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AIR AND WATER POLLUTION CONTROLS

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The recent advent of increasingly stringent regulations regarding environmental protection have made the task of air and water pollution control in the minerals processing industry more complex, more costly, and in some instances, more uncertain. This article reviews technology currently in use for controlling selected pollutants and possible future developments where data are available.

WATER POLLUTION CONTROL

The Federal Water Pollution Control Act established a national goal of pollutant discharge elimination. To achieve this goal, waste water treatment technologies must become effective enough to reduce pollutants to near detectable limits. Pursuing the goal has stimulated the development of several new or improved water treatment techniques.

The most widely practiced method for treating minerals processing waste water is lime neutralization. This simple, low-cost method effectively precipitates many heavy metals when complex compounds are not involved. The most recent advance in lime treatment technology is sludge recirculation, which more effectively uses the lime, reduces supersaturation, and promotes sludge densification.[1]

Complementary techniques are used when lime treatment alone is only partly effective in removing pollutants. For example, neither cyanide nor molybdenum is removed by conventional lime treatment, and advanced technologies must augment this method at the Climax, Colo., mine of Climax Molybdenum Co. Moly is removed from a 2,000-gpm stream by an amine-type anion-exchange resin in a Chem-Seps (Chemical Separations Corp.) continuous countercurrent ion exchange unit. Traces of cyanide are destroyed by oxidation using sodium hypochlorite, and then the remaining heavy metals can be precipitated with lime.

Climax also employs a new technique for removing small concentrations of solids from the very cold waste water, after a conventional sedimentation method proved ineffective. The precipitate is floated by tiny, electrolytically generated bubbles produced in a Dravo Corp. cell. The precipitate is skimmed and filtered, and the effluent water is polished using a high-rate sand filter. The combined Climax treatment operations remove more than 90% of the iron, manganese, molybdenum, copper, zinc, and cyanide in the waste water.[2] Amax is developing a similar process to treat mine drainage and tailings water at its Keystone mine near Crested Butte, Colo.

Another method of cyanide destruction using ozone was extensively tested by the Homestake Mining Co., at Lead, S. Dak.[3]; however, Homestake abandoned the method because of high ozone consumption and failure of the method to completely destroy the cyanide complexes in the waste water stream. The company is testing other treatment methods.

Sulphate is removed as filterable gypsum by neutralizing waste acid generated during the production of titanium dioxide from rutile. The recovered gypsum is used for agricultural purposes. The operation, located at the American Cyanamid Co. in Savannah, Ga., is licensed by Singmaster and Breyer.[4]

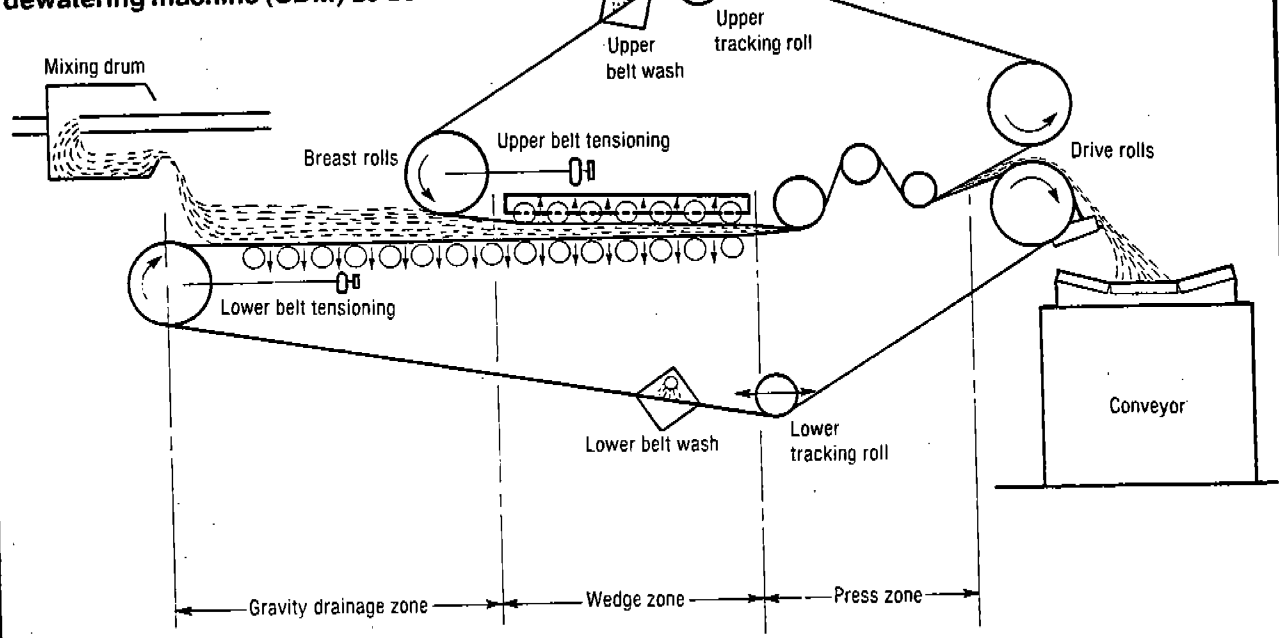
The trend in controlling liquid effluents in the minerals processing industry is toward closed systems for tailings basin management, especially in phosphate fertilizer production.[5] Environmental restrictions and the expense involved in obtaining fresh water dictate the use of such systems. The common factors in closed systems are no regular outflows and recycling of excess water to the plant. For example, Texasgulf Inc. employs a zero-discharge water recycling system at its Lee Creek, N.C., phosphate operation,[6] and Mississippi Chemical Co. uses a closed-loop waste water treatment system at its Pascagoula production facility.[7]

In a new approach to sand filtration, Parkson Corp. claims that its Dynasand filter permits isolated and continuous cleaning of the sand bed, thus eliminating the need for backwashing. In operation, the dirtiest sand is continually withdrawn from the bottom, washed, and then returned to the top.

DEWATERING

The traditional method of dewatering waste slimes is to place the slimes in a tailings pond and permit them to dewater naturally. The supernatent water is decanted for

Fig. 1—Tait-Andritz mobile double-belt filter sludge dewatering machine (SDM) 20 S3



reuse or discharge. However, the increasing cost and declining availability of land, and regulatory pressures that are increasing the cost of building dams and reclaiming abandoned tailings ponds are forcing minerals processers to consider alternative methods of disposal.

One of tne more attractive alternatives to ponding is to place slimes, other tailings, and waste rock back into mined-out areas. However, this method can be costly, can have a negative influence on hydrology, and can inhibit the mining of adjacent areas.

The low pulp densities (less than 15%) and extreme fineness of sludges often make it difficult to use tailings ponds for dewatering. The long settling times require that large amounts of land be tied up and that large, engineered embankments be constructed. These ponds may visually degrade an area and may be prohibitively expensive to reclaim.

