Operational techniques to recover metal values from heap inventory and *in-situ* chemical alteration prior to closure

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Abstract:

The key to optimal metal recovery from a cell on a heap-leach pad is to match the solution application rate to the permeability of the material for the duration of the leach cycle and to maximize the grade of the solution flowing downward from the cells to collection. Material properties and concepts of solution flow will be presented allowing operators to optimize solution management and metal recovery, thus reducing recoverable metals found in inventory.

A heap is mature when the ore is no longer being placed on the pad. This is usually due to achievement of the permitted height or the mine discontinuing ore excavation. Generally closure permits require the resloping of the sides of the heap prior to capping. This side-slope disturbance allows operations to leach these new surfaces. Designs and operational techniques are shown to recover additional metal values from this phase of leaching.

Mature heap-leach pads may contain about 6% of the recoverable metal values even after the final rinse operation. The heap may contain zones where the chemistry affects the quality of the drain-down solution as meteoric water passes through the pad. Hydro-Jex™ is a 3-D leach technology invented to reduce heap rinse time, change the chemistry of targeted zones, and recover the stranded metal inventory from the pad. This technology is used widely in the United States and is available to aid operators worldwide during leaching and rinsing before heap-leach closure. Examples of the use of this technology are presented.

Introduction:

Nearly 10% of the entire world's gold production is from heap-leaching operations--236 metric tons gold/yr (Marsden, 2006). Thus, heap leaching is an important process for the mining industry.

After working many years as a metallurgical manager for several large heap-leach operations and utilizing the experience to conduct a variety of field experiments and tests, the author has developed several techniques and methods that improved metal recovery at Carlin-type heap-leach operations, thus reducing the metal inventory and promoting rapid closure. These operational concepts and technology are presented.

Methodology:

Solution Application:

Optimization of heap-leach solution application involves managing unsaturated flow through unconsolidated and unsaturated particles with a wide range of particle sizes, from crushed to run-of-mine (ROM), and combinations thereof. The stacked ore has a variety of local void spaces or voidage. The rocks have internal particle cracks or micropores where diffusion of solution in and out via capillary action controls the internal metal dissolution. The optimal solution application rate provides just a thin fluid film on all the rock particles with sufficient reagents to support reagent diffusion to the site of the target metal, leaching the target metal and then diffusing of the dissolved metal in a pregnant solution to the thin fluid film on the rock surface to be washed away with applied solution which contain fresh reagents to begin the diffusion and leaching cycle again. Adding too much solution will cause solution path bottlenecks to fill the voidage and force solution horizontally to the path of least resistance and cause channeling while diluting the amount of the dissolved metal in the pregnant solution. Adding too little solution provides insufficient fluid film on each particle resulting in a lack of sufficient reagents for optimal diffusion and dissolution of the target metal. This practice promotes slower leaching kinetics, or a longer leach cycle.

