Proceedings of Heap Leach Solutions, 2014
November 10–13, 2014, Lima, Peru
Published by InfoMine, © 2014 InfoMine, ISBN: 978-0-9917905-6-2

Leach pad cost benchmarking

Mark E. Smith, RRD International Corp., USA
Denys Parra, Anddes Asociados SAC, Peru

Abstract

The cost of construction of the leach pad is an important part of the total capital cost of any heap leach project, whether a green-field development or expansion of an existing operation. The authors present and discuss costs from 48 phases of work on 28 heap leach projects in 8 countries, including North and South America, Africa and Asia. Costs were compiled from feasibility studies, detailed designs, NI43-101 technical reports, and as-built analyses. In a few cases, when the detail was suitably advanced, costs from prefeasibility studies have also been used. All costs are presented in 2014 United States dollars (US$) using an escalation rate based on the 10-year average ENR Construction Cost Index.

This data and the accompanying analyses should provide assistance to engineers and owners in preparing project cost studies. It may be useful to reviewers, investors, regulators, and sureties in determining the reasonableness of third party cost estimates. It may also help in the future to determine trends in heap leach costs (for example, relative to general construction cost escalation). This paper will also discuss the purpose of and methodology used in performing a benchmark study, which may be of broader application.

Introduction

One definition of benchmarking is to compare one's business practices with those at other, similar sites or companies in the same or similar industries. The purpose can be to verify best practices, provide high-level data without detailed site-specific analyses, monitor industry or regional trends, prepare order-of-magnitude estimates, verify more detailed cost estimates, and so forth. Benchmarking is commonly used in mining and mineral processing for a range of performance metrics, most commonly related to costs and productivity. In this paper the authors focus exclusively on the capital and sustaining capital costs for leach pad construction for gold and silver, copper, nickel, and uranium projects. These costs would also be generally applicable to heap leaching of other minerals such as rare earths and nitrates.

Construction cost estimating methods generally fall into three categories (in order of increasing accuracy): benchmarked estimates, built-up estimates, and estimates based on contractor and supplier quotes. While benchmarking can be the least accurate of these three it is the most readily available. The larger the database and the better one can correlate to site-specific factors the more reliable a benchmark-based estimate becomes. With a modest level of effort and a small database, an estimate with a reliability of +/−50 percent to +/−35 percent can be achieved. With a more robust effort and larger database, that can be considerably improved. The authors have extensive experience producing benchmark-based cost estimates in the range of +/−25 percent to +/−15 percent of detailed engineering cost estimates.

Methodology

Data sources

The cost data used in this study came from several sources in about equal proportion: the authors' project files; personal interviews with other design engineers, construction managers and owners; and publicly available Canadian National Instrument (NI) 43-101 reports for TSX-listed companies. Except when the authors' own project files were the source, it was generally not practical to verify the information beyond a high-level reasonableness test; about 10 percent of the data collected was disregarded as not meeting that criteria.

Key parameters

Capital costs were gathered for three items: earthworks, liner system, and total. The liner system costs included the geosynthetics only (geomembrane, any other geosynthetics in the liner system, and installation). All other costs were included in the earthworks category, including the gravel overliner (in some cases, as discussed below), clay underliner (where present), and drainage pipe. This is an imprecise method of categorization but the simplification was necessary because, in most cases, more accurate classification was not possible given the data available.

Leach pad area was taken as either (i) the actual or horizontal projection of the lined leach pad from the external edge of the perimeter berms and collection ditches (in most cases the difference between actual and horizontal projection is very small), or (ii) the total geomembrane liner area (which will be slightly larger due to overlap, anchorage and trim). In some cases the pond costs were included but the area of the ponds was in all cases excluded. In the early stages of data analysis the authors attempted to remove the pond costs so that all reference projects used the same assumptions. It was found that, since pond costs were rarely available as a line item, more error was introduced by attempting to estimate and remove those costs than in allowing them to remain. The costs for external ponds were included for 15 phases of construction on 9 of the projects, or 31 percent of the total number of phases considered. As a reference point, the authors analyzed the costs both with and without ponds for one project with 3 phases. For a 470,000 m^2 leach pad the ponds added US$7.15/$m^2$ of leach pad (21.5 percent) to the total pad construction cost. Extrapolating this to the entire database, pond costs may be about US\$2.22/m^2 of pad area or 5 percent of the average total costs reported in the tables. Given the goal of benchmarking is to produce a cost estimate with a fairly wide tolerance (e.g., +/−25 percent), the error introduced by the pond cost question is minor. On the other hand, some refinement is possible if a closer estimate is desired. One way to achieve this would be to use the costs from the tables presented herein, deduct the pond costs (either US\$2.22/m^2 or 5 percent), and then add a more detailed estimate for the ponds at the project in question.