One potential solution for dewatering fine sludges is to apply direct current to electrodes submerged in a settling pond. This procedure is effective for a variety of slimes and sludges, as demonstrated in extensive laboratory and field tests conducted by the USBM, but it has not yet been adopted commercially.[8-14] A related procedure, patented by Westinghouse Electric Corp., uses alternating current to effect clarification.

Rapid dewatering is also possible using the newly developed belt press, such as the Tait-Andritz mobile double-belt filter sludge-dewatering machine (SDM) 20 S3 (Fig. 1). The Washington Irrigation and Development Co. (WIDCO) coal mine near Centralia, Wash., uses this machine, which operates by applying gradually increasing pressure to a slurry to force water through Wagner 21 x 15-mesh wire screen belts. A polymer and lime pretreatment is necessary to produce a satisfactory cake and high recovery. This minus 325-mesh product containing mostly bentonite is sufficiently dewatered to be stored with overburden or coarse waste. Belt presses may also be used to dewater finely divided metallic and nonmetallic tailings.

The most extensive dewatering problem in the minerals industry occurs at Florida phosphate mining operations. The current practice in the phosphate industry is to dispose of clay wastes by impoundment behind earth dams up to 30 ft high.[8-9] As the clay waste consolidates in the impoundment, water is removed and reused in the beneficiation process. Water lost to the clays in these impoundments ranges from 500 to 1,500 gal per st of phosphate concentrate produced. Although no waste clay spills have resulted from dam failure since the 1971 enactment of strict rules within the state of Florida, the demands on water and land, due to increasing urbanization and high water use by the citrus, cattle, and phosphate industries, dooms the continued use of impoundments for waste clay disposal.

As a result, the phosphate industry and private and public institutions have actively engaged in research to eliminate the use of impoundments. Any technique that will dewater the clay waste to 30% solids within a year will virtually eliminate the need for large impoundments. Four techniques are under evaluation in large-scale tests: sand-spray, flocculation-thickening, dredge-mix, and flocculation followed by dewatering using mechanical means other than thickening.

Brewster Phosphate, a partnership between American Cyanamid Co. and Kerr-McGee Corp.,[10-11] developed and is currently testing the sand-spray method. The method consists of placing diluted plant slimes in mined-out areas with a "U-shaped" configuration. In these cuts, initial settling to 12 to 15% solids occurs over a period of several months. Then, a floating pipeline equipped with spray nozzles is used to sprinkle sand tailings produced during beneficiation of phosphate ore over the clay. The pore pressure of the sand forces additional release of water from the clay. Test results indicate that clays containing 30% solids, by weight, can be obtained in one year.

Mobil Chemical Co., Gardinier Inc., and Estech Chemical Co. [12-13] are testing the use of chemical flocculants in several devices to reduce the time needed for pre-thickening of clay waste to 12 to 15% solids. Thickeners in which feed is introduced to the sludge bed at a controlled velocity in a horizontal direction have produced promising results. The thickened clay waste is then mixed with sand and placed in a mine cut for further dewatering. This technique can yield waste containing 22-30% solids, by weight, in nine months.

The dredge-mix method involves placing clay waste in small settling ponds for three to 12 months. The thickened clay waste, containing about 17% solids, is removed from the ponds with a suction dredge and mixed with dewatered sand tailings from the phosphate processing operation. The mixture is then pumped to mine cuts for further consolidation. After one year, the clay content should be 30% by weight. International Minerals & Chemical Corp. is conducting large-scale tests.

The USBM is developing a fourth dewatering technique[14] that consists of mixing slime waste with polyethylene oxide (PEO) flocculant and dewatering the resulting agglomerate on a rotary screen. Clay waste containing a nominal 3% solids, by weight, has been dewatered to solids contents of 20-30% in a matter of minutes. The PEO dewatering method is being evaluated in a field test unit at Estech's Silver City mine near Bartow, Fla. (Fig. 2.)

TAILINGS PONDS

There are three "standard" methods for constructing tailings ponds: 1) enclose a pit with borrowed soil (after removing organic materials and debris); 2) excavate a pit and grade soil into a berm surrounding the pit; and 3) erect a berm at one end of a wash or depression to enclose a pit. Berms are usually constructed by spreading thin layers of soil, wetting the layers to the proper moisture content, and compacting them to 90-95% relative density. Ponds must be designed with adequate drainage and storm water diversion around the pond.

Porous sand and gravels are ideal materials for berm construction. Less desirable materials are clay and silts, which drain poorly and are structurally weaker because they have lower permeabilities and higher pore water pressures. Highly organic soils are also undesirable because of their high compressibility and gradual decomposition.

After construction and rough grading of the pond, the interior soil surfaces are treated or lined to reduce permeability and seepage. Pond liners—such as compacted earth, waste tailings (slimes), clay, concrete (asphaltic or portland cement types), shotcrete (gunite), rock or brick—and synthetic membranes or soil sealants—such as asphaltic sprays, organic chemical sealants, inorganic chemical sealants, and soil cements—may all be used to control seepage.

Compacted earth liners are similar to berms, except that thin layers of gravelly or sandy clays are used. The clays are spread evenly over the pond bottom and slopes, moisture is applied, and the layer is compacted to 90-95% relative density. Compaction restricts seepage by filling interstices with fine particles but does not usually reduce seepage sufficiently to comply with environmental regulations. Permeability of earth liners can also increase with time due to cracking or freeze-thaw cycling.

Waste tailings (slimes) can reduce seepage as slimes accumulate and consolidate on the pond bottom, but once again, the method is not sufficient to meet environmental regulations. Waste slime liners also permit higher seepage rates during early pond operation.

High-swell clays, such as bentonite, can be very effective in controlling seepage. These clays will occupy 12 to 15 times their dry bulk volume if they have a high sodium:calcium ratio. Waste water quality can greatly affect the swelling of clays if sodium ions are exchanged with other ions, such as calcium or magnesium, to decrease the sodium:calcium ratio.

Concrete liners can also reduce seepage, but chemical resistance and freeze-thaw cycling are very important design considerations. For example, organic chemicals attack asphaltic concrete liners, and acidic solutions attack portland cement concrete liners. Concretes may also react with the sulphates and chlorides present in some soils.

Shotcrete and similar grout-type liners have potential in large applications, if high costs do not preclude use. These liners also tend to be brittle, so chemical and mechanical shock resistance are important design considerations.

Rock and/or brick linings are very effective, but they also may be economically unfeasible except in small ponds. Chemical resistance and freeze-thaw cycling are again important design considerations. In addition, high levels of dissolved salt in soils or water may cause chemical attack of mortar joints to form "white alkali," which weakens the joint.

Flexible synthetic membranes are very effective in controlling seepage and offer very low permeability, ease of installation, good chemical and mechanical shock resistance, and relatively low cost. Some materials may become brittle, leak (usually through installation punctures or field seams), swell, or puncture; hence, careful design and installation are imperative. Materials in use include: polyvinyl chloride (PVC), butyl rubber, polyethylene, chlorinated polyethylene (CPE), polymerized ethylene-propylene-diene-monomer (EPDM), chlorinated-sulphonated-polyethylene (Hypalon), neoprene, Nordel (hydrocarbon rubber), and vinyl.