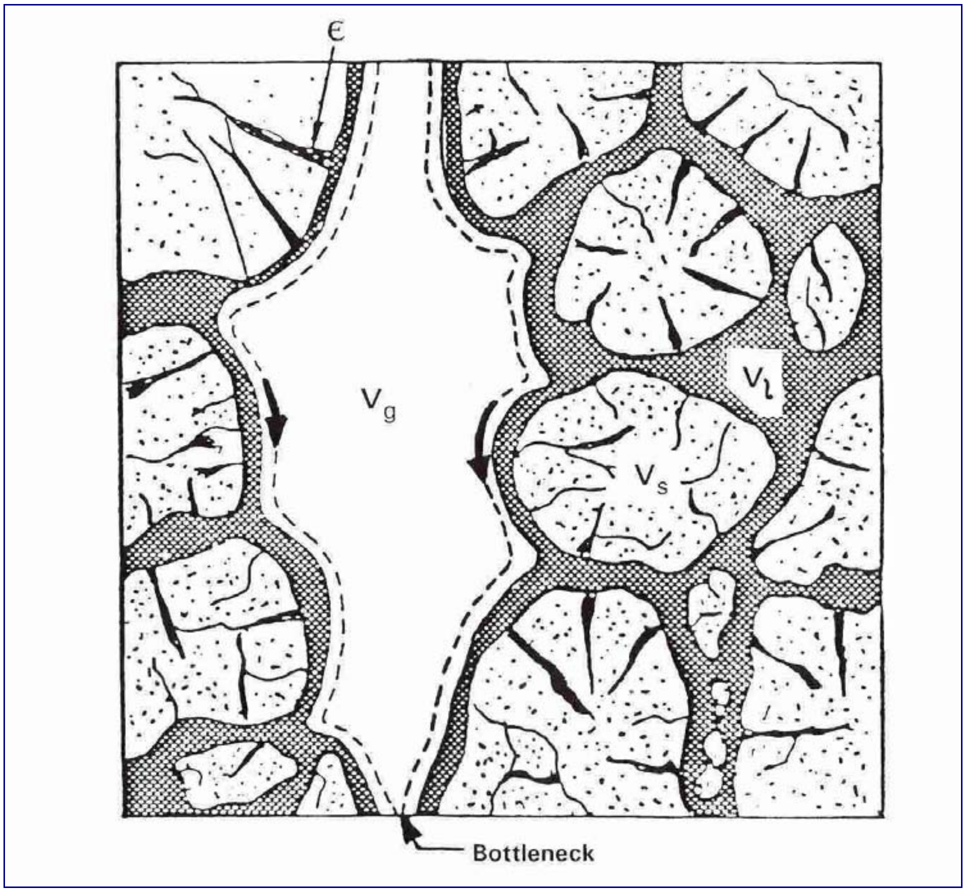

Figure 1: Schematic image of rock particles (V_S), microporosity (ε), solution film (V_l), void (V_g) space, (Bartlett, 1998).

The key to good solution management is to optimize leaching without dilution of the pregnant solution. Classifying the solution application rate to four distinct periods helps operators to understand solution management and optimize leaching. The periods are; ore wetting, leaching, rinsing, and drain down. Operational solution application experiments were done on a number of heap-leach cells (91 x 91 x 9.1 meters high) with crushed and ROM mixed Carlin-type ore. These operational experiments were modeled to optimize solution application rates. The models showed the best method was to regulate the initial application rate for wetting to 0.1 to 0.17 liters/hour/meter^2 (0.004 to 0.008 gpm/min/ft^2) for about 7 days, which matched the average wetting hydraulic conductivity for the Carlin-type ores at this cell height. The ideal leaching cycle or second period had a solution application rate of about 50% of the wetting period. This was accomplished by turning off every other emitter line. Optimally, each emitter line was cycled on/off every few days to a week during the leach cycle. At the end of the leach cycle, the rinsing period was initiated by again turning on all the emitter lines for 7 days to adequately rinse all the leached metal values from the particle fluid film, thus obtaining good sweep efficiency. This whole application rate scenario allows solution to be applied by timing the wetting, leaching, and rinsing period of the leach cycle to optimize metal recovery and obtain the highest grade of pregnant solution from the ore. As the ore size distribution, hydraulic conductivity and microporosity varies, so should the application rate for the 3 solution application periods following guidelines modeled from large and small columns testwork displayed in Figure 2.

