Environmental, Health and Safety Guidelines for Phosphate Fertilizer Manufacturing

Introduction

The Environmental, Health, and Safety (EHS) Guidelines are technical reference documents with general and industry-specific examples of Good International Industry Practice (GIIP)[1]. When one or more members of the World Bank Group are involved in a project, these EHS Guidelines are applied as required by their respective policies and standards. These industry sector EHS guidelines are designed to be used together with the **General EHS Guidelines** document, which provides guidance to users on common EHS issues potentially applicable to all industry sectors. For complex projects, use of multiple industry-sector guidelines may be necessary. A complete list of industry-sector guidelines can be found at: www.ifc.org/ifcext/enviro.nsf/Content/EnvironmentalGuidelines

The EHS Guidelines contain the performance levels and measures that are generally considered to be achievable in new facilities by existing technology at reasonable costs. Application of the EHS Guidelines to existing facilities may involve the establishment of site-specific targets, with an appropriate timetable for achieving them.

The applicability of the EHS Guidelines should be tailored to the hazards and risks established for each project on the basis of the results of an environmental assessment in which site-specific variables, such as host country context, assimilative capacity of the environment, and other project factors, are taken into account. The applicability of specific technical recommendations should be based on the professional opinion of qualified and experienced persons.

When host country regulations differ from the levels and measures presented in the EHS Guidelines, projects are expected to achieve whichever is more stringent. If less stringent levels or measures than those provided in these EHS Guidelines are appropriate, in view of specific project circumstances, a full and detailed justification for any proposed alternatives is needed as part of the site-specific environmental assessment. This justification should demonstrate that the choice for any alternate performance levels is protective of human health and the environment.

Applicability

The EHS Guidelines for Phosphate Fertilizer Manufacturing includes information relevant to facilities that produce phosphoric acid, single superphosphate (SSP), triplesuperphosphate (TSP), and compound fertilizers (NPK). Annex A contains a description of industry sector activities. This document is organized according to the following sections:

Section 1.0 — Industry-Specific Impacts and Management
Section 2.0 — Performance Indicators and Monitoring
Section 3.0 — References and Additional Sources
Annex A — General Description of Industry Activities

[1] Defined as the exercise of professional skill, diligence, prudence and foresight that would be reasonably expected from skilled and experienced professionals engaged in the same type of undertaking under the same or similar circumstances globally. The circumstances that skilled and experienced professionals may find when evaluating the range of pollution prevention and control techniques available to a project may include, but are not limited to, varying levels of environmental degradation and environmental assimilative capacity as well as varying levels of financial and technical feasibility.

1.0 Industry-Specific Impacts and Management

The following section provides a summary of EHS issues associated with phosphate fertilizer plants, which occur during the operational phase, along with recommendations for their management. Recommendations for the management of EHS issues common to most large industrial facilities during the construction and decommissioning phases are provided in the **General EHS Guidelines**.

1.1 Environment

Environmental issues associated with phosphate fertilizer plants include the following:

- Air emissions
- Wastewater
- Hazardous materials
- Wastes
- Noise

Air Emissions

Combustion Source Emissions

Exhaust gas emissions produced by the combustion of gas or diesel in turbines, boilers, compressors, pumps and other engines for power and heat generation, are a source of air emissions from phosphate fertilizer manufacturing facilities. Guidance for the management of small combustion source emissions with a capacity of up to 50 megawatts thermal (MWth), including air emission standards for exhaust emissions, is provided in the **General EHS Guidelines**. Guidance for the management of energy conservation, which can significantly contribute to the reduction of emissions related to energy production, is also presented in the **General EHS Guidelines**. Production of phosphate fertilizers is an energy intensive process typically requiring significant use of energy from fossil fuels and resulting in significant generation of greenhouse gases. The nitrophosphate production route requires the use of CO_2. Recommendations for the management of GHGs, in addition to energy efficiency and conservation, are addressed in the **General EHS Guidelines**.

Process Emissions – Phosphoric Acid Production

Two different production processes can be used in the manufacture of phosphoric acid:

- The wet process, which is the most commonly used in fertilizer plants, where phosphate rocks are digested with an acid (e.g. sulfuric, nitric or hydrochloric acid). The tri-calcium phosphate from the phosphate rock reacts with concentrated sulfuric acid to produce phosphoric acid and calcium sulfate (an insoluble salt); and
- The thermal process, where elemental phosphorous is produced from phosphate rock, coke, and silica in an electrical resistance furnace and is then oxidized and hydrated to form the acid. Thermal-generated acid is highly purified, but also expensive, and hence produced in small quantities, mainly for the manufacture of industrial phosphates;

Process emissions include gaseous fluorides in the form of hydrofluoric acid (HF) and silicon tetrafluoride (SiF4), released during the digestion of phosphate rock, which typically contains 2-4 percent fluorine.

The emissions typically associated with the thermal production process of phosphoric acid include phosphate, fluoride, dust, cadmium (Cd), lead (Pb), zinc (Zn), and radionuclides (Po-210 and Pb-210). Dust emissions, containing water-insoluble fluoride, may occur during the unloading, storage, handling and

grinding of the phosphate rock, which is transferred to storage and grinding sections by conveyor belts or trucks[2].

Recommended emission prevention and control measures include the following:

- Properly select the phosphate rock (in terms of P_2O_5-content, F-content, CaO/ P_2O_5 ratio, and physical quality) to minimize the amount of acid required in the wet production process, reduce emissions into the environment and increase the possibility of phosphogypsum reuse;
- Select proper size of screens and mills (e.g. roller or chain mills);
- Use covered conveyor belts and indoor storage;
- Apply good housekeeping measures (e.g. frequently cleaning / sweeping facility surfaces and the quay);
- Recover dust from phosphate rock grinding through use of properly operated and maintained fabric filters, ceramic filters, and / or cyclones;
- Treat gaseous fluoride emissions using scrubbing systems (e.g. void spray towers, packed beds, cross-flow venture, and cyclonic column scrubbers). Fluorine is recovered as fluosilicic acid, from which silica is removed through filtration. A diluted solution of fluosilicic acid (H_2SiF_6) may be used as the scrubbing liquid. Recovering of H_2SiF_6 is an additional possibility for fluoride emission reduction.

Process Emissions – Superphosphate Phosphate Fertilizer Production

Dust emissions may be generated during unloading, handling, grinding, and curing of phosphate rock, in addition to granulation and crushing of superphosphates. Emissions of gaseous hydrofluoric acid (HF), silicon tetrafluoride (SiF4), and chlorides may also generated from acidulation, granulation and drying. Ammonia (NH_3) and nitrogen oxides (NO_x) may be generated during the drying and neutralization phases of ammonium nitrate fertilizers. In addition, during the reaction of phosphate rock with acid, limited amounts of organic compounds (including mercaptans), present in the phosphate rock, are released and may cause odor.[3]

Phosphate rock dust emissions should be prevented and controlled through similar measures to those discussed in the phosphoric acid production section. Additional emission prevention and control measures include the following:

- Use of direct granulation may reduce the levels of fugitive emissions compared with curing emissions from indirect granulation. If indirect granulation is used, the curing section should be an indoor system with vents connected to a scrubbing system or to the granulation section;
- Use of plate bank product cooling systems to reduce air flow requirements (e.g. instead of rotary drums or fluid bed coolers);
- Consider use of fabric filters or high efficiency cyclones and/or fabric filters rather than a wet scrubbing system to treat exhaust air from neutralization, granulation, drying, coating and product coolers and equipment vents, in order to avoid creation of additional wastewater. Filtered air should be recycled as dilution air to the dryer combustion system;
- Emissions from granulation should be minimized through application of surge hoppers to product size distribution measurement systems for granulation recycle control.

