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Phosphogypsum Disposal - The Pros & Cons of Wet Versus Dry Stacking

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Abstract

There are a number of factors that an operator should consider before pursuing wet or dry stacking of the phosphogypsum by-product from a phosphoric acid plant. In addition to process considerations, important factors include the climatologic regime, water balance considerations, hydrogeology, topography, capital cost, operating cost (and maintenance), closure costs (and handling of drainable pore water), availability (or scarcity) of a fresh water source, distance from the plant to the disposal site (and viability of dry versus wet transport methods), P_2O_5 recovery, impacts on the environment (from leakage, dusting, accidental spills, etc.) and applicable regulations.

A review of dry/wet transport methods and dry/wet disposal methods is presented using illustrative examples from various countries worldwide, with particular emphasis on the advantages and disadvantages of wet and dry stacking in the various environments. In most instances, wet stacking is preferred over dry stacking based on economic and maintenance considerations.

The author wishes to acknowledge the invaluable contributions of his former colleague and mentor, the late Dr. Anwar E. Z. Wissa, who contributed since the early seventies to improving our understanding of this important topic.

1. Introduction

Worldwide, phosphogypsum by-product from a phosphoric acid plant is mostly stacked on land, and in some countries (Morocco, Tunisia, South Africa and Mexico) discharged into the sea. More than 200 million tonnes of phosphogypsum are produced annually. Less than 5% of the production is used commercially, primarily for agriculture. This paper focuses on the transport and on-land disposal of phosphogypsum in dry stacks and wet stacks.

2. Factors to Consider

There are several factors that one must consider when choosing between wet and dry stacking. First is the process factor, i.e., whether the by-product of phosphoric acid production is dihydrate or hemihydrate gypsum. In that regard, there was a misconception that if a plant produced hemihydrate, then the operator would have to adopt dry transport and dry stacking. The hemi which is unstable would convert to di, and the thought was that there would be no expulsion of water from the

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gypsum as the filter cake water would be entirely consumed in the conversion of the gypsum from hemi to di. In practice, we now know that that is not the case, i.e., dry stacked hemi does expel remnant pore water. There are today several hemi plants using wet transport and wet disposal, for example PCS in North Florida.

Capital costs, operating costs, closure costs, and operation and maintenance considerations all in the judgment of the author favor wet stacking over dry stacking. Wet stacking is typically more economical because manpower and equipment requirements are not as significant and because a wet stack is normally much easier to operate.

Climate is another important factor. In wet climates, like most of the USA, wet stacking is exclusively used. Even if dry stacking were to be adopted in a humid climate, the operator would end up with a wet stack anyway. In arid climates, both wet and dry stacks are used - sometimes wet, sometimes dry - like in Tunisia which has both wet and dry stacks. In other dry countries like Jordan, all stacks are dry. Climate is important not only from the standpoint of precipitation and water balance, but also because of dust induced by high winds, particularly in dry stacking operations.

Hydrogeology used to be a determining factor but with the premise that a liner is now deemed necessary to control seepage from either a dry or wet stack, then hydrogeology is no longer a controlling factor, except for the fact that a thick layer of natural clay can serve as the protective liner in lieu of, or in conjunction with, a synthetic liner. Topography is an important factor for both wet and dry stacks. Distance from the chemical plant is another important factor, i.e., whether the disposal site is close to the plant or 10 kilometers away, with related conveyor belt cost and operational considerations for dry stacking, as opposed to more cost effective low maintenance slurry pipelines for wet stacks.

Water availability in arid climates like North Africa, the Middle East or even Australia is a significant factor favoring dry stacking because of the cost of fresh water (e.g., need for reverse osmosis treatment of sea water). In wet stacks, one typically consumes more fresh water, although if a liner is used, the losses in an arid climate are basically limited to evaporation which can be controlled by minimizing ponded areas. Whereas fresh water use favors dry stacking in dry climates, a wet stack allows an operator to recover P_2O_5 through recirculation of the process water, thus increasing the efficiency of the plant by as much as 1 to 3 %. Hence, P_2O_5 recovery is an important consideration.