Most flexible synthetic membranes are not pure materials but complex formulations of resin, plasticizers, and fillers. Many liner materials may have the same generic name but exhibit considerably different properties. Frequently, liners are fabricated by laminating unreinforced sheet stock with a reinforcing scrim of polyester or nylon. Liner thickness ranges from 10 to 60 mils. Since strength and ultraviolet resistance requirements may differ, different material may be used on slopes than on the bottom. However, joints between dissimilar materials are a potential source of failure and should be used only when known to be reliable. Frequently, liners must be covered with soil to prevent embrittlement by exposure to the sun's ultraviolet rays. When zero seepage rates are needed, double-lined ponds with a drain located in the sand layer between liners are used.

Soil sealants are usually sprayed or spread on inside pond surfaces and allowed to cure. Some sealants are mixed with the top few inches of soil. Considerable reductions in soil permeability are possible with the right sealant; choice of sealant depends on the chemical nature of the pond liquors. In addition, since the sealant is present only in relatively thin, structurally weak layers, mechanical damage and freeze-thaw cycling are important design considerations.

Asphaltic sprays form a thin, impermeable membrane on the soil surface. Organic sealants form impermeable agglomerates, which are subsequently compacted, while inorganic sealants form insoluble salts and gels, which lower permeability. Soil cement is mixed with soils, which serve as a crude form of aggregate, then watered, and allowed to harden.

In summary, there are many methods for controlling containment pond seepage that comply with environmental regulations. Important considerations during design include chemical resistance of the liner or sealant to the impounded solutions, local soils, mechanical shock resistance, freeze-thaw cycling, and weathering. Given the broad range of available methods, it is important to use competent, experienced personnel to design and select containment pond liners or soil sealants.

CARLIN TAILINGS IMPOUNDMENT

The Carlin Gold Mining Co. has a good example of intelligent tailings pond design. The company has been operating a large open-pit gold mine-mill complex in north-central Nevada for nearly 20 years. Mill feed has been nearly

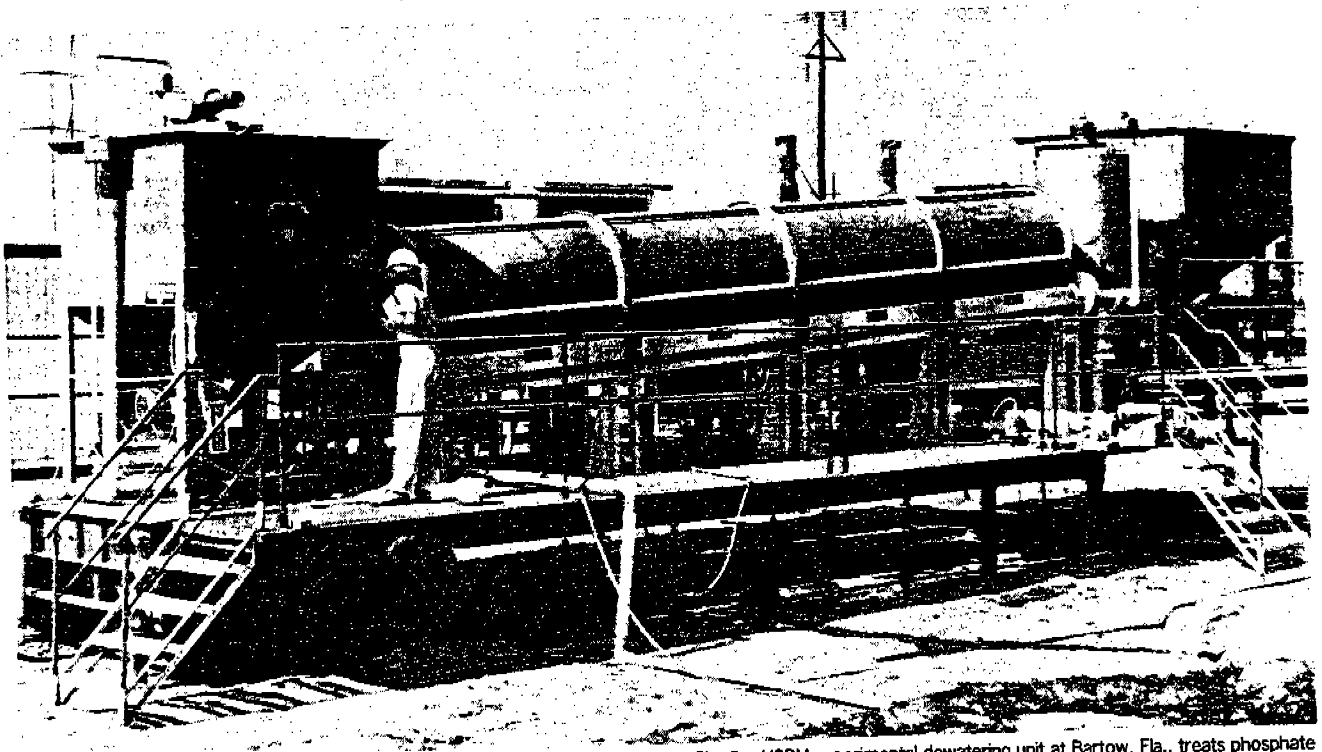


Fig. 2—USBM experimental dewatering unit at Bartow, Fla., treats phosphate slime waste with the flocculant polyethylene oxide (PEO) and dewaters the resulting aggolomerate on a 3-ft-dia x 24-ft-long rotary screen.

constant at 2,300 stpd since start-up. Gold is extracted by conventional cyanide treatment, and then recovered by cementation on zinc after liquid-solid separation. The gold-free "barren" solution containing small amounts of cyanide is then discharged to a tailings pond.

The mill water sequence is a closed circuit operation, and thus there is no deliberate discharge of spent solution to the surrounding environment. The tailings pond in part serves as a large reservoir of cyanide solution for use in the mill, and if not properly maintained, could pose a seepage threat to downstream wildlife and cattle. Consequently, a well-designed tailings dam and emergency cyanide destruction system are important parts of the Carlin operation.

The tailings dam is located across a natural valley. Relatively high relief in the vicinity necessitated a high dam, which was raised in increments from an original 90 ft to the current 225-ft-high, 2,000-ft-long version. The essential design feature of the dam is a sand core, which drains percolating solution from the interior of the dam. This so-called weep system ensures that the dam will not fail due to waterlogging of dam fill material.

Prior to constructing the original 90-ft-high compacted earth dam, the area in the vicinity of the dam base was excavated to bed rock. Subsequent dam additions consisted of compacted mine waste, but a cycloned sand section about 12 ft thick was located between upstream and downstream sections of the dam. This sand section is connected to perforated pipe underdrains to complete the weep system. Monitor wells drilled into the dam are checked routinely to determine that the phreatic line remains at normal levels.

