PN-ABY-029

The Hashemite Kingdom of Jordan

Ministry of Water and Irrigation

Water Quality Improvement and Conservation Project

Industrial Audit Background Paper:

Phosphate Mining Industry

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Development Alternatives, Inc.

USAID

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United States Agency for International Development
Contract No. 278-0288-00-C-4026-00

August 1994

PREFACE/ACKNOWLEDGMENTS

This report presents the background materials for Phosphate Industry prepared with emphasis on the pollution prevention/waste minimization (PP/WM) and water conservation practices for this industry. The report was prepared by Mr. Krishna Mayenkar, P.E. of Harza Consulting Engineers and Scientists (Harza), Chicago, Illinois, under subcontract with Development Alternatives, Inc. (DAI), Washington, D.C.

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Special appreciation is given to Dr. Mohammed Bani Hani, Secretary General of MWI; Eng. Qusai Qushad, Seretary General of WAJ; Mr. Khaldun Abuhassan, Chairman of the Chamber; Mr. Walid Al-Khatib, Director Genaral of the Chamber; Dr. Muwaffaq Saqqar, Project Coordinator; and to DAI, as represented by Edwin D. Stains, Chief of Party; for their cooperation and confidence.

BACKGROUND MATERIAL REPORT
PHOSPATE INDUSTRY

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United States Agency
For International Development

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HES 3335KVM/ksb6
H0005HD 941019

PHOSPHATE MINING INDUSTRY BACKGROUND MATERIALS

INDUSTRIAL WASTEWATER DISCHARGE PREVENTION WATER QUALITY IMPROVEMENT AND CONSERVATION PROJECT

Amman, Jordan

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1.0 INTRODUCTION

This document presents the materials collected as background information for a pollution prevention, waste minimization, and water conservation audit of the Jordan phosphate mining industry.

1.1 BACKGROUND

Development Alternatives, Inc. (DAI) under a contract with the United States Agency for International Development (USAID) is performing an Industrial Wastewater Discharge Prevention Program in Amman, Jordan. This Program is one of the four components of the Water Quality Improvement and Conservation project funded by the USAID. The Program is being performed by DAI with full coordination between the Ministry of Water and Irrigation and the Amman Chamber of Industry. This Program includes conducting pollution prevention and waste minimization (PP/WM) audits, feasibility studies, and designing for demonstration activities at selected industrial facilities.

PP/WM techniques are defined as any techniques to prevent or reduce waste generation by source reduction or recycling activities. These activities must reduce either the volumes or the concentrations of pollutants generated prior to treatment, storage, or disposal of the waste.

Based on a ranking methodology, the PP/WM Committee has selected ten industries with potential needs for PP/WM audits. One of these industries is the "phosphate mining industry." Harza Consulting Engineers and Scientists (Harza), Chicago/USA, has been retained by DAI to lead the PP/WM audit for this industry.

The purpose of these audits is to assist the industries in the Amman-Zarqa Basin to assess pollution problems and the alternative solutions to achieve desired levels of pollution prevention, water conservation, and wastewater treatment under the following subtasks:

- Subtask 1.1 - Audit Coordination;
- Subtask 1.2 - PP/WM Background Materials Preparation;
- Subtask 1.3 - Pre-Investigation Meeting;
- Subtask 1.4 - Audit;
- Subtask 1.5 - Post-Inspection Meeting; and
- Subtask 1.6 - Audit Evaluation Report.

1.2 OBJECTIVES

In this document, background information has been assembled by performing a comprehensive literature review. The purpose of the literature review was to identify the available techniques and technologies being practiced for PP/WM for the industry under Subtask 1.2. The objective of this document is to present the results of this review with a focus on the most effective techniques and clean technologies being practiced for PP/WM for the phosphate industry.

The literature review included, at the least, the following sources: published literature and personal contacts with the United States (U.S.) Environmental Protection Agency (EPA). The literature consisted of PP/WM related articles, journal articles, conference proceedings, U.S. EPA documents and communications, and books on pollution and pollution controls.

2.0 PHOSPHATE MINING

The phosphate fertilizer industry is totally dependent on phosphate rock as its major raw material. After mining and preparation, the rock is used directly in the production of phosphoric acid, normal superphosphate, triple superphosphate, nitrophosphate, electric furnace phosphorus, and defluorinated animal feed supplements. Phosphoric acid is subsequently used to produce superphosphate, ammonium phosphates, complex fertilizers, superphosphoric acid, and dicalcium phosphate. The phosphate rock industry consists of mining and rock processing operations centered close to ore reserves.

Chemically, phosphate rock may be considered to contain a substituted fluorapatite, $3Ca_3(PO_4)_2.Ca_2F$. Nearly all phosphate ores contain a modified form of this structure in which some of the phosphate is replaced by fluoride and carbonate. The total fluoride content of typical phosphate rock is approximately 4 to 5% by weight, expressed as fluorine.

The ingredient of the rock that is of economic interest is tricalcium phosphate (TCP), $Ca_3(PO_4)_2$, also known in industry as bone phosphate of lime (BPL). The rock is usually graded on the basis of its BPL content, e.g., 62 BPL rock contains 62% TCP by weight.

2.1 PHOSPHATE MINING INDUSTRY IN JORDAN

Jordan Phosphate Mines Co. Ltd. (JPMC) was founded in 1934 as a private firm to exploit the phosphate reserves of the Russeifa area, 15 kilometers (km) northeast of Amman. In 1953, JPMC was incorporated as a public shareholding company jointly owned by the government of Jordan and the private sector. From 1953 until 1988 three other production sites were developed in south Jordan, namely the Alhassa mine (1962), the Alabaid mine (1979), and the Elshidiya mine (1988). The current yearly production of JPMC is approximately 7 million tons of phosphate rock ranging between 66-75% TCP. The design production capacities of these three operating mines are given in Table 1. The Alabaid mine has been selected for the PP/WM audit.

The phosphate formations mined in Jordan cover about 60% of the country's total area in the formations of the Upper Cartaceous, covering a wide belt of central Jordan, and lie near the surface. The phosphate deposits at Alhassa and Alabaid are found in two horizons in a lenticular bed whereas at Russeifa and Elshidiya they occur in continuous beds.

Phosphate mining in Jordan is typically open pit mining. An overburden layer is removed and a layer of phosphate rock is exposed. The rock is then removed from the deposit by dynamite blasting. Rocks are usually hauled by truck to the processing plant.

JPMC produces several grades of phosphate rock ranging from 66 to 75% TCP content in addition to the lower grades (62 to 66% TCP) produced to meet the special requirements of some customers. Upon completion of new beneficiation units at Elshidiya mine, scheduled for 1995, a higher grade production unit of approximately 77% TCP will be installed. After 1995, the production of mine-oriented materials should continue to follow the increased production in Elshidiya mine through 2000, and substantially increase production after the year 2000. The production in Alhassa and Albaid will stop by the year 2000 or before.

2.2 PHOSPHATE MINING PROCESS IN JORDAN

The following section generally described the phosphate mining process used in Jordan, shown pictorially in Figure 1 of this report.