Process Emissions – Compound Fertilizer Production

NPK fertilizers are typically produced from mixed acids or nitrophosphate. Air emissions from NPK produced using the mixed acids route include ammonia emissions from the ammonization reactors; nitrogen oxides (NO_X), mainly NO and

[2] IPPC BREF (2006) and EFMA (2000a)

[3] IPPC BREF. October 2006

NO_2 with some nitric acid, from phosphate rock digestion in nitric acid; fluorides from the phosphate rock reactions; aerosol emissions, including ammonium nitrate (NH_4NO_3), ammonium fluoride (NH_4F), and ammonium chloride (NH_4Cl), formed in the gas-phase neutralization reaction between ammonia and acidic components, as well as by sublimation from the boiling reaction mixture; and fertilizer dust originating from drying and cooling drums, and from other sources (e.g. screens, crushers, and conveyors).

Air emissions from NPK produced using the nitrophosphate route are similar to those discussed for the mixed acids route, however they also include aerosol emissions (e.g. from the dryer and granulator) of ammonium chloride (NH_4Cl), originating from the reaction of ammonia and hydrogen chloride (HCl) when potassium chloride (KCl) is added to the powder.[4] Other significant air emissions include ammonia from the neutralization of nitrophosphoric acid. Ammonia emissions may also be generated from the calcium nitrate tetrahydrate (CNTH, empirical formula: $Ca(NO_3)_2*4H_2O$) conversion section, the ammonium nitrate (AN, empirical formula: NH_4NO_3) evaporation section, and the granulation or prilling sections. Aerosols of ammonium nitrate may also be formed during the different production steps, and emissions of hydrogen chloride (HCl) may be present in the exhaust gases from drum granulators, cyclones, and scrubber systems.[5]

Recommended measures to prevent and control air emissions include the following:

- Reduce NO_X emission from nitric acid use in phosphate rock digestion by controlling the reactor temperature,[6] optimizing the rock / acid ratio, and adding urea solution;
- Treat gases from the digestion reactor in a spray tower scrubber to recover NO_X and fluorine compounds. The pH may be adjusted by the addition of ammonia;
- Reduce NO_x and odor emissions by selecting high grade phosphate rock with low contents of organic compounds and ferrous salts;
- Control particulate matter emissions, as discussed in the phosphoric acid production section;
- Prevent and / or control emissions from granulation and product cooling include:
  - Scrubbing of gases from the granulator and the dryer in venturi scrubbers with recirculating ammonium phosphate or ammonium sulfo-phosphate solution;
  - Discharge of scrubbed gases through cyclonic columns irrigated with an acidic solution;
  - Use of high efficiency cyclones to remove particulates from dryer gases prior to scrubbing;
  - Recycling of the air coming from the cooling equipment as secondary air to the dryer after de-dusting;
  - Treating ammonia emissions by scrubbing with acidic solutions;
- Fluoride emissions should be controlled through scrubbing systems, as discussed for phosphoric acid production;
- Emissions to air from phosphate rock digestion, sand washing and CNTH filtration should be reduced by applying appropriate controls (e.g. multistage scrubbing, conversion into cyanides);
- Ammonia in off-gases from the nitrophosphoric neutralization steps should be removed through counter-current scrubbers, with pH adjustment to most efficient scrubbing condition (pH 3-4), with a mixture of HNO_3 and/or H_2SO_4;
- Ammonia emissions from the granulation / drying sections should be treated by scrubbing with acidic solutions;

[4] These emissions can cause the so-called "Tyndall-effect" creating a blue mist at the stack.
[5] EIPPCB BREF (2006) and EFMA (2000b,c)
[6] High temperature leads to excessive NO_X formation.

- Minimize contact between wastes containing NO_X and NH_3 to prevent aerosol formation in NPK nitrophosphate route;
- Reduce aerosol emission by installing cyclones and scrubbers;
- Reduce fluorides emissions by recycling of warm air.

Fugitive Emissions

Fugitive emissions are primarily associated with operational leaks from tubing, valves, connections, flanges, packings, open-ended lines, floating roof storage tank and pump seals, gas conveyance systems, compressor seals, pressure relief valves, tanks or open pits/containments, and loading and unloading operations of products.

Recommended measures for reducing the generation of fugitve emissions include:

- Selection of appropriate valves, flanges, fittings during design, operation, and maintenance;
- Implementation of monitoring, maintenance, and repair programs, particularly in stuffing boxes on valve stems and seats on relief valves, to reduce or eliminate accidental releases;
- Installation of leak detection and continuous monitoring in all sensitive areas;
- Use of open vents in tank roofs should be avoided by installing pressure relief valves. All storages and unloading stations should be provided with vapor recovery units. Vapor processing systems may consist of different methods, such as carbon adsorption, refrigeration, recycling collecting and burning.

Wastewater

Effluents – Phosphoric Acid Production

Effluents from phosphoric acid plants consist of discharges from the vacuum cooler condensers and the gas scrubbing systems used for condensation and cleaning of vapors from process operations. Condensed acidic vapors may contain fluorine and small amounts of phosphoric acid. Water from the slurry used to transport phosphogypsum, the by-product from wet phosphoric acid production, may be released as effluent if it is not recirculated back into the process. Emissions to water for the disposal of gypsum may contain a considerable amount of impurities, such as phosphorus and fluorine compounds, cadmium and other heavy metals, and radionuclides. Drainage from material stockpiles may contain heavy metals (e.g. Cd, mercury [Hg], and Pb),fluorides, and phosphoric acid. Specific emissions to water from the thermal process of phosphoric acid production may include phosphorus and fluorine compounds, dust, heavy metals, and radionuclides (e.g., Po-210 and Pb-210). Recommended effluents management measures include the following:[7]

- Select phosphate rock with low levels of impurities to produce clean gypsum and reduce potential impacts from disposal of gypsum;
- Consider dry systems for air pollution abatement (versus wet scrubbing) to reduce wastewater generation. To reduce fluoride emissions, the installation of scrubbers with suitable scrubber liquids may be necessary;
- Recover fluorine released from the reactor and evaporators as a commercial by-product (fluosilicic acid);
- Scrubber liquors should be disposed of after neutralization with lime or limestone to precipitate fluorine as solid calcium fluoride, if the fluorine is not to be recovered;
- Recycle water used for the transport of phosphogypsum back into the process following a settling step;
- Where available, consideration should be given to use seawater as scrubbing liquid, to facilitate reaction of fluorine to harmless calcium fluoride;

[7] IPPC BREF (2006) and EFMA (2000a)

- Minimize contamination of the scrubber effluent with phosphorus pentoxide (P_2O_5) by conveying vapors from vacuum flash coolers and vacuum evaporators to a separator to remove phosphoric acid droplets;
- Minimize contamination of the scrubber effluent with phosphorus pentoxide P_2O_5 using entrainment separators. Additional phosphate removal can be achieved by applying magnesium ammonium phosphate (struvite) or by calcium phosphate precipitation;
- Consider decadmation of H_3PO_4 up to 95% by reactive extraction with an organic solvent.