Because this type of tailings dam permits some seepage, a catch basin is used to collect the underdrain effluent. This solution is then pumped back to the tailings pond by reclaim pumps. The below-dam facility is equipped with an automatic caustic soda-chlorinated feed unit to neutralize cyanide should the catch basin for some reason fill and overflow. The unit is maintained on a ready basis, although it has not been needed yet.

Two monitor wells downstream from the dam complete the environmental system. Water samples are checked periodically for cyanide, but none has ever been detected.

URANIUM TAILINGS MANAGEMENT

The tailings from uranium milling operations represent a double threat to the environment. First, the tailings contain radionuclides of uranium and radium; and second, iron, vanadium, molybdenum, and copper are commonly dissolved in the spent acidic leach solutions used to transport the slurried tailings to the tailings pond. Studies of 25 to 30-year-old tailings demonstrate that toxic concentrations of these radioactive and metallic impurities have migrated considerable distances from the tailings ponds[15,16].

The US Nuclear Regulatory Commission (NRC) will no longer allow construction of tailings ponds that permit such leakage. Consequently, the agency has issued the following interim guidelines concerning performance objectives for tailings management:

Siting and design:

1) Locate the tailings area remote from people so that population exposures would be reduced to the maximum extent reasonably achievable.

2) Locate the tailings area so that disruption and dispersion by natural forces are eliminated or reduced to the maximum extent reasonably achievable.

3) Design the isolation area so that seepage of toxic materials into the groundwater system would be eliminated or reduced to the maximum extent reasonably achievable.

During operations:

4) Eliminate the blowing of tailings to unrestricted areas during normal operating conditions.

Post-reclamation:

5) Reduce direct gamma radiation from the impound-

ment area to essentially background.

6) Reduce the radon emanation from the impoundment area to about twice the emanation rate in the surrounding environs.

7) Eliminate the need for an ongoing monitoring and maintenance program by following a successful reclamation plan.

A number of plans for tailings ponds that meet the above criteria have been proposed, primarily in response to the third criterion above. All of these plans provide for an impervious barrier between the tailings and the surrounding environment, and placement of tailings above the local water table.

When a tailings pond is filled to capacity, solid residue from evaporation ponds and other waste materials will be placed on top of the tailings. The entire pond will then be covered with an impervious layer sufficiently thick to reduce gamma radiation and radon gas emanation to the required level. The disposal area will be contoured and topped with soil, and vegetation will be induced to grow in the soil cover to beautify the area and anchor the soil.

Pioneer Uravan Inc.'s Slick Rock mill in Colorado will use a horizontal belt filter and impoundment system to dispose of radioactive mill tailings, in line with NRC interim guidelines. The system, which was designed by Dames & Moore and will be constructed by Kaiser Engineers Inc., uses a horizontal belt filter (Fig. 1) to dewater the tailings to about 20-25% moisture content and a 3,000-ft conveyor to transport the material to the burial site. The burial site will be made up of trenches, the bottom of which will be no lower than 5 ft above the water table.

TAILINGS STABILIZATION

Inactive tailings ponds must be stabilized. Three methods are commonly employed:

- Physical—covering of tailings with soil, rock, or other restraining materials;
- Chemical—use of chemicals to interact with fine-sized materials to form a surface crust;
- Vegetative—growing plants in the tailings or in a surface cover to restrain movement.

Water sprinkling is probably the prime method of suppressing dust in fine tailings, followed by covering with layers of rock and soil from nearby areas. Soil often offers an effective cover while providing a habitat for local vegetation. Crushed or granulated smelter slag has also been used to stabilize a variety of fine wastes, including inactive tailings ponds. However, unlike soils or country rock, slag does not provide a favorable habitat for vegetation. Other physical methods include the use of bark as a covering and harrowing of straw into the top few inches of tailings to form a windbreak.

For chemical stabilization, a reagent is mixed with mineral wastes to form an air- and water-resistant crust that will effectively stop dusts from blowing and inhibit water erosion. Chemical stabilizers can be classified as petroleum-based (Coherex, Landscape, Pentaprime), inorganic silicates, lignin sulphonates (Trastan, Toronil, Norlig, Goulac), and polymeric (Soilgard, DCA-70, Nalco 8820, Crust 500, M-166, Curasol). Chemical stabilization is not as durable as soil covering or vegetation. However, chemicals can be used on sites unsuitable for the growth of vegetation because of harsh climatic conditions or the presence of plant poisons in the tailings, or in areas that lack access to a soil-covering material. Chemical stabilization can also control erosion at active tailings ponds; it will restrict air pollution on portions of these ponds while other portions remain active.

Esthetic considerations and renewability generally favor the use of vegetative waste stabilization, but several adverse factors inhibit the successful initiation and perpetuation of such vegetation. For example, mill wastes are usually deficient in plant nutrients,[37] contain excessive salts and heavy metal phytotoxicants,[38] and consist of unconsolidated sands, which, when wind-blown, can destroy young plants by sandblasting and/or burial.[39] They also lack normal microbial populations.[40] Other, less easily defined problems also inhibit vegetative growth. The sloping sides of waste piles receive greatly varying amounts of solar radiation, depending on direction of exposure, which in turn affects soil temperature and plant photosynthesis. Some slopes are too steep, the waste material sloughs, and plants die. Furthermore, most mill tailings are light-colored and may reflect excessive radiation to plant surfaces, thus intensifying physiological stresses. Other mineral wastes may be extremely dark-colored and absorb excessive heat, thus inhibiting germination or killing seedlings.

Other than excessive acidity, basicity, or salinity in the tailings, wind-blown sands present perhaps the greatest barrier to establishing vegetation. Solutions to this problem include water sprinkling and drip irrigation, covering of the tailings with soil or country rock, hydroseeding, straw mulching, using excelsior-filled matting as a cover, and a combination chemical-vegetative procedure.

Each mineral waste site is unique, and extensive site analysis and reclamation planning are necessary before selecting a stabilizing method.

AIR QUALITY CONTROLS

The minerals industry's "traditional" air pollution problem is the release of sulphur dioxide (SO_2) to the atmosphere. Copper, lead, and zinc smelters generate sulphur dioxide in large quantities, and the industry has dedicated a great deal of time, effort, and money to developing the technology to limit SO_2 emissions consistent with government air quality standards. Other emission problems include volatile fluorides from phosphate processing operations and dust, particulates, and fugitive emissions common to the industry as a whole.

