tests is a packer system. Tests were run with one packer or with two packers connected so as to isolate or "straddle" a particular zone of interest (figure 1). Three-inch inflatable packers were purchased from Baske Water Instruments, Denver, Colorado. Each had an inflatable element of about 20 inches long. Pressure to inflate the packers was obtained from a nitrogen gas cylinder connected to each packer through 1/8-inch plastic tubing. Water to be injected into the formation was carried to and through the packers by 1-inch stainless steel pipe connected in 5-foot sections. Since the packers likely will later be used for leaching solution injection, their components were fabricated from 316 stainless steel.

Water under pressure was supplied to the packers for injection from an apparatus (constructed by Noranda) consisting of holding tank, 2-HP Lincoln electrical pump, flow meter, and a regulated bypass line (figure 2). A valve on the bypass line regulated pressure in the hole much more easily than could a valve regulating the flow directly to the injection line. The flow to the injection zone was transmitted from the supply apparatus to the pipe at the well head via flexible hose that is normally used in drilling operations. A pressure gauge also was attached to the end of the tubing by a "T" pipe section. Although a flow meter was attached to the water supply apparatus, it was relatively insensitive over the range of four flow rates experienced; more accurate readings were obtained by monitoring water level in the supply tank over timed intervals. The calibration for the tanks was: 1 inch change in water level = 1.96 gallons.

Procedure

A test site was selected on the 1,100 level of the mine at the entry to the "old" lunch room. Three holes were cored at a 30° angle down from the horizontal so that they would be approximately normal to the plane of a major joint set (figure 3). The holes ranged from 70 to 75 feet long. Hole PT-1 produced a poor quality core and was presumed by the driller to be significantly caved or closed. Hole PT-2 produced the poorest quality core of the three holes and was presumed to be partially caved. Hole PT-3 produced the best quality core and was open over its entire length. Core from hole PT-3 was air freighted from Arizona to the Bureau.

Since a significant threat of sticking the packers in holes PT-1 and 2 existed, permeability tests as a function of depth were conducted only in PT-3.

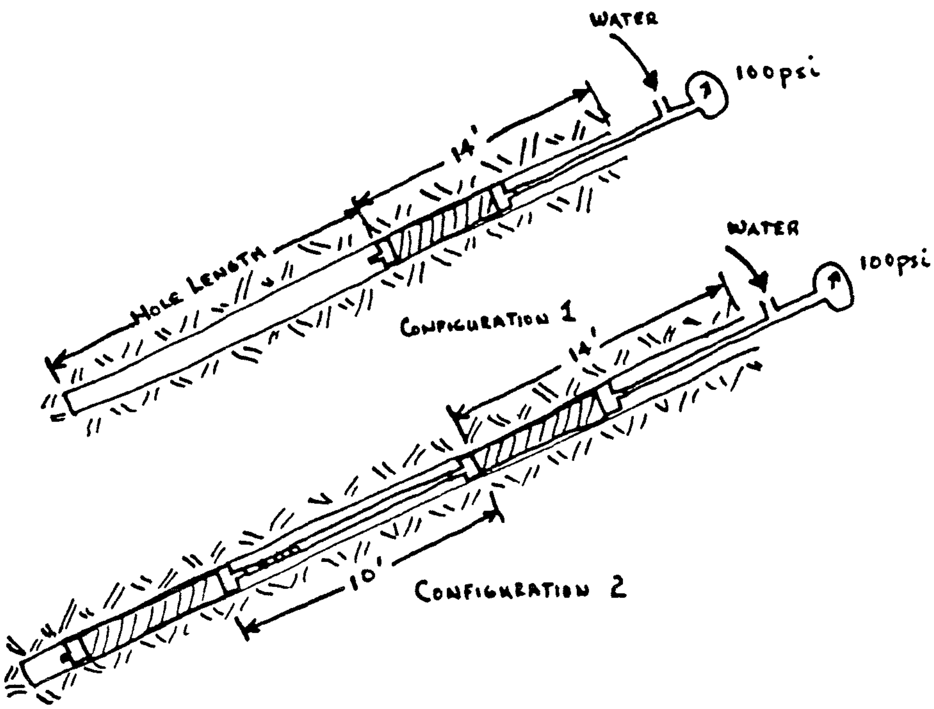

FIGURE 1. - Packer configurations.

