PILOT SCALE ILS TREATMENT OF CYANIDE PROCESS SLUDGES[1]

by

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Abstract. This paper summarizes the construction and use of an in-line system (ILS) for oxidation of heap leach process pond sludges at the Minnie mine millsite, Okanogan County, Washington. Prior to their shipment to a waste disposal facility, this pilot scale system treated approximately 45,000 liters of sludge composed primarily of reagents, process precipitates, organic detritus and water to reduce total cyanide concentration from 1200 ppm to below 280 ppm. Treatment included oxidation with atmospheric oxygen alone and oxidation with a combination of atmospheric oxygen and calcium hypochlorite [$Ca(OCl)_2$]. The ILS proved effective in oxidizing cyanide compounds in the sludge and was an efficient reagent mixer. Analytical results were variable, however, total cyanide reductions averaging 4 percent for each pass through the system for air alone and 60 percent for air and calcium hypochlorite were indicated. These results suggest that further investigation of the ILS process as a component or stand-alone system for cyanide oxidation and toxicity reduction is warranted.

Additional Key Words: in-line system

Introduction

Beginning in 1983, operators at the Minnie mine used cyanide heap leach technology to recover gold and silver from oxidized quartz-sulfide vein ore mined in a small open pit located on National Forest System Lands. This operation resulted in the placement of approximately 6,300 metric tons of crushed and cement-agglomerated ore upon a 26 m by 36 m pad underlain by a 30-mil polyvinylchloride (PVC) geomembrane liner and compacted soil. Pregnant and barren process ponds constructed adjacent to this pad were about 15- by 15- by 2.5-m deep with a capacity of approximately 280,000 liters of ore heap leachate each. (Figure 1). Ponds were double lined with 36-mil Hypalon© liners separated by geotextile fabric and a leak detection monitoring system.

After mine shutdown in 1986, precipitation continued to pass through the heap, collect soluble cyanide compounds and enter the ponds. Pond levels rose because inflow exceeded evaporation. To prevent overflow the operator and the United States Forest Service (USFS) periodically treated and disposed of these post-closure leachate fluids by onsite land application or off-site shipment. Pond water treatment utilized batch process alkaline chlorination to lower cyanide toxicity by oxidizing cyanide and cyanide compounds to less bioreactive forms. After cyanide concentrations reached target levels, sodium sulfide (Na_2S) was used to precipitate heavy metals as sulfides in order to meet State and Federal heavy metals discharge and/or storage standards.

Emergency actions to prevent pond overflow continued until the operator declared bankruptcy and a final cleanup process was chosen. The USFS then proceeded with final cleanup of the site, in consultation with Olympus Environmental of Auburn, Washington. Cleanup began with the decanting and transport of supernatant pond fluids to a Treatment, Storage, and Disposal Facility (TSD). Sludges resulting from ore processing and post-closure fluid treatment remained in the pond. Due to elevated cyanide levels, these sludges required further treatment prior to transportation and storage at a TSD . To meet TSD waste acceptance requirements of 30 ppm amenable and 590 ppm