Mining

The exploitation of phosphate started at the Russeifa mine by manual underground mining, using the "room and pillar" method. In 1956, semi-mechanized mining was adopted and was also used at the Alhassa mine starting in 1962. Mechanized open cast mining was first applied in 1959 at Russeifa, where the stripping ratio of overburden to phosphate is favorable. Since then, this method has been in continuous use at Russeifa. It was introduced in 1966 at Alhassa and in 1979 at Alabaid.

In open cast mining, the overburden is drilled, blasted, and the broken and loosened material is piled and loaded into dumptrucks. The sterile material is transported into waste dump areas less than 1,000 meters away.

The uncovered phosphate bench is usually loosened by ripping, drilled and blasted if necessary, and loaded into dumptrucks for hauling to crushing and screening plants.

Piles of mined phosphate can literally form mountains that may potentially provide obstacles for water courses, contaminate groundwater basins, and increase the salinity of surface and groundwater.

Ore Processing

Crushing and Screening.

Raw phosphate from the mine sites is hauled to jaw or impact crushers, rated at 250 - 450 tons per hour. All material is fed to the crushing and screening plants where the oversized material (> 1/2 inch) is rejected and stockpiled for further treatment in the future. The < 1/2 inch material is either fed to the dryers or to the beneficiation plants.

Beneficiation and Drying.

Phosphate from the crushing and screening plants, which contains 66 to 68% TCP from the Russeifa mine or 70 to 72% TCP from both the Alhassa and Alabaid mines, is fed directly to rotary cascading dryers operated with heavy fuel oil to produce a dry product which contain 1 - 3% moisture, know as unbeneficiated grade phosphate. Phosphate ores which contain 60 - 62% TCP at Russeifa or 66 - 68% TCP at Alhassa and Alabaid are fed to beneficiation plants for upgrading.

In the beneficiation plants, phosphate is fed to slurriers, log washers, and wet screens to reject the 4 mm (or + 6 mm) oversize material. Two or three stages of agitation are followed by hydrocycloning, where the underflow of + 270 mesh products are fed to pusher centrifuge filters to produce phosphate cakes which contain 16 - 18% moisture. The overflow of the

hydrocyclones is rejected as slimes which contain poor phosphates with impurities of silica, carbonates, and clayey materials. The phosphate cakes are fed to heavy fuel oil-fired dryers to produce beneficiated grades of 66 - 68% TCP at Russeifa and 73 - 75% TCP at Alhassa and Alabaid.

Fine phosphates from dryers separated by the electrostatic precipitator at Russeifa mine are collected and bagged in 50 kilogram bags. This material, named "JORPHOS", is sold for direct application in acidic soils. It contains 29.3 - 30.2% P_2O_5 and its granulation is 80% <100 mesh size which contains 30% <200 mesh size.

3.0 PHOSPHATE MINING AND PROCESSING IN THE UNITED STATES

Typical unit operations involved in the phosphate mining industry are crushing, grinding, screening, flotation, thickening, filtering, drying, bagging and storage. The mining and beneficiation processes vary somewhat at different locations based on grade, screen analysis and pebble concentrate in the feed.

There are two reported beneficiation process in the U.S.: eastern and western. They are briefly described below and shown in Figures 2 and 3.

Eastern Process

This process consists of the following unit operations:

- Screened slurry pumping to the beneficiation facility
- Washing using hammer mills and log washers
- Separation of sand and clay (slimes) from phosphate bearing pebbles and sands by screening
- Cyclone separation of slimes (colloidal clays, fine sands)
- Slimes discharge to ponds
- Underflow coarse material to flotation processing (tailings to disposal)
- Drying and grinding
- Packaging

Western Process

This process varies slightly from the eastern process and consists of the following unit operations:

- Crushing and scrubbing of ore material
- Screening, crushing by pug mill and classification
- Slimes removal using cyclones and thickeners. (Slimes to settling pond or tailings pond)
- Underflow coarse material to floatation and filtration
- Drying and grinding
- Packaging

The process used in the Jordan facilities appears to be similar to the eastern process but without the flotation operation.

4.0 WASTEWATER, SOLID WASTES AND PARTICULATE EMISSIONS

The significant pollution problems reported in the phosphate mining industry are:

Wastewater

- Thickener overflows
- Hydrocyclone overflow
- Flotation cell underflow
- Minewater drainage

Air Emissions

- Particulate emissions from crushing, drying and packaging operations

Solid Wastes

- Slimes (fine waste material)
- Tailings (heavy waste material)

Each of these waste discharges is discussed briefly below.

4.1 WASTEWATER DISCHARGES

Phosphate mining operations use large amounts of water primarily for washing, wet screening, flotation processing and transportation. Other uses are for non-contact cooling water and for domestic purposes. A typical water usage rate is 41.00m^3/metric ton of product.

Other discharges, such as rainfall and surface runoff, may contribute to the total effluent flow generated at a mining facility.

Suspended solids are the principal pollutant in wastewater discharges. Treatment technologies available for removing suspended solids are varied, and only a small number are widely used. The unlined settling pond is, by far, the most widely used form of control technology.

The phosphate rock slimes problem may well be the most important of all phosphate ore processing difficulties. The industry has been active for a number of years attempting to devise methods for dewatering the slimes, but until available schemes become economically feasible, settling ponds will continue to be widely used.

Phosphate slime, which constitutes about one-third of the total matrix mined, has been a disposal problem to the phosphate industry ever since mining began in Polk County, Florida, about 1890. The disposal problem increased significantly in the late 20's with the introduction of the flotation process: the matrix mined for flotation has a higher clay content than ore mined before the use of flotation.

The treatment of slimes consists of gravity settling through an extensive use of ponds. At 3 to 5% solids, the slimes either flow by gravity through open ditches with necessary lift stations or are pumped directly to the settling ponds.

After an initial settling and clarification period, some of the water containing the slimes is reclaimed and can be recycled to the plant. However, subsequent settling of the slimes to release more water is very slow. The slow settling characteristic, or inability to dewater, is a common property of Florida phosphate slimes. At present, over 202.5 x 10^6 m^2 of active and inactive settling areas exist, surrounded by more than 480 km of earth dams. About 16.2 x 10^6 m^2 of new settling areas are being constructed each year. The magnitude of the disposal problem is readily appreciated when it is realized that the industry produces some 36 million metric tons of these waste clays (dry basis) annually. A chemical analysis of slimes solids is presented in Table 2.

Current dewatering concepts are briefly presented in Figure 4. Other processes which have been proposed include freeze-thawing, electro-osmosis, chemical coagulation, spherical agglomeration, and drainage systems.

These potential solutions to the problem are being evaluated, and the likelihood of finding feasible alternatives to above-ground impoundments appears very good.

Mine water drainage is generated only when phosphate mines lie below the water table. In these cases, the water table must be lowered with massive pumping to drain the mine.

4.2 AIR EMISSIONS

The major air pollutant of concern emitted by the production of chemical and fertilizer minerals is respirable (less than 7-um geometric mean diameter) particulate matter. This particulate contains free silica, the crystalline silicon dioxide which is mostly quartz, tridymite, and cristobalite.

