Tailings Co-Disposal™

Innovations for Cost Savings and Liability Reduction

By Marc Leduc, P. Eng.[i]

Mark E. Smith, P.E.[ii]

INTRODUCTION

Tailings co-disposal™ is a novel concept for the containment and disposal of mill tailings. The method utilizes the void space in mine waste rock for the disposal of the fine grained tailings. Because waste rock is commonly a course, run-of-mine product created from blasting of hard rock, there are large voids created when the waste is placed in a waste dump. When applied to competent waste, these large void spaces make a perfect place for the placement of tailings. Clayey and sandy wastes may not be suitable for this technology, depending on the gradation, ratio of waste-to-tailings and, ultimately, the available void ratio.

TAILINGS CO-DISPOSAL™ TECHNOLOGY

There are many ways to accomplish mixing of tailings with waste rock and each should be evaluated to determine their feasibility at a given site. The first step is to evaluate the tailings and waste rock to determine their suitability for use in co-disposal. Below is a list of tests typically used to evaluate the materials.

- Shear strength tests of different tailings to waste blends, including tailings and waste alone (to set lower and upper boundary values),
- Gradation of waste rock (typically requires laboratory testing below a practical size limit plus a field estimate of the discarded "oversize" fraction),
- Gradation and consolidation of the tailings,
- Permeability tests of tailings and tailing-waste blend ratios,
- Drained moisture content of tailings and blend ratios,
- Permeability at various simulated dump depths for different blend ratios,
- Unconfined compressive strength of tailings mixed with cement or other binder (to evaluate the potential to increase the ratio of tails-to-waste or otherwise enhance stability, if applicable),
- Chemical leaching tests such as TCLP or humidity cells,
- Whole rock chemistry and acid-base accounting.

The purpose of this testing program is to characterize the geotechnical and geochemical properties of the material and examine how the material will behave in different waste dump scenarios. This is only a first step of "screening" level testing.

Additional and more complex tests will be required as the evaluation process continues towards detailed design.

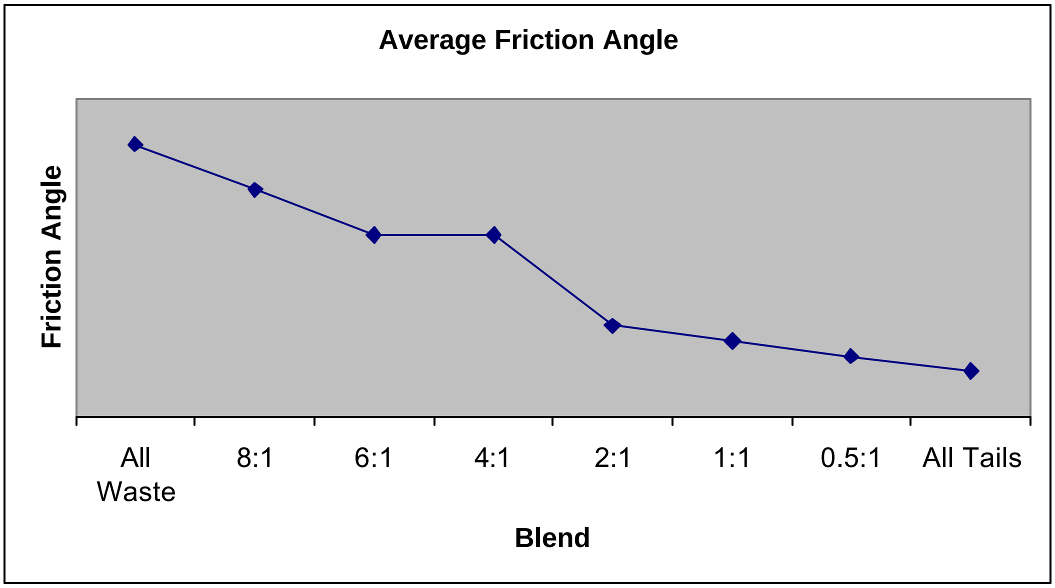

Figure 1 – Variation in angle of friction with blend ratio

Typically (and intuitively) the strength and permeability tests will show a relationship between the ratio of waste -to-tailings, with both approaching the values for tailings alone at very low ratios. What is of particular concern is if and where there is a sharp reduction in either parameter with an incremental reduction in waste, showing that the mix starts to behave more like tailings than waste rock. Figure 1 shows a typical variation in friction angle with the different blend ratios that one might expect. The typical relationship of permeability to blend ratios is shown in figure 2. For this particular material, a 5 order -of-magnitude reduction in permeability was realized. Based on figures 1 and 2 the limiting blend ratios would be 2:1 based on permeability and 4:1 based on strength, indicating that only waste -to-tailings ratios of 4:1 and higher (more waste) should be considered.