Phosphogypsum, a waste residue from phosphoric acid production is vacuum washed on a filter at the plant in conjunction with either wet or dry stacking operations, and filtration is an important step in P_2O_5 recovery, i.e., the lower the water content of the gypsum filter cake, the better the recovery. Belt filters and tilt table type (Prayon) filters are suitable for use with both dry and wet transport or stacking. Flat table with screw type (Ucego) filters are not compatible with dry transport and dry stacking because the screw has to be washed. From the filter, a chute directs the filter cake to a conveyor belt in the case of a dry stack, or the gypsum cake is jetted into a slurry tank for hydraulic pumping in the case of a wet stack.

3. Wet Transport and Wet Stacking

3.1 Slurry pipelines for hydraulic transport

With wet transport, the gypsum slurry is transported hydraulically by pumping through pipelines at 15 to 30 % solids. Wet hydraulic transportation (which is more conventional than dry transportation) involves pulping the gypsum cake, using fresh water or re-circulated process water, to form a slurry that is pumped through a pipeline from the plant to the disposal site. Typically, there are two gypsum slurry lines, one in reserve, i.e., a spare or back-up. In some cases, there is also a return water pipeline for re-circulating process water back to the plant, although use of a return water ditch is normally preferred. The pipelines may be buried to prevent inadvertent mechanical damage and protect from vandalism, e.g., on public property and at road crossings, but burial makes it more difficult to access the lines for repair and maintenance. In most situations on private property, e.g., in Florida where the mine and chemical plant properties often abut each other, the HDPE pipelines are simply laid on the ground. In special cases, the black HDPE is painted white to control contraction and expansion by reducing heating from exposure to the sun, thus limiting lateral movement and "snaking" of the line. High pressure steel pipes lined with either rubber or HDPE are used on occasion to allow for high pumping pressures over long distances or to great heights without the need for booster pumps. Metal pipes also provide protection from vandalism on public property.

Fig. 1. (a) High pressure gypsum slurry pipelines; (b) HDPE slurry line to stack top

At the disposal site, the pipelines are laid up the relatively steep side slope of the stack as needed to direct the slurry flow into one of the settling compartments atop the stack. Because of the need to occasionally flush and clean the line after a power failure, it is good practice to include flanges within the slurry line at a low point near the toe of slope. Gypsum sediment that settles in the line and accumulates at the low point could then be cleaned if needed by quickly opening and re-bolting the flange connection without having to cut and re-weld the line. Flanges are also convenient to include along the slope as pipe sections could easily be added (at say 5-meter height intervals) as the stack is raised.

3.2 Single discharge with alternating compartments

Wet stacking practice through the mid-seventies in the USA (and current practice in some other countries like Tunisia) consisted of a single point slurry discharge in one of two alternating adjacent compartments, one being actively used for slurry deposition while the other is allowed to dewater and dry-out, and is being prepared by digging gypsum and raising the perimeter dikes. Such a disposal scheme is not efficient because the gypsum in the compartment slopes from the discharge end to the opposite side at a grade ranging from 3 to 8 m per 1000 m depending on the rock source, plant process and slurry solids content. The water thus accumulates at the low end where the gypsum fines are very wet and difficult to handle. (Note that in spite of construction difficulties, wet gypsum is preferred over very dry gypsum excavated from the high end of a dry compartment as wet gypsum solidifies into a suitable material after placement, whereas powdery dike material that is too dry will have to be wetted and moisture conditioned prior to compaction). Moreover, with a single slurry discharge point, the dike at the low end is subject to overtopping during a heavy storm event.

