Potential Problems in Copper Dump Leaching

By Mark E. Smith, PE

Abstract

Copper dump leaching is the most rapidly growing copper recovery process. Unlike it's predecessors, which are typified by unlined, unmanaged dumps which presented a myriad of environmental concerns and anything but an optimized process circuit, modern dump leaching uses engineered containment and drainage systems, and the facilities are generally designed to modern standards. Like other successful technologies in mining, it is also pushing the envelop of known performance standards. Which requires engineers and operators to both think out of the box and, sometimes, tread on thin ice. It is that thin ice which is the focus of this article.

Background

Frequently defined as heap leaching of run of mine ore and occasional expanded to include large valley fill facilities, dump leaching is not a new technology. But the modernization of this old technology, using advances developed principally in the heap leach sector, has allowed us to build larger and higher dumps, faster than ever. It is this rapid expansion in geometry, combined with the precise engineering required in the containment and drainage systems, that marks the point of departure between heap leaching and dump leaching.

Modern Dump Leaching is:

- A rapidly expanding technology with little precedence,
- Pushing the envelop of all known performance parameters,
- Developing some of the world's largest man-made structures.

Mining has a hit-and-miss history of applying new technologies. In the case of mill processes, the history is one of mostly successes. In terms of tailings it's a bleaker story with major dam failures still occurring at the rate of one every few years. In terms of general waste containment, our industry is responsible for a killer event once every 5 years with an average of 100 peopled killed with each event. Arguably this is improving, but it might be too early to say. A recent search on the internet for the key words "mine waste failure" reported 147,000 hits. Structural failures aside, there is also a mixed history in terms of economics and reliability.

None of this is intended to suggest that we should stop advancing dump leaching technology. On the contrary, the technology is ideally suited to modern, large scale mining. Rather, the message is: to anticipate is to avoid problems.

Heap leaching is a shinning example of this. The industry progressed very cautiously at first, and spent most of the 1980's fully commercializing this technology. It was only after nearly two decades of experience did we first begin to seriously advance the practice and really push the limits. The result is both a technological conversion that happened with very few major glitches, and some lost economic opportunities some projects suffered from over-conservatism.

Because of the limited nature of this article and the specific expertise of the author, this paper will focus on construction, geotechnical and closure related areas. But, certainly, areas such as process, environmental and economics present their own unique challenges.

Construction Concerns

- Schedule – Dumps are very large facilities and require vast areas of geomembrane liners. A recent conceptual design was completed for a design capacity of 2,000 million metric tonnes! The resulting lining area was nearly 10 million square meters. Modern liner installation rates are pushing limits of supply, especially in places like Chile where there are only two modern plants, or in Peru and Argentina where none exist.

- Thin liner – as dumps get higher and copper prices lower, owners need to improve economies at every level. One result is that, for the same design criteria, dumps use thinner liners.

Heights v. Liner Thickness

Heap or Dump	Typical Ore Depth (m)	Typical Liner Thickness (mm)	"All In" Costs[1] (per m^2)
Heap	50 – 100	1.5 – 2.0	\$7 - \$11
Valley Fill	100+	2.0 – 2.5	\$20 - \$30
Dump	100+	1.5	\$5 - \$10

General Geotechnical Issues

- Liner System Long-Term Performance: Heap leach liner systems were developed with careful study, a great deal of laboratory research, the synergism resulting for the parallel advancement of landfill technology, and a number of case histories which included double liner systems which produced very reliable performance data. None of this exists in dump leaching. There is no other industry to which we can look for similar experience. There are no reliable monitoring systems being used for leakage at any existing dump leach (though the deep, gold valley fills are producing some data.)

---

[1] Smith, Mark E. 2002. Technological Advances in Low Grade Leaching. ExpoMin 2002, Santiago, Chile, May 10th.

- Ore Degradation: always a concern in both heap and dump leaching, the related problems can be exasperated in a deep dump, especially with sulphide or mixed ores. And, to date, no reliable testing has been developed for long term performance. So, we use adaptations of rules of thumb developed from 50 meter deep oxide heaps to predict the performance of 150 meter sulphide dumps.