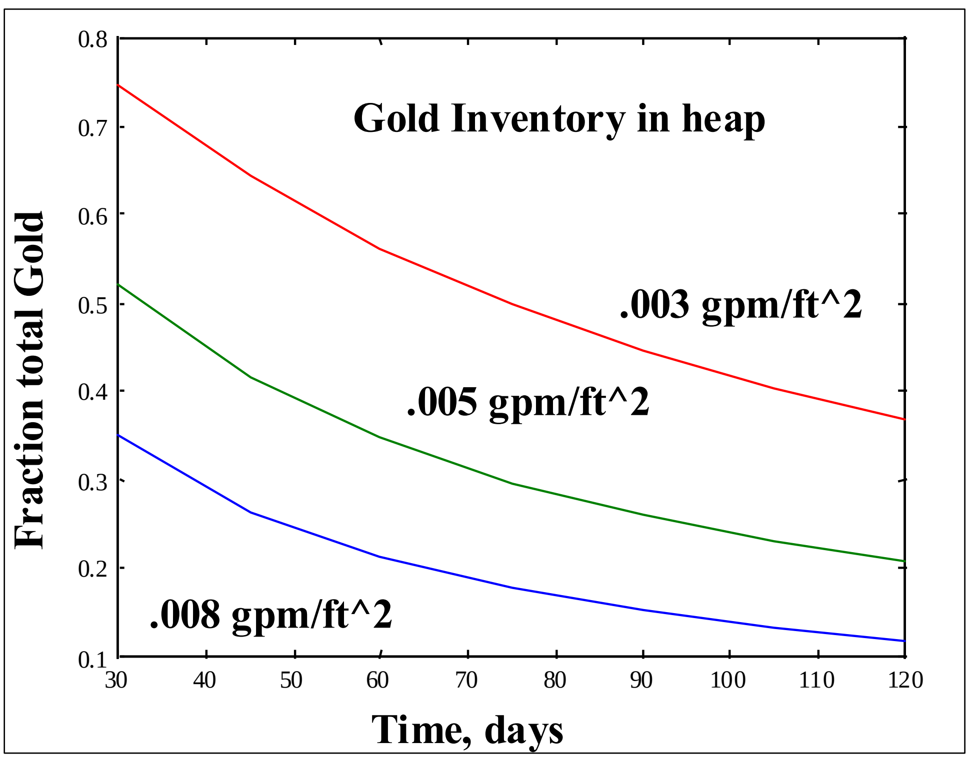

Figure 2: The fraction of total gold remaining in a heap after different application rates of 0.06, 0.11 and 0.17 litres solution per hour per square meter (Seal, 2004).

As the ore is stacked higher and a heap grows taller, the ore weight settles and the voidage at the lower lifts compresses with a resultant lower permeability. Figure 3 shows the change in permeability for a typical Carlin-type heap to a permitted height of 91 meters.

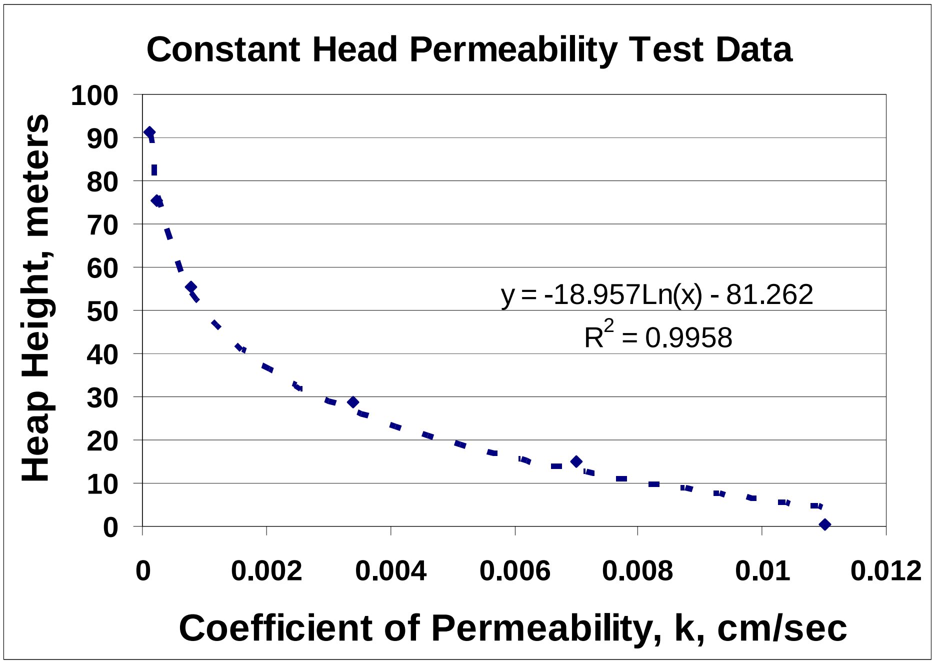

Figure 3: The coefficient of permeability in cm/sec as per depth in a heap, derived from laboratory testing of Carlin-type ore (Seal, 2004).