Effluents - Superphosphate Fertilizer Production

The main source of wastewater in phosphate fertilizer production is the wet scrubbing systems to treat off-gases. Contaminants may include filterable solids, total phosphorus, ammonia, fluorides, heavy metals (e.g. Cd, Hg, Pb), and chemical oxygen demand (COD). Recycling of scrubber liquids back into the process should be maximized. Production of acidulated phosphate rock (PAPR), a fertilizer product consisting of a mixture of superphosphate and phosphate rock, in addition to superphosphate (SSP), and triplesuperphosphate (TSP) products can reduce wastewater volumes[8].

Effluents - Compound Fertilizer Production

Effluents are usually limited from NPK mixed acids route facilities, mainly consisting of wastewater from granulation and exhaust gas scrubbing.

Effluent from NPK facilities employing the nitrophosphate route may contain ammonia, nitrate, fluoride and phosphate. Ammonia is found in the effluents of the condensates of the ammonium nitrate evaporation or the neutralization of the nitro phosphoric acid solution. Solutions containing ammonium nitrate must be pumped with care to limit the risks of explosions. The main sources of nitrate and fluoride levels in effluent are the scrubber liquors from phosphate digestion and sand (removed from the process slurry) washing. Washing of sand also generates phosphate content in the effluent.

Recommended effluent management measures include the following[9]:

- Recycle the sand washing liquor to reduce phosphate levels in wastewater effluents;
- Avoid co-condensation of vapors from ammonium nitrate evaporation;
- Recycle NO_X scrubber liquor to reduce ammonia, nitrate, fluoride and phosphate levels;
- Recycle liquors resulting from scrubbing of exhaust gases from neutralization;
- Consider reusing effluents as scrubber medium;
- Treat multi-stage scrubbing liquors, after circulation, through settling (separation of solids), and recycle the thickened portion back to the reactors.
- Consider combined treatment of exhaust gases from neutralization, evaporation and granulation. This enables a recycling of all scrubber liquids to the production process and reduce waste water generation;
- Treat waste water through a biological treatment with nitrification/denitrification and precipitation of phosphorous compounds.

Process Wastewater Treatment

Techniques for treating industrial process wastewater in this sector include filtration for separation of filterable solids; flow and load equalization; sedimentation for suspended solids reduction using clarifiers; phosphate removal using physical-chemical treatment methods; ammonia and nitrogen removal

[8] IPPC BREF (2006)

[9] IPPC BREF (2006) and EFMA (2000b,c)

using physical-chemical treatment methods; dewatering and disposal of residuals in designated waste landfills. Additional engineering controls may be required for (i) fluoride removal and (ii) advanced metals removal using membrane filtration or other physical/chemical treatment technologies

Management of industrial wastewater and examples of treatment approaches are discussed in the **General EHS Guidelines**. Through use of these technologies and good practice techniques for wastewater management, facilities should meet the Guideline Values for wastewater discharge as indicated in the relevant table of Section 2 of this industry sector document.

Other Wastewater Streams & Water Consumption

Guidance on the management of non-contaminated wastewater from utility operations, non-contaminated stormwater, and sanitary sewage is provided in the **General EHS Guidelines**. Contaminated streams should be routed to the treatment system for industrial process wastewater. Recommendations to reduce water consumption, especially where it may be a limited natural resource, are provided in the **General EHS Guidelines**.

Hazardous Materials

Phosphate fertilizer manufacturing plants use, store, and distribute significant amounts of hazardous materials (e.g. acids and ammonia). Recommended practices for hazardous material management, including handling, storage, and transport, are presented in the **General EHS Guidelines**. Manufacture and distribution of materials should be conducted according to applicable international requirements where applicable.[10]

Wastes

Non-hazardous solid wastes may be generated from some phosphate fertilizer manufacturing processes, including phosphogypsum from wet phosphoric acid production, and quartz sand from NPK production using the nitrophosphate route. Quartz sand should be separated, washed, and recycled as a building material. There is limited hazardous waste generated from the phosphate fertilizer manufacturing processes. In addition to the industry specific information provided below, guidance on the management of hazardous and non-hazardous wastes is provided in the **General EHS Guidelines**.

Phosphogypsum

Phosphogypsum is the most significant by-product in wet phosphoric acid production (approximately 4 - 5 tons of phosphogypsum is produced for every ton of phosphoric acid, as P_2O_5, produced[11]). Phosphogypsum contains a wide range of impurities (residual acidity, fluorine compounds, trace elements such as mercury, lead and radioactive components[12]). These impurities and considerable amounts of phosphate might be released to the environment (soil, groundwater and surface water).Industry-specific pollution prevention and control practices include[13]:

- Depending on its potential hazardousness (e.g. whether it emits radon) phosphogypsum may be processed to improve its quality and reused (e.g. as building material). Possible options include:
  - Production of cleaner phosphogypsum from raw materials (phosphate rock) with low levels of impurities
  - Use of repulping

[10] For example, the Rotterdam Convention on the Prior Informed Consent (PIC) Procedure for Certain Hazardous Chemicals and Pesticides.

[11] Gypsum contains a wide range of impurities (residual acidity, fluorine compounds, trace elements such as mercury, lead and radioactive components). IPPC BREF (2006)

[12] Phosphate rock, phosphogypsum and the effluents produced from a phosphoric acid plant have generally a lower radioac-tivity than the exemption values given in the relevant international regulations and guidelines (for example, EU Directive 96/26/EURATOM)

[13] IPPC BREF (2006) and EFMA (2000a,b,c)

- Use of di-hemihydrate recrystallization process with double stage filtration;
- If phosphogypsum can not be recycled due to the unavailability of commercially and technically viable alternatives, it should be managed as a hazardous or non-hazardous industrial waste, depending on its characteristics, according to the guidance in the **General EHS Guidelines.**[14] Additional management alternatives may include backfilling in mine pits, dry stacking[15], and wet stacking.

Noise

Noise is generated from large rotating machines, including compressors and turbines, pumps, electric motors, air coolers, rotating drums, spherodizers, conveyors belts, cranes, fired heaters, and from emergency depressurization. Guidance on noise management is provided in the **General EHS Guidelines**.

