

Environmental, Health, and Safety Guidelines for Ceramic Tile and Sanitary Ware 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

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.

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 Ceramic Tile and Sanitary Ware Manufacturing include information relevant to ceramic tile and sanitary ware manufacturing projects and facilities. Annex A contains a full description of industry activities for this sector. It does not include extraction of raw materials, which is included in the EHS Guidelines for Construction Materials Extraction.

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
- Annex A — General Description of Industry Activities

1.0 Industry-Specific Impacts and Management

The following section provides a summary of EHS issues associated with ceramic tile and sanitary ware manufacturing that 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 construction and decommissioning phases are provided in the **General EHS Guidelines**.

1.1 Environment

Environmental issues associated with ceramic tile and sanitary ware manufacturing primarily include the following:

- Emissions to air
- Wastewater
- Solid waste

Emissions to Air

Air emissions may be generated from storage and handling of raw materials and during firing or spray drying of ceramics. In the latter case, emissions may be derived from the raw materials and / or from the fuels employed for heat and power generation.

Particulate Matter

The main sources of particulate matter emissions include the handling of raw materials (e.g. screening, mixing, weighing, and transporting/conveying); dry grinding / milling (less common than wet milling); drying (e.g. spray drying); glaze-spraying processes (e.g. for both tiles and sanitary ware production); ware decorating and firing; and fired ware finishing operations.

Prevention and control techniques to reduce fugitive particulate matter emissions include the following:

- Segregation of storage areas from other operational areas;
- Use of enclosed silos to store bulk powder materials;
- Use of wind protection, barriers for wind protection (e.g. either artificial barriers or vertical greenery, such as densely growing trees and shrubs) if raw material is stored in open piles;
- Enclosed dry raw material transportation systems (e.g. conveyors, enclosed screw feeders, and feed pocket enclosures);
- Dust extraction equipment and baghouse filters, particularly for dry materials loading and unloading points, and where products are cut / ground and polished;²
- Reduced air leakage and spillage points through maintenance activities;
- Maintaining negative pressure in closed systems used for material handling, and dedust air from suction;
- Use of wet dust separators to treat emissions from spray drying and glazing processes in fine ceramic manufacturing. Sintered lamellar filters may also be used to separate wet dust from spray glazing and to clean off-gas from the spraying cabins. These filters have a high resistance to abrasion and enable collection efficiencies of up to 99.99 percent.

Sulfur Oxides

The emission of SO₂ in ceramic kiln exhaust gases depends on the sulfur content of the fuel and certain raw materials (e.g. gypsum, pyrite, and other sulfur compounds). The presence of carbonates in raw materials may, however, prevent the formation of sulfur emissions because of their reaction with SO₂.

² The use of baghouse filters is frequent in the ceramics industry and is especially important if dust contains significant levels of metals. The filters can be used in silo dedusting, dry raw material preparation and handling, spray drying, and dry grinding or shaping. Corrosion control necessitates the maintenance of appropriate temperatures. These filters enable collection efficiencies of up to 95 percent.

Pollution prevention and control techniques for the reduction of SO₂ emissions include:

- Use of fuels with a low sulfur content, such as natural gas or liquefied petroleum gas (LPG);
- Use of low-sulfur raw material and low-sulfur body additives to reduce sulfur levels in processed materials;
- Optimizing the heating process and firing temperature, reducing the latter to the lowest temperature range (e.g. up to 400°C);
- Use of dry or wet scrubbers. If dry sorption cannot produce a sufficient clean-gas concentration, implement the use of wet scrubbers (e.g. reactive scrubbers or quench reactors) by adding basic reactive chemicals (e.g. calcium- and sodium-based chemicals) dissolved into wash water (wet abatement).

Nitrogen Oxides

The main sources of NO_x are the generation of thermal NO_x caused by high firing temperatures (>1,200°C) in the kiln, the nitrogen content in the raw materials, and the oxidation of nitrogen contained in fuels. Recommended measures for the reduction of NO_x emissions include the following:

- Optimizing peak flame temperatures in the kiln, and use of computerized control of kiln firing;
- Reducing the nitrogen content in raw materials and additives;
- Use of low NO_x burners.

Greenhouse Gas Emissions

Greenhouse gas (GHG) emissions, especially CO₂, are mainly associated with the use of energy in the kiln and spray dryer.