Reagent concentration in solution:

Due to the variable chemistry of the material found in a given ore, it is difficult to determine the optimal set point for the concentration of cyanide in the barren solution that is added to the top of a cell on a heap-leach pad. From lab column tests on a cell's ore type, reagent consumption data is collected and the total cyanide utilized is calculated during the test. The total cyanide utilized during the column test leach cycle divided by the amount of solution applied provides the heap-leach operator with the initial solution cyanide concentration for the barren solution to be applied to the top of the heap. A method for optimizing cyanide addition was conducted by taking daily pregnant solution samples of the solution flowing from the bottom of the heap and tracking the quantity of free cyanide [CN^-]. If sufficient free cyanide is flowing from the bottom of the heap, then sufficient cyanide is in the heap for leaching. Thus more cyanide is added to the barren solution, step by step until 1-3 ppm of free cyanide flows from the bottom of the heap in the pregnant solution. If more than 5 to 10 ppm of free cyanide is in the pregnant solution, then the cyanide solution added to the barren solution should be trimmed down. Too much cyanide in the pregnant solution will retard the CIC absorption efficiency (Marsden and House, 2006). The operator must also consider the length of time it takes for the applied solution to come out of the heap or break through and only adjust the concentration of the cyanide periodically to account for the heap's conductivity or solution velocity through the heap. Experience on large Carlin-type heaps of 91-meter-height allowed monthly cyanide addition adjustment.

Side-Slope Leaching:

The volume of ore found in the side slopes for a typical heap varies according to the heap design and height which can be a substantial quantity. One heap on the Carlin Trend had about 30% of the ore in side slopes, which was not leached very well due to solution management and ore-stacking schedules. The closure plan for the heap required contouring to 2.5:1 slope angle. Operationally, the side slopes were wetted with irrigation sprays to cover each lift and side slope to reduce the metal inventory by re-leaching and evaporate solution accumulated in the spring months as shown in Figure 4.

Figure 4: A picture of spray leaching and evaporation on a Carlin-type heap-leach operation (Seal, 2003).

The side slopes were then allowed to dry, and during the summer months the slopes were re-contoured using a dozer, with care not to overtop or puncture the liner under and adjacent to the bottom lift. This operation mixed, rechanneled, and exposed under-leached ore to be leached.

Figure 5: The dozer side-slope contouring of a Carlin-type heap-leach operation (Seal, 2003).

Emitters were then strung vertically with special built point-source emitters and pressure regulators to keep an even flow of barren solution to the under-leached ore as shown in Figure 6. Leach-pad crews would stage the tubing reels on top of the heap and walk down with several lines, placing the tubes to the bottom of the pad, and then take a ride to the top to keep the piping project moving quickly. Other operations used horizontally strung emitters. Daily recovery from the heap-leach pad increased from an average 14 troy ounces gold/day to an average of 80 troy ounces gold/day and a peak of 160 ounces gold/day when the side slopes were under leach, as shown in Figure 11.

Figure 6: Side-slope leaching with vertical emitters and pressure regulators on a Carlin-type heap-leach operation (Seal, 2003).

Hydro-Jex:

A heap is labeled “mature” when the ore is stacked to the permitted height and leached. Reagents continue to be added to the barren solution to remove inventory from the heap and side slopes. The metal recovery drops to a small consistent average value that pays for the reagents and pumping costs, but before rinsing and evaporation of solution prior to closure. Drilling heaps with hole sample analytical data analysis (such as mine bench kriging) can determine the location and quantity of metal in inventory as shown in Figure 7. Experience on heap-leach pads located on the Carlin Trend showed that about 6-8% of the recoverable gold values remain in the interior of the heap. This inventory is due to stacking schedules and solution management, compaction under haul roads, incomplete ripping of the surface of the cells before leaching, chemical precipitation in the heap, clay zones or ore that is not adequately agglomerated, heap settlement, migration of fines, and compaction (Seal, 2008).

