EVALUATION OF ENGINEERING PROPERTIES AND WET STACKING DISPOSAL OF WIDOWS CREEK FGD GYPSUM-FLY ASH WASTE

by

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ABSTRACT

Wet stacking of by-product gypsum has been practiced by the phosphate fertilizer industry for more than 25 years. The ability to use wet stacking for disposal of flue gas desulfurization (FGD) gypsum was first demonstrated during an Electric Power Research Institute sponsored project on Chiyoda Thoroughbred 121 FGD gypsum produced at the Scholz Electric Generating Station of Gulf Power Company in Sneads, Florida. Wet stacking of FGD gypsum containing fly ash, however, has not been previously demonstrated. Accordingly, as part of an overall project investigating various FGD waste disposal alternatives, the Tennessee Valley Authority constructed a pilot-scale wet stacking disposal facility to evaluate the feasibility of wet stacking FGD gypsum-fly ash waste produced at the Widows Creek Steam Plant in Stevenson, Alabama. Operational experience and results from geotechnical laboratory testing performed on the waste are presented. The results indicate that although the Widows Creek FGD gypsum-fly ash had settling, dewatering, and structural characteristics not as favorable for stacking as phosphogypsum or CT 121 FGD gypsum, they were adequate for wet stacking. Therefore, the project findings should extend the ability of the utility industry to employ wet stacking disposal to facilities which also use FGD/forced oxidation systems as the primary particulate removal process.

INTRODUCTION AND OVERVIEW OF WIDOWS CREEK STEAM PLANT

The Tennessee Valley Authority (TVA) has been developing scrubber operating and waste disposal experience with limestone flue gas desulfurization (FGD) systems via a series of demonstration projects on Unit 8 of the Widows Creek Steam Plant in Stevenson, Alabama (1) (2) (3). Unit 8 is a coal-fired 550-MW boiler which became operational in 1964, and is the newest of eight coal-fired units at Widows Creek. With its sister unit, Unit 7, it occupies a separate powerhouse about one-quarter mile from the powerhouse containing Units 1 through 6. The aggregate capacity of the eight units is 1,950 MW. A schematic site plan of the Widows Creek Steam Plant is shown in Figure 1.

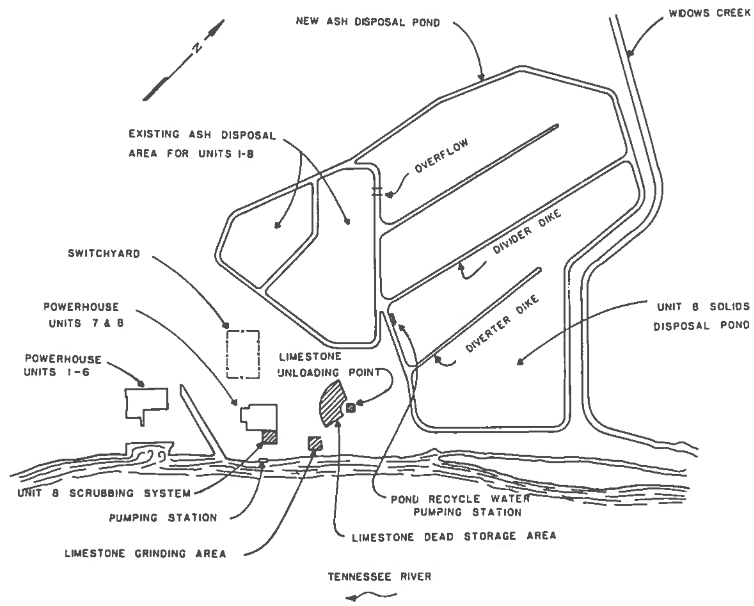

Figure 1. Widows Creek Steam Plant Site Plan.

Various landfilling methods involving dewatering, stabilization, and fixation of FGD calcium sulfite wastes produced by Unit 8 have been studied by TVA. Primary among these studies was the use of dry fly ash for stabilization of dewatered FGD calcium sulfite waste and landfill disposal. This methodology did not appear feasible for Unit 8, because insufficient dry fly ash was available for stabilization.

Subsequently, one of the four modules of the Unit 8 FGD system was modified to permit forced oxidation of calcium sulfite to calcium sulfate (gypsum), which is a waste considered more suitable for disposal. As part of an evaluation of various disposal alternatives for FGD gypsum-fly ash waste, a wet stacking disposal demonstration project was initiated. Gypsum produced as a by-product at phosphate fertilizer plants, i.e., phosphogypsum, is disposed of using the wet stacking method, and hence it was anticipated that FGD gypsum-fly ash waste could also be disposed of using the wet stacking method.

The objectives of the demonstration project were to evaluate the engineering properties of FGD gypsum-fly ash waste produced by the scrubber relevant to wet stacking, and to evaluate the feasibility of using the wet stacking method for a full-scale disposal facility at Widows Creek. Specifically, the objectives of the project were to:

- Demonstrate the construction and operation of a pilot-scale wet stacking disposal facility for FGD gypsum-fly ash waste.
- Determine the handling, stackability and trafficability characteristics of the gypsum-fly ash waste and identify potential wet stacking disposal construction and operation problems.
- Develop a supporting data base of engineering properties from laboratory and field testing for use in the design of a full-scale FGD gypsum-fly ash wet stacking disposal facility.

This paper presents the engineering properties of Widows Creek FGD gypsum-fly ash waste relevant to wet stacking and field observations obtained during construction and operation of a 0.3-acre, 12-foot high pilot scale wet stacking disposal facility at the Widows Creek Steam Plant. The findings of this study were used as the basis for design of a 120-acre wet stacking disposal facility for Units 7 and 8 which is scheduled to become operational in the fall of 1985.