The **General EHS Guidelines** provides additional information regarding management strategies, including energy conservation, for greenhouse gas emissions. The following

measures may be used to reduce energy consumption in this sector:

- Replace inefficient kilns (e.g. down-draft kilns), and install new, adequately sized tunnel or shuttle kilns or fast-firing kilns (e.g. roller hearth kilns). In the sanitary ware industry, consider installing roller hearth kilns, especially if a reduced number of patterns is produced;
- Substitute heavy fuel oil and solid fuels with clean fuels (e.g. natural gas or LPG);
- Improve kiln sealing to reduce heat losses arising from excessive air flow (e.g. metal casing and sand or water seals in tunnel kilns and intermittent kilns);
- Improve thermal insulation of kilns to reduce heat loss;
- Use low thermal mass insulation in intermittently fired kilns;
- Use low thermal mass kiln cars to improve overall efficiency (e.g. using materials such as cordierite-mullite, sillimanite, and recrystallized silicon carbide), as well as minimize other parasitic loads³;
- Use high-velocity burners to obtain a higher combustion efficiency and heat transfer;
- Optimize peak flame temperatures in the kiln, and install computerized control of kiln firing;
- Optimize dried-material transfer between the dryer and kiln, and where possible, use the preheating zone of the kiln for completing the drying process (to avoid unnecessary cooling of the dried ware before the firing process);
- Recover excess heat from the kiln, especially from the cooling zone, for heating dryers and predrying products;
- Recover heat from kiln exhaust gas to preheat combustion air.

Energy efficiency opportunities in spray dryers include the following:

³ Low thermal mass kiln cars allow significant fuel savings in tunnel kiln furnaces and increase throughput by increasing the space available for wares. They also permit closer adherence to the preferred heating and cooling temperature profiles and minimize thermal shock to the products.

- Selection of spray dryer with an optimized nozzle;
- Installation of insulation for the spray dryer;
- Proper sizing of exhaust fans and installation of inverter-based variable-speed controls, rather than fixed-speed fans and dampers.

Other energy efficiency opportunities include the following:

- Use of high-pressure hydraulic presses in ceramic tiles;
- Use of press casting in sanitary ware plants;
- Optimization of grinding-cycle time in ball mills;
- Optimization of the amount of water in the mill mix;
- Limitation of electrical load in mills, through adoption of dual-speed electrical motors or electrical motors fitted with fluid couplings;
- Use of moisture sensors for dryness and coating control in ceramic tile manufacturing;
- Use of cogeneration of heat and power to generate power with waste heat from gas turbine-based operation of the spray dryer.

Chlorides and Fluorides

Chlorides and fluorides are pollutants found in waste gases from ceramic kilns, and are generated from impurities in clay materials. The use of additives and water containing chloride during the preparation of the raw materials may generate hydrochloric acid (HCl) emissions. Hydrofluoric acid (HF) may be generated by the decomposition of clay fluorosilicates. Recommended measures to prevent and control emissions of chloride and fluoride include the following:

- Use low-fluorine raw material and additives, which can be used to dilute emissions in the processed material;
- Use dry scrubbers. Both HF and HCl can be controlled using basic absorbents, including sodium bicarbonate (NaHCO₃), calcium hydroxide [Ca(OH)₂], and lime, in dry or wet conditions.

Metals

The heavy metal content of most ceramic raw materials is generally low and of limited concern, with the exception of some ceramic pigments glaze materials. In order to reduce metal emissions:

- Use commonly available glazes that do not contain lead or other toxic metals. Chromium-based pigments and colorants that contain antimony, barium, cobalt, lead, lithium, manganese, or vanadium should be avoided;
- Use colored compounds (e.g. stain-containing pigments) which are stable at high temperatures and generally inert in silicate systems. The risk of metal volatility with this type of glaze can be further reduced with short firing cycles;
- Use high-efficiency dust-abatement techniques (e.g. fabric filters).