Liquefaction of waste dumps is a critical concern and predictive modeling of flow slide susceptibility is an emerging technology. Given the potential for catastrophic flow slide failures, evaluation of issues such as permeability, degree of saturation and residual shear strengths must be consi dered in any dump deign but is especially important for co -disposal schemes. Taking all of these various factors into consideration, table 1 provides a guide for determining if co-disposal should be considered as a project option.

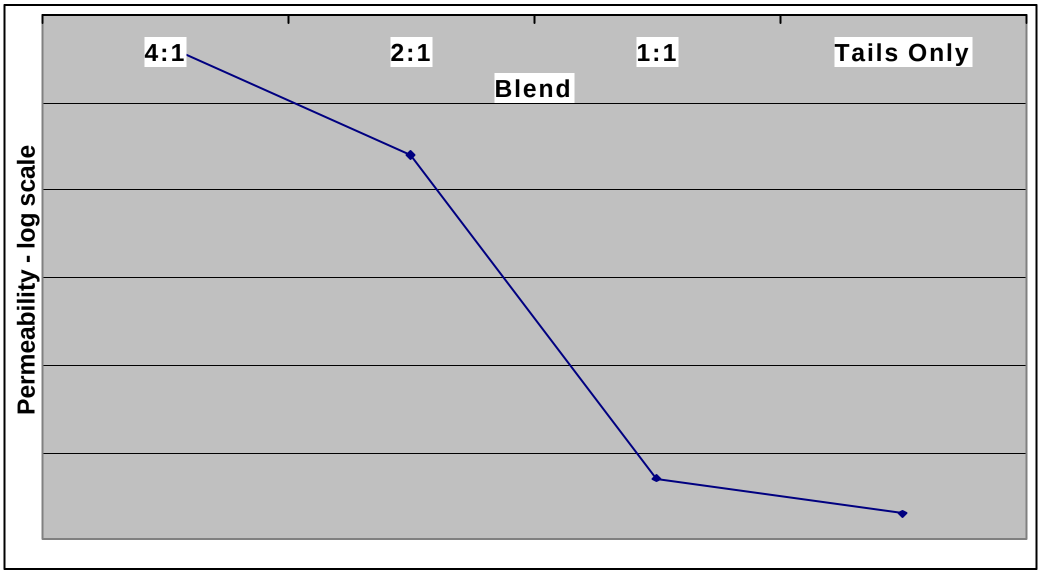

Figure 2 – Variation of permeability with blend

OPTIONS FOR TAILINGS CO-DISPOSAL™

There are several (possibly endless) ways to commingle tailings with waste rock. Presented below are some of the more obvious methods:

1. Placing the tailings in discrete ponds or layers in the dump, which can then be buried as new lifts of waste are placed;
2. Blending the waste rock and tailings together to make a relatively homogenous material – either by blending in a haul truck, on a conveyor belt or by mixing at the dump crest;
3. Injecting the tailings as a paste or thickened slurry into the waste rock dump, either by drilling holes for injection or simply installing injection lines along the working face for use after the dump has advanced; and,
4. Placing a thin veneer of tailings on the face of the dump and allowing the tailings to infiltrate into the dump and dry, then the veneer can be covered by another layer of waste rock.

The analyses summarized in this paper focus on how each method will perform. The stability of mixed waste and tailings has been examined, as well as the performance of each method with regards to environmental issues such as drain water quality and production of acid rock drainage (ARD).