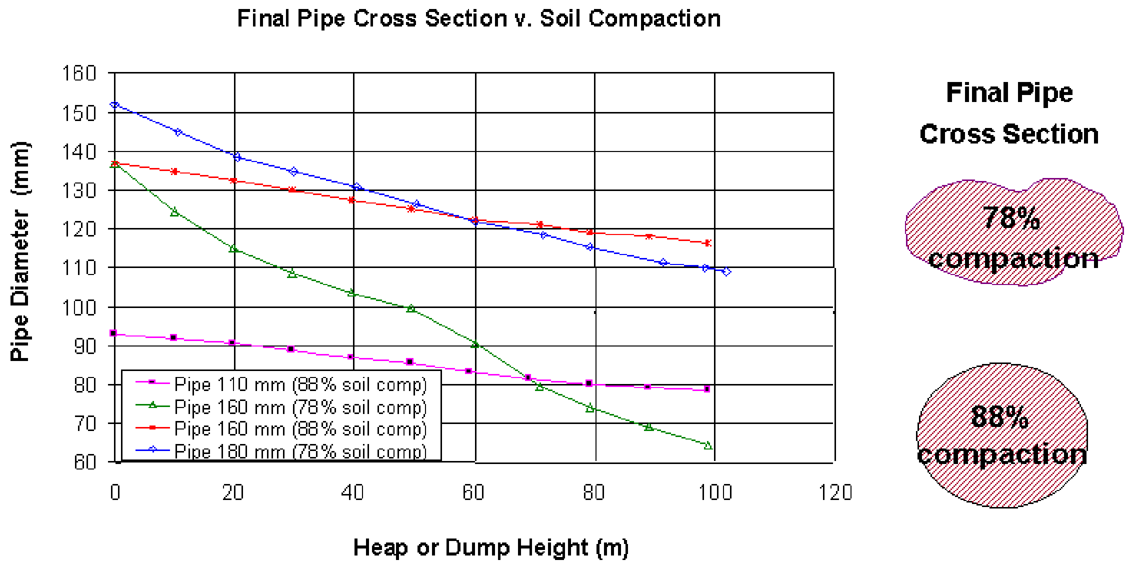
Ore Degradation

Mode/Change	Effect
Chemical (sulphides)	• Lower permeability • Increased saturation • Plugging of pipes, filter zones • Sealing of zones within dump • Higher water levels • Loss of support for pipes, collapse
Weathering of surface	• Salt, silt deposits seal top • Erosion, slumping • Ponds
Physical	• Traffic in haulage areas • Segregation in dumping • Creep movement of slopes, foundation • Other physical degradation not common

- Long-Term Drainage: With dump heights in the 100 to 200 meter range, the limits of known performance of pipes has long been passed. Laboratory testing is struggling to keep up, but with each increase in maximum depth the nature of the laboratory test – and the resulting costs – takes a disproportionately large increase. Furthermore, design details, such as compaction around and bedding for drain pipes, becomes more critical since drainage pipes gain their structural strength from the supporting gravel.

- Slope Stability: Dumps use higher inter-lift slopes, they tend to include more variable ore quality, and the dumps are deep enough to trigger foundation failures, which are rather rare for the shallower heaps. And a higher dump produces a lower internal angle of friction.

- Channelling within the dump: A problem long known in heap and dump leaching, is exasperated when the lift thickness increases. Inclined zones of preferential flow are created when dumping ROM ore and the large rocks collect along the working face. For thin lifts, these zones are interrupted and the solutions are redistributed, thus limiting their effect to small pockets. The thicker the lift, the more influence any one pathway will have and the more likely preferential paths will interconnect vertically.



Liquefaction Potential

Liquefaction is a phenomenon of collapse and large deformation that can be triggered by a number of events. Liquefaction is caused by a combination of a collapsible material such as loose rock, water, and a collapse 'trigger' event. Classical liquefaction has as its trigger an earthquake. Dynamic failures are generally limited to relatively shallow (i.e., less than 20 meter) depths, since higher confining stresses reduce the susceptibility to this failure mode. They therefore are relatively limited in their destructive potential. A later-day form of liquefaction called static or flowslide liquefaction is only just becoming understood and predictive models are being developed and field proven, the leading model having been advanced as recently as 1998 by Dawson, Morgenstern and Stokes[2].

Flowslide Liquefaction Defined

"…characterized by the sudden collapse and extensive, very to extremely rapid run-out of a mass of granular material or debris, following some disturbance. An essential feature is that the material involved has a meta-stable, loose or high porosity structure….The consequent loss of strength gives the failing material, briefly a semi-fluid character and allows a flow slide to develop." (Hutchinson[3])

---

[2] Dawson, R.F., N.R. Morgenstern and A.W. Stokes 1998. Liquefaction flowslides in Rocky Mountain coal mine waste dumps. Canadian Geotechnical Journal 35:328-343.