The American Conference of Governmental Industrial Hygienists (ACGIH) has suggested a threshold limit value (TLV) for respirable particulates as shown in the following equation:

$$TVL = \left(\frac{10}{\%\ quartz + 2}\right) \ (for\%quartz>1\%)$$

where TVL = *threshold limit value, mg/m*^{3}
$\%\ quartz$ = *percent of quartz as respirable dust*

Respirable particulates with less than 1% quartz are termed "inert" and a TLV of 1- mg/m^3 is suggested for these. The criteria document on crystalline silica published by the National Institute of Occupational Safety and Health (NIOSH) states that occupational exposure shall be controlled so that no worker is exposed to a time-weighted average concentration of free silica greater than 50 *u*g/m^3 as determined by a full shift sample for up to a 10-hr workday, 40-hr workweek. In addition, particulate matter is one of the air quality criteria pollutants and has a 24-hr primary ambient air quality standard of 260 *u*g/m^3.

Phosphate rock production in the U.S. accounts for an estimated 44% of the total particulate emission from chemical and fertilizer industry mining and benefication. The high percentage is caused by the large volume of phosphate rock production and the kinds of operations necessary

to run an industry of its size. For example, the loading of railroad hopper cars, a major source of particulates, is an operation used only by industries with large amounts of material to handle.

The sources of air emissions during phosphate rock mining and processing are pictured in Figure 5. The emission factor which corresponds to each source and the following discussion are summarized in Table 3.

No sampling for the dragline source in Florida has been done. However, some estimates have been made on fugitive emissions from other source assessment studies on mining. Dust emissions from surface mining of coal were measured by MRC as 0.085 g/kg of overburden removed. Studies have indicated that overburden removal was the largest emission source at strip mines, estimated at 0.05 g/kg. Engineering Research and Technology, when providing input on the air quality aspects of coal development in northwest Colorado, proposed an emission factor of 0.024 g/kg of overburden removal, including a correction for climatic conditions and control measures (watering) at the mines.

Overburden removal for phosphate rock mining is believed to be much less of a fugitive dust source than in coal mining because much less overburden material is handled; the average overburden depths in Florida are about 6 m versus up to 60 m for coal mining. Also, phosphate rock deposits in Florida are generally mined in areas where the water table is near the surface. Because the moisture content of the overburden is high, less dust is produced.

An emission factor for the overburden removal of phosphate rock lies toward the bottom of the range offered by PEDCo–0.024 g/kg to 0.05 g/kg of overburden. PEDCo estimated particulate emissions from dragline operations at an open pit cooper mine in Butte, Montana. The emission rate of ore mined was 0.0004 g/kg. This excavation area was noted to be moist and nondusting. Although actual measurements were not taken at phosphate rock mines, an emission factor of this order of magnitude was felt to be representative for the mining of the ore.

After the overburden is removed, the ore is placed into sluice pits, broken up by hydraulic monitors, and subsequently pumped to the benefication plant. Each company's beneficiation methods differ slightly and are dependent on the characteristics of the matrix. In each case, however, the benefication is a wet process and therefore not a source of air emissions.

The beneficiated rock is transferred to open storage piles. As this material is often moist, no controls are used or expected in the future, although some emissions do result from the operations. The moist material is usually conveyed to a rotary dryer.

Emission factors for phosphate mining are based on Florida phosphate operations. Western phosphate mining operations are recognized as having greater air emissions because the rock is not generally wet-sluiced to beneficiation operations and dust may occur in transport from pit to processing plant. In addition, the overburden removal for western phosphate mining averages more than 6 m and is drier than the Florida overburden. For western mines, a more realistic overburden emission factor would be near the high end of the range or 0.05 g/kg of overburden. Thus for western mines, the overall emission factor could be about 7% greater than the factor for Florida mines.

4.3 SOLID WASTES

Solid wastes generated in mining operation are non-phosphate pebbles, clay, and sands separated from phosphate bearing materials. These solids are discharged as slimes (very fine and colloidal materials) and tailings (coarser materials) and stored in ponds for permanent disposal.

5.0 STATE OF THE ART - AIR POLLUTION PREVENTION AND CONTROL

If the overburden stripping and phosphate matrix mining is carried out under somewhat "wet" conditions, industry does not consider this a source of air emissions. Therefore, they have no controls on this operation and do not expect a future need. In the absence of wet conditions controls may be needed.

The beneficiated rock in open storage piles is moist. No controls are used or expected in the future, although some emissions do result.

Typically, the moist material is conveyed by an underground belt to a rotary dryer. The dust from the dryer is handled by cyclone-wet scrubber combinations. In this way, the emission becomes a stack emission. Collection efficiencies of this control device are greater than 95%, and no further controls are expected in the future. At this point, the material may be ground, sometimes under wet conditions; the procedure varies from plant to plant. One plant does not use a grinding operation at all.

The material is transferred from the dryer to storage silos. Control devices on rock transfer junctions are typically scrubbers, with an average collection efficiency greater than 95%. From the storage silos, the rock is dropped into railroad hopper cars for transportation to fertilizer manufacturing centers. In facilities typical of the phosphate industry, loading is accomplished manually from overhead storage by an operator standing at the roof level of the railroad car. Usually the drop areas have flexible rubber couplings which deliver the rock to within about 0.610 m (2 ft) of the top of the loading door; this helps direct the rock. However, the loading problem is not dusting caused by the drop, but the pickup of dust in the displaced air from the railroad car. The industry is working to control the dust in this operation.

Companies have installed extensive ductwork systems to capture the dust and exhaust it to a scrubber. However, the equipment must be used properly. Dust-catching enclosures must be clamped onto the railcar doors tight enough to capture the dust. One plant uses a mechanized system in which the ends of eight loading ducts fit over the tops of the eight railcar doors and exhaust the displaced air to a scrubber. In older facilities, this may not be possible. At one location, for example, the available headroom between the bottom of the storage silo and the top of the railcars is limited, and cars are typically not of uniform height or door configuration. This situation required the design of a system to load the cars from an outside hopper adjacent to the silos, allowing for more working space. In either case, it appears that the future trend is first to contain the fugitive emission and then to treat it as a stack emission.

Table 4 lists the latest technologies used to prevent air pollution at each unit operation.

Control practices such as judicious selection of raw materials, good housekeeping, and minimizing leaks and spills are of limited importance in the mineral industries. Raw materials are fixed by the composition of the ore. Good housekeeping, leaks, and spills have little impact on waste loads. Non-contact water is rarely used in these processes.

The areas where control is important include wastewater containment and separation and control of mine drainage water, process water, and rain water. These areas are further described below:

Containment

Most wastewater treatment and control facilities in the chemical and fertilizer minerals industry use one or more settling ponds. During periods of heavy rainfall, these "ponds" are often washed out, and the settled solids may be swept along as well. In many other cases, the pond may remain intact during rainfall, but its function as a settling pond is significantly impaired by the large amount of water flowing through it. In addition to problems caused by rainfall and flooding, waste containment in ponds can be troubled with ground seepage around and beneath the pond, escape through pot holes, faults and fissures below the water surface, and the physical failure of pond dams and dikes.