1.2 Occupational Health and Safety

The occupational health and safety issues that may occur during the construction and decommissioning of phosphate fertilizer manufacturing facilities are similar to those of other industrial facilities, and their management is discussed in the **General EHS Guidelines**.

Facility-specific occupational health and safety issues should be identified based on job safety analysis or comprehensive hazard or risk assessment, using established methodologies such as a hazard identification study [HAZID], hazard and operability study [HAZOP], or a quantitative risk assessment [QRA]. As a general approach, health and safety management planning should include the adoption of a systematic and structured approach for prevention and control of physical, chemical, biological, and radiological health and safety hazards described in the **General EHS Guidelines**.

The most significant occupational health and safety hazards occur during the operational phase of phosphate fertilizer manufacturing facilities and primarily include:

- Process Safety
- Chemical hazards
- Decomposition, fires and explosions

Process Safety

Process safety programs should be implemented, due to industry-specific characteristics, including complex chemical reactions, use of hazardous materials (e.g. toxic, reactive, flammable or explosive compounds), and multi-step reactions.

Process safety management includes the following actions:

- Physical hazard testing of materials and reactions;
- Hazard analysis studies to review the process chemistry and engineering practices, including thermodynamics and kinetics;
- Examination of preventive maintenance and mechanical integrity of the process equipment and utilities;
- Worker training;
- Development of operating instructions and emergency response procedures.

Chemical Hazards

Ammonia and acids vapors, especially HF, are common toxic chemicals in phosphate fertilizer plants. Threshold values associated with specific health effects can be found in internationally published exposure guidelines (see Monitoring below). In addition to guidance on chemical exposure provided in the General EHS Guidelines, the following are

[14] The classification of phosphogypsum as a hazardous or non-hazardous waste may depend on the level of radon emissions of the material. Removal of this material from stack and subsequent disposal may be subject to specific regulatory requirements depending on the jurisdiction.
[15] It should be noted that dry stacking does not eliminate acid water seepage except in very arid climates.

recommendations to prevent and control chemical exposure in this sector:

- Avoid contact of acids with strong caustic substances. The resulting reaction is exothermic and may cause splashes;
- Control fluoride gas build up in phosphoric acid storage tanks;
- Install gas detectors in hazard areas;
- Provide adequate ventilation (e.g. air extraction and filtration systems) in all areas where products are produced, stored, and handled;
- Provide training and personal protection equipment for personnel as described in the General EHS Guidelines.

Decomposition, Fire and Explosions

Decomposition[16], fire and explosion hazards may be generated from slurry pump explosions due to insufficient flow through the pump or incorrect design; slurry decompositions due to low pH, high temperature and contaminated raw materials; and hydrogen gas generation due to phosphoric acid contact with ferrous metals.

The risk of decomposition, fire and explosion can be minimized by adopting measures such the following[17]:

- Inventory of ammonia, nitric and sulfuric acids should be kept as low as possible. Supply by pipeline is recommended in integrated chemical complexes;
- NPK fertilizer decomposition hazard should be prevented through temperature control during production, adjustment of formulations, and reduction of impurities. Compound build–up on the inlet vanes in the dryer should be avoided and uniform temperature profile of the air inlet should be ensured;
- Segregating process areas, storage areas, utility areas, and safe areas, and adopting of safety distances.
- Implementing well controlled operation and procedures in avoiding hazardous gas and slurry mixtures;
- NPK storage should be designed according to internationally recognized guidance and requirements[18]. Adequate fire detection and fighting system should be installed.
- Storage areas should be cleaned before any fertilizer is introduced. Spillage should be cleared up as soon as practicable. Fertilizer contamination with organic substances during storage should be prevented; and
- Fertilizers should not be stored in proximity of sources of heat, or in direct sunlight or in conditions where temperature cycling can occur.
- Contact of phosphoric acid with ferrous metal component should be prevented. Stainless steel should be used for components possibly in contact with the acid.

1.3 Community Health and Safety

Guidance on the management of community health and safety impacts during the construction and decommissioning phases common to those of other large industrial facilities are discussed in the **General EHS Guidelines**.

The most significant community health and safety hazards during the operation of phosphate fertilizers facilities relate to the management, storage and shipping of hazardous materials and products, with potential for accidental leaks / releases of toxic and flammable gases, and the disposal of wastes (e.g. phosphogypsum, off-spec products, sludge). Plant design and

[16] The manufacture, storage and transport of NPK fertilizers may generate a hazard related to self-sustaining decomposition of fertilizer compounds with ammonium nitrate at temperatures in excess of 130°C[16]. Decomposition is dependant on product grades and formulations, and may release significant amounts of toxic fumes.

[17] EFMA. 2000b,c

[18] See for example the EC Fertilizer Directives EC 76/116 and EC 80/876 and the COMAH Directive 96/82/EC.

operations should include safeguards to minimize and control hazards to the community, including the following measures:

- Identify reasonable design leak scenarios;
- Assess the effects of potential leaks on surrounding areas, including groundwater and soil pollution;
- Assess potential risks arising from hazardous material transportation and select the most appropriate transport routes to minimize risks to communities and third parties;
- Select plant location with respect to the inhabited areas, meteorological conditions (e.g. prevailing wind directions), and water resources (e.g., groundwater vulnerability). Identify safe distances between the plant area, especially the storage tank farms, and the community areas;
- Identify prevention and mitigation measures required to avoid or minimize community hazards;
- Develop an Emergency Management Plan with the participation of local authorities and potentially affected communities.

Guidance on the transport of hazardous materials, the development of emergency preparedness and response plans, and other issues related to community health and safety is discussed in the **General EHS Guidelines**.

2.0 Performance Indicators and Monitoring

2.1 Environment

Emissions and Effluent Guidelines

Tables 1 and 2 present emission and effluent guidelines for this sector. Guideline values for process emissions and effluents in this sector are indicative of good international industry practice as reflected in relevant standards of countries with recognized regulatory frameworks. The guidelines are assumed to be achievable under normal operating conditions in appropriately designed and operated facilities through the application of pollution prevention and control techniques discussed in the preceding sections of this document.

Effluent guidelines are applicable for direct discharges of treated effluents to surface waters for general use. Site-specific discharge levels may be established based on the availability and conditions in use of publicly operated sewage collection and treatment systems or, if discharged directly to surface waters, on the receiving water use classification as described in the **General EHS Guidelines**. These levels should be achieved, without dilution, at least 95 percent of the time that the plant or unit is operating, to be calculated as a proportion of annual operating hours. Deviation from these levels in consideration of specific, local project conditions should be justified in the environmental assessment.

Combustion source emissions guidelines associated with steam- and power-generation activities from sources with a capacity equal to or lower than 50 MWth are addressed in the **General EHS Guidelines** with larger power source emissions addressed in the **Thermal Power EHS Guidelines**. Guidance on ambient considerations based on the total load of emissions is provided in the **General EHS Guidelines**.

