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COMMERCIAL BIOOXIDATION CHALLENGES AT NEWMONT'S NEVADA OPERATIONS

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ABSTRACT

In December of 1999, Newmont Mining Corporation's Eastern Nevada Operations commissioned its commercial biooxidation facility. The commercial biooxidation facility is a refractory gold whole ore heap process that uses bacteria to assist with the oxidation of sulfide minerals thus liberating occluded gold for further processing by cyanide for gold extraction. Before the commercial biooxidation facility was started, a decade of research went in to developing this state-of-the-art process. During final design and construction of the commercial facility a decline in gold price necessitated cost saving and project scope changes. As a result, the biooxidation process experienced many challenges. Some of the more significant challenges include poor heap permeability due to haul truck stacking, unhealthy bacteria population due to a lack of solution aeration, and insufficient biooxidation time because of limited pad space and high carbonate content in the ore. This paper discusses the many challenges encountered and addressed during the first 2-3 years of commercial biooxidation operation.

INTRODUCTION

Biooxidation is not an unfamiliar process to Newmont Mining Corporation's Carlin Operation. Laboratory test work of whole-ore column biooxidation began in 1988 (Shutey-McCann et al., 1997). To a large extent, the initial test work was pursued out of scientific curiosity and the desire to explore new and innovative processing methods for gold ore. In addition, as the Carlin open pit plunged deeper, low-grade sulfide mineralized material became more abundant. In order to add this material into mine reserves a method for processing had to be established and whole ore heap biooxidation became the chosen process.

Successful laboratory tests led to the construction and startup of a demonstration biooxidation facility in 1994 (Shutey-McCann et al., 1997). The pilot facility contained a lined pad area that could accommodate up to five 136,000 tonne test cells. Many different operating conditions were tested over the course of 4 years. The test results of the demonstration facility led to the development of detailed design criteria for a commercial-scale biooxidation facility.

The commercial biooxidation facility was planned as biooxidation followed by heap cyanide leach. The pilot test work established the best process flow chart and ideal operating parameters for this processing method. After considerable analysis and development of project costing, the commercial biooxidation project was approved at $63MUS.

As the commercial project began construction, the price of gold declined resulting in a dramatic change to the design of the project. Concurrent to a reduction in gold price, one of Carlin's oxide milling facilities encountered a shortfall of feed. The decision was made to trim the size and scope of the proposed commercial biooxidation facility and change the gold recovery method from heap leach to milling followed by carbon-in-leach (CIL). A limited amount of laboratory test work that examined biooxidation followed by milling and CIL indicated that the benefit of accelerated and improved gold recovery outweighed the higher processing cost.

The Carlin facility's first-hand experience with the challenges of operating a commercial-scale whole ore heap biooxidation facility is shared in this paper.

DESIGN VERSUS AS-BUILT

Comparing some of the discrete components of the original design of the commercial biooxidation facility, against the as-built facility, will reveal that significant cost-cutting changes were implemented. Table I summarizes a few of the most significant changes to the original design plans.

The changes in design led to problems regarding solution and air permeability within the heaps due to compaction from truck stacking. Also, fewer pads rendered a shortened biooxidation cycle resulting in lower sulfide sulfur oxidation than the original design had intended. Additionally, the design did not consider direct aeration to the biosolution contained in the pond. The thought was that the pad air distribution system supplied by a 200 hp fan would provide the needed oxygen for bacterial conversion of ferrous to ferric iron. Compaction and permeability issues from haul truck stacking hindered air transport in the heap and as a result, bacteria healthiness was poor which also lessened sulfide sulfur oxidation.

The detrimental effect of the coarser particle size in the as-built facility likely helps to counter a portion of the low permeability issue in the heaps caused from truck placement of ore. The absence of a water treatment method to reduce metal ion concentrations in the pond biosolution has not proven to be a detriment to the biooxidation process at this point. Fewer pads than the original design, along with the need for makeup water addition, have maintained metal ion concentrations within design guidelines. However, metal ions in the

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Table I. Comparison of Original Design Versus As-Built of the Commercial Biooxidation Facility