Table 1: Suitability for co-disposal based on waste-to-tailings ratios

Waste-to-Tailings Ratio	Suitability for Co-disposal
Greater than 8:1	Probably suitable for co-disposal
Between 4:1 and 8:1	Requires significant testing and detailed analysis to determine suitability
Less than 4:1	Probably not suitable for co-disposal

Tailings placed in discrete ponds within the waste dump

One way to create this configuration is to build berms that would form discrete ponds, to be filled with tailings. While one pond is being filled, another would be drying and a third would be under construction. Once the first cell is full, the new cell would receive tailings. After a period of time (based on factors such as tailings thickness, solids content and consolidation rate), the next waste lift will be placed over the consolidated tailings. More tailings will be placed in a similar manner on the next lift of waste rock, and so on. A typical cross-section of this configuration is seen in figure 3. For example, consider a system with a ratio of waste-to-tailings thickness of 4:1. Thus, a 5 meter deep tailings pool would be covered by 20 meters of waste. The outer waste zone, near the final face of the dump, would not receive tailings to improve stability, avoid erosion and spills, as well as other water quality issues.

One of the primary advantages of this method is that mobile equipment will not be required for the placement and handling of tailings. However, the major disadvantage is lift stability. If the covering waste lift is placed too quickly or too soon, excess pore pressures can develop in the tailings, possible subjecting the lift to a sudden failure. Thus puts at risk not only the active area of the dump but also equipment and personnel working near the crest.

To overcome the concern of lift failures, cement or some other binding agent can be added to improve the cohesion and short-term strength of the material. For one particular case with no cement and a reasonable rate of waste advance for the 20 m of waste placed over 5 m of tailings, the resulting factor of safety was less than 1.0. All other factors held constant and using a small amount of pozzolanic binder, the factor of safety improves to 1.4 and 2.4 with the addition of 1% and 3% cement, respectively.

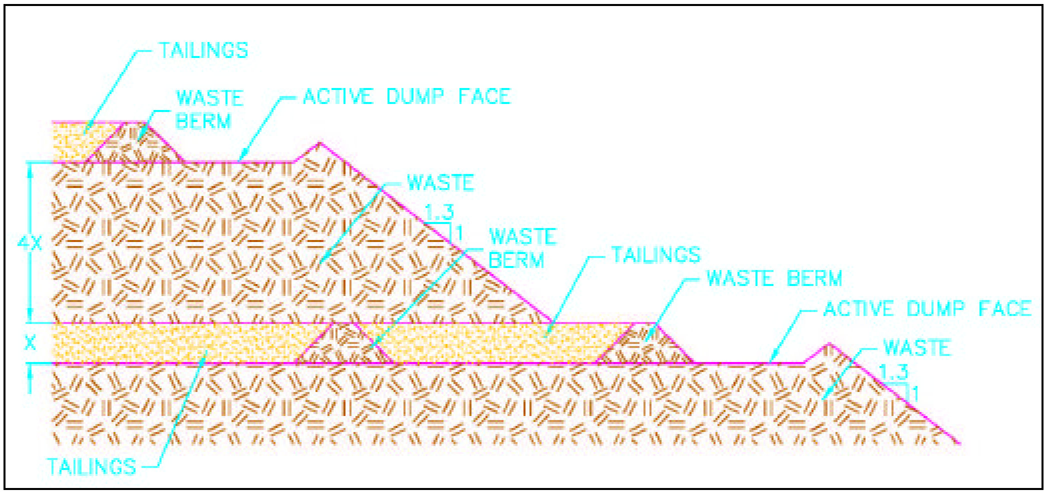

Figure 3 – Ponds of tailings placed in waste dump

For these stability analyses, the conservative assumption has been that there will be no mixing of the tailings with the waste layer. In fact, a considerable amount of mixing could be created if the right geometries and ratios are used, similar to the "displacement method" of placing rock fill over soft ground. In this method, a lift of rock fill is advanced at such a rate and thickness to cause local bearing failures in the foundation. The soft foundation soils then mix with or are displaced by the advancing rock fill, resulting in a considerable increase in strength of the foundation layer.

A beneficial but difficult-to-predict factor comes about because much of the tailings placed in the ponds will infiltrated into the body of the waste dump. This phenomenon has been documented in pilot-scale field trials. This infiltration effect could be increased by proper berm and bench construction, by pre-ripping of the base of the pond, and by controlling the slurry density.

Advantages

- Mobile equipment does not come in contact with the tailings;
- Lowest operating and capital costs of all options presented in this paper;
- Straightforward disposal method requiring no additional equipment; and,
- No additional mobile equipment is required for placement of tailing in the cells.