Where leach pad liner system costs were unavailable, estimates were used based on what the authors knew about the system, its location, and the year of construction. The estimates used for liner costs ranged from US\$5.50 to US\$7.50/m^2; in one case the system had a double geomembrane liner and thus the estimate was a combination of two geomembranes and a geocomposite. These estimated costs were used both to cite liner cost and back calculate earthworks costs from the total.

Overliner cost was one of the more difficult parameters to pin down, as some data sources either did not identify whether such costs were included, comingled some or all of those costs with general earthworks, or simply ignored. Overliner cost is especially important for two reasons: this cost often exceeds the cost of the liner (as discussed later in this paper, it can be 150 percent of the geomembrane cost), and not all leach pads require overliner. The authors were ultimately able to identify whether overliner costs were included (either accurately or otherwise) with some precision; these costs were included in 16 phases of 8 projects, or 33 percent of the phases (see Table 4).

Indirect costs have been excluded. Examples of indirect costs are owner's costs, EPCM and specialty engineering, worker camps, insurance, bonding, and financing. Indirect costs can range from under 15 percent to over 50 percent of the direct costs. Except where as-built costs were used, contingencies were also excluded.

Cost escalation

All construction costs were escalated to 2014 using the Engineering News Record Construction Cost Index (ENR, 2014). The 10-year average escalation rate from May 2004 to May 2014 is 3.33 percent. For the purposes of simplicity the authors used 3.0 percent and applied this to all time frames; for example, costs from 2007 and 2011 were both escalated at the compounded rate of 3.0 percent annually. In several cases the leach pads were built during multiple phases of construction over several years; the costs for each year were separately escalated to arrive at the total 2014 costs. Escalation rates were applied in whole-year increments; a project cost estimate from January, 2007 would be escalated the same as one from December, 2007.

Leach pad construction costs

Table 1 summarizes leach pad costs by country. Subsequent tables summarize the costs in other ways, such as by metal produced, heap type, pad type, overliner, and phase of construction.

Peru warrants special consideration since those costs bracket the largest range and the highest costs. Essentially all of the Peruvian projects include either a compacted clay liner (CCL) or a geosynthetics clay liner (GCL), and in some cases both (in different areas of the pad). GCLs are more common in Peru than any of the other countries reported (none of the costs for Chile, Turkey, Namibia or the Philippines include GCLs). Some valley leach pad (VLP) sites also use geocomposites, either in combination with GCLs or otherwise, under the geomembrane to protect the liner from overly aggressive subgrade. In Table 1, CCL costs reports to the earthworks column while GCL and geocomposite costs report to the liner system column. The terrain in Peru is perhaps the most variable and aggressive of any country with a significant heap leach industry; of the 12 Peruvian projects considered 11 are valley leach pads (VLPs). Many of the Peruvian pads are relatively modest in size and thus have less efficiency of scale; the average ultimate (total) leach pad in Peru is 38 percent of the size of the Chile pads. Some of the sites are in high rainfall areas (e.g., Pierina, La Arena, Lagunas Norte, and others), which affects both construction unit costs and design requirements. Finally, one of the large Peruvian VLP projects, the highest unit cost project in the database, has some unique site and owner criteria that drove those costs higher than would otherwise be expected.

Table 1: Leach pad costs by country (2014 dollars)

Country	Number of projects	Earthworks costs, average US$/m²	Liner system costs, average US$/m²	Total leach pad costs, US$/m²		
				Average	Range	Standard deviation
Chile	3	30.84	6.33	37.16	25.29–44.26	10.34
Colombia	1	56.35	9.52	65.88	–	–
Peru	12	45.51	9.91	55.42	28.31-95.68	18.33
Philippines	1	30.34	8.93	39.27	–	–
Mexico	5	30.14	8.25	38.39	23.24–58.84	14.77
Namibia	2	25.78	8.39	34.17	30.92–37.42	4.60
Turkey	1	21.60	6.81	28.41	–	–
USA	3	19.07	9.81	28.88	21.53–34.46	6.65
Total	28	35.94	8.95	44.90	21.53–95.68	17.59

Table 2 presents the costs categorized by leach pad type; “conventional leach pads” and “valley leach pads.” VLPs are defined herein as those constructed in mountainous terrain where either a toe buttress or a graded flat area is required to contain the heap on one side, and the other three sides are contained by natural terrain (Breitenbach and Smith, 2012). Most valley leach pads are of the nonimpounding type where solutions flow by gravity out of the heap and off of the leach pad without creating an internal impoundment. A few, such as Pierina gold in Peru and Veladero gold in Argentina, impound process or storm water upstream of the toe buttress, using the interstitial voids in the ore. Examples of nonimpounding VLPs include Dolores gold in Mexico, La Arena gold in Peru, and Cerro Verde copper in Peru. As of 2012, there had been 17 impounding and 22 nonimpounding VLPs worldwide (Breitenbach and Smith, 2012). All other leach pads considered in this study were classified as conventional and include Hycroft gold in Nevada (USA), Trekkopje uranium in Namibia, and Radomiro Tomic copper in Chile.