Design Component	Original Design	As-Built Facility
Quantity of 305m x 147m pads	12	3
Crushing	Tertiary, P_{80} = 10mm	Secondary, P_{80} = 19mm
Agglomeration Method	Drum	Belt Transfer
Material Transport	Overland Conveyor to Ore Bin	Haul Truck to Pad
Ore Stacking Method	Radial Stacker	Haul Truck Dumping
Ore Reclaim	Bucket Wheel Excavator	Shovel and Haul Truck
Biosolution Pond Water Treatment	Lime Precipitation	None
Recovery Process	Heap Leach	Milling and CIL

Table II. Comparison of Original Design Operating Criteria Versus Actual Operating Criteria

Operating Criteria	Original Design	Actual
Biooxidation Time (days)	270	150
Pad Stacked Height (m)	10.7	12.8
Ore Chemistry:		
Sulfide Sulfur Content (%)	1.67 – 2.10	1.40 – 1.80
Maximum Carbonate Content (%)	2.50	1.25
Biosolution Addition at Truck Loadout (% moisture by weight)	4.0	2.0 – 4.0
Sulfuric Acid Consumption for pH Control (kg H_2SO_4/tonne of placed ore)	0.38	0.92
Bacteria Inoculum	Acidithiobacillus ferrooxidans, Leptospirillum ferrooxidans, Sulfobacillus thermosulfidooxidans	Acidithiobacillus ferrooxidans, Leptospirillum ferrooxidans, Sulfobacillus thermosulfidooxidans, extreme-thermophile archaea
Heap Temperature (°C)	38 - 60	11 - 81
Biosolution Pond Eh (mv)	> +550	range 385 – 745, average 519
Dissolved Oxygen in Biosolution (ppm)	4 - 6	0 - 7
Biosolution Pond Iron Concentration (gpl)	13	range 8 – 36, average 18
Replacement of Air Pipe at Pad Base	Replace after each cycle	Replace after 3 cycles
Gold Recovery (%)	71	49 - 61

contained moisture of the biooxidized ore that is processed in the mill do result in increased cyanide consumption in the CIL processing stage.

OPERATING CHALLENGES

The as-built changes led to operational challenges that added to the complexity of the biooxidation process. Many of the operating criteria evolved different from the original design criteria. Table II identifies the primary differences in original design criteria versus actual operating criteria.

Operational issues resulted in genuinely creative solutions from a variety of individuals who were driven to make the biooxidation process a success. This was especially important since the allowable time for biooxidation was reduced from 270 days to 150 days.

Pad Stacking and Compaction

After one year into operation of the commercial facility and with the knowledge that compaction from haul trucks measures 2.4 m into the heap on average, mine department personnel suggested that ore on the pads be stacked to 13.7 m and dozed off to a final height of 12.8 m. After dozing, the pad is ripped by a Caterpillar® D10 with 1.5 m shanks. This method of stacking higher than the final height, dozing off 0.9 m and then ripping, helps to mitigate the 2.4 m compaction layer. Additionally, mine personnel fitted the facility's dozer with a global positioning system that helps to maintain grade as the pad is loaded and offloaded. Maintaining grade while offloading helps to protect the air pipe at the base of the pad from being crushed.

Ore Characteristics

Operation of the commercial biooxidation facility has shown that the source of ore has a dramatic impact on the ability of the ore to readily biooxidize. The two primary sources of ore are the Gold Quarry pit and ore mined from several neighboring pits at the North Area operation, 16 km away.

The pre-biooxidation sulfide sulfur content of the ore from the two sources is slightly lower than design but within 1.4% to 1.8%. The North Area ores contain a higher carbonate content than the Gold Quarry ore yet the amount was well below a design limit of 2.5%. Pre-biooxidized ore is limited in its carbonate content because when ferric iron-laden biosolution comes in contact with carbonate in the ore, the ferric iron precipitates and as a result, is not available for sulfide sulfur oxidation until the carbonate in the ore is neutralized, thus slowing the biooxidation process.

Within one year of operating the commercial facility, visual observations and images taken with a thermal imaging camera revealed cold and hot areas within the oxidizing heap. Upon offloading the ore, samples taken from the cold areas of the heap indicated lower sulfide sulfur oxidation than samples taken from the hot areas. The samples taken from the cold areas were diagnosed as North Area ore, based upon the carbonate content and gold grade. North Area ore has a higher carbonate content and a higher gold grade than Gold Quarry ore.