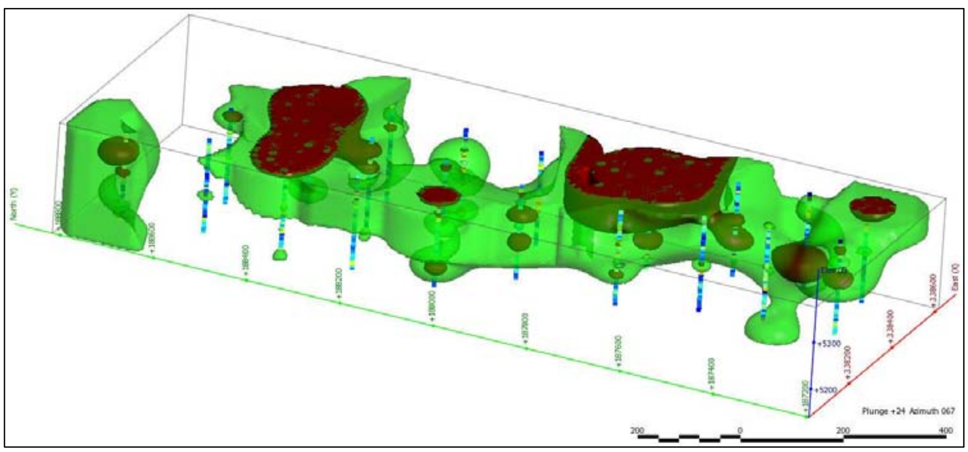

Figure 7: Kriged gold assay data from drill samples identifying under-leached zones in the heap interior for a Carlin-type heap-leach operation, green 0.34 g/MT, red 0.48 g/MT (Seal, 2008).

The key to recovering this metal inventory is to transport the lixiviants to the unleached or under-leached zones to leach the metal values and rinse the pregnant film off the individual rock surfaces.

Geophysical resistivity measurements were conducted on the surface of the heap-leach pad to identify the interior dry zones (noted in red) with under-leached inventory as shown in Figure 8.

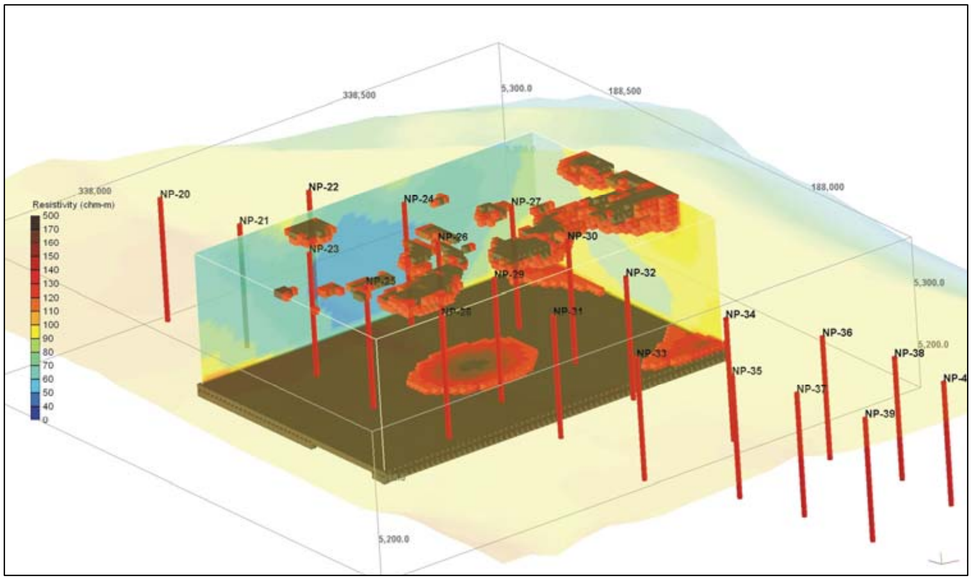

Figure 8: Plotted geophysical resistivity data from a surface array identifying under-leached zones in the heap interior for a Carlin-type heap-leach operation (Seal, 2008).