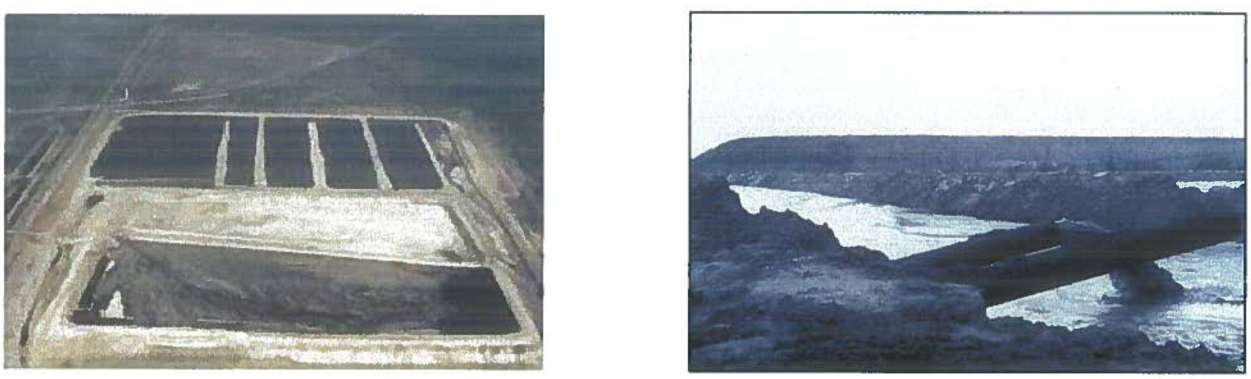

Fig 2. (a) Wet stack with single location discharge; (b) Gypsum slurry discharge to rim ditch

3.3 Rim ditching and stack operation/raising

A much more efficient and economical way of managing a wet stack is through use of elevated rim ditches. The slurry is discharged at a single point into the perimeter rim ditch and routed around the stack, with the rim ditch sloping at 3 to 8 meters per kilometer, i.e., at the natural angle of deposition of the gypsum slurry. The rim ditch is maintained at a higher level than the ponded inner compartment, so the material in the rim ditch is always readily available and is typically suitable for dike construction without the need for moisture conditioning. Once the rim ditch is filled with gypsum, the operator simply breaches the inner rim ditch dike to allow the slurry to be directed to the inner compartment, forming gypsum beaches in the vicinity of the rim ditch, essentially all around the compartment. This is achieved by sequentially breaching the inner dike at progressively more distant locations. Hence, the slurry pipe is maintained at one location and the rim ditch transfers the gypsum to where it is needed in a most efficient manner. In such a sedimentary type deposit, beaches are developed and their extent can be controlled in such a manner to either have a very deep pond (e.g., 10 meters of water depth), or a shallow pond, thus allowing the operator to manage the water inventory on top of the stack using a very flexible and convenient method that optimizes water management (without a need for a high dike at the far end).

Fig 3. (a) Elevated sloping rim ditch; (b) Beaches formed from rim ditch cuts

Gypsum excavated from the rim ditch (above the water table) is used to raise the perimeter dike using the upstream method of construction, as well as the inner windrow or inner dike separating the rim ditch from the ponded compartment. Draglines with a long reach were commonly used in the past along with a wide rim ditch and a narrow inner dike or windrow, but these machines were slow and required high maintenance. With time, the industry has moved to replace draglines with smaller hydraulic excavators having shorter arms (10 to 15 m reach) and much faster digging efficiency. The transition to hydraulic excavators required incorporating a trafficable inner dike or berm (with a much wider crest than the windrow), and even though the quantity of material needed for dike construction increased with use of the wider inner dike, construction proceeded at a faster pace using hydraulic excavators, a method preferred by operators or contractors charged with managing and raising the wet stacks. A second rim ditch inboard of the inner dike may be added for convenience and to improve efficiency if needed. Moist gypsum excavated from a rim ditch above the water table is an ideal construction material which can be simply placed on the dike crest and inner berm, quickly tamped with the backhoe bucket or rolled and shaped with a tracked dozer. Construction proceeds in this manner even while the inner compartment is full of water.