DESCRIPTION OF WIDOWS CREEK FORCED OXIDATION FGD LIMESTONE SCRUBBER SYSTEM

A FGD limestone scrubber system was installed on Unit 8 of the Widows Creek Steam Plant. Unit 8 is a 550-MW coal-fired boiler employing four identical parallel FGD trains, namely trains A, B, C and D, that scrub flue gas from the

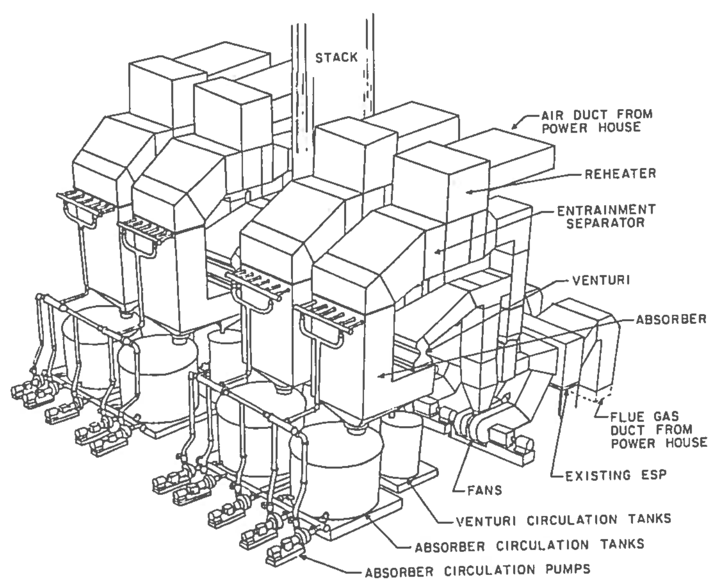

Figure 2. Widows Creek Steam Plant Unit 8 Scrubber Facility.

boiler. One FGD train is connected to each of the four flue gas ducts from the boiler. A schematic illustration of the Unit 8 FGD scrubber system is presented in Figure 2.

As shown, the FGD scrubber consists of an adjustable throat venturi followed by a grid-type absorber spray tower. For the forced-oxidation demonstration project, the D train was modified to allow forced oxidation of the scrubber sludge by installing air-sparging and turbine agitation equipment in the D train absorber and venturi circulation tanks.

The forced oxidation of calcium sulfite to calcium sulfate requires: aeration of the scrubber slurry in the absorber and venturi circulation tanks at atmospheric pressure; and maintaining a suitable pH in the slurry at the point of air introduction. Since the scrubber was also used as the primary particulate removal system, the resulting waste was a combination of calcium sulfate and fly ash. Unreacted limestone and unoxidized calcium sulfite also occurred within the waste.

Aeration in the absorber and venturi circulation tanks was provided by four screw type diesel air compressors. The compressors were rated at 1,600 acfm and 100 psig at the outlet. Air flow to the absorber and venturi circulation tanks was controlled by a rubber pinch valve at the inlet to the tanks. The venturi circulation tank was 18 feet in diameter and 25 feet high with a working capacity of 40,700 gallons (Figure 3). The absorber circulation tank was 33 feet in diameter and 25 feet high with a working capacity of 147,000 gallons (Figure 3).

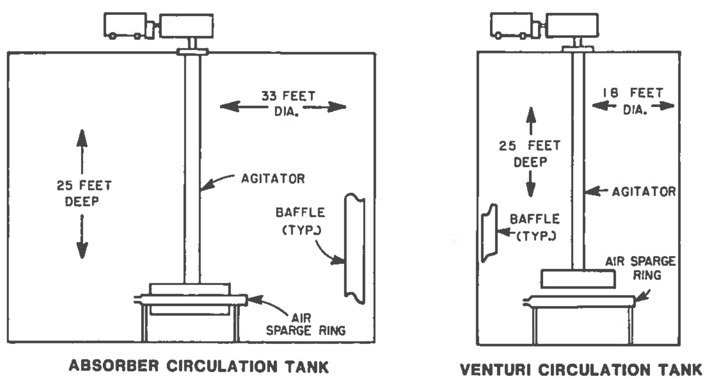

Figure 3. Absorber and Venturi Circulation Tanks.

Normally, only two compressors were needed for complete oxidation, with the other two compressors serving as standby units. The compressed air was distributed within the absorber and venturi circulation tanks by means of a sparge ring (Figure 4) consisting of a perforated annular duct surrounding the agitator impeller. The sparge rings were held above the tank floor by supports welded to the floor.

The turbine agitators installed inside and directly above the sparge rings in the absorber and venturi tank, respectively, were significantly larger than standard circulation tank agitators to enhance mixing. The bladed turbine agitators were constructed of carbon steel and coated with rubber. The agitators generated turbulent eddies which sheared the air bubbles emitted from the sparge ring. This provided a high gas/liquid mass transfer area, increased oxygen uptake by the slurry, and prevented gypsum crystals from settling.

Limestone was added to adjust the pH as necessary to maintain a suitable pH for SO_2 removal and yet achieve complete oxidation. Limestone was ground by a wet ball mill before preparation into a slurry. The limestone slurry was stored in one tank feeding the four FGD trains. The limestone slurry tank was 36 feet in diameter and 27 feet high with a working capacity of 193,000 gallons. The limestone slurry tank was equipped with an agitator to mix the slurry and to keep limestone particles in suspension. The limestone slurry was pumped to the absorber circulation tank by slurry feed pumps, one pump for each of the four FGD trains.

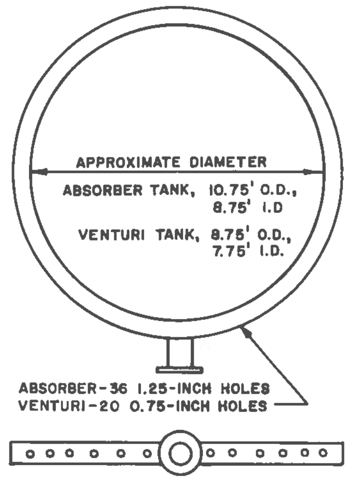

Figure 4. Air Sparge Ring.

The pH in the absorber circulation tank was regularly monitored. The slurry pH was adjusted by varying the limestone slurry flow into the absorber circulation tank. Under normal conditions, the optimum pH in the absorber circulation tank for complete oxidation was 5.8.

Oxidized FGD gypsum-fly ash waste from the scrubber was transported as a slurry to the wet stack disposal area by piping connected to an 8-inch gate valve near the bottom of the venturi circulation tank. A 250-gallon per minute pump was initially installed to pump the slurry from the venturi circulation tank to the disposal area, which was located approximately one-quarter mile from the scrubber facility. However, during the majority of the test program the slurry flowed by gravity to the stacking area because the pump drew the venturi circulation tank level down too fast, resulting in the loss of the venturi slurry seal which allowed partially scrubbed flue gas to escape. Eventually, the pump was abandoned and an automatic control system was installed to monitor the venturi circulation tank slurry level. Gravity flow was then stopped automatically when the slurry level dropped to a predetermined level.

After clarification in the stacking area, the process water was decanted into a sump area and pumped to the existing Unit 8 scrubber pond (Figure 1). The pump operated on a float switch which controlled the water level in the sump.