The challenge of leaching these interior dry zones was solved by the use of Hydro-Jex, which was invented and patented as a doctoral research project (Seal, 2004). The technology basically involves drilling and sampling a heap-leach pad and installing a well with zonal perforations. The zones are isolated using standard drill tools, and high-pressure solution is pumped in, to open solution pathways and channels, achieving 3-D leaching. In addition, any pumpable solution or slurry can be metered into a specific location in the interior of the heap. Due to the encasement of all the solutions delivered into the heap's interior, strong reagents can be used without surface wildlife exposure. The reagents are mixed and diluted with other fluids that make up the pregnant solution flowing from the heap. The horizontal component of the solution profile ranges from a 20- to 30-meter radius depending on the depth of the targeted zone and the size distribution of the rock in the heap. Geotechnical studies show a slope stability factor of greater than 1.5 during the pumping and the follow-up rinse process (Seal, 2008).

Figure 8: Hydro-Jex operations on a valley-fill heap-leach operation (Seal et al., 2011)

The injection pump is initially horizontal with very little vertical component until in-heap solution friction allows gravity to slope the pumped solution profile as shown in Figure 9, where sensors were placed adjacent to the Hydro-Jex well. With low internal pH in the heap, milk-of-lime slurries were added to the injection operation to change the pH in the zone and alter the pregnant solution pH, as shown in Figure 10. In a normal gold mining heap, the voidage has sufficient oxygen to dissolve into the fluid film encompassing the rock particles. As heap-leach pads reach higher elevations, the voidage volume decreases and if organic carbon and/or sulfides are present in the heap, then the oxygen concentration in the voidage decreases or is non-existent. Leaching gold and silver requires dissolved oxygen and if oxygen is depleted, then leaching kinetics are reduced. The Hydro-Jex technology mixes sparged air into the injection fluid to reach 11-13 ppm dissolved oxygen, as determined in bench scale tests (Seal, 2004).