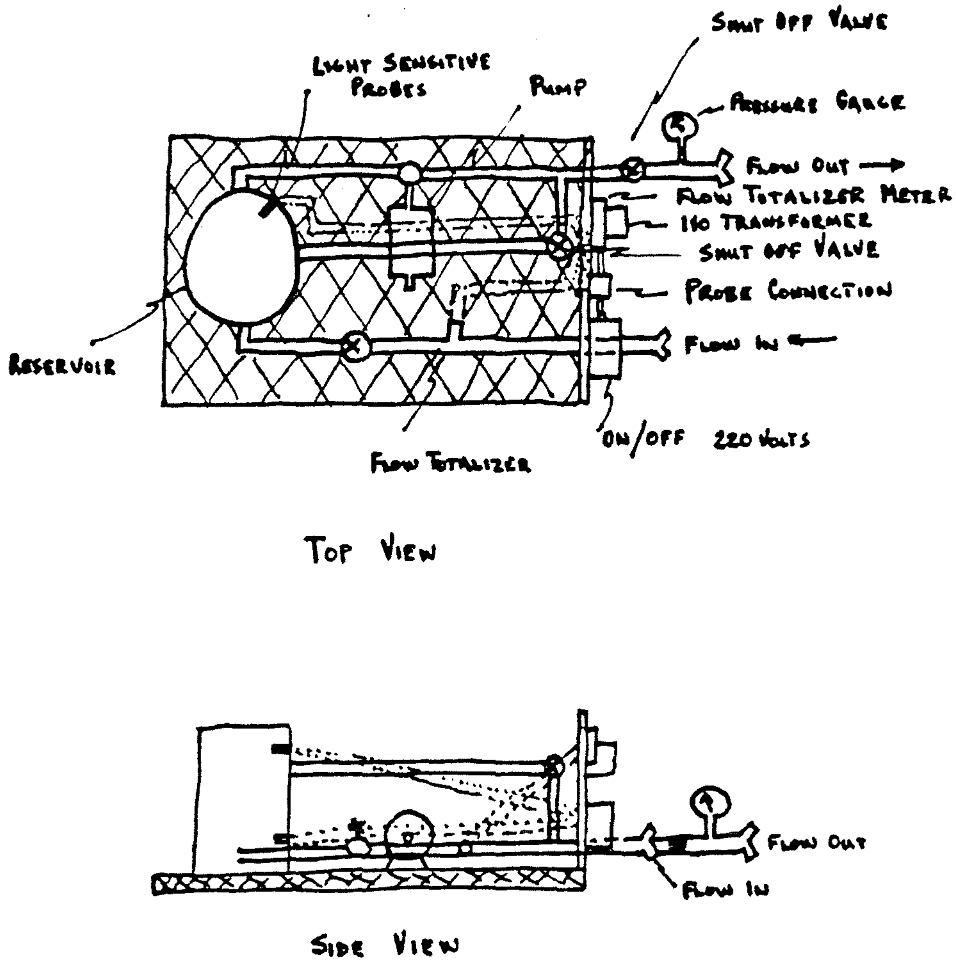

FIGURE 2. - Water/leach solution supply system.

Permeability testing zones were selected based on an examination of the core recovered from hole PT-3 (table 1). The upper zone was selected as 14 feet to 20 feet-4 inches (minimum straddle packer spacing) since the region above 14 feet was obviously influenced by fracturing induced by blasting in the drift.

Tests were conducted by first connecting the packer to the 1-inch steel pipe segments and lowering, by hand, down the hole. Plastic tubing for inflating the packers was connected to the top of the packer and fed down the hole as the packer was lowered. When the packer reached the correct depth, the nitrogen gas cylinder was opened and gas pressure increased to about 200 psi until the packer was firmly seated. Flexible hose and pressure gauge were then connected to the top of the pipe. After sufficient water was added to the tank, the electric pump was turned on and the valve on the bypass line slowly closed until the pressure gauge at well head showed 100 psi. As the water flowed into the injection zone, time intervals and the volume of water were monitored until several successive readings spanning 20 to 30 minutes had stabilized (flow rate became linear with respect to time). Since the flow meter that was mounted on the system was insensitive for the low flows experienced (less than 1 gallon/minute), the volume of water in the tank was simply measured as a function of its depth in the tank with a tape measure.

Upon completion of the test, the water pump was turned off after the bypass valve was opened to assure that no fluid pressure remained in the test zone. The gas cylinder inflation pressure was released which immediately unseated the packer(s). If the packer spacing did not have to be changed, the packers could be moved to the new zone in the well and then reseated by applying nitrogen gas.

Communication between wells was established by running the total open hole permeability test in one hole and monitoring the level of water in the adjacent holes at each time reading. Volume of water reaching the adjacent holes was calculated from the change in water level and the diameter of these holes.

Calculation Procedure

Permeability (k) is calculated from single-packer and straddle-packer configurations from the following equation from page 544 of Earth Manual (1).

$$k = \frac{Q \ln\left(\frac{L}{r}\right)}{2\pi L H}$$

where Q = flow rate in ft^3/yr.

L = length of hole tested, ft.

H = pressure in the test zone expressed in terms of water head, ft.

r = radius of hole, ft.