In most cases, satisfactory pond performance can be achieved by proper design. When this is not possible, alternative treatment methods--thickeners, clarifiers, tube and lamella separators, filters, hydrocyclones, and centrifuges--can be utilized.

Separation and Control of Wastewater

In these industries, wastewater may be separated into three categories: mine drainage water, process water, and rain water runoff.

Mine drainage water and process water are typically controlled and contained by pumped or gravity flow through pipes, channels, ditches and ponds. Rain water, though, is often uncontrolled; it may either contaminate process and mine drainage water or flow off the land independently as nonpoint-source discharges. Rain water runoff increases suspended solid matter in rivers, streams, creeks or other surface waters used for process water supply.

Suspended solids are the principal pollutant in the wastewater discharges of the mineral industry. The treatment technologies available for removing suspended solids from wastewater are numerous and varied, but only a relatively small number are used widely.

Table 5 shows the approximate breakdown of usage for the various techniques.

Generally, the current industry experience with settling ponds shows effluents with total suspended solids concentrations ranging from 14,000 mg/m^3 to 703,000 mg/m^3. Performance data for some treatment systems are presented in Table 6.

Chemical and fertilizer mineral operations are typically conducted in relatively isolated regions where there is no access to publicly owned wastewater treatment plants.

6.0 POLLUTION PREVENTION, WASTE MINIMIZATION AND WATER CONSERVATION OPPORTUNITIES

Pollution prevention is achieved by implementing programs which will result in reduction in waste generation. Waste generation, in turn, can be achieved by looking into ways to improve and/or modify unit processes and operations and process efficiency without affecting the product quality. Some of the approaches being evaluated are discussed below.

6.1 EMERGING TECHNOLOGIES

New methods to collect dust emissions from beneficiation plants, particularly in the rail car loading area, are coming into view.

The development of hydrometallurgical processes to recover phosphorus from matrix or concentrates by direct acidulation may make it possible to improve recovery rates and reduce water disposal problems. New mining and processing techniques may be developed to utilize the potential resources of the Florida Hawthorn Formation or the Phosphoria Formation in the Western United States.

Wet grinding is one of the technologies being considered to minimize air pollution for phosphate rock processing facilities. It is described below:

Wet Grinding

The most promising air pollution control technique for dryers and calciners is the recent move toward wet grinding of rock for the manufacture of wet-process phosphoric acid (WPPA). The rock is ground in a water slurry and then added to the WPPA reaction tanks without drying. This has not been done previously because the water entrained with the ground rock would require a stronger acid in the WPPA reaction (or be removed by evaporation) to maintain the 54% P_2O_5 strength needed for production of fertilizer. Historically, 93% sulfuric acid has been diluted to 58% for the WPPA reaction prior to addition to the reactor to permit removal of the heat of dilution. If added to the reactor at 93% strength, the heat of dilution coupled with the heat of reaction would exceed the capacity of the vacuum flash cooler used for temperature control. Also, it was widely accepted that the higher temperatures would result in formation of smaller crystals of waste gypsum which would complicate the separation of product acid from waste gypsum.

Two companies have overcome their reservations about the wet grinding process. They have designed larger flash coolers on the reactors to remove the heat of dilution, and have found no significant difference in the crystal size of the gypsum. The products from the reactor are fed to the evaporators at 28 to 32% P_2O_5 acid, the same as the conventional WPPA process.

The only significant problem created by wet grinding is the water balance around the plant. EPA's effluent water regulations require zero discharge by 1980. Wet grinding adds about 300 gallons per minute to an effluent discharge volume which operators of

WPPA plants are already finding difficult to control. However, the potential savings (elimination of the energy intensive phosphate rock dryer and its air pollution control system and air pollution controls for the grinder) is a strong incentive to the operator.

Plant management contends that the major driving force for the process is not improvements in technology, but increasingly expensive fuel costs and stringent air emission regulations. It is now less expensive to treat the wet rock than to contend with high energy costs and increasingly stringent air regulations.

The impact of the wet grinding process could be far-reaching since about 70% of all phosphate rock is ultimately used to produce fertilizer, and 85% of the rock used for fertilizer must first be converted to phosphoric acid. If wet grinding proves to be a trend in the industry (and present indications are that it will), the growth rate for phosphate rock dryers will become negligible. Of course, there will continue to be a requirement for dry rock unless ways are found to introduce wet ground rock into the processes other than WPPA. Much of this need may be filled by the capacity of existing dryers rather than construction of new ones. The need for emission controls on phosphate rock grinders, though diminished, will continue since the calcination process will probably continue at its current rate of growth and calcined rock must be ground.

Wet-rock grinding has five advantages:

(1) Reduces by about half the capital expense - from receipt of unground wet rock through the point of feeding it into the acid processing system.

(2) Eliminates dry-rock dust pollution.

(3) Improves fuel economy by 2.5 gallons per ton of phosphate rock ground, which combines with electrical power savings to reduce operating costs by $3.00-$4.25 per ton of P_2O_5.

(4) Improves reliability, thus reducing the required amount of surge of ground rock. If a plant is located near a mine, a rock slurry can be pumped directly to the plant from the mine, eliminating rail transportation and belt conveyors.

(5) Reduction in radiation levels will occur as dry-rock grinding is replaced with wet-rock grinding and dryers are eliminated. This will lower fugitive dust levels, thus lowering escaping radionuclides, and also result in lower radiation levels in the immediate vicinity of the grinders and the eliminated dryers.

By converting from dry to wet grinding, a company expects to save 8 million gallons of fuel oil and 18 million kWh of electricity per year in producing wet process phosphoric acid at its New Wales complex. Conversion will cost about $11.3 million.

6.2 WATER POLLUTION CONTROL, PREVENTION AND MINIMIZATION

As discussed earlier, the slime water discharge is the major source of wastewater. Any improvement in slime settling characteristics will tremendously assist in improving the quality of

water associated with slime discharge, thereby allowing the industry to recycle more and better quality water.

The improvement in settling of colloidal or fine clay particles can be achieved by using effective and appropriate flocculating and coagulating agents. Clay particles are negatively charged. A coagulating agent such as alum (aluminum sulfate) can effectively bind these particles and improve their settling rate. An addition of other polymeric flocculating agents, either cationic or non-ionic, generally further improves the settling properties.

Addition of flocculating agents prior to dissolved air floatation, hydroclones, centrifuges, or slime pond will improve the dewatering performance of these systems. This will result in better solid/water separation. The important aspect is to determine if addition of such agents will impact the product quality. Certainly addition of flocculating agents prior to the slime settling ponds will help improve settling and overflow water quality.

As stated in Section 4.0, other processes currently being evaluated are electro-osmosis, freeze-thawing, spherical agglomeration and drainage system. High efficiency clarifier designs, such as tube settlers, inclined plate clarifiers, and reactor-clarifiers with sludge recirculation can be further considered to improve the slime settling and removal processes and improve water recycle quality.