[3] Hutchinson, J.N., 1988. General Report. Morphological and geotechnical parameters of landslides in relation to geology and hydrogeology. 5th International Symposium on Landslides, Switzerland, Vol. 3, pp. 3-35.

Static liquefaction events do not require an earthquake to trigger failure. The trigger event is the introduction of water by rain, snow melt or, potentially, irrigation. Originally thought to be a problem of fine grained wastes, the Aberfan, Wales disaster of 1966[4] made it clear that course rock was also susceptible. Unfortunately, it took the loss of 144 lives for this geomechanical reality to be brought to light. A recent study of Canadian coal waste failures suggest that nearly one-third of active coal mine waste dumps in British Columbia are potential high run-out flowslide hazards[5]. Run-out distances of several kilometres are common and some of the larger failures have included debris masses on the order of several million tonnes.

Flowslides are of particular interest because of their terrible, destructive history. In the last 4 decades and including all types of mine wastes, our industry has averaged one killer flowslide each 5 years with an average of 50 deaths per event. Beyond the sheer human disaster are the raw economic impacts, which can devastate any company.

Flowslides with Lost Lives

Event	Lost Lives
1962: El Cobre, Chile: Tailings failure.	250
1966: Aberfan, Wales. Coal waste dump failure.	144
1970: Mufulira Mine, Zambia. Tailings failure into underground workings.	89
1972: Middle Fork Buffalo Creek, WV, USA. Two coal dump failures.	125
1974: Bafokeng Mine, South Africa. Tailings failure.	9
1994: Merriespruit, Harmony Mine, South Africa. Tailings failure.	17

The good news is that, to the author's knowledge, there as not been a single case of flowslide liquefaction in heap or dump leaching (though dynamic liquefaction is a known failure mechanism of heaps, as was demonstrated recently at the Cuajone Mine in Peru[6]). In fact, the nature of heap leaching – stack the material in thin lifts and then irrigate – tends to pre-collapse the rock and make it less susceptible to liquefaction of any kind as compared to a waste dump, all other things equal. So, why are we concerned about this hypothetical failure mode in dump leaching? The answer lies in the fact that, in some regards, leach dumps are more like waste dumps then they are like heaps. The total heights are rapidly approaching 200 m, while few heaps exceed the 100 m threshold

---

[4] Bishop, A.W. 1973. the stability of tips and spoil heaps. Quaternary Journal of Engineering Geology, 6:335-376.

[5] Piteau Assoc. Engineering Ltd. 1991. Investigation and design of mine dumps: interim guidelines. Report to British Columbia Ministry of Energy, Mines and Petroleum Resources.

[6] Rodriquez-Marik, A., P. Repetto, J. Wartman, D. Baures, E. Rondines, J. Williams and J. Zegarra-Pellanne, 2001. Geotechnical Earthquake Engineering Reconnaissance of the June 23, 2001, Southern Peru Earthquake, A Preliminary Report. National Science Foundation, Washington State University, Drexel University, Catholic University of Peru and URS Corporation.

commonly associated with flowslides. The lifts are not thin and are now approaching 50 meters – much like a waste dump. They are built on variable and sometimes steep terrain. And they have two seriously negative features that makes them more susceptible than a "typical" waste dump:

- Unlike waste dumps in, for example, the North of Chile, dump leaches have ample water and an automatic trigger mechanism (water or a seismic event), both essential ingredients; and,
- There is usually a low strength liner system at the base of the dump, rather than a firm foundation, exasperating potential run-out distance and velocity.

Economic Costs of Major Flowslide Failures

Direct Costs	Costs to Industry
• Clean up of failure mass. • Restoration of dump or dam. • Environmental liability. • Restitution to victims/Off site damage. • Lost production. • Legal fees for settlement of claims. • Continuing costs for government and community relations programs. • Loss of shareholder confidence. • Increased costs for future expansions as government demands more security. • Lost production during term of rehabilitation.	• Market wide loss of capital valuation in stock market. • Increased cost of financing. • Increased cost of permitting projects. • Higher insurance premiums. • Loss of shareholder confidence industry wide (the Bre-X syndrome). • Delays in permitting & financing. • Loss of ore reserves that are pushed out of the limits of marginal economics by the cumulative effects.

Using the Dawson-Morgenstern-Stokes model, the Piteau research and earlier contributory works, a working guideline for identifying leach dumps that might be susceptible to flowslide liquefaction is proposed as the following. However, the models and applicable case histories are not sufficiently advanced to allow any such rules of thumb to govern the final analysis. Rather, these should be considered screening tools for preliminary design and the final analysis should include a specific consideration of this failure mode. A very good first step in the analysis is to estimate the degree of saturation expected within the dump under leach.