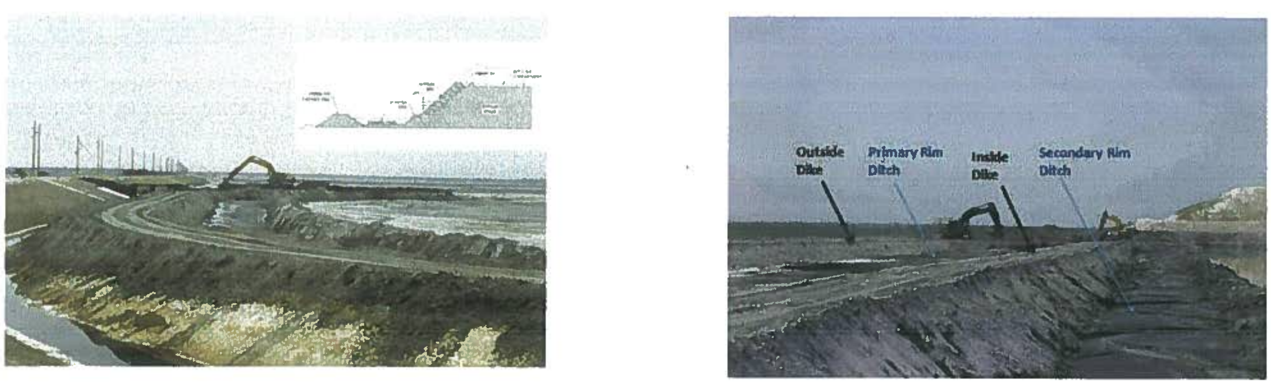

Fig 4. (a) Upstream method of construction; (b) Equipment accessible inner & outer dikes;

3.4 Spigoting

Another way of spreading the gypsum slurry discharge around the compartment is through use of spigots (in lieu of a rim ditch). In this method, the slurry pipeline is placed on the crest of the perimeter gypsum dike with branches or take-offs through spigots, formed by adding T's and discharge lines branching out from the main slurry pipe, feeding the inner compartment at regular intervals and activated one at a time by breaking the line each time. This method which is used in some countries with cheap labor is very labor intensive and requires continuously moving the pipeline network upslope as the stack is being raised. More sophisticated ways of spigoting would include T's with flanges and knife valves that can be used to control the flow along the slurry line and into the compartment (without a need for breaking the line each time). Such a system is suitable for use if the gypsum stack is located in a valley where only one wall is being raised (with other sides abutting the mountain), so the pipe does not need to be frequently moved upslope. The spigot system functions like a rim ditch, but is more labor intensive. The crest of the stack can be maintained level if the spigoting method is used which may be an advantage for stacks founded on very soft ground where stability and strength gain over time are important considerations.

Fig 5. Gypsum slurry deposition using spigots

3.5 Clarified process water decantation

The settling compartment atop the stack must be large enough to provide for adequate settling and sedimentation of the fine gypsum particles and to allow sufficient time for clarification prior to decanting and recirculation of the process water to the plant for re-use. Wooden or stainless steel high fixed vertical riser structures with an outlet pipe at the base of the stack had been commonly used in the past for decanting purposes, but these type decant structures are subject to downdrag forces associated with on-going settlement of the sedimented gypsum, causing buckling and failure of the structures as the stack increases in height. Hence, fixed vertical riser structures are no longer used except on setback benches where the stack is not growing. Moveable stage decant systems with a small riser box and an exposed outlet pipe laid on the slope of the stack are much safer and in more common use. This type decant structure is typically excavated and raised regularly (at say 2 meter intervals), along with its discharge line (which crosses beneath the rim ditch), as the stack increases in height. Floating siphon lines are also used for process water decanting and can be relocated to allow for siphoning from more than one location. A siphon has to be primed and needs to be fitted with a vent valve at the top of slope and flow control valve at the toe. Alternatively, decanting through a cut in the gypsum perimeter dike is a very easy, convenient, safe and inexpensive method practiced at many wet stacks in Central Florida. In this method, a cut is made through the gypsum dike and process water is simply allowed to flow down the slope of the stack. Such a decant method is feasible with gypsum saturated water high in fluorosilicates that precipitate on the slope of the stack forming an erosion resistant hard crust that resists erosion in spite of the turbulent flow. (Such a decant method is not feasible for use with earthen materials which would be highly susceptible to erosion.) Care must be exercised when properly filling the cut made through the gypsum dike.