It should, however, be noted that an addition of a chemical agent may increase the sludge volume but it will be offset by increased density and sludge compactness.

Improving the settling characteristics should allow the facility to recycle an improved quality water from slime holding ponds or clarification devices. The recycled water can be used for washing and wet screening. A small amount of water will need to be blown down to control the build-up of impurities within the system. The impurities that will need to be controlled are:

- Total suspended solids;
- Total phosphorous;
- Fluoride; and
- pH.

The blowdown water can be treated and further recycled. A two-stage lime neutralization process can be used for the blowdown treatment.

The first treatment stage provides sufficient neutralization to raise the contaminated water (Containing up to 9000 mg/L F and up to 6500 mg/L P) from pH 1.0 - 2.0 to pH 3.5 - 4.0. The resultant treatment effectiveness is largely dependent on constancy of the pH control. At a pH level of 3.5 to 4.0, the fluorides will precipitate principally as calcium fluoride (CaF_2).

The partially neutralized water following separation from the CaF_2 (pH 3.5 - 4.0) now contains 30 - 60 mg/L F and up to 5500 mg/L P. This water is again treated with lime sufficient to increase the pH level to 6.0 or above to removal phosphorous.

The reduction of the P value is strongly dependent upon the final pH level, holding time, and quality of the neutralization facilities, particularly mixing efficiency. The sludge from these systems can be disposed in the slime ponds. Ultimately, however, the additional fluorides and particulates (phosphate) and other minor impurities collected become part of the solid waste generated through the system.

7.0 REFERENCES

The following documents were reviewed to prepare this report:

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8. U. S. Geological Survey. "Hydrology and Water Quality of Unmined and Reclaimed Basins in Phosphate-Mining Areas, West-Central Florida." U. S. Department of the Interior. Washington, D.C. 1993

9. U. S. Environmental Protection Agency. "Phosphate Rock Plants- Background Information for Proposed Standards (Draft EIS)." Office of Air Quality Planning and Standards, Research Triangle Park, NC. 1979

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TABLES

TABLE 1: CURRENT DESIGN PRODUCTION CAPACITIES OF JORDAN PHOSPHATE ROCK MINES

Mine	Production (million tons/year)
Alhassa	3.5
Alabaid	2.5
Elshidiya	3.25 (as of 1995)
Total	9.25 (as of 1995)

TABLE 2: CHEMICAL ANALYSES OF AS-RECEIVED SLIMES SOLIDS
(Percent)

Chemical Analyses	Sample																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average	High	Low
Calcium oxide	8.3	12.8	18.5	18.6	18.4	26.9	21.6	16.4	9.1	18.7	18.7	9.6	24.6	11.2	10.1	16.2	26.9	8.3
Phosphorus pentoxide	5.1	8.2	13.7	15.7	16.2	19.7	17.3	11.6	5.9	13.5	11.0	8.3	17.2	8.7	9.7	12.0	19.7	5.1
Equivalent BPL[a]	11.1	17.9	29.9	29.9	35.4	43.0	37.8	25.3	12.9	29.5	24.0	18.1	37.6	19.0	21.2	26.2	43.0	11.1
Calcium oxide / Phosphorus pentoxide	1.63	1.56	1.35	1.36	1.14	1.37	1.25	1.41	1.54	1.39	1.70	1.16	1.43	1.29	1.04	1.35	1.70	1.04
Magnesium oxide	6.7	2.3	4.0	1.5	0.8	2.0	1.4	3.2	3.6	2.7	6.2	1.6	3.0	2.2	1.6	2.9	6.7	0.8
Aluminum oxide	10.3	13.7	12.2	13.5	16.8	10.4	12.9	12.6	12.5	10.7	7.6	12.5	8.2	13.0	12.1	11.9	16.8	7.6
Iron (III) oxide	4.6	4.3	2.5	1.9	1.7	1.6	3.2	2.3	5.5	5.4	2.1	3.3	1.6	8.3	2.8	3.4	8.3	1.6
Silicon dioxide	47.6	46.1	30.4	33.4	28.2	23.1	27.5	33.5	45.8	34.5	34.0	49.1	28.6	39.5	46.6	36.5	49.1	23.1
Sodium monoxide	0.3	0.3	0.2	0.3	0.1	0.2	0.3	0.2	0.3	0.2	0.3	0.3	0.5	0.4	1.2	0.3	1.2	0.1
Potassium monoxide	0.5	1.4	0.6	0.8	0.6	0.6	0.8	0.2	1.3	0.5	0.5	1.5	0.4	1.1	0.8	0.8	1.5	0.2
Fluorine	1.1	1.2	2.3	1.6	1.6	2.2	1.8	1.6	0.7	1.4	1.4	1.0	1.8	1.0	1.2	1.5	2.3	0.7
Carbon	1.1	0.8	1.7	1.0	0.5	1.5	0.5	1.9	1.0	0.6	1.8	0.4	1.0	0.6	0.7	1.0	1.9	0.4
Carbon dioxide	2.2	1.3	5.0	1.5	1.0	3.4	1.3	4.6	2.9	1.2	5.3	0.7	2.2	1.1	1.0	2.3	5.3	0.7
Sulfur	0.22	0.17	0.21	0.31	0.11	0.36	0.12	0.22	0.10	0.14	0.18	0.12	0.31	0.21	0.17	0.20	0.36	0.10

[a]*BPL = Bone phosphate of lime (% BPL x 0.4576 = % P_2O_5)*

TABLE 3: AIR EMISSION SOURCES OF PHOSPHATE ROCK MINING AND BENEFICATION[a]

	Dragline		Drying	Silo Storage	Loading	Total
	Stripping of Overburden	Mining of the ore				
Emission factor, g/kg	0.025	0.0004	0.071	0.105	0.161	0.362
Control devices:						
Existing Types	None	None	Cyclone and wet scrubbers	Scrubbers	Enclosure	b
Effectiveness, %	None	None	>95	>95	c	b
Future trends	None	None	None	None	Exhaust fugitive dust to control device	b

[a]*Numbers were derived from six sample runs made at one site. See Appendix H.* [b]*Not applicable.* [c]*Not available.*

TABLE 4: AIR POLLUTION CONTROL TECHNOLOGIES

Unit Operation	Major Applied Pollution Control Technology
1. Mining	Wetting mining area by trucks
2. Beneficiation	No air emissions due to wet operation
3. Conveyance	Generally rock is wet. No controls required.
4. Drying	Scrubbers
5. Calcining	Scrubbers
6. Grinding	Fabric Filters
7. Material Handling and Storage	▸ Enclosure for conveyors and piles ▸ Fabric filters for pneumatic conveyance

TABLE 5: CONTROL TECHNOLOGY AND ITS USE FOR REMOVAL OF SUSPENDED SOLIDS

Control Technology	Percent of Facilities Using Technology
Settling ponds (unlined)	95 to 97
Settling ponds (lined)	<1
Chemical flocculation (usually with ponds)	2 to 5
Thickeners and clarifiers	2 to 5
Hydrocyclones	<1
Tube and lamella settlers	<1
Screens	<1
Filters	<1
Centrifuges	<1

TABLE 6: PERFORMANCE OF TREATMENT SYSTEMS

Plant	Total Suspended Solids, g/m³		Percent Reduction	Treatment
	Infuent	Effluent		
Phosphate rock:				
A	5,620	193	96.56	Pond.
B	329	50	84.80	Ponds.
C	1,684	21	95.45	Ponds.
D	2,036	39	96.26	Unknown.
E	6,500	17	99.36	Ponds.
F	2,985	645	78.39	Flocculating agent, thickener.