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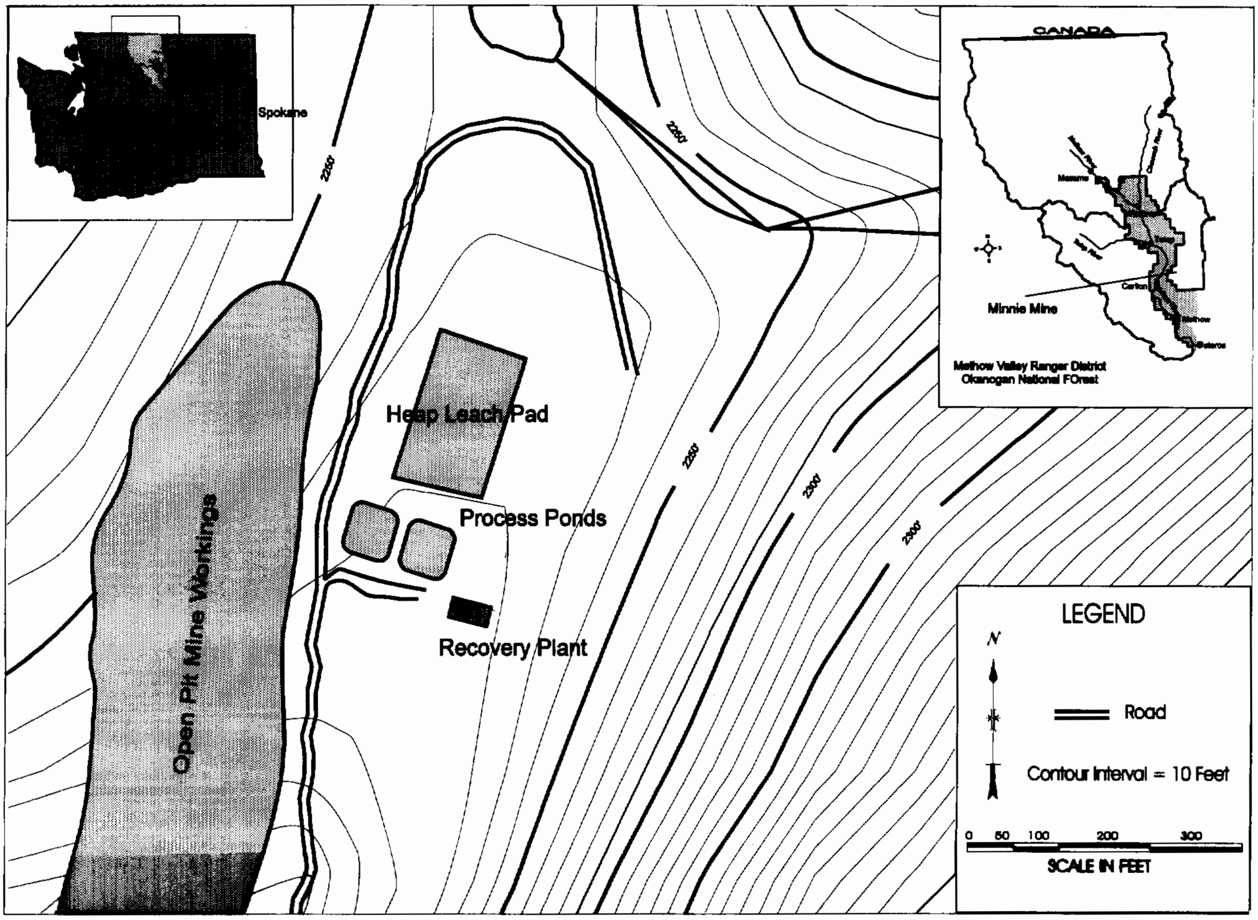

Figure 1. Minnie mine site and location map

total cyanide, the US Bureau of Mines (USBM) suggested the use of an In-line Aeration and Treatment System (ILS)[3] for sludge neutralization, a technique developed by USBM for mixing, aeration, and treatment of acid mine waters (USBM 1985).

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Sludge/Fluid Description

Major Sludge Components

For the purposes of this paper, sludges are considered the dense slurry of solids and interstitial fluids which settled in the bottom of the ponds during mine operations and fluid treatments. During gold and silver recovery operations, hydrated lime [$Ca(OH_2)$] and granular sodium cyanide (NaCN) were added regularly to the barren pond to maintain alkalinity and cyanide concentrations. Because of poor mixing, some of the lime and possibly a minor amount of NaCN remained as solid aggregates or cakes at the reagent addition points. A small (~ 4 cu. m.) delta of heap-derived detrital sediments was also discovered below the heap inlet pipe in the pregnant pond. This sediment, which originating from the heap, continued to enter the pond until the leach pad-to-pond connection was severed in 1992. The coarse texture and greater density of these sediments (silt, sand, and fine gravel) hindered slurry formation and pumping

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[3] U.S Patent No. 4,695,378, September 22, 1987, Terry E. Ackman and John M. Place, Titled: Acid Water Aeration and Treatment System, Assignee: U.S. Department of the Interior.

operations. Finally, appreciable quantities of pine needles and other plant debris from surrounding vegetation accumulated in the sludge and also added to pumping and handling difficulties.

The operators and the USFS added approximately 3,600 kilograms of granular 65% calcium hypochlorite [$Ca(OCl)_2$] to the ponds between 1986 and 1993 to oxidize cyanide and metallo-cyanide complexes after mine production ceased. These actions contributed 1,300 kilograms of inert binder/filler to the sludges. During the same period, the alkalinity in the ponds was maintained with hydrated lime and ground limestone using a combined weight of 270 kilograms. In addition to increasing sludge volumes, a significant portion of this alkaline material sank unreacted to the bottom of the ponds because of poor mixing.

