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Filtered Dry Stacked Tailings – The Fundamentals

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Abstract

Filtered tailings are becoming an increasingly common consideration for tailings management at many mines. There are more filtered dry stack tailings storage facilities than there are surface paste facilities yet the amount of guidance documentation on filtered tailings is virtually non-existent in compare to those same paste tailings facilities. The reason for this lack of guidance materials is uncertain but it has led to some unfortunate tailings management decisions based on misinformation about dry stacked tailings facilities in general.

This paper provides practical guidelines for the design and development of filtered dry stack tailings facilities. These guidelines are based upon the successful conceptualization, design, and operating experience at a number of these facilities. Issues related to target moisture content, appropriate testing methods and criterion, geotechnical conditions and placement considerations are included. The guidelines include specific reference to "lessons learned" from existing operations that will benefit designers and owners alike.

Filtration – End Member of the Tailings Continuum

The vast majority of the world's tailings facilities involve tailings impoundments. These impoundments are developed to store tailings slurry that typically arrives at the impoundment at solids contents of about 25% to 60% depending upon whether any thickening is carried out prior to deposition. These impoundments require construction and maintenance of structural integrity for the retention structures as well as management for what are typically immense quantities of water. Following operating these complex entities, closure of these impoundments can represent significant challenges in terms of both physiochemical reclamation as well as geotechnical considerations.

As the future of mining includes increasing scrutiny on the industry's stewardship of the natural environment, including use of water in most regions in the world, a commitment to alternatives beyond impoundments is often sought. The amount of water that is "lost" to the voids in the stored tailings, seeps or evaporates from the tailings impoundments is something being increasingly viewed by critical regulatory and public eyes that insist on evaluating whether there are viable alternatives for any given proposed mining development. This pressure to seek alternative tailings management approaches exists today and the future will likely only see these pressures intensified.

Conventional tailings impoundments remain the best alternative for the majority of operating and proposed mines around the world. These facilities are developed using tailings slurries that are the end waste product of the milling process. However, with advances in dewatering technologies over the past few decades, that tailings slurry is actually being only part of a continuum of tailings "states" available to the modern tailings designer. Development of large capacity vacuum and pressure filter technology has presented the opportunity for storing tailings in an unsaturated state, rather than as conventional slurry and/or in the "paste like" consistency associated with thickened tailings. For the minority set of projects that can find a non-slurried tailings alternative advantageous to optimal permitting and/or operating conditions, filtered tailings are often an excellent alternative.

Figure 1 shows the continuum of water contents available for tailings management and includes the standard industry nomenclature. With decreasing water content comes increased expense at hauling the tailings (e.g. pumping costs increase and then, upon becoming a wet cake, the tailing are no longer pumpable and other transport methods are required). However, as the water content decreases, which means increased water recovery within the process, the tailings are far more readily able to be used in self-supporting structural situations such as stacks.