It has been estimated that liquefaction is unlikely if the degree of saturation is less than about 85%[7]. Solution application rates are commonly quoted as flow rate per area (i.e., gpm/ft^2 or l/m^2/hr). They can also be expressed in the same units as permeability (cm/s). The typical application rate for copper leach solutions is between 1x10^{-4} and 5x10^{-4} cm/s. By comparing the application rate with the unsaturated permeability of the ore (which is a function, among other things, of the degree of saturation) the under-leach degree of saturation within the heap can be predicted.

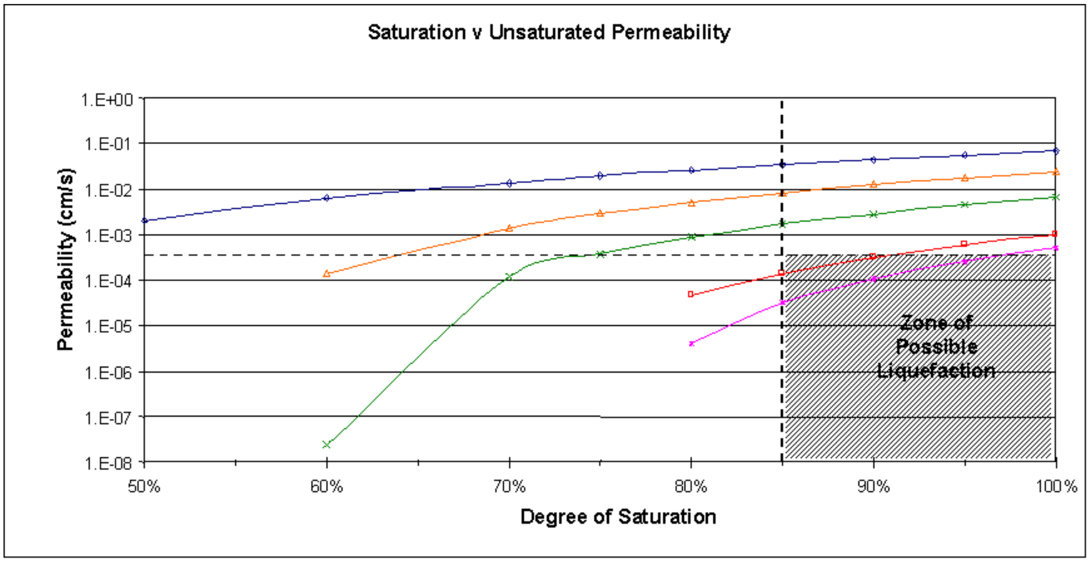
Indicators of Flowslide Susceptibility

Parameter or Characteristic	**Threshold (approximate)**
Maximum height	≥ 100 m
Foundation slope	≥15 degrees
Location, Terrain	Incised valley
Inter-bench slopes	Near angle of repose
Heaped moisture content of ore	≥ 5%
Saturated permeability of ore	≤ 1 x 10^{-2} cm/sec
Saturation (at any point in the dump)	≥ 85%
Other factors:	• No toe support • Finer material near the base • Water, impermeable layer at base

Typical values for permeability as a function of saturation are shown in the graph. Based on these trends, if the saturated permeability of the ore is greater than about 5x10^{-3} cm/s one would not expect that the degree of saturation would exceed the threshold 85% and thus liquefaction would be unlikely. However, for lower saturated permeabilities, liquefaction may be possible and further analysis is recommended. It is also important to understand how the permeability will vary with depth and time.

---

[7] Sassa, K. 1985. The mechanism of debris flows. Proc. of the 11th Int'l. Conf. on Soil Mech. and Foundation Engineering, San Francisco, V. 3, pp. 1173-1176.



Closure

The first heaps are only now going to closure and thus there is little precedent with which to base any designs for closure of large dump leach facilities. What can be said is that all of the problems inherent in the closure of a heap will be amplified in a dump.

Based on performance of relatively small, soil covered heap leach facilities in Nevada (USA), the stabilized drainage – even for the driest sites – can be expected to be at least 0.01 liters per second per hectare (lps/ha). Given that dump leach pads encompass on the order of 500 ha, a post-closure flow of 5 to 10 lps could be expected at an arid site. Obviously, many factors affect the actual yield and local climatology and the capping system are key among them. The Nevada data is presented[8] normalized to the ratio of potential evapotranspiration to precipitation and this ratio can be used to estimate flows based on average annual or wet cycle precipitations[9].

