The present work was submitted to the Faculty of Engineering

Impact of Dump and Heap leaching on the environment – Future trends in renaturation and reclamation measures

Bachelor Thesis

by

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Impact of Dump leaching on the environment – Future trends in renaturation and reclamation measures

I did not use any sources other than those stated. In case that the work is additionally submitted on a data medium, I declare that the written and the electronic form are completely identical. The work was not submitted in the same or similar form to any examination authority.

16th May 2022 Ulaanbaatar, Mongolia	
Place, Date	Signature

Acknowledgement

To begin, I would like to express my heartfelt appreciation to all the professors and staff at the German-Mongolian Institute for Resources and Technology and to the German Academic Exchange Service/DAAD for their continuing support throughout the years.

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Abstract

Environmental quality standards may be violated around active and inactive leach dump or heap facilities by leachates discharges that can seep into the ground. This dissertation reviews the literatures of dump leaching and heap leaching which share many similarities with dump leaching procedures, with an emphasis on environmental monitoring, environmental impact assessment, and future closure actions.

The environmental impacts of the leaching process are generally modest with heap leaching because a geomembrane layer is provided in the base to prevent leakage. Dump leaching is more detrimental to the environment because there is often no base sealing system. The treatment of each leaching solution used for copper and gold leaching is investigated, as are rehabilitation and reclamation measures and treatment technologies.

Possibilities for dump or heap capping and utilizing it for rehabilitation have yielded promising results for implementation. New forthcoming techniques, like as vitrification, could be one alternative for sealing a dump base and covering the surface of a spent dump or heap. The possibility of calculating leakage flowrate from punctured geomembrane sheet and leaking from dump base with no geomembrane sheet using mathematical methods without any field inspection and measurement is investigated. As result, the leakage calculation equation of circular defects from a single-composite liner (geomembrane liner) was accessible for exploitation. For dumps with no geomembrane layer at bottom base, an equation based on liquid mass balance difference was created.

Key words: **Dump leaching, Heap leaching, dump reclamation, sulfuric acid treatment, cyanide treatment, reclamation measures, leakage calculation**

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1. Introduction

1.1 Objective

What is a future trend for technology and advancement? Whether it's AI and the Fourth Industrial Revolution, or the ever-expanding concept of renewable energy or nanotechnology, the mining industry, which offers the most vital raw material, copper, and gold production, will always be present. Renewable energy is uprising industry. What is needed for most for renewable energy is the copper. Production of gold is also essential in economic terms and future technologies. So, demand for copper and gold production will expand even more.

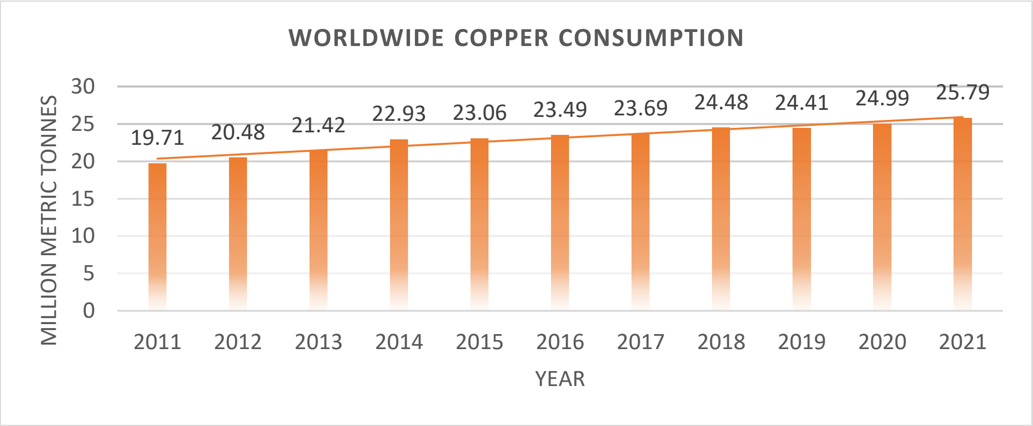


Figure 1:Global copper consumption data.

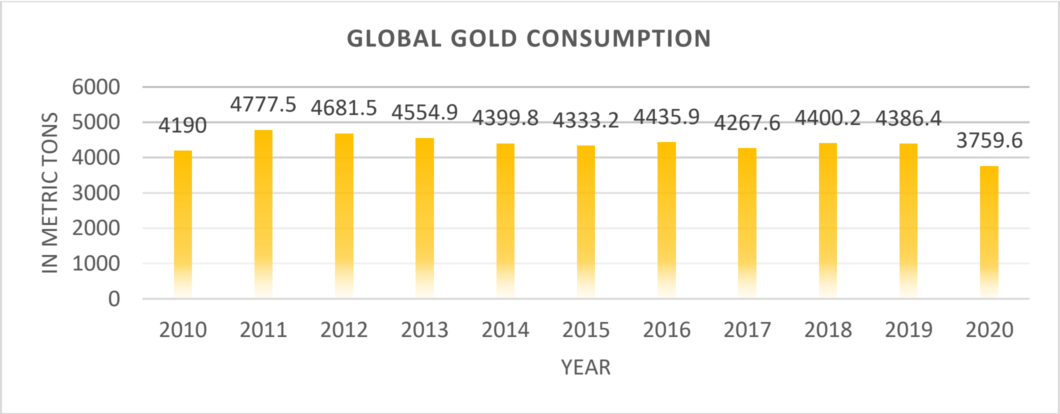


Figure 2: Global gold consumption data.

Both precious metals, on the other hand, are not only difficult to obtain, but also have a lesser source of supply than other minerals. Mongolia's gold and copper production has been gradually expanding year after year, as gold, copper, and coal are the country's primary reserves. The industry that accounts for 93 percent of overall exports.

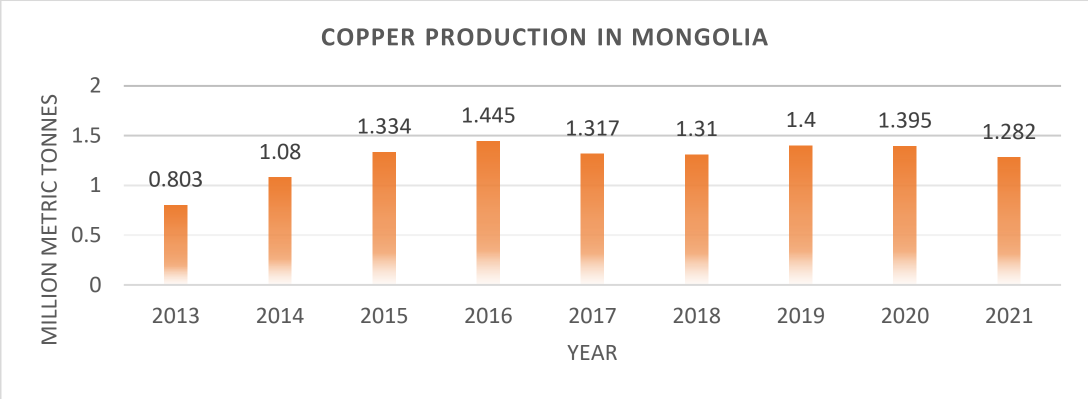


Figure 3: Copper production in Mongolia.

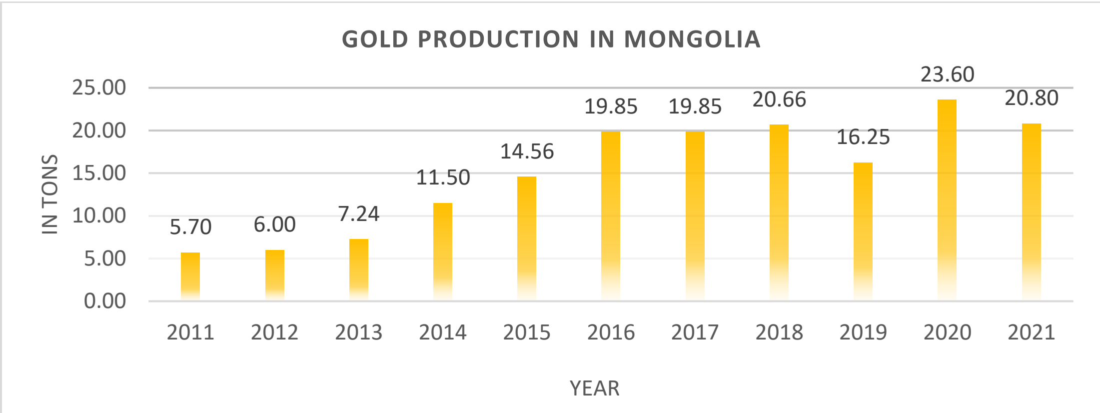


Figure 4: Gold production in Mongolia.

To increase production and not to waste sources of copper and gold extraction, leaching method will likely expand to meet its future demands. Being able to harness and improve efficiency while wasting little as possible recourse is a favorable condition. However, whether by intuition or by regulations and law, environmental protection invariably follows heavy industry. It is critical to investigate the environmental impacts of heap and dump leaching methods, which are commonly employed in copper and gold extraction.

1.2 Problem statement

Most mining operations generate waste rock, also known as spoil or tailings, as a byproduct of gaining access to an ore body. Waste rock is referred to in a variety of ways, depending on its proximity to the mineral. For instance, the phrase "overburden" refers to waste material that lies on top of an ore body. It is possible to gain from waste rocks by taking a few extra measures. One such instance is the treatment of lower-grade materials, some of which were formerly considered trash. The primary example is the leaching of low-grade ores to recover copper, gold. Depending on the mineral type, sulfuric acid or cyanide are used as the primary leach solution. Environmental and social concerns are usually always present during mine development but are particularly prevalent when acid is used. If dumps or heaps are not constructed properly, they can have a significant impact on the environment through hazardous solution leakage. Acid and cyanide leaks will disrupt the ecosystem and have lengthy consequences. Not only is spilling a concern, but a myriad of other risks exists throughout the leaching process, including evaporation of the leaching solution into the atmosphere, leakage from the liner pad into groundwater, and buildup of polluting effects, etc. Dump leaching is essentially predecessor of heap leaching method and share many similarities. In Mongolia only known dump leaching case is Achit Ikht LLC's copper hydrometallurgical plant but for heap leaching operations there are more to it. This study will also focus on heap leaching operations in addition to dump leaching operations as more heap leaching projects would take place in Mongolia.

1.3 Goal

The goal of this study is to document treatment methods of sulfuric acid and cyanide solution that are used for leaching solution and list environmental impacts of dump and heap leaching methods and as well as discover less know innovative ideas for renaturation and reclamations.

2. State of the art

2.1 Dump and Heap leaching

Leaching is the process of selectively dissolving a soluble metallic compound from an ore in a solvent such as water, sulfuric or hydrochloric acid, caustic soda, or cyanide solution. It is a process that involves a two-phase system and absorption techniques. Mineral leaching is frequently carried out in a solid-liquid phase, with the solid (minerals) suspended in a liquid medium (leaching solution) for a specified period (leaching time). Chemical precipitation or another chemical or electrochemical method is then used to extract the desired metal from the 'pregnant' leach solution.

Dump leaching

The term 'dump leaching' originates from the process of leaching materials that were originally deposited as waste rock. However, it is now also applied to of run-of mine, low-grade sulfide or mixed grade sulfide and oxide rock, dumped specifically for leaching. Copper leach dumps are often large, with low-grade rock piled into piles ranging in height from ten to thirty meters, contain millions of tons of waste rock and low-grade ore. Dump leaching may involve the application and recovery of leach solutions, or it may involve recovery and processing of leachate from rainfall percolating through the dump. Generally, the waste rock will not have been crushed, so that particle sizes will be relatively large and metal extraction will be low compared to other leach operations. Copper is the most common metal recovered in this manner, with sulfuric acid serving as the primary leach solution. The fundamentals are the same as they are for heap leaching. The primary potential consequences of concern are groundwater and surface water contamination.

Heap leaching

Ore is deposited in heaps on prepared leach pads during the heap leaching process. Leach solution fed to the heaps' surface through drip irrigation or sprinklers percolates through the ore and emerges as 'pregnant solution' at the heap's base; this solution is collected in drains and discharged to a pregnant solution pond, from whence it is pumped for metal recovery. The 'barren' solution is stored in a separate barren solution pond after processing and piped for reuse. For low-grade ores, some gold mining operations use heap leaching, while for higher-grade ores, conventional vat leaching is used.

In summary: Heap leaching refers to the process of leaching ores that have been mined, crushed, and transported on impermeable pads for leaching by sprinkling or ponding and percolation of the solution through the ore stack. Dump leaching refers to the process of leaching dumps or accumulations of very low-grade ore or overburden without the use of constructed pads beneath them. The grade and quantity of the available ore determine whether a dump- or heap-leaching technique is used. Permeability is the most important factor in any circumstance. There will be no percolation, dissolution, or commercially viable gold or copper extraction if there is insufficient permeability.[1]

Table 1: Advantages and disadvantages of leaching of heap/dump. [18]

Advantages of heap and dump leaching
Low capital and operating cost
Low energy requirements in terms of comminution: absence of milling step, may require crushing and agglomeration
Simplicity in equipment and operation of atmospheric leach processes
Treatment of low-grade ores, wastes, and small deposits are possible
Absence of liquid-solid separation step allows counter current operation
No separate tailing disposal
less water requirement compared to flotation method
Disadvantages:
Lower recoveries than mill/float
Long leach cycles and hold-up
Lack of options to control the process
Large footprint and possible environmental contaminations
For design data, a lengthy large scale column test work program is necessary
Issues with long-term closure due to the vast footprint and the possibility of acid rock drainage from used dumps or heaps, particularly if sulfides are present

Due to economic benefits, leaching of precious metals has increased from a handful in 1980 to more than two hundreds in 2014. Not only gold and copper, production of other metals and as well as uranium has risen simultaneously over last three decades.

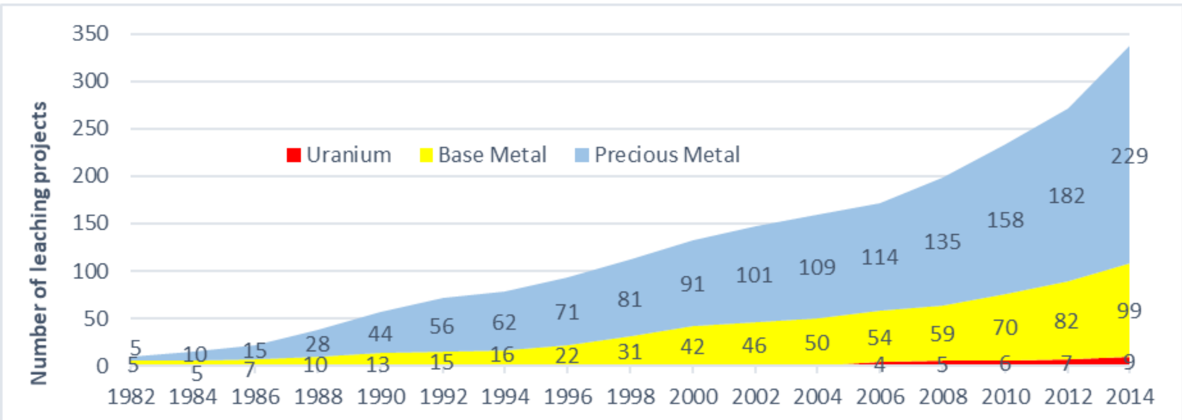


Figure 5: Trends in Heap Leaching, number of heap leaching operations. [16]

Ore agglomeration for heap leaching

Unlike dump leaching, in almost all modern heap leach operations (for both copper and gold recovery), agglomeration is used as an intermediate step between crushing and stacking. In 1970s, to ameliorate the undesirable leaching condition (i.e., improved percolation, more porous heap, uniform solution distribution) and obtain better extraction efficiency, the agglomeration and its processing controls were firstly mentioned in Nevada of the United States[4]. Agglomeration allows uniform application of lixiviant solutions to all surfaces of the ore particles to cure the ore and improve kinetics of leach. The agglomeration can be also used for ore minerals that have become too fine into larger particles so that they do not reduce the permeability of the heap (See Figure 6). Ore agglomeration can be also utilized to reduce presence of clays in heap. In short, it is used to help bond fine particles to coarser particles, resulting in a more permeable heap. As an effective, innovative method, ore agglomerations directly affected the intra-particle pores and liquid retention of the heap, potentially affecting the recovery of valuable metallic minerals.