The cyanide oxidation process produced another sludge component consisting of precipitates from the reaction of calcium hypochlorite with simple and metal-complexed cyanide ions. Under alkaline conditions, calcium hypochlorite oxidizes cyanide and cyanide compounds to cyanogen chloride (CNCl), then cyanate, and finally ammonia and carbonate ions.

$$2CN^- + Ca(OCl)_2 + 2H_2O = 2CNCl + Ca(OH)_2 + 2(OH)^- \quad (1)$$

$$CNCl + 2OH^- = CNO^- + Cl^- + H_2O \quad (2)$$

$$2CNO^- + 4H_2O = (NH_3)_2CO_3 + CO_3^{-2} + 2H^+ \quad (3)$$

Many metallic cations are precipitated as insoluble hydroxides as a by-product of the oxidation under alkaline conditions.

$$M^{+2} + 2OH^- = M(OH)_2 \downarrow \quad (4)$$

Like the unreacted reagents, these hydroxide precipitates also accumulated in the bottom of the ponds where they contributed to both the metals' concentration and sludge volume. Final pond fluids treatment included the addition of about 90 kilograms of sodium sulfide which scavenged heavy metal ions from solution to be precipitated as sulfides.

$$M^{+2} + 2S^- = MS_2 \downarrow \quad (5)$$

Approximately 30-46 cm of generally light gray or bluish-gray sediment remained in each pond after process fluid treatment was complete. These sludge deposits had not been substantially disturbed during heap leaching activities or the post-production fluid treatment. One sample analysis by the USBM indicated a precipitate slurry density of 1.119 kg/l and weight percent and volume percent solids of 16.6 and 6.7, respectively. "Shoals" of white, sand- and fine gravel-sized granules of unreacted lime were also discovered in places around the margin of the ponds or beneath the precipitates. The combination of detrital sediments from heap runoff and lime aggregates made up some 20 percent of the total sludge volume. The density of these detrital sediments was estimated at 1.90-2.15 kg/l. Thin horizons of dark gray sulfide-rich material were also observed near the base of the sludge column. Figure 2 summarizes the major sludge components and the various source contributions and losses.

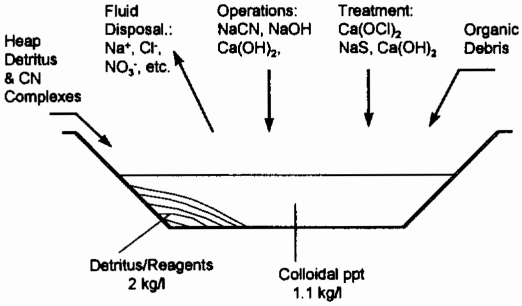


Figure 2. Minnie mine process pond sludge components and chemical balance

Chemical Composition

Analysis using semiquantitative X-Ray diffraction, induction coupled plasma spectroscopy, and atomic absorption spectroscopy of 4 grab samples of pre-treatment sludge (Table 1) suggested that the solids portion of the sludge was composed primarily of calcium carbonate with lessor amounts of calcium, zinc, and magnesium hydroxides. These analyses also revealed traces of various other metallic sulfides and hydroxides, silicon dioxide, and hydrous calcium sulfate. Percents by weight of calcium (21%), magnesium (6%), zinc (5%) and copper (2%) were substantial. Other notable metals included cadmium (518 ppm), silver (209 ppm), lead (<86 ppm), and mercury (0.07 ppm).

Analyses also revealed significant differences in pH and metals concentrations between sludge samples taken from different locations in the ponds. This is illustrated by the wide range of values for some parameters shown in Table 1. The pH tended to be bimodal with pH values around 8.8 and 11.6. Certain

Table 1. Minnie Mine Sludge Composition[1]

Mineral Composition by X-Ray Diffraction

Calcite ($CaCO_3$)	Major Component
$Ca[Zn(OH)_3]_2$-H_2O	Minor Component
Brucite ($Mg[OH]_2$)	Minor Component
Quartz (SiO_2)	Trace
Bassanite ($CaSO_4$-H_2O)	Trace
Vaterite (calc var)	Trace
Unidentified	Trace

Elemental Composition by ICP (ppm unless otherwise noted)