Wastewater

Industrial process wastewater

Process wastewater is mainly generated from cleaning water in preparation and casting units, and various process activities (e.g. glazing, decorating, polishing, and wet grinding). Process wastewater is characterized by turbidity and coloring, due to the very fine suspended particles of glaze and clay minerals. The potential pollutants of concern include suspended solids (e.g. clays and insoluble silicates), suspended and dissolved heavy metals (e.g. lead and zinc), sulfates, boron, and traces of organic matter. Sector-specific measures to prevent and minimize the generation of wastewater include the following:

- Use dry off-gas cleaning systems instead of wet off-gas cleaning systems;
- Where practical, install waste glaze collection systems;
- Install slip conveying piping systems;

- Separate process-wastewater streams from other process steps, and implement closed-circuit water reuse systems;⁴

Process Wastewater Treatment

Techniques for treating industrial process wastewater in this sector include flow and load equalization with pH adjustment; sedimentation for suspended solids reduction using settling basins or clarifiers; multimedia filtration for reduction in non-settleable suspended solids; dewatering and disposal of residuals in landfills, or if hazardous in designated hazardous waste disposal sites. Additional engineering controls may be required for 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**.

Solid Wastes

Process waste originating from the manufacture of ceramic products mainly consists of different types of sludge, including sludge from process wastewater treatment, and process sludge

resulting from glazing, plaster, and grinding activities. Other process wastes include broken ware from process activities (e.g. shaping, drying, and firing); broken refractory material; solids from dust treatments (e.g. flue-gas cleaning and dedusting); spent plaster molds; spent sorption agents (e.g. granular limestone and limestone dust); and packaging waste (e.g. plastic, wood, metal, paper).

Recommendations for solid waste management include the following:

- Reduce waste production through process enhancements such as:
 - Replacing slip casting in plaster molds with pressure slip casting units (isostatic presses) with polymer molds;
 - Increasing the lifespan of plaster molds (e.g. using harder plaster molds obtained through use of automatic plaster mixers or vacuum plaster mixers);
 - Installing electronic controls for the firing curve (to optimize the process and reduce the amount of broken ware);
 - Installing spray booths that allow reclaiming of excess glaze;
- Reduce waste generation by recycling and internal reuse of cuttings, broken ware, used plaster molds, and other by-products, including sludge through the following techniques:
 - Recycle sludge into the ceramic molds, particularly in facilities where wet milling is implemented in raw material preparation;
 - Reuse sludge from fine ceramic and sanitary ware manufacturing as a raw material or additive in the manufacture of bricks or expanded clay aggregates;
 - Recycle, as raw material, dust collected in abatement systems and through different process activities, in addition to cuttings and other process losses;

⁴ Water recycling for ceramic tile manufacturing is typically 70–80 percent and 30 – 50 percent for sanitary ware manufacturing.

- For materials that cannot be recycled, dispose according to industrial waste management guidance included in the **General EHS Guidelines**.

1.2 Occupational Health and Safety

Occupational health and safety impacts during the construction and decommissioning of ceramic tile and sanitary ware manufacturing facilities are common to those of most industrial facilities, and their prevention and control are discussed in the **General EHS Guidelines**. Occupational health and safety issues associated with the operations phase of ceramic tile and sanitary ware manufacturing primarily include the following:

- Respiratory hazards
- Exposure to heat
- Exposure to noise / vibration
- Physical hazards
- Electrical hazards

Respiratory Hazards

Workplace exposure to fine airborne particulate in the form of silica dust (SiO₂), deriving from silica sands and feldspar, is the main occupational hazard in this sector. Other potential hazards may result from glaze application, airborne refractory ceramic fibers, and combustion by-products. Recommended techniques to prevent and control exposure include the following:

- Segregate raw material storage from other operational areas;
- Install local exhaust ventilation systems with filter units (e.g. fettling hoods);
- Install kiln venting systems (e.g. use adjustable vents mounted over the top of the kilns) to facilitate kiln loading and unloading;

- Implement periodic dust removal from surfaces (e.g. vacuum cleaning equipment with high-efficiency particulate air [HEPA] filters);
- Vacuum, hose down, or wet sweep work areas instead of dry sweeping;
- Purchase premixed materials, if feasible, to reduce the need for mixing. Limit the need for shoveling dry powder, and arrange for reception of raw materials in larger containers, for handling by forklift;
- Transport raw material through enclosed conveyors or tubes;
- Conduct glazing applications in well-ventilated areas, and install spray booths. Avoid using low-solubility glazes containing lead and other heavy metals;
- Provide personal protective equipment (PPE), (e.g. overalls, goggles, gloves, and face masks) to workers operating in dusty environments and applying glaze.