Environmental Monitoring

Environmental monitoring programs for this sector should be implemented to address all activities that have been identified to have potentially significant impacts on the environment, during normal operations and upset conditions. Environmental monitoring activities should be based on direct or indirect indicators of emissions, effluents, and resource use applicable to the particular project. Monitoring frequency should be sufficient to provide representative data for the parameter being monitored. Monitoring should be conducted by trained individuals following monitoring and record-keeping procedures and using properly calibrated and maintained equipment.

Monitoring data should be analyzed and reviewed at regular intervals and compared with the operating standards so that any necessary corrective actions can be taken. Additional guidance on applicable sampling and analytical methods for emissions and effluents is provided in the **General EHS Guidelines**.

Table 1. Air Emissions Guidelines for Phosphate Fertilizers Plants

Pollutant	Units	Guideline Value
Phosphoric Acid Plants		
Fluorides (gaseous) as HF	mg/Nm³	5
Particulate Matter	mg/Nm³	50
Phosphate Fertilizer Plants		
Fluorides (gaseous) as HF	mg/Nm³	5
Particulate Matter	mg/Nm³	50
Ammonia	mg/Nm³	50
HCl	mg/Nm³	30
NO_X	mg/Nm³	500 nitrophosphate unit 70 mix acid unit

Table 2. Effluents Guidelines for Phosphate Fertilizer Plants

Pollutant	Units	Guideline Value
pH	S.U.	6-9
Total Phosphorus	mg/L	5
Fluorides	mg/L	20
	kg/ton NPK	0.03
	kg/ton Phosphorus oxide (P_2O_5)	2
TSS	mg/L	50
Cadmium	mg/L	0.1
Total Nitrogen	mg/L	15
Ammonia	mg/L	10
Total Metals	mg/L	10

Resource Use and Energy Consumption, Emission and Waste Generation

Table 3 provides examples of resource consumption indicators for energy and water in this sector. Table 4 provides examples of emission and waste generation indicators in this sector. Industry benchmark values are provided for comparative purposes only and individual projects should target continual improvement in these areas.

Table 3. Resource and Energy Consumption

Product	Unit	Industry Benchmark
Phosphoric Acid	Ton phosphate rock/ton P_2O_5	2.6-3.5 (1)
	Ton H_2SO_4/ton P_2O_5	2.1-2.3 (1)
	KWh/ton P_2O_5	120-180 (1)
	m³ cooling water/ton P_2O_5	100-150 (1)
NPK A	KWh/ton NPK	30-33 (1)(2)
	Total energy for drying MJ/ton NPK	300-320 (1)(2)
NPK B	KWh/ton NPK	50 (1)(2)
	Total energy for drying MJ/ton NPK	450 (1)(2)
NPK C	KWh/ton NPK	50-109 (2)
NPK C	m³ cooling water/ton NPK	17 (2)
NPK C	Ton CO_2 required/ton P_2O_5	1(1)(2)
SSP	KWh/ton SSP	19-34 (2)
SSP	m³ water/ton SSP	0.1-2 (2)

Notes:
NPK PLANTS A Granulation with a Pipe Reactor and Drum with ammoniation
NPK PLANTS B Mixed Acids Process
NPK PLANTS C Nitrophosphate Process
1. European Fertilizer Manufacturers Association (EFMA). 2000.
2. EU IPPC - Reference Document on Best Available Techniques in Large Volume Inorganic Chemicals – Ammonia, Acids and Fertilizers Industries. December 2006

Table 4. Emissions, Effluents and Waste Generation		
Parameter	**Unit**	**Industry Benchmark**
Phosphoric acid plants		
Fluoride SO_2	mg/Nm³kg/ton HF	5–300.001 – 0.01
Solid Waste Generation (phosphogypsum) (thermal/wet process)	ton/ton P_2O_5	3.2/4-5 (1)
NPK Production – Nitrophosphate Process		
NH_3 air emissions	kg/ton P_2O_5	0.2
NO_X (as NO_2) air emissions	kg/ton P_2O_5	1.0
Fluoride airFluorides air emissions	kg/ton P_2O_5	0.01
Total nitrogen effluents	kg/ton P_2O_5	0.001 – 0.01
P_2O_5 effluents	kg/ton P_2O_5	1.2
Fluorides effluents	kg/ton P_2O_5	0.7
NPK Production – Mixed Acids Process		
NH_3 emissions	kg/ton NPK	0.2
NO_X (as NO_2) emissions	kg/ton NPK	0.3
Fluorides emissions	kg/ton NPK	0.02
Dust emissions	kg/ton NPK	0.2
Total nitrogen effluents	kg/ton NPK	0.2
Fluorides effluents	kg/ton NPK	0.03
Fluorides air emissions	mg/Nm³	0.4-4
Dust air emissions	mg/Nm³	30-50
Chloride air emissions	mg/Nm³	19-20

2.2 Occupational Health and Safety Performance

Occupational Health and Safety Guidelines

Occupational health and safety performance should be evaluated against internationally published exposure guidelines, of which examples include the Threshold Limit Value (TLV®) occupational exposure guidelines and Biological Exposure Indices (BEIs®) published by American Conference of Governmental Industrial Hygienists (ACGIH),[19] the Pocket Guide to Chemical Hazards published by the United States National Institute for Occupational Health and Safety (NIOSH),[20] Permissible Exposure Limits (PELs) published by the Occupational Safety and Health Administration of the United States (OSHA),[21] Indicative Occupational Exposure Limit Values published by European Union member states,[22] or other similar sources.

Accident and Fatality Rates

Projects should try to reduce the number of accidents among project workers (whether directly employed or subcontracted) to a rate of zero, especially accidents that could result in lost work time, different levels of disability, or even fatalities. Facility rates may be benchmarked against the performance of facilities in this sector in developed countries through consultation with published sources (e.g. US Bureau of Labor Statistics and UK Health and Safety Executive)[23].

Occupational Health and Safety Monitoring

The working environment should be monitored for occupational hazards relevant to the specific project. Monitoring should be designed and implemented by accredited professionals[24] as part of an occupational health and safety monitoring program. Facilities should also maintain a record of occupational accidents and diseases and dangerous occurrences and accidents. Additional guidance on occupational health and safety monitoring programs is provided in the **General EHS Guidelines**.

[19] Available at: http://www.acgih.org/TLV/ and http://www.acgih.org/store/
[20] Available at: http://www.cdc.gov/niosh/npg/
[21] Available at: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992
[22] Available at: http://europe.osha.eu.int/good_practice/risks/ds/oel/
[23] Available at: http://www.bls.gov/iif/ and http://www.hse.gov.uk/statistics/index.htm
[24] Accredited professionals may include Certified Industrial Hygienists, Registered Occupational Hygienists, or Certified Safety Professionals or their equivalent.