Element	**SOLIDS**		**FLUIDS**	
	Range	**Average**	**Range**	**Average**
Ag	58-554	289.2	1.1-1.4	1.2
Al	0.7-1.9	1.3 (w%)	<1.3[2]	<1.3
As	0.0-0.2	0.1 (w%)	<1.1	<1.1
Ba			*0.2-0.3*[3]	*0.2*
Be	<1.1-<1.2	<1.15	<0.01	<0.01
Bi	*<210-514*	*295.5*	1.9-2.1	<2.0
Ca	19.6-22.7	21.0 (w%)	634-3880	2167
Cd	389-618	518	<0.06	<0.06
Co	*<12.0-33.9*	*21.7*	*0.2-0.3*	*0.2*
Cr	*<35.0-95.2*	*68.3*	<0.37-0.56	0.42
Cu	0.8-2.7	1.7 (w%)	302-2020	1078
Fe	0.6-2.6	1.5 (w%)	<0.05-<0.0	<0.05
Hg (ppb)	50-96	72.0	6.2-1160	541
K	0.1-0.5	0.3 (w%)	34.7-43.1	37.8
La	<29	<29	*0.4-0.8*	*0.6*
Li	*<10.0-18.2*	*14.3*	*0.1-0.2*	*0.2*
Mg	4.0-8.7	6.2 (w%)	<0.9-180	87.3
Mn	305-681	471.8	<0.02	<0.02
Mo	<19.0	<19.0	<0.19-<0.7	<0.46
Na	0.4-0.8	0.6 (w%)	2890-3140	2988
Nb	*24.9-37.3*	*30.3*	*0.34-0.61*	*0.45*
Ni	44.8-110.0	82.7	4.5-6.8	6.1
P	*300-440*	*370.0*	50-269	155
Pb	<65-<93	*<86*	<0.8	<0.8
Sb	<95-<96	<95	<1	<1
Se	<0.3	<0.3	<0.3	<0.3
Si			<0.3-0.6	0.4
Sn	*<32.0-96.9*	*63.3*	<0.3-1.1	0.7
Sr	118-163	142.5	<0.3-2.6	1.6
Ti	335-1120	738	<0.09	0.09
V	<24-155	97	0.8-1.2	0.9
W	220-425	316	<0.6	<0.6
Y	*6.7-12.9*	*9.3*	*0.1-.6*	*0.3*
Zn	4.4-5.2	*4.9* (w%)	<0.4-<0.7	<0.5

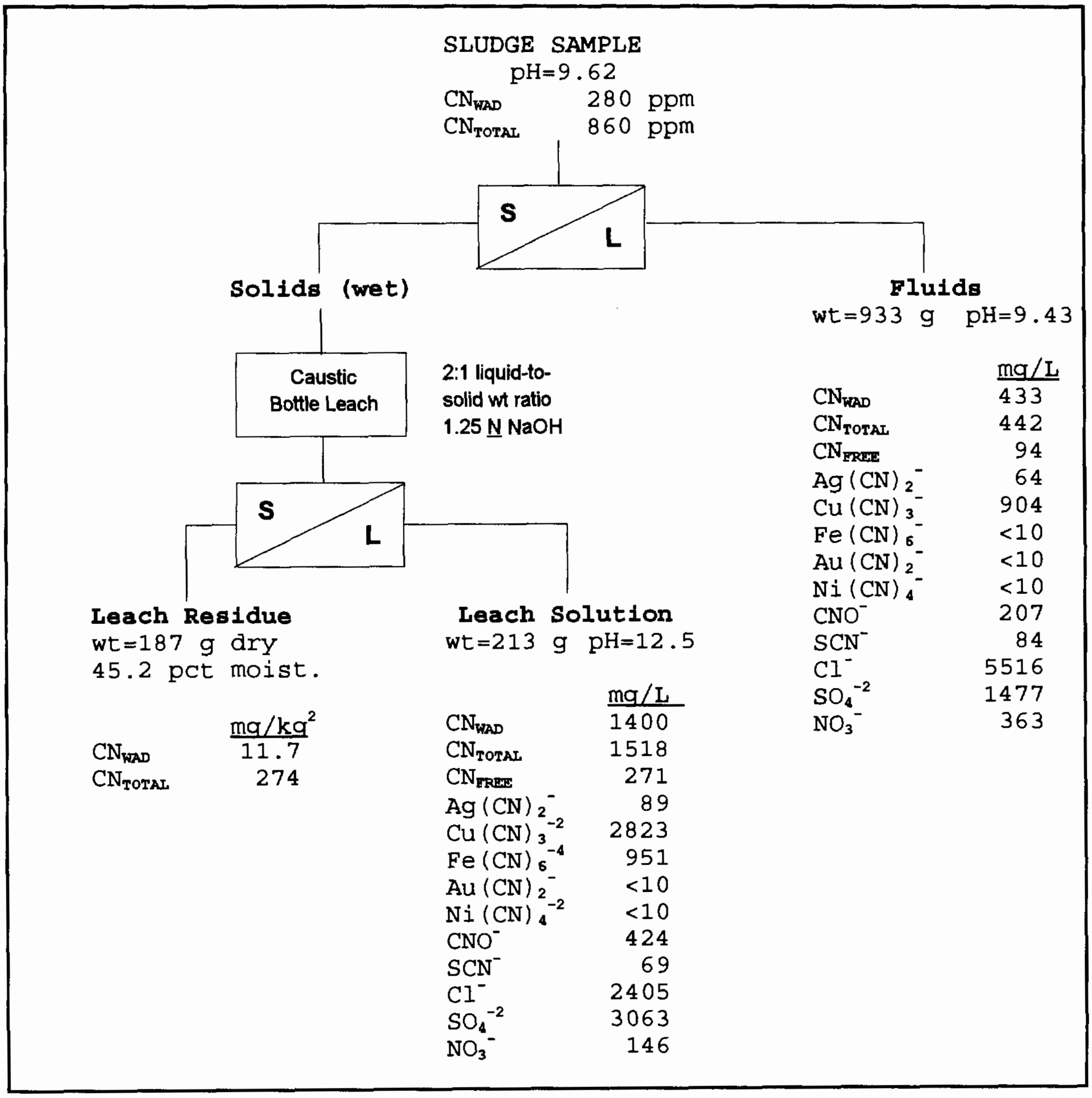
[1] Data from four grab samples.