After discovering the cold and hot areas of the heap the decision was made to blend the ores because previously, ores were stacked separately depending upon mining logistics. Even after the ores were blended, the post-biooxidized North Area ore still proved to be less

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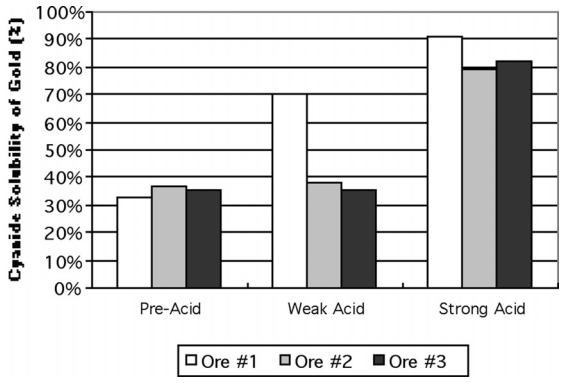

Figure 1. Response of Gold Cyanide Solubility to Bio-amenability Assay by Ore Type

bioamenable than the Gold Quarry ore and appeared to have a negative impact on the sulfide sulfur oxidation of the more amenable Gold Quarry ore.

Mineralogy of the two ores did not reveal any conspicuous differences. The only clear difference was the subtle variation in carbonate content. Ore blending was discontinued and the decision was made to implement an upper threshold carbonate content in pre-biooxidized ore from 2.5% to 1.25%. The 150-day biooxidation cycle does not provide the time required for neutralization prior to biooxidation.

This experience led to the realization of the need to have a timely way to gauge how readily a given ore might perform at the commercial biooxidation facility. Subsequently, Newmont personnel at the Carlin laboratory refined a useful analytical procedure. Technicians developed what is referred to as the bioamenability assay or BAA. The BAA procedure is a series of nitric acid digestions that reveal how readily the sulfide sulfur in the ore can be oxidized at different acid strengths and most important, what improvement in cyanide solubility can be achieved as the degree of sulfide sulfur oxidation increases. Results from the BAA predict how well an ore will perform in the biooxidation process and the timely information assists with economic decisions when considering an ore for heap biooxidation.

Figure 1 demonstrates BAA test results that are typical of ore processed at the commercial biooxidation facility. Ore #1 is from Gold Quarry and Ore #2 and Ore #3 are both from the North Area. The cyanide solubility of the Gold Quarry ore is significantly improved after the weak acid digestion. Both of the North Area ores show little to no improvement in cyanide solubility upon digestion with weak acid. This response is confirmed in field heap results.

While all three samples show a dramatic improvement in cyanide solubility after the strong acid digestion, the biooxidation process as it exists to-date, does not render this degree of improvement in cyanide solubility from biooxidation. Improvements in biooxidation may one day produce results of this magnitude or it could be that the strong acid digestion only mirrors more forceful processes such as roasting or autoclave.

Assaying Considerations

An interesting analytical issue was the detected disparity between sulfide sulfur assays of samples of biooxidized ore taken at the heap as ore was being offloaded versus sulfide sulfur assays of cyclone overflow samples from the mill. Generally, the whole ore samples taken at the heap were 0.5% higher in sulfide sulfur than the mill cyclone overflow samples.

One way to measure the performance of the biooxidation process is to compare the sulfide sulfur content of pre-biooxidized ore to the sulfide sulfur content of mill cyclone overflow solids to determine how much sulfide oxidation has occurred. Most often the amount of sulfide oxidation calculates between 30% to 50%. Even though the samples taken at the heap dig face were not used to determine the degree of sulfide oxidation of the ore, the disparity between the two samples raised questions.

The predominant method for sulfide sulfur determination in the analytical lab at Carlin is through the Leco® roast. The Leco® instrument measures sulfur in both the sulfide and sulfate form. Initially, a sample is analyzed for total sulfur then a split of the sample is roasted at 550°C for one hour to volatilize the sulfides. After roasting, the sample is analyzed on the Leco® again. The difference between the sulfur content of the pre-roasted sample and the sulfur content of the roasted sample is the amount of sulfide sulfur present in the sample.

After a thorough sampling and test campaign, analytical personnel concluded that some sulfate minerals in the post-biooxidized samples taken at the heap volatilize during the roast and render an artificially high sulfide sulfur. These temperature-sensitive sulfates are not prevalent in the cyclone overflow samples from the mill because they stabilize by forming gypsum with the lime that is added for pH control during wet grinding.