FIGURES

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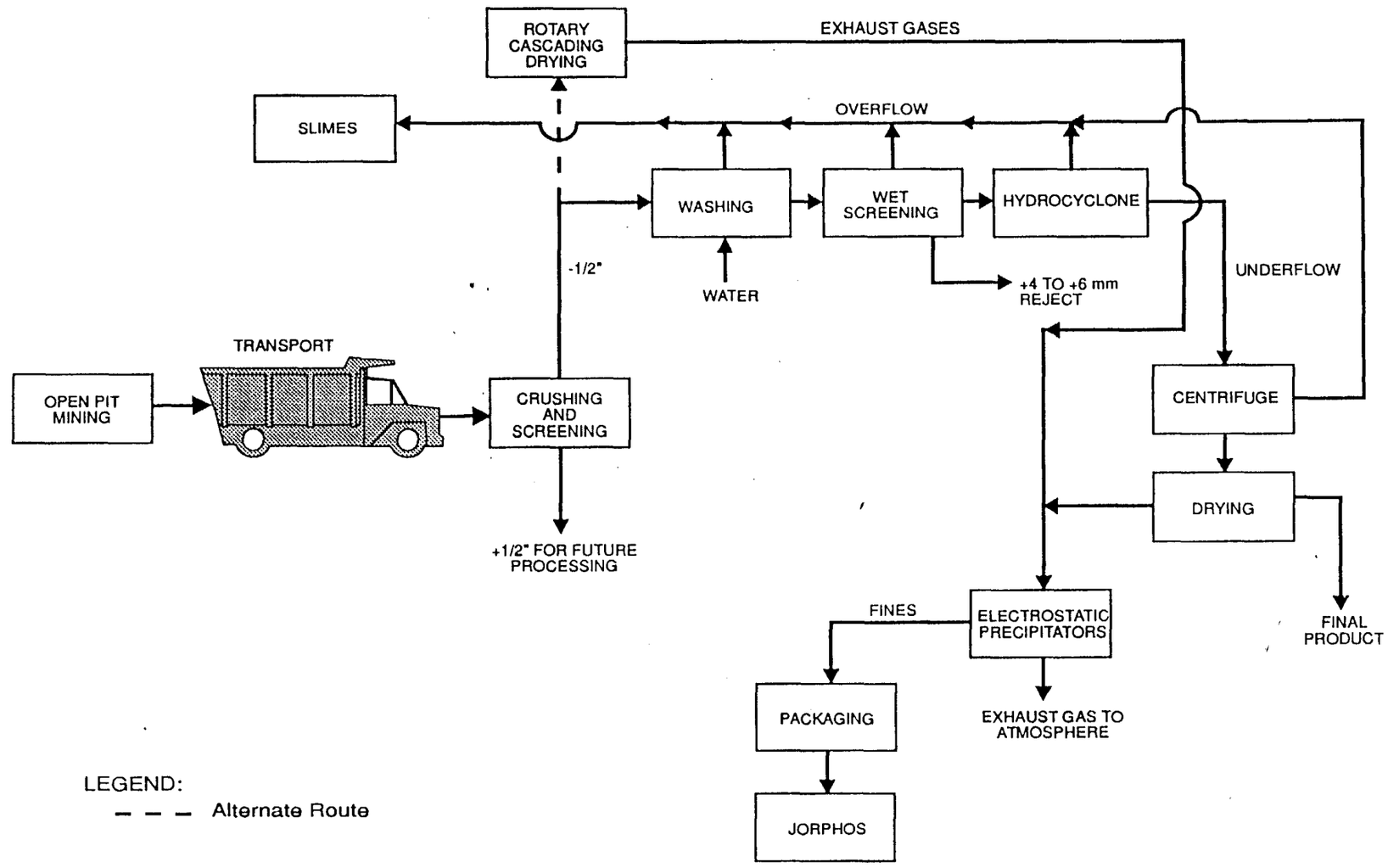

SOURCE: Phosphate Rock Plants, modified Figure 3.3 (EPA, 1979)

Figure 1

GENERALIZED FLOW SCHEME FOR JORDAN PHOSPHATE ROCK MINING INDUSTRY

INDUSTRIAL WASTEWATER DISCHARGE PREVENTION
WATER QUALITY IMPROVEMENT AND CONSERVATION PROJECT

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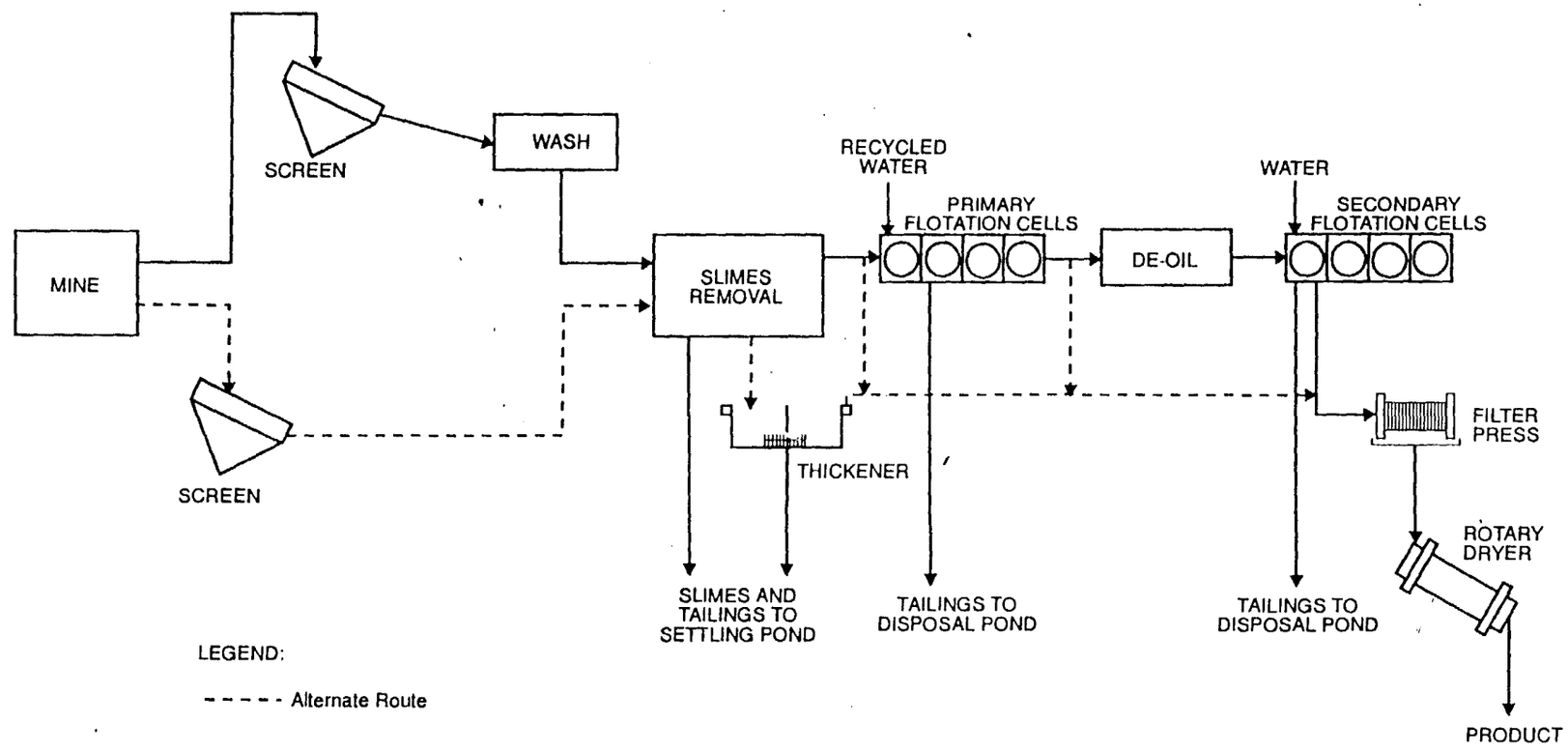