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Annex A: General Description of Industry Activities

A modern phosphate fertilizer manufacturing complex is characterized by large volume productions and is normally highly integrated with upstream (e.g. ammonia, and acids such as nitric, sulfuric, and phosphoric) and downstream (e.g. ammonium nitrate and calcium ammonium nitrate) production with the aim at optimizing production cost, logistics, safety and environmental protection (Figure A.1). Phosphate fertilizer plants may produce single (or normal) superphosphate (SSP) and triple superphosphate (TSP); mixed fertilizers such as Mono-Ammonium Phosphate (MAP) and Di-Ammonium Phosphate (DAP); and all grades of compound fertilizers (NPK) using the nitrophosphate / nitric acid route and the mixed acid / sulfuric acid route. Facilities are usually equipped with an integrated steam and electric power distribution grid servicing all the plants and supplied by a central steam boiler and power station. A waste water treatment plant is usually present.

Sulfuric Acid

Sulfuric acid (H_2SO_4) is used in the phosphate fertilizer industry for the production of phosphoric acid. Sulfuric acid is manufactured mainly from sulfur dioxide (SO_2), produced through the combustion of elemental sulfur. The exothermic oxidation of sulfur dioxide over several layers of a suitable catalyst (e.g. vanadium pentoxide) to produce sulfur trioxide (SO_3) is the most common process in sulfuric acid manufacturing plants.[25]

Sulfuric acid is obtained from the absorption of SO3 and water into H2SO4 (with a concentration of at least 98 percent) in absorbers installed after multiple catalyst layers. The warm acid produced is sparged with air in a column or in a tower to collect the remaining SO2 in the acid. The SO2 laden air is returned to the process.

Phosphoric Acid

Phosphoric acid (H_3PO_4) is primarily used in the manufacture of phosphate salts (e.g. for fertilizers and animal feed supplements). Two different processes can be used in the manufacture of phosphoric acid. In the first process, known as the thermal process, elemental phosphorous is produced from phosphate rock, coke, and silica in an electrical resistance furnace and is then oxidized and hydrated to form the acid. Thermal-generated acid is highly purified, but also expensive, and hence produced in small quantities, mainly for the manufacture of industrial phosphates.

The second type of process, known as the wet process, involves digesting phosphate rocks with an acid (e.g. sulfuric, nitric or hydrochloric acid). The tri-calcium phosphate from the phosphate rock reacts with concentrated sulfuric acid to produce phosphoric acid and calcium sulfate, which is an insoluble salt. The operating conditions are generally designed so that the calcium sulfate is precipitated as anhydrite, hemihydrate (HH) and dihydrate (DH).

Different processes are needed because of different rocks and gypsum disposal systems.[26] The main production steps include grinding of phosphate rock (if necessary); reaction with sulfuric acid in a series of separate agitated reactors at a temperature of 70-80°C, filtration to separate the phosphoric acid from the calcium sulfate; and concentration up to commercial phosphoric acid with a concentration of 52-54 percent phosphorus pentoxide (P_2O_5).

[25] IPPC BREF (2006)

[26] EIPPCB BREF (2006) and EFMA (2000a)

When the phosphoric acid plant is linked to a sulfuric acid plant, the high-pressure steam produced in the waste heat recovery boiler from the sulfuric acid is normally used to produce electric power, and the low-pressure exhaust steam is used for phosphoric acid vacuum concentration. The steam consumption needed for the concentration can be reduced by using waste heat originating in the sulfuric acid plant. This may be recovered as heated water and used in the process of concentrating weak acid to intermediate concentration. Phosphoric acid is most commonly stored in rubber-lined steel tanks, although stainless steel, polyester and polyethylene-lined concrete are also used. Storage tanks are normally equipped to keep the solids in suspension to avoid costly cleaning of the tank[27].

Phosphate Fertilizers (SSP / TSP)

Phosphate fertilizers are produced by adding acid to ground or pulverized phosphate rock. If sulfuric acid is used, single or normal, superphosphate (SSP) is produced, with a phosphorus content of 16–21 percent as phosphorous pentoxide (P_2O_5). SSP production involves mixing the sulfuric acid and the rock in a reactor. The reaction mixture is discharged onto a slow-moving conveyor belt. If the reaction The mixture is directly fed to a granulator, the process is the so called "direct" granulation. In "indirect" granulation, the reaction mixture is stored for "curing" for 4 to 6 weeks before bagging and then granulated.[28]

If phosphoric acid is used to acidulate the phosphate rock, triple superphosphate (TSP) is produced with a phosphorus content of 43–48 percent as P_2O_5. Two processes are used to produce TSP fertilizers: run-of-pile and granulation. The run-of-pile process is similar to the SSP process. Granular TSP uses lower-strength phosphoric acid (40 percent, compared with 50 percent for run-of-pile method). The reaction mixture, a slurry, is sprayed onto recycled fertilizer fines in a granulator. Granules grow and are then discharged to a dryer, screened, and sent to storage.[29]

Compound Fertilizers (NPK)

Compound fertilizers are a large group of products, varying based on the particular nitrogen / phosphorus / potassium (N/P/K) ratios. Production processes are also numerous and product types include PK, NP (e.g. DAP), NK and NPK. This can be achieved by using two different routes, namely production by the nitrophosphate route, and production by the mixed acid route.

Nitrophosphate Route

The integrated nitrophosphate (NP) process produces compound fertilizers (NPK) containing ammonium nitrate, phosphate, and potassium salts (Figure A.2). The integrated process starts with the dissolution of the phosphate rock in nitric acid. Varying amounts of volatile compounds, such as carbon dioxide (CO_2), nitrogen oxides (NO_X) and hydrogen fluoride (HF), may be emitted, depending on the phosphate rock characteristics. The resulting digestion solution contains different amounts of suspended solids (e.g. quartz sand) that are removed by centrifuges, hydrocyclones or, lamella separators.[30] After washing, the solids can be reused in the building industry.

The liquor obtained from the process contains calcium ions in a proportion that too high to guarantee the production of plant available P_2O_5. The solution is therefore cooled so that calcium nitrate tetrahydrate (CNTH) crystallizes out. The solution of phosphoric acid, remaining calcium nitrate, and nitric acid, called nitrophosphoric acid, can be separated from the CNTH

[27] EFMA (2000a)
[28] EIPPCB BREF (2006)
[29] EIPPCB BREF (2006)
[30] EFMA (2000b)

crystals by filtration. The nitrophosphoric acid is then neutralized with ammonia, mixed with potassium / magnesium salts, sulfate and/or micro-nutrients, and converted to NPK in a rotary granulation drum, fluidized bed, prilling tower, or pug-mill to obtain solid compound fertilizers.[31]

The separated calcium nitrate crystals are dissolved in an ammonium nitrate solution and treated with an ammonium carbonate solution. This solution is filtered to remove the calcium carbonate crystals and it is used for the production of granular calcium ammonium nitrate (CAN) fertilizer. The resulting dilute ammonium nitrate solution is concentrated and also used to produce CAN or NPK. The calcium nitrate solution may also be neutralized and evaporated to obtain a solid fertilizer.[32]