ENGINEERING PROPERTIES OF WIDOWS CREEK FGD GYPUM-FLY ASH WASTE

As part of the evaluation of the feasibility of wet stacking FGD gypsum-fly ash waste produced at Widows Creek, a laboratory testing program was performed to characterize the engineering properties of the waste relevant to wet stacking disposal, and to provide properties for use in the design of a full-scale facility (4). The chemical composition, crystal morphology, and physical characteristics of the waste are first addressed. Specific engineering properties regarding settling, consolidation, permeability and shear strength are subsequently discussed.

CHEMICAL COMPOSITION AND CRYSTAL MORPHOLOGY

The chemical compositon of a FGD gypsum-fly ash waste is expected to influence its engineering properties. Generally, the presence of calcium sulfite, due to reduced oxidation levels, inhibits dewatering, decreases settling rates, increases compressibility, and decreases permeability and shear strength. Further, high fly ash content wastes are expected to be less suitable for wet stacking than those higher in gypsum content.

During operation of the scrubber facility, the chemical composition of gypsum-fly ash solids within the venturi bleed stream was typically determined three times daily. The chemical composition of the venturi bleed stream solids was characterized by the following average constituents:

- 41% gypsum
- 43% fly ash
- 13% limestone
- 0.7% sulfite

As shown, the chemical composition was characterized by essentially equal weights of gypsum and fly ash with 13% unreacted limestone and 0.7% unoxidized calcium sulfite. The low calcium sulfite content resulted from the high average degree of oxidation achieved of 97.9%. The fly ash content never decreased below

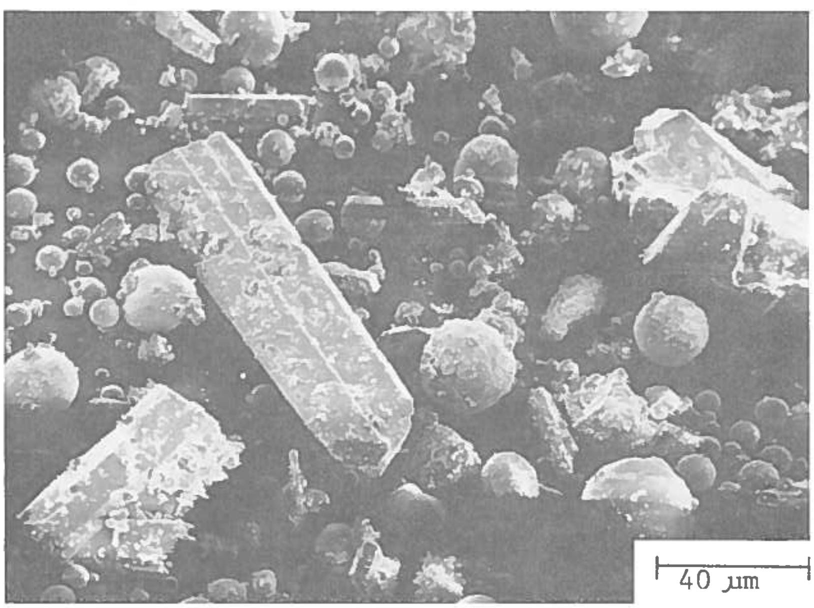

Figure 5. Scanning Electron Photomicrograph of FGD Gypsum-Fly Ash Waste.

26.6%, and occasionally reached as high as 75.6%. The gypsum content never exceeded 61.6%, and decreased to as low as 5.9%. Crystalline phases detected from X-ray diffraction analyses were gypsum, magnetite, hematite, calcite, dolomite and quartz, which are consistent with the constituents found via wet chemistry.

TVA anticipates that FGD gypsum-fly ash waste generated from the full-scale forced oxidation scrubber on Units 7 and 8 will have an average chemical composition of: 60% gypsum, less than 30% fly ash, less than 10% unreacted limestone and less than 1% unoxidized calcium sulfite. Accordingly, the full-scale facility is projected to produce waste higher in gypsum and lower in fly ash than produced during the demonstration project, since fly ash will be removed in Unit 7 prior to scrubbing.

The crystal morphology of the Widows Creek FGD gypsum-fly ash waste was determined via scanning electron microscopy. The typical crystal morphology found for the gypsum-fly ash waste is illustrated in Figure 5.

As shown, the major features visible in the photomicrograph include lath-shaped gypsum crystals, spheres (fly ash) with a wide range of sizes, and a general "dusty" appearance on the gypsum crystals and fly ash spheres.

PHYSICAL CHARACTERISTICS

The Widows Creek FGD gypsum-fly ash waste was found via sieve and hydrometer analyses to be predominantly a silt-sized material. As shown by the particle size distribution in Figure 6, the gypsum-fly ash waste exhibited a range of 64 to 94% and an average of 76% by dry weight of the particles finer than the 74 μm size. Less than 10% of the particles by dry weight were finer than the 45 μm clay particle size. Most of the plus 74 μm size particles are unreacted

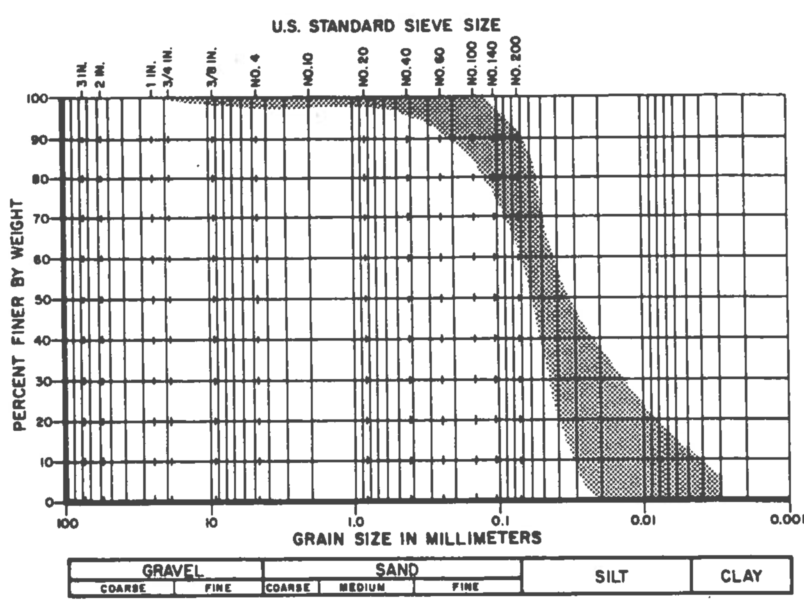

Figure 6. Particle Size Distribution of FGD Gypsum-Fly Ash Waste.

limestone, with the gypsum, fly ash and unoxidized calcium sulfite phases occurring within the minus 74 μm size fraction.