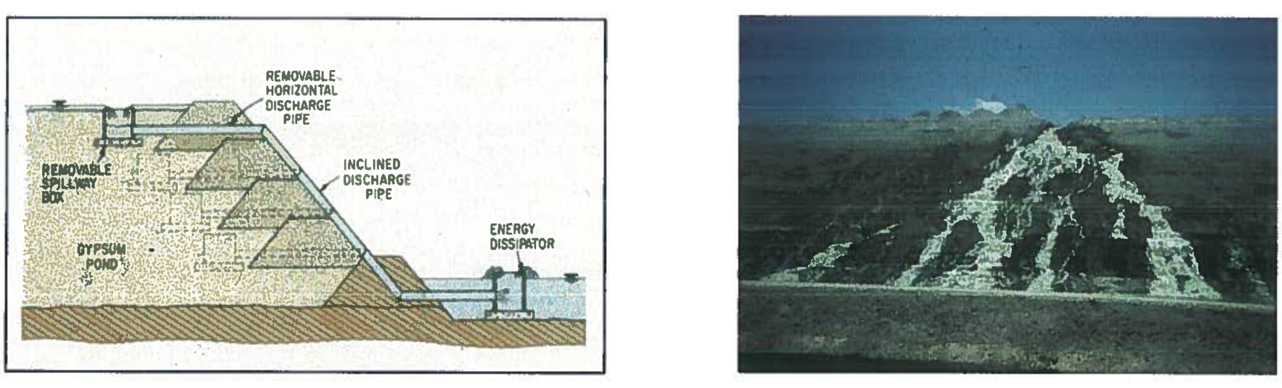

Fig 6. (a) Movable stage decant system; (b) Process water decantation through cut

3.6 Cooling ponds and process water return systems

At-grade cooling ponds and/or surge ponds need to be adequately sized to provide adequate cooling of the re-circulated process water and sufficient surge storage capacity based on water balance analyses during extreme storm events. In dry climates, smaller and deeper ponds would be desirable to reduce evaporation losses compared to facilities in moderate climates. Narrow channels around the stack are useful for containing accidental spills and are very effective in promoting plug flow cooling (as opposed to mixed flow). The process water typically flows back towards the plant in an open return ditch. In situations where chutes are present between different elevation return water ditch sections, scaling and crystal formation frequently occurs over time within the chute because of turbulence, but the return flow is not impeded as a result of crystal growth in such open ditch situations. On the other hand, when HDPE pipelines are used for process water return in lieu of open ditches, scale formation can be problematic. In some chemical plants located some distance from the stack, under certain conditions, scaling and crystal growth in return water pipelines can seriously impede flow, causing major problems. Such crystal growth (in process water return lines as opposed to slurry lines) is dependent on a number of factors and in particular the rock source, temperature, equilibrium concentration, turbulence, and size of the decant pond (i.e., the larger the pond, the more time for precipitation in the pond). When scaling is an issue, return water lines must be cleaned regularly when the crystals are still small, thus limiting the seeding and formation of larger harder crystals in the line. Additives may also be used if scaling is a problem.

3.7 P_2O_5 Recovery

Return water is typically picked up from the pond or return ditch by vertical pumps for recirculation to the plant to wash the filters and re-slurry the gypsum cake. Washing with high P_2O_5 content water improves P_2O_5 recovery which is one of the significant advantages of wet stacking. In a wet stack, the operator recovers soluble P_2O_5 from water entrained in the gypsum cake, with some additional P_2O_5 recovery from unreacted rock over time, as well as P_2O_5 contained in plant spills diverted to the cooling/surge pond. It is not uncommon to improve P_2O_5 recovery in a wet stack by as much as 1 to 3 %, thus improving plant efficiency by up to 3%.