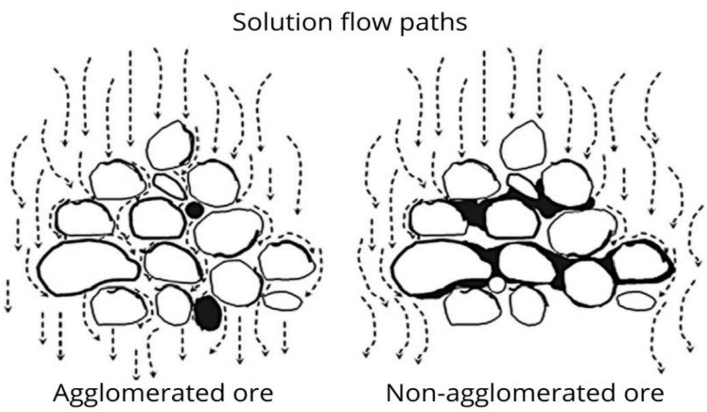


Figure 6: Comparison of solution percolation of agglomerated VS non-agglomerated ore. [4]

Binders are products that are applied to agglomerates to strengthen their strength. A binder or additive would aid in the adhesion of fine particles to coarser particles, reducing percolation and permeability issues. In the gold and copper industries, various binding agents have been investigated as agglomerating aids. In Table 2 a variety of binders are listed that are used in gold and copper ore.

Table 2: Summary of binders tested in various leaching operations for gold and copper ore.[5]

Description	Binder	Ore type used	Additional comments
Process materials	Solution	Gold and Silver	The amount of moisture added was discovered to be particularly critical to agglomeration stability.
	Pulp	Gold	Although it would not be suitable for all ore types, it did improve recovery.

Inorganic binders	Calcined dolomite, calcium chloride, magnesia	Gold and Silver	When calcined dolomite and calcium chloride agglomerates were exposed to cyanide leach solution, they disintegrated. Magnesia reduced fines migration but resulted in massive agglomerates. Channeling was also observed.
	Cement	Gold and Silver	Agglomerate stability was improved, and recovery was enhanced.
	Lime	Gold and Silver	Improved percolation rates
	Leach-it	Gold	Lime-based product; reduced leach time; possible reduction in cyanide usage.
Polymer Binders	Cross-Linked Borated Polyvinyl Alcohols	Gold	Extraction rates and recoveries have been improved.
	Extract-Ore 9760	Gold	The polymer acrylamide/acrylate improved extraction and reduced detoxifying time. It also reduced slumping and fines migration.
	Polyethylene oxide resins	Gold	Improved percolation flow rates when used with lime.
	Acrylamide/ acrylic acid copolymers and polyacrylamide	Gold and Copper	Decreased detoxification wash time. The molecular weight and ionic charge were discovered to be important properties. The copper ore performed better in the soak test, percolation flooded columns, and long-term leach columns.
Organic binders	Cellulose	Copper	Acid resistance is negligible.
	Lignin	Copper	Negligible resistance to sulfuric acid.
	Tall oil pitch	Copper	Improved agglomeration stability in soak tests and percolation-flooded columns, but somewhat reduced recovery in long-term leach columns.
Polymer Binders	Extract-Ore 9560	Copper	Due to the latex copolymer, particles migrated, leaving areas of the heap partially or completely un-leached. However, it yielded better recoveries than the current operational conditions.
	PolyDADMAC	Copper	Although it produced significantly less particle migration than raffinate, the results were very varied.
	Polyvinyl acetate emulsion	Copper	Soak tests, percolation flooded columns, and long-term leach columns all improved.
	Waste treatment additive	Copper	Soak tests, percolation flooded columns, and long-term leach columns all improved.
	Other	Copper	Although it had no effect on recovery or acid consumption, it did reduce bed compaction.

2.1.1 Heap designs

Heap leaching design methods	Unique characteristics
Typical/standard leach method Figure 7	• Although a somewhat level topography is desirable, it can be built on rougher terrain • Low initial capital cost • A large area is necessary for pad construction and expansion • Can tolerate variables in ore production
Reusable-pad method Figure 8	• Generally, less expensive to construct than other pads, but higher operational cost per tonne (double-handling ore) • Applied to ore with short leach cycles • Not appropriate for soft ores that cannot be stacked very high • Requires flat, firm ground, a durable pad liner • Higher maintenance is required • Lower operational freedom • To ensure continuous operation, at least three pads or cells must be built • Suitable for arid climates with no temperature extremes • lack of flexibility in the leach time
Expanding-pad method Figure 9	• Subsequent re-leaching and/or washing are feasible • A vast area for leaching pads and large ponds for rain and storms is required • The relatively high cost of the pad per ton of ore • Potential multiplication of "polluting" discharges • High metal recovery • Spoiling of an extensive area
Valley-leach method Figure 10	• Uses topography (valley, drainages, basins) to form heap pad • Foundation slopes can often get very steep (40 to 50 percent) • Generally, more expensive than other leach pads (more upfront earthwork) • Requires hard, durable ore • Internal solution storage (no external ponds). Internal ponds are double lines

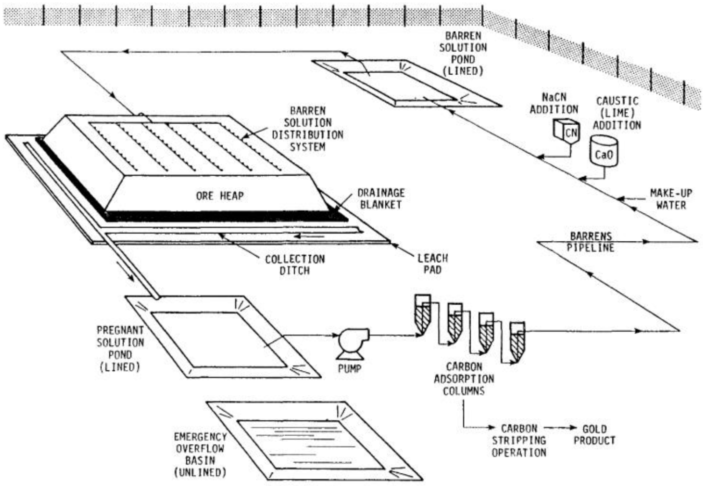


Figure 7: Conceptual flow diagram of typical gold heap leach operation. [14]

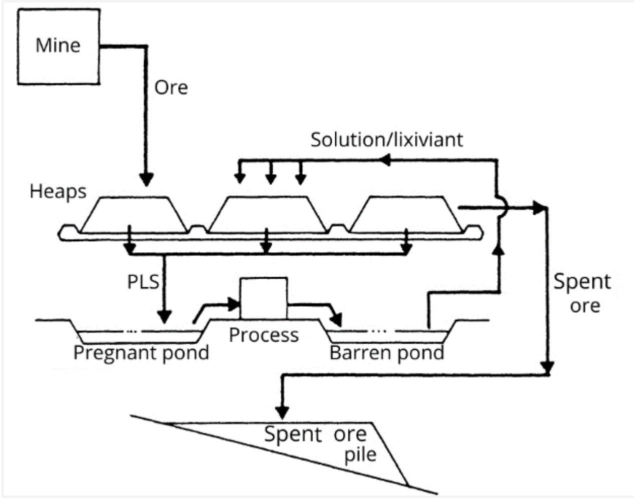


Figure 8: Reusable-pad method of heap leaching.[1]

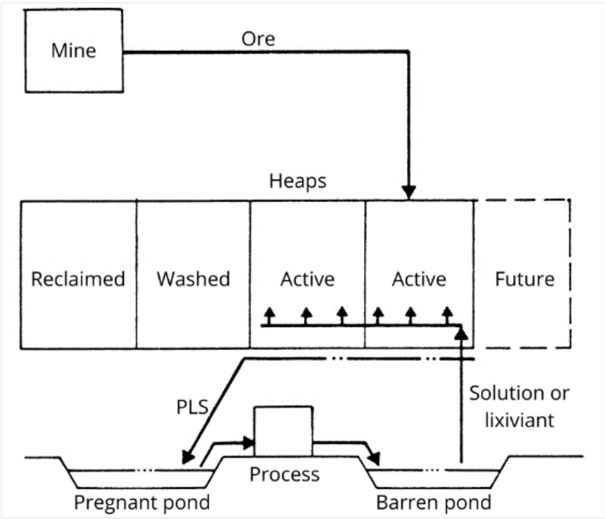


Figure 9: Expanding-pad method of heap leaching.[1]

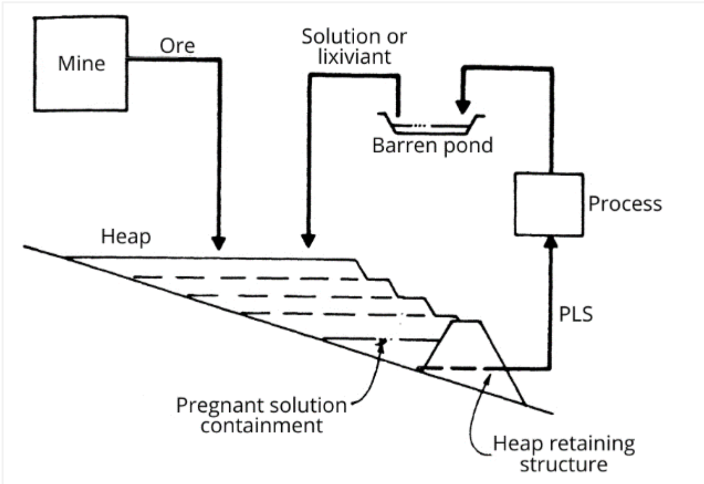


Figure 10: valley-leach method.[1]

2.1.2 Geotechnical Design

When considering geotechnical design of the base pad, it is important to remember that the pad on which the ore mass must be stacked must be constructed on solid ground, robust enough to withstand the weight of the ore, and equipped with three ponds at one of the pad's sides: Pregnant pond, Barren pond, and the overflown pond/ stormwater pond. The topsoil and vegetation must be cleared, and a uniformly sloping ground configuration with 3-4 percent slope along the length of the pad must be created by grading and filling as needed to accommodate the pad's sloping nature [1]. The three solution ponds, which will be located on the drainage side of the pad, must be constructed with sufficient capacity. The pregnant-solution pond is responsible for collecting the drainage from the heap; therefore, it should be designed with a capacity sufficient to accommodate the maximum amount of runoff from the anticipated rainfall at the specific location.

2.2 Gold leaching

Globally approximately 1.27 million tons of cyanide are produced annually. Of this total, thirteen percent is used to produce cyanide reagents for mineral processing to recover gold, copper, zinc and silver. For gold ores, weak cyanide solutions with a cyanide (CN–) concentration with the typical range of 0.02% to 0.05% sodium cyanide (NaCN) are used. The pH value is also important. The majority of cyanide leaching proceeds at an alkaline pH of 10 to 11. Notably, the mining, crushing, and grinding of gold bearing ores contribute more to the environmental impact; the processes that are highly dependent on the content of gold. A lower grade ore would require more comminution and consumes more electricity. In practice, significant cyanide loss occurs because of side reactions, and substantially more cyanide (200-300g) is required for each ton of ore for gold leaching. For sure, ten times more cyanide is used for gold leaching than the stoichiometry ratio of cyanide to gold (approximately 3-4g [3]). To control such losses, the International Cyanide Management Code has set a maximum of 50ppm cyanide solution for gold mining.[3]

History

The process of gold cyanidation was discovered in the late 18th and early 19th centuries. In 1782, the Swedish chemist Carl Wilhelm Scheele discovered the dissolution of gold into cyanide solution in 1783 [3]. In 1887, John Stewart MacArthur (1856–1920) in Glasgow applied the knowledge to gold ores and patented the cyanidation process [3]. It is found that the rate of gold leaching in cyanide solution increases linearly with increasing cyanide concentration until the maximum point is reached. A further increase in cyanide concentration does not improve gold leaching; rather, it has a retarding impact and reduces the gold content in leach liquid. An excess of cyanide creates unnecessary cyanide consumption, which does not favor leaching reactions. The large quantity of cyanide would result in cyanide complexes with impurities.[3]

2.2.1 Toxicity of Cyanide

Approximately 13%–20% of globally produced hydrogen cyanide is used in gold mining for heap leaching[3]. Because it is stable when dry cyanide is usually stored and transported as a solid. Most cyanide solids will dissolve in water to produce toxic cyanide gas. Cyanide is naturally produced in small amounts in a variety of plants, including apple seeds, apricot pits, soil microbes, and invertebrate organisms. However, cyanide is highly toxic making its one of the applications into the killing agent used in gas chambers. Cyanide poisoning can occur through inhalation, ingestion, or skin or eye contact. A teaspoon of cyanide solution containing 2% cyanide can kill a human. Cyanide concentrations in the microgram per liter (part per billion) range kill fish and other aquatic life, whereas milligram per liter quantities kill birds and mammals (part per million).

For cyanidation, three types of cyanides mainly are considered; those are: free cyanides, weak acid dissociable cyanides (WADs), and strong acid dissociable cyanides (SADs).

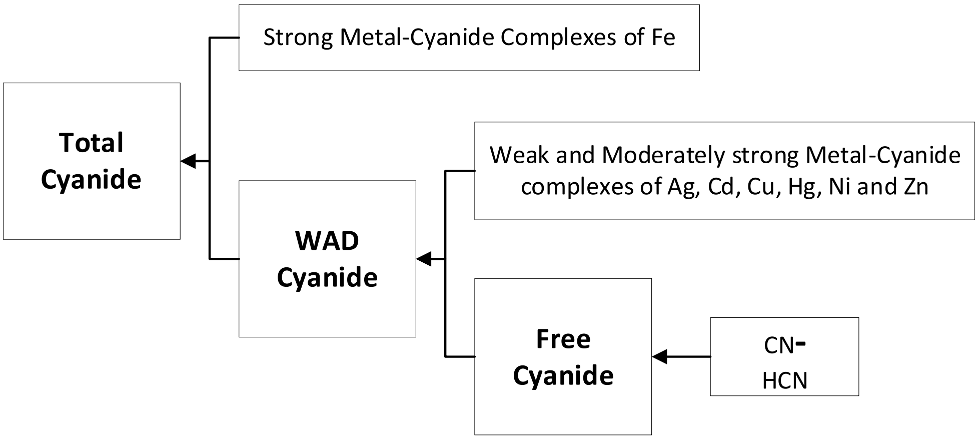


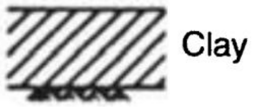
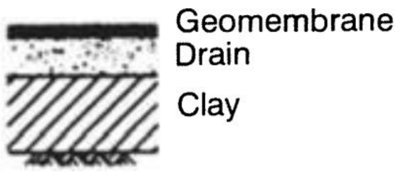
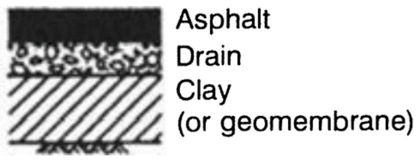
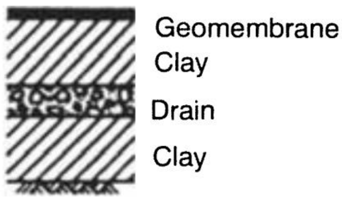
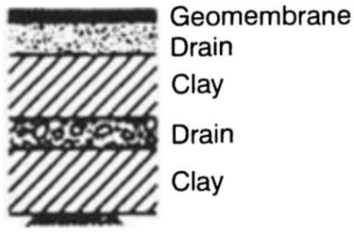
Figure 11: Forms of cyanide.

The toxicity of cyanide varies widely with the form of the cyanide; it can be inhaled, ingested orally (through contaminated water or food), and diffused through the skin The most toxic form of cyanide is free cyanide in a form of HCN. Cyanide in the form of HCN, prevents the intake and subsequent transportation of oxygen to the cells[3]. The body, on the other hand, can detoxify small amounts of cyanide into less harmful cyanate, preventing cyanide buildup in the human body. Cyanide diffusion through the skin is supported by the small molecular size of HCN and the fact that cyanide dissolves readily in lipids of human bodies. Concentrations of 20–40ppm HCN in the air are toxic; increasing the concentration up to 250ppm (1–3mg CN per kg body weight) causes death within minutes[3].

2.2.2 Liners/ Impermeable base layers

Leach heaps are usually built on an impermeable base. Leaching pads are constructed on level land that has been sufficiently graded and compacted, with a 3-4 percent slope throughout their length and a 1 percent slope toward one side. All flows run toward the collecting corner where the pregnant solution discharges, through a lined ditch, and to the pregnant-solution pond. To prevent seepage and loss of valuable pregnant solution, as well as contamination of ground water with cyanide solution, the pad must be effectively impermeable. Compacted clay is a very effective sealant and, and in some instances, there are only-line of defense against seepage, yet complete sealing is impossible to guarantee. In many cases, dump leaching operations rely on a natural compacted clay layer and do not have an impermeable base, like heap leaching. Other means of constructing impermeable pads/base layers include the following three methods. Some systems contain additional layers as shown in Table 3.The additional layers are a liner and a drainage layer. Leak detection sensors are often placed in the drainage layer[1]. Leak detection monitoring can be often required for project permitting.