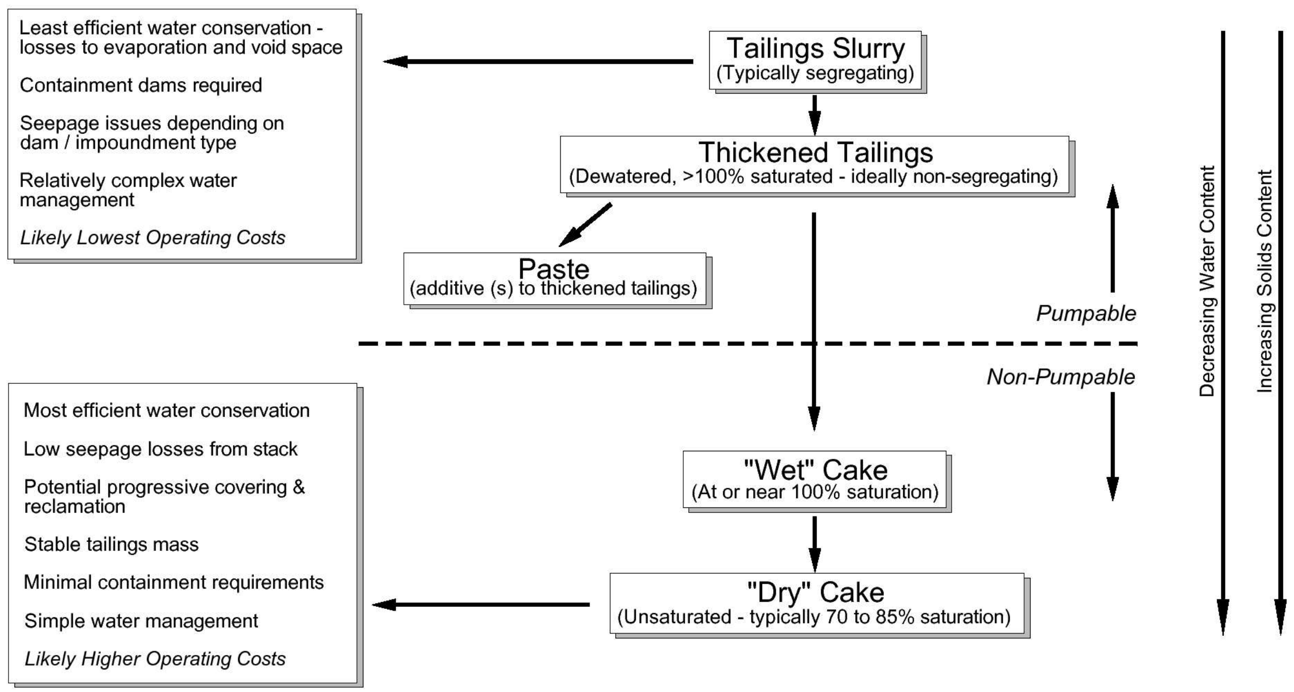

Figure 1: Tailings Continuum

Filtered tailings are typically taken to be the dry cake material shown in Figure 1. This material has enough moisture to allow the majority of pore spaces to be water filled but not so much as to preclude optimal compaction of the material.

Filtering and Dry Stacking

The Basics

Filtering of tailings can take place using pressure or vacuum force. Drums, horizontally or vertically stacked plates and horizontal belts are the most common filtration plant configurations. Pressure filtration can be carried out on a much wider spectrum of materials though vacuum belt filtration is probably the most logical for larger scale operations.

The nature of the tailings material is important when considering filtration. Not only is the gradation of the tailings important, but the mineralogy is as well. In particular, high percentages of <74 µm clay minerals (i.e. not just clay-sized but also with clay mineralogy) tend to contraindicate effective filtration. Furthermore, substances such as residual bitumen (e.g. oil sands tailings) can create special difficulties for a filtration plant.

Determining the most cost-effective manner to obtain a filtered product consistent with the geomechanical requirements of the tailings can be a challenge. Filter suppliers are both knowledgeable and helpful in this regard but some form of pilot test(s) is essential as every tailings product will exhibit its own unique filtering behaviour. It is important to anticipate mineralogical and grind changes that could occur over the life of the project. The candidate filtering system(s) must be able to readily expand/contract with future changes at the mine with the least economical impact.

Filtered tailings emerge from the process facility within a prescribed range of moisture contents discussed later. The tailings are then transported by conveyor or truck and then placed, spread and compacted to form an unsaturated, dense and stable tailings “stack” (often termed a "dry stack") requiring no dam for retention with no associated tailings pond. The filtered tailings are not “dry” but are unsaturated so the early nomenclature referring to them as dry is incorrect. However, it is doubtful this mislabeling has led to any misunderstandings amongst experienced designers, operators and regulators.

Each project needs to assess the potential applicability for filtered tailings based upon technical, economical and regulatory constraints. Experience shows the most applicable projects are those that have one or more of the following attributes:

1. Reside in arid regions, where water conservation is crucial (e.g. Western Australia, Southwest United States, much of Africa, many regions of South America, arctic regions of Canada and Russia)
2. Have flow sheets where economic recovery (commodity or process agent(s)) is enhanced by tailings filtration
3. Reside in areas where very high seismicity contraindicates some forms of conventional tailings impoundments
4. Reside in cold regions, where water handling is very difficult in winter
5. Have topographic considerations that exclude conventional dam construction and/or viable storage to dam material volume ratios
6. The operating and/or closure liability of a conventional tailings impoundment are in excess of the incremental increase to develop a dry stack.