Air quality standards for sulphur dioxide limit the amount of emission and also set limits on ambient SO_2 concentration. To meet US air quality standards, copper, lead, and zinc smelters use contact acid plant technology to produce sulphuric acid from strong SO_2 gases. For economic production of sulphuric acid, a clean, cool, dry, 5-7% SO_2 gas is heated and catalytically oxidized to SO_3. The SO_3 is then absorbed in strong sulphuric acid (98-99% H_2SO_4). Older standard contact sulphuric acid plants produce stack gas emissions in excess of 2,000 to 3,000 ppm SO_2[17]. These emissions may not conform to modern-day air pollution regulations, so double contact or double absorption plants were developed, which have reduced stack gas emissions to less than 250 ppm SO_2.[17,18] Smelters also deal with emissions problems by building tall stacks to increase dispersion of weak SO_2 gases and by scheduling production to meet air quality standards.

Several other processes have been developed to recover SO_2. The Asarco Dimethylamiline (DMA) process recovers liquid SO_2 from copper converter gases.[19,20] At Asarco's Tacoma, Wash., smelter, SO_2 is absorbed by DMA in a scrubbing tower. A strong SO_2 gas is recovered from the SO_2-rich DMA, and the DMA is regenerated in a steam stripping tower. The strong SO_2 gas is dried and compressed to a liquid SO_2 product.

The Japanese have developed three different commercial-scale flue gas desulphurization (FGD) processes for weak SO_2 smelter gases. In the wet lime or limestone scrubbing process, developed by Mitsubishi Heavy Industries and in use at Onahama Smelting and Refining Co.'s Onahama Smelt-

The deer and the antelope play on reseeded tailings disposal area at Exxon's Highland uranium operation in Wyoming's Powder River Basin.

er,[22] a slaked lime slurry removes SO_2 from the flue gas in scrubbing towers and forms a calcium sulphite, which is then oxidized to calcium sulphate (gypsum) at the rate of approximately 400 stpd. The recovered gypsum ($CaSO_4 \cdot 2H_2O$) is used to make wallboard or cement.

The second FGD process is the (sodium-limestone) double alkali process, developed by Showa Denko for Nippon Mining Co.'s Saganoseki smelter.[22] A sodium sulphite solution absorbs SO_2 from the acid plant tail gas in a scrubber and forms sodium bisulphite. The sodium bisulphite is reacted with limestone to regenerate sodium sulphite and precipitate calcium sulphite. The calcium sulphite is apparently filtered and disposed of as solid waste at Saganoseki, but in some double alkali process plants, the calcium sulphite is repulped and oxidized to produce calcium sulphate.

A basic aluminum sulphate-limestone double alkali process treats acid plant tail gas at Dowa Mining Co.'s Okayama smelter.[22] Basic aluminum sulphate [$Al_2(SO_4)_3 \cdot Al_2O_3$] solution absorbs SO_2 in a scrubber and forms $Al_2(SO_4)_3 \cdot Al_2(SO_3)_3$. The SO_2-rich solution is oxidized with air to form $Al_2(SO_4)_3$, which is treated with powdered limestone to precipitate gypsum and regenerate the $Al_2(SO_4)_3 \cdot Al_2O_3$.

The third FGD process is the magnesium oxide scrubbing process, also in operation at the Onahama smelter.[22] In this process, SO_2 is absorbed by a magnesium hydroxide slurry to form magnesium sulphite hexahydrate crystals. The sulphite crystals are filtered, dried, and calcined to regenerate magnesium oxide for recycling and release a strong SO_2 gas, which is sent to a 240-stpd sulphuric acid plant.

Mitsui Mining Co. has constructed a zinc oxide scrubbing process at its Kamioka plant to treat acid plant tail gas.[22] The process is similar to the magnesium oxide process, but the calcination temperature is much lower.

VOLATILE FLUORIDE CONTROL

Phosphate rock contains 3-4% fluorine, and when phosphoric acid is produced, a considerable portion of this fluorine is released as the gases hydrogen fluoride (HF) and silicon tetrafluoride (SiF_4). About 25% of the fluorine remains in the product acid and 25%-plus goes into by-product gypsum. The remainder is released as one of the two gases, which are scrubbed with recycled pond water for emission control and are not usually recovered.

In most wet phosphoric processes, only about 35% of the fluorine in the original rock is available for recovery as fluosilicic acid, that is, the fluorine emitted during evaporation of weak phosphoric acid to concentrate the solution to 52-54% P_2O_5. Recovery is accomplished by scrubbing evaporated gases in a void spray tower with a recycle stream containing approximately 15% H_2SiF_6. Acid strength is maintained by removing strong fluosilicic acid and constantly adding small amounts of water to the recycle tank. Product acid contains 15-25% H_2SiF_6. Texasgulf, Farmland Industries, and USS Agri-Chemicals currently produce such acid.[23]

Two techniques for fluorine recovery from evaporators are in use. The Swenson system, invented by Bennett and Dedert,[24] first condenses all vapors from the phosphoric acid evaporator in a weak solution of fluosilicic acid. The liquor then passes to a flash vessel at a lower pressure, where water equal in amount to that orginally condensed evaporates. This vapor passes to a condenser, where it is totally condensed with cooling water, and then on to the cooling system. The flash evaporation has the effect of cooling the liquor sufficiently to recycle it to the first scrubber. A small amount of liquor is bled from the flash vessel as a 15% solution of fluosilicic acid and water is added to the recycle solution as make-up. Due to entrainment and partial pressure losses, the recovery of fluorine is 90-95% of that evaporated.

The Swift system, invented by W. P. Parish,[25] seems to be gaining in popularity, possibly due to its simplicity of operation. Vapors from the flash chamber of a phosphoric acid evaporation plant pass to a void spray tower, where they are contacted with a solution of fluosilicic acid from three spray levels. This acid is equal in temperature to the vapors, so essentially no condensation of vapors takes place. Fluorine vapors are removed from the stream as fluosilicic acid at any concentration up to 28%; concentrated acid is then bled from the recirculation tank and water is added to maintain the required concentration. The vapors from the scrubber pass through an entrainment separator to remove droplets and then to a normal total condenser and vacuum system. The efficiency of scrubbing depends on partial pressure considerations, so that the stronger the fluosilicic acid produced, the greater the loss in the scrubber. At normal strengths (usually 18-20% fluosilicic acid), a recovery efficiency of 92-93% is possible. The method can be employed for one-stage concentration of all kinds of phosphoric acids, regardless of the source of the phosphate rock and its SiO_2 content.[26]

DUST CONTROL

Currently, nearly all major companies involved in mining and mineral processing are designing and installing improved dust control systems to meet government health and safety regulations. In processing, the basic functions of dust control systems are containment, suppression, and collection.

Containment is accomplished by partially or fully enclosing dust sources, such as material transfer points, screens, conveyors, feeders, crushing equipment, etc. Enclosures must be designed for convenience of plant personnel and for efficient operation and maintenance, and they are usually custom designed for each application and for fabrication at the job site. Ductwork is probably the most commonly employed enclosure in materials processing, especially at material transfer points. Such enclosures should be tight fitting with adequate internal volume and vertical takeoff to enhance material movement and minimize dust loads and power requirements.[27]

Suppression methods attempt to keep an ore from generating dust by applying a moistener, which dampens and agglomerates ore particles to prevent dispersion in the air. Sonic Development Corp. markets the "Sonic Dry Fog Dust Suppression System," which uses a wetting agent and a spray nozzle to direct "fog" at the dust source. Deter Co. Inc. markets the "Pressure Foam" system, which combines air, a foaming agent, and water to produce a foam that is directed under pressure at the dust source.[28] Such systems are fairly effective, but the wetting or foaming agents can have an adverse effect on subsequent mineral processing, such as froth flotation or thickening.