SOURCE: Source Assessment-Chemical and Fertilizer Mineral Industry State of the Art (EPA, 1978)

Figure 2

U.S. PHOSPHATE ROCK MINING AND BENEFICIATION- EASTERN PROCESS

INDUSTRIAL WASTEWATER DISCHARGE PREVENTION
WATER QUALITY IMPROVEMENT AND CONSERVATION PROJECT

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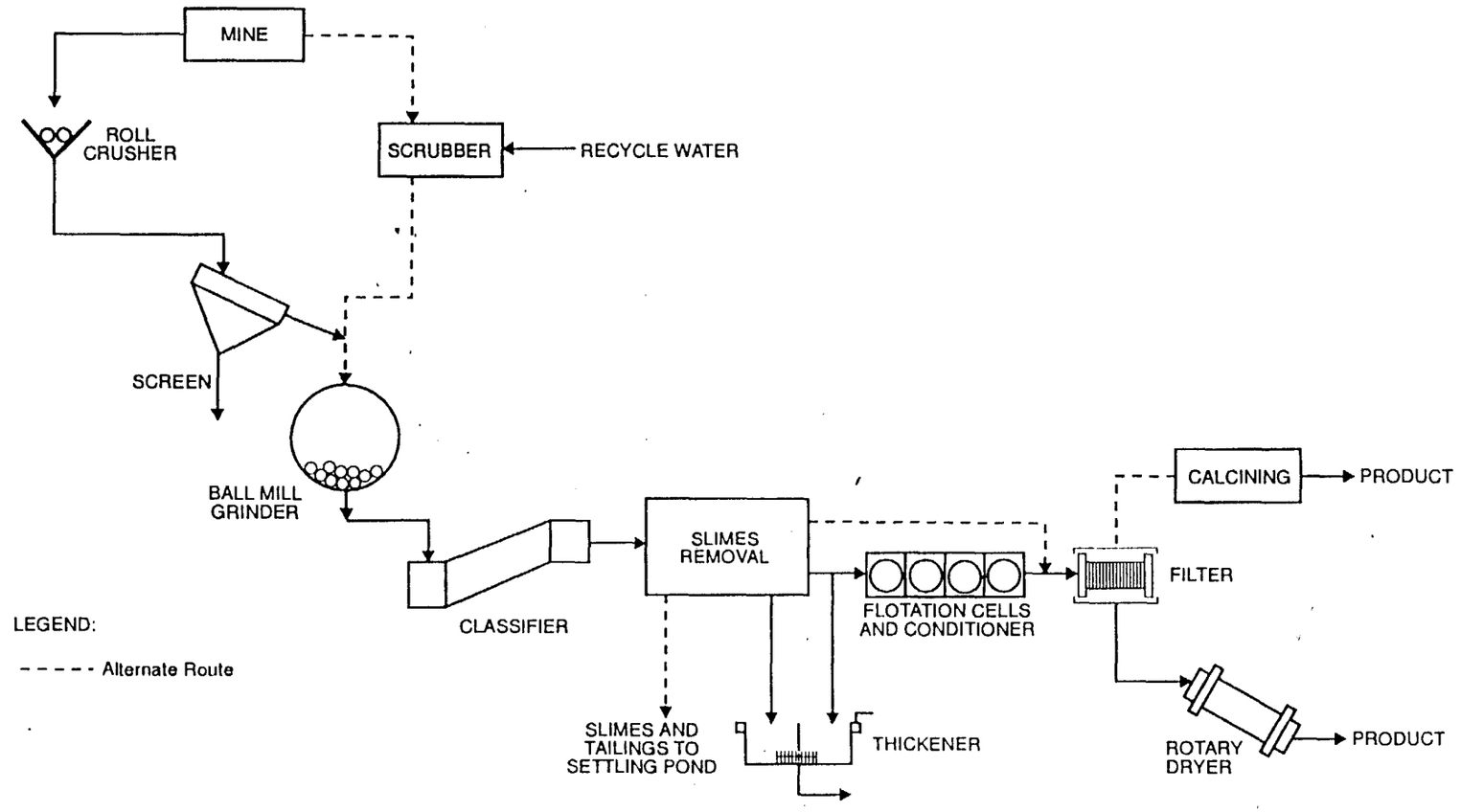

SOURCE: Source Assessment-Chemical and Fertilizer Mineral Industry State of the Art (EPA, 1978)