To date, the two most common reasons to select dry stacked filtered tailings as a management option have been to recover water for process water supply and where terrain/foundation conditions contraindicate conventional impoundments. The recovery of water is particularly important in arid environments were water is an extremely valuable resource and the water supply is regulated (e.g. Chile, Western Australia, and Mexico). This recovery of water has a cost benefit to the project, which offsets the capital and operating cost of the tailings system. It should be noted that water surcharge storage needs to be factored in to the design of a filtered tailings system. Depending upon the application this can be a small water supply reservoir or tank. Where water is relatively scarce, either year round or seasonally due to extreme cold, sending immense quantities of water to quasi-permanent storage in the voids of a conventional impoundment can severely hamper project feasibility. By reclaiming the bulk of the process water in or near the mill, far more efficient recycle is achieved. Moreover, the amount of water “stored” in a dry stack facility will be typically >25 to 50% less than that in a conventional slurried impoundment even if 100% pond reclaim efficiency is achieved with the impoundment.

One of the main advantages of dry stack tailings over other tailings management options is the ease of progressive reclamation and closure of the facility. The facility can often be developed to start reclamation very early in the project life cycle. This can have many advantages in the control of fugitive dust, in the use of reclamation materials as they become available, and in the short and long term environmental impacts of the project. Progressive reclamation often includes the construction of at least temporary covers and re-vegetation of the tailings slopes and surface as part of the annual operating cycle.

How Common is Dry Stacking?

On a global basis, conventional tailings facilities (e.g. slurry tailings direct from mill into a tailings impoundment) make up by far the majority all existing tailings facilities. In terms of dewatered tailings, meaning those that are "lower" on Figure 1 than slurried tailings, there are a similar number of thickened/surface paste tailings facilities to filtered tailings facilities in terms of number of worldwide operations. There is, however, an intriguing dichotomy between available information about paste/thickened tailings and filtered tailings.

For paste/thickened tailings there has been a steady stream of publications (far outnumbering actual projects where the methods have been applied) and even annual specialty conferences. For example, each year since the late 1990s, there is an international conference on paste and thickened tailings where the presentations focus has necessarily been on potential advances and such more than actual case studies simply as there have not been sufficient projects to write about. Including the papers from these annual, and other, conferences, there are more than 200 publications on paste/thickened tailings including several guidebooks.

Filtered tailings, on the other hand, have simply not had the attention other dewatered tailings have had yet, as noted above, there are a similar number of actual operating mines using filtered tailings in comparison to, for example, thickened/paste tailings surface storage. There are but a handful of publications on filtered tailings/dry stacks and rare mention in conference proceedings. This is a curious development when the comparative number of actual projects using the various methods of tailings management is considered.

Figure 2, taken from a recent evaluation of global trends in dewatered tailings practice (Davies et al, 2010) provides a summary of the relative number of dewatered facilities on a global scale.