[2] <=Parameter was less than the detection limit.

[3] *0.2*=Indicates two or more of sample concentrations were >1 and <3 X Standard Deviation, Use with caution.

metals, such as silver, cobalt, manganese, nickel, and titanium were two- to six-times more abundant in the samples with higher pH. These differences in sludge chemistry between ponds and between samples taken within one pond were attributed to poor mixing and uneven distribution of lime and sulfide treatment chemicals added to each pond.

Table 1 also gives the chemical analysis of the liquid or interstitial fluid portion of the slurry samples for comparison purposes. USBM completed cyanide speciation work on a composite grab sample of Minnie millsite sludge (T.G. Carnahan, Written communication, 1993). The results of this analysis are given in Figure 3. Total and Weak Acid Dissociable (WAD) cyanide were determined by colorimetric procedure, while metal cyanide species, cyanate (CNO^-), thiocyanate (SCN^-), chloride (Cl^-), sulfate [$(SO_4)^{-2}$], and nitrate [$(NO_3)^-$] were determined using an ion chromatograph.



[1] Sample analysis by USBM. [2] Dry weight basis.

Figure 3. Cyanide speciation, Minnie mine sludge

Total and WAD cyanide content of the stirred sludge sample was 860 and 280 ppm respectively (Figure 3). The sludge sample was then filtered. Interestingly, the total cyanide concentration of the filtrate was less than that of the stirred sludge (860 ppm versus 442 ppm) while the WAD cyanide value was greater (280 ppm versus 433 ppm). The differences between the stirred sludge and filtrate were attributed to the presence of precipitated cyanides in the unfiltered sludges being included in the total cyanide value and the dilution effect of sludge solids on the WAD analysis.

Copper cyanide [$Cu(CN)_3^{-2}$] was the dominant precipitated metallo-cyanide complex in the sludge solids. Ferrocyanide [$Fe(CN)_6^{-4}$) and silver cyanide [$Ag(CN)^-$] were also represented in smaller yet appreciable amounts. Cyanide species were present in both the solids and the fluids in similar proportions, with the exception of ferrocyanide. Thiocyanate concentrations were not particularly high in either the solids or the filtrate (61 and 84 ppm).

Sludge Disposal

Initially sludge cleanup plans called for transport and disposal of the untreated Minnie Mine process sludges at the nearest TSD. However, the TSD refused to accept the sludges due to high total cyanide content (1100 ppm) in the test sample. Two alternatives were considered: (1) shipment to another TSD having suitable cyanide treatment capability (nearly doubling disposal costs) or, (2) treating the sludges onsite using alkaline chlorination techniques previously used on the supernatant liquids. The USFS chose the latter alternative because our previous experience treating the process liquids indicated that alkaline chlorination could be performed onsite safely, with reasonable effectiveness, and at a much reduced cost.

In-Line Aeration and Treatment System

The ILS was selected for sludge treatment because it offered improved mixing efficiency for alkaline chlorination and an opportunity to explore the potential for cyanide oxidation in the absence of a strong oxidizer. Chatwin (1988) found that cyanide can be converted to cyanate on the surface of organic and inorganic materials in soils under natural conditions; a reaction apparently enhanced by the presence of copper and nickel.

$$HCN + O_2 + Cat. = 2HCNO \qquad (6)$$

The Minnie mine sludge contained organic materials and metals but, unlike soil particles, occurred in a liquid medium. Because the ILS aerates and vigorously mixes, it was postulated that the process might encourage a weak oxidant such as O_2 to react in a similar fashion in the sludge matrix.

It was also hoped that the ILS would increase the efficiency of alkaline chlorination by limiting the formation of intermediate compounds [such as cyanogen chloride during cyanide oxidation (Equations 1-3)] because of the generally more favorable oxidizing environment found in the ILS.

Design and Assembly

The ILS system is composed of two basic components, a commercially available jet pump and a static mixer. Fluid enters under pressure and is converted by the jet pump to a high-velocity stream, which passes through a suction chamber that is open to the atmosphere (Figure 4). Low pressure in the suction port of the jet pump causes atmospheric air to flow into the jet pump (venturi action). The suction port is an ideal site to introduce treatment chemicals such as calcium hypochlorite and lime. Typically, static mixers consist of PVC pipes filled with trickling media (small hollow plastic cylinders with internal baffles) that are placed down stream of the jet pump in a vertical position. Commercially produced static mixers are available but for this project two 6-inch (15.2 cm) diameter by 2-meter-long PVC columns packed with trickling media were built and installed in parallel after the jet pump (Figure 5).