Dust collection is the most complex and most widely used dust control method. The selection or design of dust collection systems depends on the design of the primary processing equipment, the characteristics of the dust particles, and emission control standards. Four general types of equipment are available: mechanical collectors (gravity separators), wet collectors (scrubbers), filters, and electrostatic precipitators (ESP). Their respective efficiencies range from 30 to 90%, 80 to 99%, 99%-plus, and 95 to 99%-plus.[29] The Environmental Protection Agency (EPA), which maintains a continuous program to evaluate existing and new dust collection equipment and technology, considers fabric filters and ESP to be the most effective means for removing particulates. These two techniques represent the "state of the art" of dust collection. Most new dust collection equipment is a variation of existing equipment and is usually designed to treat specific types of dust.

DRY PARTICULATE COLLECTION

Dry collectors include fabric filters, electrostatic precipitators, granular bed or mechanical filters, and cyclonic collectors. Fabric filters may be shaker type, reverse air, pulse jet, or may use a combination of methods to periodically clean the fabric. The pulse jet is the most widely used filter for dust control in a dry system. ESP and granular bed filters require large capital expenditures and are used for operations such as gypsum and lime calcination. Cyclonic collectors, which are the least effective and the least costly, are generally limited to pretreatment stages to reduce dust loading in final control equipment.

WET PARTICULATE COLLECTION

Wet collectors include irrigated precipitators, cyclonic spray chambers, liquid-level scrubbers, tower-type scrubbers, dynamic scrubbers, and Venturi scrubbers.

Irrigated precipitators are essentially electrostatic precipitators that use water to wash away the collected dust.

Cyclonic spray chambers usually incorporate internal spray nozzles, a top vertical gas outlet, tangential gas inlet, and bottom drain. Internal spin dampers may be used to induce higher velocities at the tank wall. The device operates at a pressure drop of 4-6 in. of water.

Tower-type scrubbers employ a horizontal, perforated plate or series of plates with rising gases and descending liquid. Gas flow upward interferes with descending water flow through the perforations, so that a layer of highly agitated liquid builds up on each plate. Pressure drop is in the range of 4-8 in. of water.

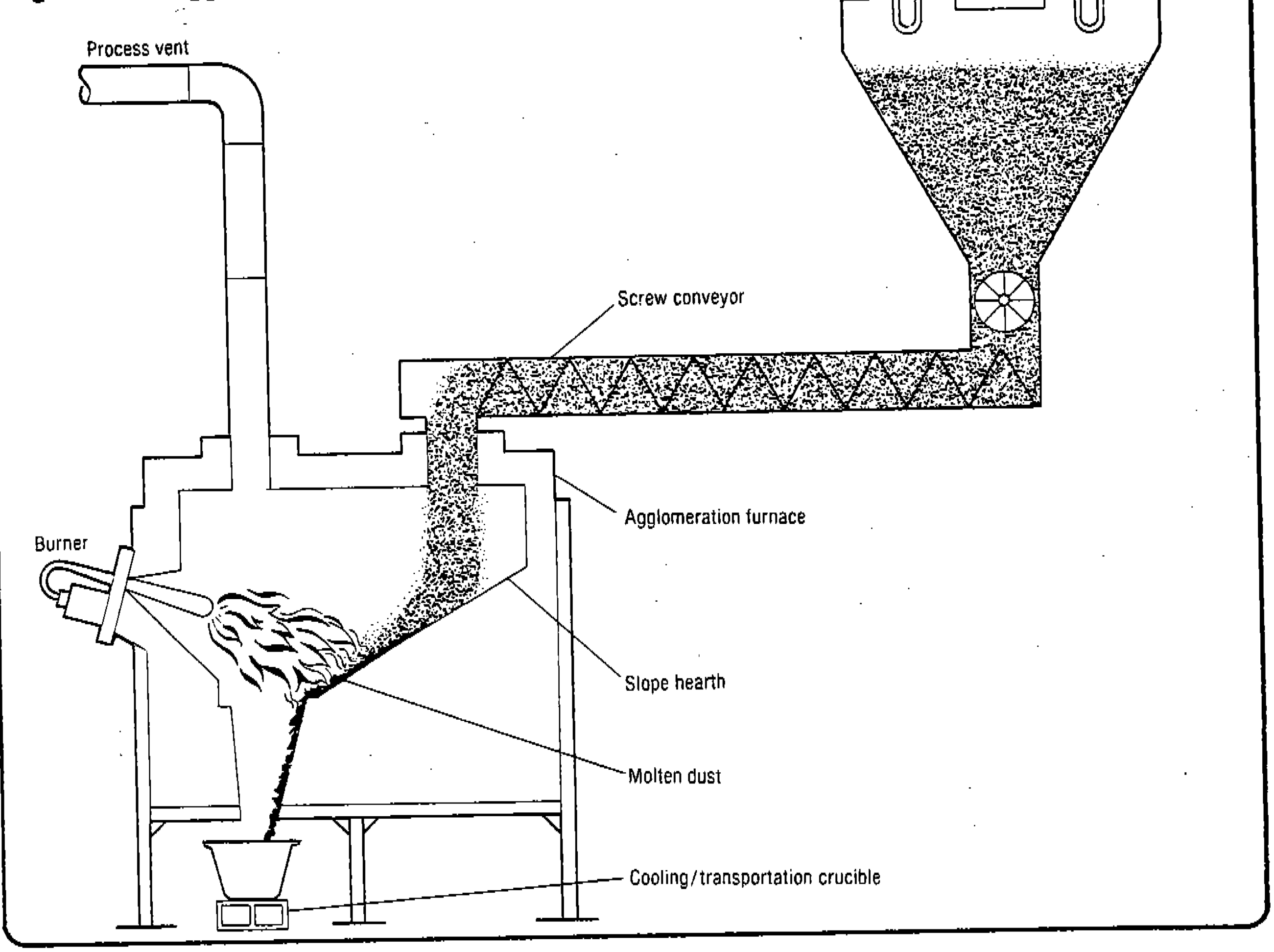
Dynamic or wet fan scrubbers depend on the rotational motion of a wet fan to enhance contact between the dust-laden air and a wet surface. The wet fan also serves as a means of inducing air flow. Dust collection efficiency is higher than for the liquid-level or tower-type scrubber, but energy requirements are also higher.

Venturi scrubbers offer the highest dust collection efficiency, but also require the most energy. Fixed-throat Venturies operate at pressure drops of 10-12 in. of water for typical dust control, but a pressure drop of 90 in. is required for submicrometer fume control. Generally, the higher the input energy, the higher the collection efficiency for all wet scrubbing devices.