Table 3: Variation of liner/impermeable base layer systems.[1]

<table>
<tr><th colspan="12">Single liner</th></tr>
<tr><td colspan="3">Clay</td><td colspan="3">Geomembrane</td><td colspan="3">Concrete</td><td colspan="3">Asphalt</td></tr>
<tr><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td></tr>
<tr><th colspan="12">Double liner</th></tr>
<tr><td colspan="4">• Geomembrane
• Clay</td><td colspan="4">• Geomembrane (with layer that can be drained under it)
• Clay</td><td colspan="4">• Asphalt (with layer that can be drained under it)
• Clay or geomembrane</td></tr>
<tr><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td></tr>
<tr><th colspan="12">Triple liners</th></tr>
<tr><td colspan="4">• Geomembrane
• Clay
• Drainage layer
• Clay</td><td colspan="4">• Geomembrane
• Drain geomembrane
• Clay</td><td colspan="4">• Geomembrane (with layer that can be drained under it)
• Clay
• Drain
• Clay</td></tr>
<tr><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td></tr>
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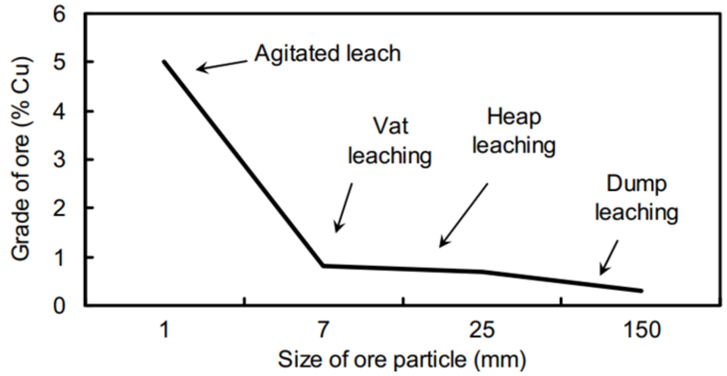
2.3 Copper leaching

Recovering copper mineral from low grade by using leaching method is the one of the 3 essential steps of hydrometallurgy including solvent extraction and electrowinning (See Figure 13). About 20% of copper production comes from hydrometallurgical process. For copper leaching process there are present 6 main methods including dump and heap leaching.

Copper leaching methods	Figure 12: **C**opper grade and particle size of ore relationships for different leaching methods.[2]
In-situ leaching Dump leaching Heap leaching Vat leaching Agitation leaching Pressure oxidation leaching	

The choice of leaching method depends on the mineralogy of the copper-bearing ore, the copper grade of the ore, and the particle size (Figure 12). Heap leaching and dump leaching involve trickling the H_2SO_4 lixiviant through large heaps or dumps of ore under normal atmospheric conditions. Leaching involves dissolving Cu^{2+} (or Cu^{+}) from copper-containing minerals into an aqueous H_2SO_4 solution, known as the lixiviant, to produce a pregnant leach solution (PLS). PLS then undergo solvent extraction and electro winning stages to extract copper from sulfuric acid solution and recycled sulfuric acid is used again to dump or heap. In addition to copper, the PLS will contain other impurity species that may be present in the ore and are leached with the copper, such as Fe, Al, Co, Mn, Zn, Mg, Ca, and so on.

Table 4: Dump and Heap leaching characteristics. [2]

Details	**Dump leach**	**Heap leach**
Ore type	Typically for low-grade run-of-mine (ROM) ore (sometimes overburden with significant copper concentration)	Oxides and lower-grade secondary sulfide ores
Copper concentration/assay	<0.5% Cu	up to ~2% Cu
Rock size	Ranging up to ~500 mm	Typically, 12-50 mm
Impermeable base	Sometimes	Has impermeable base
Irrigating solution/lixiviant	Sulfuric acid H_2SO_4	Sulfuric acid H_2SO_4
agglomeration	Not necessarily	Often

Table 5: Copper leaching recovery flowsheet, simplified and detailed.

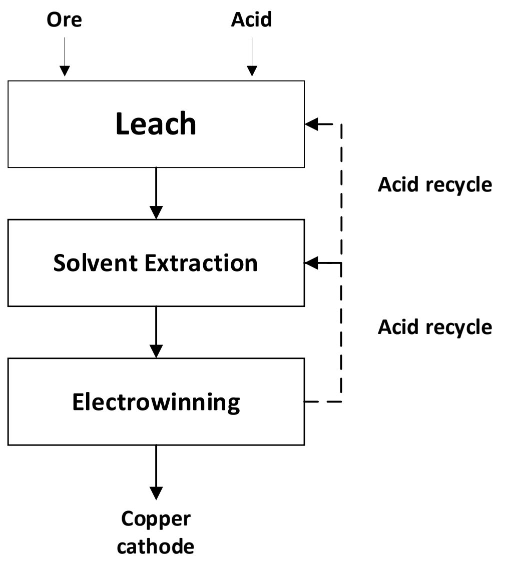


Figure 13: Simplified hydrometallurgical flowsheet.

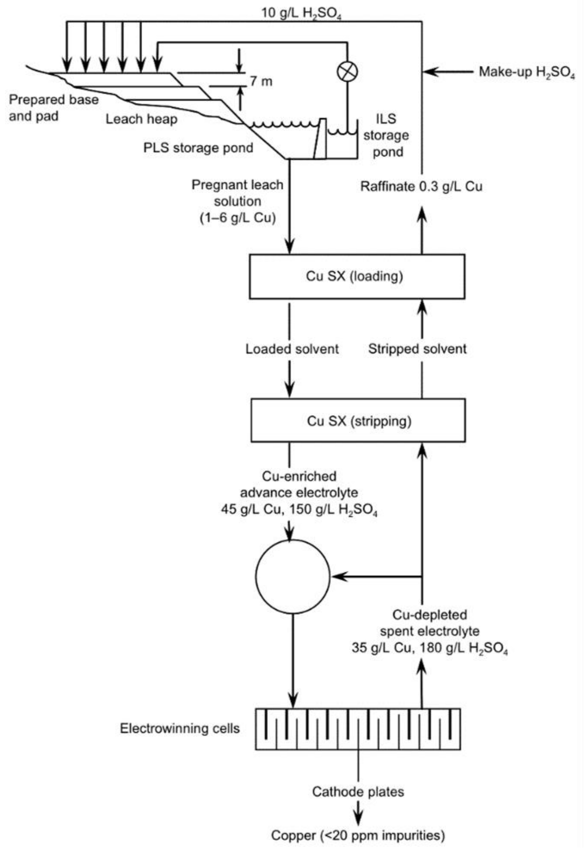


Figure 14:Copper heap and dump leach/ solvent extraction/ electrowinning detailed flowsheet. [2]

2.3.1 Toxicity of sulfuric acid

According to Occupation Health Guideline for Sulfuric acid the current Occupational Safety and Health Act (OSHA) standard for sulfuric acid is **1 milligram of sulfuric acid per cubic meter of air (mg/m^3)** averaged **over 8-hour work shift**. According to National Institute for Occupational Safety and Health (NIOSH) recommended permissible exposure limit is **1 mg/m^3** averaged over a work shift of up to **10-hours per day**, 40 hours per week.[8] Sulfuric acid can harm the body if breathed or comes into contact with the eyes or skin. It can also affect the body if it is swallowed.

Effect of overexposure to sulfuric acid	
Short-term exposure	**Long term exposure**
May cause irritation of the eyes, nose, and throat. By breathing in mist or vapor of can cause sour mouth, making breathing difficult, and teeth erosion.	Prolonged or recurrent exposure to a dilute sulfuric acid solution may cause skin irritation, chronic eye irrigation, and chronic inflammation of the nose, throat, and bronchial tubes.

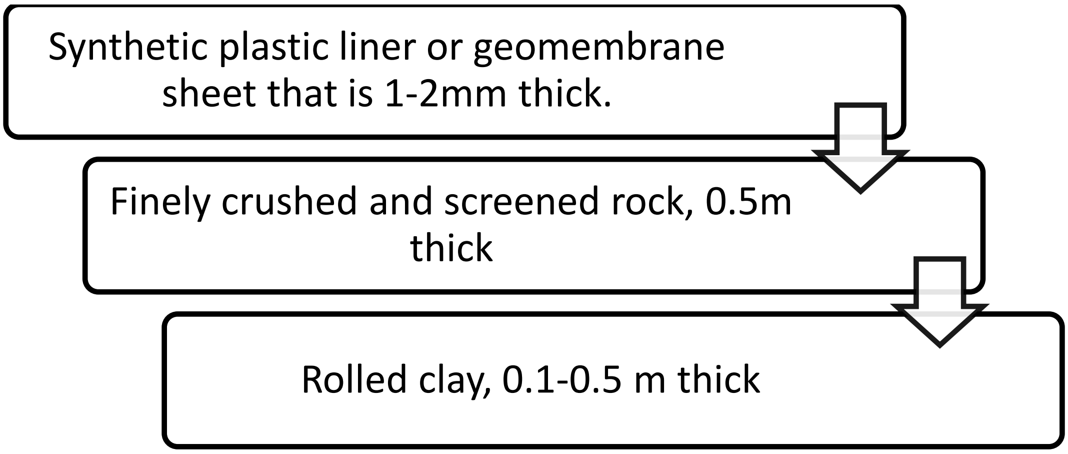
Sulfuric may not be combustible on its own, but it is very reactive and capable ignite into finely divided combustible materials on contact. Contact between acid and organic compounds such as chlorates, carbides, and fulminates can result in flames and explosions. Contact of acid with metals may from toxic sulfur dioxide fumes and flammable hydrogen gas. Good industrial hygiene practices recommend that engineering controls be used to reduce environmental concentration to the permissible exposure level. Air samples should be taken in the employee's breathing zone. Several short-time interval samples up to 30 minutes may also be used to determine the average exposure level. For ore leaching and processing operations controls of process enclosure, local exhaust ventilation, personal protective equipment (PPE) are effective.

Table 6: Respiratory protection for sulfuric acid.[8]

Condition	**Minimum Respiratory Protection (Required above 1mg/m³)**
Particulate concentration	
50 mg/m³ or less	A gas mask featuring a chin-style or front-or-back mounted acid gas canister and a high efficiency particulate filter. A high efficiency particulate filter respirator with a complete facepiece. Any supplied-air respirator with a full facepiece, helmet, or hood. Any self-contained breathing gear with a complete facepiece.
100 mg/m³ or less	A Type C supplied-air respirator with a full facepiece operated in pressure-demand or other positive pressure mode or with a full facepiece, helmet, or hood operated in continuous-flow mode.
Greater than 100 mg/m³ or entry and escape from unknown concentrations	Self-contained breathing apparatus with a full facepiece operated in pressure-demand or other positive pressure mode. A combination respirator which includes a Type C supplied-air respirator with a full facepiece operated in pressure-demand or other positive pressure or continuous-flow mode and an auxiliary self-contained breathing apparatus operated in pressure-demand or other positive pressure mode.
Fire Fighting	Self-contained breathing apparatus with a full facepiece operated in pressure-demand or other positive pressure mode.
Escape	A chin-style gas mask or a front- or back-mounted acid gas canister with a high-efficiency particle filter. Any escape self-contained breathing apparatus.

2.3.2 Liner/Impermeable base layers

Like the gold leaching variation impermeable layer is prepared before stacking the heap or dump. This allows for complete collection of the leached Cu^{2+} in the PLS while preventing solution penetration into the underlying environment and potential groundwater pollution. Even though same impermeable base layer construction from gold leach is possible, there are other variables. For example:



Geomembrane[1] sheet can be made by	low-density polyethylene, LDPE High-density polyethylene, HDPE Polyvinyl chloride, PVC Chlorinated PVC

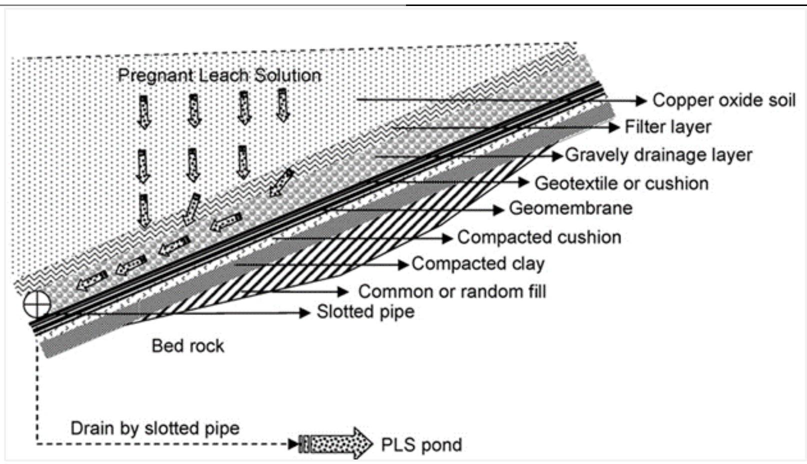


Figure 15: Example of more sophisticated impermeable base pad.[15]

From many variants HDPE geomembrane pads are mostly used in leaching operation. This is because HDPE geomembranes have the finest track record in terms of durability and chemical resistance[24]. Long-term performance has been demonstrated by mines in North America, South America, and Australia that have employed HDPE geomembranes for almost 20 years with no symptoms of geomembrane liner

[1] Geomembrane is, by definition an impermeable manufactured liner (other than compacted clay).

deterioration. [25]. In a country like Mongolia with extreme climate conditions as long, cold winters and short summers, HPDE is more suitable for leaching pads compared to the other options (See Table 7).

Table 7: The advantages and downsides of regularly used geomembranes.[25]

Geomembrane material	Advantages	Disadvantages
HPDE	• Resistance to a wide range of chemicals • Good weld strength • Excellent properties at low temperatures	• Potential for stress cracking • Significant thermal expansion • Puncture resistance is poor • Poor multiaxial strain resistance
LLDPE	• Better flexibility than HDPE • Better layflat than HPDE • Good multiaxial strain properties	• Lower UV resistance than HDPE • Lower chemical resistance than HDPE
PVC	• Good workability and layflat behavior • Easy to seam • Because it can be folded, there are less seams in the field	• Poor resistance to UV and ozone unless specially formulated • Poor resistance to weathering • Poor performance at high and low temperatures

Leach solutions are introduced onto or into dumps/heaps by a variety of methods. These include:

- Flooding the surface by use of a series of small-diked ponds.
- Spraying the solution with hoses or sprinkler heads
- Injecting the solution through holes drilled in the dump and cased with perforated plastic pipe.
- A combination of these methods.

The climatic circumstances, dump height, surface area, operation scale, mineralogy, and size of the leach material all influence how the leach material is dispersed. The solution application rate to the dump will vary due to the fact that most distribution methods do not provide completely uniform coverage. Most dumps are leached in sections in practice. Each section's leaching period normally lasts 4 to 6 weeks, depending on the efficacy of the surface infiltration.

2.4 Application of leaching in Mongolia

2.4.1 Achit Ikht LLC

Achit Ikht hydrometallurgical plant uses low grade mixed ore deposits from Erdenet Mining Corporation. In 2014, the hydrometallurgical plant began producing copper using 56 million tons of ore deposits that were unsuitable for Erdenet Mining Corporation's flotation technique. To recover copper from the ore, the company first used a dump leaching process, then later added a heap leaching method. The company's plant, which is about 20 kilometers from Erdenet, has a capacity of producing 10,000 tons of cathode copper with a purity grade of 99.999%. The leaching solution for both the dump and the heap is diluted sulfuric acid with a pH of 1.7-2.7.