4. Dry Transport and Dry Stacking

4.1 Dry transport by conveyor belts and/or trucks

Dry stacking is thought to be a simpler way of phosphogypsum disposal compared to wet stacking. Even though from one perspective dry stacking is simpler, it does present significant challenges that an operator has to overcome.

"Dry transportation" (as it applies to conveying or hauling) means that the gypsum is transported at the same moisture content as when it discharges from the filter. The term is somewhat misleading since the actual moisture content of gypsum after filtration is typically between 20 and 25%†. Dry transportation can be achieved by one or a combination of the following methods: (i) mechanical belt conveyors; (ii) trucks; and (iii) railroad cars. The most widely used dry transportation options are mechanical belt conveyors and trucking.

Fig 7. (a) Dry transport by conveyor belts; (b) Dry transport by trucks

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† Moisture content herein is defined as $w_w/(w_g + w_w) \times 100$, where w_g is the weight of dry gypsum ($CaSO_4.2H_2O$) and w_w is the weight of free water in the gypsum cake.

Mechanical belt conveyor systems can extend over many kilometers. The stationary conveyor belts from the phosphoric acid plant to the gypsum disposal site are usually less than 5 km long. With such a system, to minimize down time, it is good practice to have a back-up parallel conveyor system. Alternatively, a temporary or emergency gypsum stacking area at the plant site with a 15-day minimum storage capacity could eliminate the need to have a long back-up conveyor system to the disposal site. Using trucks to convey the gypsum cake off the filters to the disposal site is usually only feasible for relatively small phosphoric acid plants. For trucking, the dewatered gypsum cake off the filters is transported by a belt conveyor system to a short reversing cross conveyor or a diverter chute at the discharge end of the conveyor. Truck drivers control the changes in direction such that when one truck is full, the driver actuates a control switch which reverses the conveyor to start filling the next truck.

Effective dewatering of the gypsum cake by adequate filtration (or by temporary stockpiling) prior to dry transportation may be required (and could involve double handling) as needed to preclude liquefaction and prevent spillage from conveyor belts or trucks. Spillage off the conveyor belt along the route due to vibrations, and/or due to gypsum adhesion to the belt or blockages in transfer hoppers may not be environmentally acceptable. Since the gypsum cake tends to clog conveyor belt transfer hoppers, frequent inspections and unclogging would be required. Moreover, the corrosive nature of phosphogypsum causes maintenance of a belt conveyor system to be especially high. In addition, dusting during high winds and cold temperatures may have an adverse effect on roller bearings and/or grease in bearings, thus adversely affecting operation of the conveyor equipment. As to trucking, safety is always of concern, especially at night. Moreover, in cold climates, trucks may not be capable of operating all year round particularly during snow storms or icy conditions.

4.2 Dry stacking in valley

At Aqaba, in Jordan, gypsum is dry stacked in a narrow, deeply incised, unlined valley up to a height of 200 m. A fixed belt conveyor transfers the gypsum cake from the chemical plant, which is located at the low end of the valley, to a ridge at the other end of the valley where a hopper feeds a fixed extendable belt conveyor running along the crest of the gypsum pile. The conveyor in turn feeds a single radial stacker on rails which automatically rotates up to 180° as it senses the build-up of gypsum. As designed, the system is essentially fully automated requiring very little support equipment and personnel. Unfortunately as the stacker advanced on the deposited gypsum, the self-weight settlement of the previously deposited gypsum became too large (up to 1 m per day) for the stacker to maintain its vertical alignment. Therefore, the advance of the stacker along the valley had to be slowed down by having to keep adding material under the conveyor belt and stacker sleepers, and by laterally feeding grasshoppers on both sides to spread the gypsum more broadly across the valley. Such a disposal scheme advances via gypsum avalanches and sliding/sloughing which may not be feasible at other sites.

Fig 8 (a) Dry transport to stack in valley; (b) Settlement cracks in dry stack in valley

4.3 Settlement cracks

The side slopes of a dry stack advancing by avalanches are barely stable, and the gypsum creeps with time, causing the stack to develop large and wide longitudinal cracks that pose a safety hazard to operation personnel. Heavy rainfall events (which occur even in arid climates) may fill open cracks and could then cause a massive sliding failure of the slope of the stack. Therefore, such cracks should be properly backfilled as soon as they are detected.