Table 2: Leach pad costs by pad type (2014 dollars)

Pad type	Number of projects	Average leach pad size, m²	Total leach pad costs, US$/m²		
			Average	Range	Standard deviation
Conventional pads	15	975,061	34.53	21.53–65.88	11.27
Valley leach pads	13	616,609	55.26	30.38–95.68	16.87

Table 3 summarizes cost by heap type, static versus dynamic. Dynamic heaps (which leach pads are also known as on/off pads) are those where the leached ore (often called “ripios” in South America) is removed from the pad and replaced with fresh ore after each leach cycle (Smith, 2011). All others discussed herein have been considered static heaps (also known as conventional pads, permanent heaps, or multistack heaps). Examples of dynamic heaps are the Radomiro Tomic and Cerro Colorado copper projects in Chile. Many nickel laterite heap leach projects are also planning to adopt dynamic heap technology. The primary difference between the leach pads for dynamic and static heaps are (i) the thickness of the geomembrane liner and (ii) the thickness of the overliner (Smith, 2011; Smith and Steemson, 2009). Dynamic heap leach pads tend to use slightly thicker geomembranes (e.g., 2.0 mm versus 1.5 mm HDPE) and much thicker overliner layers (e.g., 700 to 1,500 mm versus 400 to 500 mm). The overliner system for a dynamic heap leach pad is often divided into two layers: the bottom layer similar to the overliner in a conventional pad (static heap), and the upper part a much coarser stone that is often primary crushed ore. The costs reported herein for dynamic heap leach pads exclude the overliner. Therefore, the average dynamic and static heap leach pads have similar construction costs. To apply these benchmarked costs to a dynamic heap cost estimate one would need to add the costs for both layers of the overliner system and the incremental cost for a more robust geomembrane.

Table 3: Leach pad costs by heap type (2014 dollars)

Heap type	Number of projects	Total leach pad costs, US$/m²		
		Average	Range	Standard deviation
Static heaps	23	45.32	21.53–95.68	18.42
Dynamic heaps	5	42.96	25.29–65.88	14.75

Table 4 presents costs with and without overliner included. There were 16 phases of 8 projects with overliner costs included in the database, and the balance without. The data in Table 4 suggests that the average cost for overliner is US$10.76/m^2, with a standard deviation much higher than for costs that exclude overliner. This is consistent with the authors' experience.

Table 4: Leach pad costs with and without overliner cost included (2014 dollars)

Overliner costs	Number of projects	Total leach pad costs, US$/m²		
		Average	Range	Standard deviation
Without overliner	20	41.74	21.53–65.65	15.07
With overliner	8	52.50	30.92–95.68	22.01

Another way to consider the data is costs based on the metal(s) produced (gold/silver, copper, nickel, uranium), as shown in Table 5. Since the gold and silver projects also include the VLPs, that group has been divided to also consider just the conventional pads. As mentioned above VLPs are generally more expensive to construct. The copper leach pads listed are all for dynamic heaps, and the gold/silver pads are all for static heaps; this may help explain the cost differences. That Peru and Mexico (where the gold/silver projects are located) may have lower constructions costs than Chile (where the copper pads are located) is also a consideration. Two of the nickel leach pads are in the tropics, which increases costs. The third is in Turkey, a higher cost area with more stringent regulatory criteria. The uranium database is too small to draw any conclusions from it, but may be influenced by the fact that both pads are in a low cost country (Namibia) and a low risk environment (the Namib Desert). As a side note, nickel leaching can also produce cobalt and other trace elements; those should not affect the leach pad cost.

Table 5: Leach pad costs by metal produced (2014 dollars)

Metal produced	Number of projects	Average leach pad size, m^2	Total leach pad costs, US$/$m^2$		
			Average	Range	Standard deviation
Gold/Silver (all)	20	564,104	47.18	21.53–95.68	19.00
Gold/Silver (conventional)	6	441,594	28.35	21.53–34.46	4.96
Copper	3	1,669,300	37.16	25.29–44.26	10.34
Nickel	3	1,022,797	44.52	28.41–65.88	19.28
Uranium	2	1,745,000	34.17	30.92–37.41	4.60
Total	28	816,013	44.90	21.53–95.68	17.59

Table 5 also presents the average leach pad size for each metal produced. The authors' databases do not include the total leach pad area for each mine studied; for example, in one case the database includes the areas for phases 1, 3, and 4. Thus, the actual leach pad is larger than represented in the database. Such gaps are principally in the gold/silver project data, in part because it is a larger group and in part because those leach pads tend to be constructed in more and smaller phases. Thus, there may be a downward bias in the reported average leach pad size in the gold/silver category.