Flow rate, Q, is determined from the linear portion of the injected water volume/time plot. Since the plot is made based on gallons per minute, the flow rate must be converted to feet per year for dimensional compatibility. The head, H, is the head due to gravity plus the head measured by the gauge pressure applied at the surface. For unsaturated materials, the gravity head is the head to the upper packer plus L/2 (the middle of the test zone). Since the subject holes were inclined 30^{o}, the gravity head was the distance to the middle of the test zone multiplied by Sin 30^{o}. Loss of head due to friction in the pipe was not considered because of the low flow rates experienced.

RESULTS

Permeability Variation Within PT-3

Permeability measured in hole PT-3 over intervals ranging from 6 feet-4 inches to 11 feet-6 inches varied from 0.35 ft/yr (0.35 millidarcys or 0.33 x 10^{-3} cm/sec) to 1.3 ft/yr (1.3 millidarcys or 1.2 x 10^{-3} cm/sec) as shown in table 1. The high and low permeability zones seemed to correspond fairly well to zones of high and low fracture density in the core. A single packer was used to test the lower 11 feet-6 inches of the hole; all other tests employed straddle packers to isolate the zone of interest.

TABLE 1. - Permeability variation within PT-3

	Permeability		
Test interval, ft	ft/yr	millidarcys	10^{-3} cm/sec
14 - 20.3	0.35	0.35	0.33
18 - 28	1.3	1.3	1.2
28 - 38	0.13	0.13	0.12
38 - 48	.46	.46	.44
48 - 58	1.1	1.1	1.1
58 - 69.5	1.3	1.3	1.2

Permeability Variation Between Holes

A single packer was seated at 14 feet in each test hole to get an average permeability for the total open length of hole below that depth. The permeabilities ranged from 0.95 ft/yr (0.95 millidarcys or 0.91 x 10^{-3} cm/sec) to 1.1 ft/yr (1.1 millidarcy or 1.1 x 10^{-3} cm/sec) as shown in table 2.

TABLE 2. - Permeability variation between holes

Hole	Permeability		
	millidarcy	ft/yr	10^{-3} cm/sec
PT-1	0.95	0.95	0.91
PT-2	2.6	2.6	2.5
PT-3[1]	1.0	1.0	1.0
PT-3[2]	1.1	1.1	1.1

[1]Before the individual test zones within the hole were tested.
[2]After the individual test zones within the hole were tested.

Communication Between Wells

During the total-open-hole permeability tests that provided the data on permeability variation between wells, it was obvious that water being injected into any of the three holes was reaching the other holes. Water level in adacent holes responded almost immediately after we began injecting water into the test well. The volume of water reaching adjacent holes ranged from 2 percent to 17 percent of the volume being injected (table 3). During injection into hole PT-1, the rate of water reaching hole PT-2 changed inexplicably halfway through the test and both steady state inflow values are reported in the table.

TABLE 3. - Communication between wells

Injected in hole PT-3 @ 130 psi	
Injection rate:	0.28 gal/min
Inflow to hole 1:	0.048 gal/min (17 pct)
Inflow to hole 2:	0.006 gal/min (2 pct)
Injected in hole PT-2 @ 100 psi	
Injection rate:	0.54 gal/min
Inflow to hole 1:	0.018 gal/min (3 pct)
Inflow to hole 3:	0.03 gal/min (5 pct)
Injected in hole PT-1 @ 100 psi	
Injection rate:	0.21 gal/min
Inflow to hole 2: (first 10 min)	0.023 gal/min (11 pct)
Inflow to hole 2: (10 - 25 min)	0.0076 gal/min (4 pct)
Inflow to hole 3:	overflowed before measurement

DISCUSSION AND RECOMMENDATIONS

Permeability values overall are quite low and, if considered alone, would suggest that additional fragmentation of the orebody is necessary to assure adequate flow through the formation. Permeability in sandstone formations leached for uranium commonly averages two orders of magnitude higher than we found at Lakeshore. An interesting feature of the Lakeshore orebody is, however, that the very leachable copper oxides occur in the fractures. This provides optimism over the possibility that leaching will rapidly open fractures and improve the permeability so that acceptable injection/recovery rates can be achieved in a relatively short time.

The communcation established between wells 3 to 5 feet apart supports this optimism by demonstrating that leaching fluid can be pushed through the formation so that it can dissolve and remove the copper mineralization. Although this communication between wells is necessary, it would be extremely undesirable for all fluid injected into a well to travel along one or two major fractures to the adjacent wells. Our tests show that the water injected in any well did not seem to channel directly to adjacent wells since only a small percentage of the water injected actually reached these wells. Most of the fluid was dispersing, hopefully in a radial direction along numerous fractures.