---

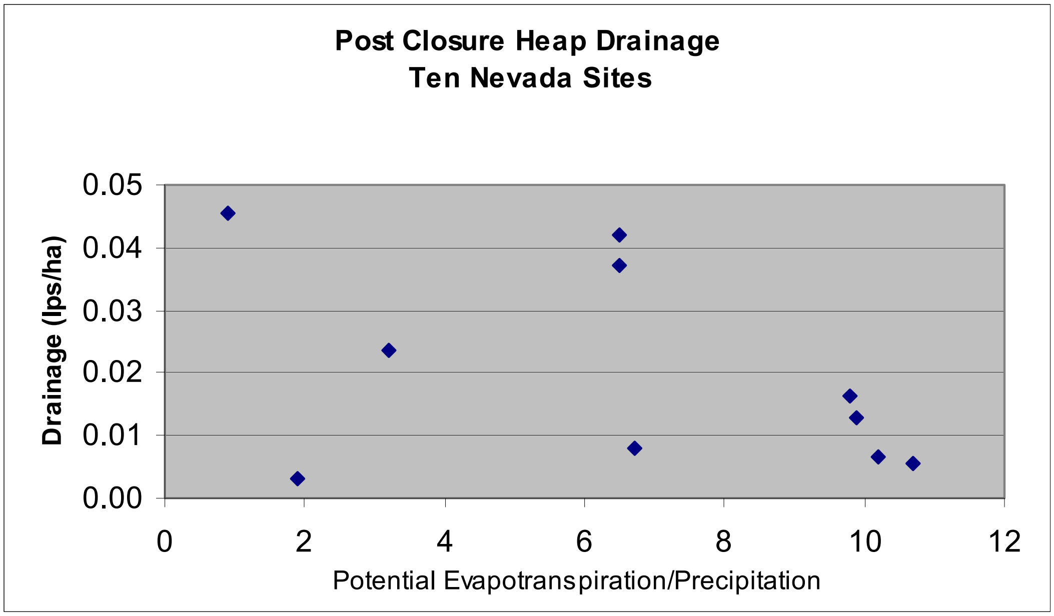
[8] Tyler, Dr. Scott W., Hydraulic Behavior of Heaps: Estimations of leachate quantity. Mining Life-Cycle Center, Makay Sch. Of Mines, Heap Leach Workshop Series, January 26, 2001.

[9] Leduc, Marc, 2002. Heap Leach Closure. Presented at the International Gold Conference, Lima, Peru, May 16th.

Typical Closure Issues for Dump Leach Facilities

Area	Concern
Slope Protection	• Very large inter-bench angle of repose slopes are difficult to protect against erosion, rock fall and other post-closure threats.
Wet Climate Issues	• Long term erosion control • Capping • "Permanent" diversion of surface flows • Stability, considering long-term water levels and drainage performance.
Solution Yield	• Modelling tends to under-predict post-closure yield. • Requires system to manage contaminated leach solution. • Lower flows tend to result in higher contamination levels. • Acid rock drainage.

An interesting case history is the closure of the waste dump for the Gibraltar Mine in British Columbia. The dump began to produce acid post-closure and the remediation was to install as SX/EW circuit. For several years this was the lowest cost copper produced at the mine. Had this been planned as a dump leach, it could have been build as an engineered facility with proper containment, controls and planning. Thus, the copper production could have been optimized and the environmental exposure minimized, probably with a higher overall profit.



Conclusions

For many projects the addition of a dump leach circuit, be it for ROM sub-grade ore or the re-leaching of spent ore (ripios) from a dynamic (on/off) pad, adds important profitability. Local communities gain from increased employment, tax revenues and, sometimes, an extended life of the mine. The industry experience with heap leach technology demonstrates that such technological adaptations as dump leaching can be accomplished without the problems we have seen in other areas. That is, assuming that the projects are properly planned and executed and this becomes more important as the facilities increase in size. Unfortunately, the current trend in the industry is to dedicate proportionally *less* effort – in terms of engineering, monitoring, forensic studies and quality control – in a dump leach because of the low grade ore and incrementally low profitability. This might be called the "scavenger circuit" mentality.

It is perhaps asking too much to both extend the limits of technology without apparent bounds and do so with diminishing engineering and science.

Mark E. Smith is the founding principal of Vector Engineering, Inc. of Grass Valley, California and now resides in Peru as the manager of South American operations. He is a civil and geotechnical engineer with dozens of professional publications and over 20 years experience in heap and dump leach design, construction and operation. He can be reached via email at: smith@vectoreng.com.

Published in *Mining* magazine, July, 2002.