Biosolution Addition for Ore Agglomeration

One unique operating aspect of Newmont's biooxidation process is its patented addition of biosolution prior to placement of ore on the heap (Brierley, 1993). Biosolution is added onto the conveyed crushed ore as it falls into a haul truck at the truck loadout facility before transport to the pad. Biosolution addition at this point helps to jump-start sulfide sulfur oxidation and acts as an ore agglomeration aid to improve solution and air permeability within the heap.

Design criteria called for 4% by weight biosolution addition at the truck loadout facility. For one year, the facility struggled with a pump that was sized too small and during that time, biosolution addition never exceeded 2% moisture by weight. Agglomerates were hearty yet the need to counter the impact of carbonate in the ore with the acid biosolution beckoned for the 4% by weight addition.

Eventually the undersized pump was replaced and the 4% addition was achieved. Biosolution addition was controlled by the weight of the ore on the truck loadout conveyor. Unfortunately, the weight of the conveyed ore included the existing moisture of post-crushed ore. At times, particularly during winter months, the moisture addition after crushing was high and 4% additional moisture from biosolution resulted in ore that was too moist and caused sloughing on the heap after the ore was truck dumped.

The ideal biosolution addition control loop would include input from a moisture analyzer of the post-crushed ore. Because a moisture analyzer does not exist in the circuit, biosolution addition control relies on input from the operator at the biooxidation facility. The control room operator can lessen biosolution addition based upon input from the operator who periodically performs a "squeeze" test on freshly stacked ore. The "squeeze" test is from Note 6 of ASTM standard D698 (ASTM, 1998). The control loop does not allow moisture addition to fall below 2%.

Since the 4% addition of biosolution is not always feasible due to wet ore, the desire to counter the carbonate content of the ore prior to ore stacking is addressed with sulfuric acid addition to the biosolution that is added to the ore at the truck loadout facility.

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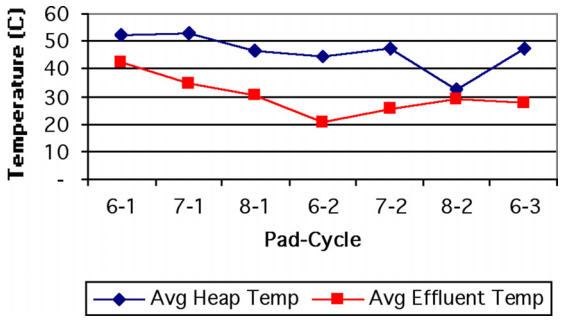

Figure 2. Comparison of Average Heap Temperature to Average Effluent Temperature.

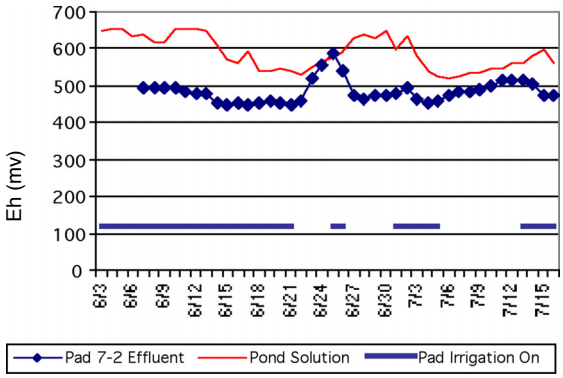

Figure 3. Relationship between Effluent Eh and Pond Eh During Solution Irrigation.

Sulfuric Acid Consumption

Operation of the pilot plant predicted that sulfuric acid consumption at the commercial facility would be 0.38 kg per tonne of placed ore. Operation to date has shown that sulfuric acid consumption is higher and has averaged 0.92 kg per tonne of placed ore.

Sulfuric acid is regularly added to the biosolution pond to keep the pH of the pond solution between 1.75 and 1.90. Acid addition to the pond solution is required because the effluent of some of the heaps, particularly at the onset of heap irrigation, shows a pH up to 2.4 indicating a high heap carbonate content.

The need for more acidification before the ore is placed onto the pad led to the configuration of acid addition into a surge tank that pumps biosolution to the truck loadout facility at the crushing plant. The amount of acid can be increased or decreased with a pH controller whose set point is determined by the metallurgist. This system is in its infancy and the effectiveness of the system will be determined over time.