Disadvantages

- Slow dump face advance (to allow proper consolidation) means that the dump locations must be carefully planned and there may be a reduction in flexibility in the management of the dump;
- If a section of the dump is advanced too quickly there could be a failure in the dump face, possibly resulting in a serious accident;
- Scheduling of tailings cell construction must be closely coordinated with dumping.
- If cement were needed for stability, this would add to the operating cost; and,
- Exposed ponds might become sources of dust or erosion (less so if a binder is used).

Blending tailings with waste rock at the dump face

Three methods of blending have been considered:

a) Mixing at the face by placing both tailings and waste rock near the crest of the active dump, then pushing both over the face with a dozer;
b) Place the tailings in a haul truck pre-loaded with waste rock (for example, with a load-out silo) and then dump the un-mixed material at the dump face; and,
c) Mix the waste and tailings together on a conveyor belt. This would only be feasible if the mine transported the waste by conveyor.

There are advantages and disadvantages common too all three methods, summarized as follows. The first method is illustrated in figure 4, the others are self-evident.

Advantages

- The blending is thorough and homogenization of the material can be controlled and verified;
- Highly flexible dump sequencing;

- Straightforward method of mine waste placement requiring only slight coordination between the tailings discharge and the waste rock placement; and,
- Better mixing decreases stability issues, making it l ess likely that cement will be required and allowing lower ratios of waste-to-tailings.

Disadvantages

- Mobile equipment will come into contact with the tailings. This may result in considerable carry-back of tailings, which may be prohibited due to environmental restrictions, especially for cyanide tailings;
- Possibly extra dozer or truck time required, increasing haulage costs and capital investment in mobile equipment; and,
- Special equipment (and possibly additional personnel) required to add tailings to the trucks or conveyor belt.

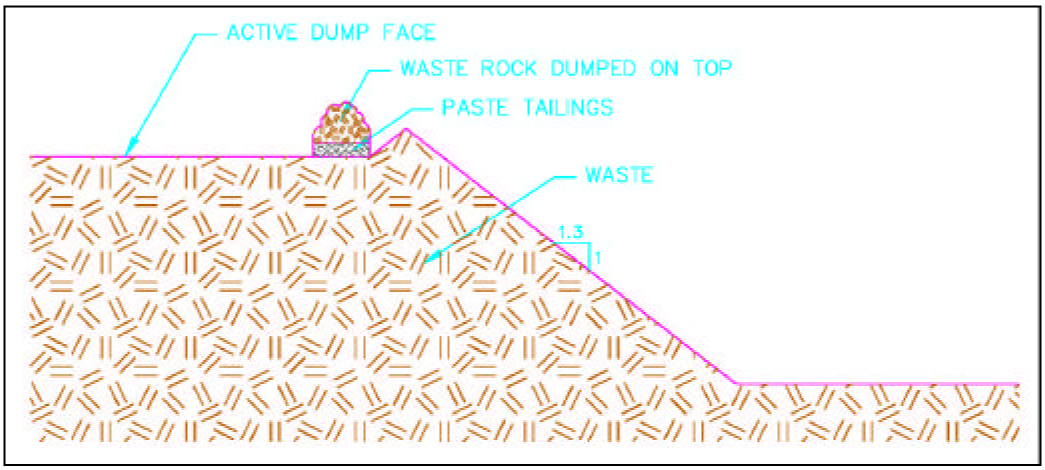

Figure 4 - Mixing of tailings and waster rock at the face

Injection into the waste dump

The injection method involves charging the paste or thickened tails into the body of the waste dump through perforated pipes. Research suggests that the best way to achieve this is to place pipes on the dump face and then cover them with waste. Once the dump face has advanced sufficiently, the pipes in the dump will be connected to the tailings distribution system and tailings will be injected into the body of the dump. This method is illustrated in figure 5. If this method is not feasible (such as with old waste dumps) then pipes can be installed by drilling and casing vertical holes (figure 6).