The particle size distribution is similar to that previously reported for Widows Creek gypsum-fly ash waste (5), and is also consistent with particle size distributions typically reported for FGD gypsum (6)(7) and fly ash (6).

The specific gravity of the gypsum-fly ash waste was determined to vary from 2.34 to 2.93 with an average of 2.50 ± 0.14. This average value is in general agreement with the specific gravity of 2.46 reported for a waste with 25% gypsum and 75% fly ash (7) and 2.29 reported for a waste with 55% gypsum, 20% limestone, 25% fly ash, and 1% calcium sulfite (5). For comparison, the specific gravity of the various minerals within the waste are: gypsum (2.33); calcium sulfite (2.50); magnetite (5.18); hematite (5.25); calcium carbonate (2.70); magnesium carbonate (2.85); and quartz (2.66). A much higher specific gravity is calculated using the mineral specific gravities and the weight percent of each mineral within the waste. The measured average gypsum-fly ash waste specific gravity of 2.50, however, is consistent with the expected value using a fly ash specific gravity of 2.50 as often reported. The fly ash specific gravity is typically lower than its constituent mineral specific gravities, due to the "porous" nature of the spheres.

SEDIMENTATION CHARACTERISTICS

Settling tests performed on the venturi bleed stream solids indicated that the settling rate, Q, varied from a minimum of 0.32 cm/min, for a poor level of oxidation (62.9%), to a maximum of 4.8 cm/min with an overall average of 3.0 cm/min. The effect of oxidation of solids on the settling rate is presented in Figure 7. As expected, although the data are limited, the settling rate decreases

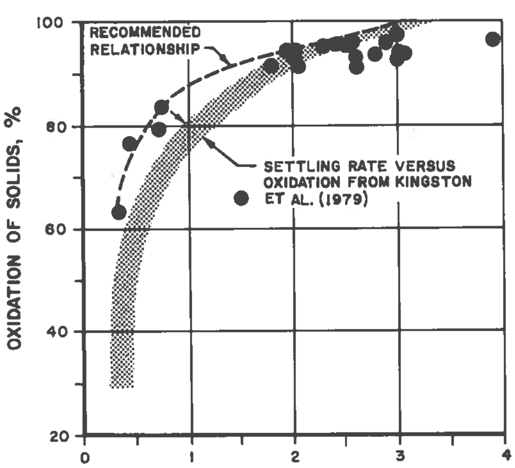

Figure 7. Settling Rate Versus Oxidation of Solids.

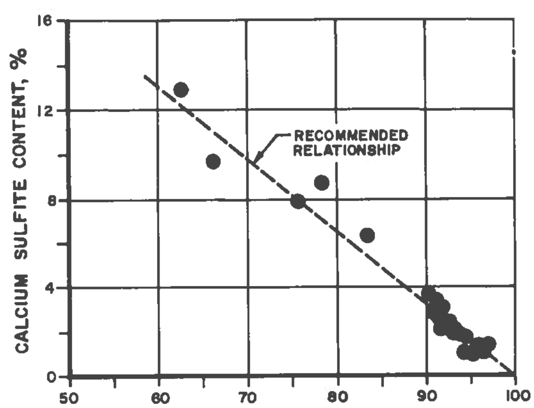

Figure 8. Oxidation of Solids Versus Calcium Sulfite Content

markedly below an oxidation level of approximately 90% when the calcium sulfite content exceeds about 3% (Figure 8).

The settling rate versus oxidation of solids previously found for Widows Creek FGD gypsum-fly ash waste (8) is also included on Figure 7 for comparison. As shown, the correlations are similar.

The "final" settled solids content, S_F, determined at the end of the settling tests when no additional change in height was observed ranged from 44.6% to 84.1%, with an average of 63.5%. Accordingly, an average solids content of 63.7% is initially expected in the disposal area after sedimentation, but before consolidation under subsequent layers of sedimented waste. The average "final" settled solids content corresponds to a moisture content of about 57%. For a specific gravity of 2.50, the "final" settled solids content corresponds to a dry density of 64.3 lb/ft^3 and a total saturated unit weight of 101.0 lb/ft^3.

The presence of calcium sulfite in FGD wastes, due to poor solids oxidation, decreases the settling rate and "final" settled solids content. These effects are illustrated in Figure 9. Although the data are limited at higher calcium sulfite contents, the trends of decreasing settling rate and decreasing "final" settled solids content with incresing calcium sulfite content are clear. The trends also

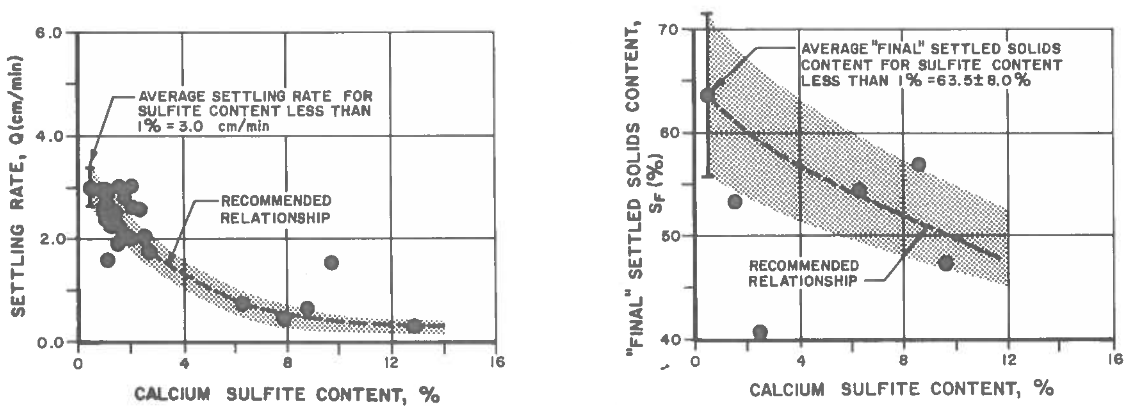

Figure 9. Effect of Calcium Sulfite Content on Settling Rate and "Final" Settled Solids Content.

indicate that relatively small percentages of unoxidized calcium sulfite can affect settling characteristics. Gypsum-fly ash waste with 3% calcium sulfite, which corresponds to about 90% oxidation (Figure 8), results in a reduced settling rate of