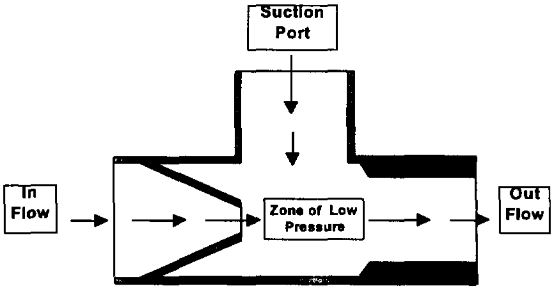


Figure 4. Schematic of jet pump

ILS construction proceeded along lines suggested by the USBM from their previous work with the system. Deviations from their general design were made to adapt the device to the specific conditions at

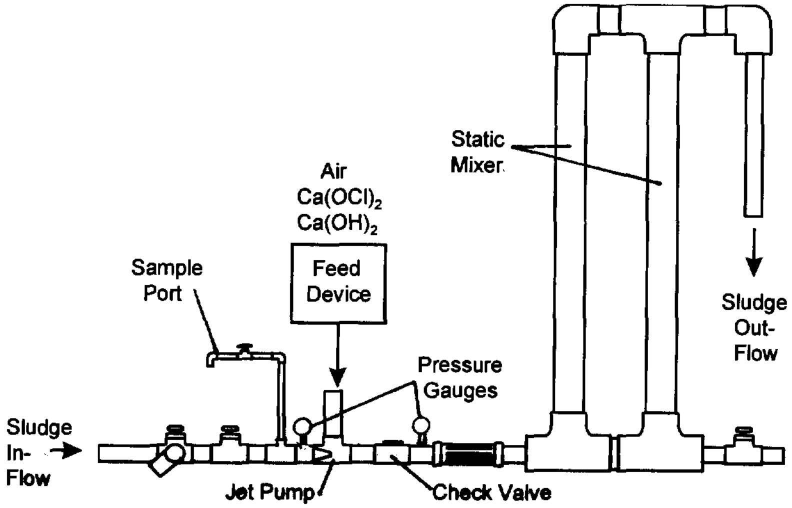


Figure 5. ILS design for sludge treatment

the mine. Assembly required standard PVC Schedule 40 pipe and fittings connected by solvent welded joints. The PVC components avoided problems associated with the reactivity of the sludges. A 3-inch (7.6 cm) check valve made of brass was inserted to prevent backflow from the elevated columns after pump shutdown (Figure 5). This one-way valve operated without failure during the short project life of about one month.

A 5 horsepower gasoline - powered volume pump with a capacity 500 liters per minute at 75 pounds per square inch (psi) was used to pump sludges from the ponds into the ILS. This pump was mounted on a floating platform to facilitate its movement around the ponds during pumping. The USBM provided a jet pump manufactured from high density plastic with a 3/4-inch (1.9 cm) nozzle and 3-inch (7.6 cm) inlet and outlet fittings. A lawn spreader was converted and motorized to provide measurable flow of dry, granular calcium hypochlorite into the suction port of the venturi. Pressure gauges inserted before and after the jet pump measured the operating pressures generated by the pump and back pressure generated by the static mixer columns and resistance in the piping network. A 4-inch (10.2 cm) leadoff pipe directed treated fluids from the static mixer back to the ponds.

Sludge Treatment

Sludge treatment began by consolidating and mixing the sludges in the pregnant pond. Early ILS operating tests were conducted during this process. Because of pine needles and other organic debris in the sludge the jet pump's nozzle frequently clogged. A 1/4-inch (63 mm) mesh screen was subsequently installed to filter the organic debris and reduce potential clogging of the ¾-inch (1.9 cm) nozzle..

Oxidation began by transferring the sludges back and forth between ponds though the ILS. Because of sludge density, pumping pressures remained well below the rated 75 psi capacity of the pump-- 40 psi being an operating maximum and 20 to 25 psi the operating norm. Except when unusually heavy sludges were encountered or the nozzle became clogged back pressure was near zero during sludge treatment. Empirical data from the jet pump manufacturer indicate that for a 3-inch (7.6 cm) jet pump operating in the 20-25 psi range, back pressure must remain near zero to produce 7-7.5 scfm air suction (Penberthy Houdaille Industries 1981). However, we found moderate suction was produced at the suction port even with up-stream pressures under 20 psi.