Completion of this first step in testing and evaluation leaves several unanswered questions. Grade of return leaching solutions and the time needed to improve the permeability must be determined from actual acid injection. The maximum distance away from an injection well that effective fluid flow can be established must be measured before reasonable well patterns are designed. the following series of tests, tentatively established during discussions with E. Ahrens, Noranda Lakeshore, is recommended:

1. Inject acid in PT-3 and monitor return in PT-1 and PT-2 for quantity and copper grade. (Noranda)

2. Drill a hole parallel to holes PT-1, 2, and 3, but 20 feet away (perpendicular distance which is 40 feet horizontal distance towards the back of the lunch room). Plug PT-1 and PT-2 then inject acid in PT-3. (Noranda)

3. If no communication to the 20 feet distant hole exists within a week or so, conduct a series of push-pull injections in PT-3 to improve permeability around PT-3 so that communication to the 20 feet distant hole can be established. (Noranda)

4. Repeat the above series of tests in a brochantite zone on the 900 level at the mouth of a new slusher drift. (Noranda and Bureau)

5. Drill a fan of three holes up into the oxide orebody above the 500 to 380 level. (Noranda)

6. Conduct an injection and recovery test by injecting acid into the middle hole and recovering solutions from the other two holes. (Noranda and Bureau)

7. Expand the injection and recovery test to include several fans in a "unit cell". (Noranda and Bureau)

CONCLUSION

Permeability tests conducted at the Lakeshore mine did not provide any information that would eliminate further consideration of in situ leaching at the mine. Although the permeability was very tight, there is reason to believe that this permeability would increase significantly after leaching commenced as leaching solution dissolves copper minerals contained in fractures. The modest communication between the wells drilled for these tests (3 to 5 feet apart) allows "cautious optimism" over the possibility that adequate flow between wells can be developed. The test results support continuing the research plan outlined in the Discussion and Recommendations section.

REFERENCES

1. Bureau of Reclamation. Earth Manual. Dept. of Interior, Denver, Colorado 1963. Des. E-18, pp. 541-546.

2. O'Rourke, J. E., R. J. Essex, and B. K. Ranson, "Field Permeability Test Methods With Application to Solution Mining. Final Report on Contract J0265045 with Woodward-Clyde Consultants, 1977, 180 pp. Available as publication PB 272452 from NTIS, Springfield, Virginia.

FRACTURE ANALYSIS
STUDIES
NORANDA LAKESHORE MINE DRILL CORE, Hole PT-3

INTERVAL		SURFACE AREA COVERED WITH MINERALIZATION	TOTAL SURFACE AREA OF FRACTURES	% OF SURFACE AREA COVERED WITH MIN.
2.4 - 14		111.02	403.38	27.52
14 - 20.3		115.10	312.61	36.82
18 - 28		37.38	134.79	27.73
28 - 38		48.27	237.32	20.34
38 - 48		32.16	132.30	24.31
48 - 58		219.31	463.34	47.33
58 - 69.5		155.77	309.78	50.28
	TOTAL	719.01	1993.52	36.07
2.4 - 69.5		704.00	1923.54	36.60%

Fracture Analysis Studies

Code	Interval	Distance	Field Perm.	No Fractures	Ave. % Cu	Wt. Core / Int.	Wt. Cu / Int.	Wt. Cu / Fractures	% Cu In Fractures
	2.4 - 14	11.6		105	2.27	25.38	.576	.064	11.11
A	14 - 20.3	6.3	0.35	89	1.77	13.78	.244	.081	33.20
B	18 - 28	10	1.30	51	2.20	21.88	.481	.022	4.57
C	28 - 38	10	0.13	69	2.25	21.88	.492	.029	5.89
D	38 - 48	10	0.46	69	2.69	21.88	.589	.017	2.89
E	48 - 58	10	1.10	123	2.08	21.88	.455	.206	45.27
F	58 - 69.5	11.5	1.30	93	1.71	25.16	.430	.189	43.95
		69.4		599			3.267	.608	18.61
	2.4 - 69.5	67.1		579	2.15	146.8	3.156	.597	18.92

Notes

Wt of Ore Core 146.8 #
Length of Core 67.1 '
Wt/Foot Core 2.188 #/Foot

Chemical Formula for Chrysocolla $CuSiO_3 \cdot 2H_2O$

SiO = 34.3 %
CuO = 45.2 %
H_2O = 20.5 %

Cu in Chrysocolla 36.1 %

SALIENT FEATURES - CORE ANALYSIS

PERCENTAGE OF COPPER CONTAINED IN FRACTURES	18.92 %
PERCENTAGE COPPER DISSEMINATED THROUGHOUT	81.08 %
FRACTURE FREQUENCY (FRACTURES/FOOT CORE)	8.63
PERMEABILITY	1 MILLIDARCY (FIELD MEASUREMENT)
ROCK SURFACE AREA EXPOSED BY FRACTURES AND COVERED WITH MINERALIZATION	36.6 %