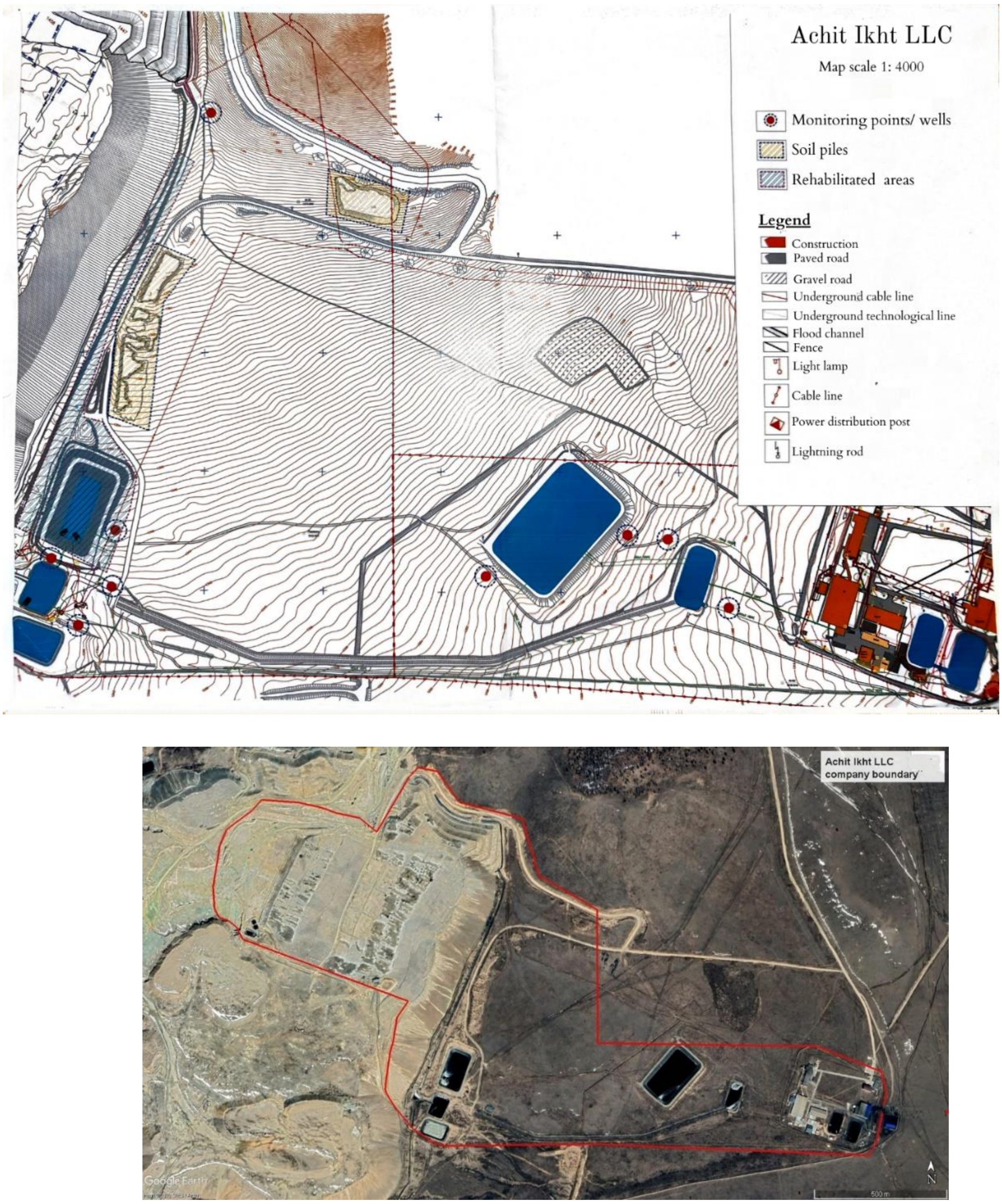


Figure 16: The Achit Ikht LLC's overview map and company boundary.

Dump and heap construction

Figure 17: Achit Ikht LLC dump.

Figure 18: At the base of Achit Ikht LLC dump.

The dump is made up of the 2nd overburden from Erdenet Mining Corporation and at the highest point from the base, it is 80m high. For dump, there is no geomembrane sheet. According to their worker, there is a natural clay liner underneath the dump which can prevent the seepage of sulfuric acid to a certain extent. As for the later constructed heap, a 2mm thick geomembrane sheet is constructed to prevent leakage. For size comparison, the heap is much smaller than the dump and is placed alongside the dump. At the base of the dump, the company had a constructed structure that is similar to a protective berm made out of old truck tires that were about 2-3m high. In front of the dump, there is a long line of open channel for collecting pregnant leach solution along the edge. Then leach solution makes its way to the pregnant solution pond.

Environmental monitoring

Air monitoring: Air quality measurement of air pollutants such as SO^2, NO^2, PM 2.5, PM 10 are to be taken from 6 different location in every 1 month. The monitoring locations include :

- At the dump
- chemical warehouse
- PLS pond
- at the downwind of heap
- at the downwind of steam boiler
- Solvent extraction building

Additionally, the sulfur dioxide concentration in the workplace air should be monitored monthly in areas such as electrowinning, solvent extraction, and steam boilers.

Underground and surface water monitoring: Achit Ikht installed ten monitoring wells to keep an eye on their pregnant leach solution ponds, barren ponds, stormwater ponds, and wastes (Figure 19). Each week, a water sample is obtained to evaluate whether any changes have occurred to the ground beneath, such as an increase or reduction in the pH value. Because ponds are sloped to gather any leaking to the monitoring well's drawdown, leakage may be detected by continuous monitoring.

Soil monitoring: According to environmental consulting firms, soil agrochemical characteristics (i.e., compost/organic matter, electrical conductivity, pH, P_2O_5, $CaCO_3$, NH_4, NO_2, NO_3, K_2O) should be analyzed twice a year at the foot of dump and heap stacks and in the center of the plant site. In addition, conduct soil heavy metal content tests twice a year from the dump's foot, the waste disposal site, near the steam boiler building, around the sewage treatment plant, and 300 meters southeast of the factory site fence.

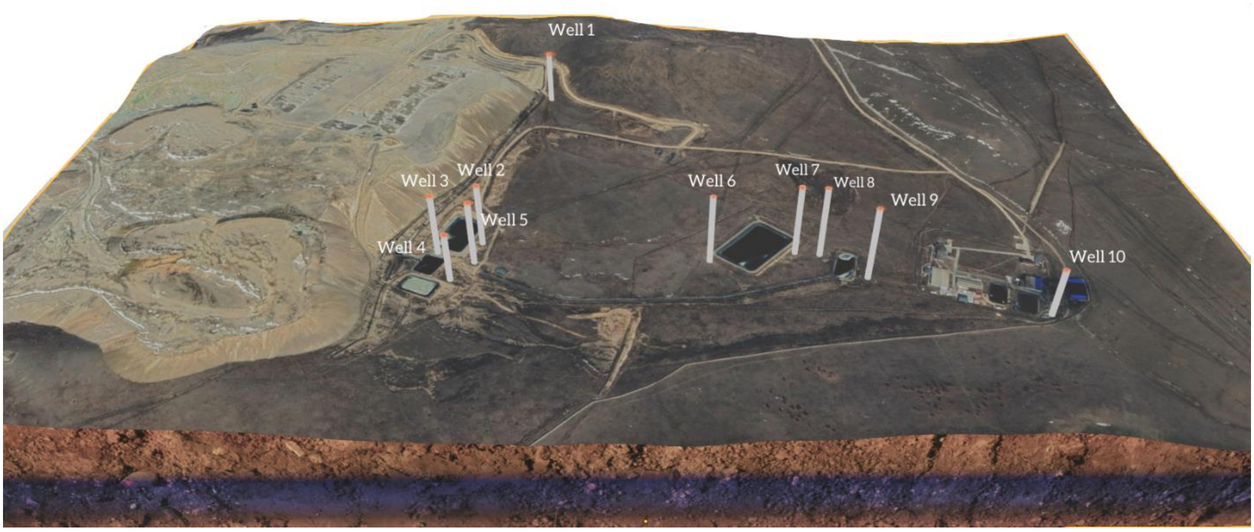


Figure 19: Monitoring wells.

Facing challenges

Mongolia has four distinct seasons, with the difference between the hottest and lowest temperatures in summer and winter ranging from 60 to 70 degrees Celsius, and extreme weather commonly occur throughout the year. During the summer, vast dump surfaces and ponds collect water. During the rainy season, a considerable amount of water is added to sulfuric acid, resulting in overflow of ponds.

In the event of an earthquake there is a chance that the stockpile will fracture or fall, the pond to burst or tear, and Industrial buildings and warehouses will also be vulnerable. It is possible to dust to disperse during heavy storms or dust storms. There is also high risk of explosion or fire burning at the facilities or in the warehouse due to power outages, technological delays and accidental human activities.

2.4.2 Boroo gold LLC

The heap leach project at Boroo Gold involves heap leaching of 9.8 million tons of low-grade ore. It is estimated that 4407 kg of gold might be produced that cannot currently be processed using Boroo Gold LLC's processing plant [6]. Bayangol soum, Selenge aimag, is home to the heap leaching project. There are 14 million tons of ore with an average gold grade of 0.72g/t and the potential for 10247 kg of gold, according to a research on stockpile reserves and pit. A total of 9.8 million tons of ore have been placed into the heap leach pad. The leach pad is approximately 600m by 500m in size. The heap leach stockpile is organized into four sections and covers 24.9 hectares in total. The stockpile's tallest point is 51 meters high, while its lowest position is 5 meters. On the pad, ore is piled in 10 m high stacks with 5 m protective berms. The stockpile has a slope of 1:1.5 and a total height of 51 meters. Over the course of a 30-day leaching cycle, a 0.05–0.1 percent sodium cyanide (NaCN) solution will be sprayed onto stacked ore at a rate of 0.2 l/min/m2 via sprinkler pipes on one work block containing 484,500 tons of ore.[6]

Figure 20: Heap construction of Boroo Gold LLC.

Heap leach pad

The leach pad is approximately 600m by 500m in size and can hold up to 18.5 million tons of ore. The stockpile's capacity was calculated based on the average density of piled ore being 2 t/m3 and the stockpile's height above the pad liner being 60 m. The leach pad is 300 mm thick with a compacted clay base, 1.5 mm thick with a linear low density polyethylene synthetic liner (LLDPE), and 600 mm layer of crushed rock cover.[6]

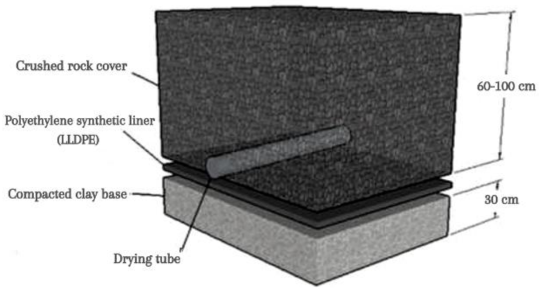
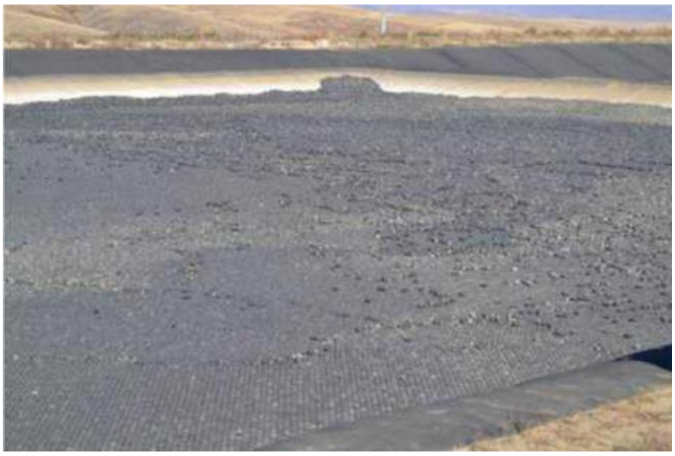


Figure 21: Heap leaching pad construction layers at Boroo Gold LLC.[6]

Storm water pond

The pregnant leach solution (PLS) pond contains 14,274 m^3 of water below the overflow level, whereas the storm water pond contains 28,701 m^3 of water below the overflow level. In the case of a power outage or pump failure, as well as a violent storm or heavy rain, the solution in the PLS pond will flow naturally into the adjacent storm water pond. The leach pad is constructed of a compacted soil base of 300 mm, 1.5 mm thick LLDPE, a geonet layer for leak detection, and a 2 mm thick HDPE liner. The storm water pond's base is made up of a 300 mm thick compacted soil base layer and a 2 mm thick HDPE liner. The pond is surrounded by a fence to prevent animals from entering and is completely covered in floating "bird balls" to keep out birds.

(Not a site picture)



Floating bird ball cover (October 20, 2012)

Figure 22: Floating bird ball cover.

Assessment of potential impacts of the heap leaching

The project's primary impacts include soil destruction on 33 ha of land[6] due the heap leach pad's construction, as well as dust pollution from the movement of heavy-duty equipment employed in heap leaching operations. The heap leach stockpile may release cyanide and other toxic pollutants into the air or infiltrate to the soil. Spills of oil and lubricants used in equipment have the potential to pollute the soil and vegetation.

Table 8: Assessment of potential impact of the Heap leach project of Boroo Gold LLC.[6]

Environmental component	Form			Duration				Intensity		
	Direct	Indirect	Self-coordinated	Long tern	Short term	Re-impacting	One-time impacting	Strong	Moderate	Weak
1. Environmental issues related to the project location										
Impact on underground water	■			■						■
Degradation of soil and vegetation	■			■					■	
Impact on air	■				■				■	
2. Environmental issues related to the project activities										
Environmental impacts caused by chemicals and cyanide	■			■					■	

Environmental impacts caused by machinery and equipment	■			■				■		
Impacts on water (underground)	■			■						■
Noise impacts due to project activities	■				■				■	
Impacts on air quality	■				■				■	
Impacts of the Heap Leach facility's operations		■					■		■	
3. Natural resource use										
Underground water		■			■					■
Soil, ground	■				■			■		
Use of accumulated precipitation water		■			■					
Soil fertility		■					■			
Vegetation	■			■				■		
4. Environmental changes										
Quality and quantity of potable water (underground)										
Soil erosion and pollution	■			■					■	
Air pollution	■						■		■	
5. Socio-economic issues										
Increase of private property and tax revenue	■				■				■	
Increase of local government revenue	■				■			■		

Table 9: Main impacts that can cause from heap leaching operation according to environmental impact assessment report.[6]

Listed main impacts	**Environmental damage assessment**	**Probability**	**Proposed solution**
Formation of certain amount of dust pollution	Medium damage	Definite to occur	Solution to mitigate the impact has been
Oil and lubricant spillage from vehicles and equipment	Low damage	Potential	Operational control and proper use
Formation of waste ore stockpile	Medium damage	Might occur	Use for reclamation at mine areas
Noise and vibration pollution	Medium damage	Definite to occur	Use protective equipment

Environmental monitoring

Air monitoring: Near the Boroo tailings facility, the mine site has an automated weather station. Boroo Gold has been monitoring and measuring six chemicals, including O_2, CO, SO_2, NO_2, HCN, and NH_3, at 13 locations around the mining territory on a ten-day cycle.

Soil monitoring: Soil samples are taken at pre-defined locations throughout the mine and submitted to authorized laboratories as well as to laboratories in the United States.

Underground water monitoring: Underground water monitoring is carried out at 14 monitoring wells positioned across the project area, with eight located east of the tailings dam and five at the Heap Leach project site.

2.4.3 Steppe gold LLC

The Altan Tsagaan Ovoo (ATO) gold and silver project is located in the territory of Tsagaan Ovoo soum of Dornod province in eastern Mongolia. The ATO Project is comprised of an area of 5,492.63 hectares.[7]

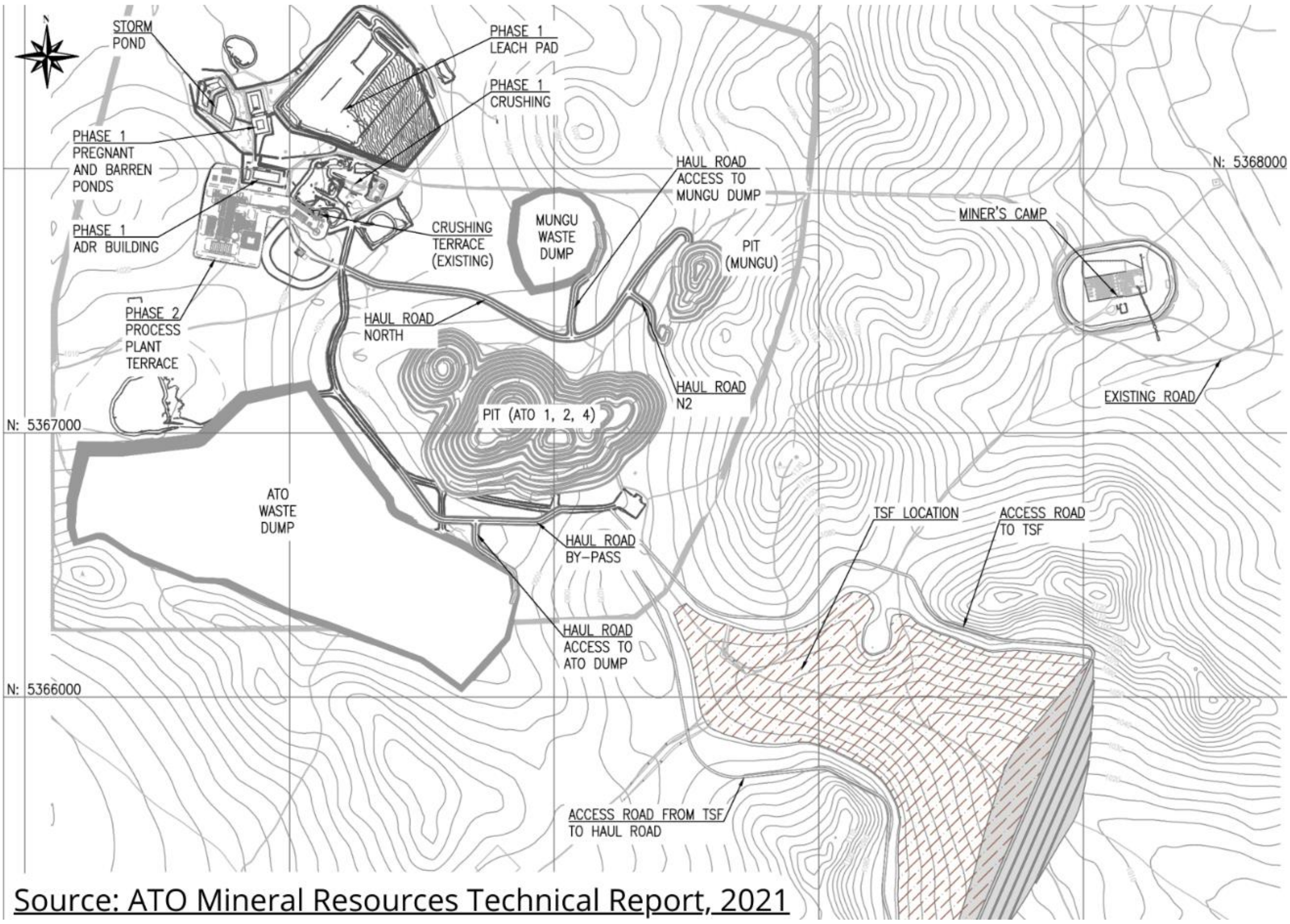


Figure 23: Site map in general [7]

Heap leach pad

- A gradated subgrade was used to provide a non-puncturing surface for the geosynthetic liner
- Leak detection using horizontal wick drains to operate as large-scale lysimeters
- Primary geomembrane liner, 1.5 mm thick linear low-density polyethylene (LLDPE), with aggressively textured bottom side
- Drainage pipes were constructed above the geomembrane to drain the solution and reduce the hydraulic head.
- Gravity drainage from the leach pad to the pregnant tank at the Adsorption-Desorption-Recovery (ADR) plant or (in the case of an upset) events ponds in double-contained and buried pipes.