Figure 3

PHOSPHATE ROCK MINING AND BENEFICIATION- WESTERN PROCESS

INDUSTRIAL WASTEWATER DISCHARGE PREVENTION
WATER QUALITY IMPROVEMENT AND CONSERVATION PROJECT

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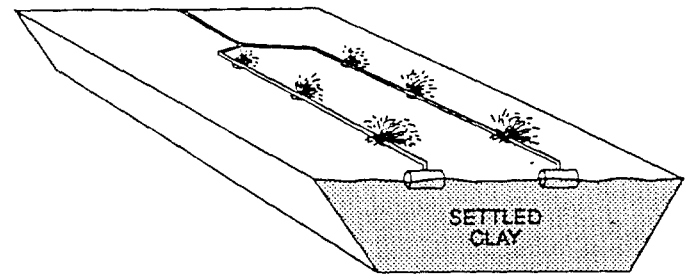
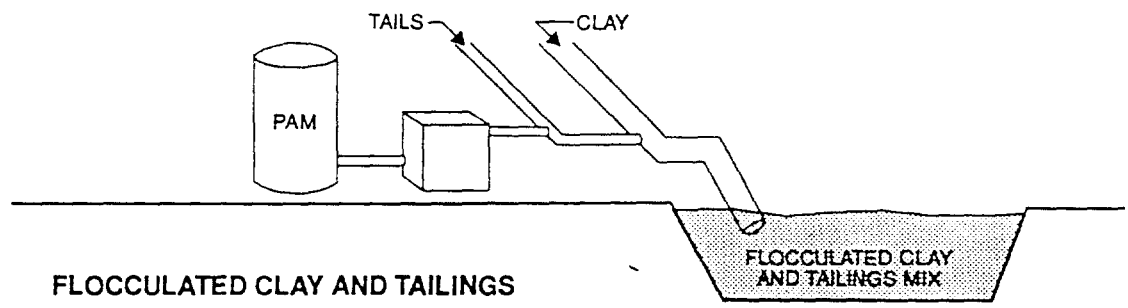
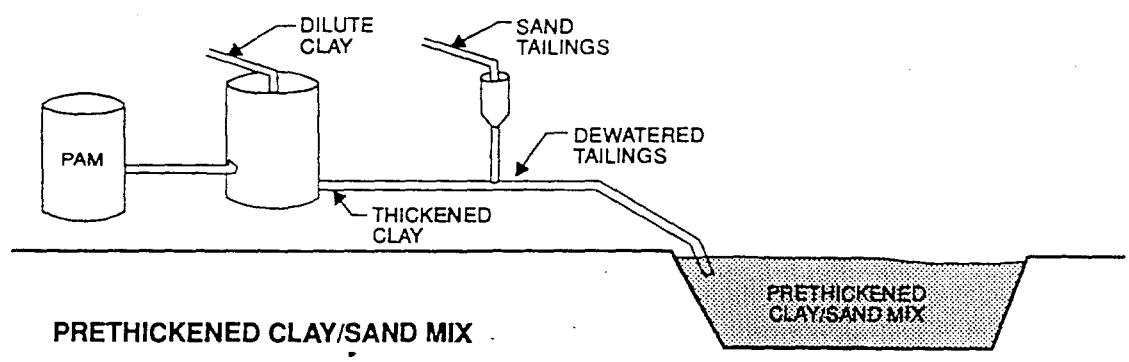


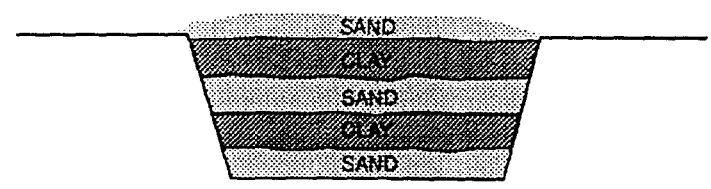
SAND SPRAY



FLOCCULATED CLAY AND TAILINGS



PRETHICKENED CLAY/SAND MIX



CLAY SANDWICH

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Figure 4

CURRENT DEWATERING CONCEPTS

INDUSTRIAL WASTEWATER DISCHARGE PREVENTION
WATER QUALITY IMPROVEMENT AND CONSERVATION PROJECT
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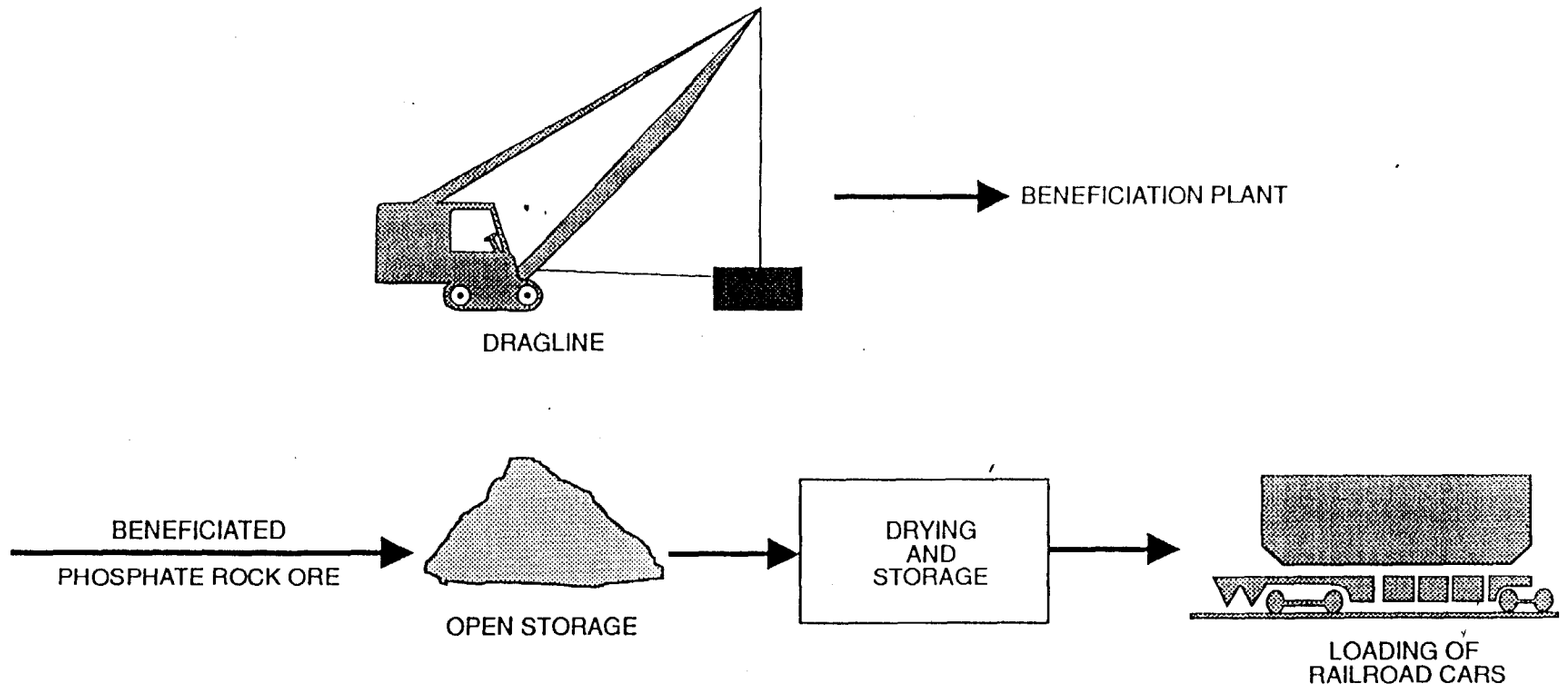

Figure 5

SELECTED PHOSPHATE ROCK EMISSION SOURCES

INDUSTRIAL WASTEWATER DISCHARGE PREVENTION
WATER QUALITY IMPROVEMENT AND CONSERVATION PROJECT

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UNITED STATES AGENCY
FOR INTERNATIONAL DEVELOPMENT

REFERENCE MATERIALS

PHOSPHATE MINING INDUSTRY

WATER QUALITY IMPROVEMENTS AND CONSERVATION PROJECT

Industrial Wastewater Discharge Prevention Program

Development Alternatives, Inc.

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August 1994