Exposure to Heat

Heat exposure may occur during operation and maintenance of furnaces or other hot equipment. Exposure to radiant heat and temperature changes, and to high ambient humidity, is an industry-specific hazard. Recommended techniques to prevent and control exposure to heat include the following:

- Ensure adequate ventilation of the workplace (e.g. ducting in fresh air, allowing cross-ventilation, and installing exhaust fans);
- Provide air-cooled rooms for worker to take breaks;
- Shield surfaces where workers are close to hot equipment;
- Reduce the time required for work in high temperature environments (e.g. shorter shifts at these locations);
- Use PPE (e.g. insulated gloves, shoes, and air- or oxygen-supplied respirators), especially during maintenance operations;

Noise and Vibration

Noise sources include raw material preparation (e.g. crushing, grinding, milling, dry and wet mixing, screening, and clarification), pressing and granulation processes, cutting, grinding and polishing, fan burners in kilns, and packaging activities. Guidance on the management of noise is provided in the **General EHS Guidelines**.

Physical Hazards

Activities related to the operation and maintenance of equipment (e.g. mills, mill separators, and belt conveyors) represent a source of exposure to physical impacts, especially during equipment start-up and shutdown. Other typical hazards include handling sharp materials, lifting heavy objects, performing repetitive motions. Guidance on the prevention and control of physical hazards is described in the **General EHS Guidelines**.

Electrical Hazards

Workers may be exposed to electrical hazards due to the presence of electrical equipment throughout ceramic tile and sanitary ware manufacturing facilities. Recommendations to prevent and control exposure to electrical hazards are provided in the **General EHS Guidelines**.

1.3 Community Health and Safety

Community health and safety impacts during the construction, operation, and decommissioning of ceramic manufacturing plants are common to those of most industrial facilities and are 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. These guidelines are 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. 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.

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

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 the 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**.

Table 1. Air emission levels for ceramic tile

Pollutant	Unit	Guideline Value
Particulate Matter	mg/Nm ³	50 ^a
SO ₂	mg/Nm ³	400 ^b
NO _x	mg/Nm ³	600 ^b
HCl	mg/Nm ³	30
HF	mg/Nm ³	5
Lead	mg/Nm ³	0.5
Cadmium	mg/Nm ³	0.2
TOC	mg/Nm ³	20
Notes:		
^a Dryer and kiln stacks; ^b Kiln operations (at 10 percent O ₂).		

Table 2. Effluent levels for ceramic tile

Pollutants	Units	Guideline Value
pH	S.U.	6–9
BOD ₅	mg/L	50
TSS	mg/L	50
Oil and grease	mg/L	10
Lead	mg/L	0.2
Cadmium	mg/L	0.1
Chromium (total)	mg/L	0.1
Cobalt	mg/L	0.1
Copper	mg/L	0.1
Nickel	mg/L	0.1
Zinc	mg/L	2
Temperature increase	°C	<3 ^a
^a At the edge of a scientifically established mixing zone which takes into account ambient water quality, receiving water use, potential receptors and assimilative capacity		

Resource Use

The following Tables, 3 to 5, provide examples of resource consumption and load indicators in this sector. Industry

benchmark values are provided for comparative purposes only and individual projects should target continual improvement.

Table 3. Energy consumption

Inputs per unit of product	Unit	Industry benchmark
Ceramic tile manufacturing — energy consumption		
Thermal energy: Spray drying process	kJ/kg	980–2,200
Thermal energy: Drying process	kJ/kg	250–750
Thermal energy: Firing: once-fired tiles (Tunnel kilns)	kJ/kg	5,400–6,300
Thermal energy: Firing: twice-fired tiles (Tunnel kilns)	kJ/kg	6,000–7,300
Thermal energy: Firing: once-fired tiles (Roller hearth kilns)	kJ/kg	1,900–4,800
Thermal energy: Firing: twice-fired tiles (Roller hearth kilns)	kJ/kg	3,400–4,600
Electric energy: Pressing	kWh/kg	50–150
Electric energy: Drying	kWh/kg	10–40
Electric energy: Firing	kWh/kg	20–150
Sanitary ware manufacturing — energy consumption		
Conventional tunnel kiln	kJ /kg	9,100–12,000
Modern tunnel kiln with light fiber insulation	kJ /kg	4,200–6,500
Roller heath kiln	kJ /kg	3,500–5,000
Modern shuttle kiln	kJ /kg	8,500–11,000
Source: EU BREF (2005)		

Table 4. Waste generation

Output per unit of product	Unit	Industry benchmark
Glaze waste produced in tile surface glazing	g/m ² of tile surface	100
Sludge	g/m ² of tile surface	90–150
Solid waste — cuttings and defective tiles	g/m ² of tile surface	700–1300
Recovery and re-use of glaze in sanitary ware manufacturing	m ³ /day	0.08–0.1
Glaze used per sanitary ware item	kg/item	1.5–3

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**.