4.4 Dry stacking on level ground

At relatively flat disposal sites (e.g., in Tunisia), the fixed belt conveyer from the plant feeds a series of movable belt conveyors with hoppers (grasshoppers) that are staggered and that feed a stacker which may be a simple short conveyor belt at the discharge end running at high speed to eject the gypsum down the face of the advancing dry stack slope, or alternatively a spreader at the end of the conveyor system. The belt conveyors for a dry stack on flat ground are moved often using a tractor as needed to distribute the gypsum cake uniformly across the wide disposal site area. The gypsum slopes formed by the stacker on flat ground will also be at the angle of repose for loose gypsum, and will have a factor of safety of essentially unity against failure. As with the case of a dry stack in a valley, the stack on flat ground advances via avalanches and develops significant cracks.

Fig 9 (a) Cracks in dry stack on level ground; (b) Dry stacking using grass hoppers; (c) Advancing face of dry stack

4.5 Dusting and maintenance

Gypsum in a dry stack formed using movable conveyors and a stacker is bulked and looser than that in a similar wet stack and, therefore, for a given site, a dry stack would have a shorter storage life than a wet stack. Moreover, dusting could be a very significant environmental problem with a dry stack because the top surface will be frequently trafficked by movement of conveyor systems, trucks and/or dozers, and such traffic will break down the protective crust that forms on the desiccated surface of a stack. Significant additional operation and maintenance costs are typically associated with a dry stack because of high maintenance equipment requirements compared to wet stacking and the need for around the clock equipment operation with increased potential for accidents and breakdowns. In contrast, a wet stack requires less equipment, only two operating shifts at the disposal site instead of three (because there is no need for the night shift when the slurry is being discharged into a large compartment), and thus, will have relatively little down time that could impact production of the plant.

4.6 Pore water expulsion

Experience with dry stacking indicates that the lower portion of a dry stack will be saturated even in a desert or arid climate due to gypsum self-weight consolidation and settlement. Hence, even without rain infiltration, the lower portions of dry stacks become saturated with time. This occurs to some extent in all dry stacks, even where the gypsum cake is well filtered, i.e., at a moisture content less than 25%. Since significant seepage can be expected at the base of the stack even if dry stacking is used, one of the previously perceived advantages of dry stacking is no longer justified because a liner is required in either case to control seepage of entrained process water from the stack. Note that for a dry stack advancing via avalanches, it is almost impossible to install a liner or underdrains because they will be destroyed by the sloughing gypsum slopes.

Fig 10. Seepage from base of dry stack

4.7 Dry stacking on liner system with super conveyors

To limit traffic required to service and move the grasshoppers, which cause dusting problems, and to preclude damage to the bottom liner and drain system, Ma'aden in Saudi Arabia will be using a series of track-mounted, 76-m long self-propelled "super portable" conveyors fed through a tripper by two 1 to 2 km long fixed conveyor systems located on each side of the stack. The movable conveyors are set in series, one feeding the other, and they in turn feed a self-propelled track-mounted 55-m long "horizontal conveyor" and a 61 m radial stacker. Grasshoppers and super portable systems must run perpendicularly to the slope of the stack and must be kept level. Such a system is quite sophisticated and expensive, probably requiring significant maintenance, but it allows for raising the stack systematically in 5 to 8 m thick lifts. For such a lined dry stack, the cost for lining the stack will almost be the same as for a lined wet stack, and will likely be even higher because the liner would have to be protected from mechanical damage by conveyor belts (or earthwork equipment) hauling and spreading the gypsum.