Calcium hypochlorite addition began via the suction inlet of the jet pump on the second pass of the sludges through the ILS. Reagent addition rates were determined largely by the rate of production of cyanogen chloride, an extremely toxic gas. Offgassing occurred when $CNCl$ production in the first stage of oxidation (Equation 1) exceeded its conversion to CNO^- (Equation 2). Generation of cyanogen-chloride gas was evidenced by visible frothing of the treated sludge. As cyanide concentrations dropped, OCl^- addition rates could increase correspondingly. Average feed rates were 0.9 pounds per minute of 65% granular $Ca(OCl)_2$ with a maximum rate of 1.7 pounds per minute. Superior mixing efficiency was demonstrated by the ILS over the batch methods used earlier in the project. Based upon total reagent mixed per day, the ILS allowed up to six times more reagent to be mixed than the batch method.

Two difficulties slowed the ILS treatment: Incomplete filtration of organic debris caused occasional clogging of the nozzle. High sludge densities encountered near the bottom of the ponds also caused static mixer back pressures to exceed 5 psi, with some corresponding loss of venturi suction. Sludge densities were reduced by agitation and mixing of sludges at the mouth of the intake hose. This was accomplished by installing another pump to direct a high pressure sludge stream at the ILS pump intake.

Sampling

Objectives for sampling and analyses were two fold: (1) assure that TSD target levels for total and amenable cyanide concentrations in the sludge as a whole were met; and (2) assess the effectiveness of the ILS. The first objective was met by conducting CN^- analyses of composite sludge samples collected after each cycle of treatment and mixing. The pH of these composite samples was not adjusted to preserve cyanide species but was left unchanged to emulate expected conditions of sludge transport to the TSD.

The second objective was met by sampling inlet and outlet sludge streams during ILS operations. Inlet and outlet samples were taken simultaneously to minimize errors caused by variation in sludge composition or air/chlorine feed rates. The ILS treatment system was evaluated with air injection alone and using air and calcium hypochlorite in combination. Two sets of samples using air/chorine oxidation were collected. One set was preserved with sodium arsenate to inhibit further CN^- oxidation by residual chlorine. The second set was preserved with both sodium arsenate and sodium hydroxide (pH>11) to preserve CN^- species. Samples were drawn only when jet pump back pressure was less than 5 psi.

Seventeen sample pairs and 4 composite samples were collected before and during sludge treatment. Because of complications in the analysis only six of the seventeen sample pairs were analyzed by the USBM lab. These included two of the air-only treatments and four of the air and chlorine treatments. Sample numbers including an "A" had sodium arsenate added as a post-treatment preservative while sample numbers containing an "AN" were preserved with both sodium arsenate and sodium hydroxide.

Results

ILS treatment of the Minnie mine sludges successfully reduced total and amenable cyanide concentrations to levels acceptable to the TSD. Total cyanide concentrations in composite sludge samples of 280 ppm and less were attained, well under the 590 ppm target.

Analytical results for the sample pairs are shown in Table 2. The average reduction of cyanide, expressed as a percentage, is displayed in Figure 6. While

Table 2. Minnie mine ILS treatment results

	WAD CN (ppm)			**Total CN (ppm)**		
Sample No.	Pre-Trtmt	Post Trtmt	% Change	Pre-Trtmt	Post Trtmt	% Change
SO1	48	67	40	200	190	-5
SO4	220	130	-41	770	740	-4
SO7A[1]	96	46	-52	540	320	-41
SO10A	4.4	4.5	2	320	390	22
SO13AN[2]	63	6.1	-90	640	240	-63
SO15AN	34	20	-41	220	100	-55

[1] Sample preserved with sodium arsenate only.

[2] Sample preserved with sodium arsenate and NaOH (pH>11).

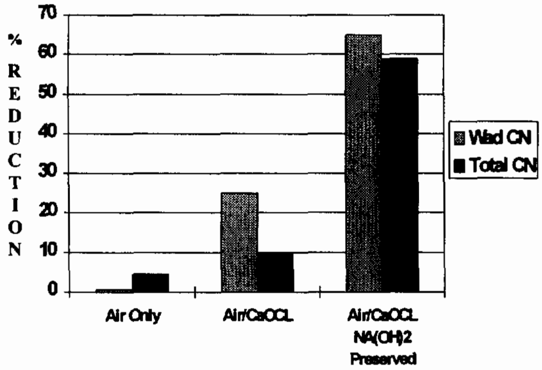


Figure 6. Average cyanide reduction

individual sample analyses were variable, on average 1-4 percent of the WAD and total cyanide was oxidized by one pass through ILS treatment with only air addition, while 10-66 percent was oxidized using the combination of air and $Ca(OCl)_2$.