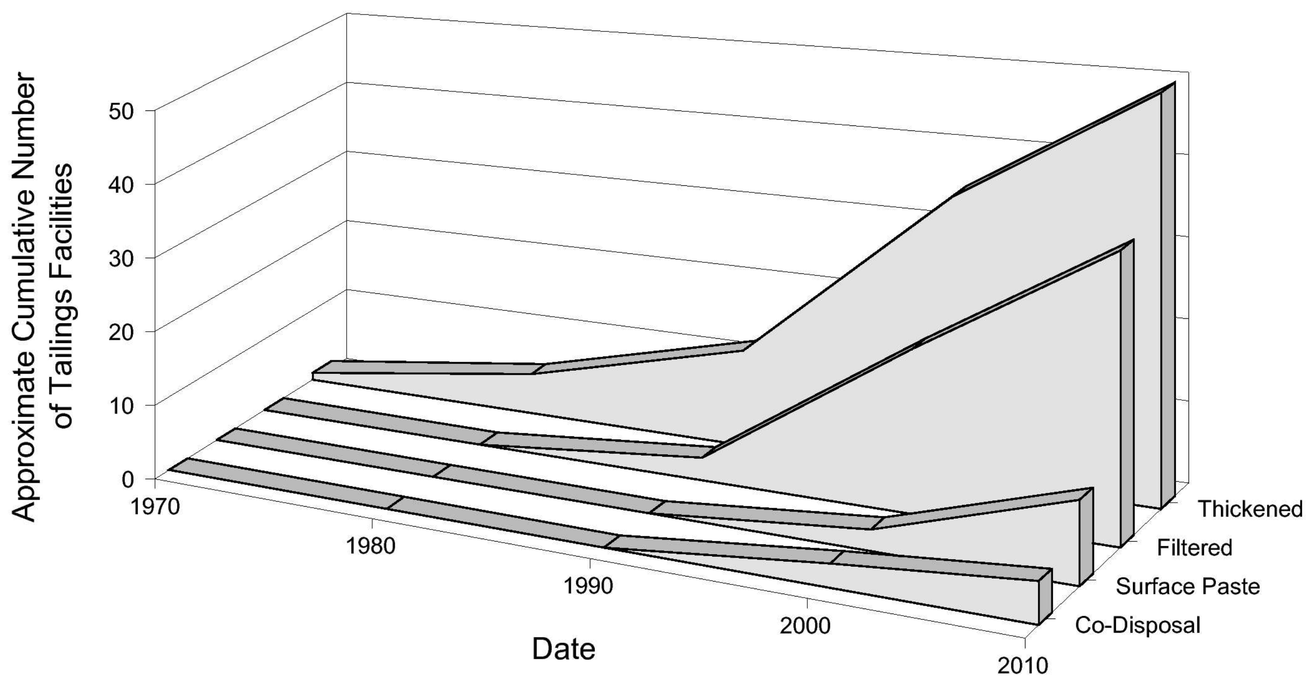

Figure 2: Trends in Use of Dewatered Tailings in Mining (after Davies et al, 2010)

Filtered Tailings - Design Guidelines

Overview

The strength, moisture retention and hydraulic conductivity characteristics of the tailings need to be established for any given project considering the technology. The strength and hydraulic parameters from saturated tailings should be determined to "anchor" the results and tests as variable moisture contents are required to demonstrate the impact of the inevitable range of operating products. The other important geomechanical characteristic to determine is the moisture-density nature of the tailings. The unsaturated moisture-density relationship indicates in-situ density expectation as well as the sensitivity of the available degree of compaction for any given moisture content. From a compaction perspective, the filtered tailings should neither be too moist nor too dry. The optimal degree of saturation is usually between 60 and 80%.

Filtered tailings can be placed in a relatively dense state meaning that more solids per unit volume can be achieved. Furthermore, more aggressive use of available land (e.g. valley slopes) can be used with filtered tailings. Lesser foundation conditions can also be considered in comparison to conventional impoundments.

Siting Considerations

While a filtered tailings dry stack will still require a foundation consistent with acceptable deformation criteria provided the loading conditions that the stack would be projected to be subjected to, static and dynamic, the range of topographic settings and foundation conditions where dry stacking will work is substantially wider than for conventional tailings impoundments. Avoidance of concentrated runoff water flows directed at the stack is one essential siting consideration. Other key siting considerations include:

- Placing the stack to avoid fugitive dusting from prevailing winds
- Avoiding placing where "blinding" off groundwater discharge areas (unless a sufficiently robust underdrainage system is designed, constructed and maintained)
- Optimizing the haulage and/or conveyance from the filtration plant; the tailings are no longer a slurry and a common "error" with those not familiar is dry stacks is to site the facility in same way one would a conventional slurry impoundment
- Potential ability to co-dispose with and/or abut waste rock dumps.

Tailings Testwork

The testwork required to provide sufficiently detailed engineering decisions at all project stages is relatively modest with filtered tailings. Minimum testing requirements are provided based upon project stage as follows:

Conceptual – Prefeasibility Project Stage(s)

- Approximate tailings gradation and mineralogy
- Flask or similar filtrate testing
- Standard Proctor (moisture-density)
- Vendor engagement – filtration and transportation

Feasibility Stage

- Tempe Cell laboratory testing
- Geochemical testwork
- Bench scale filtration testing
- Extended moisture density work
- Transport behavior evaluation

Detailed Engineering Stage

- Variable moisture testwork
- Possible field compaction trial

More detailed strength testing (e.g. triaxial) is an option and is only typically required for the largest of stacks as the range of strength parameters for the majority of tailings is within the margin of accuracy of the stability estimation programs used by designers. Strength testing that includes an ability to obtain key deformation moduli for the tailing is important, at the feasibility level, where deformation of the facility will govern performance (due, for example, to a weaker foundation scenario). Again, such considerations are only typically of relevance for the larger dry stacks being considered.