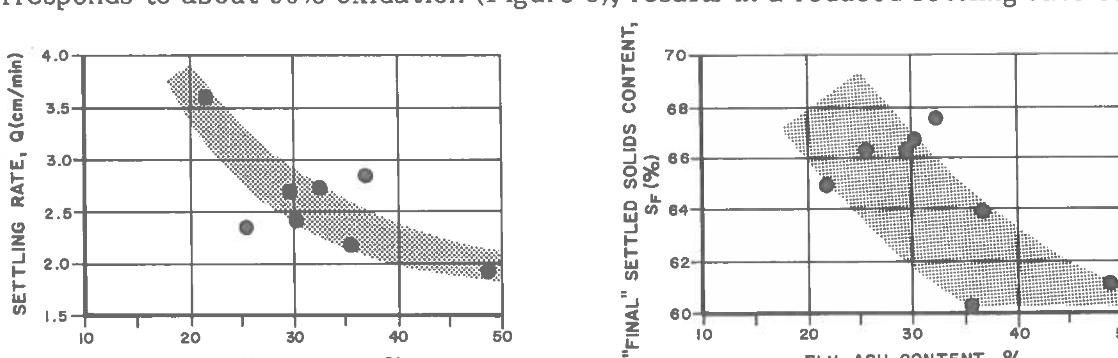

Figure 10. Effect of Fly Ash Content on Settling Rate and "Final" Settled Solids Content.

approximately 1.5 cm/min rather than 3.0 cm/min, and a "final" settled solids content of 58% rather than 63.5%.

Correlations between gypsum and fly ash content with settling rate and "final" settled solids content were attempted. No definitive correlations were apparent. As shown in Figure 10, however, weak trends of decreasing settling rate and decreasing "final" settled solids content with increasing fly ash content were observed.

COMPRESSIBILITY AND CONSOLIDATION CHARACTERISTICS

The void ratio, e, (or solids contents) versus effective vertical consolidation stress, $\bar{\sigma}_{vc}$, curve developed for the FGD gypsum-fly ash waste from the slurry-consolidation and settling tests is presented in Figure 11. As shown, the void ratio, e, ranges from 1.3 (S=65.9%) at low effective stresses typical of self-weight consolidation stresses existing after sedimentation, to 0.80 (S=75.8%) at an effective stress of 4.0 kg/cm^2 which corresponds approximately to the effective stress existing at the base of a 150-foot high stack. The compression ratio, or slope of the void ratio versus effective stress curve expressed in terms of strain is approximately 0.05 between stresses of 0.01 to 1.0 kg/cm^2. Comparatively, this compression ratio is similar to that expected for a loose sand. At low stresses between 0.001 to 0.01 kg/cm^2, i.e., below less than 1 foot of material, the material is relatively more compressible, with a compression ratio of 0.14.

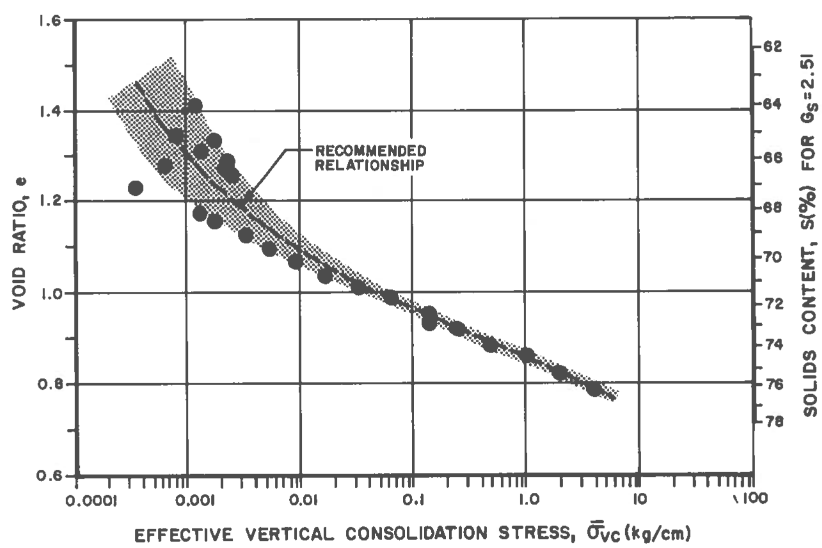

Figure 11. Void Ratio Versus Effective Stress Compressibility Curve.

Typically, FGD gypsums consolidate quickly under self-imposed or externally applied loads. Following consolidation, drained creep or secondary compression occurs resulting in slight increases in dry density with time at a given effective stress. The Widows Creek FGD gypsum-fly ash waste was also found to consolidate quickly with representative coefficients of consolidation, c_v, in the range of 0.01 to 0.10 cm^2/sec. For comparison, low to high plasticity clays typically have coefficients of consolidation in the range of 0.001 to 0.0001 cm^2/sec.

The one-dimensional coefficient of secondary compression, C_α, governs the magnitude of secondary compression or drained creep deformations which occur after consolidation is complete. For the Widows Creek FGD gypsum-fly ash waste, the coefficient of secondary compression was found to vary from 0.09% to 0.23% with an overall average of 0.15%. This value is relatively small, and hence the effects of secondary compression are not projected to be significant.

PERMEABILITY CHARACTERISTICS

The void ratio, e, versus coefficient of permeability, k, relationship developed from laboratory permeability tests on resedimented and undisturbed samples of Widows Creek FGD gypsum-fly ash waste is presented in Figure 12. As shown, over the range of void ratio (or solids contents) of the test specimens, the coefficient of permeability is generally insensitive to void ratio and varies within the range of $5x10^{-5}$ to $5x10^{-4}$ cm/sec. At a void ratio of 1.1, typical of the void ratio at a depth of about 1 foot, the coefficient of permeability is on the order of $2x10^{-4}$ cm/sec. At a void ratio of 0.8, coresponding to an effective consolidation stress of about 4.0 kg/cm^2 (Figure 11) typical of the effective stress at the base of a 150-foot high stack, the coefficient of permeability is on the order of $1x10^{-4}$ cm/sec. Accordingly, the coefficient of permeability of FGD gypsum-fly ash waste disposed of within a stack is not projected to vary significantly.