Conclusion

Without presenting the entire raw database there are limits to how much a reader can reprocess the data presented herein. That is a fundamental limitation of such a paper and the alternative would be to considerably complicate this paper and its preparation; it would also exceed the length limitations for this publication. The costs have been presented in such a manner as to allow a range of reprocessing and the use of the data in a variety of ways and thereby achieve greater precision. For example, valley leach pads will generally be better represented by the figures in Table 2 than in Table 1. On the other hand, there is no material difference in the costs of leach pads for dynamic and static heaps, except in the additional overliner thickness; thus, the larger database represented by Table 1, with site-specific adjustments for overliner and possible a more robust geomembrane, should yield good accuracy for dynamic heap leach pads. However, there is a difference in the heap leach pads in Peru and those in the balance of the database. Thus, there is value in considering the costs separately, as presented in Table 6.

With the division of liner system costs presented in Table 1, users can further improve accuracy by adjusting the total cost to accommodate the specific liner type and thickness planned. For example, there are two polyethylene liner plants each in Chile and Peru, none in Namibia, Turkey or the Philippines.

Table 6: Leach pad costs with and without Peru and Chile (2014 dollars)

Country	Number of projects	Total leach pad costs, US$/m²		
		Average	Range	Standard deviation
Chile	3	37.16	25.29–44.26	10.34
Peru	12	55.42	28.31–95.68	18.33
Total except Peru and Chile	13	36.96	21.53–65.88	13.29
Total	28	44.90	21.53–95.68	17.59

Preproduction or Phase 1 construction costs can be considerably higher, on a per unit basis, than ultimate or total pad costs. This is due to the front-loading of such items as roads, borrow sources, and other supporting facilities, the inclusion of most ponds in the first phase of construction, and (especially for VLPs) the higher costs associated with getting a project "out of the ground." In the authors' database there was sufficient detail to compare the Phase 1 to the total costs for 8 projects with 20 phases. Those are summarized in Table 7 with the Phase 1 unit costs (US$/m^2) presented as a percentage of the unit cost for the total pad area. With only one exception, all of the first phases of construction cost more per square meter than the ultimate leach pad.

Table 7: Phase 1 leach pad unit costs

Country	Number of projects	Phase 1 cost in US$/m² as a percentage of total leach pad cost in US$/m², %		
		Average	Range	Standard deviation
Mexico	1	118	–	–
Peru	7	120	85–151	22.8
Total	8	120	85–151	20.8

Local jurisdictional or social requirements can also have a significant effect on costs. To produce reasonable results, such adjustments may be required to the costs presented herein. For example, a uranium leach pad in the United States would likely require a double geomembrane liner; there are no double-lined pads in this cost database. To apply these costs to such a project one would start with the applicable benchmarked cost (say, from Table 1 or 6), and then add the costs for the additional components to upgrade to a double geomembrane system (an additional geomembrane liner, a leak collection layer, and the solution recovery system). Further, some locations have an expectation (either informal or formal) of exceptionally low leakage rates, and in some cases zero leakage. This is not easily achieved and application of these costs in such an environment requires both caution and detailed analysis. Examples of such jurisdictions include parts of California and Oregon, USA, and much of Argentina. There is also an emerging trend in this direction in parts of Europe.

As a closing observation, many of the differences between the various costs are in the upper limit of the range data. While the lower bound varies in the narrow spread of only US$9.39/$m^2$ (US$21.53 to US$30.92), the spread of upper bound costs is a robust US$61.22/$m^2$ (US$34.46 to US$95.68). Thus, cost-related risk reduction efforts should concentrate on addressing the factors that may affect the higher range figures, principally high rainfall sites and the use of VLP technology, including its implementation.

References

Breitenbach, A.J. and Smith, M.E. 2012. Design Considerations for Impounding Valley Leach Pads, *Mining Engineering Magazine,* July: 49-55.

ENR Engineering News Record. 2014. Construction Cost Index History as of June 2014, viewed 20 June 2014, http://enr.construction.com/economics/historical_indices/construction_cost_index_ history.asp

Smith, M.E. 2011. Leach pad liner alternatives for dynamic heaps, *The Mining Record*, February.

Smith, M.E. and Steemson, M.L. 2009. Problemas geotécnicos asociados a la lixiviación de lateritas niquelíferas en pilas, *Revista Minería y Medio Ambiente*, June.