The Steppe Gold LLC has created five water circuits (Raw Water, Potable Water, Fire Water, Gland Water, and Process Water) to meet the plant's needs, as well as the surrounding infrastructure. To satisfy the requirements, about 4,800 m^3 of daily make-up water will be required, with a ratio of 0.79 m^3 of fresh water/tonne of dry ore fed to the plant. oreholes drilled at the heap leach pad reached a maximum depth of about 20 meters, but no groundwater was discovered. As a result of the findings, the groundwater water table is estimated to be deeper than 20 meters[7].

Table 10: Water circuit and distribution plans at Steppe Gold LLC.[7]

Name of water circuits	Brief descriptions
Raw Water	Reagent preparation and filter press wash water are both done with raw water. Reticulation of process water meets most process water demands, reducing raw water demand for the process.
Potable Water	In the safety showers and eyewash stations, as well as for potable water reticulation to non-process infrastructure, potable water (filtered and UV sterilized) is used.
Fire Water	Within the raw water tank, there is a dedicated fire water volume. A typical fire water skid consists of a primary electric fire water pump, a pressure maintaining jockey pump, and an emergency diesel powered fire water pump to ensure that there is still fire water accessible in the event that the process plant loses power.
Gland Water	A gland water circuit has been supplying gland water to all slurry pumps within the process. The raw water tank supplies this water, which is filtered on the suction side of the gland water distribution pumps.
Process Water	The process water settling pond collects the various thickener overflow streams, reclaim water, and fresh makeup water to enclose the water balance. The process water is then distributed throughout the concentrator plant via the delivery pipework and process water pumps.

Environmental monitoring

Environmental monitoring at Steppe Gold LLC:[26]

Air quality and dust monitoring	at 16 points
Soil quality monitoring	at 18 points
Ground and surface water monitoring	at 34 points
Flora monitoring	at 19 points
Wildlife monitoring	In 3000 km2 area

Groundwater monitoring stations (one shallow and one deep) will be placed downstream of the Tailing Storage Facility (TSF) to allow for early detection of changes in groundwater level and/or quality during and after decommissioning. To inform stability assessments, standpipe piezometers will be installed in the TSF wall to monitor pore water pressures at various places.[7]

Operation monitoring falls into three basic categories:[7]

- Short-term operation monitoring: Includes offtake location (whether pipe joints are leaking, etc.), which are part of ensuring that the TSF is operating smoothly.
- Compliance monitoring: Includes tasks such as assessing settlement pins for movement and checking bores for contamination to ensure that the project is delivering on its promises of a safe and secure operation.
- Long-term performance monitoring: Includes tasks such as tailings level surveys and tailings and water flow measurements (using flow meters installed at designated locations), which are used to track the facility's long-term performance and refine future embankment lift levels and final tailings (and low permeability soil liner) extents.

3. Leaching environmental impacts

3.1 Positive environmental impacts

Waste rock disposal causes more environmental harm than any other aspect of mining operations in many cases. Of all impacts caused by waste rock disposal, those involving acid mine drainage[2] are by far the most serious. This phenomenon can occur for both copper and gold ores. If low-grade ore/ overburden or tailing contains sulfide minerals. Mining often exposes sulfide-bearing minerals to the atmosphere pyrite (FeS_2), pyrrhotite (Fe_xS_x), chalcopyrite($CuFeS_2$). Metal processing does not completely eliminate pyritic minerals, and tailings contain considerable amounts of sulfide. The amount of acidity produced by sulfide bearing mineral is dependent on a number of variables, including temperature, oxygen availability, sulfide concentrations, the starting pH of the surrounding environment, total Fe concentrations, and the presence of bacteria. Metals in acidic soils become more mobile and available to plants, resulting in an increase in metal leaching, plant absorption, and runoff from soils. Tailings or low-grade ores from gold and copper minerals often contain sulfide minerals, and a number of cases of acid mine drainage have occurred as a result of their tailings. If leaching gold or copper low-grade ore is practicable and economically beneficial, uncontrolled acid mine drainage can be avoided. In the future, if a large amount of sulfide-containing mineral pile is neglected, rainwater will form acid. However, when an effective environmental protection plan and closure plan are in place, leaching industrial processes reduce the dangers that described above (Figure 25). Electricity costs associated with milling and crushing processes might account for up to 50% of mining expenses. The heap and dump method are useful since it eliminates the requirement for milling low-grade ore. However, the advantage of leaching is not limited to the high cost of grinding. Due to the low electricity use, leaching produces a lower carbon footprint than other beneficiation processes. Furthermore, dust emission from dry milling and water usage (in case of wet milling) is non-exist in the leaching method.

[2] When sulfuric acid is generated in connection with coal or metal mining, it is referred to as acid mine drainage (AMD) or mine-influenced water. Without the anthropogenic effect of mining, acid production is usually referred to in the literature as acid rock drainage (ARD), and in some countries, ARD refers to low pH mine-related drainage.[12]

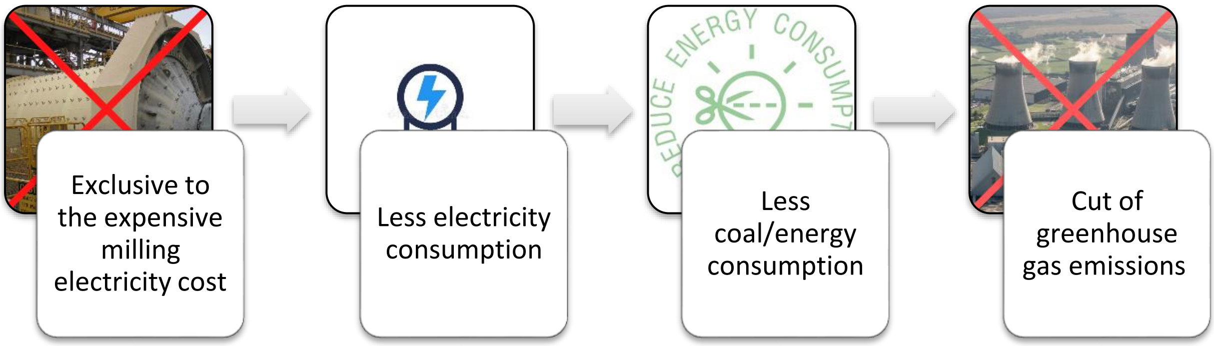


Figure 24: The advantage of being exclusive to the milling process in terms of greenhouse gas emissions.

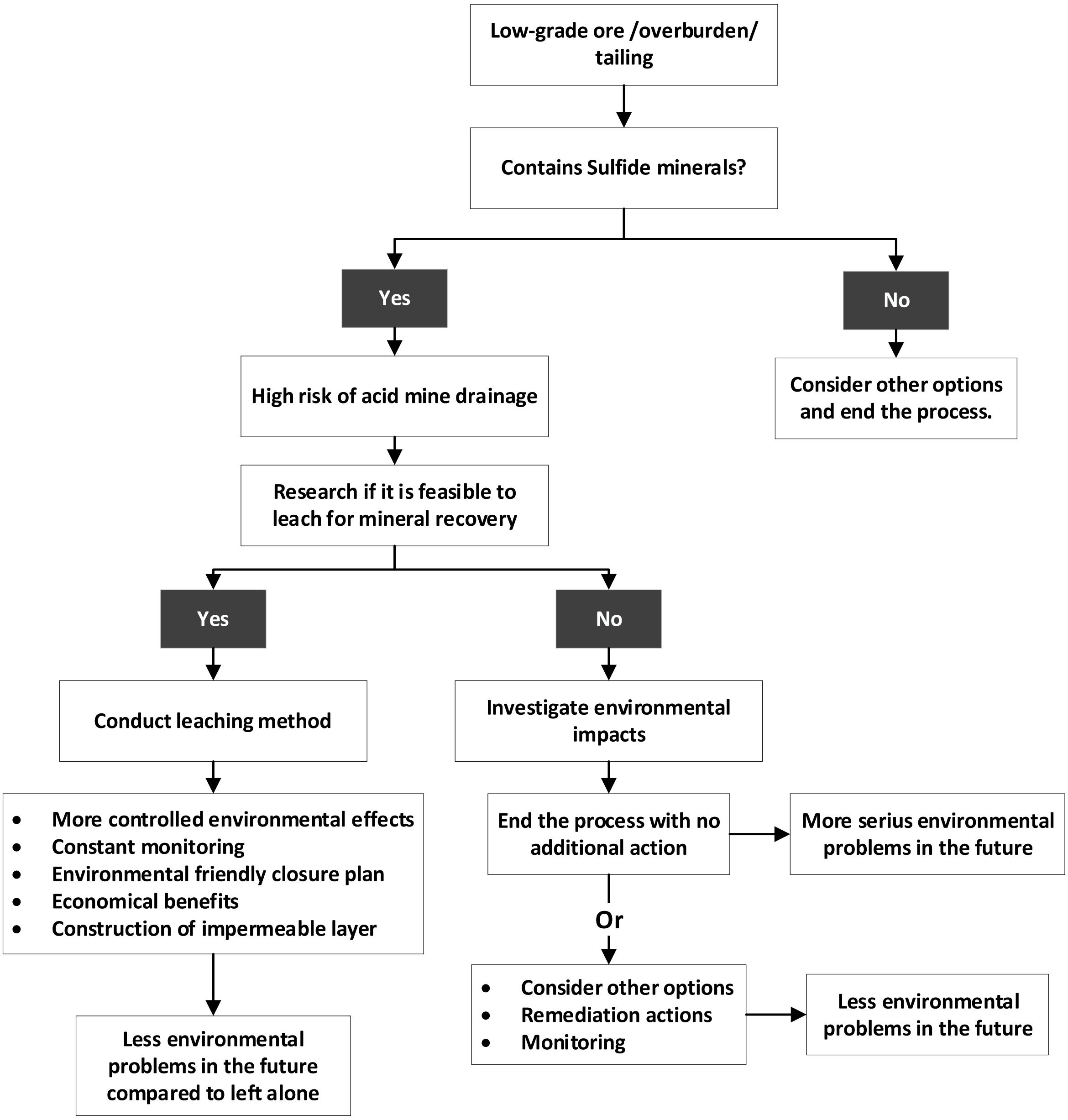


Figure 25: Flowchart diagram exhibiting the process of dealing with low-grade ore and the resulting environmental impacts.

3.2 Negative impacts on the environment

Environmental concerns associated with dump and heap leach facilities revolve primarily around contain process solutions within the heap/dump leach circuit. Because most landfills, holding ponds, and transfer channels are placed directly on the existing terrain, seepage can occur. Changes in climatic conditions, exceptional storm occurrences, or mechanical equipment failure might result in excess liquid in the solution cycle. Much the same issue may develop if the pumping machinery used to drain the holding ponds fails due to mechanical failure or power outage. A variety of causes of weathering and decomposition caused by contact with the acid leaching solutions and exposure to air can contribute to the failure of transfer pipes, holding pond dams, and liners. Seismic activity, rockslides, and operator error are also potential failure mechanisms. Most leach piles are situated within natural drainage basins, and the runoff from rainfall and snow melt happening within these basins would considerably raise the flow rates into the holding ponds. If the excess flow cannot be handled by the recovery process or diverted into secondary containment areas, the liquid may overrun the solution containing ponds and onto the adjacent property. At the end of the gold leaching, if the dump or heap is not rinsed or rinsing is inadequate, the solution remaining in the interior of heap/dump may remain alkaline for and be a potential source of free cyanide [14]. Like so for copper leaching case, solution remaining in the dump/heap may remain acidic and be a source of acid leakage. As such, the following are the remaining key possible environmental impacts:

- Dust generation from agglomeration process and from construction of heap and dump
- Evaporation of lixiviant/ leaching solution into the atmosphere
- Overflowing of ponds due to excessive rain
- Seepage/ infiltration of toxic leaching solutions into the groundwater and contamination of ground soil (highly possible for dump leaching case)
- Leakage from solution holding ponds and transfer channels
- Spills from ruptured pipes
- Failure of the dams
- Emission of toxic gas in the processing plant
- Toxic gas production from vehicles
- Soil erosion
- Dust dispersion
- Wildlife cyanide or acid toxicity

3.2.1 Evaporation of leaching solution

Evaporation of cyanide

HCN forms when cyanide solution is at pH=9.7, and if the pH of the heap leach is less than 9, some or most of the free cyanide will be released to the atmosphere [14]. If the pH is greater than 9, free cyanide[3] will remain in the solution. Therefore, pH of solution should be higher, 11 in average. When pH is too high, it increases the use of lime and contaminates activated carbon, therefore, the optimal pH is 11. It is hazardous when concentration of HCN reaches 5 ppm in atmosphere and when it reached 10 ppm , the condition is considered as extremely hazardous and evacuation plan should be prepared for this case. Therefore, HCN sensors are to be installed. When the sodium cyanide evaporates, it can easily react in air and convert to hydrogen cyanide which creates a toxic substance content in air. The hydrogen cyanide HCN is a flammable and extreme toxic gas when temperature exceeds 26^0C. Permitted quantity in the air of working place is 0.3 mg/m^3 and human body will be weakened and poisoned slightly when spend 1 hour in the air with quantity of 40-50 mg/m^3. Biodegradation is possible at low concentrations of soluble free cyanide. High concentration of free cyanide is not easily biodegraded and could lead to cyanide contamination in runoff or in liquids that percolate down to the soil and ground water. Almost all of the free cyanide is in the form of HCN, and equilibrium is maintained with atmospheric HCN vapor [14]. It takes around 1–3 years for half of the hydrogen cyanide to be removed from the atmosphere. Most cyanide in surface water will form hydrogen cyanide and evaporate [3].

Evaporation of sulfuric acid

Sulfuric acid dissolves in water present in the air and can remain suspended for varied periods of time. It is removed from the air in the rain. Sulfuric acid in the rain contributes to the formation of acid rain. Sulfuric acid dissolves in water, forming hydrogen and sulfate ions. It's ability to affect the acidity (pH) of water is proportional to its concentration and the ability of other substances in the water to neutralize hydrogen ions (buffer capacity).

3.2.2 Pond overflowing

Heap dump or dump leaching takes place carried out long time. If stormwater pond is not designed correctly in other word not large enough, overflowing is inevitable. In high-rainfall areas, a surplus water balance can occur as a buildup during the wet season or during intense short-duration storm events. In cold climate regions, this surplus water balance may also result from spring snowmelt runoff. Because the majority of leach piles are placed in natural drainage basins, runoff from rainfall and snow melt inside these basins will elevate liquid flow rates into the holding ponds. If this additional flow cannot be handled by the recovery process or be diverted into secondary containment areas, the liquid may overflow the banks of the pond onto the surrounding property. Resulted overflow will damage surrounding soil. Sulfuric

[3] Free cyanide: refers to either molecular hydrogen cyanide (HCN) or ionic cyanide (CN^-)

acid is totally miscible in water, and it fully dissociated into protons and sulfate ions in water. Sulfuric acid mobility increases[27] when water is present in the soil environment, and when sulfuric acid plume reaches the saturated zone in the underground it migrates downward due to its higher density than groundwater. However, its concentration decreases by dispersion and diffusion. When acidity builds up to high levels in water, it poisons vegetation in and near streams and ponds. Not only acidic water is harmful to one's health and it can cause skin irritation. Mosquitoes, which can tolerate acidic water considerably better than the insects that feed on them[31]. As a result, acidified wetlands may be a source of mosquito plagues.