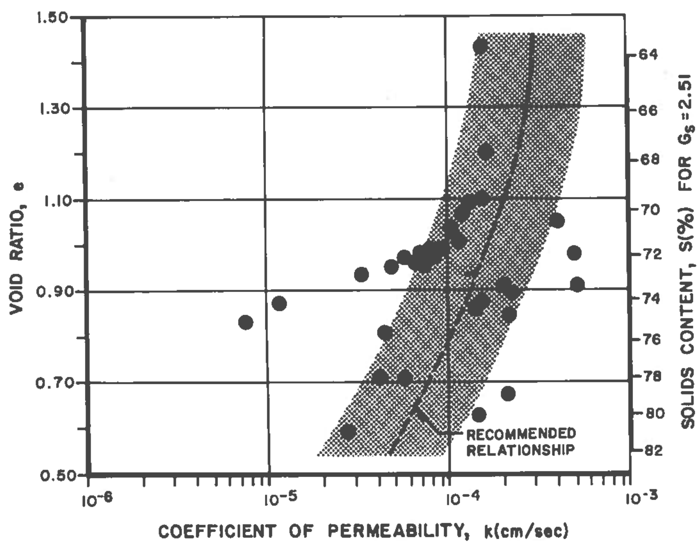

Figure 12. Void Ratio Versus Coefficient of Permeability.

STRESS-STRAIN-STRENGTH BEHAVIOR

The relationship for Widows Creek FGD gypsum-fly ash waste between pre-shear dry density and peak angle of internal friction determined in drained ($\bar{\phi}_d$) and undrained ($\bar{\phi}$) shear for zero effective cohesion ($\bar{c}$) is presented in Figure 13. As shown, the angle of internal friction increases from 40^o at dry densities of 72.5 to 80.0 lb/ft^3 to 49^o at a dry density of 99.0 lb/ft^3. For the range of dry densities expected to exist within a stack, the lower angle of internal friction of 40^o with zero effective cohesion is projected for Widows Creek gypsum-fly ash waste disposed of via wet stacking.

Stress-strain curves for Widows Creek FGD gypsum-fly ash waste from three consolidated drained triaxial tests performed on undisturbed samples recovered from the pilot-scale stack are presented in Figure 14. The test samples displayed pre-shear solids contents, S, of 71.2% to 74.1%, dry densities, γ_d, of 78.2 lb/ft^3 to 84.0 lb/ft^3 and were isotropically consolidated under effective confining stresses, $\bar{\sigma}_c$, of 0.5 to 3.0 kg/cm^2. The samples display similar behavior mobilizing peak strengths at axial strains, ε, of 6.7% to 11.5% and displaying slight strain softening behavior or decreases in strength with additional strain. Volume change measurements during drained shear indicate that the samples initially compressed (i.e., positive volume change), prior to a slight increase in volume at large strains.

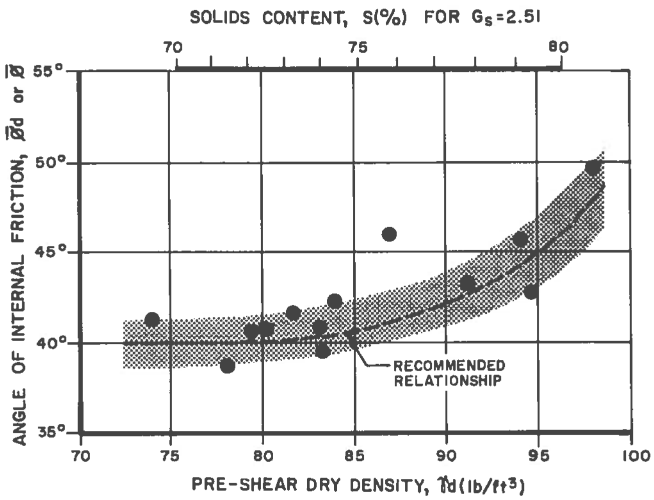

Figure 13. Dry Density Versus Angle of Internal Friction.

WET STACKING OF GYPSUM IN THE PHOSPHATE FERTILIZER INDUSTRY

Wet stacking of by-product gypsum, i.e., phosphogypsum, has been practiced by the phosphate fertilizer industry for more than 25 years. In Florida alone, more than 21 million tons of phosphogypsum are disposed of annually using the wet stacking method. The resulting gypsum stacks are typically large (50 to 300 acres), structurally stable stockpiles reaching heights greater than 100 feet. A gypsum stack located near Bartow, Florida is shown in Figure 15.

DESIGN CONSIDERATIONS

Wet stacking as performed by the phosphate fertilizer industry uses the upstream method of construction. In this method, illustrated in Figure 16, an earthen starter dike is first constructed to form a sedimentation pond and stacking area. Gypsum is pumped to the sedimentation pond in slurry form, usually at 15 to 20 percent solids, and allowed to settle and drain to approximately 60 to 70 percent solids. Process water is decanted and returned to the plant. Once sufficient gypsum sediments within the pond, the gypsum is excavated with a dragline to raise the perimeter dikes of the stack. The cast gypsum is then shaped to form a road on the crest of the dike using a bulldozer. The process of sedimentation, excavation, and raising of the perimeter dikes continues on a regular basis during the active life of the stack.

Using the upstream method of construction, some gypsum stacks have reached heights exceeding 100 feet with slopes as steep as 1.5 horizontal to 1.0

vertical which is approximately the angle of repose of phosphogypsum. The steep slopes result from casting the gypsum with a dragline and allowing some gypsum to roll down the outside of the stack thus eliminating shaping. Consequently, the outside slopes of some stacks have a factor of safety very close to unity and from a conventional geotechnical engineering point of view, failures of gypsum stacks do occur. Fortunately, gypsum is a very forgiving material, and unlike many mine tailings, gypsum does not readily flow. Therefore, the consequences of these failures are usually not dramatic.

In plan, the gypsum stack is usually a square or a rectangle. A typical layout is shown in Figure 17. The required area of the gypsum stack is generally selected to allow raising the perimeter dikes approximately 5 to 8 feet per year.