Three types of processes are normally used for the production of NPK fertilizers from the NP liquor, namely prilling, drum or pug-mill, and spherodizer granulation. In prilling, NP liquor, mixed with the required salts and recycled product, overflows into a rotating prill bucket from which the slurry is sprayed into the prill tower. Fans at the top of the tower cause ambient air to flow counter-current to the droplets formed by solidification.[33]

In drum or pug-mill granulation, the NP liquor, together with required salts and recycled products, is sprayed into a rotating drum granulator where granules formed are dried in a rotating drying drum with hot air. The air leaving the drums contains water vapor, dust, ammonia and combustion gases. The air from the granulation and drying drums is treated in high performance cyclones.[34]

In spherodizer granulation, the slurry is sprayed into a special rotating drum, called a spherodizer, where warm air, heated to 300-400°C, flows co-currently thus evaporating the water building up on granules.[35]

In all processes, the dry NPK granules are screened. The on-size fraction passes to the conditioning process, and the over-size fractions are taken out, crushed and recycled together with the under-size fractions. The screen, crusher, and conveyor discharges are de-dusted using the air required for granulation. The commercial product from the drying and screening is cooled in a fluidized bed, a bulk flow heat exchanger, or a rotating drum. Off-gases from these latter stages, containing minor amounts of dust, and generally no ammonia, are de-dusted in cyclones. Finally, the product is cooled and coated before storage, to minimize the subsequent caking of the material. The coating consists of a treatment with an organic agent and inorganic powder, added in a drum. The calcium nitrate crystals from the nitrophosphate process can be processed to a solid calcium nitrate (CN) fertilizer, using prilling or pan-granulation technology, as an alternative to the combination of CNTH conversion and subsequent processing to CAN.[36]

Mixed Acid Route

Processes applied in the mixed acid route of production are numerous, the most common including granulation with a pipe reactor system; drum granulation with ammoniation; and a mixed acid process with phosphate rock digestion.[37] A simplified flow chart showing the three processes together is presented on Figure A.3.

Granulation with a pipe reactor system works with a classical granulation loop with one or two pipe reactors. One pipe reactor

[31] Ibid.
[32] Ibid
[33] Ibid
[34] Ibid
[35] Ibid
[36] EFMA (2000b)
[37] EFMA (2000c)

is fitted in the granulator and another may be used in the dryer. Phosphoric acid or a mixture of phosphoric and sulfuric acids is neutralized in the pipe reactors with gaseous or liquid ammonia. A wide range of grades, including ammonium phosphates (monoammonium phosphate – MAP, and diammonium phosphate – DAP), can be produced.[38] The required solid raw materials such as potassium chloride, potassium sulfate, superphosphate, secondary nutrients, micronutrients and filler are fed into the granulator together with the recycled material. The pipe reactor fitted in the granulator is designed to receive phosphoric acid, part of the ammonia, and all the other liquid feeds such as sulfuric acid and recycled scrubber liquor. Concentrated ammonium nitrate solution may be added directly into the granulator and ammoniation rates in the pipe reactor vary according to the product. Further ammoniation may be carried out in the granulator. A pipe reactor fitted in the dryer is fed with phosphoric acid and ammonia.

Drum granulation with ammoniation consists of a classical granulation loop using mainly solid raw materials. Ammonium nitrate solution and / or steam is / are fed into the granulator. The process is very flexible, and is able to produce a broad spectrum of grades including products with low nitrogen content. Ammonium nitrate solution is sprayed directly into the granulator and sulfuric acid may be fed into the granulator followed by ammoniation[39]. The granules obtained in both granulation processes are dried in a drying section using a heated air stream.[40] The dry granules are managed as discussed for the NP route.

Gases from the granulator and the dryer are scrubbed in venturi scrubbers with recirculating ammonium phosphate or ammonium sulfo-phosphate solution. The scrubber liquor which is being recycled is fed to the pipe reactor in the granulator. Finally, the gases are vented through cyclonic columns irrigated with an acidic solution. The gases coming from the dryer are de-dusted in high efficiency cyclones to remove the majority of the dust before scrubbing. The air coming from the cooling equipment is generally recycled as secondary air to the dryer after de-dusting.[41]

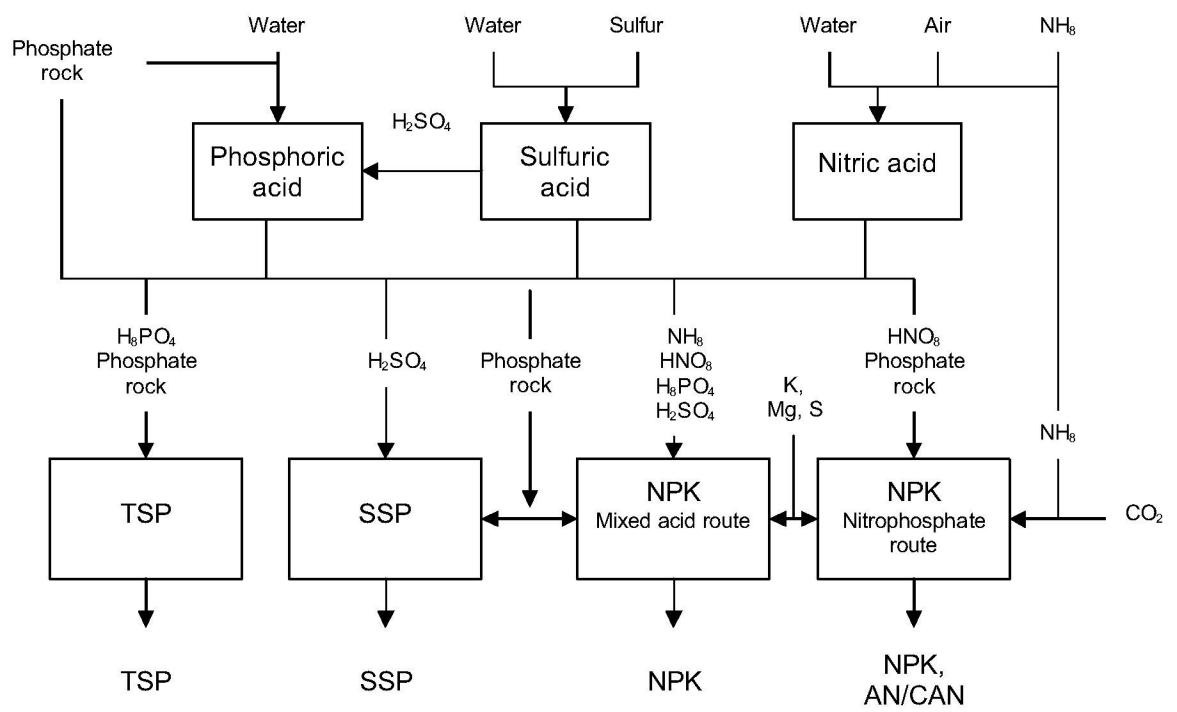
The mixed acid process with phosphate rock digestion is very flexible and produces grades with varying degrees of phosphate water solubility. The first step of the process is the exothermic digestion of phosphate rock with nitric acid resulting in a solution of phosphoric acid and calcium nitrate. Acid gases such as oxides of nitrogen and fluorine compounds are formed during the digestion, depending on the type of phosphate rock. Other raw materials such as phosphoric, sulfuric, and nitric acids or AN solution are added after the digestion. The acid slurry is ammoniated with gaseous ammonia and after neutralization, and other components such as ammonium phosphates, superphosphates, ammonium sulfate, and compounds containing potassium and magnesium are added. Most of these materials may also be added before or during neutralization, but if the raw material contains chloride, the pH of the slurry should be 5 – 6 to avoid the production of hydrogen chloride. The reactor battery ends with a buffer tank. The slurry granulation can then be performed by different equipment such as drum, blunger and spherodizer.[42]