Target Moistures

Likely one of the most misunderstood design parameters for any filtered dry stack is the target moisture content for the filtrate. The degree of dewatering readily achievable depends upon the filtering technology adopted, the application rate of tailings into that technology and the tailings physical characteristics. However, what should be the more driving discriminator is what is required to develop the stack itself in a manner that expedites construction, maintains structural integrity post-compaction and provides all of the water management advantages that an appropriately developed dry stack exhibits.

From experience of developing more than ten dry stacks and testwork on many more, a very useful rule of thumb is to have the target moisture content be equivalent to the tailings Standard Proctor optimum moisture content as described by ASTM D-698 (ASTM 2011). While this target can vary as much as 1 or 2% under (wetter climates) to 1% over (extremely dry climates), the target has worked extremely well on all facilities presently existing that include those up to, and including, throughputs to 20,000 tpd. As filtered dry stacks increase in size, and appropriately the size of compaction equipment, it is probably that target moistures more consistent with the Modified Proctor may become more appropriate.

Facility Zonation

One of the most consistent “challenges” that operators of filtered dry stacks have is that no ore body is entirely consistent let alone the mechanical and human variability elements involved in transporting and placing/compacting those tailings. As a result, the filtrate’s character will vary and occasionally not meet the target moisture contents. Moreover, there can be extreme cold seasons in a year and/or infrequent but intense rainfall/snow events throughout a year that can all impact abilities to achieve consistent compaction of the filtered tailings.

The best solution for addressing filtrate and climatic variation is to design and operate the dry stack with “zones”. The facility can have, for example, a “shell” that is reserved for only filtrate that meets all specifications and is placed in optimal conditions during a day/week/year. The shell can then surround an interior of tailings that are provided the same/similar compactive effort but there is, and appropriately so, less expectation of these materials in global stability and otherwise evaluations.

Zonation can also exist for placement of waste rock within the dry stack. There are not fewer than five operating dry stacks that are provide encapsulation of mineralized waste rock that is provided the excellent oxygen barrier than a considerable thickness of unsaturated compacted tailings provides.

Water Management

Surface water, particularly concentrated runoff, should not be permitted to be routed towards a dry stack. As important, the catchment and routing of precipitation (and any snow melt in colder climates) on the stack itself must be appropriately designed for. For the surface runoff within the overall catchment containing the dry stack, one (or more) of perimeter ditches, binds or under-stack flow through drains designed for an appropriate hydrological event(s) should be included in the design. For on stack water management, routing of flows to armored channels and limiting slope lengths/gradients to keep erosion potential at a minimum are the best design criteria.

Site development for a dry stack normally consists of the construction of surface and groundwater control systems. There are normally two systems:

1. A collection and diversion system for non-contact water (i.e. natural surface water and groundwater from the surrounding catchment area that has not yet come into contact with the tailings). This system usually consists of ditches to divert surface runoff around the site and if necessary a groundwater cut-off and drainage system usually combined with surface water diversion. The cut-off system can range from simple ditches to sophisticated cut-off walls depending upon site conditions.
2. An interception and collection system for contact surface water, impacted groundwater, and seepage from the dry stack. This system usually consists of an under-drainage system of finger drains, toe drains, drainage blankets and French drains; collection sumps and ponds. Water collected in the ponds and sumps is usually used in process or pumped to a water treatment plant depending upon the site water balance. Liners for the facilities can also be components of the interception and collection system depending upon predicted impacts and regulatory requirements.

Finally, the subject of facility lining is a prevalent topic and bound to arise on most every project where tailings are involved whether dry stacked or not. There is no hard set rule for lining versus no lining as, for the most part, lining with an appropriately designed and operated dry stack is more for political purposes than technical ones. Well-compacted filtered tailings at/near “optimum” moisture will have an equivalent hydraulic conductivity in a similar range to a typical liner element with average installation and other defects. The moisture content specified for optimal compaction is often very similar to the residual moisture content for the material and “drain down” is both slow and very limited in actual quantity of flow in most cases.

Tailings Transport/Placement

The design of any tailings dry stack needs to be compatible with how the stack can be practically constructed using the selected haulage and placement equipment. Haul distance, placement strategy and compactive effort and additional works for closure and reclamation make a larger incremental difference to the unit cost of a dry stack facility.