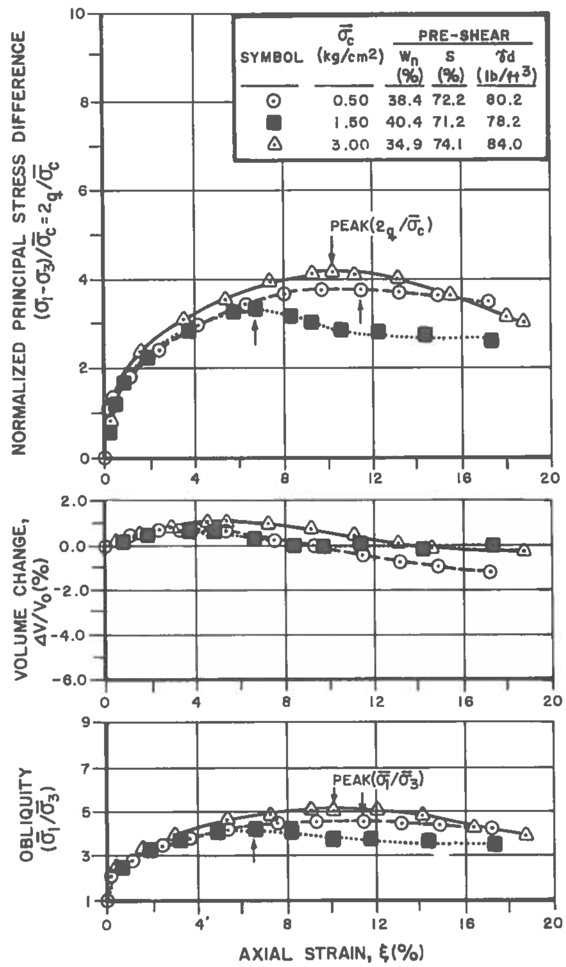

Figure 14. Drained Stress-Strain Behavior of Sedimented FGD Gypsum Fly Ash Waste.

OPERATIONAL CONSIDERATIONS

Two important considerations in the operation of a gypsum stack are the retention of fine-grained gypsum within the stack and the characteristics of the gypsum deposited around the periphery of the stack.

If sufficient retention time is not provided within the ponded area on top of the stack, complete clarification will not occur and the finer particles of gypsum will discharge through the spillway and sediment within the return ditch.

Although finer-grained gypsum can be cast to raise the perimeter dikes, the lower permeability and higher compressibility does not allow drainage to occur as quickly as with coarser-grained gypsum. Consequently, it is more difficult and time-consuming to use the finer material to raise the stack. For this reason, it is desirable to deposit the coarser material around the entire periphery of the stack.

Figure 15. Phosphate Fertilizer Plant Gypsum Stack Near Bartow, Florida.

It is possible to operate a gypsum stack so the coarser material is deposited around the perimeter of the stack while simultaneously providing sufficient retention time for the finer particles to settle within the interior of the stack. This is accomplished by using an elevated ditch to carry the gypsum around the periphery of the stack and to create a ponded area within the interior of the stack. This concept is shown schematically on Figure 17.

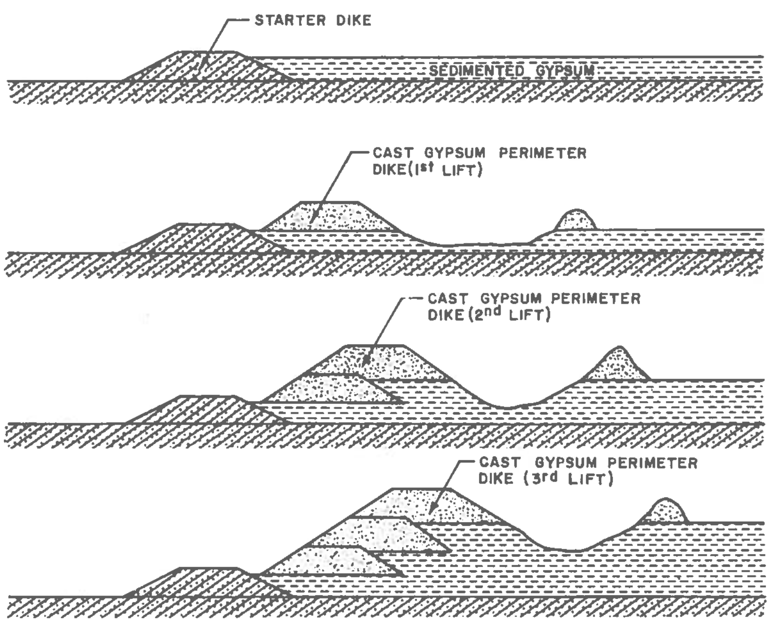

Figure 16. Upstream Method of Gypsum Stack Construction.

It is also desirable to divide the gypsum stack into at least two ponds. This allows one pond and its associated rim ditch to drain while the other pond is in use. The dragline can then excavate gypsum from the inactive rim ditch to raise the perimeter dike. It is often possible, however, using a dragline, to raise the stack without draining the gypsum.

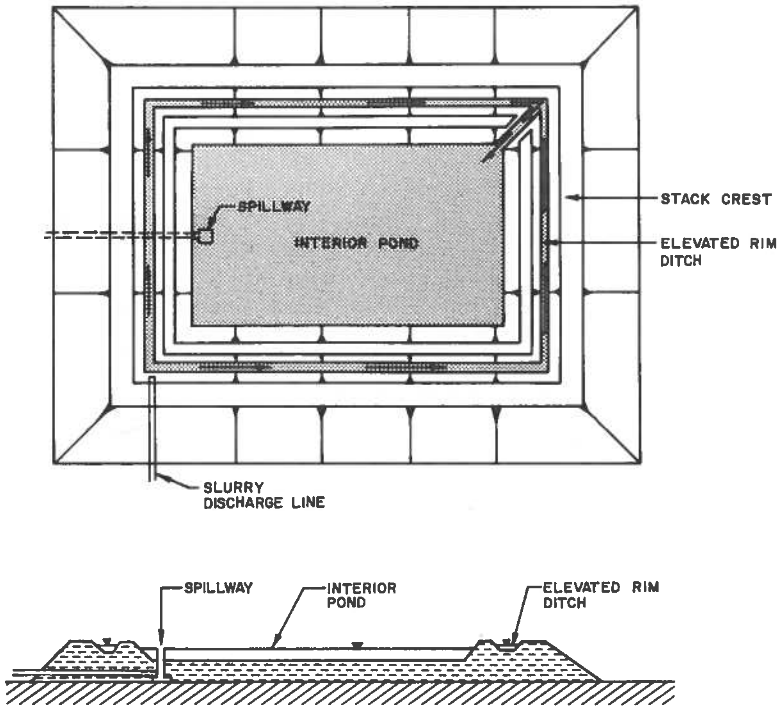

Figure 17. Typical Gypsum Stack Layout Illustrating Elevated Rim Ditch.