2.2 Occupational Health and Safety

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),⁵ the Pocket Guide to Chemical Hazards published by the United States National Institute for Occupational Health and Safety (NIOSH),⁶ Permissible Exposure Limits (PELs) published by the Occupational Safety and Health Administration of the United

States (OSHA),⁷ Indicative Occupational Exposure Limit Values published by European Union member states,⁸ 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)⁹.

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 professionals¹⁰ 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**.

⁵ Available at: <http://www.acgih.org/TLV/> and <http://www.acgih.org/store/>

⁶ Available at: <http://www.cdc.gov/niosh/npg/>

⁷ Available at: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992

⁸ Available at: http://europe.osha.eu.int/good_practice/risks/ds/oel/

⁹ Available at: <http://www.bls.gov/iif/> and <http://www.hse.gov.uk/statistics/index.htm>

¹⁰ 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

Ceramic products are manufactured from clays and other non-metallic inorganic materials. Ceramic tiles are thin slabs, generally used as coverings for floors and walls. Tiles typically are shaped through extrusion or dust pressing at ambient temperature, then dried and fired to maintain their form permanently. Ceramic products used for sanitary purposes (e.g. lavatory bowls, wash basins, cisterns, and drinking fountains) are collectively referred to as sanitary ware and are mainly manufactured from vitreous china (semi-porcelain) or earthenware. The typical production levels for ceramic manufacturing facilities vary from 10 to 50 tons / day for fine ceramics and 450 to 500 tons / day for ceramic tiles.

The common process activities of the ceramic tile and sanitary wares manufacturing sector include the mixing of basic raw clay minerals with other additive minerals and the firing / fusion process. In the firing / fusion process, the raw materials are transformed in a glassy phase (vitrification) at temperatures between 1,000°C and 1,400°C. The vitrification process provides the ceramic products with specific chemical and physical properties, including resistance to heat and fire, strength, and chemical inertness. The main manufacturing processes covered in this guideline include raw storage and preparation of raw materials, shaping, drying, surface treatment (e.g. glazing or enameling), firing, treatment (e.g. polishing), sorting, and packaging. A typical ceramic manufacturing process is shown in Figure A.1.

Raw Materials Storage and Handling

Products manufactured by the ceramic industry predominantly consist of a complex mixture of clay minerals (aluminum silicates that serve as plastic materials) complemented with other minerals (e.g. additives, fillers and fluxing agents [nonplastic materials], and glaze components). Table A-1

summarizes the main raw materials used in ceramic manufacturing.

Body components are usually delivered to the raw material storage area in bulk and are generally stored in open stockpiles or in containers / silos to limit interaction with atmospheric agents and dust generation issues. Raw materials are prepared through several processes (e.g. primary and secondary crushing, grinding, screening, dry or wet milling, dry screening, spray-drying, calcining), mixed and pressed, and extruded or slip cast into shape (shaping / forming). Preparation of glazes is conducted using silica (as major glaze component), fluxing agents (e.g. alkalis, alkaline earths, boron, lead), opacifiers (e.g. zirconium and titanium), and coloring agents (e.g. iron, chromium, cobalt, manganese). Water is regularly used to enhance mixing and shaping, followed by a drying stage. Surface treatment and decoration of the clay products may also be used. The products are then placed in kilns for firing / vitrification.