Bacteria Inoculum and Heap Temperature

The initial inoculum was comprised of a mesophilic iron-oxidizing bacteria and a moderate-thermophilic iron-oxidizing Sulfobacillus-type bacteria. It was originally anticipated that this blend of bacteria would allow biooxidation to persist over the range of internal heap temperatures that would be experienced. However, the temperature regime in the heaps was wider than expected.

Temperature sensors placed in 50 mm pipe and buried within the heap revealed temperatures up to 81°C in areas of the first commercial pad. Concern for the liner at the base of the pad, that was rated for a temperature up to 60°C, led to continuous biosolution irrigation in an attempt to drive the heap temperature down to protect the liner.

Continuous irrigation flooded the heap, resulting in little to no oxygen transfer which impaired the ability of the bacteria to convert ferrous iron to ferric iron. Because the biosolution pond initially had no direct aeration, the bacteria became unhealthy and the effectiveness of the bacterial population declined.

Approximately 6 months into the operation of the commercial facility a hyper-thermophilic archaea was added directly into the biosolution pond. Also, temperature probes were placed at the heap liner to monitor liner temperature to determine if the liner was in jeopardy. The probes showed that the temperature at the liner was cooler than the heap temperature. Analyzing effluent temperature shows that the average effluent temperature is generally 10° to 15°C cooler than the average internal heap temperature (Figure 2). The one meter drain rock layer acts as a thermal break to protect the liner from the internal heap temperature.

The archaea population responded favorably to the environment at the commercial biooxidation facility. In fact, cell counts of archaea and the mesophile bacteria remain at 106 to 108 cells/mL. The moderate thermophiles have diminished in population to 102 cells/mL since the addition of archaea, probably due to crossover of viable temperature ranges among the different microbes. Within 2 months after the addition of the archaea, the population thrived and still thrives, supporting the need for an extreme thermophile in heap biooxidation at Carlin's commercial facility.

Biosolution Pond Eh and Dissolved Oxygen

One of the most fascinating features of commercial biooxidation has been the sensitivity of the bacterial population to solution irrigation. As biosolution irrigation cycles on and off, heap effluent Eh shows significant swings. As soon as biosolution breaks through at the onset of irrigation, heap effluent Eh is low indicating that the ferrous iron, from the chemical oxidation of pyrite, is produced at a rate that exceeds the rate at which the microbes can convert the ferrous iron back into ferric iron.

One might presume that once the effluent biosolution returns to the 23 million L pond, the large concentration of microbes in the pond would quickly convert the surplus ferrous iron to ferric iron. Instead, as the high ferrous-laden biosolution returns to the pond, the pond Eh drops and remains low until the irrigation to the pad is ceased and the effluent Eh rises. Generally only then will the pond experience a rise in Eh.

Figure 3 shows a time period when the relationship between heap effluent Eh and pond Eh during heap cycling is evident. At times, it is difficult to see this relationship because the facility contains 3 separate heaps whose solution characteristics impact the pond at different rates depending upon the timing of solution cycling. It is a certainty, however, that the pond Eh will drop as the heaps undergo irrigation. The microbes only seem to be able to bring about complete conversion of ferrous iron to ferric iron when heaps are at rest and solution irrigation is on standby.

The most notable improvement to the operation of the commercial biooxidation facility has been the installation of an aeration system in the commercial pond. Prior to pond aeration, freedom to cycle solution to the heaps according to a prescribed schedule was not possible. Had the heaps been irrigated as much as desired without aeration, the ferrous content of the pond would remain high, rendering an Eh well below 450. Continuously high ferrous content in the pond

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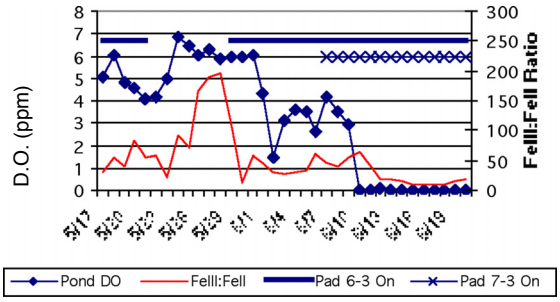

Figure 4. Relationship between Pond Dissolved Oxygen and Ferric:Ferrous Ratio During Solution Irrigation.

biosolution has an adverse impact on the chemical oxidation of the pyrite, contributing to slower sulfide sulfur oxidation.