3.2.3 Seepage of leaching solution

When constructing impermeable base, only one layer of line is might not be enough to prevent any seepage or leakage from heaps and dumps into the underground. Typically for gold leaching, to maintain alkalinity pH 10-11, lime is added to sodium cyanide (often in the barren pond). Under those conditions, the cyanide present is mostly free cyanide, as required in the leaching reaction. The PLS pond contains lesser concentration of free cyanides because of the destruction, losses, and complexation that occur in the heap/dump. Failure of containment system, impermeable layer puncture would result in free cyanide in the alkaline solution being released to the environment for the gold leaching.

As for the copper leaching, a dilute sulfuric acid solution with a pH of 1.7-3 can have a direct effect on ground soil and underground water due to seepage. Even though a geomembrane liner is needed for dump leaching, in many cases, no such liner is present. Dump at Achit Ikht is one of the cases in Mongolia. Initially, no leaching processes were planned, and Erdenet Mining Corporation's overburden was simply dumped, resulting in acid mine drainage with high copper content. Like mentioned before, Erdenet mining corporation prepared no geomembrane sheet or liner at the dumping site and now for this dump natural compacted clay layer is serving as protective layer.

Compacted clay layer

The mineral liner, which is composed of a layer of compacted clay, would be at least 0.5 m deep, composed of numerous layers with a thickness of 0.15–0.20 m, and have a hydraulic permeability of $1*10^{-9}$ m/s or lower.[30]

Table 11: Permeability of clay soil with comparison to the other soil types [29]

Soil type	Permeability coefficient K, cm/sec	Degree of Permeability
Gravel	10^{-1}	Very high
Sand, fine sand	$10^{-1} > k > 10^{-3}$	High to medium
Dirty sand, silty sand	$10^{-3} > k > 10^{-5}$	Low
Silt, silty clay	$10^{-5} > k > 10^{-7}$	Very low
Clay	$K > 10^{-7}$	Virtually impermeable

Compact clay liners may degrade over time owing to many drawbacks such as: Compaction may be difficult where the underlying layer is not structurally stable, if not well protected, the layer may suffer due to desiccation, freeze/thaw cycles, which resulting in cracking and due to the reason if clay layer system is damaged it cannot be repaired.

Even geomembrane sheet is present under the dump or heap occurrence of seepage and leakage from defects or puncture is undeniable. The quality of the liner determines the performance of geomembranes in heap leach pad applications. When considering the vertical forces involved, the form of the liner grading curve has a direct impact on the risk of geomembrane puncture. [24]. Thus, seepage from dump and even heap is most predominant problem that could occur from dump/heap leaching operation.

3.2.4 Soil acidification

Leaf and needle wetting with acid precipitation:

Both H_2S0_4, HNO influence leaf organs via aqueous films. Until a few years ago, tree damage could usually be attributed to a single cause. Continuous exposure to acids, on the other hand, damages the soil's buffering capacity and might eventually lower the pH value of the soil solution. As a consequence, nutrients are leached from the soil to a much greater extent. Acids can cause nutrient loss by directly damaging the stomata of leaves and needles. In addition, when pH values fall below critical thresholds, metals such as aluminum are dissolved and are then biologically available.

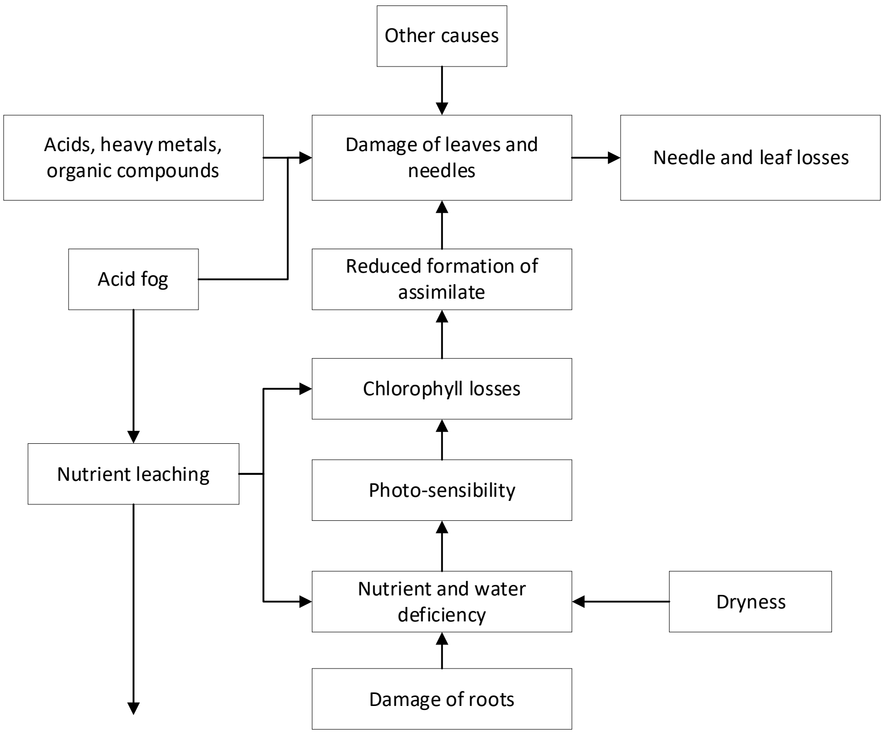


Figure 26: Estimated impact relations on needles due to acidic precipitation.[9]

Sulfuric acid in soil solution lowers pH, increases acidity, increases soluble sulphate content, and decreases microbial activity. Increased acidity leads to lower concentrations of calcium and other basic ions, higher concentrations of phytotoxic ions. Sulfuric acid dissolves cations (e.g., calcium, magnesium, and aluminum) from soil and carbonate minerals, and forms salts from the cations. Analyzing microbial community dynamics and measuring pH, mineral composition, and cation dissolution can help to identify the toxicity change of acids in soil environments. Acid sulfate soil by lowering pasture quality and increasing grazing animal uptake of aluminum and iron. Acidity and increased soluble metal liberation may cause direct plant toxicity and reduced nutrient absorption availability, as well as a potential drop in farm productivity.

4. Environmental impact assessment

Because of variances in the geography, geology, hydrogeology, weather, and detailed operating parameters of the site, a particular kind or combination of management strategies is rarely appropriate for all leaching activities. External factors such as the price of copper and gold, as well as the operation's competitiveness in the global market, are also key considerations in establishing the economic feasibility of a particular technology. As a result, each leaching operation has put in place a set of management practices that ensures the most efficient and cost-effective recovery at that plant. As part of the leaching process, these activities are intended to manage solution losses and monitor fluid balances. The main Environmental impact assessment procedures that will be followed in the assessment of any environmental component are summarized in Figure 27.

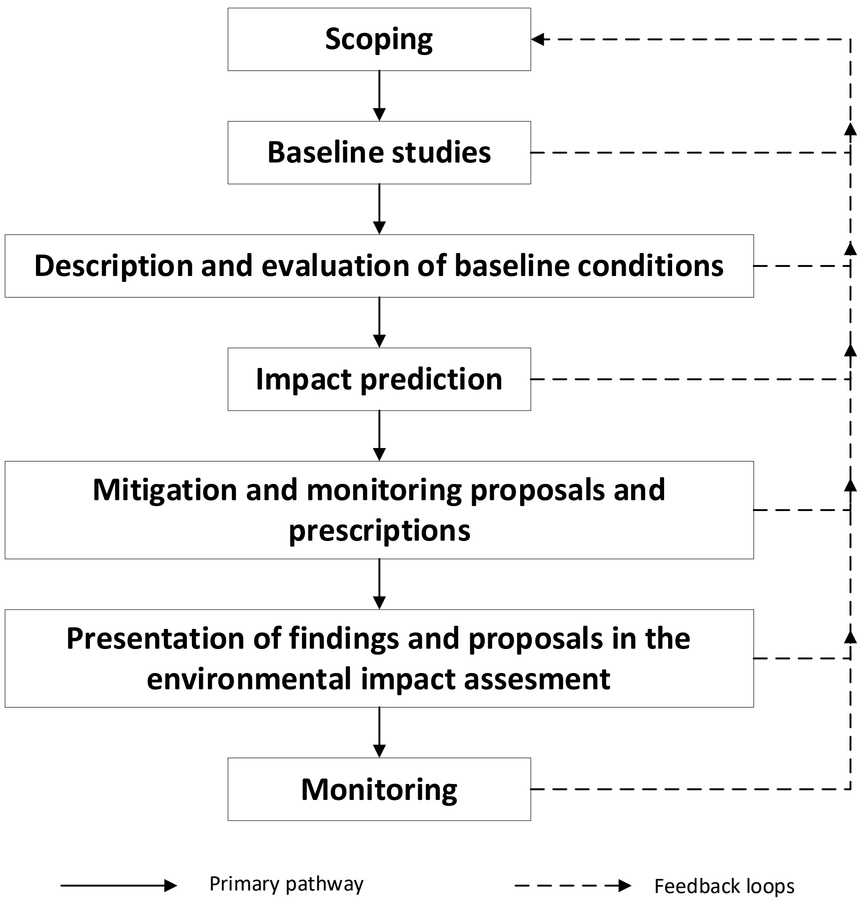


Figure 27: Assessment procedures for an environmental impact [11]

4.1 Failure Modes and Effects Analysis

Failure Mode[4] and Effect Analysis[5] (FMEA) techniques have been around for over 40 years. FMEAs were originally created to help detect and remedy safety issues. FMEA (Failure Mode and Effect Analysis) is a systematic method for identifying and preventing product and process problems in advance of their occurrence. FMEAs are used to identify and eliminate flaws, improve product safety, and boost customer happiness. FMEAs become a critical tool for safety improvement, particularly in the chemical process industries. The FMEA process is a technique for identifying failures, impacts, and hazards and then eliminating or mitigating them. Each probable failure mode and effect is assessed on a scale of 1 to 10 for each of these three elements, from low to high, based on the facts and information about the process or product. A risk priority number (RPN) for each possible failure mode and consequence will be determined by multiplying the rankings for the three factors (severity, occurrence, and detection).

$$RPN = O * S * D$$

The risk priority number (which will range from 1 to 1,000 for each failure mode) is used to rate the importance of remedial measures to eliminate or decrease probable failure modes. Failure modes with the highest RPNs should be prioritized, but extra attention should be paid when the severity rating is high (9 or 10) regardless of the RPN[17].

4.2 Environmental Failure Modes and Effects Analysis on risk assessment

Beyond product design and production processes, the FMEA method has a wide range of applications. It can be utilized for safety, accounting/finance, software design, marketing, and human resources, etc. Unlike a conventional risk evaluation matrix, which considers consequences and likelihood/probability to determine risk spectrum, the environmental application of FMEA takes into account detection factor to determine RPN, which can bring out most severe environmental impacts that could put more harm to the surrounding environment from other inferior impacts. There are ten essential steps for FMEA which is shown in the Table.12 [17]. For leaching method, Environmental-FMEA, those ten steps are slightly altered. The first three steps of the EFMEA for heap/dump leaching are considered completed in the previous section. Because no EFMEA risk priority number calculation has been performed earlier (step 7), steps 9 and 10 are skipped in this section. Instead, actions are taken up to step 8. Hypothetically those ten steps for EFMEA are in a sense like the stepwise environmental impact assessment procedures from Figure 27. Continuous appraisal and readjustment also play a critical role in EFMEA procedures as written in step 9 and step 10 just like feedback loops.

[4] "Failure modes" means the ways, or modes, in which something might fail.
[5] "Effects analysis" refers to studying the consequences of those failures

Table 12: 10 Steps for an FMEA

Steps	10 Steps for an FMEA [17]	10 Steps for a EFMEA for heap/dump leaching method	
Step 1	Review the process or product	Review the heap or dump leaching process	
Step 2	Brainstorm potential failure modes	Brainstorm potential environmental impacts of heap/dump leaching operations	
Step 3	List potential effects of each failure mode.	List potential effects of each environmental impacts	
Step 4	Assign a severity ranking for each effect.	Assign a severity ranking for each effect from leaching method.	
Step 5	Assign an occurrence ranking for each failure mode	Assign an occurrence ranking for each impact	
Step 6	Assign a detection ranking for each failure mode and/or effect.	Assign a detection ranking for each failure and/or impact	
Step 7	Calculate the risk priority number for each effect.	Calculate the risk priority number for each environmental effect/impact.	
Step 8	Prioritize the failure modes for action.	Prioritize the impact for action.	
Step 9	Take action to eliminate or reduce the high-risk failure modes.	Take action to eliminate or reduce the high-risk impacts or failures	**Not applied**
Step 10	Calculate the resulting RPN as the failure modes are reduced or eliminated.	Calculate the resulting RPN as the impacts, failures are reduced or eliminated.	

Table 13: Directions to adopt the O,S,D indicators

Occurrence ,O (Probability)		**Significance, S (Consequence)**			**Detection, D (Monitoring)**		
Points		**Points**		Characteristics	**Points**		Characteristics
1	**Does not occur**	**1**	**Insignificant**	No environmental damage	**1,2**	**Easily detectable**	Requires no detection method:
2	**Almost impossible**	**2,3**	**Minor consequences**	Minor environmental damage	**3,4**	**Detectable and predictable**	Requires detection method:
3	**Rarely**	**4,5,6**	**Moderate**	Predictable / cumulative environmental damage	**5,6**	**Limited detectability**	Monitoring requires common apparatus
4,5,6	**Likely to very likely**	**7,8**	**High**	Visible environmental damage	**7,8**	**Hard to detect**	Monitoring requires specific apparatus and build up
7,8	**Frequently**	**9**	**Major**	High environmental damage	**9,10**	**Complicated to detect**	Requires specialist and carried out projects
9	**Very common**	**10**	**Catastrophic**	Toxic environmental damage			
10	**Almost certain**						

4.3 Environmental impact risk assessment chart

*Possible environmental impacts of **dump and heap** leaching operation*	*Occurrence, O*	*Significance, S*	*Detection, D*	*Risk priority number, RPN=O*S*D*	*Evaluated risk level*
Evaporation of lixiviant/ leaching solution into the atmosphere	6	6	5	180	High
Emission of toxic gas in the processing plant	6	10/ for human health	3	180	High
Toxic gas production from vehicles	9	4	2	72	Moderate
Overflowing of ponds due to excessive rain	4	7	2	56	Moderate
Leakage from solution holding ponds and transfer channels	4	5	4	80	Moderate
Spills from ruptured pipes	5	5	3	75	Moderate
Seepage/ infiltration of toxic leaching solutions into the groundwater and contamination of ground soil (heap leaching case)	3	10	8	240	High
Seepage/ infiltration of toxic leaching solutions into the groundwater and contamination of ground soil (dump leaching case)	6	10	8	480	Very harmful
Failure of the dams	2	8	5	80	Moderate
Dust generation from agglomeration process and from construction of heap and dump	5	2	2	20	Low
Dust dispersion	6	3	3	54	Moderate
Soil erosion	7	6	4	168	High
Soil acidification	5	10	8	400	Very harmful
Wildlife cyanide or acid toxicity	3	4	3	36	Low

Table 14: Evaluation of RPN to risk level

Occurrence, O	Significance, S	Detection, D	RPN	Evaluated risk
Points within 3	Points within 3	Points within 3	**1-27**	**Low**
Points within 5	Points within 5	Points within 5	**28-125**	**Moderate**
Points within 7	Points within 7	Points within 7	**126-343**	**High**
Points >7	Points >7	Points >7	**> 343**	**Very harmful/ critical**

According to risk assessment results soil acidification and seepage of toxic leaching solution into underground has a highest risk to impact the environment than others and potentially have critical environmental impact if occurs. Evaporation of toxic solutions into atmosphere as well as from processing plant will impact directly to the human health and as well as to the environment because those are direct root cause of soil acidification. Even though dust dispersion has evaluated to impact the environment moderately it is also one the key factor for soil erosion. Overall, other environmental impacts are calculated have lesser risk level compared to ones mentioned former.

5. Future trends in renaturation and reclamation

In the perspective of limiting solution losses from the process circuit, dump leaching is probably the type of extractive metallurgy where companies should have the biggest economic motive to enforce the strictest of environmental controls. The infrastructure of dump and heap leaching stretched over a much broader area than other metallurgical plants, making effective control much more difficult. Allied to this, instead of being confined in process vessels and pipes with limited access, the process solution is usually exposed to the environment in open solution trenches and process ponds, creating a far larger hazard to inhabitants. There may also be potential risks to workers health and safety associated with the windblown dispersion of process solution droplets and dust from leach pad, particularly from facilities.

Despite its apparent toxicity, cyanide has shown to be the most successful and ecologically acceptable reagent for gold leaching, out of a number of chemicals explored as alternatives (sodium bisulphide, thiosulphates, thiocyanate, thiourea, hypochlorite, bromide, and iodide solutions). This is since cyanide undergoes natural degradation reactions which can render it non-toxic (decomposing to carbon dioxide and nitrogen compounds). These natural reactions have been utilized by the mining industry as the most common means of attenuating cyanide. However, the pace of natural degradation is highly dependent on environmental circumstances and may not end in desirable effluent in all cases. After the dump/heap closure actions are completed, there should be two additional action stages: post closure monitoring and corrective actions if there are still negative impacts that cannot be ignored. However, unlike other nations such as Germany, Mongolia does not use post-closure activities and corrective plans effectively.