Table A-1. Ceramic Forming Raw Materials

Additives	kaolin, limestone
Basic Raw Materials (plastic materials)	kaolinite, montmorillonite halloysite
Fillers and Fluxing Agents (non plastic materials)	quartz, feldspar, chalk, dolomite, wollastonite, iron oxides, gypsum, steatite, talc.
Glaze Components	Silica, alkalis, lead, boron, zirconium, iron, chromium, cobalt

Firing Process

The firing process allows the vitrification of the shaped and dried clay products. Firing is conducted in kilns, which may be of continuous or intermittent operation. The continuous kilns include tunnel kilns and roller hearth kilns. Tunnel kilns are refractory tunnels served by rail tracks carrying kiln-cars. The

cars have refractory decks on which dried ware is set in defined, stable patterns. The cars are pushed through the kilns at set intervals, countercurrently to a flow of air drawn by fan(s) to an exhaust duct located near the car entry zone. Most tunnel kilns are gas-fired. Dried raw material on the cars is preheated by hot gases drawn from the firing zone, while incoming air cools the fired material and is preheated before combustion. A part of the air from the cooling zone is usually drawn off to the adjacent dryers. To reduce firing times and energy consumption, a gas-tight firing chamber is needed and, therefore, the firing chamber and kiln-cars are usually sealed at the sides of the tunnel with a sand seal (or by water or other mechanical solutions) against secondary air.

Single-deck roller hearth kilns are most commonly used for wall and floor tile production. Firing is provided by natural gas-air burners located at the sides of the kiln. The firing process has been reduced to less than 40 minutes and tiles travel over driven rollers. The main heat transmission mechanisms are convection and radiation. Roller hearth kilns are sometimes used for the production of clay roof tiles and sanitary ware.

Intermittent kilns include shuttle and hood-type kilns, based on single chambers, which are charged with dried ceramic products, sealed, and then exposed to a defined firing cycle. The kilns are usually provided with gas burners, and intermittent kilns are sometimes used for smaller-scale manufacture of special sanitary ware.

Product Finishing

Several treatments are applied after firing to finish the products. These treatments include grinding (either wet or dry), sawing, and polishing. The addition of auxiliary materials is also possible for specific productions. Sorting, packaging, and storing of ceramic products concludes the typical manufacturing process.

Figure A.1: A Typical Ceramic Tile Manufacturing Process

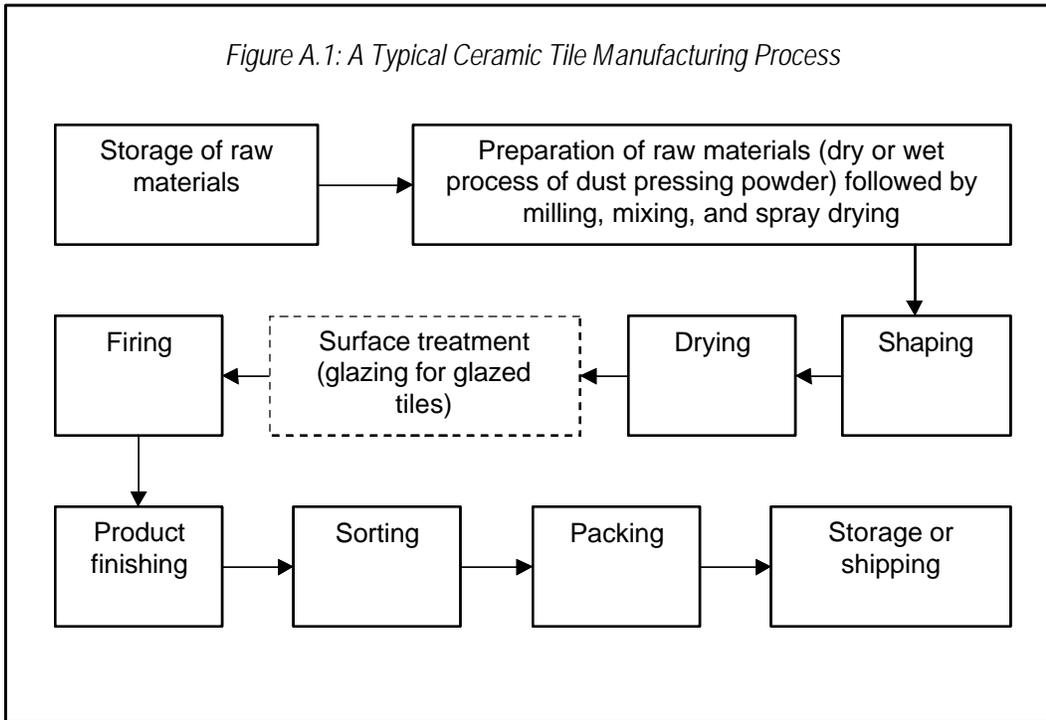


Figure A.2: A Typical Sanitary Ware Manufacturing Process