Many alternatives for solution aeration were considered and the final choice was a system supplied by Nelson Environmental in Winnipeg, Manitoba, Canada. The system, named ADS, is commonly installed at wastewater treatment plants. The system is extremely reliable and virtually trouble-free. Adjustments are required only between the summer and winter months when the change in ambient temperature requires small corrections to airflow to maintain desired pressure in the system.

The original design criteria proposed that the dissolved oxygen in the biosolution pond would remain between 4 and 6 ppm, without direct aeration to the pond. After the startup of the ADS system, a dissolved oxygen probe was installed in the pond. Even with the aeration system, the probe shows that dissolved oxygen readings well below 4 ppm are experienced when heaps are irrigated.

Figure 4 shows the relationship between pond dissolved oxygen, ferric to ferrous iron ratio, and solution cycling. At pond dissolved oxygen levels above 1 ppm, the proportion of ferric iron to ferrous iron is robust. In this graph, pad 6 was at the end of its biooxidation cycle and pad 7 at the beginning of its biooxidation cycle. Note the impact to pond chemistry, especially when pad 7 is first irrigated, supporting the evidence that the bacteria are overcome by the amount of ferrous iron that results from the chemical oxidation of pyrite. When this occurs, the only way to recover pond dissolved oxygen is to place all pads on a rest cycle.

Biosolution Pond Iron Concentration

Total iron concentration in the biosolution pond ranges between 8 gpl to 36 gpl, averaging 18 gpl over the life of the pond. The average iron concentration of the pond was designed to not exceed 13 gpl, using a lime precipitation circuit to reduce metals concentration.

The iron concentration in the pond varies depending upon solution irrigation to the pads and depending upon the addition of fresh water for makeup solution. The highest concentration of iron in the pond generally occurs when a heap first undergoes solution irrigation. When a heap is irrigated with biosolution for the first time, the effluent renders high amounts of total iron, as high as 59 gpl, due to the ore that has biooxidized from contact with biosolution at truck loadout.

The need to treat the biosolution to lower metals concentration will be mandatory if more heaps are constructed. Treating the biosolution to lower metal ions is also desired because the contained moisture in the post-biooxidized ore that is offloaded to the mill for treatment, results in high cyanide consumption in the CIL circuit. Cyanide consumption of biooxidized ore is three times higher than the cyanide consumption of historic oxide ore treated at the mill in the past.

Plans are in place to test an ion exchange resin plant to preferentially remove metal ions contained in the biosolution. This method of treatment is favored over a lime precipitation circuit. Preliminary tests indicate that cyanide consumption at the mill can be lowered by 30%, which will offset the cost to treat the solution by ion exchange.

Pad Air Pipe

A 200 hp fan at the base of each pad, provides aeration to the heap. The air is distributed through a one meter header that is connected to a system of 102 mm diameter perforated pipe spaced throughout the pad base. The air pipe rests on top of a one meter bed of drain rock. The drain rock, air pipe and ore are placed in this configuration to promote lateral airflow within the heap (Bartlett, 1990).

The original operating guidelines stipulated replacing the air pipe after each pad cycle. However, with only three pads the production cycle does not allow the time required for pipe replacement. Leaving the air pipe in place demands that one meter of ore at the pad base, placed on the pad during its first cycle, must remain on the pad as a protective layer.

Subsequent loading and off-loading of the pad results in damage to the air pipe in spite of the one meter protective layer. Between pad cycles, random trenches are dug and air pipe is severed to test airflow from both sides of the header system. If air does not flow, the crushed pipe is located and replaced. The number of trenches that are excavated to inspect air pipe depends upon the amount of time available before the pad is to be re-stacked.

Reusing air pipe has an economic advantage but disadvantages have been experienced. Certainly, the method of air pipe inspection does not detect all the crushed air pipe. Areas with crushed air pipe will not benefit from the addition of air that is so crucial to the biooxidation process.

As the base of the pad becomes exposed during offloading, the biooxidized ore in some areas dries and hardens as strong as cement around the air pipe. Investigation of the cemented material, referred to as evaporites, indicates the presence of iron sulfates.

The evaporites are a deterrent to oxidation in the heap. They will eventually dissolve as they re-wet with biosolution yet before that happens, they prevent the penetration of air through the perforations in the air pipe at the onset of each pad cycle. In an attempt to minimize the impact of evaporites around air pipe, the initial irrigation time is 3 weeks to one month. Subsequent irrigation intervals are only one week in duration. A recommendation that remains to be implemented is to humidify the air in the system during the summer months.