Figure 18 illustrates the seepage pattern within a gypsum stack on an impervious foundation or liner. Under these conditions, the gypsum stack slope below the spring line is subjected to seepage forces. Under these conditions, sloughing of the outside slope of the gypsum stack may occur unless relatively flat slopes or internal drains are used.

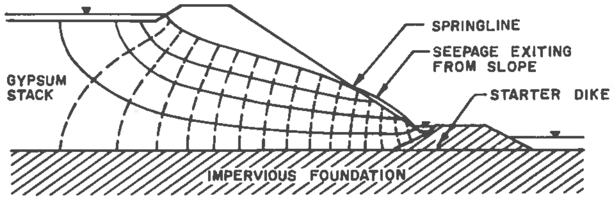

Figure 18. Seepage Pattern Through a Gypsum Stack on an Impervious Foundation.

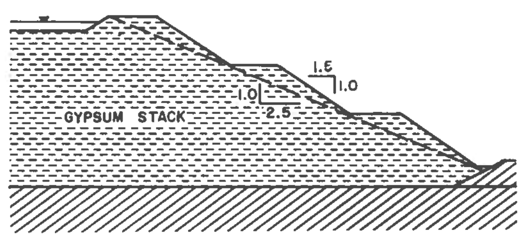

Figure 19. Flattening Gypsum Stack Slopes by Benching.

It is not common to provide erosion protection on the outside slope of a gypsum stack. Experience indicates there is essentially no erosion of the slope from rainfall, and dusting has not been a significant problem. If long-term maintenance and reclamation require the slopes be grassed, it may be expedient to flatten the slopes to 2.5 horizontal to 1.0 vertical or flatter as the stack is raised. These flatter slopes will generally hold topsoil cover and can be maintained using conventional equipment.

Gypsum stacks within the phosphate fertilizer industry are generally built as steeply as possible so that the storage capacity of the stack is maximized. If an average slope flatter than the angle of repose is required for stability, the perimeter dikes are generally offset from the outer perimeter as shown in Figure 19 to form benches in the slope. The excess material can be removed with a dragline to provide a uniform slope.

The wet stacking method of waste disposal was also demonstrated for FGD gypsum during operation of the Chiyoda Thoroughbred 121 Scrubber at the Scholz Electric Generating Station of Gulf Power Company in Sneads, Florida (6). A pilot scale gypsum stack similar to those used in the phosphate industry was successfully constructed (Figure 20) at Plant Scholz using the essentially pure gypsum produced by the CT 121 process.

EVALUATION OF WET STACKING DISPOSAL OF WIDOWS CREEK FGD GYPSUM-FLY ASH WASTE

Gypsum-fly ash waste was initially discharged into a 1.0-acre disposal area at Widows Creek on November 15, 1982 and continued intermittently through August 4, 1983. During this time, the scrubber was operational for 70 days and sufficient waste was provided to raise a 0.3-acre stack to a height of about 10 to 12 feet. The venturi bleed stream solids content varied considerably during operation of the scrubber from a minimum of 1.6% to a maximum of 15.7%, with an average of 8.1%. Based on an average venturi bleed stream solids content of 8.1%, average venturi bleed stream flow rate of 100 gal/min and 70 days of scrubber operation, an estimated 3,600 tons of waste were deposited within the disposal area. Waste deposited within the disposal area was characterized by approximately equal portions of gypsum and fly ash with average constituent contents of 42% gypsum, 43% fly ash, 13% unreacted limestone and 0.7% unoxidized calcium sulfite.

Figure 20. CT-121 FGD Gypsum Stack.

OPERATIONAL EXPERIENCE AND IMPLICATIONS

Photographs of stacking operations are presented in Figures 21 and 22. Excavation of gypsum-fly ash waste and casting onto the surface of sedimented waste to form the perimeter dike is illustrated in Figure 21. As shown in this photograph, relatively coarser and drier gypsum-fly ash waste near the slurry inlet line was easily cast. Relatively wetter gypsum-fly ash waste further away from the slurry inlet line did not cast well, and tended to slough and "run" after casting (Figure 22).

Figure 21. Casting of Gypsum-Fly Ash Waste.

The cast perimeter dike was not trafficable with a dozer until after several days of drying and dewatering. After additional drying and dewatering, rehandling and recasting, and grading by a dozer the perimeter dike was successfully constructed as shown in Figures 23 and 24. Note that the cast perimeter dike slopes are relatively steep, generally 1.0 horizontal to 1.0 vertical.

During construction of the stack, the pond was drained and a drying/ dewatering period of 7 to 53 days allowed prior to stacking. Even with the drying/ dewatering period, however, only coarser and drier material near the inlet to the stack was easily cast. Sedimented gypsum-fly ash waste further from the inlet was difficult to cast and required considerable rehandling due to the tendency to slough and "run" after casting.

Figure 22. Casting of "Wet" Gypsum Fly Ash Waste.

At the end of the first few days of construction the trafficability of the cast dikes was generally poor. In some areas, the cast dike was not capable of supporting a small dozer. With continued rehandling and drying/dewatering, the cast dikes were satisfactorily constructed (Figure 24). Based on the results of in situ moisture content and density determinations, it appears that drying/dewatering of the gypsum-fly ash waste to a solids content of 80% is necessary before the material can be easily cast and shaped into a trafficable perimeter dike.

The slopes of the cast perimeter dike after stacking were steep, generally 1.0

horizontal to 1.0 vertical. Below the line of seepage the slopes were flat and sloughing of the cast slope immediately above the line of seepage was observed. The use of relatively flat slopes at the toe of the stack or an internal drain may be necessary to prevent similar conditions in a full-scale facility.

Figure 23. Completed Cast Gypsum Fly Ash Perimeter Dike.

In a full-scale wet stacking disposal facility some of the handling problems encountered during the demonstration project may be minimized by the use of an elevated rim ditch along the perimeter of the stack. Rehandling of the waste during casting, however, may still be required. The ability to allow drying/dewatering periods of 30 days in the rim ditch and/or pond prior to raising the stack should be considered in the design of a stack. Further, the stacking characteristics are sensitive to the fly ash and calcium sulfite content. Accordingly, gypsum-fly ash waste should be produced with a minimum amount of fly ash and calcium sulfite. Based on experience at Widows Creek, fly ash contents should be maintained less than 40% and calcium sulfite contents less than 1%. Improvement in the stackability of the gypsum-fly ash waste will result if the fly ash and calcium sulfite contents are minimized and the gypsum content maximized.

Figure 24. Completed Cast Gypsum Fly Ash Perimeter Dike.

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