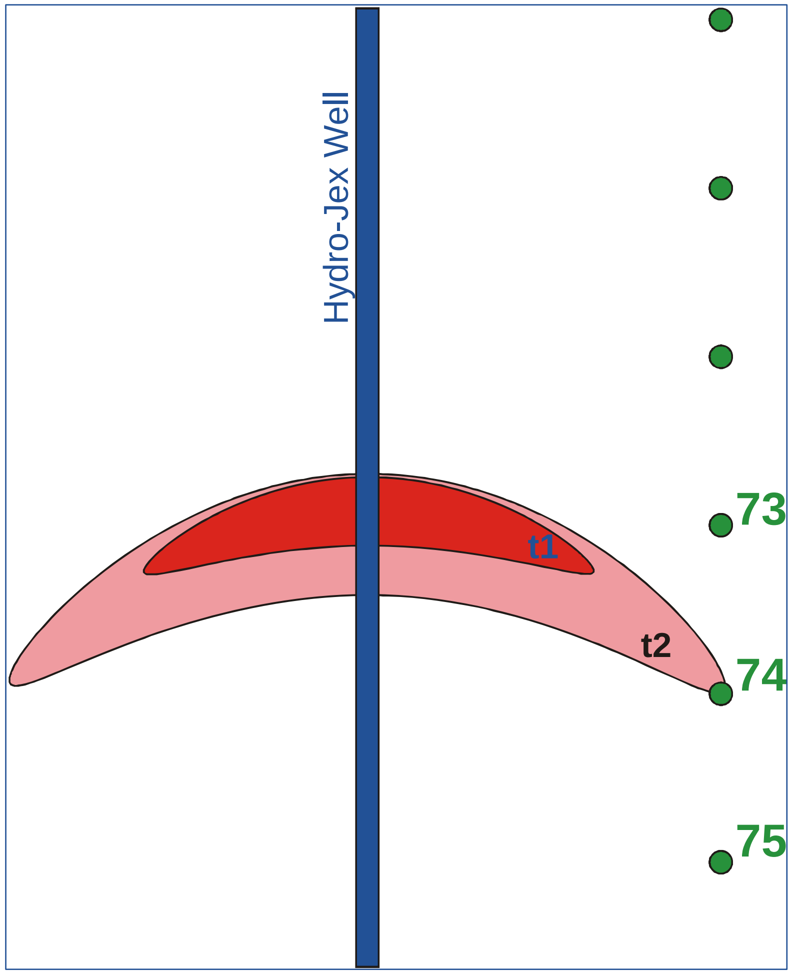

Figure 9: Hydro-Jex pumping plume in a valley-fill heap-leach operation (Seal et al., 2011)

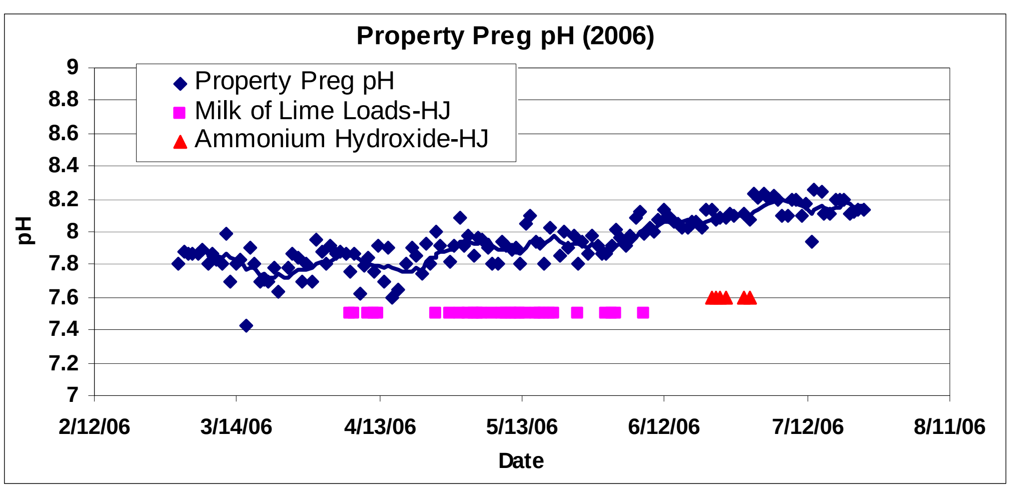

Figure 10: pH changes in the pregnant solution with to milk-of-lime and ammonium hydroxide injections into the heap interior via Hydro-Jex (Seal, 2008)

Post injection, the wells are revisited periodically with barren solution to each zone to rinse the dissolved metal values and re-establish fresh reagents using the channels established during the injection pumping. This system can operate concurrently with the closure plan and can shorten the rinse time while recovering previously unrecoverable metal inventory. This allows operators to recover the reclamation bond earlier.

Conclusion and Discussion:

The main operational key to heap-leaching efficiency is to recover the maximum amount of metals from the heap in the shortest time. The effect of side-slope recontouring and re-leaching is displayed in Figure 11. Gold production from Hydro-Jex wells is found in Figures 12 where at Lone Tree an average of 15.2 troy ounces gold was recovered per meter of a Hydro-Jex well during stimulation and rinsing. Prior to the stimulation and Hydro-Jex pumping, the weekly gold production was about 10 troy oz. per week (Seal, 2008).