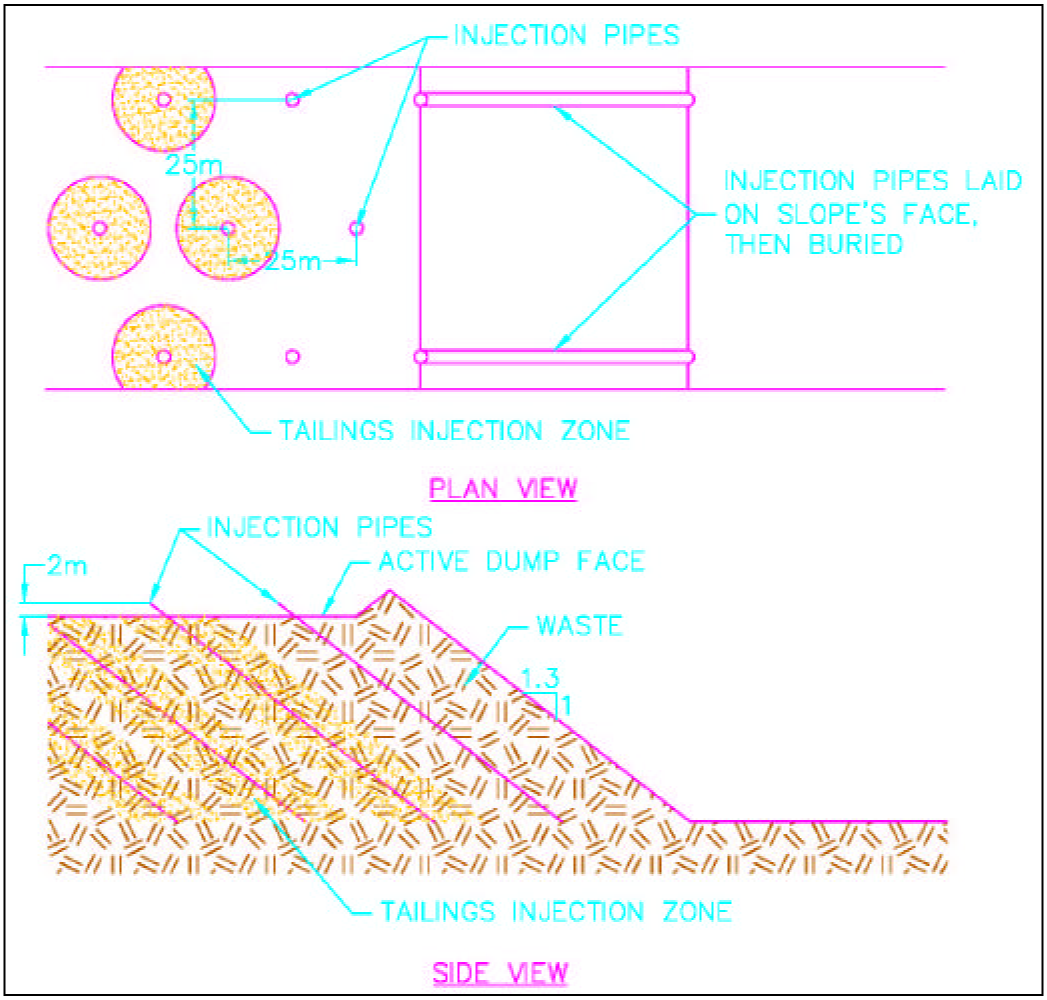

Figure 5 – Injection by a pipe initially placed on the advancing dump face

Initial studies of tailings rheology and typical coarse waste rock gradations have indicated that tailings – for this particular project - will penetrate radially as much as 30 meters into the body of the dump. In underground mines in Canada where paste tailings has been injected in rock fill, 10 meters of tailings penetration has been achieved.

Injecting the tailings into the dump has the following advantages and disadvantages

Advantages

- Mining equipment does not come in contact with tailings;
- Operating cost should be very low with only the cost of pipe and the labor to connect piping system;
- Straightforward method of mine waste placement requiring no additional mobile equipment;
- Zones of low waste -to-tailings ratios will be away from the dump face; thus, lift stability is easily assured;
- Flexible dump sequencing;
- Ability to use the available void space in old dumps; and,
- Cement usage would be reduced or eliminated; though (as in all co -disposal situations) cement addition may be warranted to achieve higher strengths and reduce possible environmental contamination from ARD or leaching of the tailings.