The air pipe at the commercial facility is scheduled to be replaced after the third pad cycle. Because the evaporites form fully around the air pipe, there is concern over the amount of drain rock that will be lost while the air pipe is extracted. Replacing drain rock will add to the cost and time required for air pipe replacement. More experience will help determine the best system for air pipe maintenance and replacement.

Gold Recovery

The biggest disappointment has been the lower-than-expected gold recovery. However, recovery improves as enhancements are made to the process.

Figure 5 summarizes gold recovery for the first seven pads at the commercial biooxidation facility. The cyanide solubility of pre-biooxidized ore ranges from 30-39%.

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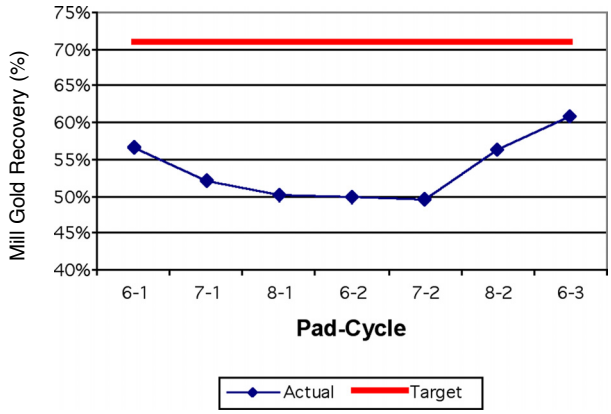

Figure 5. Mill Gold Recovery by Pad at the Commercial Biooxidation Facility.

Additional improvement in recovery is anticipated if approval is gained for the construction of two more pads. A total of five pads will allow the 270-day biooxidation time that was outlined as one of the requirements for 71% gold recovery in the milling process.

CONCLUSIONS AND RECOMMENDATIONS

Operation of a biooxidation process is a challenge because unlike a mill process, there are virtually no instruments directing input to a controller so that process enhancements can be made in real time. Instead, the process is slow and control is accomplished by analyzing manually recorded data, consulting with the operators who monitor the system on a 24-hour basis, and instituting changes as required.

The following comments and recommendations are based upon experience at Newmont Mining Corporation's commercial biooxidation facility, given the configuration of the facility at Carlin:

• Provide enough pads to supply the required biooxidation time and the time necessary to perform pad maintenance between biooxidation cycles,

• Observations indicate that the chemical oxidation of pyrite by ferric iron occurs at a faster rate than the bacteria can convert the ferrous iron back into ferric iron especially in the commercial heaps yet also in the commercial pond. This requires that solution irrigation to the pads undergo periodic rest cycles,

• The microbe population requires direct aeration to the pond solution. Aeration will improve the health of the microbes and provide more flexibility in solution irrigation to the heaps resulting in improved sulfide sulfur oxidation,

• The inoculum must contain a population of microbes that cover a wide temperature regime, including an extreme thermophile,

• In spite of high internal heap temperatures, a one meter layer of drain rock between the heap and the pad liner will act as a thermal break and the pad's effluent temperature will generally be 10o to 15oC cooler than the internal heap temperature,

• An analytical method to determine the bioamenability of feed ore is essential. Do not blend ores that have different bioamenabilities in an attempt to create a more consistent feed,

• Construct enough pads to allow varying biooxidation cycles for ores with different bioamenabilities,

• Sulfate species in post-biooxidized ore may interfere with sulfide sulfur assay results and yield unreliable calculations for percent oxidation.

• Acidifying ore is best accomplished indirectly through contact with acidified biosolution rather than by direct acid addition onto the ore and the best time for acidification is immediately after crushing,

• While metal ion concentrations in the pond may be low enough to not adversely impact biooxidation, solution treatment to lower metal ion concentrations will have a positive impact on down-stream processes that use cyanide.

• Avoid using haul trucks to load and offload the heaps. The use of haul trucks ensures that air and solution permeability problems will prevail,

• A global positioning system will provide better precision at maintaining grade during pad loading and offloading which can help mitigate some truck compaction,

• Replacing air pipe after each pad cycle is ideal. If that is not possible, be aware that iron sulfates will encrust the air pipe, reducing air and solution permeability until the iron sulfates are re-wetted.

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