There are two methods in common use for transport of the filtered tailings to the tailings storage facility. These are conveyors or trucks and the equipment selection is a function of cost. Placement in the facility can be by a conveyor radial stacker system or trucks depending upon the application and the design criteria. Conveyor transport of tailings to the disposal site can be combined with placement by truck, so conveyor transport does not automatically result in placement by radial stacker.

The main issue associated with the placement of the filtered tailings by truck is usually trafficability. The filtered tailings are generally produced at or slightly above the optimum moisture content for compaction. This means that a construction/operating plan is required to avoid trafficability problems. This is especially true in wetter environments since trafficability drops as moisture content rises and if the tailings surface is not managed effectively it can quickly become un-trafficable resulting in significant placement problems and increased operating costs. In addition, in high seismic areas there is often a design requirement to compact the tailings to a higher density in at least the perimeter “structural” component of the facility. This requirement increases the need for construction quality control. It is the authors’ experience that the degree of compaction required for assured and efficient trafficability is often higher than the compaction required to achieve design densities to meet geotechnical considerations.

Reclamation/Closure

Dry stack facilities can be developed to consist of, or closely approximate, their desired closure configuration. There is negligible facility deformation post-placement versus the considerable consolidation settlement conventional tailings undergo over what can be a very long period. Commensurately, the tailings can be progressively reclaimed in many instances.

The most important closure element is an assured surface runoff management plan with redundancy. In all cases, a closure cover material is required to resist runoff erosion, prevent dusting and to create an appropriate growth media for project reclamation.

The lack of a tailings pond, very low (if any) appreciable seepage from the unsaturated tailings mass and general high degree of structural integrity allows dry stacks to present the owner/operator with a comparably straight forward and predictable facility closure in comparison with most conventional impoundments.

Key Lessons Learned from Operating Dry Stacks

From design, operating and review knowledge of a majority of the world’s dry stack tailings facilities, there are a number of “lessons learned” that should assist in any new facility being considered and/or in optimizing an existing facility. There are presented in no particular order of importance:

- Zonation is essential to a pragmatic and efficient tailings dry stack. Having an ability to deal with slightly off-specification material and/or still place in any weather condition removes many of the constraints that some have placed on dry stack development. It would be an extremely rare/unique situation that would not benefit and/or allow for a zoned approach to managing a given dry stack. Davies and Veillette (2007) describe the zonation approach adopted for the Pogo Mine in Alaska.
- If there is proper compaction and maintenance of target moisture contents, seepage is negligible. Instead of creating a complex system to capture seepage that will likely never appear, spend those resources more appropriately on surface water management measures that include a collection pond downgradient of the dry stack.
- Resaturation of properly placed and compacted filtered tailings is extremely difficult and not the concern many presume.

- Diversion ditches should be appropriately lined and the water routed in such a way that erosion of the tailings surface is not permitted to occur.
- Compaction specifications can be achieved in sub-freezing conditions if tailings windrows are compacted within a few hours of being transported from the plant.
- Heated bed liners are essential in colder climates.
- Tarps are excellent, though not elegant, way to provide short-term erosion protection in areas of intense rainfall where tailings windrows cannot be compacted prior to such rainfall events occurring (e.g. where they are daily events).
- Carrying on from the point above, dry stacks can be effectively developed in very wet conditions.
- Fugitive dust generation can be considerable in colder months (in cold climates) due to freeze drying of surface of the tailings stack.
- Filtration plants have occasional challenges and a temporary storage area(s) for one to three days of storage of material unsuitable for the dry stack is of great value to provide operational flexibility. This storage area should be close to the filtration plant so that the material can be readily reintroduced to the filtration process for permanent storage in the dry stack. In the case of lower tonnage operations, this storage can be achieved in large vessels/tanks whereas for larger operations, a lined impoundment is usually required.

Finally, filtered tailings dry stacks are not a panacea for mine waste management. They should be appropriately viewed as an alternative form of tailings placement and a part of the overall tailings continuum of options for today's designer/operator. There are site conditions, including regulatory regime, that make a tailings dry stack the best choice for certain projects. Where that is the case, the guidelines offered in this paper should provide a sufficient point to avoid the pitfalls that earlier dry stacks met and attain the successes that many current dry stacks demonstrate.

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