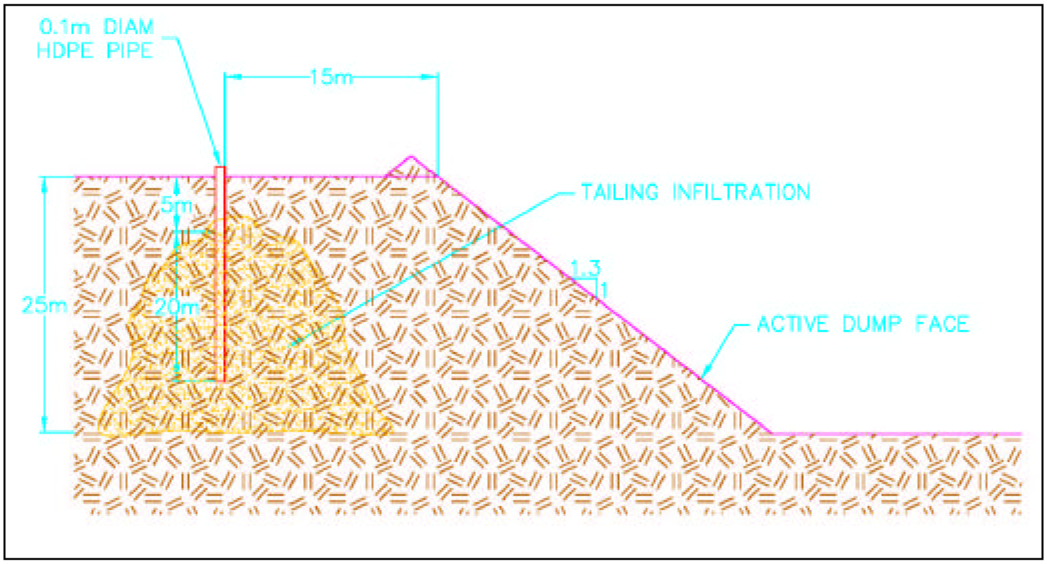

Figure 6 – Injection of tailing in a drilled vertical hole

Disadvantages

- This technology is yet to be tried at full scale. However, it combines paste tailings and slurry injection technologies, both of which are well established and well accepted;
- May require costly high pressure piping to achieve desired penetration of tailings;

- Pipes will need to be guarded prior to use so they are not damaged by haul traffic; and,
- Injection will need to be monitored so that an over pressurization of tailings does not cause instability.

Applying a veneer of thickened tailings on the waste face

This method involves placing a thin veneer of paste or thickened tailings on the waste rock face and then allowing the tailings to infiltrate into the waste. After a short period of time (hours to days depending on the tailings and waste rock), the veneer will be covered by another layer of waste rock. Figure 7 shows a cross-section of this method. The tailings layer might be 200 to 500 mm thick and the waste would be 1 to 5 m thick. The veneer would be placed on the face by installing a perforated discharge pipe, channel or launder along the top of the face and allowing the tailings to slowly be discharged down the slope. The width of the application area is dependent on the dump face height and the rate of tailings production. In most cased the disposal area will be moved on a daily basis.

Since the tailings layers are very thin, the concerns about excess pore pressure generation in pooled tails are essentially eliminated. Also, a considerable infiltration of tailings into the waste is anticipated (as verified by field scale pilot tests). Further, since the individual rocks in the waste are very large relative to the thickness of the tailings, there should be a significant amount of interlocking between layers, above and below the veneer of tailings, reducing the destabilizing effect of the weak layers.

Thin layering of tailings on the waste face has the following advantages and disadvantages.

Advantages

- Mining equipment does not come in contact with tailings;
- Visual monitoring of system allows reliable quality control;
- Straightforward method of mine waste placement requiring no additional mobile equipment;
- No high pressure pumps required to inject the tailings; and,
- Cement needs are reduces or avoided.

Disadvantages

- Other than in pilot tests, this is an untried system with combines paste tailings and slurry injection technologies in a unique manner;
- Application area must be guarded so that haul truck traffic does not damage piping;
- There could be uneven application that could cause flowing of material to the toe.
- If a thick layer of tailings is applies there could be pore pressure buildup and resulting instability;
- In rainy conditions the tailings veneer may be washed off the face; and,
- Sedimentation controls will need to be incorporated into the design of this management system to accommodate the possible washing off of tailings from the face.