NEW PARTICULATE TECHNOLOGY

Air Pollution Systems Inc. has devised the "Ionized Enhanced Scrubber System," which imposes a high electrostatic charge on particles in a gas stream before they enter the inlet of a venturi scrubber.[31] Testing of the system on titanium dioxide aerosol demonstrated efficiencies of 92% to 99% for 0.8 to 2.0-micrometer particles, respectively.

Fig. 3—Flash agglomeration furnace



The Southern Research Institute, under contract with the EPA, is developing a novel electrostatic precipitator consisting of a precharger and a downstream collector to remove particulates with high electrical resistivity. Pilot plant testing on highly resistive fly ash (10^{12} ohm-cm) demonstrated that the precharger doubles the effective specific collector area of the electrostatic precipitator. Initial estimates indicate that the precharger will cost about one-third to one-half that of one conventional electrical section.[33]

The Beltran tubular polystage electrostatic precipitator has an "egg crate" grid arrangement with needle-like, high-voltage electrodes, and it can run intermittently or continuously wet, making it essentially self-washing. It reportedly avoids re-entrainment of highly resistive or conductive particles and operates at high face velocities with reduced energy costs.

"Electrostatic Filtration," which involves imparting an electrical charge to particulates followed by collection through fibrous or fabric filters and through an "Electrofluidized Bed" (EFB), is being used to improve recovery efficiencies of very fine particles.[34] The system offers increased collection efficiency over conventional ESP for highly resistive dusts.

High-Gradient Magnetic Separation (HGMS) is being evaluated as a means of removing magnetic particulates from blast furnace gaseous effluents.[32] The gas passes through a cannister packed with fibrous ferromagnetic material contained in a magnetic field. Magnetic particles collect on the magnetic fibers, and when the magnetic field is removed, the particles are flushed from the matrix by a pulse of air. The technique recovers 99%-plus 0.5-micrometer-dia particles. Power requirements are estimated at 3.2 kJ per cu m (2.0 hp per 1,000 cfm).

Acoustical agglomeration techniques employ sonics for conditioning fine dust particles to increase mean particle size and decrease the number and density of particles. This increases the efficiency of dust collection systems downstream. The method is recommended for collection of fine particles (0.02 to 2 micrometers) where conventional collection devices are ineffective.[27]

The Bergsoe Flash Aggolomeration Furnace[35,36] reduces airborne metallic-bearing dusts in smelters. The dust is collected in a baghouse dust hopper, fed into a small furnace where it melts instantaneously, runs down a permanently open taphole into an iron vessel, and cools. The unit illustrated in Fig. 3 is in operation at a secondary lead smelter. At this smelter, the solidified agglomerated material, which equals 20% of the volume of the original dust, is fractured and fed into the lead blast furnace. The technique minimizes dust handling by operators and eliminates fugitive emissions from stored flue dusts, but it is limited by the melting point of the dusts. Dusts containing large amounts of zinc oxide or tin oxide are ruled out; dusts containing copper and low amounts of zinc and tin require pretreatment before blast agglomeration.

FUGITIVE EMISSIONS

Fugitive emissions may be classified into process fugitive emissions and open dust source fugitive emissions. Process fugitive emissions include particulates and gases generated by grinding, classifying, and beneficiation operations. Open dust source fugitive emissions may come from raw material storage piles, from which wind and machinery generate emissions.

Several techiques will control process fugitive emissions. A building may be used as an evacuation system by employing the sealed roof as a collection hood. However, major disadvantages include large flow rates, high energy requirements to move the air volume, and possible environmental problems inside the building. A second approach is the use of canopy hoods in conjunction with fabric filter removal devices. A canopy hood can operate with less air volume, but peak generation of fumes or dusts can cause problems. A third method of control is total machine enclosure, which is a compromise between the other two techniques. However, this can create major problems when introducing and removing materials.

For open dust source emissions, total or partial enclosures may be used, but maintenance can be a problem. Spray systems using water and/or chemical wetting agents are effective methods of dust control, but these techniques cannot be applied at temperatures below freezing. Other methods include reducing the material drop distance, using chutes, and using a mobile or stationary stacker. To minimize the effect of wind erosion, stabilizing the surface layer of a pile by wetting and binding the surface particulates is often effective. Shielding of storage piles from the wind has also been used. Dust is controlled on roadways by watering and oiling, and by using chemical dust suppressants.

SUMMARY

The minerals processing industry is taking major strides to adapt state-of-the-art control technology to more complex environmental problems, to develop new procedures to meet environmental regulations, and most importantly, to comply with today's regulatory requirements. Future environmental R&D activities will certainly reflect the philosophy of environmental protection at a cost that can be borne by the industry.■