Discussion

Several features of the data are worthy of note. First, is the variation in cyanide concentrations within the sludges. This is illustrated by sample pairs SO1 and SO4 which showed pre-treatment total cyanide levels of 200 versus 770 ppm (Table 2). Sample SO1 was collected during the first sludge transfer when sludges were not completely mixed. Sample SO4 was taken later in the process after more thorough mixing had occurred. Similar variations of pH occurred in sludge samples described previously.

Note also the small increase of total cyanide and/or WAD cyanide (rather than the expected decrease) in two of the sample pairs, SO1 and SO10. These anomalies are attributed largely to spatial variation of sludge chemistry and the difficulty of sampling the same sludge mass before and after passing through the ILS process. It is possible that analytical variation may also be partially responsible for these anomalous results. Throughout the project and regardless of the analytical method employed, consistent cyanide values were difficult to obtain because of interferences from various components of the complex chemical matrix represented by the sludges.

Samples preserved with both sodium arsenate and sodium hydroxide after treatment appear to show about 2.5- to 5-times greater cyanide reduction than those without added sodium hydroxide (Figure 6). This difference is largely caused by anomalous results for sample SO10A which showed post-treatment cyanide increases. If analyses for this sample were discarded the apparent difference between samples preserved with and without sodium hydroxide would be much reduced.

Cost

Labor, materials and reagents expended to construct, test and operate the ILS pilot system and treat 45,000 liters of sludge totaled approximately $5,000. The alternative, shipping the sludge to another TSD having cyanide treatment capability, would have cost $45,000. Much of the later amount can be attributed to the greater distance to the alternate TSD and the high cost of hazardous waste transport.

Conclusions/Recommendations

Our experience with the ILS and the above data support the following conclusions:

1. ILS is effective in combination with alkaline chlorination in the treatment of cyanide-bearing sludges. A combination of air and calcium hypochlorite may reduce cyanide levels by 60 percent in a single pass.

2. ILS functions as a very effective reagent mixer when incorporated into the alkaline chlorination circuit. This can result in increased reagent efficiency and greater labor efficiency in terms of reagents mixed per day.

3. ILS may enhance cyanide oxidation in metals-containing fluids or sludges by introducing air and turbulence into a pressurized stream. A possible explanation is the enabling (by the mixing process) of the catalyzing surface effects of metals and other substances found in the complex matrix represented by heap leach process pond sludges.

4. Use of ILS processing may substantially reduce cyanide sludge disposal costs, particularly if transport distances are large.

Offsetting these positive features is the necessity for filtering and/or mixing of sludges prior to treatment. Effectiveness is dependent upon adequate ILS design to assure minimum back pressure and maximum air/reagent injection. Such project design features as the diameter and height of the static mixer should be re-evaluated in order to reduce system back pressure.

Several possibilities for application of the ILS system to cyanide oxidation are suggested. Especially in the case of fluids with a relatively low cyanide concentration, oxidation during a single pass through the ILS alone may be sufficient. Because of its effectiveness as a mixer, the ILS can be used in combination with other chemical oxidants to enhance their performance. The suction port lends itself to the introduction of solid, liquid, and gaseous oxidants such as hydrogen peroxide, ozone, gaseous oxygen and chlorine, sulfur dioxide and calcium hypochlorite. The ILS may also be combined with the application of ultraviolet light to further enhance the destruction of cyanide compounds. A combination of these methods could result in significant cyanide destruction with each pass through the ILS. Finally, the ILS could be inserted into a cyanide oxidation circuit that included other oxidation or metal scavenging devices.

The data from this study suggest that further research in the use of ILS for the treatment of various sludges is warranted and recommended. In addition, it is recommended that the ILS be evaluated as an industrial cyanide oxidation system, that could be more effective and inexpensive than current methods.

Literature Cited

Chatwin, T.D. and Trepanowske, J.J., 1987, Utilization of soils to mitigate cyanide releases: Western Regional Conference on Precious Metals, Coal and Environment, Rapid City South Dakota, 1987 proceedings, p. 151.

Smith, A., and Mudder, T., 1991, The chemistry and treatment of cyanidation wastes: London, U.K. Mining Journal Books Ltd., 345 p.

Smith, A., and Struhsacker, D.W., 1988, Cyanide geochemistry and detoxification regulations, In Introduction to Evaluation, Design, and Operation of Precious Metal Heap Leaching Projects, Eds. Van Zyl, Hutchinson, and Keil, Soc. Of Mining Eng., 15 p.

USDI, Bureau of Mines, 1987, Inline Aeration and Treatment of Acid Mine Drainage: Technology News No. 215, 2 p.

Penberthy Houdaille Industries, 1981, Jet pump technical data—Pumping gases; Technical Bulletin 1300, Section 1000, Issue 7/81.