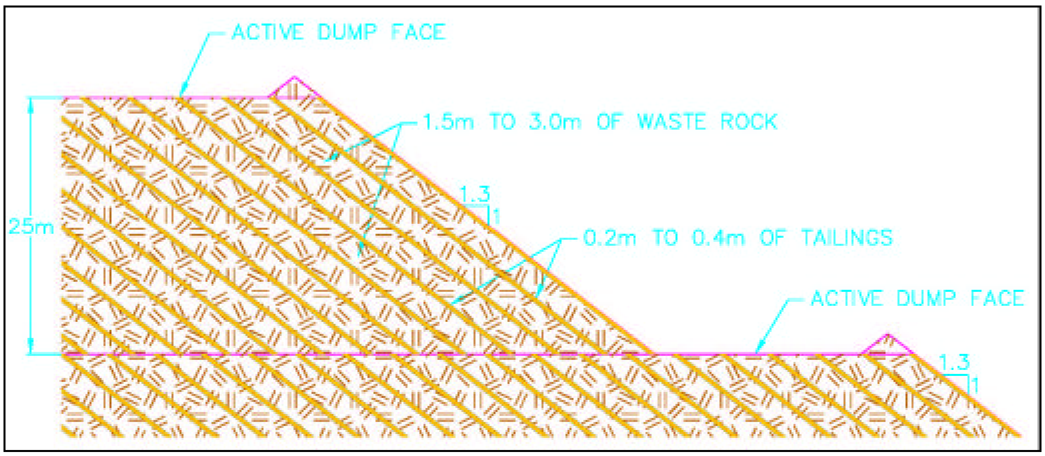

Figure 7 – Layering of tailings on the dump face

COST IMPLICATIONS OF TAILINGS CO-DISPOSAL™

Each installation requires consideration of the site-specific conditions, including especially mine planning, waste characteristics, geotechnical parameters and environmental factors. An economic trade-off study should be undertaken to compare co-disposal options with other tailings management methods, such as a convention tailings impoundment, underground backfill, and so forth. The study should take into account other benefits of co-disposal such as water conservation, reduced closure costs, reduced land use and especially possible reductions in long-term liabilities.

Table 2 presents a summary of "rule of thumb" costs for the two most common tailings impoundment configurations as recent project estimates for co-disposal. In addition to be competitive with the most efficient impoundment options, significant advantages come from savings associated reduced amounts of disturbed area, closure and post-closure liabilities.

Another advantage is at sites where water supply costs are high. In these cases, much of the cost associated with producing a thickened tailings slurry can be offset by savings in water demand. Related benefits accrue at sites with net water gain scenarios (such as in tropical locales) where elimination of a tailings impoundment could also switch the project water balance to a "no discharge" situation – saving considerable amounts for capital and operating and also improving project acceptability to communities and regulatory authorities.

Table 2 : Typical tailings disposal costs including capital and operating

Disposal Option	**Typical "All-In" Costs** US $ / tonne of tailings
Cyanide Gold Tailings: Compacted fill embankment, downstream construction, geomembrane impoundment liner	$0.50 to $1.20
Copper Sulfide Tailings: Starter dam plus cycloned tailings for centerline raises. No liner.	$0.20 to $0.50
Co-disposal with waste rock	$0.15 to $0.50

ENVIRONMENTAL BENEFITS

Perhaps the most important benefit of tailings co-disposal™ is elimination of the tailings impoundment and dam. Because of the well-publicized problems with tailings containment systems and the sensationalistic press coverage of recent failures, there are considerable benefits to eliminating tailings impoundments and dams from new projects. It is possible, perhaps likely, that in the future many regulatory agencies – as well as corporate shareholders – will greet co-disposal with more acceptance then conventional tailings management systems for a wide range of conditions

Another advantage to co-disposal manifests in ARD mitigation. Tailings make the perfect carrier for additional alkalinity. When this alkalinity is in the form of a "binder" such as lime, cement or fly ash, the result can be effective encapsulation of the sulfide minerals or creation of internal containment cells for isolation of the higher ARD potential rock. Cement encapsulation of mobile metals is a well established technology in hazardous waste remediation. When applied to mine waste management, it should be well received by regulatory agencies.

In high wind dry environments a co-disposal system can also reduce the potential for fugitive dust emissions. Regardless of the mixing system, there will simply be a smaller area of tailings exposed to the wind. Thus, there is a reduced source of dust during both operations and post-closure. In addition, if a binder is used then the exposed tailings may not be a dust source at all

At closure, the tailings can be used as part of a cover system that will reduce the amount of water that will infiltrate into the dump. This could prove to be a substantial savings, eliminating the requirement for a synthetic or compacted clay capping system. For example, if cement is added the dosage could be increased during the final months of operation. This could be used as a "soil cement" for final capping, either over the entire dump or only in those areas proving to be problematic

The environmental risks of this technology stem from the addition of water to the waste dump. In some circumstances this simply may not be wise, but in many circumstances the amount of water is either negligible (as in the case of paste applied in a very high waste-to-tailings ratio), beneficial (as in alkaline tailings to an ARD waste), or a neutral effect (such as tailings to an inert waste).