1) Smith, J. H., "The Advantage of a Crowd for Acid Waste Liquors," MINING ENGINEERING, Dec., 1972, pp 57-59.
2) Gott, R. O., "Development of Waste Water Treatment at the Climax Mine," MINING CONGRESS JOURNAL, April, 1978, pp 28-34.
3) Jeffries, L. F., and A. Tczap, "Homestake's Grizzly Gulch Tailings Disposal Project," MINING CONGRESS JOURNAL, Nov. 1978, pp 23-28.
4) CHEMICAL ENGINEERING, Jan. 16, 1978, p 148.
5) Skaglund, Timothy W., and Warren E. Hansen, "Water Balance and Tailing Deposition Aspects of Closed System Tailings Basins," MINING CONGRESS JOURNAL, Vol. 65 No. 11, Nov. 1979, pp 27-31.
6) Mercer, Douglas G., "A Zero Discharge Acid-Water Recycle System For Wet Process Phosphoric Acid Plants," Preprints, ISMA Technical/Economic Conference, Orlando, Florida, Oct. 23-27, 1978, pp 195-207.
7) "Plant Closes Loop On Its Wastewater Treatment," ENVIRONMENTAL SCIENCE AND TECHNOLOGY, Vol. 12, No. 3, March 1978, pp 260-263.
8) US Bureau of Mines, "The Florida Phosphate Slimes Problem, A Review and a Bibliography," Bureau of Mines IC 8668, 1975, 41 pp.
9) Lamont, W. E., J. T. McLendon, L. W. Clements Jr., and I. L. Feld, "Characterization Studies of Florida Phosphate Slimes," Bureau of Mines RI 8089, 1975, 24 pp.
10) Lawver, J. E., J. D. Ravlerson, and C. C. Cook, "New Techniques in Beneficiation of Phosphate Rock," AIME Fall Meeting, Orlando, Fla., September 1978.
11) Timberlake, R. C., "Disposal of Mining Waste In Central Florida Phosphate Field," *Proceedings, Second Mineral Waste Utilization Symposium*, ITTRI and US Bureau of Mines, Chicago, Ill., 1970, pp 237-240.
12) Oxford, T. P., and L. G. Bromwell, "Dewatering Florida Phosphate Waste Clays," Annual AIME meeting, Las Vegas, Nev., Feb. 1980.
13) Bromwell, L. G., and D. T. Raden, "Disposal of Phosphate Mining Wastes," *Current Geotechnical Practice in Mine Waste Disposal*, ASCE, New York, 1979, pp 88-112.
14) Smelley, A. G., and I. L. Feld, "Flocculation Dewatering of Florida Phosphate Clay Wastes," Bureau of Mines RI 8349, 1979, 21 pp.
15) Taylor, M. J., and P. E. Antommaria, "Immobilization of Radionuclides at Uranium Tailings Disposal Sites," *Proceedings of Symposium on Uranium Mill Tailings Management, Vol. 2*, Colorado State University, Fort Collins, Colo. Nov. 20-21, 1978, pp 13-45.
16) Johnson, J. E., "Pathways of Radionuclides Released From Tailings Piles," *Proceedings of Symposium on Uranium Mill Tailings Management, Vol. 1*, Colorado State University, Fort Collins, Colo., Nov. 20-21, 1978, pp 51-58.
17) Browder, T. J., "Modern Sulfuric Acid Technology," CHEMICAL ENGINEERING PROGRESS, Vol. 67, No. 5, May 1971, pp 45-50.
18) Mandelik, B. G., and W. Turner, "Selective Oxidation Sulfuric and Nitric Acid Plants: Current Practices," CHEMICAL ENGINEERING, April 25, 1977, pp 123-130.
19) Henderson, J. M., and J. B. Pfeiffer, "Liquid SO_2 From Copper Converter Gases—The Asarco Dimethylanaline Process," paper in *Air Pollution Control and Clean Energy*, edited by C. Rai and L. A. Spielman, AIChE Symposium Series, Vol. 2, No. 156, 1976, pp 69-73.
20) Henderson, J. M., and J. B. Pfeiffer, "How Asarco Liquifies SO_2 Off-Gas at Tacoma Smelter," MINING ENGINEERING, Vol. 26, No. 11, November 1974, pp 36-38.
21) Rosenbaum, J. B., Masami Hayashi, and G. M. Potter, "Sulfur Dioxide Emissions Control in Japanese Copper Smelters," Bureau of Mines IC 8701, 1976, 15 pp.
22) Ando, Jumpei, "SO_2 and NO_x Removal Technology in Japan—1976," Environmental Technology Information Center, Japan Management Association, 3-1-22, Shiba Park, Minato-ku, Tokyo, 1976, 61 pp.
23) Williams, J. M., "Phosphate Rock End-Use Products and Their Costs," Zellars-Williams Inc., Final Report, Contract No. J0377000, Prepared for US Department of Interior, Bureau of Mines, OFR 102-79, July 1978, 73 pp. (This report is available for public inspection at the Interior Library, Washington, D.C.; the Florida Bureau of Geology, Tallahassee, Florida; and at the following Bureau of Mines offices: Washington, D.C.; Pittsburgh, Pa.; and Denver, Colo.)
24) Bennett, R. C., and W. G. Dedert (assigned to Whiting Corp.), "Apparatus for Removing Impurities From Vapors Released in Evaporation Process," US Patent 2,929,690, March 22, 1960.
25) Parish, W. P. (assigned to Swift & Co.), "Fluorine Recovery," US Patent 3,091,513, May 28, 1963.
26) English, M., "Fluorine Recovery From Phosphatic Fertilizer Manufacture," CHEMICAL AND PROCESS ENGINEERING, Vol. 48, No. 12, December 1967, pp 43-47.
27) Mular, Andrew L., and Roshan B. Bhappu, "Mineral Processing Plant Design," Society of Mining Engineers of AIME, N.Y., 1978, pp 733-753.
28) ENGINEERING & MINING JOURNAL, "Health Consciousness Spurs Dust Control," June 1979, pp 140-141.
29) Lasater, R. C., and J. H. Hopkins, "Removing Particulates from Stack Gases," *Chemical Engineering Deskbook*, October 17, 1977, pp 111-119.
30) *Environmental Science and Technology*, Vol. 12, No. 11, October 1978, pp 11-24.
31) Kearns, M. T., "High Intensity Ionization Applied to Venturi Scrubbing," JOURNAL OF THE AIR POLLUTION CONTROL ASSOCIATION, April 1979, Vol. 29, No. 4, pp 383-385.
32) Gooding, C. H., and D. C. Drehmel, "Application of High Gradient Magnetic Separation to Fine Particle Control," JOURNAL OF THE AIR POLLUTION CONTROL ASSOCIATION, May 1979, Vol. 29, No. 5, pp 534-538.
33) Sparks, L. E., G. H. Ramsey, and B. E. Daniel, "Collection of Fly Ash with High Electrical Resistivity in a Pilot Plant Electrostatic Precipitator Preceded by the EPA/SoRI Precharger," JOURNAL OF THE AIR POLLUTION CONTROL ASSOCIATION, July 1979, Vol. 29, No. 7, pp 745-747.
34) Ariman, T., M. S. Ojalvo, and D. C. Drehmel, "Novel Concepts, Methods and Advanced Technology in Particulate/Gas Separation, Report on a Work Shop," JOURNAL OF THE AIR POLLUTION CONTROL ASSOCIATION, Vol. 29, No. 8, August 1979, pp 818-822.
35) Mackey, T. S., and S. Bergsoe, "Flash Agglomeration of Flue Dust," JOURNAL OF METALS, November 1977, pp 12-15.
36) Meek, R. L., (editor), Symposium Proceedings, "Control of Particulate Emissions in the Primary Nonferrous Metals Industry," Monterey, Calif., March 18-21, 1979, pp 98-122. (Sponsored by the US Environmental Protection Agency, Office of Research and Development Metals and Inorganic Chemicals Branch, Industrial Environmental Research Laboratory, Cincinnati, Ohio.)
37) McDonald, W. R., and M. B. Shirts, "Vegetative Stabilization Tests on an Acidic Copper Tailing," SME-AIME Fall Meeting and Exhibit, Tucson, Ariz., Preprint No. 79-321, 1979, 7 pp.
38) McKell, C. M., "Selection, Propagation and Field Establishment of Native Plant Species on Disturbed Arid Lands," Bulletin 500, Utah Agricultural Experiment Station. Utah State University, Logan, Utah, 1979, 49 pp.
39) Reynolds, J. F., M. J. Cwik, and N. E. Kelley, "Reclamation of Anaconda's Open Pit Uranium Mine, New Mexico," RECLAMATION REVIEW, Vol. 1, 1978, pp 9-17.
40) Russell, T. V. (chairman), *Vegetative Rehabilitation and Equipment Workshop, 33rd Annual Report*, Casper, Wyo., February 11-12, 1979, Range Management Staff, USDA Forest Service, P.O. Box 2417, Washington, D.C. 20013, 65 pp.