Fig 11. Self-contained movable spreader/stacker

4.8 Dry stacking with trucks and dozers

At small plants, trucks and dozers may be used to dry stack the gypsum. Building a dry stack in relatively small lifts with trucks and dozers increases the dry density of the gypsum and limits cracking to some extent. Nevertheless, some moisture conditioning will likely be required in order to compact the gypsum in high traffic areas, and that may present problems during wet weather periods. The distance that a dozer can efficiently move gypsum is about 50 m and, therefore, trucks will need to dump the gypsum relatively close to the advancing face of the stack. The disposal site needs to be well illuminated because of traffic and because of the need for the disposal equipment to be manned around the clock. A relatively large number of dozers would be required even if working continuously over a 24-hour period. In practice, additional dozers would be needed considering spare equipment, and if spreading work is limited to daylight hours only. During the dry season, dust generated by truck traffic will need to be controlled by frequent watering. In addition, safety is always of concern with truck traffic, especially at night. Moreover, in cold climates, trucks may not be capable of operating all year round particularly during snow storms or icy conditions.

5. Dry Transport and Wet Stacking

At a hemi plant in Queensland, Australia, the gypsum is transported "dry" by conveyor belt from the plant to a mixing tank at the disposal site where the gypsum is then slurried, converted from hemi to di, and then pumped as a slurry via pipeline for disposal on a wet stack.

Dry transport to a wet stack is the exception rather than the norm, and was implemented in this special case because of perceived concerns about the viability of hydraulic transport of hemi gypsum. Dry transport and wet stacking has high maintenance costs and no economic advantage.

6. Wet Transport and Dry Stacking

At a di plant in China, the filtered gypsum cake is slurried and pumped in high pressure lines to the disposal site where a supplementary second filter is used to wash the gypsum with fresh water to a neutral pH. After wet transport, with double filtration, the wash water is returned to the plant for re-use and P_2O_5 recovery, and the "dry" cake is conveyed on a belt to a chute, loaded on trucks for dry stacking on the side of a mountain, using trucks and dozers.

Wet transport to a dry stack is rarely used in spite of its environmental advantage. The company in this case has since abandoned this disposal scheme because operating and maintenance costs were too high.

7. Conclusions

The large majority of wet phosphoric acid plants worldwide use wet transport (by hydraulically pumping the gypsum slurry at solids contents ranging from 15 to 30 %) and wet disposal of the gypsum in a wet stack. Wet stacking is practiced not only in wet climates but also in dry climates (e.g., Iraq, Syria, Queensland-Australia, and some stacks in Tunisia). In dry climates, the wet stack top surface need not be maintained fully ponded as needed to control evaporation losses and limit fresh water use and consumption.

Only 10 to 20% of the facilities worldwide use dry transportation and dry stacking of the phosphogypsum and most these facilities are located in arid climates (where fresh water resources are scarce) like North Africa (e.g., Tunisia) and the Middle East (Jordan and Saudi Arabia), or in very cold climates like the former soviet union (e.g., Russia).

Wet stacking is generally the most cost effective and economical disposal method requiring less operating equipment and moving parts, less manpower, less shifts, and less maintenance and downtime. Wet stacking also improves P_2O_5 recovery and plant efficiency, an important advantage. It is also more environmentally friendly than dry stacking when one considers dusting. Moreover, since even a dry stack in a dry climate will expel drainable pore water as a result of consolidation and settlement, one of the previously perceived advantages of dry stacking is no longer valid because a liner will likely be required beneath most dry and wet stacks.

A wet stack can more easily handle precipitation from extreme storms compared to a dry stack which has very limited surge storage capacity. Cracks in a dry stack present a safety risk unless they are routinely filled. The only advantage a dry stack presents is a reduction in water use notably in arid climates where fresh water resources are scarce. Nevertheless, in most instances, even in dry climates, it is the author's opinion that wet stacking is preferred over dry stacking based on economic and maintenance considerations.

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In closing, I would like to recognize Dr. Anwar E. Z. Wissa who was my colleague for over 35 years, my teacher and a friend. We lost him on June 23, 2010, so this paper is dedicated to his cherished memory. The author's understanding of wet and dry transport and disposal options is largely credited to the pioneering adventure in phosphogypsum that Anwar and I undertook together at Ardaman & Associates, Inc., with Dr. Wissa at the helm.

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