EXAMPLES OF CO-DISPOSAL SYSTEMS

While co-disposal can be considered a new technology, it is also a reapplication of existing technologies. In one form or another, these methodologies have been applied in many situations. What is new is considering those separate technologies in a holistic manner. Some examples of the application of thickened or paste tailings with surface disposal, as well as fledgling co-disposal projects, include the following.

Antamina, Ancash, Perú – This mine co-disposal of lake sediments with the mine waste. The lake sediments are a saturated silt with physical properties nearly identical to tailings. Both concurrent face tipping and isolated pooling (both in the upper reaches of the dumps) have been used successfully.

Minas Congas, Cajamarca, Perú – A feasibility study showed that co-disposal of mine waste and dredger tailings (organic soils and lake bed sediments) was both economically and technologically feasible. Co-disposal would be accomplished via concurrent face tipping or slurry discharge at the active face of the waste dump.

Esquel Project, Argentine Patagonia – Tailings co-disposal™ with both face discharge and injection of thickened tailings has been selected as the preferred option from the feasibility study. Permitting is in process and the regulatory agencies view the absence of a tailings impoundment as a significant benefit.

Pulp Agglomeration – Various Sites - This is a system of blending tailings with heap leach ore and then stacking the mixed and agglomerated material on the leach pad. This method has been successfully used at the **Castle Mountain** and **Ruby Hill** mines in California and Nevada, respectively. It also received favorable consideration in the pre-feasibility study for the **Veladero** Mine in Argentina. This process involves secondary or tertiary crushing of heap leach ore. The tailings slurry (or preferable belt filter cake) is mixed with the crushed ore in an agglomerator. The blended material is then stacked on the pad using a conveyor-stacker system.

Bulyanhulu, Tanzania, Africa – Tailings paste is spigotted onto the ground surface from a 12 meter high tower and spread with a 5 degree deposition angle. This method was selected because a paste plant for underground backfill was already planned. Thus, the incremental capital costs were minor. Also, at this location the cost of make up water is high, so use of paste tailings disposal recovered more water, partially offsetting the cost of the paste system. It is also believed that this method will help reduce ARD potential, improve cyanide management issues and reduce closure costs and liabilities.

Kidd Creek, Ontario, Canada - This is a base metal mine which uses a high compression thickener, discharging tailings from a central spigot forming a flat cone of tailings. The tailings are 85% passing a 200 mesh, and obtain a deposited slope of 2.5 to 3%. The placed tailings have a coefficient of permeability of about 1×10^{-7}; thus, any surface water tends to run off the pile rather than infiltrate. They report that the entire *in situ* deposit of tailings has dried and consolidated to 80% solids.

Alcoa TSF, Kwinana, Australia - This operation disposes of approximately 15 million tonnes of residue from the processing of alumna. Because of the proximity to population centers and a desire to reduce possible impacts to groundwater, they adopted a thickened tailings disposal scheme using a super thickener. The tailings are deposited into evaporation beds at 50% solids (by weight) and achieve a final dry density of 70% solids.

CONCLUSIONS

Co-disposal technology promises to replace conventional tailings disposal methods at sites with high strip ratios or plentiful old dumps. While the mine waste needs to be relatively strong and low in fine material, and chemical compatibility must be assured, when these parameters are satisfied there are no other significant hurdles to its implementation. The resulting benefits range from substantial reduction in capital and operating costs to reduction or essential elimination of the short- and long-term liabilities associated with tailings dams and impoundments. Since tailings dam failures are arguably the greatest environmental liability and public relations problem in the industry, reducing the quantity of tailings managed behind dams is a worthy goal.

---

[i] Marc Leduc, P. Eng. is a mining engineer and director of mine services for Vector Engineering, Inc. in their headquarters office, Grass Valley, California (Leduc@vectoreng.com)

[ii] Mark E. Smith, P.E. is a geotechnical engineer and vice president of South American operations for Vector Engineering, Inc., working from their Lima, Peru office (smith@vectoreng.com)

Originally published in *The Latin America Mining Record*, July/Aug. 2003