Active life → **Closure** → **Post Closure** → **Corrective plan**

5.1 Cyanide treatment technologies

There are several treatment methods for neutralizing or detoxifying cyanide solutions, e.g., rinsing of heaps; sulfur processes; INCO process; Noranda process; alkaline chlorination process; hydrogen peroxide process; AVR cyanide recovery process; and biological treatment.

Table 15: Cyanide treatment technologies.[19]

Rinsing of Heaps	Fresh water or recycled rinse water that has been treated to contain little cyanide can be used to rinse dumps/heaps.
Sulfur Processes	In the sulfur processes, cyanide in solution is oxidized to cyanate in the presence of copper ion using sulfur dioxide or ferrous sulfate and air: $CN^- + SO_2 + O_2 + H_2O \dashrightarrow CNO^- + H_2SO_4$ The sulfuric acid formed in the reaction is neutralized with lime. Cyanate may be less toxic than cyanide to fish, animals, and humans. Higgs and Associates (1992) report that CNO^- is 3,000 - 5,000 times less toxic than CN^-.
INCO Process	In general, the INCO method reduces the amount of CN by utilizing a retention period of several minutes in a one-stage reactor or two reactors in series with a retention time of several minutes in each, and vice versa. INCO studies, for example, shown that a feed stream could be lowered from 1680 mg/l CN to 0.13 mg/l CN utilizing a retention time of 97 minutes in a one-stage reactor.
Noranda Process	The Noranda method is a heap cyanide detoxification of tailings effluent. When copper and ferrous sulfate are introduced to cyanide effluent, the following reaction occurs: $Cu^{2+} + Fe^{2+} + 3OH^- \dashrightarrow Cu^+ + Fe(OH)_3$ The ferrous ion is oxidized to ferric oxide in the presence of hydroxide ions, while the cupric ion is simultaneously reduced to cuprous ions. As an insoluble precipitate of cuprous cyanide, the cuprous ion eliminates free cyanide (Konigsmann et al 1989). The production of cuprous cyanide reduces the availability of free cyanide ions in solution, resulting in further cyanide elimination by dissociation of soluble metal cyanide complexes of copper, zinc, and nickel into simple cyanide and metal ions. In a second stage, hydrogen hydroxide at high pH is added to oxidize the residual simple cyanides, completing the cyanide elimination.
Alkaline Chlorinati on Process	One of the oldest cyanide destruction procedures is alkaline chlorination. Using chlorine or hypochlorite in solution, cyanide in solution is oxidized to cyanate: $CN^- + Cl_2 \rightarrow CNCl + ClCNCl + 2OH^- \rightarrow CNO^- + Cl^- + H_2O$ Alkaline chlorination can be applied to both clear wastewaters and slurries.
Hydrogen Peroxide Process	In the hydrogen peroxide process, cyanide in solution is oxidized to cyanate using hydrogen peroxide in the presence of copper ion: $CN^- + H_2O_2 \dashrightarrow CNO^- + HO$. This method can be used with wastewater.

AVR Cyanide Recovery Process	This principle is immediately opposed by the Acidification-Volatilization Recovery (AVR) process. The addition of sulfuric acid lowers the pH of a cyanide solution, resulting in the formation of HCN gas. After that, the gas can be absorbed in a NaOH solution: CN (aq) + H (aq)-> HCN(g) HCN(g) + NaOH(aq)-> NaCN(aq) The procedure has mostly been used on barren solutions.
Biological Treatment	Microbial action converts cyanide to ammonia, which can happen spontaneously or as part of a cyanide detoxification process. Metal ions produced by metal cyanides will be absorbed by biomass, and thiocyanates will be converted to sulfate: $Cu_2CN + 2\ H_2O + ½\ O_2$ -> Cu-biofilm + $HCO_3 + NH_3$ $SCN^- + 2H_2O + 2½O_2$ -> $SO_4^{2-} + HCO_3^- + NH_3$ The ammonia will be converted to nitrate by further microbial action: $NH_4^+ + 1½\ O_2$ -> $NO_2^- + 2H^+ + H_2O$ $NO_2^- + ½\ O2$ -> NO_3^- The main objective of biological treatment processes is to greatly accelerate the rate of these natural transformations.
Pintail's Biotreatment Process	Pintail System Inc.'s technique to biotreatment of heap leach pad cyanide solutions employs microorganisms indigenous to the project site. The procedure includes identifying and improving natural bacteria with the ability to utilize or change cyanide into non-toxic components such as carbon dioxide, water, and nitrogen. These "working" bacteria are cultivated to concentrations sufficient for successful biotreatment, while "non-working" bacteria are selectively removed from the microbial population. Cyanide biotreatment in cold weather is conceivable as long as the biotreatment solutions are heated and the solution is efficiently applied to the heap.
Natural Degradation	Natural degradation refers to any process that reduces a waste's overall cyanide content without requiring human involvement. Barren solution lagoons, tailings impoundments, and piles all exhibit natural degradation processes to some extent. In the core of piles and at the bottoms of lagoons, cyanide destruction efficiency may be low. Among them are: • Microbial generation of cyanate/ammonia in soil: $CN^- + ½\ O_2$ + enzyme -> CNO^- $CNO^- + H_2O$ -> $NH_3 + CO_2$ • After absorption of CO_2 or SO_2 from the environment, cyanide volatilizes from solution, resulting in acid production: CO_2 (g) + H_2O -> H_2CO_3 (aq) <<>> $HCO_3^- + H_3O^+$ $H_3O^+ + CN^-$ -> HCN(g) • Soil hydrolysis: HCN + 2 H_2O -> NH_4COOH • Anaerobic biodegradation: $CN^- + H_2S$(aq) -> HSCN + H^+ HSCN + 2 H_2O -> $NH_3 + H_2S + CO_2$ • Complexation: Zn $(CN)_2$ + 2CN^- -> Zn $(CN)_4$

Treating cyanide waste or residue

Few researchers have described the effects of treatment such as freshwater rinse and treatment with hypochlorite on cyanide concentrations in the heap. However, alkaline rinses, and rinses with oxidizing agents are some of the methods that may be used to increase rates of destruction of free cyanide and thus more quickly reduce the cyanide concentrations remain in the heap leach residue.[14]

For cyanide wastewater, alkaline chlorination is one of the most widely used methods of treating. In this process, cyanogen chloride (CNCl) is formed , which then at pH>8 it is hydrolyzed to cyanate ion (CNO^-). If free chlorine is present, CNO^{--} can be further oxidized. Other methods used in cyanide waste management include:[10]

- Lagooning for natural degradation (retain wastewaters in impoundments for several days to months. Volatilization, photodegradation, chemical oxidation, and, to a lesser extent, microbiological oxidation all contributes to removal of cyanide)
- Exposure to the ultraviolet radiation
- Evaporation
- Aldehyde treatment
- Ozonization
- Acidification-volatilization-reneutralization
- Ion exchange
- Activated carbon absorption
- electrolytic decomposition, catalytic oxidation, and biological treatment with cyanide-metabolizing bacteria

The use of sulfur dioxide in a high dissolved oxygen environment with a copper catalyst allegedly reduced total cyanide in metal plating shop rinse waters to less than 1mg/L. This process may have application in cyanide detoxification of tailing ponds.[10]

5.2 Treating sulfuric acid waste and acid treatment technologies

Although experience with the closure of precious metal heaps has established methodologies for closure, substantially less experience with the closure of copper dumps here sulfuric acid is used as a lixiviant is known in the literature.

For example: The European Chemicals Agency (ECHA), which provides a database of substance information as well as physical and chemical properties, environmental fate and pathways, ecotoxicological information, and toxicological information, has no data on the environmental fate of sulfuric acid, including hydrolysis, biodegradation, bioaccumulation, sorption, and desorption.[27] Similarly, only information on sulfuric acid's environmental fate is available in the Hazardous Substances Data Bank (HSDB) is a toxicological database that contains information on human exposure, industrial hygiene, emergency response methods, environmental fate, regulatory requirements, nanomaterials, and other topics. [27]

For Sulfur waste treatment

Limestone (a compound of calcium and magnesium carbonates), hydrated lime (calcium hydroxide), and quick lime (calcium oxide) are acid neutralizing agents that can be used in sulfur waste treatment. Other acid neutralizing agents, such as sodium hydroxide, that might raise soil pH above ideal agricultural or forestry production levels or cause soil structure degradation should not be utilized in a sulfur waste management program.

The general approach to heap and dump rehabilitation of copper leaching are:

If the appropriate lixiviant levels are not achieved by natural degradation, leached ore is rinsed with circulation of water (or particular solution) at the end of each completed leaching cycle of a heap or dump. First step toward to close spend dump or heap from copper leaching is to make sure to check soil contamination and groundwater purity condition. In case of there was considerable amount of leakage to the underground and sulfuric acid reached water table it is important to find acid trails which lead to this problem and block those trails. Dewatering and drainage measures are to be taken in that case (e.g., groundwater pump and treat system combined with re-circulation process). This would typically include installing a leachate collecting and treatment system. Field examinations of soil and water should be performed if feasible by a sufficiently qualified and experienced environmental expert to offer an early indication of the presence of acid.

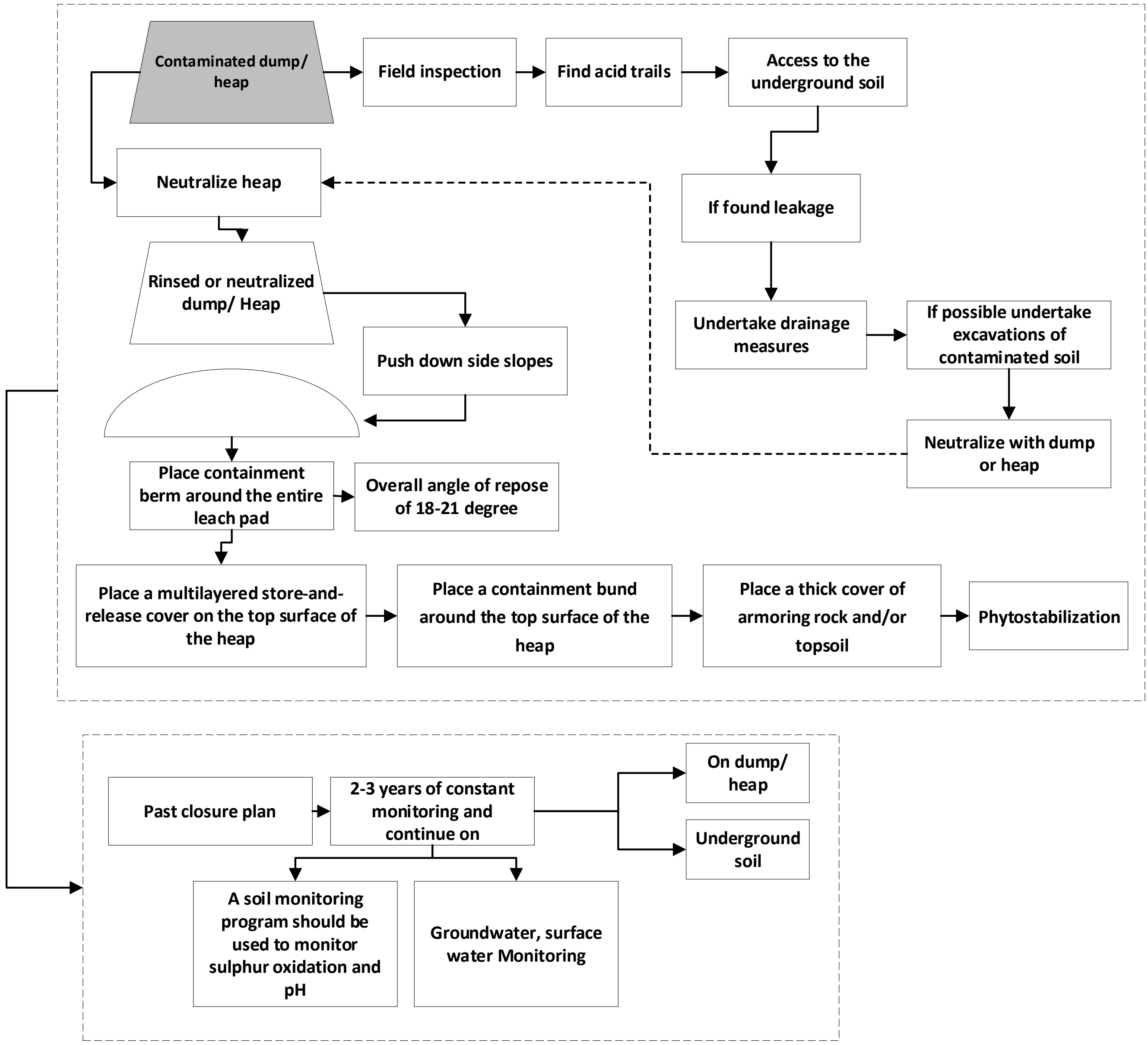


Figure 28: General approach for dump/heap rehabilitation

To neutralize acidic condition in the heaps or dumps, neutralizing agent such as limestone, hydrated lime, or quick lime should be used. When sulfuric acid and these agents are mixed, the acid is neutralized and calcium sulphate (gypsum) is formed by the following reactions:

$H_2SO_4 + CaCO_3 \rightarrow CaSO_4 + CO_2 + H_2O$

$H_2SO_4 + Ca(OH)_2 \rightarrow CaSO_4 + 2H_2O$

$H_2SO_4 + CaO \rightarrow CaSO_4 + H_2O$

Gypsum is only slightly soluble in water, so soil salinity issues are unlikely. Limestone, on the other hand, can contain magnesium carbonate, which dissolves in the acidic environment produced by sulfur oxidation. Because of the increased salinity, the acid neutralization reaction products would include magnesium sulphate, which is much more soluble than gypsum and can cause soil productivity and groundwater contamination problems. As a result, a limestone product used to counterbalance the acidifying effects of sulfur oxidation should contain no more than about 2% magnesium[28]. Limestone must be applied to the dump and heap at a rate equal to 3.2 times the weight of sulfur in the material and incorporated to the depth of contamination. For its superior acid neutralizing efficiency, finely ground limestone is preferred over coarser products; however, site management issues such as trafficability and dusting with high winds may negate using a finely ground limestone product. The limestone used for this purpose should be finely ground so that at least 90% of the weight passes through a 60-mesh sieve. A laboratory study that involved leaching a sulfuric acid solution through columns of limestone product revealed that a significant margin of safety is provided as long as a significant content of fine particles is present. Removing particles that pass through a 60-mesh sieve increased percolation rate and jeopardized pH control.[28]

Following neutralization, side slopes with an overall angle of 18-21 degrees are targeted for repose to prevent dump or heap collapse and to stabilize terrain, depending on regional environmental guidelines[30]. Some jurisdictions may mandate "geomorphic reclamation," which involves contouring the dumps to match the surrounding terrain. Additionally, if necessary, a containment berm around the entire leach pad/pond footprint is recommended to prevent surface runoff penetration and the release of possibly polluted solutions. Dump or heap capping option is now more commonly accepted method for rehabilitation. The top surface of the dump/heap can have a multilayered cover layer made up of waste rock fill, sand, compacted clay, geosynthetic clay liner, topsoil, and vegetation. A containment bund is built around the top surface of the heap to limit the possibility of side slope erosion from surface runoff. Phytostabilization[6] is particularly applied to ore mining waste heaps. Thick cover of topsoil with vegetation high organic matter and stabilizing grasses (Agrostis tenuis, Agrostis capillaris, Festuca rubra) are planted to stabilize the heaps and to prevent erosion and deflation of the material contaminated by copper, lead, and zinc[23]. Furthermore, plantation of waste heaps/dumps is used to reduce water percolation after uncontaminated material is disposed of. In general, phytostabilization is applicable to every soil type but is most effective for cohesive soils with organic matter.

5.3 Possibilities of cover system (rooftop, capping, pond cover)

Pond overflowing is a problem that can occur in regions with high annual precipitation, especially because the leaching phase is much longer and slower, and it could take many years to properly recover precious metals from the heap/dump. PLS pond, barren pond, and stormwater pond all have a wide catchment area. The cover system could be one of the possible solutions to the pond's overflow. Covering ponds used in the leaching process is far more feasible than attempting to cover the surface of a hole heap/dump. Even if many retractable roofing systems and roof truss designs are used in the world's major

[6]Phytostabilization is establishing a plant cover on the surface of contaminated sites with the goal of reducing pollutants' movement within the vadose zone by collection by roots or immobilization inside the rhizosphere, hence reducing off-site pollution.[32]

stadiums, the cost of construction would be unimaginable for the companies. However, there have been numerous cases when mining corporations and other businesses used floating cover systems to control evaporation. Furthermore, in the heap leach business, raincoat liner is becoming used for successfully covering huge heaps and dumps.