The gases from the digestion reactors, where phosphate rock is digested in nitric acid, are treated separately in a spray tower scrubber to recover NO_X and fluorine compounds. The pH is adjusted by the addition of ammonia. The ammoniation reactor gases are scrubbed in several stages of counter-current

[38] Ibid.
[39] EFMA (2000c)
[40] Ibid.
[41] Ibid.
[42] Ibid.

scrubbing. The pH is adjusted to the most efficient scrubbing condition, pH 3-4, with a mixture of HNO_3 and/or H_2SO_4. The first scrubbing stage ensures a saturation of the gases; the second high pressure venturi stage is designed to remove aerosols. The subsequent stages make the recovery efficiency high and the final stage operates with the cleanest scrubbing liquid. A droplet separator is installed in the stack or immediately before it. The gases from the dryer (granulator / dryer) are led through cyclones before entering the scrubber. The scrubber consists of a variable throat venturi with subsequent two-stage scrubbing. The last stage should be operated with the cleanest liquid. A part of the liquor, after the circulation, goes to a settler for the separation of solids. The thickened part is fed to the reactors.[43]

Figure A.1: Integrated Phosphate Fertilizer Plants



[43] EFMA (2000c)

Figure A.2: Compound Fertilizers: Nitrophosphate Route

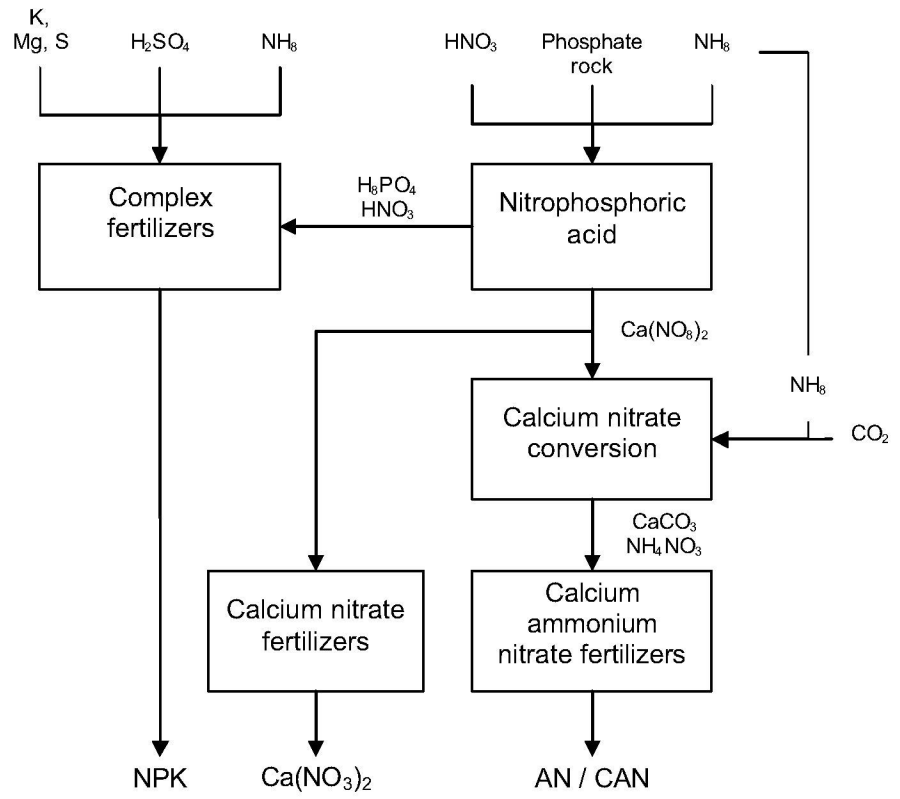
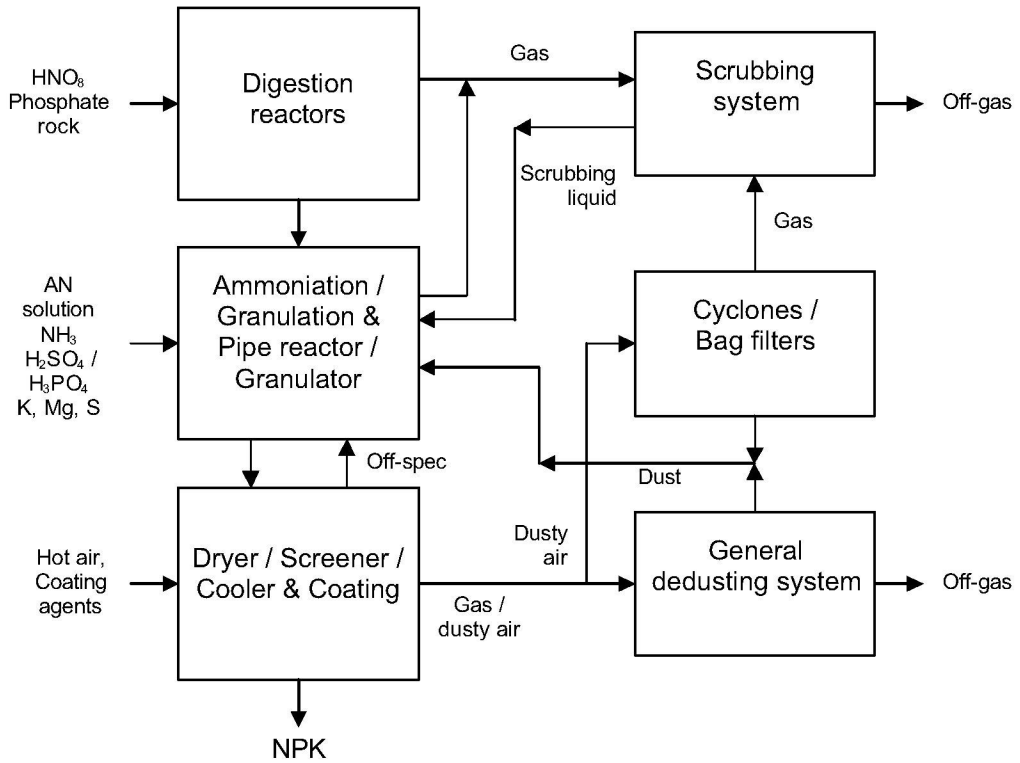



Figure A.3: Mixed Acid Route