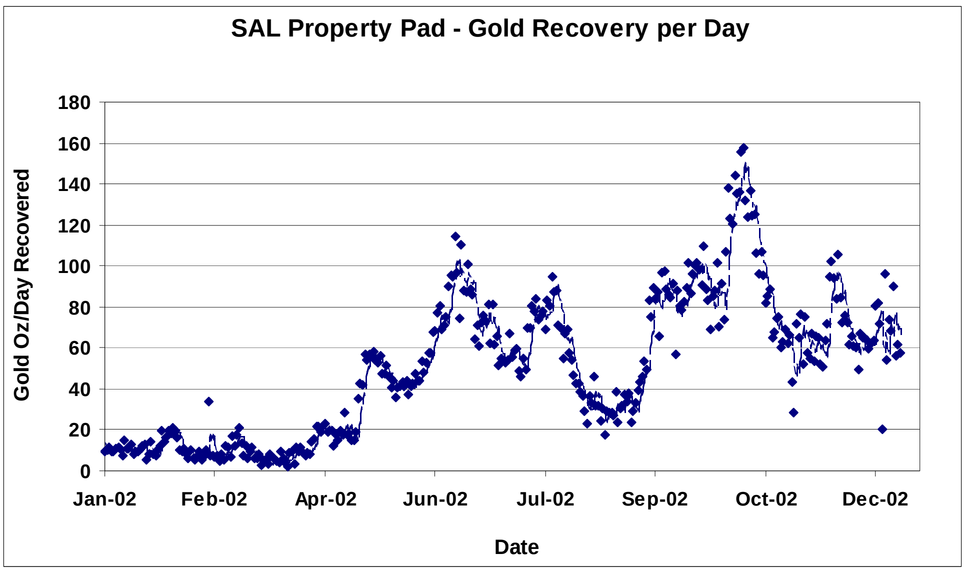

Figure 11: Increase in gold production due to side-slope recontour and re-leaching (Seal, 2003)

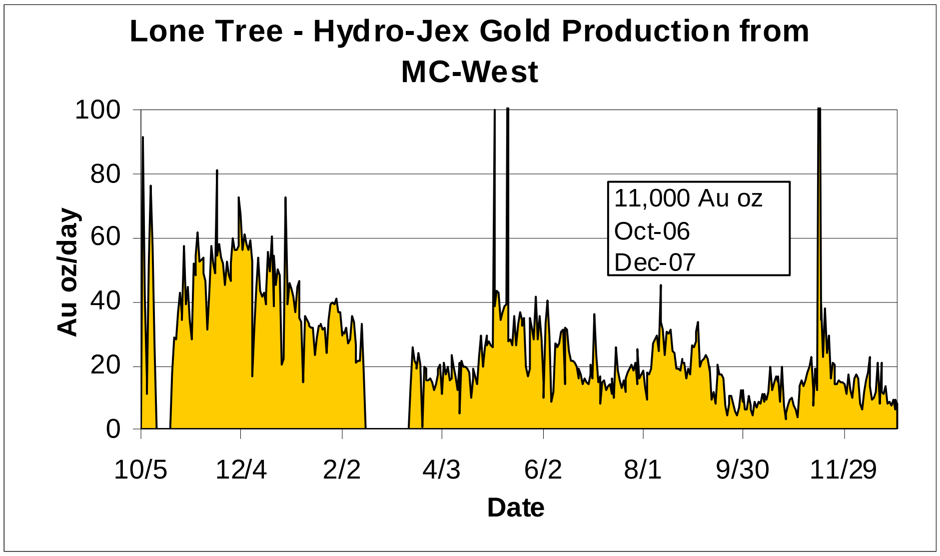

Figure 12: Increase in gold production from 10 troy ounces per week due to Hydro-Jex stimulation on the Lone Tree MC West pad (Seal, 2008)

Heap-leach operators have a wide variety of techniques to maximize gold production by optimizing solution management, recontouring and releaching side slopes, and by using the Hydro-Jex technology to target and stimulate dry zones of underleached inventory of recoverable metal values and to change the internal heap-leach chemistry while shortening the rinse and closure cycle. In addition, Hydro-Jex offers a new solution management tool for operators of heaps.

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