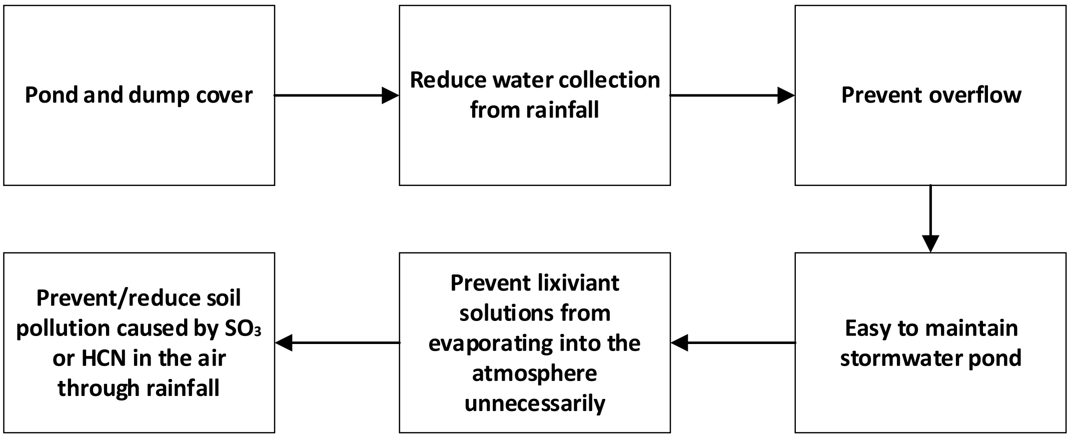


Figure 29: Advantages of cover system

Raincoat liner

Raincoat liner (RCL) is a temporary exposed geomembrane cover (EGC) used in the mining heap leach industry to prevent rain stormwater infiltration into the ore heap fill and divert cover surface storm runoff to natural drainages. Raincoat liners were first used in the late 1980s on gold mining heap fills in Costa Rica [20] to allow continuous heap leaching in a very high-rainfall climate. Cover provides following advantages:

- Improved handling of surplus water balances
- Reduced dilution of process solutions for better metal recovery
- Reducing reagent usage in recirculated barren solutions.
- Reduced the risk of accidental spills caused by high storm pond water accumulation.
- On/off installation flexibility

5.4 New approaches in environmental protection

5.4.1 High alkalinity ponds to stop acid sources

Building a high alkalinity pond on top of the dump would be an easy way to neutralize the acid leaching solution. This requires little equipment and is simple to implement. Chemical treatment with alkalinity-delivering compounds can aid in the re-vegetation of acidic heaps. To neutralize groundwater, high-alkalinity ponds are recommended. They enhance alkalinity infiltration into the acidic soils (ore) by having limestone on the bottom.

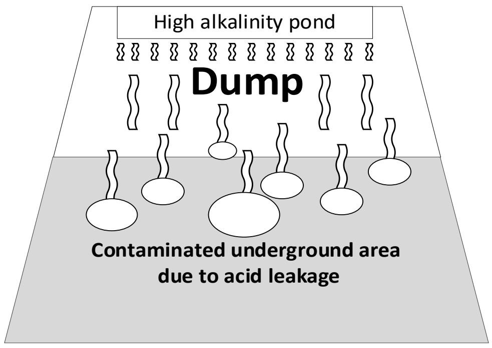


Figure 30: High alkalinity pond on top of acidic dump

5.4.2 Model hypotheses: leakage calculation

As previously stated, even if an impermeable pad is built beneath the heap/dump, there is still the possibility of leakage from the dump/heap, whether due to a rupture in the geomembrane sheet or the clay layer's inability to entirely insulate from underground. Unlike the modern versions (heap leaching) which have an impermeable layer, dumps typically do not have a preceding base implementation. When there is no geomembrane sheet, only clay layer is acting as a natural stopper to the leakage, while slotted pipes or drainage are collecting pregnant leach solution at the base of dump. Due to the reason, dumps are more vulnerable to the leakage of leaching solution. In theory it may be possible to calculate volume of leakage from heap by developing formula using mass balance equation concept.

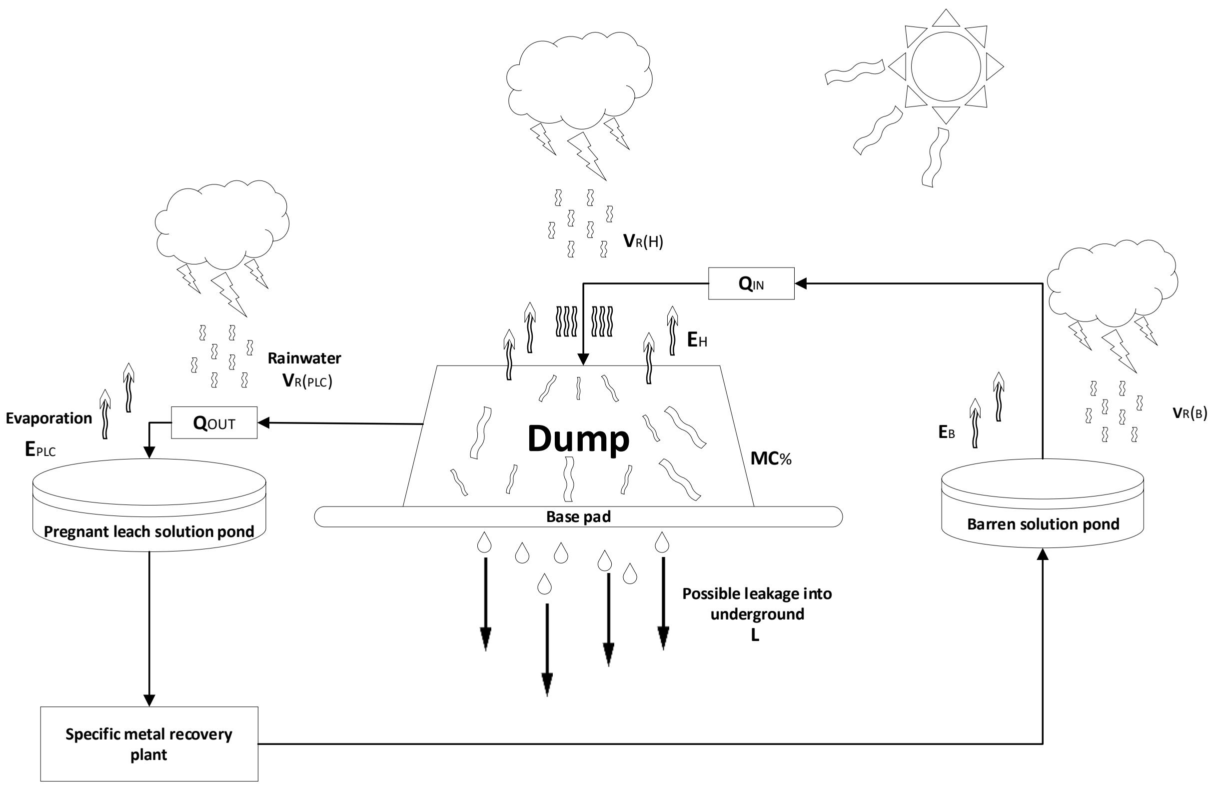


Figure 31: Illustration of the liquid cycle on a dump/heap

Calculating possible leakage from Dump:

$L = Q_{IN} + Q_{R(H)} - (Q_{OUT} + E_H + \Delta MS\% * M_H)$ —›From Figure 31

L=Leakage flow rate into underground, **Volume/Time period**

Q_{IN}= Flow rate of solution (lixiviant) introduced into heap/dump from barren pond, **Volume/Time period**

Q_{out}= Flow rate of mineral rich solution collected from heap/dump into pregnant solution pond, **Volume/Time period**

$Q_{R(H)}$=Quantity of rainwater collected from rainfall in the heap/dump, **volume**

$Q_{R(H)}$=Rainfall * surface area of heap/dump

E_H=Volume of evaporated liquid from heap, **Volume/Time period**

M_H= Heap/dump mass

ΔMS%= Change in moisture content of heap/dump, **unitless**

Main concept of this equation is that liquid volume difference between in and out of dump/heap can be considered either leaked into the underground or saturated in the dump or heap. When saturated, the moisture content of the dump/heap is typically in the range of 10-15 percent by weight. Solution equivalent to 10 percent of the weight of the dump/heap may be required to wet the dump/heap, and an additional 10 percent may be stored in the dump/heap during steady state leaching. Hence, when dump/heap is saturated calculation of moisture content can be negligible for further calculations after a month or so. Thus, equation simplified to:

$$L = Q_{IN} + Q_{R(H)} - (Q_{OUT} + E_H)$$

Total volume of water entered the dump/heap by rainwater is rather easy to calculate. It is simple to collect rainfall data from a weather forecast or to use a standard instrument (rain gauge) to record the amount of water in the cylinder wall in millimeters when it rains (the most common rainfall data measurement is the total rainfall depth during a given period, expressed in millimeters). When the total surface area of the dump/heap is known, the total volume of rainwater receipt in the heap/dump is computed as follows:

$Q_{R(H)}$=Rainfall (mm) * surface area of heap/dump (m^2 or km^2)

From a technical standpoint, the flow rate of solution received to PLS pond from heap/dump and flow rate of solution sprayed to dump/heap from barren pond are key factors in the calculation for a certain period (a week, month). The challenging factor would be calculating the volume of evaporated liquid from heap/dump throughout the selected period and determine the surface evaporative capacity. To determine evaporation capacity, carried out on the site experiments may require and recommended.

Leakage calculation of circular defects from single-composite liner (geomembrane):

The equations below can be used to determine leakage in circular defects with diameters ranging from 2 to 20 mm, as well as bigger situations such as 100-600mm[24].The base layer is made up of a geomembrane liner and bedding soil, with the liner and bedding soil in good contact.

Table 16: Calculation equations for leakage caused by defects in the geomembrane liner.[24]

Case of circular defect size ranging from 2-20mm	$\boldsymbol{Q = 0.21 * h_w^{0.9} * a^{0.1} * k_s^{0.74}\left(1 + 0.1\left(\frac{h_w}{H_s}\right)^{0.95}\right)}$
Case of large circular defect size ranging from 100-600mm	$Q = 0.64 * h_w^{0.8} * a^{0.18} * k_s^{0.77}\left(1 + 0.1\left(\frac{h_w}{H_s}\right)^{0.027}\right)$
$\boldsymbol{Q}$ = Flow rate, **m³/s**	
$\boldsymbol{h_w}$= Hydraulic head on top of geomembrane, **m**	
$\boldsymbol{a}$ = Circular defect area, **m²**	
$\boldsymbol{k_s}$= liner bedding soil hydraulic conductivity, **m/s**	
$\boldsymbol{H_s}$ = liner bedding soil thickness, **m**	

All the parameters in small defect size equation are typically affected by uncertainties. Variations in liner bedding soil hydraulic conductivity will be mostly dependent on local variables in terms of uncertainty. Evidently, in order to provide estimates of expected ranges of variation, it is vital to rely on local data as well as professional judgment when calculating soil hydraulic conditions.[24]

5.4.3 Vitrification

In general vitrification is turning substance into glass by heating to high temperature and cooling down rapidly. Furthermore, in geo-environmental engineering, soil vitrification is a method that embeds the waste to glassy form preventing hazardous material from leaking out. Like original method it requires high temperature to melt the soil then refrozen into glass-like solid. Since the glass-like solid is chemically inert and has minimal leaching characteristics, it performs exceptionally well in separating waste from the environment. As a result, soil vitrification is a frequently utilized approach for treating hazardous and radioactive waste[22].Soil vitrification is applicable to any type of soil; however, it is not usually used on soil with high water content, since this would make the procedure more expensive. Water must be evaporated before the vitrification process can begin in damp soil. In case of *in-situ* vitrification electrodes are inserted into the soil in $1m^2$ and heated electrically by generators by temperature ranging between 1,000°C-1,800°C[23]. It would be more difficult if dump or heap ore contains too many voids . To collect and treat the gas produced by high temperatures, a gas-effluent treatment system is necessary. To allow the current to flow through the soil, there must be sufficient monovalent alkali cations to provide needed electrical conductivity. If the soil does not meet the requirement, fluxing materials containing cations should be added to the base material such as sodium silicates, borosilicates, sand, limestone, and dolomite stone.

Due to its effectiveness to seal contaminants and produce glass layer, its application for rehabilitation of dump or heap leaching is certainly not absent. This method can be one of the cover measures of dump or heap after leaching is done and possibly after rinsed. For sealing the dumps from ground beneath to prevent toxic saturated leach solution. The maximum soil depth for vitrification is roughly 10 meters[23], which means it cannot be used to seal the base of a dump from underground in its current state because most dumps are much higher than 10 meters. In the case of dumps, the applicability depth of this method is a drawback; instead, electrodes can be introduced sideways at an acceptable angle and vitrified at the dump's base to access the ground beneath and circled around to seal as much possible area (the dump base's center may be left without a seal).

Bigger disadvantage would be collection and treatment of produced off-gases from surface combustion can challenging and requirement of high energy. The drawback of this technology's unknowns is it that for this technology the special equipment is necessary and in often case rarely available.

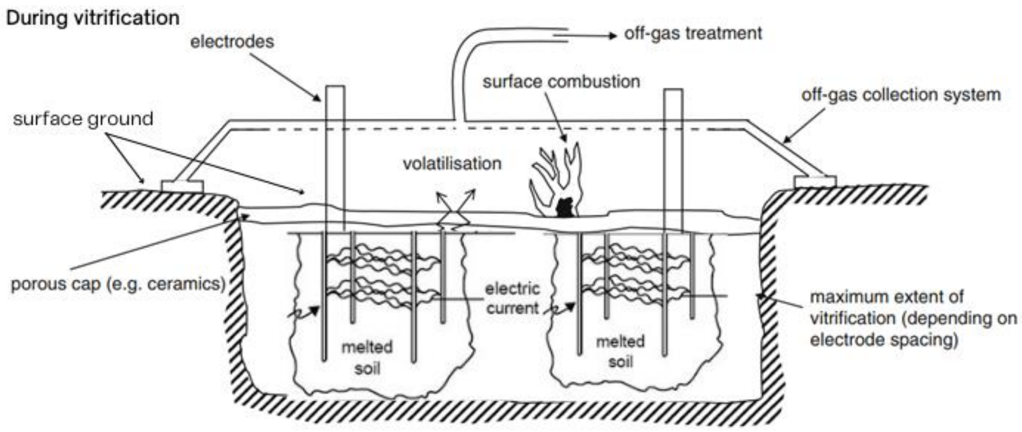


Figure 32: Scheme of vitrification [23]

6. Discussion / Conclusions

This thesis represents the study on environmental impacts of dump and heap leaching of copper and gold ore. The study was conducted via investigation and review of the literatures. Both negative and positive effects are studied, but main focus was to list possible negative environmental impacts. To evaluate risks of such impacts, Failure Modes and Effects Analysis method is used. Unlike traditional risk assessment matrices, more sophisticated 3 parameter computation was available, and modifications were made as needed. By evaluation, the most predominant problems concerns for dump leaching method were seepage of harmful leaching solution into subterranean and soil acidification. Because, unlike modern heap leaching, the lack of a geomembrane layer makes it more susceptible to leakage.

From research, it was clear to see that treatment of cyanide dump or heap leaches was more developed than leaching by sulfuric acid. Nevertheless, practical sulfuric acid dump leach treatment and reclamation strategies are described in this study by neutralizing the acidic condition of the dump/heap using limestone, followed by dump/heap capping techniques with Phytostabilization. Additionally high alkalinity pond on the top of dump for easy and inexpensive approach is for neutralization is recommended for further consideration. To treat the cyanide, from simple rinsing dumps/heaps to more complex techniques such as alkaline chlorination and sulfur dioxide processes and as well as natural degradation and biological treatment of cyanide is also discussed. Complex techniques can treat both spent cyanide solutions and dump/heap rinsate solutions and slurries.

Aside from Achit Ikht LLC's dump leaching, there are no other dump leaching operations in Mongolia because it is prohibited. However, heap leaching is becoming more popular in Mongolia (e.g., the ATO project from Steppe Gold LLC, the Boroo Gold Heap leaching project, and the latest heap extension of Achit Ikht LLC) and is expected to grow. These big leaching projects featured well-monitored environment and geomembrane layers to avoid solution leakage to the ground. Geomembrane can be defected from usage and high pressure from ore can puncture holes in the geomembrane sheet. There are equations available to calculate flowrate of leakage from defected hole depending on the diameter. For dumps with no geomembrane sheet, using mass balance of equation, it is possible to determine how much solution is losing from the dump and it is covered in section 5.4.2. Module hypothesis.

Recommendation

If permit it is possible to make 3D Modeling of contaminated site from leaching operation by using several dozen soil samples data. The model will help to determine the source of the chemical spill, visualize the horizontal and vertical extent of contamination at multiple different remediation objectives, and calculate the mass of the various contaminants. Simmakers Ltd, C Tech's Earth Volumetric Studio, and Voxler 3D modeling are examples of software that produces and delivers services in the field of environmental modeling computer simulation.

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